Dairy Farming and the Effects of Agricultural, Nonpoint-source Pollution on Stream Water Quality, Johnson Creek Watershed, Whatcom County, Washington

Max Thomas Wills
Western Washington University, maxwills60@gmail.com

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DAIRY FARMING AND THE EFFECTS OF
AGRICULTURAL, NONPOINT-SOURCE POLLUTION
ON STREAM WATER QUALITY,
JOHNSON CREEK WATERSHED, WHATCOM COUNTY, WASHINGTON

BY

MAX THOMAS WILLS

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Moheb A. Ghali, Dean of Graduate School

ADVISORY COMMITTEE

Chair, Dr. Donald Easterbrook

Dr. Scott Babcock

Dr. Richard Berg, PE
MASTER'S THESIS

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Max Wills
March 17, 2018
DAIRY FARMING AND THE EFFECTS OF
AGRICULTURAL, NONPOINT-SOURCE POLLUTION
ON STREAM WATER QUALITY,
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A Thesis Presented to the Faculty
of Western Washington University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By

Max Thomas Wills
May, 1998
ABSTRACT

The Johnson Creek watershed, which supports one of the highest densities of dairy farms in Washington State, suffers from degraded stream water quality, primarily in the form of high fecal coliform concentrations, elevated nutrients, and low levels of dissolved oxygen. Despite the implementation of best management practices (BMPs) over the past two decades, poor stream water quality has persisted. The Washington State Department of Ecology (DOE) is therefore required under section 303(d) of the federal Clean Water Act, to establish a Total Maximum Daily Load (TMDL) policy for the basin as a means of remediating the impaired water bodies. The current project was undertaken to assist DOE with this task by conducting a water quality study to determine the present quality of the surface waters and determine the location and mode by which farm waste enters the stream. BMP effectiveness was also reassessed by conducting historical water quality comparisons.

Currently, stream water quality within the watershed remains impaired by fecal coliform, ammonia, nitrates, phosphates, and dissolved oxygen. An examination of standard box plots shows a redundant pattern of water quality impairment at specific sampling sites, indicating the general location of potential source areas. Box plots arranged by sampling date also show that stream water quality is most severely impaired during the wettest portion of the year and tends to improve as precipitation diminishes through the summer months. This suggests that runoff from fertilizer-laden fields is the primary mode by which dairy waste enters the stream. Stream water models, constructed to predict nutrient transport, confirm the box plot interpretations and show, through a process of load-accounting, that the majority of the nutrient loading originates from specific dispersed (nonpoint) source areas.

Historical comparisons of median data values, substantiated with Mann-Whitney hypothesis testing, showed decreasing trends for ammonia and fecal coliform concentrations, and
improvements in the dissolved oxygen levels over the past 20 years, indicting BMPs have been at least partially successful at preventing the direct input of farm waste into the stream. Numerous farms within the basin, however, are presently operating without up-to-date farm waste management programs and a correspondence was found between these operators and the portions of the stream identified as farm waste input source areas. In addition, increasing trends were observed for nitrates and phosphates, which corresponds with a nearly two fold increase in the total herd size and subsequent manure production within the basin over the last two decades.

To approach stream water quality compliant with state and federal regulations, at a minimum, all of the dairies operating within the watershed need to adhere to prudent waste management techniques. To attain complete water quality compliance, future regulatory policies within the Johnson Creek watershed may need to be more intrusive and could include herd size caps, a moratorium on winter manure spreading, or the establishment of a stream buffer.
ACKNOWLEDGMENTS

Much appreciation is owed to numerous people, without whose assistance, this project may not have been completed. I would like to express my appreciation to the Washington State Department of Ecology for their review and comments, and special thanks to Gail Dorf with the Nooksack team for acting as the DOE liaison, for providing an immense amount of technical literature, and for diverting a continuous stream of field assistants toward this project. Thank you also to the people who assisted me in the field, rain or shine, including William Hirschi, Jamol Beckham, Carey Riggins, Ryan Houser, Geoff Klize, Jennifer Robins, and Nicole Schlueter. I would also like to thank the members of the Whatcom Conservation District and Mr. John Gillies with the United States Department of Agriculture, Natural Resource Conservation Service for helping to develop this project and for providing invaluable information pertaining to the local dairies and farming practices. My sincere thanks is also owed to the late Dr. Robert (Pete) Peters for his unique style of encouragement and for helping me organize this manuscript.

I am also deeply indebted to Dr. Robin Matthews and Joan Vandersypen at the Institute for Watershed Studies at Western Washington University for allowing me to use their facility and supplies, and to Joan, for the hours spent teaching me how to perform water quality analyses. Much thanks is owed to the Geology Department at WWU as well for providing a much needed grant to pay for chemicals and supplies, and to George Mustoe, who seemed to always know the answer to every question or have just the right piece of equipment within an arms length of where ever he happen to be sitting. I'm also indebted to Mrs. Nancy Elkins with the Huxley College of Environmental Studies for loaning me literally crates of Huxley's sampling equipment.

Last, but most assuredly not least, I would like to thank my advisory committee, Dr. Donald Easterbrook, Dr. Scott Babcock, and Dr. Richard Berg, PE, for all their advice and guidance, and timely edits of this manuscript, and my wife, Hope, for helping me in the field on occasion, for hours of data entry, and for her enduring patience throughout this project.

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INTRODUCTION

As a consequence of intensive dairy farming, poor stream water quality, primarily in the form of high fecal coliform concentrations, excessive nutrients, and low levels of dissolved oxygen, has persisted in the Johnson Creek watershed for nearly two decades. Johnson Creek, the principle stream within the watershed together with its tributaries drain some of the most concentrated dairy land in Washington State. In 1990, the 50 commercial dairies operating within the 21 square mile drainage were estimated to produce 40 million gallons of animal waste annually (Dickes and Merrill, 1990). In 1979, prompted by increasing water quality degradation and severe declines in several species of anadromous fish, the United States Department of Agriculture-Natural Resource Conservation Service (NRCS) began a program of “Best Management Practice” (BMP) implementation (Overdorff, 1981; and Overdorff, 1982). BMPs, which include agronomic, managerial, and/or structural techniques for controlling nonpoint source pollution, were implemented to reduce nonpoint source input of animal waste throughout the watershed in an attempt to restore stream water quality to state, class-A-stream standards. A decade later, despite the installation of nearly 80% of the BMP projects, the Washington State Department of Ecology (DOE) found that the water quality in Johnson Creek had not improved and, in many respects, had instead degraded further (Dickes and Merrill, 1990).

Project Objectives

Johnson Creek currently exceeds federal stream water standards for fecal coliform, dissolved oxygen, and pH (United States Environmental Protection Agency, 1994). Because the waters of Johnson Creek do not meet minimum federal water quality standards, DOE is required under section 303(d) of the federal Clean Water Act to regulate stream loading through the implementation of Total Maximum Daily Load (TMDL) allocations (US EPA, 1991; and
Washington DOE, August, 1991). TMDL allocations represent the amount of pollutant a water body can assimilate without exceeding water quality standards and may be implemented via National Pollutant Discharge Elimination System (NPDES) permits, state waste discharge permits, grant projects, watershed action plans, and/or other nonpoint source control activities.

The objective of this project was to provide DOE with a preliminary stream water quality assessment on which an appropriate TMDL strategy could be based. Specifically, this project was undertaken to (1) determine the present condition of water quality relative to state, class-A-stream standards, (2) identify areas of excessive farm waste input along the stream corridor, and (3) evaluate the effectiveness of BMPs by assessing the trend of stream water quality in the basin over the past two decades. In addition, this project provides scenarios for restoring stream water quality to meet state, class-A-stream standards.

Project Setting

The Johnson Creek watershed occupies an area of approximately 21 square miles (54 square kilometers or 13,450 acres) in the north-central portion of Whatcom County, Washington (Figure 1) (Gillies et al., 1981; and Dick and Merrill, 1990). The drainage area, which is a subbasin of the Sumas watershed, encompasses approximately 40% of the total Sumas drainage area. The Johnson Creek watershed is bounded to the north by the US-Canadian border and to the south by the main stem of the Nooksack River (Figure 2). Johnson Creek, the main stream within the basin, originates from springs just north of the town of Everson and flows generally northeastward across the nearly flat Sumas Valley floodplain. Three principle tributaries, Squaw Creek, Pangborn Creek, and Sumas Creek, drain uplands along the western and northwestern edge of the basin and contribute year-round flow to Johnson Creek. During periods of high precipitation, additional flow enters Johnson Creek through a series of ditches that drain the
Figure 2. Johnson Creek Watershed

Reference: USGS 7.5 min. Topographic Series
Sumas Quadrangle
floodplain of the basin. The total length of Johnson Creek is approximately 12 miles (19 kilometers) from its headwaters to the confluence with the Sumas River 1.4 miles (2.3 kilometers) south of the international border. Johnson Creek is connected to the sea via the Sumas River and the Fraser River, which enters Georgia Strait just south of Vancouver, British Columbia.

Johnson Creek possesses a nearly flat stream gradient. The elevation difference between its headwaters near Everson and its point of termination east of Sumas is only 40 feet (12 meters) for an average gradient of 3.3 feet/mile (0.6 meters/kilometer). Consequently, average stream velocities within Johnson Creek are typically very low, usually less than 0.5 feet/second (0.1 meters/second). The three major tributaries however, possess steeper gradients and therefore exhibit higher average velocities.

The average annual discharge within Johnson Creek is approximately 50 cfs (15 cms) near its downstream point of termination. Discharge is normally highest in early to mid winter and lowest during the late summer months. During a baseline water quality study by Overdorff (1981), the highest and lowest discharge values recorded for Johnson Creek at the farthest-downstream sampling site were 94.5 cfs (28.8 cms) in late February and 18.5 cfs (5.6 cms) in late August respectively. During a follow-up study by Dickes and Merrill (1990), at the same location, the highest and lowest discharge values were recorded as 266.4 cfs (81.2 cms) in mid January and 11.4 cfs (3.5 cms) in mid September respectively. The highest and lowest discharge values recorded during this project at the same downstream location were 183.7 cfs (56.0 cms) in early February and 21.7 cfs (6.6 cms) in mid July. Discharge data for this study are presented in Figures 14 and 15 and Appendices A, B and J. The volume of water passing through Johnson Creek at any given time is predominantly influenced by antecedent precipitation.
Climate

The Johnson Creek watershed has a moderately wet climate, which is strongly influenced by Georgia Strait and adjacent waterways to the west and the Cascade Range to the east. The mean annual rainfall in the basin is about 47 inches (119 centimeters) (Gillies et al., 1981). During a typical year, approximately 70% of the total annual precipitation falls as rain between October and March. A small percentage of additional precipitation may also occur as snowfall during the winter months. Typically, the ground within the basin is saturated by the end of October and additional rainfall runs off as overland flow throughout the wet-season. Because precipitation can have a significant influence on nonpoint source pollution input, rainfall data were obtained from National Oceanic and Atmospheric Administration (NOAA) daily precipitation reports for the Clearbrook station (Figure 2). The total monthly precipitation for each of the three study years, as well as the 20 year mean, are compared in Figure 3.

The mean annual temperature in the basin is approximately 9 °C with mean maximum temperatures of about 24 °C occurring during July and August and mean minimum temperatures of -1 °C usually occurring during January. Moderate temperatures during the wet-season (October - March) are the result of prevailing southwesterly winds. When prevailing winds occasionally shift from southwesterly to northeasterly, severe winter weather occurs and may persist for several days. Wind-chill temperatures during these events have been reported by local residents as low as -45 °C. Normally the frost-free period, and the corresponding growing season in the watershed, is about 140 days from early May to late September (Gillies et al., 1981; and Whatcom Conservation District, 1990). Temperature data for this study were also obtained from reports for the Clearbrook station and are presented in Figure 4.
Figure 3: Total Monthly Precipitation

- 1980/1981
- 1988/1989
- 1995/1996
- 20 yr mean

Figure 4: Average Monthly Temperature

- 1980/1981
- 1988/1989
- 1995/1996
- 20 yr mean
Land Use

Land use in the Johnson Creek watershed is primarily agricultural and is dominated by dairy farming (Gillies et al., 1981; and Dickes and Merrill, 1990). Of the 13,450 acres (54 square kilometers) comprising the basin, nearly 80% (10,700 acres or 43 square kilometers) is utilized for pasture and hayland associated with dairy operations. Approximately 7% (1,000 acres or 4 square kilometers) is used as cropland to raise sweet peas, sweet corn, and silage corn. About 20% of the pasture and hayland is also in rotation with silage corn. The remaining land in the drainage consists of woodlands (5% - 750 acres or 3 square kilometers), developed areas (7% - 1,000 acres or 4 square kilometers), and permanent wetlands (1% - 50 acres or < 1 square kilometer). The population of the watershed is about 5,000, of which approximately half reside in the rural portion of the basin, and the remainder are concentrated in the towns of Everson, Nooksack, and Sumas.

Dairy farming has persisted as the dominate industry in the Johnson Creek watershed over the past 100 years despite significant changes in land use throughout other areas of northern Whatcom County (Gillies et al., 1998; and Timblin, 1998). In the mid 1980s, approximately 15% of the farms in Whatcom County participated in a federal dairy buy-out program. However, this only included two farms located in the Johnson Creek watershed and, following the prescribed five year non-operation period, both of these farms resumed operation under new ownership. The total number of dairies operating in the basin has steadily declined over the past two decades but, the land and livestock from these farms has been transferred to neighboring farms and, the total herd size in the watershed is presently nearly twice what it was in 1980 (Overdorff, 1981; Washington DOE, 1995; and Gillies et al., 1998). Despite land use transitions in other parts of the county and a reduction in the number of dairies operating in the Johnson Creek watershed, the
majority of the land within the basin has been consistently utilized to support increasingly larger dairy operations.

**Previous Work**

Because of poor water quality and declining fisheries within the Johnson Creek watershed, the NRCS, in cooperation with the Whatcom Conservation District (WCD), initiated a two-phase program in 1979 to improve stream water quality to meet state, class-A-stream standards and improve the wildlife habitat within the basin (Overdorff, 1981; and Overdorff, 1982). The first phase involved dredging Johnson Creek and several of the major tributaries to remove Reed Canary Grass (Phalaris arundinacea) and manure residue which obstructed the stream channels. During the second phase, contracts were initiated with area farmers to better manage and dispose of livestock waste through implementation of BMPs. The second phase also included a water quality study (October 1980 - September 1981) to determine baseline water quality conditions for later use in evaluating the effectiveness of BMPs. Baseline water quality during 1980/1981 was found to violate state, class-A-stream standards for fecal coliform, dissolved oxygen, and pH. High levels of nutrients and excessive turbidity were also documented.

In 1988, after approximately 80% of the contracted BMP projects were installed, DOE conducted a second water quality study (September 1988 - May 1989) to determine water quality conditions relative to state, class-A-stream standards and to assess BMP effectiveness (Dickes and Merrill, 1990). Water quality during 1988/1989 was again found to violate state, class-A-stream standards for fecal coliform, dissolved oxygen, and pH. High levels of nutrients were also documented. In addition, DOE found that fecal coliform and nutrient concentrations had increased significantly since the 1980/1981 study. DOE attributed the increased loading to the fact that dairy waste continued to enter the stream despite the implementation of BMPs and may be largely the result of improper waste management and/or non-participating farms.
PROJECT DESIGN AND METHODOLOGY

As a means of assisting DOE with the task of planning and implementing an appropriate TMDL for the Johnson Creek watershed this project was designed to address three principal objectives:

- Determine present-day stream water quality relative to state, class-A-stream standards and assess the trend of water quality since initial BMP implementation
- Locate areas of excessive farm waste input along the Johnson Creek corridor
- Provide possible scenarios for restoring stream water quality to state, class-A-stream standards

Stream water quality was assessed through a series of water quality surveys conducted between December 1995 and September 1996. Statistical comparisons of current water quality data with the data obtained during the two previous studies, was used to decipher water quality trends. The location and magnitude of potential nonpoint source input was assessed by evaluating standard box plots of the water quality data (Helsel and Hirsch, 1992), as well as through the construction and calibration of stream water models. Scenarios to improve stream water quality were developed through manipulations of the various models.

**Water Quality Surveys**

Existing stream water quality within Johnson Creek was assessed during 13 separate water quality surveys conducted between December 1995 and September 1996. The 13 surveys consisted of one reconnaissance survey (December, 1995), eight wet-season surveys (January - May, 1996), and four dry-season surveys (June - September, 1996). Reconnaissance was conducted to determine the approximate dilution levels that would be required during subsequent nutrient analyses and as a means of exposing logistical or procedural asperities. Wet-season
surveys were conducted every 2 to 3 weeks, starting in mid January, and continued throughout the wettest portion of the year through mid May. Data collection was conducted over three consecutive days, usually during the early to mid portion of each day in order to obtain average results. Dry-season surveys were conducted monthly starting in mid June and continued past the first major fall rain event in early September. Data collection was conducted during a single day and included morning and afternoon measurements for use in assessing diurnal variation.

At the onset of this project, 14 sampling sites (J1 - J14) were utilized. Sampling site D15 was added during the March 23 - 25 survey and monitored throughout the remainder of the project (Figure 5). The majority of sampling sites were located at or near sites used during the 1980/1981 and 1988/1989 studies so that direct comparisons could be made with previously collected data. The location of all sampling sites and a description of each is presented in Table 1. A sample schedule is shown in Table 2, and a summary of field measurements and analytical methods is presented in Tables 3 and 4. As a means of assessing and controlling data quality, a comprehensive quality control (QC) program was also developed and implemented.

Field Measurements

Field measurements for this project were made either using DOE approved methods (Washington DOE, 1994) or in accordance with the equipment manufacture’s instructions. The results of all field measurements are presented in Figures 14 through 27 and in Appendices A and J.

Discharge values were determined using two principle techniques. Discharge at open-channel sites (J1, J3, J4, J5, J6, J8, P10, SQ12, and J13) was determined by measuring velocity and water depth at equal increments across the stream channel and calculating the partial...
Figure 5. Sampling Site Locations
<table>
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<tr>
<th>Sample Site Designations</th>
<th>River Mile</th>
<th>Lat. &amp; Long.</th>
<th>Location Description</th>
<th>Special Notes</th>
</tr>
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<tbody>
<tr>
<td>J1</td>
<td>1.0</td>
<td>48° N 59' 50&quot; 122° W 15' 41&quot;</td>
<td>(Johnson Cr.) Down-town Sumas, Sumas Ave. Bridge, upstream side.</td>
<td>80/81 &amp; 88/89 site one block upstream at Cherry St. Bridge. 80/81 site Jan. - Sep. 1981 (moved from 1996 J3 site).</td>
</tr>
<tr>
<td>SM2</td>
<td>0.1</td>
<td>48° N 59' 53&quot; 122° W 15' 56&quot;</td>
<td>(Sumas Cr.) Down-town Sumas, culvert under Third St., downstream side.</td>
<td>88/89 site on upstream side of bridge. 80/81 site Oct. - Dec. 1980 (moved to 1996 J3 site).</td>
</tr>
<tr>
<td>J3</td>
<td>1.5</td>
<td>48° N 59' 36&quot; 122° W 15' 54&quot;</td>
<td>(Johnson Cr.) Lyons Park, just west of down-town Sumas, downstream side of bridge.</td>
<td>88/89 site on upstream side of bridge.</td>
</tr>
<tr>
<td>J4</td>
<td>2.8</td>
<td>48° N 59' 11&quot; 122° W 16' 27&quot;</td>
<td>(Johnson Cr.) Where creek parallels Hill Rd., downstream side of private bridge.</td>
<td>88/89 site on upstream side of bridge.</td>
</tr>
<tr>
<td>J5</td>
<td>3.6</td>
<td>48° N 59' 22&quot; 122° W 17' 04&quot;</td>
<td>(Johnson Cr.) Lynden-Sumas Hwy. north of Clearbrook Rd., downstream side of bridge.</td>
<td>88/89 site on upstream side of bridge.</td>
</tr>
<tr>
<td>J6</td>
<td>5.9</td>
<td>48° N 58' 58&quot; 122° W 18' 25&quot;</td>
<td>(Johnson Cr.) North end of Nooksack Rd., downstream side of private bridge.</td>
<td>88/89 site on upstream side of bridge.</td>
</tr>
<tr>
<td>CB7</td>
<td>0.2</td>
<td>48° N 58' 44&quot; 122° W 18' 37&quot;</td>
<td>(Clearbrook Ditch) Culvert under Clearbrook Rd., downstream side.</td>
<td>88/89 site on upstream side of bridge.</td>
</tr>
<tr>
<td>J8</td>
<td>6.6</td>
<td>48° N 58' 44&quot; 122° W 19' 01&quot;</td>
<td>(Johnson Cr.) Clearbrook Rd. Bridge, upstream side.</td>
<td>88/89 site on upstream side of double culvert.</td>
</tr>
<tr>
<td>---</td>
<td>6.8</td>
<td></td>
<td>(Johnson Cr.) Approx. 50 feet upstream of Johnson / Pangborn confluence, on Steiner Farm.</td>
<td>88/89 site on upstream side of double culvert.</td>
</tr>
<tr>
<td>P9</td>
<td>0.1</td>
<td>48° N 58' 45&quot; 122° W 19' 30&quot;</td>
<td>(Pangborn Cr.) Double culvert under Clearbrook Rd., downstream side.</td>
<td>80/81 &amp; 88/89 site downstream ~100 ft. at railroad bridge.</td>
</tr>
<tr>
<td>P10</td>
<td>0.7</td>
<td>48° N 59' 06&quot; 122° W 19' 45&quot;</td>
<td>(Pangborn Cr.) Approx. 50 feet downstream from culvert under Van Buren Rd. (culvert submerged most of the year).</td>
<td>88/89 site at former Van Buren Rd. Bridge.</td>
</tr>
<tr>
<td>---</td>
<td>1.5</td>
<td></td>
<td>(Pangborn Cr.) North of Pangborn Rd., between Trap Line Rd. and Van Buren Rd.</td>
<td>88/89 site on upstream side of double culvert.</td>
</tr>
<tr>
<td>SQ11</td>
<td>0.2</td>
<td>48° N 58' 06&quot; 122° W 19' 46&quot;</td>
<td>(Squaw Cr.) Double culvert under Van Buren Rd., downstream side.</td>
<td>88/89 site on upstream side of double culvert.</td>
</tr>
<tr>
<td>---</td>
<td>0.7</td>
<td></td>
<td>(Squaw Cr.) Lynden-Sumas Hwy., east of Trap Line Rd., downstream side of bridge.</td>
<td>88/89 site on upstream side of double culvert.</td>
</tr>
<tr>
<td>Sample Site Designations</td>
<td>River Mile</td>
<td>Lat. &amp; Long.</td>
<td>Location Description</td>
<td>Special Notes</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------</td>
<td>-------------</td>
<td>----------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>SQ12</td>
<td>1.4</td>
<td>48°N 57' 51&quot; 122° W 21' 34&quot;</td>
<td><strong>Squaw Cr.</strong> Lynden-Sumas Hwy., west of Trap Line Rd., upstream side of bridge.</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>2.7</td>
<td>48°N 57' 51&quot; 122° W 19' 34&quot;</td>
<td><strong>Squaw Cr.</strong> Hammer Rd., upstream side of bridge.</td>
<td></td>
</tr>
<tr>
<td>J7</td>
<td>6.8</td>
<td>48°N 57' 51&quot; 122° W 19' 34&quot;</td>
<td><strong>Johnson Cr.</strong> Between Pangborn Cr. and Squaw Cr. confluences, downstream side of private foot bridge.</td>
<td></td>
</tr>
<tr>
<td>J13</td>
<td>8.2</td>
<td>48°N 57' 51&quot; 122° W 19' 34&quot;</td>
<td><strong>Johnson Cr.</strong> Lynden-Sumas Hwy., upstream side of bridge.</td>
<td></td>
</tr>
<tr>
<td>J14</td>
<td>10.0</td>
<td>48°N 56' 31&quot; 122° W 20' 28&quot;</td>
<td><strong>Johnson Cr.</strong> Culvert under Hampton Rd., downstream side.</td>
<td></td>
</tr>
<tr>
<td>D15</td>
<td>0.2</td>
<td>48°N 56' 58&quot; 122° W 19' 48&quot;</td>
<td><strong>North End Ditch</strong> Culvert under Lindsay-Frick Rd., downstream side.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 2. Sample Schedule

<table>
<thead>
<tr>
<th>Sampling Site</th>
<th>1st Monthly Survey</th>
<th>2nd Monthly Survey</th>
<th>Dry Season Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st Day</td>
<td>2nd Day</td>
<td>3rd Day</td>
</tr>
<tr>
<td>J3</td>
<td>P</td>
<td>P, N, (J3-2)</td>
<td>P</td>
</tr>
<tr>
<td>J4</td>
<td>P</td>
<td>P, N, (J4-2)</td>
<td>P</td>
</tr>
<tr>
<td>J5</td>
<td>P</td>
<td>P, N, (J5-2)</td>
<td>P</td>
</tr>
</tbody>
</table>

P = Discharge, DO, Water Temperature, TDS, pH, Turbidity  
N = Nutrients  
F = Fecal Coliform  
B = BOD  
(J1-1) = Sample Identification Number
### Table 3. Summary of Field Measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method / Description</th>
<th>Primary Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge</td>
<td>Current Meter</td>
<td>pygmy-Price current meter</td>
<td>DOE, 1994</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>EPA 360.1/360.2, DO Probe/Winkler Azide</td>
<td>YSI model 500 DO probe</td>
<td>APHA, 1989</td>
</tr>
<tr>
<td>Water Temperature</td>
<td>Digital Thermometer</td>
<td>YSI model 500 DO probe</td>
<td></td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>TDS Meter</td>
<td>Hanna Instruments Dist WP</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>pH Meter</td>
<td>Hanna Instruments pHep3</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>Nephelometer</td>
<td>In-House Nephelometer</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4. Summary of Analytical Methods

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Method / Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ammonia</td>
<td>Colorimetric, Manual, Phenate</td>
<td>Solorzano, 1969</td>
</tr>
<tr>
<td>Nitrate + Nitrite</td>
<td>EPA 353.2 - Colorimetric, Automated, Cd Reduction</td>
<td>USEPA, 1983</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>Colorimetric, Automated, Cd Reduction, Persulfate Digestion</td>
<td>Ebina, 1983</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>EPA 365.2 - Colorimetric, Manual, Ascorbic Acid, Single Reagent, Persulfate Digestion</td>
<td>USEPA, 1983</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand</td>
<td>Bioassay (5 Day, 20° C)</td>
<td>APHA, 1989</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>Membrane Filter</td>
<td>APHA, 1989</td>
</tr>
</tbody>
</table>
discharge for each increment using the general equation

\[ q_i = v_i d_i \frac{(b_{i+1} - b_{i-1})}{2} \]

where:
- \( q \) = discharge in partial area \( x \)
- \( v \) = average velocity in partial area \( x \)
- \( d \) = depth of partial area \( x \)
- \( b_{i+1} \) = distance from the initial point to the following point of partial area \( x \)
- \( b_{i-1} \) = distance from the initial point to the preceding point of partial area \( x \)

Partial discharge values were then summed to determine the total discharge (Washington DOE, 1994; and Watson and Burnett, 1995). Discharge at culvert sites (SM2, CB7, P9, SQ11, J14, and D15) was determined using the general equation

\[ Q = VA \]

where:
- \( Q \) = total discharge
- \( V \) = average velocity
- \( A \) = cross sectional area of the wetted surface

Average stream velocity was approximated by measuring the stream current at approximately 6/10 of the water depth as measured from the water surface at the center of the culvert. The cross sectional area of the wetted surface was determined from the water depth and the diameter of the culvert (Fetter, 1994; and Watson and Burnett, 1995). At sites with double culverts (P9 and SQ11) the process was repeated for each culvert and the results summed. With the exception of sampling sites J8 and J13 during the August 11 and September 4 surveys, all stream velocity measurements were made using a pygmy-Price current meter. During the late summer stream velocity at sites J8 and J13 was too low to turn the current meter so velocity was estimated by measuring the travel time of a half filled sample bottle over a length of stream (Washington DOE, 1994; and Watson and Burnett, 1995).

Dissolved oxygen (DO) was measured using a “YSI, model 55” DO probe which has a manufacture’s precision rating of ± 0.05 mg O₂/L. Use of the probe allowed for relatively quick
dissolved oxygen measurements as well as simultaneous percent saturation and water temperature measurements. The probe was calibrated to the appropriate elevation and salinity just prior to each sampling day or each time the probe was restarted. Winkler titrations were occasionally used to determine dissolved oxygen levels when probe readings seemed erroneous or were outside of the probe’s scale (USEPA, 1983; and American Public Health Association, 1989).

TDS and pH measurements were made with “Hanna Instruments Dist WP and pHep3 field probes” respectively. The manufacture gives a precision rating of ± 5 ppm for the TDS probe and ± 0.1 units for the pH probe. Both probes were pre- and post-calibrated on each sampling day and fresh calibration solutions were used for each field survey. In addition, mid-day instrument drift checks were made for both probes throughout the project. No significant differences were noted between corresponding pre- and post-calibration values and no significant drift was observed. Estimated conductivity values were obtained indirectly by dividing the TDS values observed in the field by 0.62 (US National Research Council Committee on Water Quality Criteria, 1972; APHA, 1989; and Mayer, 1996).

Turbidity was measured using an in-house field nephelometer constructed by Western Washington University which could be reasonably read to a precision of 1 NTU. The unit was pre- and post-calibrated on each sampling day using both a 0 and a 200 NTU standard. Mid-day instrument drift checks were conducted throughout the study as well. The standards used for calibration were occasionally checked at the Institute for Watershed Studies using a Hach Company Ratio Turbidimeter. No significant differences were noted between corresponding pre and post calibration values and no significant drift was observed.

**Analytical Methods**

All of the analyses for this project except fecal coliform were performed under the direct supervision of the Institute for Watershed Studies at Western Washington University. Fecal
coliform analyses were conducted by Avocet Environmental Testing Inc. Both laboratories participate in the reference sample quality control program of United States Environmental Protection Agency (EPA) as well as the EPA's Water Study and Water Pollution quality control programs. In addition, both laboratories are accredited by DOE to perform all of the respective analyses for this project with the exception of BOD. BOD analyses were, however, performed in accordance with a DOE approved method. Indirect calculations were used to estimate organic phosphorous, organic nitrogen, unionized ammonia, and nitrogenous BOD (NBOD) concentrations. The results of all analyses are presented in Figures 28 through 47 and in Appendices C through I.

All nutrient analyses for this project were performed colorimetrically. Total ammonia, soluble reactive phosphorous, and total phosphorous analyses were conducted manually using a "Milton Roy, Spectronic 21D" spectrophotometer to measure absorbance. Nitrate + Nitrite and total nitrogen analyses were performed using "Alpkem, RFA300" and "Scientific, CFA200" autoanalyzers respectively. Standard curves for each manual-type analysis were generated at the beginning of the project and utilized to its completion. Standard curves for the manual analyses are presented with the corresponding data in Appendices C, F, and G. Automated analyses required standard curve generation each time an analysis was performed. Standard curve data for automated analyses are presented at the beginning of each sample set in Appendices D and E.

Organic nitrogen concentrations were estimated by subtracting the sum of inorganic nitrogen from total nitrogen (APHA, 1989; and Joy et al., 1991). Organic phosphorous concentrations were estimated similarly by subtracting soluble reactive phosphorous from total phosphorous. Condensed phosphates are also a potential constituent of the total phosphorous measurement, but because their use has largely been discontinued, the majority of the difference between total and
soluble reactive phosphorous is assumed to be organically-bound (APHA, 1989). The organic
nitrogen and organic phosphorous estimates presented in this report (Figures 36, 37, 42 and 43,
and Appendix J) should be viewed cautiously as the analytical error inherent in each of the
individual analyses used to calculate the organic values may be cumulative and potentially
excessive for the reported organic values.

Unionized ammonia accounts for a small percent of total ammonia but can be highly
detrimental to fish (Rand and Petrocelli, 1985), and is, therefore, the form that is regulated
(USEPA, 1986; and Washington Administrative Code, 1995). The proportion of total ammonia
in the unionized form varies with fluctuations in water temperature and pH. Unionized ammonia
concentrations were calculated using the general equations

\[ F = \frac{[\text{NH}_3]}{[\text{NH}_3] + [\text{NH}_4^+]} = 10^{\text{pH}} / 10^{\text{pH}} + (K_d/K_w) \]

where:
- \( F \) = proportion of total ammonia in the unionized form
- \( \theta \) = water temperature in degrees Celsius

(Loehr, 1977; and Rand and Petrocelli, 1985). Unionized ammonia estimates are presented in
Figures 32 and 33, and in Appendix J. Individual concentrations in excess of the federal and
state chronic criteria were assessed using the general equation

**Chronic Unionized Ammonia Limit = 0.80/(FT)(FPH)(RATIO)**

where:
- \( FT = 10^{0.03(20-\text{TCAP})}; \) \( \text{TCAP} < T < 30 \)
- \( FT = 10^{0.03(20-T)}; \) \( 0 < T < \text{TCAP} \)
- \( FPH = 1; \) \( 8.0 < \text{pH} < 9.0 \)
- \( FPH = (1 + 10^{(7.4 + \text{pH})}/1.25; \) \( 6.5 < \text{pH} < 8.0 \)
- \( \text{TCAP} = 20 \text{°C}; \) Salmonids present
- \( \text{TCAP} = 25 \text{°C}; \) Salmonids absent
- \( T = \) water temperature, °C
- \( \text{RATIO} = 16; \) \( 7.7 < \text{pH} < 9.0 \)
- \( \text{RATIO} = (24 \times 10^{(7.7 + \text{pH})}/(1 + 10^{(7.4 + \text{pH})}); \) \( 6.5 < \text{pH} < 7.7 \)
In all cases, TCAP was set at 20 °C because several types of Salmonids are known to be present in Johnson Creek (Overdorff, 1981; and Overdorff, 1982). Concentrations exceeding state and federal chronic criteria are designated with a red “c” in Appendix J.

BOD analyses, in general, were performed by collecting three replicate stream samples. One sample was used to measure the initial DO. Following a 5 day incubation, the other two were used to determine BOD (total BOD) and carbonaceous BOD (CBOD). Nitrification was inhibited in the CBOD samples by adding TCMP (Hach Company, Formula 2533™ 2-chloro-6 trichloromethyl pyridine). NBOD was estimated by subtracting CBOD from BOD. Samples were seeded using a commercial seed (Hach Company, Polyseed Inoculum) and then incubated in the dark at a constant temperature of 20° C (+/- 1°) using an incubator provided by the Huxley College of Environmental Studies at Western Washington University. All DO determinations were made using the Winkler Titration (Azide Modification) Method (USEPA, 1983; APHA, 1989; and Hach et al., 1995).

**Water Quality Data Presentation**

The water quality data obtained for this project are presented in Figures 14 through 47 using standard box plots (Figure 6) (Helsel and Hirsch, 1992). The “box” portion of each plot represents the distribution of data occurring between the 25th and 75th percentiles (interquartile). The 50th percentile (median) is represented by the center line across each “box”. The “up and down whiskers” extend from either end of the “box” to the highest and lowest data points within one step (1.5 times the interquartile range) of the box ends. The data points denoted with an “x” (outside values) represent the data occurring between one and two steps from the “box” in either...
Figure 6. Standard Box Plot Components

"Far Outside Values" Indicates values occurring more than 2 steps (3 times the length of the interquartile) above or below the limits of the box

"Outside Values" Indicates values occurring between 1 step (1.5 times the length of the interquartile) and 2 steps (3 times the length of the interquartile) above or below the limits of the box

"Up Whisker" Extends to the highest value occurring between the upper limit of the box and 1 step (1.5 times the length of the interquartile) above the upper limit of the box

"75th Percentile"

"Median" 50th percentile

"25th Percentile"

"Down Whisker" Extends to the lowest value occurring between the lower limit of the box and 1 step (1.5 times the length of the interquartile) below the lower limit of the box
direction and values marked with an "o" (far-outside values) represent the data occurring outside of two steps.

For normal distributions, it has been found statistically that outside values occur fewer than once in 100 times and far-outside values occur less than once in 300,000 times (Helsel and Hirsch, 1992). The frequent occurrence of these values within a number of the data sets, particularly when associated with off-set medians, (i.e. ammonia; Figures 30 through 33), suggests that the data probably originate from a population which does not have a normal distribution.

**Quality Control**

The quality of the data obtained during this project was controlled and assessed through an exhaustive employment of QC procedures and analyses. Data quality was maximized through a regimented use of standard sample collection and preservation procedures as well as strict adherence to laboratory protocols. The quality of the data related to analytical procedures were assessed through the analyses of blanks, replicate samples, spikes, and standards. The quality of the data obtained from direct field measurements were also assessed by performing replicate measurements either with duplicate equipment or by alternate methods.

All stream water samples were obtained as grab-type samples. To insure collection of a representative sample, containers were filled from approximately center channel, either at elbow depth in deep water or approximately mid depth in shallow water. Samples were collected in sterile glass or polyethylene containers as appropriate, and were rinsed a minimum of three times with stream water prior to obtaining a final sample. Care was also exercised to minimize the disturbance of bottom sediments during the collection of samples. Samples were kept dark and cool (<4 °C) during transport to the laboratory. Additional care was employed during the
collection and transport of DO and BOD samples to minimize the addition of extraneous oxygen or excessive exposure to ultraviolet light. All DO samples were “fixed” in the field by adding to the sample bottles two ml each of manganous sulfate, sodium hydroxide-iodide-azide solution, and concentrated sulfuric acid (APHA, 1989).

Upon returning to the laboratory, samples were either analyzed immediately or frozen for later analysis. All samples were analyzed within prescribed holding times (USEPA, 1983; and APHA, 1989). During the preparation of samples, pipettes, flasks, and other measuring apparatus were rinsed a minimum of three times with sample prior to delivery, and all sample dilutions were made with deionized distilled water. Prior to use, all laboratory glassware and miscellaneous equipment were thoroughly cleaned with non-phosphate-containing soap and 2N HCl, as appropriate, and rinsed with copious amounts of distilled water.

QC samples were analyzed throughout this project to detect potential procedural inadequacies, assess variation, and measure analytical precision. At a minimum, one field blank and randomly chosen field replicates equal to 10% of the total number of samples collected were analyzed for each field survey. A minimum of three method blanks, one matrix spike, a high and low check standard, and randomly chosen laboratory replicates equal to 10% of the total number of samples analyzed were used each time a nutrient analysis was performed. In addition, at least two nitrite recovery standards were analyzed during each automated nutrient analysis. The minimum number of QC samples analyzed during each BOD analysis included a similar proportion of replicate samples, one laboratory blank, and one glucose/glutamic acid standard. Relative percent difference (RPD) distributions for replicate samples are presented in Figures 7 and 8 using standard box plots (see Figure 6), and summarized in Tables 5 and 6. The
distribution of matrix spike percent recovery values is summarized in Table 7. The results of all QC analyses are presented in Appendices C through I. Two separate analytical QC discrepancies that could not be resolved were encountered over the course of this project. During the February analyses of total phosphorus and soluble reactive phosphorous, high RPD values in both the field and laboratory replicate samples were observed. Low spike recovery was also observed for total phosphorus during the same analysis. The high RPD values observed in the laboratory replicates are attributed to inadequate blending of color reagent during sample preparation. The high RPDs for field replicates and the poor spike recovery are attributed to the inability to replicate samples in the laboratory. February phosphorous data may be biased low and should be regarded as estimations. Also, the BOD of the glucose/glutamic acid standard for the June BOD analysis was substantially lower than what is prescribed (APHA, 1989). This may have resulted from inefficient seeding, and associated BOD results may also be biased low. All other analytical QC discrepancies were resolved.

The quality of the data obtained by direct field measurement (pH, TDS, water temperature, turbidity, discharge, DO) was assessed by replicating the measurements with duplicate equipment or an alternate measuring technique. Replicate pH and TDS measurements were made using duplicate probes and water temperature measurements were repeated using a mercury thermometer. Turbidity QC measurements were performed using the ratio turbidimeter at the Institute for Watershed Studies. Variation for discharge measurements was assessed by constructing rating curves over the course of the project and evaluating the correlation ($r^2$) values of each regression (Fetter, 1994; Helsel and Hirsch, 1992; Watson and Burnett, 1995; and Zar, 1996). DO data quality was assessed by analyzing replicate samples using the Winkler Azide modification method (APHA, 1989). With the exception of discharge, random replicate
Figure 7: Laboratory Replicate Distributions

Figure 8: Field Replicate Distributions
### Table 5. Field Replicate RPD Distributions

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Range (%)</th>
<th>Mean (%)</th>
<th>Rel. Std. Dev. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ammonia</td>
<td>0.00 - 27.44</td>
<td>1.17</td>
<td>7.51</td>
</tr>
<tr>
<td>Nitrate + Nitrite</td>
<td>0.10 - 6.95</td>
<td>0.09</td>
<td>1.64</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>0.00 - 27.41</td>
<td>0.32</td>
<td>7.09</td>
</tr>
<tr>
<td>Soluble Reactive Phosphorous</td>
<td>0.00 - 38.17</td>
<td>0.82</td>
<td>8.38</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>0.23 - 6.36</td>
<td>0.54</td>
<td>2.58</td>
</tr>
<tr>
<td>Fecal Coliform</td>
<td>0.00 - 34.29</td>
<td>6.50</td>
<td>13.71</td>
</tr>
<tr>
<td>$BOD_5$</td>
<td>1.72 - 40.23</td>
<td>6.17</td>
<td>20.85</td>
</tr>
</tbody>
</table>

### Table 6. Laboratory Replicate RPD Distributions

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Range (%)</th>
<th>Mean (%)</th>
<th>Rel. Std. Dev. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ammonia</td>
<td>0.15 - 49.75</td>
<td>4.31</td>
<td>10.54</td>
</tr>
<tr>
<td>Nitrate + Nitrite</td>
<td>0.00 - 6.53</td>
<td>0.04</td>
<td>1.54</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>0.00 - 27.50</td>
<td>0.31</td>
<td>5.48</td>
</tr>
<tr>
<td>Soluble Reactive Phosphorous</td>
<td>0.00 - 4.96</td>
<td>0.98</td>
<td>1.59</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>0.00 - 10.79</td>
<td>0.22</td>
<td>3.18</td>
</tr>
<tr>
<td>$BOD_5$</td>
<td>0.00 - 5.46</td>
<td>1.80</td>
<td>2.46</td>
</tr>
</tbody>
</table>

### Table 7. Matrix Spike Percent Recovery Distributions

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Average Range (%)</th>
<th>Average Mean (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ammonia</td>
<td>96 - 134</td>
<td>110</td>
</tr>
<tr>
<td>Nitrate + Nitrite</td>
<td>90 - 102</td>
<td>98</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>99 - 108</td>
<td>105</td>
</tr>
<tr>
<td>Soluble Reactive Phosphorous</td>
<td>90 - 103</td>
<td>97</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>74 - 128</td>
<td>98</td>
</tr>
</tbody>
</table>

Measurements were performed on a minimum of 10% of the total number of measurements made during each field survey.

Little to no variation between the primary and QC measurements for pH, TDS, water temperature, and turbidity was observed and no statistical comparisons were performed. The pH
values obtained during both the December reconnaissance and February field surveys seemed anomalously high when compared with the pH values observed during other periods of this project and with both of the previous studies. Because pH has a strong influence on unionized ammonia concentrations, if the December and February pH values are erroneously high, then the calculated unionized ammonia values reported for December and February would be biased high as well. The results of all QC field measurements are presented in Appendix A.

Rating curves were developed for 12 sampling sites (J1, SM2, J3, J4, J5, J6, J8, P9, P10, SQ11, SQ12, and J13). Rating curves were not developed at sites CB7 and J14 because the culverts at these sites were occasionally plugged with debris which resulted in nonlinear discharge to water depth plots. No attempt was made to develop a curve at sampling site D15 because it was established late in the project. Based on the calculated coefficient of determination ($r^2$) values, potential errors ranged from 5.8 to 21.3% at sampling sites J5 and SM2 respectively. The mean potential error was 12.4%. Rating curves and regression results are presented in Appendix B.

Figures 9a and 9b show a comparison of the Winkler QC samples and corresponding DO probe readings. The figures indicate that the preponderance of QC samples analyzed during the wet-season surveys tend to be lower than the probe readings, and QC samples analyzed for the dry-season appear to be more evenly distributed about the probe readings. The entire sample population has an RPD range of 0.25 - 20.44% with a mean RPD of 4.04% and a relative standard deviation of 7.53%.

When a comparison is conducted for the populations representing the wet and dry-season surveys separately a significant statistical improvement for the dry-season samples occurs.
Wet-season samples have a mean difference of 0.49 mg O$_2$/L and a standard deviation of 0.61 mg O$_2$/L. In comparison, dry-season samples have a mean difference of 0.01 mg O$_2$/L and standard deviation of 0.35 mg O$_2$/L. Correspondingly, wet-season samples have a mean RPD of 6.20% and a relative standard deviation of 7.66%, where dry-season samples have a mean RPD of
0.49% and a relative standard deviation of 4.67%. Despite fixing QC samples in the field, oxygen depletion of wet-season QC samples appears to have occurred frequently, which may be a result of a longer holding time (up to 24 hours). The QC samples obtained during the dry-season surveys were titrated much closer to the time of collection (within 4 hours) and may reflect more accurately the true variation between the two methods. The variation of the Winkler method was also assessed by analyzing additional field and laboratory replicate samples equal to at least 10% of the total number of Winkler samples collected. Field replicate RPDs ranged from 0.00 - 3.96% with a mean RPD of 0.07% and a relative standard deviation of 1.72%. Laboratory replicate RPDs ranged from 0.00 - 1.95% with a mean RPD of 0.02% and a relative standard deviation of 1.01%.

**Stream Water Modeling**

Computer generated stream water models for both nitrogen and phosphorus were constructed to help identify sources of farm waste loading along the Johnson Creek stream corridor. These models were also utilized to develop scenarios for improving stream water quality. A similar computer generated DO model was constructed as well but, because BOD data was only collected during the dry-season surveys, the model is limited to the low-flow period and was utilized primarily for assessing water quality improvement scenarios.

Although fecal coliform is a primary focus of regulation, attempts to produce a meaningful fecal coliform model were unsuccessful, principally because of its variable nature. However, if both the nutrient and fecal coliform constituents result from the direct input of farm waste, sources of high nutrients, particularly ammonia which is indicative of fresh farm waste input (Storch, et al., 1993), would coincide with sources of high fecal coliform. Therefore, aims to reduce nutrient input, particularly ammonia, should over time, effect a reduction in fecal coliform
concentrations as well. Figures 10 and 11 show step-trends (Helsel and Hirsch, 1992) for total ammonia and fecal coliform concentrations respectively, for the 1980/1981, 1988/1989, and 1996 study periods. The figures show a corresponding overall reduction in both the total ammonia and fecal coliform concentrations over the past 20 years, which is likely attributable to BMP implementation and efforts to reduce the direct input of farm waste into the stream.

A reduction in nutrient loading is also likely to coincide with a reduction in the organic material present in the stream and a corresponding improvement in the DO levels. Figure 12 shows a slightly improving step trend for the dissolved oxygen concentrations over the same period of total ammonia reduction shown in Figure 10.

**Model Structure**

Stream models were constructed using a spreadsheet format with the basic model structure, including the equations incorporated to simulate constituent transport, modified from The Enhanced Stream Water Quality Model - QUAL2E (US EPA, 1987). Pertinent excerpts from the QUAL2E user's manual are presented in Appendix P. All of the simulations conducted for this project assume steady-state conditions and laminar flow.

Figure 13 presents a schematic of the model structure. Modeling was confined to the main channel of Johnson Creek between the Johnson Creek/Sumas River confluence (RM 0.0) and sampling site J14 (RM 10.0). The modeled stream is divided into seven reaches ranging in length from 0.5 miles (Reach 2) to 2.3 miles (Reach 4). The hydraulic characteristics over the length of the modeled stream are relatively uniform so reach divisions were established principally around the location of sampling sites. Each reach is further subdivided into individual computational sections, each representing 0.1 miles of stream length.
Figure 10. Twenty Year Total Ammonia Step-Trend

Comparison of Total Ammonia, Combined Values from Sampling Sites J1 and J13

Figure 11. Twenty Year Fecal Coliform Step-Trend

Comparison of Fecal Coliform, Combined Values from Sampling Sites J1 and J13
Figure 12. Twenty Year Dissolved Oxygen Concentration Step-Trend

Comparison of Dissolved Oxygen, Combined Values from Sampling Sites J1 and J13
Figure 13. Johnson Creek Stream Model Schematic
Tributary data were collected near each confluence with the main stream and were therefore simulated as point sources. Nonpoint source (dispersed) loading was simulated by incorporating input equations from each computational section. The dispersed loading equations were configured to input both the discharge and water quality constituent data uniformly within each reach. Mixing at each tributary or computational section junction with the main stream was simulated using the dilution equation

\[
\frac{(Q_1C_1)+(Q_2C_2)}{(Q_1+Q_2)}
\]

where:
- \( Q_1 \) = main stream discharge
- \( Q_2 \) = tributary or dispersed input discharge
- \( C_1 \) = main stream concentration
- \( C_2 \) = tributary or dispersed input concentration

Nitrogen transport and loading were simulated for total ammonia and nitrate+nitrite. The downstream oxidation of total ammonia to nitrite was simulated using the differential equation

\[
d\frac{\text{NH}_3}{dt} = -\beta_{\text{NH}_3}\text{NH}_3
\]

where:
- \( \beta_{\text{NH}_3} \) = rate constant for the oxidation of \( \text{NH}_3 \) to \( \text{NO}_2 \), \( \text{day}^{-1} \)
- \( \text{NH}_3 \) = total ammonia concentration, mg N/L
- \( t \) = time

(US EPA, 1987). This equation was modified to

\[
\Delta \text{NH}_3 = -\beta_{\text{NH}_3}\text{NH}_3 \Delta t
\]

and \( \Delta t \) was converted to distance utilizing the average velocity measured along each reach. The \( \beta_{\text{NH}_3} \) input value for each simulation was further modified within the model to be reach specific by applying an oxidation inhibition factor based on the DO concentrations measured along each reach. This factor was calculated using the equation

\[
\text{COR}_{\text{DO}} = 1.0 - \exp(-K_{\text{NIT INHB DO}})
\]
where: \( \text{COR}_{DO} \) = nitrification rate correction factor
\( K_{NIT \text{ INHIB}} \) = 1st order nitrification inhibition coefficient, (mg/L)\(^{-1}\)
\( \text{DO} \) = average dissolved oxygen within the reach or section of reach, mg O\(_2\)/L

(US EPA, 1987). Nitrogen oxidation rate constants (\( \beta \)) in QUAL2E are temperature dependent (Appendix P) and utilize a Streeter-Phelps type equation to account for changes in stream water temperature. For this project, a distinct \( \beta \) value was determined empirically for each simulation (see “Input and Calibration” section), and significant variation in water temperature along the main stream was not observed during individual surveys. A \( \beta \) water temperature compensation equation was, therefore, not incorporated into the model structure.

Nitrate+nitrite transport was modeled by simulating the nitrite and nitrate components separately and then summing the two. Nitrite and nitrate transport were simulated using the differential equations

\[
d \frac{d \text{NO}_2}{dt} = \beta_{\text{NH}_3} \text{NH}_3 \beta_{\text{NO}_2} \text{NO}_2 \quad \text{and} \quad d \frac{d \text{NO}_3}{dt} = \beta_{\text{NO}_2} \text{NO}_2
\]

where: \( \beta_{\text{NO}_2} \) = rate constant for the oxidation of \( \text{NO}_2 \) to \( \text{NO}_3 \), day\(^{-1}\)
\( \text{NO}_2 \) = nitrite concentration, mg N/L

(US EPA, 1987). As with ammonia, both equations were modified to

\[
\Delta \text{NO}_2 = \beta_{\text{NH}_3} \text{NH}_3 \beta_{\text{NO}_2} \text{NO}_2 \Delta t \quad \Delta \text{NO}_3 = \beta_{\text{NO}_2} \text{NO}_2 \Delta t
\]

with \( \Delta t \) converted to downstream distance utilizing the average velocity. The oxidation inhibition factor applied to \( \beta_{\text{NH}_3} \) was also applied to \( \beta_{\text{NO}_2} \) (US EPA, 1987).

Phosphorous loading and transport were simulated for total phosphorous only. The relationship between organic and soluble reactive phosphorous can generally be described by the differential equations

\[
d \frac{d \text{P}_{\text{ORG}}}{dt} = -\beta_{\text{ORG}} \text{P}_{\text{ORG}} \quad \text{and} \quad d \frac{d \text{P}_{\text{SRP}}}{dt} = \beta_{\text{ORG}} \text{P}_{\text{ORG}}
\]
where: $P_{ORG} = \text{organic phosphorous concentration}$
$P_{SRP} = \text{soluble reactive phosphorous concentration}$
$\beta_{ORG} = \text{organic phosphorous decay rate}$

(US EPA, 1987). Because of this relationship and the fact that changes in the relative proportions of organic to soluble reactive phosphorous concentrations do not affect the total phosphorous concentration, total phosphorous transport simulations did not require the use of differential equations. Total phosphorous transport was simulated using dilution equations alone.

DO and BOD transport were simulated using the differential equations

$$\frac{dO}{dt} = K_2(O_s-O)-K_1BOD$$
$$\frac{dBOD}{dt} = -K_1BOD$$

where: $O = \text{DO concentration, mg O}_2/L$
$O_s = \text{DO saturation concentration at local temperature and pressure, mg O}_2/L$
$BOD = \text{concentration of ultimate carbonaceous BOD, mg/L}$
$K_1 = \text{carbonaceous BOD deoxygenation rate constant, day}^{-1}$
$K_2 = \text{DO reaeration rate constant, day}^{-1}$

(US EPA, 1987). As with the nutrient models, the differential equations for DO and BOD were modified to

$$\Delta O = K_2(O_s-O)-K_1BOD \Delta t$$
$$\Delta BOD = -K_1BOD \Delta t$$

and $\Delta t$ was converted to distance using average velocity values. DO saturation concentrations were incorporated into the model using the equation

$$\ln O_s = -139.34410+(1.575701 \times 10^5/T)-(6.642308 \times 10^7/T^2)$$
$$+(1.243800 \times 10^{10}/T^3)-(8.621949 \times 10^{11}/T^4)$$

where: $T = \text{water temperature, °K}$

for temperatures within the range 0 to 40 °C and $O_s$ concentrations at 1.000 atm (US EPA, 1987). DO reaeration rates were determined along each reach by incorporating the equation

$$K_{20}^{20 \text{C}} = 9.4\mu^{0.67}/2.31d^{3.85}$$

where: $\mu = \text{mean velocity, ft/sec}$
$d = \text{mean depth, ft}$
which was then adjusted to local water temperature using the equation

\[ K^\text{LOC}_2 = K^2_20 \theta (T-20) \]

where: \( \theta \) = empirical constant for QUAL2E reaction coefficients
\( T \) = water temperature, °C

(US EPA, 1987). BOD\(_5\) input and output values were converted to BOD\(_u\) within the model by incorporating the equation

\[ \text{BOD}_5 = BOD_u (1.0 - \exp(-5 \times K_{\text{BOD}})) \]

where: \( K_{\text{BOD}} \) = BOD conversion rate coefficient, day\(^{-1}\)

(US EPA, 1987).

**Input and Calibration**

Simulations were performed for each of the 12 water quality surveys conducted between January and September 1996. With the exception of nitrite, water quality constituent input for each simulation was derived from the corresponding data obtained during the second day of each wet-season survey and the morning of each dry-season survey. This was considered appropriate for nutrient input since minimal data variation was observed over the course of each survey and, based on the observed range of velocities and the length of the stream, the average residence time between sampling sites J14 and J1 was estimated to be approximately two days. The diurnal variation of DO over the course of the dry-season surveys averaged approximately three mg O\(_2\)/L with low values occurring in the morning. The DO simulations are therefore considered representative of worst-case conditions.

Because nitrite was not measured directly during either this project or the 1988/1989 study, nitrite input had to be estimated from the data obtained during the 1980/1981 study. A value of 50 µg N/L, which is the approximate median nitrite value observed during the 1980/1981 study,
was used as the nitrite headwater input value for each simulation (Overdorff, 1881; and Overdorff, 1982). No simulated downstream nitrite concentration exceeded 0.5 mg N/L, which assumably would be an order of magnitude above actual stream conditions.

QUAL2E default values for $K_{\text{NitInhib}}$, $\theta$ (for $K_2$), and $K_{\text{BOD}}$ of 0.65 (mg/L)$^{-1}$, 1.024, and 0.23 day$^{-1}$ respectively were utilized for all of the simulations (US EPA, 1987). Distinct $\beta_{\text{NH3}}$ and $K_1$ values were determined empirically for each simulation by manipulating the coefficient values to a point at which the modeled data corresponding with the observed data along the length of reach 2. This reach was selected for this task because flow balancing required a minimal amount of dispersed flow input. $\beta_{\text{NO2}}$ values were set equal to the $\beta_{\text{NH3}}$ values to maintain the assumed low nitrite levels.

The $\beta_{\text{NH3}}$ and $\beta_{\text{NO2}}$ values required to explain ammonia decreases and the corresponding nitrate+nitrite increases ranged from 1.0 to 5.7 day$^{-1}$. The higher values generally coincided with the wet-season simulations and associated higher ammonia concentrations. These values exceeded the typical QUAL2E range of 0.10 to 1.00 day$^{-1}$ for $\beta_{\text{NH3}}$ and 0.20 to 2.00 day$^{-1}$ for $\beta_{\text{NO2}}$ (US EPA, 1987). However, a nitrification value of 4.0 day$^{-1}$ was used to model ammonia along the lower Puyallup River where ammonia concentrations were elevated (Pelletier, 1993) and values as high as 9.0 day$^{-1}$ have been reported for other rivers (US EPA, 1985).

The $K_1$ values required to explain the observed BOD decay ranged from 1.0 to 3.4 day$^{-1}$. The QUAL2E model does not specify a typical range for $K_1$ but sets the default value at 1.047 day$^{-1}$ (US EPA, 1987). Additionally, EPA recommends a constant rate of 3.3 day$^{-1}$ for streams with flows less than 10 cfs (Pelletier, 1993) which is the approximate average discharge of Johnson Creek during the later dry-season months.
The discharge values observed during this project typically increase in a downstream direction (Figure 14, and Appendices A, B and J). With the exception of reach 2 (Figure 13), tributary input was not sufficient alone to account for the observed increases in discharge, and the differences were presumed to result from a combination of overland and base flow input. Flow balance for each simulation was, therefore, obtained by adding an appropriate volume of water as dispersed discharge from the computational section junctions. Once flow balance was achieved and the appropriate constituent rate constants were determined, discrepancies between observed and modeled constituent concentrations were resolved by adding appropriate dispersed load concentrations from the computational section junctions to simulate nonpoint source loading.

Through the reconstruction and balancing of the transport and loading conditions present at the time of each survey, loading sources were identified by model reach and the loads quantified. When the results of the various simulations were compared, seasonal loading trends were also discernible. Summaries of the predicted nutrient transport and loading are shown in Figures 48 through 53 and are described in greater detail in the “Project Findings” section of this report. After the existing loading conditions were determined, a number of improvements scenarios were generated by simply reducing or removing various loads from the modeled stream. The results of the improvement scenarios generated for this project are presented in Figures 72 through 79 and are discussed in greater detail in the “Conclusions and Recommendations” section of this report. The results of all the individual simulations are presented in Appendices M, N, and O.

**Historical Comparisons and Water Quality Trends**

Water quality trends and the overall effectiveness of the BMPs presently in place were assessed by comparing the dissolved oxygen, nutrient, and fecal coliform data obtained during
this project with those collected during the 1980/1981 and 1988/1989 studies. The primary comparisons were made between the median values from corresponding sampling sites for each study period. An inspection of the data revealed that the data populations for each study year possess a roughly proportional number of wet and dry-season samples so median values were calculated using entire populations. Attempts to remove data for months not sampled during comparison years became overly subjective and had a minimal effect on the calculated median values. The results of the median comparisons are presented in Figures 54 through 69. The water quality data obtained during the 1980/1981 and 1988/1989 studies are presented in Appendices K and L respectively.

To supplement the comparison of data medians, statistically significant differences between data collected for this project and the two previous studies were evaluated using the Mann-Whitney test (Zar, 1996). Adequate data for testing along Johnson Creek, which corresponded to all three studies, were only available for sampling sites J1, J8, and J13. An additional test was generated for Johnson Creek by estimating the 1996 concentrations for the location which would roughly correspond with sampling sites #5 and J7 from the 1980/1981 and 1988/1989 studies respectively (Table 1). Changes near the terminations of Pangborn and Squaw Creeks were also investigated by conducting tests on the data collected at sites P9 and SQ11. A standard significance level of $p \leq 0.05$ was used for all Mann-Whitney comparisons and positive results are presented along with each of the corresponding median comparisons.

Nonpoint source pollution can be highly influenced by precipitation, particularly in an agricultural region. Therefore, differences between the median values for each of the comparison years may be, at least in part, attributable to differences in precipitation during each of the
comparison years. The BMPs implemented within the Johnson Creek watershed, however, were
designed to prevent or at least minimize stream contamination from nonpoint source agricultural
waste under weather conditions less severe than a 25-year flood event (Gillies, et al., 1998).
Increased stream loading, regardless of precipitation, would, therefore, reflect BMP
inadequacies.

PROJECT FINDINGS

Existing Water Quality Conditions

The distributions of the water quality data obtained during this project are presented in
Figures 14 through 47 using standard box plots (see Figure 6 for box plot explanation), and are
presented by both sampling site and survey date. Plots presented by sampling site are intended to
show parameter trends for the various sampling locations. The individual boxes incorporate all
of the parameter data obtained over the course of the project at each site. The tributaries are
presented using gray boxes and outlier points to distinguished them from the main stream sites.
Plots presented by sampling date are intended to show basin trends over the course of the project
and the individual boxes are constructed from the parameter data obtained basin-wide on a
particular survey date.

Water quality parameters are assessed relative to state, class-A-stream standards as
applicable. Parameters for which no state stream standard exists are assessed relative to
appropriate alternative standards (i.e. drinking water standards) as applicable. The raw data for
all parameters are presented in Appendices A, and C through I, and are summarized in
Appendix J.
**General Parameters**

The distribution of discharge, water temperature, pH, conductivity, and turbidity measurements are presented in Figures 14 through 23. Water temperature, pH, and turbidity are the only general parameters for which state, class-A-stream standards exist. Conductivity is assessed with regards to the federal drinking water standard.

**Discharge**

Discharge values measured along the length of Johnson Creek show an expected pattern of increasing flow in the downstream direction (Figure 14). Increasing discharge between sampling sites J14 and J8 can be partially attributed to flow contributions from Squaw Creek and Pangborn Creek with the remainder assumably coming from a combination of overland and base flow input. Because no major tributaries occur between sampling sites J8 and J3, downstream increases along this reach are assumable derived from overland and base flow input exclusively. The differences in discharge between sampling sites J3 and J1 can primarily be accounted for by input from Sumas Creek. Discharge values measured over the course of this project show a pattern of high flow during the wetter portions of the year gradually diminishing into the dry-season (Figure 15). This pattern is roughly reflected by the average monthly precipitation values obtained from the Clearbrook station (Figure 3). Although discharge was observed to fluctuate in response to precipitation events, a positive correlation could not be determined mathematically.

**Water temperature**

Water temperature measurements exhibit minimal variation for individual surveys with the exception of CB7, J13, J14, and D15, which were consistently slightly elevated (Figure 16). Higher water temperature likely persists at these sites because of an absence of riparian shade and significantly shallower water than at the other shadeless sites. The water temperature pattern
Figure 14. Discharge Levels by Sampling Site

![Box plot showing discharge levels by sampling site](image)

Project-Wide Discharge Values
Plotted by Sampling Site

Figure 15. Discharge Levels by Sampling Date

![Box plot showing discharge levels by sampling date](image)

Basin-Wide Discharge Values
Plotted by Sampling Date
over the course of this project (Figure 17) closely reflects the average monthly air temperature pattern as measured at the Clearbrook station (Figure 4) with the lowest temperatures occurring during the winter and progressively warming through the summer. Water temperature exceeded the state, class-A-stream standard of 18 °C (WAC, 1995) at sampling site J13 during the June survey and at J13, J14, and D15 during the July survey. Because of an apparent strong, positive correlation between air temperature and water temperature, water temperatures probably also exceeded the 18 °C-standard on many of the other warm summer days during which sampling was not conducted.

**pH**

The state, class-A-stream standard for pH requires that levels remain between a range of 6.5 and 8.5 and that human activity does not induce a variation greater than 0.5 (WAC, 1995). The pH levels measured during this project remained within the 6.5-8.5 range with the exception of sampling sites J3 during the June survey and D15 during the March 23-25 survey (Figures 18 and 19). The pH at these sites was measured at 6.4 and 8.6 respectively, however, with an instrument drift range of 0.0 to 0.2 (Appendix A) the actual pH may have been within the state, class-A-range. The range of pH values measured at individual sites often exceeded 1.0 but natural variation can not be distinguished from anthropogenically induced variation. The typical median pH is approximately 7.4

**Conductivity**

Conductivity, which is a measure of dissolved ion concentration, was used as a general measure for detecting potential farm waste input source areas. The conductivity at all sampling sites except CB7, J13, J14, and D15 are within a range of 150 to 250 μmhos/cm (Figure 20). Undisturbed, non-granitic watersheds typical have a conductivity of approximately 170
Figure 16. Water Temperature Levels by Sampling Site

Project-Wide Water Temperature Values
Plotted by Sampling Site

Figure 17. Water Temperature Levels by Sampling Date

Basin-Wide Water Temperature Values
Plotted by Sampling Date
Figure 18. pH Levels by Sampling Site

Project-Wide pH Values
Plotted by Sampling Site

Figure 19. pH Levels by Sampling Date

Basin-Wide pH Values
Plotted by Sampling Date
μmhos/cm (Driscoll, 1986; and Mayer, 1996). Conductivity levels at sampling sites CB7, J13, J14, and D15 are markedly higher, ranging from 200 to 450 μmhos/cm. No state, class-A-stream standard exists for conductivity, but the federal drinking water standard for TDS is not to exceed 500 mg/L which is approximately equivalent to a conductivity of 800 μmhos/cm (US National Research Council Committee on Water Quality Criteria, 1972; and CFR, 1997). All of the conductivity measurements were well below this limit. No distinctive weather related pattern was apparent when conductivity was plotted against sampling date (Figure 21).

**Turbidity**

Turbidity is an indirect measure of the suspended solids present within the water column. In an agriculturally dominated watershed, turbid waters may propagate from a variety of sources including sediment run-off from devegetated stream banks, the direct introduction of manure or over-spray during fertilizer applications, or from the decay of aquatic vegetation proliferated by excessive nutrient loading. For a stream to be classified class-A, turbidity can not exceed 5.0 NTU over background when the background turbidity is 50.0 NTU or less (WAC, 1995). Turbidity measurements for this project ranged from 0.0 to 50.0 NTU with a typical median of approximately 2.0 NTU (Figure 22 and 23). The class-A-limit was, therefore, assessed at 7.0 NTU, which is safely at or below background turbidity plus 5 NTU. As with conductivity, turbidity was used as a general measure for detecting possible farm waste input source areas. Turbidity exceeded 7.0 NTU at most sampling sites at some point during the course of the project (Appendix A) but regularly exceeded this limit at sampling sites CB7, J13, and D15 (Figure 22). When turbidity is plotted against sampling date (Figure 23) no clear seasonal pattern is apparent. However, high median turbidity levels were recorded during the February 10-12 and May 18-20 surveys which were both conducted immediately following significant precipitation events.
Figure 20. Conductivity Levels by Sampling Site

Project-Wide Conductivity Values Plotted by Sampling Site

Figure 21. Conductivity Levels by Sampling Date

Basin-Wide Conductivity Values Plotted by Sampling Date
Figure 22. Turbidity Levels by Sampling Site

Project-Wide Turbidity Values Plotted by Sampling Site

Figure 23. Turbidity Levels by Sampling Date

Basin-Wide Turbidity Values Plotted by Sampling Date
**Dissolved Oxygen**

For a stream to be considered class A, the concentration of dissolved oxygen must exceed 8.0 mg O\textsubscript{2}/L (WAC, 1995). Concentrations were below this limit at all sampling sites except P9 and SQ11 at various times throughout the project (Figure 24). Median concentrations were below 8.0 mg O\textsubscript{2}/L at sampling sites J1, SM2, J3, J4, J5, CB7, P10, J13, and J14. Exceptionally low concentrations were observed at sites CB7, J13, and J14, where minimum concentrations approach anoxic conditions.

The plot of concentration against sampling site (Figure 24) reveals that dissolved oxygen tends to increase in the downstream direction within the upper reaches of Johnson Creek (sites J14 to J8). Here, stream velocity and associated reaeration also increase downstream, and discharge input from Squaw and Pangborn Creeks, which have higher gradients and numerous overfalls, is significant. Below site J8, where tributary input is minimal, concentrations tend to sag. Sumas Creek (SM2) contributes slightly higher dissolved oxygen concentrations to the main stream and, as a result, the sagging concentrations appear to level off at sampling site J1.

The plot of concentration against sampling date (Figure 25) shows that dissolved oxygen levels were below the state, class-A-stream standard throughout much of the watershed during the majority of the project. Median concentrations were below 8.0 mg O\textsubscript{2}/L during the December reconnaissance and the periods between the February 10-12 through March 9-11 surveys and the May 18-20 through September 4 surveys. The plot reveals a decreasing trend following the January 20-22 survey, which corresponds with the reports of winter manure spreading (Dorf, 1996). Then, following a significant increase in late March, concentrations steadily decrease again throughout the remainder of the project. Concentrations were consistently lowest during
Figure 24. Dissolved Oxygen Concentrations by Sampling Site

Project-Wide DO Concentration Values
Plotted by Sampling Site

Figure 25. Dissolved Oxygen Concentrations by Sampling Date

Basin-Wide DO Concentration Values
Plotted by Sampling Date

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the summer months when water temperatures were at a maximum and recharge was at a minimum.

When percent saturation levels are plotted, the pattern produced is virtually identical to the concentration plots for both location and seasonal trends (Figures 26 and 27). The typical median saturation level is approximately 60% with a range of 10% to 140%. As with concentration, the lowest saturation levels were observed during the December reconnaissance survey and the late summer months with a distinct decreasing trend observed from June through September.

Although BOD data are limited to the dry-season surveys, some information as to the location and nature of BOD loading was ascertained. Total BOD values for the project range from less than 2.0 to over 12.0 mg/L (Figure 28). The main stream of Johnson Creek possesses a typical median value of approximately 3.0 mg/L and values tend to decrease in the downstream direction. Significantly higher values were recorded at sampling sites CB7 and J13, where median values were approximately 6.0 mg/L and maximum values exceeded 12.0 mg/L.

The plot of BOD against sampling date (Figure 29) provides little information regarding the seasonal trend. However, overall BOD values appear to increase during the early portion of the summer. Chemical analyses indicate that the preponderance of the BOD measured was carbonaceous with the exception of the Clearbrook site, where significant nitrogenous values, approximately equal to the carbonaceous values, were recorded for the September 4 survey (Appendix I). Ammonia levels were relatively low during the summer as compared with the levels observed during the winter and, as a result of greater ammonia oxidation, nitrogenous BOD may be greater during the wetter portion of the year.
Figure 26. Dissolved Oxygen Percent Saturation by Sampling Site

Project-Wide DO % Saturation Values
Plotted by Sampling Site

Figure 27. Dissolved Oxygen Percent Saturation by Sampling Date

Basin-Wide DO % Saturation Values
Plotted by Sampling Date
Figure 28. Biochemical Oxygen Demand Concentrations by Sampling Site

Project-Wide BOD Values
Plotted by Sampling Site

Figure 29. Biochemical Oxygen Demand Concentrations by Sampling Date

Basin-Wide BOD Values
Plotted by Sampling Date
Nutrients

The concentration distributions for total ammonia, unionized ammonia, nitrate+nitrite, organic nitrogen, total nitrogen, soluble reactive phosphorous, organic phosphorous, and total phosphorous are presented in Figures 30 through 45. State, class-A-stream standards do not exist for nutrients and no alternative standards exist for total ammonia or total nitrogen. Unionized ammonia concentrations are assessed with regards to the federal three day chronic criteria and nitrate+nitrite concentrations are assessed with regards to the federal drinking water standard (USEPA, 1986; and WAC, 1995). Soluble reactive phosphorous, organic phosphorous, and total phosphorous concentrations are assessed with regards to the EPA suggested total phosphorous limit for flowing waters (USEPA, 1986).

Ammonia

Total ammonia concentrations, as measured by the phenate and other analytical methods, include both the unionized form of ammonia (NH₃) and ammonium ions (NH₄⁺) (Rand and Petrocelli, 1985; and APHA, 1989). Because of the ease of NH₃ diffusion over fish gill membranes, it is generally considered more toxic than NH₄⁺, and is therefore the form that is regulated. Evidence exists, however, that NH₄⁺ can be excreted across gills in exchange for Na⁺, and may be more toxic to aquatic organisms than earlier believed (Rand and Petrocelli, 1985). Regardless of its toxicity, in an agriculturally dominated watershed, the presence of high ammonia concentrations in an oxic system is a likely indication of relatively recent farm waste introduction (Storch et al., 1993).

The total ammonia concentrations recorded for this project generally remained within a range of 50 to 500 µg N/L with the exception of sampling sites CB7, J13, J14, and D15 (Figure 30). Concentrations often exceeded 500 µg N/L at sampling site J13 and regularly exceeded 500 µg
N/L at sites CB7 and J14. Site D15, which was not monitored during the early winter months, has a median concentration of approximately 500 μg N/L. A greater number of high values likely would have been observed at this site had it been monitored during the wetter months of the project. Concentrations also occasionally exceeded 500 μg N/L at sampling sites SM2, J6, J8, P9, and P10 (Figures 30 and 31 and Appendices C and J).

When total ammonia concentrations are plotted against survey dates (Figure 31), a fairly clear seasonal pattern is apparent. The plot reveals a steep increase during February, which was an exceptionally rainy month and followed the melt-off of heavy January snow; Numerous complaints were received by DOE in January regarding the spreading of manure slurry over the snow-pack in the basin (Dorf, 1996). Total ammonia concentrations diminish from February through early April as monthly precipitation totals diminish and median concentrations remain relatively low (50 to 100 μg N/L) throughout the remainder of the project. Most of the far-outside values shown in Figure 27 can be attributed to the high values observed at sites CB7, J13, and J14, which produced high concentrations throughout most of the project (Figure 30 and Appendices C and J).

Utilizing the “Spearman Rank Correlation” method (Zar, 1996), a moderate to strong correspondence was established between the total ammonia and discharge values obtained throughout the project along the main stream of Johnson Creek. \( r_{\text{spearman}} \) values ranged from 0.643 at sampling site J3 to 0.930 at J5 with a mean of 0.787. When combined with the observed seasonal trend, this suggests that ammonia enters the stream primarily with runoff.

The calculated unionized ammonia concentrations (see “Project Design and Methodology” pages 20 to 21) possess virtually identical patterns as total ammonia for both sampling site and survey date plots, but at a much lower magnitude (Figures 32 and 33). Concentrations exceeded
Figure 30. Total Ammonia Concentrations by Sampling Site

Project-Wide Total Ammonia Values
Plotted by Sampling Site

Figure 31. Total Ammonia Concentrations by Sampling Date

Basin-Wide Total Ammonia Values
Plotted by Sampling Date
Figure 32. Unionized Ammonia Concentrations by Sampling Site

Project-Wide Unionized Ammonia Values
Plotted by Sampling Site

Figure 33. Unionized Ammonia Concentrations by Sampling Date

Basin-Wide Unionized Ammonia Values
Plotted by Sampling Date
the chronic criteria at sampling sites SM2 on February 11, J13 on all three days of the February 24-26 survey as well as at J14 on February 25, D15 on March 24, and J14 during both the June and July surveys. Violations occurring during the wet-season surveys appear to be the result of high total ammonia concentrations combined with high pH. The summer violations appear to have resulted from a combination of high total ammonia and high water temperatures. In both cases, the common cause of the violations is the high total ammonia concentrations. The unionized ammonia concentrations exceeding the chronic criteria are denoted with a red “C” in Appendix J.

**Nitrate+nitrite**

For lack of a State, class-A-stream standard, nitrate+nitrite concentrations were assessed against the federal drinking water standard, which is set at a maximum of 10 mg N as NO$_3$⁻/L (CFR, 1997). Although the measurements are inclusive of nitrite, the baseline study (Overdorff, 1981) showed that nitrite concentrations tend to be minimal, and their inclusion would assumably have little affect on the assessments.

Nitrate+nitrite concentrations were markedly highest within Pangborn Creek and consistently decreased in the downstream direction (Figure 34). Concentrations at both Pangborn sites approached or exceeded 10 mg N/L throughout the year but were notably highest during the dry-season (Figure 35). The majority of the high-end outside and far outside values shown in Figure 35 are attributable to the two Pangborn sites (Appendices D and J). A similar trend was also observed within Squaw Creek but at lower concentrations. Nitrate+nitrite concentrations at the Squaw Creek sites generally remained within a range of 5 to 8 mg N/L. High nitrate+nitrite concentrations tended to correspond to reaches with higher DO and conversely, low concentrations were observed where the DO levels were depressed. The lowest nitrate+nitrite concentrations were observed where the DO levels were depressed.
Figure 34. Nitrate+Nitrite Concentrations by Sampling Site

Project-Wide Nitrate+Nitrite Values
Plotted by Sampling Site

Figure 35. Nitrate+Nitrite Concentrations by Sampling Date

Basin-Wide Nitrate+Nitrite Values
Plotted by Sampling Date
concentrations were observed at the Clearbrook site and the upper reaches of Johnson Creek (Figure 34). Concentrations within the lower reaches of Johnson Creek remained within a narrow range with a typical median of approximately 5 mg N/L.

When concentrations are plotted against sampling date (Figure 35) a seasonal trend is vaguely apparent. Median concentrations increase during the winter months and then slowly diminish throughout the spring. Concentrations also tend to increase during early summer and then diminish again through August.

The patterns observed for nitrate+nitrite differ considerably from those observed for ammonia and the exact reasons are unclear. The general cause for the differences, however, is likely related to the more complex means by which nitrates are introduced into the stream. Ammonia, which is fairly volatile, likely enters the stream primarily with overland flow or very shallow throughflow almost exclusively, which would support the observed correspondence between high ammonia concentrations and periods of high precipitation and discharge. Nitrates, in contrast, could not be correlated with discharge and are probably derived or enter the stream from a variety of sources. As nitrate is a stable end product from the oxidation of reduced forms of nitrogen, intensive farming and the continuous application of fertilizer in the basin has likely resulted in high nitrate levels in the groundwater, and a large proportion of the nitrates observed in the stream are probably delivered with baseflow. Additional nitrates also enter the stream overland and as the product of oxidation from ammonia already present in the stream. A large portion of the nitrate concentration observed within the main stream of Johnson Creek, downstream from sampling site J8, can be attributed to input from Squaw and Pangborn Creeks and is discussed in greater detail in the “Stream Water Modeling” and “Conclusions and Recommendations” sections of this report.
**Organic nitrogen**

Plots of organic nitrogen show an irregular pattern of distribution (Figures 36 and 37). This may reflect the actual mode of occurrence, excessive cumulative error inherent in the individual inorganic nitrogen analyses, or some combination of these two factors. Despite poor quantitative control and the random distribution pattern, apparently some quantity of organic nitrogen does enter and persist within Johnson Creek and its tributaries.

Organic nitrogen plots show a concentration range from 0 to 3000 μg N/L with a typical median concentration of approximately 750 μg N/L (Figure 36). Distinctly higher concentrations are observed within Pangbom Creek and the upper reaches of Johnson Creek which have typical median values of approximately 1400 and 1300 μg N/L respectively. The Clearbrook site produced the lowest median concentration at 500 μg N/L.

A vague seasonal pattern is discernible when concentrations are plotted against sampling dates (Figure 37). This plot shows the highest median concentrations occurred during January, which again corresponds to reports of manure spreading over the snow-pack, and decreases to 0 μg N/L through the later portion of March. A relatively constant median concentration of approximately 750 μg N/L is observed from April through September.

**Total nitrogen**

The preponderance of nitrogen within Johnson Creek and its tributaries occurs in the stable form of nitrate. Therefore, plots for total nitrogen (Figures 38 and 39) nearly mirror the nitrate+nitrite plots (Figures 34 and 35) but at slightly higher concentrations. As with nitrate+nitrite, the highest concentrations of total nitrogen occur within Pangbom Creek during the summer where the median concentrations exceed 10 mg N/L and the maximum value is nearly 18 mg N/L. The typical median concentration for the entire stream system is
Figure 36. Organic Nitrogen Concentrations by Sampling Site

Project-Wide Organic Nitrogen Values
Plotted by Sampling Site

Figure 37. Organic Nitrogen Concentrations by Sampling Date

Basin-Wide Organic Nitrogen Values
Plotted by Sampling Date
Figure 38. Total Nitrogen Concentrations by Sampling Site

Project-Wide Total Nitrogen Values Plotted by Sampling Site

Figure 39. Total Nitrogen Concentrations by Sampling Date

Basin-Wide Total Nitrogen Values Plotted by Sampling Date
approximately 6 mg N/L. Median total nitrogen concentrations also decrease from January through May from greater than 8 to less than 6 mg N/L, and then increase again slightly during the summer months (Figure 39).

**Soluble reactive phosphorous**

Presently, no state or federal criteria limit phosphorous levels in lakes and streams. However, as part of an evolving criterion aimed at controlling eutrophication and the development of biological nuisances, the EPA provides suggested guidelines for total phosphorous limits. For flowing waters not discharging directly to lakes or impoundments, the EPA suggest a total phosphorous limit of 100 µg P/L (EPA, 1986). For lack of a criteria specifically limiting either soluble reactive phosphorous or organic phosphorous levels, the total phosphorous limit was utilized to evaluate concentration levels for all forms of phosphorous measured for this project. If a component of total phosphorous (soluble reactive phosphorous + organic phosphorous ≈ total phosphorous) exceeds the total phosphorous limit, then total phosphorous would have to be in excess of the limit as well, by a similar or higher value.

Soluble reactive phosphorous concentrations exceed 100 µg P/L at all of the sampling sites at some point during the project except at those located along Squaw Creek (Figure 40). Concentrations were also low at the Clearbrook site, where the 100 µg P/L limit was only exceeded once during the project. Median concentrations exceed 100 µg P/L on Sumas Creek and both Pangborn Creek sites. Concentrations within Pangborn Creek are markedly higher with median values in excess of 200 µg P/L and maximum values approaching 400 µg P/L. Median concentrations also exceeded 100 mg P/L throughout most of the wet-season sampling (Figure 41) and exhibit a pattern of steady decline from winter through mid summer.
Figure 40. Soluble Reactive Phosphorus Concentrations by Sampling Site

Project-Wide Soluble Reactive Phosphorous Values Plotted by Sampling Site

Figure 41. Soluble Reactive Phosphorus Concentrations by Sampling Date

Basin-Wide Soluble Reactive Phosphorous Values Plotted by Sampling Date
**Organic phosphorous**

As with soluble reactive phosphorous, organic phosphorous concentrations exceed 100 µg P/L at all of the sampling sites during some point in the project with the exception of the upper Squaw Creek site (Figure 42). Concentrations are notably high at the Clearbrook site and the upper reaches of Johnson Creek, with median concentrations ranging from approximately 200 to over 300 µg P/L and a maximum value of over 600 µg P/L observed at CB7. When plotted against sampling date, median concentrations also exhibit a fairly consistent pattern of decline from the winter through the end of the project in early September (Figure 43).

**Total phosphorous**

With soluble reactive phosphorous and organic phosphorous combined, median total phosphorous concentrations well exceed 100 µg P/L at all sampling sites except for those located along Squaw Creek (Figure 44). Total phosphorous concentrations are also notably higher within Sumas Creek, the Clearbrook Ditch, Pangborn Creek, and the upper reaches of Johnson Creek, with median concentrations ranging from over 200 to over 300 µg P/L. Maximum values ranging from approximately 600 to 700 µg P/L were recorded at sampling sites SM2, CB7, P9, and J13. When plotted against sampling date, again, median total phosphorous concentrations exhibit a pattern of relatively consistent decline from the winter to the end of summer (Figure 45). Median concentrations were well in excess of 100 µg P/L throughout the wet-season and did not fall below the suggested limit until July.

As with ammonia, phosphates were well correlated with discharge throughout the project. Total phosphorous, along with the soluble reactive phosphorous and organic phosphorous components produced $r_{spearman}$ values (Zar, 1996) ranging from 0.825 to 0.951, 0.723 to 0.955, and 0.809 to 0.909 respectively along the main stream of Johnson Creek. Correlation with discharge,
Figure 42. Organic Phosphorous Concentrations by Sampling Site

Project-Wide Organic Phosphorous Values
Plotted by Sampling Site

Figure 43. Organic Phosphorous Concentrations by Sampling Date

Basin-Wide Organic Phosphorous Values
Plotted by Sampling Date
Figure 44. Total Phosphorous Concentrations by Sampling Site

Project-Wide Total Phosphorous Values
Plotted by Sampling Site

Figure 45. Total Phosphorous Concentrations by Sampling Site

Basin-Wide Total Phosphorous Values
Plotted by Sampling Date
combined with the observed seasonal trends, suggests that phosphates enter the stream predominately with runoff, in contrast to nitrate which likely has a significant baseflow mode of entry.

**Fecal Coliform**

The state, class-A-stream standard requires that fecal coliform concentrations do not exceed a geometric mean value of 100 organisms/100 ml and that no more than 10% of the samples used to calculate this value exceed 200 organisms/100 ml (WAC, 1995). With the exception of quality control replicates, only one sample was collected at the various sampling sites during any given survey. The state, class-A-stream standard criteria for fecal coliform cannot, therefore, be precisely applied to individual sampling sites on a particular sampling date.

The geometric mean values calculated from all of the sampling dates for the individual sampling sites that were measured (Figure 46) exceed 100 organisms/100 ml at all of the sites except J1 and SQ11, and more than 10% of the samples used to calculate each mean value exceed 200 organisms/100 ml for all of the sites (Appendices H and J). In addition, median concentrations exceeded 100 organisms/100 ml at all of the sampling sites with the exception of J1, and concentrations were in excess of 1000 organisms/100 ml at all of the sites except SQ12 at some point during the project. Fecal coliform provided little information as to the location of waste input, but concentrations were slightly higher at sampling sites SM2, CB7 and J13 where maximum concentrations exceed 3000 organisms/100 ml.

No clear seasonal pattern is apparent when concentrations are plotted against sampling date (Figure 47). However, exceptionally high concentrations were observed during the March 9-11 and September 4 surveys. For these dates, geometric mean values are in excess of 1000 organisms/100 ml and maximum concentrations exceeding 4000 organisms/100 ml were
Figure 46. Fecal Coliform Concentrations by Sampling Site

Project-Wide Fecal Coliform Values
Plotted by Sampling Site

Organisms/100 ml

Sampling Site

Downstream

Class A

Figure 47. Fecal Coliform Concentrations by Sampling Date

Basin-Wide Fecal Coliform Values
Plotted by Sampling Site

Organisms/100 ml

Sampling Date

Class A
observed (Appendices H and J). The geometric mean values as well as median concentrations exceed 100 organisms/100 ml on all of the sampling dates except the February 10-12, April 13-15, and April 27-29 surveys. More than 10% of the samples utilized to calculate the geometric mean values exceed 200 organisms/100 ml for all of the survey dates measured.

Stream Water Modeling

To supplement the box plot analyses, stream water modeling was employed to simulate nutrient transport for each of the 12 sampling surveys and for dissolved oxygen during the 4 dry-season surveys. Through the process of model calibration, existing nutrient and dissolved oxygen/BOD input conditions were reconstructed for each of the various surveys (see “Project Design and Methodology” pages 30 through 40). After accounted for tributary input, this “reconstruction” revealed a number of potential dispersed loading source areas along the main stream of Johnson Creek. Transport simulations for Squaw and Pangborn Creeks revealed minimal dispersed loading along the reaches with data control and, therefore, all tributary input to Johnson Creek were simulated as point sources. The results of the nutrient modeling are summarized in Figures 48 through 53. All of the individual simulation results, including dissolved oxygen, are presented in Appendices M through O.

Nitrogen

Computer models for nitrogen were constructed to simulate the transport of ammonia and nitrate+nitrite. The organic nitrogen constituent was not modeled because of the suspect quality of the input data. Summaries of predicted transport and the associated required loading are presented in Figures 48 through 51.

Computer modeling of ammonia shows a consistent trend of decreasing concentrations in the downstream direction throughout the project and a general decrease in the overall stream
concentrations from late February through August (Figure 48). With the exception of the February 11 simulation, the preponderance of ammonia loading can be attributed to nonpoint sources along the upper reaches of Johnson Creek (Reaches 5, 6, and 7; Figures 13 and 49). The simulation pertaining to the February 10 to 12 survey required that a high degree of dispersed ammonia loading, in excess of 5 Kg N/day/0.1 miles of stream length, be applied along much of the stream’s length in order to balance the model against the observed data.

With the exception of the February simulations, ammonia modeling within the farthest-upstream reaches of Johnson Creek (Reach 7; Figure 13) produced steep concentration inclines for the wet-season simulations and sharp declines in the simulations pertaining to the dry-season (Figure 48). The incorporation of sampling site D15 during the second March survey did not explain the wet-season increase and, in fact, input from the North Ditch had a slight diluting affect on the main stream. Although the input for this portion of the stream was, for the most part, simulated using dispersed loads, concentration increases for the wet-season may be attributable to one or a few single point sources such as tile drain outlets. Up-welling water emanating from one such outlet was observed in the vicinity of sampling site J13 and, reportedly, an extensive network of tiles has been in place in the basin for nearly 10 years (Timblin, 1998). During the summer months the velocity of the stream in the far upper reaches was extremely low. Because minimal ammonia input was required to balance the summer models (Figure 49), the steep concentration decline predicted for this portion of the modeled stream for this period (Figure 48) may reflect an accumulation in the still water and, subsequently, a nearly in-place oxidation of the ammonia.

Ammonia loading from tributary input generally did not have a significantly negative impact on Johnson Creek and, in most cases, had a diluting affect. Even when loading values were
Figure 8: Summary of Ammonia Modeling Results

Predicted Ammonia Transport

Tributary point sources:
- North Ditch (RM 4.1)
- Squaw Creek (RM 7.7)
- Pangborn Creek (RM 8.9)
- Sumas Creek (RM 1.2)
Figure 49. Summary of Ammonia Loading Calculations

Tributary point sources:

North Ditch (RM 9.1)
Squaw Creek (RM 7.7)
Pangborn Creek (RM 6.9)
Clearbrook Ditch (RM 6.2)
Sumas Creek (RM 1.2)
extremely high, as with the input from Sumas Creek for the February 11, March 10, and March 24 simulations (Figure 49), the increase in concentration below the mixing zone is minimal (Figure 48). Input from the Clearbrook Ditch, although usually slight, always elevated downstream concentrations. The most significant concentration increases, however, resulted from the input of dispersed ammonia loads along the upper Johnson Creek corridor.

Nitrate+nitrite modeling (Figure 50) produced a pattern similar to that shown by box plots (Figures 34 and 35). Concentrations tend to increase steeply downstream within the upper reaches of Johnson Creek (Reaches 5, 6, and 7; Figure 9), particularly at the confluences of Squaw and Pangbom Creeks, and then gradually diminish over the remaining length of the stream. The overall stream concentrations also tend to decrease over the course of the project with a moderate resurgence occurring during the early summer.

Unlike ammonia, a major portion of the elevated nitrate+nitrite concentrations observed in Johnson Creek can be attributed to tributary input, specifically from Squaw and Pangborn Creeks (Figure 50). Input from these two tributaries ranges from over 250 Kg N/day during the winter simulations to less than 40 Kg N/day for the summer (Figure 51). Despite the decreasing loading values over the course of the project, concentrations were consistently high in Squaw and Pangborn Creeks (Figure 34). When the water from these tributaries is combined with the relatively low concentrations from the up-stream portion of Johnson Creek, a significant increase in the nitrate concentrations below the respective mixing zones occurs. Nitrate input as dispersed loads or from the other tributaries had a less dramatic effect but, together with the conversion of the ammonia present in the stream to nitrate, served to maintain relatively constant nitrate concentrations downstream from reach 6.
Figure 50. Summary of Nitrate+Nitrite Modeling Results

Tributary point sources:
- North Ditch (RM 9.1)
- Squaw Creek (RM 7.7)
- Pangborn Creek (RM 6.9)
- Clearbrook Ditch (RM 6.2)
- Sumas Creek (RM 1.2)
Figure 51. Summary of Nitrate+Nitrite Loading Calculations

- Tributary point sources:
  - North Ditch (RM 9.1)
  - Squaw Creek (RM 7.7)
  - Pangborn Creek (RM 6.9)
  - Clearbrook Ditch (RM 6.2)
  - Sumas Creek (RM 1.2)
**Phosphorous**

Modeling of total phosphorous produces a similar concentration pattern as that of ammonia (Figure 52). The highest total phosphorous concentrations occur in the upper reaches of Johnson creek and diminish in the downstream direction. The overall stream concentrations and the dispersed loads required to balance the models (Figure 53) also tend to decrease from the wet-season to the dry-season. However, unlike ammonia, high total phosphorous concentrations and the associated loading persists into March. The majority of the total phosphorous loading can also be accounted for by applying dispersed loads in the upper reaches of Johnson Creek, and tributary point source loading, although high, actually has a diluting effect following input into Johnson Creek.

As with the ammonia model, high total phosphorous concentrations are produced by minimal input within reach 7 for the simulations pertaining to the summer surveys (Figures 52 and 53). Again, because stream velocities were nearly zero during this period within this portion of the stream, this may reflect the accumulation of total phosphorous in the nearly still water. Because total phosphorus is the constituent being modeled and the effects of oxidation are not a factor, high concentrations persist farther downstream.

**Dissolved Oxygen**

Because BOD analysis was restricted to the dry-season, dissolved oxygen modeling provides limited information. Sample collection was also confined to reaches 1 through 6 (Figure 13) and, therefore, no modeling information is available for the farthest-up-stream section of Johnson Creek. The dissolved oxygen simulations did, however, provide useful information pertaining to the transport characteristics within the different portions of the stream that were modeled. The results of dissolved oxygen modeling are presented in Appendix O.
Figure 52. Summary of Total Phosphorous Modeling Results

Tributary point sources:

North Ditch (RM 9.1)
Squaw Creek (RM 7.7)
Pangborn Creek (RM 6.9)
Clearbrook Ditch (RM 6.2)
Sumas Creek (RM 1.2)
Figure 53. Summary of Total Phosphorous Loading Calculations

Tributary point sources:
- North Ditch (RM 9.1)
- Squaw Creek (RM 7.7)
- Pangborn Creek (RM 6.9)
- Clearbrook Ditch (RM 6.2)
- Sumas Creek (RM 1.2)
Within reach 6, both BOD and dissolved oxygen are strongly influenced by discharge from Squaw and Pangborn Creeks. The BOD within both tributaries are minimal, and whether the values within Johnson Creek above the tributary mixing zones are low, as is the case for the June and August simulations, or moderately high, as with the July and September simulations, the input of lower BOD water from both tributaries has a diluting effect on the BOD in the main stream. With regards to dissolved oxygen input, the high gradient tributaries, which possess significantly greater reaeration rates than the low gradient main stream, continuously replenish dissolved oxygen within their own waters and contribute a significant amount of new dissolved oxygen to Johnson Creek.

Below the Pangborn/Johnson Creek confluence, downstream through reaches 5, 4, and 3, the modeled dissolved oxygen concentrations consistently sag. This depletion is, in part, due to the fact that no additional tributaries are present to contribute new dissolved oxygen nor does the low gradient of the main stream promote rapid reaeration. These factors combined with the low to moderate BOD appears to produce a gradual downstream oxygen depletion.

Dissolved oxygen concentrations rebound somewhat below the Sumas/Johnson Creek confluence (reach 2; Figure 13) as oxygenated water from Sumas Creek mixes with the relatively depleted concentrations in main stream. Again, as with Squaw and Pangborn Creeks, the higher velocity of Sumas Creek produces a greater rate of reaeration and, subsequently, greater dissolved oxygen concentrations. However, despite dissolved oxygen input, high BOD loading from Sumas Creek, as found for the August simulation where BOD input was calculated at 50 Kg/day, has the effect of retarding the dissolved oxygen rebound within the main stream.

In order to balance each of the four dissolved oxygen models, a moderately high level of dispersed BOD (on average, approximately 5 Kg/day/0.1 miles) had to be applied along most of
the modeled stream's length. Because minimal precipitation was recorded for the modeled period and presumable the water table was at a low level during the dry-season, dispersed BOD is unlikely to enter the stream with runoff. The loading could be attributed to one or a number of other sources, including decaying aquatic vegetation, over-spray during fertilizer application, and base flow, or more likely, discharge from tile drain outlets.

Water Quality Trends

As a means of assessing the effectiveness of the BMP projects presently in place in the basin, comparisons were made between water quality data obtained for this project and data collected during the two previous studies (Overdorff, 1981; and Dickes and Merrill, 1990). To best assess the differences between the central tendency of each data set, the primary trend analyses utilized comparisons of median values from corresponding sampling sites from each of the study periods.

To supplement the comparisons of the median data values, the Mann-Whitney test was employed to detect statistically significant differences between corresponding data sets. The results of each comparison are presented in Figures 54 through 69. Data sets for which statistically significant differences were detected ($p < 0.05$) are indicated within the appropriate median comparison figures. The water quality data obtained during the 1980/1981 and 1988/1989 studies are presented in Appendices K and L respectively.

Nutrients

Trend analyses for nutrients includes comparisons of the 1996 total ammonia, nitrate+nitrite, and total phosphorous data with like data obtained during both of the previous studies (Figures 54 through 57, 62, and 63). Soluble reactive phosphorous and organic phosphorous were not measured during the 1988/1989 study, but comparisons of these constituents, which were obtained for this project and during the 1980/1981 baseline study, were made (Figures 58
through 61). Nutrient trend analyses show some improvements at certain locations and for specific constituents, particularly ammonia. However, the overall trend for nutrients in the basin has been one of increasing concentrations since the implementation of BMPs following the 1980/1981 baseline study.

Comparisons of ammonia data show a reduction in median concentrations since 1980 along most of the length of Johnson Creek, and a statistically significant decrease at sampling site J1 (Figure 54). Decreases, however minimal, are observed along Pangborn and Squaw Creeks as well (Figure 55). In the far upper reaches of Johnson Creek, in the vicinity of site J13, large decreases in the median values were observed. However, statistically significant decreases were not found, which may be attributable to the wider range of concentrations occurring at this site. Increasing concentration trends are, in fact, observed in the upper portion of Johnson Creek at sites J8 and #5/J7, where both the comparison of median values and the Mann-Whitney test indicate a rising trend.

Plots of comparisons of median nitrate+nitrite values show an increasing trend at all of the locations compared along both Johnson Creek and Pangborn and Squaw Creeks (Figures 56 and 57). Mann-Whitney tests also indicate that statistically, highly significant increases ($p < 0.001$) have occurred since 1980 at all of the sites tested along Johnson Creek and Pangborn Creek, and moderately significant increases ($p = 0.02$) have occurred since 1989 along Squaw Creek. Despite increasing nitrate contributions from Pangborn and Squaw Creeks (Figure 57), increasing contributions from the upper reaches of Johnson Creek have also effected increased concentrations within the lower reaches of Johnson Creek (Figure 56).

Comparisons of soluble reactive phosphorous and organic phosphorous, which are restricted by data availability to the present project and the 1980 baseline study, indicate that increases in
Figure 54. Comparison of Median Total Ammonia Concentrations along Johnson Creek

[Graph showing median total ammonia concentrations along Johnson Creek with sites labeled J13, #5/J7, J8, J6, J5, J4, J3, J1.]

MANN-WHITNEY
1996 / 1980
J1: 0.005 < p < 0.01
#5 / J7: 0.02 < p < 0.05

Figure 55. Comparison of Median Total Ammonia Concentrations along Pangborn and Squaw Creeks

[Graph showing median total ammonia concentrations along Pangborn and Squaw Creeks with sites labeled SQ12, SQ11, #5/J7, #7/P3, P10, P9, J8.]

MANN-WHITNEY
1996 / 1980
SQ12 to #5/J7: 0.005 < p < 0.01
#7/P3 to P9: 0.02 < p < 0.05
Figure 56. Comparison of Median Nitrate+Nitrite Concentrations along Johnson Creek

Median Nitrate + Nitrite Concentrations, Johnson Creek Sites

Figure 57. Comparison of Median Nitrate+Nitrite Concentrations along Pangborn and Squaw Creeks

Median Nitrate + Nitrite Concentrations, Pangborn and Squaw Creeks
phosphorous within the stream have occurred largely in form of organic phosphorous (Figures 58 through 61). The plots of median soluble reactive phosphorous values indicate a slight decreasing trend in the upper reaches of Johnson Creek (Figure 58) and an increasing trend within Pangborn Creek (Figure 59). Median values for all other portions of the stream show virtually no change, and Mann-Whitney tests did not reveal any statistically significant differences.

Conversely, plots of median organic phosphorous values indicate a consistent trend of increasing concentrations along the entire length of Johnson Creek, particularly within the upper reaches, (Figure 60) and slight increases for both Pangborn and Squaw Creeks (Figure 61). In addition, Mann-Whitney tests reveal that statistically, highly significant increases ($p < 0.001$) in the organic phosphorous concentrations have occurred along the length of Johnson Creek since 1980, along with a moderately significant increase ($0.02 < p < 0.05$) within Squaw Creek.

Comparisons of total phosphorous plots of the median values reveal an overall increase since 1980 along the length of Johnson Creek (Figure 62) and within both Pangborn and Squaw Creeks (Figure 63). In addition, Mann-Whitney tests indicate statistically significant increases in total phosphorous concentrations at sampling sites J1 and #5/J7 between 1980 and 1996. Median plots show a trend of decreasing total phosphorous between 1989 and 1996 along Johnson Creek and within Pangborn Creek. However, Mann-Whitney tests do not indicate any statistically significant decreases since 1989.

**Dissolved Oxygen**

Comparisons of median dissolved oxygen concentrations (Figures 64 and 65) and median percent saturation levels (Figures 66 and 67) indicate an improving trend throughout much of the watershed, particularly within the upper reaches of Johnson Creek. Median values at sampling
Figure 58. Comparison of Median Soluble Reactive Phosphorous Concentrations along Johnson Creek

Median Soluble Reactive Phosphorous Concentrations, Johnson Creek Sites

Figure 59. Comparison of Median Soluble Reactive Phosphorous Concentrations along Pangborn and Squaw Creeks

Median Soluble Reactive Phosphorous Concentrations, Pangborn and Squaw Creeks
Figure 60. Comparison of Median Organic Phosphorous Concentration along Johnson Creek

Median Organic Phosphorous Concentrations, Johnson Creek Sites

MANN-WHITNEY
1996 / 1980
J1: p < 0.001
J8: p < 0.001
#5 / J7: p < 0.001
J13: p < 0.001

Figure 61. Comparison of Median Organic Phosphorous Concentration along Pangborn and Squaw Creeks

Median Organic Phosphorous Concentrations, Pangborn and Squaw Creeks

MANN-WHITNEY
1996 / 1980
SQ11: 0.02 < p < 0.05
Figure 62. Comparison of Median Total Phosphorous Concentrations along Johnson Creek

Median Total Phosphorous Concentrations, Johnson Creek Sites

MANN-WHITNEY
1996 / 1980
J1: \( p = 0.05 \)
#5 / J7: \( 0.002 < p < 0.005 \)

Figure 63. Comparison of Median Total Phosphorous Concentrations along Pangborn and Squaw Creeks

Median Total Phosphorous Concentrations, Pangborn and Squaw Creeks
Figure 64. Comparison of Median Dissolved Oxygen Concentrations along Johnson Creek

\textbf{Median Dissolved Oxygen Concentrations, Johnson Creek Sites}

\textbf{MANN-WHITNEY}

- \textbf{1996 / 1980}
  - J8: \(0.02 < p < 0.05\)
  - J13: \(0.02 < p < 0.05\)

- \textbf{1996 / 1989}
  - #5/J7: \(0.02 < p < 0.05\)
  - J13: \(p < 0.05\)

Figure 65. Comparison of Median Dissolved Oxygen Concentrations along Pangborn and Squaw Creeks

\textbf{Median Dissolved Oxygen Concentrations, Pangborn and Squaw Creeks}

\textbf{MANN-WHITNEY}

- \textbf{1996 / 1980}
  - SQ12: \(p < 0.001\)

- \textbf{1996}
  - \#5/J7: \(p < 0.001\)

- \textbf{1989}
  - \#7/P3: \(p < 0.001\)

- \textbf{1980}
  - SQ11: \(p < 0.001\)

\textbf{Downstream}

\textbf{Sampling Site}
Figure 66. Comparison of Median Dissolved Oxygen Saturation Levels along Johnson Creek

Figure 67. Comparison of Median Dissolved Oxygen Saturation Levels along Pangborn and Squaw Creeks
sites J13 downstream to J8, which are well below 8.0 mg O₂/L for both previous studies, were found to approach or even exceed this standard. Statistically significant improvements were also revealed by Mann-Whitney tests at site J13 for comparisons with both the 1980/1981 and 1988/1989 data, at site J8 since 1980, and site #5/J7 since 1989. Median values also indicate an improving trend for both Pangborn and Squaw Creeks with highly significant statistical improvement ($p < 0.001$) observed for Pangborn Creek since 1980. Percent saturation levels also show statistically significant improvements at sites J13 and #5/J7 (Figures 66 and 67). The improvements in dissolved oxygen closely correspond with the reductions observed for ammonia (Figures 54 and 55) and both may be related to efforts to reduce the direct introduction of farm waste into the stream.

Despite the improvements observed within the upper reaches of Johnson Creek, the downstream sag, below the influence of Pangborn and Squaw Creeks, is more pronounced, to the point that both the median dissolved oxygen values as well as the median percent saturation levels fall below previously recorded values within the lower reaches of Johnson Creek (Figures 64 and 66). Mann-Whitney tests did not show statistically significant degradation of dissolved oxygen concentrations at site J1 but did show moderately significant degradation ($0.02 < p < 0.05$) for the percent saturation levels. The apparent increase in oxygen demand below the Pangborn Creek confluence may be associated with a number of sources including the increase of ammonia observed at sampling sites J8 and #5/J7 (Figure 54), the increase in organic phosphorous (Figures 60 and 61), and/or continued input from the area of the Clearbrook Ditch.

**Fecal Coliform**

The results of the trend analysis for fecal coliform are presented in Figures 68 and 69. Comparison of median concentrations shows a substantial decrease between 1980 and 1981 and a
Figure 68. Comparison of Median Fecal Coliform Concentrations along Johnson Creek

Figure 69. Comparison of Median Fecal Coliform Concentrations along Pangborn and Squaw Creeks
lesser decline from 1989 to the present along most of the length of Johnson Creek. A similar
trend is also observed for Pangborn Creek. The trend for Squaw Creek is also one of declining
concentrations, however, at a substantially lower magnitude. Because of its highly variable
nature, trends of median fecal coliform values are less meaningful than trends for other water
quality parameters. Mann-Whitney tests, however, show statistically significant improvements
since 1980 at sampling sites J1 and P9, and since 1989 at site J8. As with dissolved oxygen, the
decreases observed in fecal coliform concentrations roughly correspond with the decreases
observed for ammonia (Figures 54 and 55) and both are likely related to efforts to reduce the
direct input of farm waste into the stream.

CONCLUSIONS AND RECOMMENDATIONS

The data obtained and assessed during this project indicate that the quality of stream water
within the Johnson Creek watershed has improved over the past two decades. This improvement
is most likely attributable to the implementation of BMPs and efforts by the WCD, working in
cooperation with many of the area dairy farmers, to better manage farm waste. However, despite
better farm waste management and general improvements in water quality, the stream water
continues to fall below state, class-A-stream standards and several areas of the stream are still
significantly impaired.

Water Quality Deficiencies and Potential Source Areas

Water quality analyses show that the streams within the basin still contain high levels of
nutrients, high fecal coliform concentrations, and lower than desired levels of dissolved oxygen.
The data also show that turbidity levels, while greatly improved, along with water temperature,
were on occasion, in excess of state, class-A-stream standards within specific areas of the stream.
Ammonia levels have diminished substantially throughout much of the stream, which has likely resulted from the construction of structural BMPs designed to curtail the direct input of farm waste (i.e. fences, containment slabs with curbs, roof gutters and down spouts, and manure lagoons), and better overall manure management. However, high ammonia concentrations still persist within certain areas of the stream, and unionized ammonia concentrations were, on occasion, found to be in violation of the state and federal chronic criteria. Nitrates and phosphates, in contrast, both exhibit trends of increasing concentrations for the past 20 years. This increase is likely a reflection of the increased herd sizes in the watershed, which have nearly doubled since 1980, and the subsequent increase in the overall volume of manure requiring dispersal (Gillies et al., 1998).

The data also show that, while still impaired relative to state, class-A-stream standards, fecal coliform concentrations have decreased and dissolved oxygen levels have improved, both of which may also be attributable to the implementation of BMPs. Turbidity levels throughout most of the watershed have also been reduced substantially, which is likely the direct result of fencing and stream-side revegetation projects (Dickes and Merrill, 1990; and Gillies et al., 1998). However, turbidity levels continue to exceed the state, class-A-stream standard within the Clearbrook Ditch and the upper reaches of Johnson Creek on a regular basis. Water temperature, which varies directly with air temperature, only exceeded the state, class-A-stream standard during the hottest summer months and only in the shallow upper reaches of Johnson Creek.

Examination of the sampling site box plots reveals a conspicuous, reoccurring pattern for particular water quality parameters at several of the sampling sites, which suggest the proximity of potential farm waste input sources. Most notable are the areas of the Clearbrook ditch (sampling site CB7) and the upper reaches of Johnson Creek (sampling sites J13, and J14), both
of which consistently exhibit higher than average levels for turbidity, conductivity, ammonia, phosphates (particularly organic phosphorous), and to the degree discernible, fecal coliform. In addition, these two areas also produced higher than average BOD levels during the dry-season and had consistently low dissolved oxygen throughout the project.

Although not as prominent as at Clearbrook Ditch and upper Johnson Creek, notably higher values for some parameters were also observed for the Sumas and Pangborn Creek sites. Sumas Creek, on occasion, contained high ammonia and fecal coliform concentrations, and regularly produced higher than average phosphates (particularly soluble reactive phosphorous). Although restricted to the summer, slightly elevated BOD values were also observed in this area. Box plots for the Pangborn Creek sites show significantly elevated levels of nitrates, and because the majority of the nitrogen within the stream is in the form of nitrate, total nitrogen values were also extremely high. Organic nitrogen and soluble reactive phosphorous levels were also conspicuously higher than average within Pangborn Creek.

Box plots for the nutrient data, when arranged by sampling date, also display an obvious seasonal trend. The plots show that the highest nutrient concentrations occur during the wettest portion of the year, when precipitation is greatest and the ground is saturated, and gradually diminish throughout the year. This alludes to the fact that the majority of the high concentrations are the result of contaminated overland flow entering the stream. The greatest concentrations were observed during February, following the melt-off of January snow. This may have resulted from farmers spreading manure over the snow-pack (which was observed), which then melted and entered the stream overland, or, in part, as a result of delayed manure spreading.

One notable exception to the seasonal trend are the nitrate concentrations within Pangborn Creek, which progressively increase over the summer months. In contrast to Johnson Creek,
nitrate+nitrite concentrations also tend to decrease in a downstream direction. One feasible explanation for the observed trend is an up-stream source, possible Pangborn Lake, which continually supplies the creek with a relatively steady quantity of nitrates. As discharge diminishes through the summer, the creek becomes progressively more concentrated. Simultaneously, groundwater dilutes the stream, gradually diminishing nitrate concentrations as the stream progresses down-slope. The groundwater itself is also a likely source for the high nitrate concentrations within the stream, in which case, the progressive increase in the concentrations observed over the course of the summer may be the result of progressively diminishing input from overland flow or interflow.

Computer models, which were used to reconstruct nutrient loading conditions, indicated several possible source areas for nutrient input and substantiated much of the box plot interpretation. The models constructed to predict nitrogen transport showed that majority of the ammonia entered the stream as dispersed loads in the upper reaches of Johnson Creek, and to a lesser degree, as dispersed loads in the vicinity of the Clearbrook Ditch. Despite high ammonia concentration within the Clearbrook Ditch, the discharge from the ditch alone is not sufficient to account for the concentrations observed within Johnson Creek and model calibration recurrently required the application of nonpoint ammonia loading along this reach of the stream. Nitrogen modeling also showed that the majority of the nitrates observed within Johnson Creek originate in Squaw and Pangborn Creeks, and enter Johnson Creek directly at the confluence of each tributary. Similar to ammonia, modeling of total phosphorous showed that the majority of the phosphates observed in Johnson Creek entered the stream as dispersed loads in the upper reaches of Johnson Creek and in the vicinity of the Clearbrook Ditch.
Nutrient modeling also reaffirmed the seasonal trend observed for the box plots. The models showed that the highest loading occurs during the wet-season, when the ground is saturated and precipitation is highest. Nutrient loading then progressively diminishes throughout the spring and summer months.

By April, 1990, following the release of the 1988/1989 DOE report, 91 percent of the BMP projects planned for the watershed had been implemented (Dickes and Merrill, 1990). Since that time, all of dairies currently operating within the basin have, at a minimum, implemented the use of structural BMPs of one form or another (Gillies et al., 1998). However, for BMPs to be fully effective, managerial tools and techniques need to be implemented as well, and revised regularly to accommodate dynamic conditions such as weather, herd size, and crop fertilization requirements.

Presently, the WCD advocates the use of a “Farm Plan” to assist dairies with the task of animal waste management and fertilization. At the request of the individual dairyman, the WCD will assist a farm in formulating an effective plan with contingencies specific to each farm. Figure 70 shows the location of all the dairies currently operating within the Johnson Creek watershed, and indicates the status of each dairy’s farm plan including whether or not a current manure application schedule is included, the present herd size, and the ratio of animal units to land receiving fertilizer. Figure 71 shows the location of only those dairies which have herd sizes greater than 300 animal units.

Of the 38 dairies currently operating in the basin, 15 have up-to-date farm plans and 14 of those have current manure application schedules. Presently, 23 farms either never formulated a management plan or are operating with outdated plans. Of these 23 farms, eight have recently
Figure 70: Dairy Location (All Farms) and Waste Management Program Status
Figure 71. Dairy Location (Farms with Herds Larger than 300 Animals) and Waste Management Program Status
requested assistance from the WCD in updated older plans, so, although operating on an outdated plan, assumably the operators of these dairies are at least cognizant of proper manure management procedures.

Within the areas with the most impaired water quality, namely the upper portion of Johnson Creek and the Clearbrook Ditch, a number of farms may be contributing to the problem. Of the 23 dairies operating without current farm plans, five are located along the upper reaches of Johnson Creek, and all of these have animal containment areas located directly adjacent to the affected water way (Figure 70). Of these five farms, two have herd sizes in excess of 400 animals units, and one has over 1000 animals units (Figure 71). Acreage information is limited, but the animal-to-acre ratio for these farms also appears to be fairly high compared to the other dairies in the basin. In the area of the Clearbrook Ditch, one farm is operating without a current plan and has a containment area located adjacent to the waterway. This farm, however, is reported to support less than 20 cows, and the impairment observed for the Clearbrook Ditch may be attributable to one or several of the larger farms with current plans located farther up-stream along the ditch (Figure 70).

In the area of Sumas Creek, which was found to have intermittent water quality problems, all of the dairies have current farm plans, including up-to-date manure application schedules. However, at least one of these farms is known to deviate from prudent management practices on occasion (Gillies et al., 1998). All of the farms in this area have animal to acreage ratios less than 3.0, and only one dairy herd size exceeds 300 animal units (Figure 71).

Within Pangborn Creek, whether or not the source of the high nitrates and elevated phosphorous levels are related to dairy farming or a natural phenomena is unknown, and further investigations in this area are needed. Pangborn Lake is one of several late-Pleistocene bogs that
formed within the Lynden outwash terrace (the upland area from which Pangborn and Squaw Creeks issue) during the waning stages of the Fraser Glaciation (Easterbrook, 1963, 1976). The nitrate and phosphate concentrations observed in the stream may be originating from organic material within the bog’s thick peat and muck deposit (US Soil Conservation Service, 1992). The nitrates observed in Squaw Creek, which also originates in a thick deposit of muck, may also propagate from a natural source. This, however, does not explain well the increase in the nitrate and phosphate concentrations observed for the past 20 years. Several farms in both areas operate with outdated or no farm plan, including one adjacent to Pangborn Creek with a herd size in excess of 300 animals (Figures 70 and 71).

In addition to the water quality problems for specific areas and farms, the overall increase of nitrate and phosphate concentrations observed throughout the basin has likely resulted from a nearly two-fold increase in the total number of animals within the watershed over the past two decades. In 1980, the basin had 50 commercial dairies with a total of approximately 7,500 animals for an average herd size of 150 animal units per farm (Overdorff, 1981). Presently, only 38 dairies still operate, but the average herd size is approximately 350 animal units per farm (Figure 70) and a total of nearly 14,000 animals live in the basin (Washington DOE, 1995; and WCD, 1998). Because manure is not generally exported from the basin (Gillies et al., 1998), the observed increase in nutrients within the streams may be wholly attributable to increased manure production.

**Water Quality Restoration**

Despite the implementation of BMPs and associated water quality improvements, water quality deficiencies, which have an effect throughout the basin, still persist and can be linked to
specific source areas. Future restoration efforts should therefore, at a minimum, focus on improvement projects which target these specific areas.

The computer models constructed to identify source areas were used to predict the potential water quality conditions that could result if loading from the major source areas were to be reduced. The conditions represented by the March 10 models were used to develop restoration scenarios for nutrients because the modeled conditions possessed moderately high loading under typical wet-season conditions. The observed conditions represented in the September 4 dissolved oxygen/BOD model were utilized for similar reasons to predict potential improvements for dissolved oxygen.

Figures 72 and 73 show the predicted ammonia concentrations following the removal of the dispersed loading from the upper reaches of Johnson Creek and the removal of all dispersed loads respectively. A significant decrease in downstream ammonia concentrations is predicted by removing just the upper Johnson Creek load. However, a peak concentration of nearly 0.5 mg N/L remains in the vicinity of the Clearbrook Ditch (Figure 72). Once the dispersed loading from this area is removed as well, all of downstream concentrations decrease to approximately 0.1 mg N/L (Figure 73). The only remaining ammonia-loads affecting Johnson Creek are derived directly from each of the tributaries, all of which show a minimum impact.

The predicted downstream nitrate+nitrite concentrations following a reduction in the concentrations emanating from Squaw and Pangborn Creeks are shown in Figures 74 and 75. Nitrate+nitrite concentrations within each tributary were reduced to 2.0 mg N/L as removing all of the nitrates is not likely achievable. A reduction in the nitrate concentrations also assumes an anthropogenic origin. A reduction in the concentrations within Squaw Creek has a minimal effect on the downstream concentrations in Johnson Creek (Figure 74). A reduction in the
Figure 72. Predicted Ammonia Transport with Dispersed Loads from Upper Johnson Creek Removed

Predicted Ammonia Transport,
Modified from March 10, 1996 Model

Figure 73. Predicted Ammonia Transport with All Dispersed Loads Removed

Predicted Ammonia Transport,
Modified from March 10, 1996 Model
Figure 74. Predicted Nitrate+Nitrite Transport with the Squaw Creek Load Reduced

Predicted Nitrate + Nitrite Transport,
Modified from March 10, 1996 Model

Figure 75. Predicted Nitrate+Nitrite Transport with the Pangborn Creek Load Reduced

Predicted Nitrate + Nitrite Transport,
Modified from March 10, 1996 Model
nitrates emanating from Pangborn Creek, which has higher initial nitrate+nitrite concentrations than Squaw Creek, has a more significant impact (nearly 1.0 mg N/L) on downstream concentrations (Figure 75). If a reduction to 2.0 mg N/L could be attained within both tributaries, the result within Johnson Creek would be concentrations typically below 4.0 mg N/L. Nitrate reductions for other minor sources such as Sumas Creek and the nonpoint source loads along Johnson Creek could also produce moderately beneficial results. Reductions in ammonia-loading, which are incorporated in the Squaw and Pangborn Creek reduction scenarios (Figures 74 and 75), do not generate a significant reduction in nitrates.

The effects of removing the dispersed total phosphorus-loads are shown in Figures 76 and 77. As with the ammonia simulations, the removal of the dispersed phosphate-load from the upper reaches of Johnson Creek effects a significant reduction in the downstream concentrations. However, a peak near the Clearbrook Ditch of nearly 2.0 mg P/L remains (Figure 76). By removing the dispersed loading in the vicinity of the Clearbrook Ditch as well, the concentrations within Johnson Creek are reduced to or below 100 µg P/L downstream to the confluence of Sumas Creek (Figure 77). The only remaining phosphate loads affecting Johnson Creek are derived directly from each of the tributaries, all of which, with the exception of Sumas Creek, have a minimum impact on the concentrations in Johnson Creek. Total phosphorous loads from Sumas Creek have a moderately significant impact on the water quality in Johnson Creek and efforts to reduce concentrations here may be warranted as well.

Johnson Creek, with its low stream gradient and associated low velocity, possesses a very low reaeration potential. Therefore, the introduction of even minimal oxygen demand below the influence of Pangborn Creek and the other higher gradient tributaries has a significant effect, typically producing an oxygen sag within the lower reaches of Johnson Creek. Squaw and
Figure 76. Predicted Total Phosphorous Transport with Dispersed Loads from Upper Johnson Creek Removed

Figure 77. Predicted Total Phosphorous Transport with All Dispersed Loads Removed
Pangborn Creeks are important sources of dissolved oxygen and the preservation of the water quality within these tributaries is vital to future improvements within Johnson Creek.

If the higher than average BOD observed for the Clearbrook Ditch and the upper end of Johnson Creek (sampling site J13) are reduced to 2.0 mg/L, minimal downstream improvements in the dissolved oxygen concentrations are produced (Figure 78). This occurs because the effects of BOD within the upper portion of Johnson Creek are quickly offset by the introduction of highly oxygenated water from Squaw and Pangborn Creeks and because the Clearbrook Ditch contributes almost no flow, particularly during the dry-season. If the oxygen demand modeled as dispersed BOD-loading is removed, the oxygen sag below the confluence of Pangborn Creek is significantly diminished (Figure 79). This dispersed BOD-load, which likely represents decaying Reed Canary Grass, could be diminished through a reduction in nutrients and a subsequent reduction in the proliferation of aquatic vegetation. The predicted dissolved oxygen concentrations produced within the lower portion of Johnson Creek under this scenario still fall below the state, class-A-stream standard, with concentrations ranging from approximately 6.0 to 9.0 mg O₂/L, which may be the natural low-flow condition.

Significant water quality improvements within the Johnson Creek watershed will likely be dependent upon 100 percent participation and adherence by area farmers in a BMP program that stresses prudent and dynamic farm waste and fertilization management. For the present, a continued effort should be made to convince all the dairymen operating in the basin to actively participate in the existing WCD “Farm Plan” program.

Because the water quality problems in the watershed are predominantly nonpoint source in origin, future implementation of a standard TMDL, originally devised to regulate point sources, may not generate the desired improvements in water quality. Future regulatory programs would
Figure 78. Predicted Dissolved Oxygen and BOD Transport with the Clearbrook Ditch and Upper Johnson Creek Oxygen Demand Reduced

Figure 79. Predicted Dissolved Oxygen and BOD Transport with All Dispersed BOD Loads Removed
be most effective if designed to oversee prudent farm waste management compliance, which may include requiring farms to provide adequate manure storage for a given herd size, capping herd sizes, and mandating appropriate manure dispersal periods. Beneficial long term programs could include the reinstatement of a dairy buy-out program to reduce the overall manure production in the basin. A buy-out program aimed at the eventual establishment of a stream buffer, particularly along the upper reaches of Johnson Creek may provide even greater long term benefit.
REFERENCES


USEPA, 1994, Washington State Department of Ecology, 303(d) list, draft: Federal Clean Water Act, Section 303(d) list, Federal Water Pollution Control Act, amended 1977, 33 USC 1251 and following.


### APPENDIX A (FIELD DATA)

#### Dec. 18 (AM)

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#### Notes:
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- Air Temp: 6.0 C windy, raining

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#### Notes:
- Sampling conducted between 7:30 AM and 11:00 AM
- Air Temp: 7.0 C windy, partly cloudy

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### FIELD DATA (Continued)

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Notes: Sampling conducted between 2:30 PM and 6:00 PM
Air Temp: 8.3°C windy, cloudy

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Post Cal. 0 @ 0 197 @ 200 7.0 @ 7.0
Drift 0 0-3 0.0-0.1

Notes: Sampling conducted between 8:00 AM and 11:00 AM
Air Temp: 8.0°C windy, cloudy

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Post Cal. 0 @ 0 197 @ 200 6.9 @ 7.0
Drift 0 0-3 0.0-0.1

Notes: Sampling conducted between 2:30 PM and 6:00 PM
Air Temp: 8.0°C windy, partly cloudy
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**Notes:** Sampling conducted between 10:00 AM and 2:00 PM

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**Notes:** Sampling conducted between 10:00 AM and 2:00 PM

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**Notes:** Sampling conducted between 11:00 AM and 3:00 PM

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**Notes:** Air Temp: 0.0°C ~1.5 ft. of snow on grnd, ~1.0" sur. ice @ J14, mod windy

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### Feb. 10

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**Notes:** Sampling conducted between 10:00 AM and 2:00 PM

**Air Temp:** 5.8°C, **mod windy, clear**

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**Notes:** Sampling conducted between 10:00 AM and 4:00 PM

**Air Temp:** 9.5°C, **mod windy, clear**

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**Notes:** Sampling conducted between 11:00 AM and 3:00 PM

**Air Temp:** 9.5°C, **calm, clear**
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Post Cal. 0 @ 0 198 @ 200 7.2 @ 7.0
Drift 0 0-4 0-0.2

Notes: Sampling conducted between 10:30 AM and 3:00 PM
Air Temp: 5.7 C calm, scattered clouds

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Post Cal. 0 @ 0 201 @ 200 7.1 @ 7.0
Drift 0 0-4 0-0.2

Notes: Sampling conducted between 10:00 AM and 4:00 PM
Air Temp: 3.7 C very windy, clear

#### Feb. 26

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Pre Cal. 0 @ 0 200 @ 200 7.0 @ 7.0
Post Cal. 0 @ 0 197 @ 200 7.0 @ 7.0
Drift 0 0-3 0-0.1

Notes: Sampling conducted between 12:00 AM and 4:00 PM
Air Temp: 6.2 C light wind, clear
### FIELD DATA (Continued)

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Pre Cal. 0 @ 0  200 @ 200  7.0 @ 7.0
Post Cal. 0 @ 0  200 @ 200  7.0 @ 7.0
Drift 0  0-1  0.0-0.1

Notes: Sampling conducted between 10:00 AM and 3:00 PM
Air Temp: 10.2°C light wind, light rain

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Pre Cal. 0 @ 0  200 @ 200  7.0 @ 7.0
Post Cal. 0 @ 0  198 @ 200  7.1 @ 7.0
Drift 0  0-3  0.0-0.1

Notes: Sampling conducted between 10:00 AM and 4:00 PM
Air Temp: 10.2°C mod windy, overcast-(rained night before)

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Post Cal. 0 @ 0  197 @ 200  7.0 @ 7.0
Drift 0  0-3  0.0-0.1

Notes: Sampling conducted between 12:00 AM and 4:30 PM
Air Temp: 10.2°C light wind, scattered clouds
### Mar. 23

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**Notes:** Sampling conducted between 10:30 AM and 3:30 PM

Air Temp: 7.3 °C

low clouds, mod. windy, inter showers

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**Notes:** Sampling conducted between 10:00 AM and 4:00 PM

Air Temp: 7.3 °C

low clouds, mod. windy, inter showers

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**Notes:** Sampling conducted between 12:00 AM and 4:00 PM

Air Temp: 6.7 °C

light wind, high clouds
### FIELD DATA (Continued)

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Pre Cal. 0 @ 0 200 @ 200 7.0 @ 7.0
Post Cal. 0 @ 0 199 @ 200 7.1 @ 7.0
Drift 0 0-1 0-0.1

Notes: Sampling conducted between 10:00 AM and 3:00 PM
Air Temp: 11.3 °C, calm, partly cloudy, occ light rain

#### Apr. 14

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Post Cal. 0 @ 0 199 @ 200 7.1 @ 7.0
Drift 0 0-1 0-0.1

Notes: Sampling conducted between 10:30 AM and 4:00 PM
Air Temp: 14.1 °C, light wind, high clouds

#### Apr. 15

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Post Cal. 0 @ 0 199 @ 200 7.1 @ 7.0
Drift 0 0-1 0-0.2

Notes: Sampling conducted between 11:00 AM and 4:30 PM
Air Temp: 12.2 °C, calm, cloudy, occ rain (rained over night), silage crops ?(grass) coming in (~4' high)
### FIELD DATA (Continued)

#### Apr. 27

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**Notes:** Sampling conducted between 10:00 AM and 3:30 PM
Air Temp: 9.8 C
Partly cloudy, mod windy, (rained hard for previous week)

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**Notes:** Sampling conducted between 10:00 AM and 3:30 PM
Air Temp: 9.8 C
Partly cloudy, mod windy, (rained hard for previous week)

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**Notes:** Sampling conducted between 11:00 AM and 3:30 PM
Air Temp: 17.4 C
Light wind, partly cloudy, (rained over night)
### May 18

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**Notes:** Sampling conducted between 1:00 PM and 5:00 PM

**Air Temp:** 11.3 C ___________ calm to light wind, partly cloudy, raining, (silage ? (grass) up to ~ 1.5 feet)

### May 19

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**Notes:** Sampling conducted between 1:00 PM and 5:00 PM

**Air Temp:** 11.7 C ___________ calm to light wind, partly cloudy, raining, (silage ? (grass) up to ~ 1.5 feet)

### May 20

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**Notes:** Sampling conducted between 11:30 AM and 4:00 PM

**Air Temp:** 11.7 C ___________ cloudy, light wind, light rain (rained over night)
### Field Data (Continued)

#### Jun. 16 (AM)

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**Notes:** Sampling conducted between 8:00 AM and 12:00 AM

*Air Temp: 16.6°C calm, scattered high clouds*

#### Jun. 16 (PM)

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**Notes:** Sampling conducted between 6:00 PM and 7:00 PM

*Air Temp: 21.8°C calm, clear, muggy (corn up 0.5 to 1.5 feet) (streams clogging with grass)*

#### Jul. 14 (AM)

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**Notes:** Sampling conducted between 8:00 AM and 12:00 AM

*Air Temp: 25.2°C calm, clear (corn up 0.5 to 1.5 feet) (streams clogging with grass)*

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<th>Flow (cfs)</th>
<th>TDS (ppm)</th>
<th>Turb. (ntu)</th>
<th>pH</th>
<th>W. Temp. (C)</th>
<th>DO (mg O₂/L)</th>
<th>DO (%sat)</th>
<th>Wink. (mg O₂/L)</th>
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**Notes:** Sampling conducted between 6:00 PM and 7:00 PM

*Air Temp: 21.8°C calm, clear, muggy*
### Field Data (Continued)

#### Aug. 11 (AM)

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**Notes:** Sampling conducted between 7:30 AM and 10:30 AM  
Air Temp: @ 9AM-13.4 C calm, partly cloudy (corn near full height) (streams clogged with grass)

#### Aug. 11 (PM)

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**Notes:** Sampling conducted between 4:30 PM and 5:00 PM  
Air Temp: 14.0 C light breeze, mostly cloudy (rained heavy over previous 24 hrs.)

#### Sep. 4 (AM)

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**Notes:** Sampling conducted between 4:30 PM and 5:00 PM  
Air Temp: 14.0 C light breeze, mostly cloudy (rained heavy over previous 24 hrs.)
## APPENDIX B (RATING CURVES)

### Sample Site J1

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### Regression

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**Site J1 Curve**

- **Observed Data**
- **Regression**

![Site J1 Curve Graph](image)
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![Site SM2 Curve](image-url)
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**Regression**

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RATING CURVES (Continued)

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**Regression**

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Site J4 Curve

- Observed Data
- Regression
**RATING CURVES** (Continued)

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**Regression (semi-logarithmic)**

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![Semi-Log Regression](image)

**Site J5 Curve**

- **Observed Data**
- **Regression**

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133
RATING CURVES (Continued)

Sample Site J6

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Semi-Log Regression

Site J6 Curve

Observed Data
Regression

134
RATING CURVES (Continued)

Sample Site J8

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Semi - Log Regression

Site J8 Curve

Observed Data
Regression
**RATING CURVES (Continued)**

**Sample Site P9**

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**Regression**

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**Site P9 Curve**

- Observed Data
- Regression
### RATING CURVES (Continued)

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**Site P10 Curve**

- **Observed Data**
- **Regression**
RATING CURVES (Continued)

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Site SQ11 Curve

- Observed Data
- Regression
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Site SQ12 Curve

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- Regression
### Sample Site J13

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![Semi-Log Regression](image)

![Site J13 Curve](image)
APPENDIX C (T NH₃ DATA)

T NH₃: Standard Dilution Series; Initial Curve Fit (Dec. 95)

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\[ r^2 = 0.98298221 \]

Slope = 174.960
Y-Int. = 2.497

Concentration vs Absorbance

- Dilution Series
- Regression
### NH₃ Analytical Results

#### Dec. 18

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<td>125 ug/L CK STD</td>
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\[ r^2 = 0.984444168 \]

| J1-1-FR  | 18-Dec (AM) | 19-Dec | 0.601 | 0.544 | 97.617 |
| J1-2-LR  | 19-Dec      |        | 0.468 | 0.411 | 74.347 |
| J6-1-SP  | *           | 19-Dec  | 0.493 | 0.436 | 984.016 |

\[ r^2 = 0.987900282 \]

| J1-1     | 18-Dec (AM) | 19-Dec | 0.702 | 0.645 | 115.288 |
| J1-2     | 18-Dec (PM) | 19-Dec | 0.653 | 0.596 | 106.715 |
| J6-1     | 18-Dec (AM) | 19-Dec | 0.264 | 0.207 | 483.193 |
| J6-2     | 18-Dec (PM) | 19-Dec | 0.241 | 0.184 | 432.892 |
| J13-1    | 18-Dec (AM) | 19-Dec | 0.383 | 0.326 | 743.446 |
| J13-2    | 18-Dec (PM) | 19-Dec | 0.305 | 0.248 | 572.860 |

#### Dec. 19

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<th>Date Anal.</th>
<th>Abs.</th>
<th>Abs. - Blk</th>
<th>Conc. (ug N/L)</th>
<th>Notes</th>
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<td>20-Dec</td>
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<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
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<td>0.064</td>
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<td>*</td>
<td>*</td>
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<td>LB</td>
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<td>*</td>
<td>*</td>
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<td>*</td>
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<tr>
<td>LB (avg)</td>
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<td>*</td>
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<td>128.468</td>
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\[ r^2 = 0.987900282 \]

| J1-3-FR  | 19-Dec (AM) | 20-Dec | 0.554 | 0.492 | 88.577 |
| J5-3-FR  | 19-Dec (AM) | 20-Dec | 0.432 | 0.370 | 336.161 |
| J3-4-FR  | 19-Dec (PM) | 20-Dec | 0.610 | 0.548 | 98.375 |
| P10-4-FR | 19-Dec (PM) | 20-Dec | 0.495 | 0.433 | 78.255 |
| SM2-3-LR | 20-Dec     | 0.674   | 0.612 | 109.573  | *              | *     |
| J4-3-LR  | 20-Dec     | 1.195   | 1.133 | 200.727  | *              | *     |
| J8-4-LR  | 20-Dec     | 0.824   | 0.752 | 339.541  | *              | *     |
| J13-4-LR | 20-Dec     | 0.596   | 0.534 | 479.628  | *              | *     |
| J1-3-SP  | 20-Dec     | 0.826   | 0.754 | 136.166  | *              | *     |

\[ r^2 = 0.987900282 \]

| J1-3     | 19-Dec (AM) | 20-Dec | 0.604 | 0.542 | 97.325 |
| J1-4     | 19-Dec (PM) | 20-Dec | 0.539 | 0.477 | 85.953 |
| SM2-3    | 19-Dec (AM) | 20-Dec | 0.667 | 0.605 | 108.348 |
| SM2-4    | 19-Dec (PM) | 20-Dec | 0.575 | 0.513 | 92.251 |
| J3-3     | 19-Dec (AM) | 20-Dec | 0.572 | 0.510 | 91.727 |
| J3-4     | 19-Dec (PM) | 20-Dec | 0.846 | 0.584 | 104.674 |
| J4-3     | 19-Dec (AM) | 20-Dec | 1.195 | 1.133 | 200.727 |
| J4-4     | 19-Dec (PM) | 20-Dec | 1.036 | 0.974 | 172.908 |
| J5-3     | 19-Dec (AM) | 20-Dec | 0.756 | 0.694 | 309.788 |

#### Notes

- avg. of 3 LB samples
- avg. of 3 LB samples
- Diluted 2/25; spike=40ug/L
- Diluted 2/25
- Diluted 2/25
- Diluted 2/25
- Diluted 5/25
### TNH3 DATA (Continued)

#### Dec. 19 (Continued)

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<tr>
<th>Sample #</th>
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<th>Date Anal.</th>
<th>Abs.</th>
<th>Abs - Blk</th>
<th>Conc. (ug/L)</th>
<th>Notes</th>
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<td>19-Dec (PM)</td>
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<td>0.648</td>
<td>0.586</td>
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<td>J6-3</td>
<td>19-Dec (AM)</td>
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<td>0.453</td>
<td>0.391</td>
<td>354.532</td>
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<tr>
<td>J6-4</td>
<td>19-Dec (PM)</td>
<td>20-Dec</td>
<td>0.453</td>
<td>0.391</td>
<td>354.532</td>
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<tr>
<td>CB7-3</td>
<td>19-Dec (AM)</td>
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<td>0.644</td>
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<td>0.657</td>
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<td>19-Dec (PM)</td>
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<td>P9-3</td>
<td>19-Dec (PM)</td>
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<td>0.573</td>
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<td>P9-4</td>
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<td>P10-3</td>
<td>19-Dec (AM)</td>
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#### Dec. 20

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<th>Abs - Blk</th>
<th>Conc. (ug/L)</th>
<th>Notes</th>
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<td>21-Dec</td>
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<td>FB-5</td>
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<tr>
<td>Ck1</td>
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<td>21-Dec</td>
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#### Jan. 20

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<th>Abs - Blk</th>
<th>Conc. (ug/L)</th>
<th>Notes</th>
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<td>22-Jan</td>
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<tr>
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<td>22-Jan</td>
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<tr>
<td>FB-1</td>
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<td>0.001</td>
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<td>22-Jan</td>
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<td>22-Jan</td>
<td>0.724</td>
<td>0.676</td>
<td>120.712</td>
<td>125 ug/L CK STD</td>
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### Notes
- **J13-3-FR**: 20-Jan
  - Abs: 0.596
  - Abs - Blk: 0.509
  - Conc: 454.259 ug/L
  - Diluted 5/25

### Avg of 3 LB samples
- Avg: 0.048 ug/L
- Std dev: 0.001 ug/L
- Spike: 40 ug/L

### Avg of 3 CK samples
- Avg: 0.323 ug/L
- Std dev: 0.001 ug/L
- Spike: 40 ug/L

---

**Legend**
- **RPD**: Relative Percent Difference
- **% Rec**: Percent Recovery
- **Notes**: Additional notes or conditions for the sample.
### Jan. 20 (Continued)

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<th>Sample #</th>
<th>Date Samp.</th>
<th>Date Anal.</th>
<th>Abs.</th>
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<th>Conc. (ug N/L)</th>
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<td>0.395</td>
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<td>0.502</td>
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### Jan. 21

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<td>22-Jan</td>
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<tr>
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### Jan. 22

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<td>LB (avg)</td>
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### TNH₃ DATA (Continued)

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### Notes

- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
- Avg. of 3 LB samples
### T NH₃ DATA (Continued)

#### Feb. 10

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<td>avg. of 3 LB samples</td>
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<td>49.328</td>
<td>125ug/L CK STD</td>
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<td>12-Feb</td>
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#### Feb. 11

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<td>12-Feb</td>
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#### Feb. 12

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### Feb. 12 (Continued)

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<td>13-Feb</td>
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### Feb. 25

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### Feb. 25 (Continued)

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**Notes:**
- Diluted 10/25
- Diluted 5/25
- Spike=40ug/L
- Spike=40ug/L (outside curve)
- Spike=50ug/L CK STD
- Spike=125ug/L CK STD
- Spike=40ug/L (outside curve)
- Spike=50ug/L CK STD
- Spike=125ug/L CK STD
- avg. of 3 LB samples
- avg. of 3 LB samples
### Mar. 24

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**Apr. 14**

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**Apr. 15**

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### Apr. 28

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### Apr. 28 (Continued)

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### May. 18

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### May. 19

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### Notes
- Avg. of 3 LB samples
- 50ug/L CK STD
- 125ug/L CK STD
- Spike=40ug/L, (outside curve)
- Spike=80ug/L
- Avg. of 3 LB samples
- 50ug/L CK STD
- 125ug/L CK STD
### May 19 (Continued)

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### May 20

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### Jun. 16

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### Jun. 16 (Continued)

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### Jul. 14

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*avg. of 3 LB samples*

### Sep 4

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*avg. of 3 LB samples*

### T NH₃ DATA (Continued)

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*spike=40µg/L*

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*Diluted 5/25*

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*Diluted 5/25*
### NH₃ DATA (Continued)

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<th>Conc. (ug N/L)</th>
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*Rec. = 121.160

Notes: spike=40ug/L

5/25 Diluted

10/25 Diluted
## APPENDIX D (NO₃ + NO₂ DATA)

### NO₃ + NO₂ Analytical Results

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<th>Sample #</th>
<th>Date Samp.</th>
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<th>Notes</th>
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* rp² = 0.999991

% Rec. = 97.3
% Rec. = 86.3
% Rec. = 102.7
### NO$_3$ + NO$_2$ Data (Continued)

#### Dec. 18, 19, 20 (Continued)

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### Feb. 10, 11, 12, 24, 25, 26

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**Apr. 13, 14, 15, 27, 28, 29**

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**Notes**

- Diluted 2.5/50
- 1000ug/L STD
- 50ug/L STD
- 100ug/L STD
- 150ug/L STD
- 200ug/L STD
- 250ug/L STD
- 500ug/L STD
- 1000ug/L STD
- 250ug/L CK STD
- 625ug/L CK STD
- 500ug/L NO2 rec. STD
- spike=25ug/L

**RPD values**

- $r^2 = 0.999993$
- $r^2 = 0.876$
- $r^2 = -0.756$
- $r^2 = 1.886$
- $r^2 = -0.228$
- $r^2 = 0.331$
- $r^2 = 0.431$
- $r^2 = 6.946$
- $r^2 = 0.893$
- $r^2 = 1.196$
- $r^2 = -0.228$
### NO$_3$+NO$_2$ DATA (Continued)

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### NO$_3$+NO$_2$ DATA (Continued)

#### May 18, 19, 20

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#### R$^2$ = 0.999985

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| J13-3-SP | 29-May     |            | *           | *            |% rec calc by autoanalyzer NO2 rec mid run NO2 rec end run |
| % Rec.   |            |            | 96.4        |              |       |
| NO2:500  | *          | 29-May     | 1894        | 507          |       |
| NO2:500  | *          | 29-May     | 1899        | 450          |       |
| J1-1     | 18-May     | 29-May     | 890         | 4294         | Diluted 2.5/50 |
| J5-1     | 18-May     | 29-May     | 1015        | 4997         | Diluted 2.5/50 |
| J13-1    | 18-May     | 29-May     | 682         | 3045         | Diluted 2.5/50 |
| J1-2     | 19-May     | 29-May     | 880         | 4206         | Diluted 2.5/50 |
| J1-3     | 19-May     | 29-May     | 892         | 4276         | Diluted 2.5/50 |
| J1-4     | 19-May     | 29-May     | 930         | 4499         | Diluted 2.5/50 |
| J1-5     | 19-May     | 29-May     | 855         | 4059         | Diluted 2.5/50 |
| J1-6     | 19-May     | 29-May     | 1003        | 4927         | Diluted 2.5/50 |
| CB7-2    | 19-May     | 29-May     | 273         | 648          | Diluted 2.5/50 |
| J8-2     | 19-May     | 29-May     | 1077        | 5390         | Diluted 2.5/50 |
| J9-2     | 19-May     | 29-May     | 1656        | 8754         | Diluted 2.5/50 |
| P10-2    | 19-May     | 29-May     | 1706        | 9047         | Diluted 2.5/50 |
| SQ11-2   | 19-May     | 25-May     | 954         | 4639         | Diluted 2.5/50 |
| SQ12-2   | 19-May     | 25-May     | 1178        | 5952         | Diluted 2.5/50 |
| J1-3     | 19-May     | 25-May     | 645         | 2828         | Diluted 2.5/50 |
| J14-2    | 19-May     | 25-May     | 472         | 1814         | Diluted 2.5/50 |
| D15-2    | 19-May     | 25-May     | 878         | 4194         | Diluted 2.5/50 |
| J1-3     | 20-May     | 25-May     | 846         | 4006         | Diluted 2.5/50 |
| J6-3     | 20-May     | 25-May     | 971         | 4739         | Diluted 2.5/50 |
| J13-3    | 20-May     | 25-May     | 639         | 2793         | Diluted 2.5/50 |
**NO$_3^+$NO$_2$ DATA (Continued)**

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### NO₂+NO₃ DATA

#### Sep. 4

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## APPENDIX E (TOTAL NITROGEN DATA)

**Total Nitrogen Analytical Results**

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* r² = 0.998895

Diluted samples spiked at 500ug/L.

Notes:
- 2000ug/L STD
- 1000ug/L STD
- 500ug/L STD
- 400ug/L STD
- 300ug/L STD
- 200ug/L STD
- 100ug/L STD

% Rec. calc. by autoanalyzer:
- NO2 rec. mid run
- NO2 rec.end run

500ug/L NO2 rec. STD
### TOTAL NITROGEN DATA (Continued)

#### Jan. 20, 21, 22 (Continued)

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#### Feb. 10, 11, 12, 24, 25, 26

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- NO2:500: 500ug/L NO2 rec. STD
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### Mar. 9, 10, 11, 23, 24, 25

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| Apr. 13, 14, 15, 27, 28, 29
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| J5-2-FR  | 14-Apr    | 10-May     | 1164        | 5870          | Diluted 0.5/5 |
| SQ12-2-FR| 14-Apr    | 10-May     | 1359        | 6956          | Diluted 0.5/5 |
| J6-3-FR  | 15-Apr    | 10-May     | 1249        | 6343          | Diluted 0.5/5 |
| J1-4-FR  | 27-Apr    | 10-May     | 989         | 4896          | Diluted 0.5/5 |
| J3-5-FR  | 28-Apr    | 10-May     | 1071        | 5352          | Diluted 0.5/5 |
| J4-5-FR  | 28-Apr    | 10-May     | 1069        | 5341          | Diluted 0.5/5 |
| J6-6-FR  | 29-Apr    | 10-May     | 1245        | 6321          | Diluted 0.5/5 |
### TOTAL NITROGEN DATA (Continued)

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- spike = 500ug/L
- % rec. calc. by autoanalyzer
- spike = 500ug/L
- % rec. calc. by autoanalyzer
- spike = 500ug/L
- % rec. calc. by autoanalyzer
### TOTAL NITROGEN DATA (Continued)

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#### Lab Replicate Variation (Apr.)

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## TOTAL NITROGEN DATA (Continued)

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%Rec. = 103 % rec. calc. by autoanalyzer spike = 250ug/L
%Rec. = 98 % rec. calc. by autoanalyzer NO₂ rec. mid run
%Rec. = 103 % rec. calc. by autoanalyzer NO₂ rec. end run
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\[^2=0.999253\]
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* RPD = 0.998561
* r² = 0.9989581
* spike = 250ug/L
* % rec. calc. by autoanalyzer
* spike = 250ug/L
* % rec. calc. by autoanalyzer
* spike = 250ug/L
* % rec. calc. by autoanalyzer
* NO₂ rec. end run
* NO₂ rec. mid run

---

183
### TOTAL NITROGEN DATA (Continued)

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### Lab Replicate Variation (Sep.)

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## APPENDIX F (SOLUBLE REACTIVE PHOSPHORUS DATA)

### Soluble Reactive Phosphorus Dilution Series: Initial Curve Fit (Feb. 96)

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<th>Lab Blanks</th>
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<th>Conc. Est. (ug P/L)</th>
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\[ r^2 = 0.9999541 \]

Slope = 325.899

Y-Int. = -1.420

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**Graph: Concentration vs Absorbance**

- Dilution Series
- Regression
### SOLUBLE REACTIVE PHOSPHORUS DATA

(Soluble Reactive Phosphorus Analytical Results)

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Notes:
- avg. of 3 LB samples
- 50ug/L CK STD
- 125ug/L CK STD

**SOLUBLE REACTIVE PHOSPHORUS DATA (Continued)**

**Feb. 10, 11, 12, 24, 25, 26 (Continued)**

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**Mar. 9, 10, 11, 23, 24, 25**

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**Notes**

- avg. of 3 LB samples
- 50ug/L CK STD
- 125ug/L CK STD
- spike=40ug/L

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### SOLUBLE REACTIVE PHOSPHORUS DATA (Continued)

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**Notes:**
- **LB:**
  - Avg of 3 LB samples
  - Avg of 3 LB samples
- **FB-2:**
  - Spike=40ug/L
- **FB-5:**
  - Spike=40ug/L
- **Ck:**
  - Spike=40ug/L
  - Spike=40ug/L
- **Ck 2:**
  - Spike=40ug/L
  - Spike=40ug/L
- **J1-1-FR:**
  - Spike=40ug/L
  - Spike=40ug/L

**Average:**
- Avg of 3 LB samples
- Avg of 3 LB samples

**50ug/L CK STD:**
- Avg of 3 LB samples

**125ug/L CK STD:**
- Avg of 3 LB samples
### SOLUBLE REACTIVE PHOSPHORUS DATA (Continued)

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## SOLUBLE REACTIVE PHOSPHORUS DATA (Continued)

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**May 18, 19, 20**

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- **Notes**: avg. of 3 LB samples
  - 50ug/L CK STD
  - 125ug/L CK STD

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- **Notes**: spike=40ug/L

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- **Notes**: spike=40ug/L

---

*RPD* = residuals to prediction of *y* from *x*.

% Rec. = % of recovery of spiked samples.

1^2 = 0.99972176

- avg. of 3 LB samples
- 50ug/L CK STD
- 125ug/L CK STD
### SOLUBLE REACTIVE PHOSPHORUS DATA (Continued)

#### May 18, 19, 20 (Continued)

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#### Jun. 16

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<tr>
<td>LB</td>
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#### Jul. 14

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<td>LB</td>
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<td>0.008</td>
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avg. of 3 LB samples
### SOLUABLE REACTIVE PHOSPHORUS DATA (Continued)

#### Jul. 14 (Continued)

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<td>SM2-1-LR</td>
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<td>12-Aug</td>
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<td>53.874</td>
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<td>29.106</td>
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#### Aug. 11

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<tr>
<td>LB</td>
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<tr>
<td>LB</td>
<td>*</td>
<td>12-Aug</td>
<td>0.011</td>
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<td>spike=40ug/L</td>
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<td>% Rec. = 108.361</td>
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<td>0.306</td>
<td>0.295</td>
<td>94.612</td>
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<td>SM2-1</td>
<td>11-Aug AM</td>
<td>12-Aug</td>
<td>0.173</td>
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<td>51.267</td>
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<td>J3-1</td>
<td>11-Aug AM</td>
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<td>0.093</td>
<td>0.082</td>
<td>25.195</td>
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<td>J4-1</td>
<td>11-Aug AM</td>
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<td>0.105</td>
<td>0.094</td>
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### SOLUBLE REACTIVE PHOSPHORUS DATA (Continued)

#### Aug. 11 (Continued)

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<th>Abs.</th>
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<th>Conc. (ug P/L)</th>
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<tr>
<td>SQ11-1</td>
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<td>0.091</td>
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#### Sep. 4

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<th>Abs. - Blk</th>
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<td>5-Sep</td>
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<tr>
<td>LB</td>
<td>5-Sep</td>
<td>5-Sep</td>
<td>0.008</td>
<td>*</td>
<td>*</td>
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</tr>
<tr>
<td>LB (avg)</td>
<td>5-Sep</td>
<td>5-Sep</td>
<td>0.008</td>
<td>*</td>
<td>*</td>
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<tr>
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<td>5-Sep</td>
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<td>0.001</td>
<td>0.000</td>
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<tr>
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<td>5-Sep</td>
<td>0.157</td>
<td>0.149</td>
<td>47.030</td>
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<td>Ck 2</td>
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<td>5-Sep</td>
<td>0.387</td>
<td>0.379</td>
<td>121.987</td>
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**J8-1-FR**

- 4-Sep AM 5-Sep 0.115 0.107 33.434
- RPD= -2.976

**SQ11-1-FR**

- 4-Sep AM 5-Sep 0.092 0.084 25.847
- RPD= -5.174

**J8-1-LR**

- 5-Sep 0.115 0.107 33.434
- RPD= -2.976

**SQ11-1-LR**

- 5-Sep 0.090 0.082 25.195
- RPD= -2.621

**J8-1-SP**

- % Rec= 102.858
- 5-Sep 0.238 0.230 73.428

**SQ11-SP**

- % Rec= 101.843
- 5-Sep 0.213 0.205 65.281

**J1-1**

- 4-Sep AM 5-Sep 0.133 0.125 39.209
- RPD= -2.976

**SM2-1**

- 4-Sep AM 5-Sep 0.184 0.176 55.830

**J3-1**

- 4-Sep AM 5-Sep 0.052 0.043 25.947

**J4-1**

- 4-Sep AM 5-Sep 0.126 0.118 36.927

**J5-1**

- 4-Sep AM 5-Sep 0.117 0.109 33.994

**J6-1**

- 4-Sep AM 5-Sep 0.141 0.133 41.816

**CB7-1**

- 4-Sep AM 5-Sep 0.105 0.097 30.084

**J8-1**

- 4-Sep AM 5-Sep 0.112 0.104 32.365

**P9-1**

- 4-Sep AM 5-Sep 0.149 0.141 44.243

**P10-1**

- 4-Sep AM 5-Sep 0.243 0.235 75.058

**SQ11-1**

- 4-Sep AM 5-Sep 0.088 0.080 24.543

**SQ12-1**

- 4-Sep AM 5-Sep 0.052 0.044 12.811

**J13-1**

- 4-Sep AM 5-Sep 0.103 0.095 29.432

**J14-1**

- 4-Sep AM 5-Sep 0.021 0.013 2.708

**D15-1**

- 4-Sep AM 5-Sep 0.659 0.661 213.891

**J1-2**

- 4-Sep PM 5-Sep 0.145 0.137 43.120

**J6-2**

- 4-Sep PM 5-Sep 0.123 0.115 35.950

**J13-2**

- 4-Sep PM 5-Sep 0.153 0.145 45.727

---

avg. of 3 LB samples

50ug/L CK STD

125ug/L CK STD

spike=40ug/L

spike=40ug/L

---

193
**APPENDIX G (TOTAL PHOSPHORUS DATA)**

Total Phosphorus Dilution Series: Initial Curve Fit -1cm Covette- (Dec. 95)

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<th>Lab Blanks</th>
<th>Avg. Blank</th>
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<table>
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<th>Abs.</th>
<th>Abs. - Avg Blank</th>
<th>Conc. (ug P/L)</th>
<th>Conc. Est. (ug P/L)</th>
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<td>0.000</td>
<td>0</td>
<td>-9.413</td>
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<tr>
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<td>0.015</td>
<td>0.011</td>
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<td>10.506</td>
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<td>0.027</td>
<td>0.027</td>
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<td>39.480</td>
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<td>64.832</td>
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<td>0.081</td>
<td>0.077</td>
<td>125</td>
<td>130.024</td>
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<td>0.119</td>
<td>0.115</td>
<td>200</td>
<td>198.837</td>
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<td>0.233</td>
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<td>0.660</td>
<td>0.656</td>
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\[ r^2 = 0.999056294 \]

Slope = 1810.870

Y-int. = -9.413

**Concentration vs Absorbance**

+ Dilution Series

- Regression

---

194
**TOTAL PHOSPHORUS DATA** (Continued)

**Total Phosphorus Dilution Series: 2nd Curve Fit -5cm Covette- (Jan. 96)**

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<th>Abs. - Avg Blank</th>
<th>Conc. (ug P/L)</th>
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<tr>
<td>0.017</td>
<td>0.017</td>
<td>0.030</td>
<td>10</td>
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<td>0.077</td>
<td>0.077</td>
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<td>1.720</td>
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- **Ck-Std. 1**
- **Ck-Std. 2**

\[ r^2 = 0.999725029 \]

**Slope** = 356.119  
**Y-Int.** = -2.583

---

**Concentration vs Absorbance**

- Dilution Series
- Regression

---

195
### TOTAL PHOSPHORUS DATA (Continued)

#### Total Phosphorus Analytical Results

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Date Samp.</th>
<th>Date Anal.</th>
<th>Abs.</th>
<th>Abs. - Blk</th>
<th>Conc. (ug P/L)</th>
<th>Notes</th>
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<tr>
<td>LB-1</td>
<td></td>
<td>16-Jan</td>
<td>0.005</td>
<td>*</td>
<td>*</td>
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</tr>
<tr>
<td>LB-1</td>
<td></td>
<td>16-Jan</td>
<td>0.004</td>
<td>*</td>
<td>*</td>
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<tr>
<td>LB-1(avg)</td>
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<td>*</td>
<td>*</td>
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<td>16-Jan</td>
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<tr>
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<td>FB-1</td>
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<tr>
<td>FB-3</td>
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<td>16-Jan</td>
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<td>FB-5</td>
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<tr>
<td>FB-3</td>
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<td>16-Jan</td>
<td>0.005</td>
<td>*</td>
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<tr>
<td>FB-5</td>
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<td>16-Jan</td>
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<tr>
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<td>16-Jan</td>
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<td>0.037</td>
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<td>0.077</td>
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**Notes:**
- avg. of 3 LB-1,2 samples
- 50 ug/L CK STD
- 125 ug/L CK STD
- spike=40ug/L
### TOTAL PHOSPHORUS DATA (Continued)

**Dec. 18, 19, 20 (Continued)**

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**Jan. 20, 21, 22**

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\[ r^2 = 0.999725029 \]

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<td>SM2-2-FR</td>
<td>21-Jan</td>
<td>26-Jan</td>
<td>0.463</td>
<td>0.446</td>
<td>156.127</td>
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<td>J8-2-FR</td>
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<td>26-Jan</td>
<td>0.633</td>
<td>0.615</td>
<td>215.666</td>
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<tr>
<td>J6-3-FR</td>
<td>22-Jan</td>
<td>26-Jan</td>
<td>0.635</td>
<td>0.618</td>
<td>217.380</td>
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<td>0.614</td>
<td>0.597</td>
<td>209.901</td>
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\[ \text{avg. of 3 LB-1,2 samples} \]

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<th>Abs. - Blk</th>
<th>Conc. (ug P/L)</th>
<th>Notes</th>
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<td>0.842</td>
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<td>0.523</td>
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<td>0.637</td>
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<td>0.518</td>
<td>0.501</td>
<td>175.714</td>
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<td>0.526</td>
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**TOTAL PHOSPHORUS DATA (Continued)**

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**Notes**

- *spike=40ug/L*
- avg. of 3 LB samples
- 50µg/L CK STD
- 125µg/L CK STD
## TOTAL PHOSPHORUS DATA (Continued)

### Feb. 10, 11, 12, 24, 25, 26 (Continued)

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*RPD* = **99969148**

Notes:

- avg. of 3 LB samples:
  - 50 ug/L CK STD
  - 125 ug/L CK STD
- spike=40ug/L
- spike=40ug/L

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### TOTAL PHOSPHORUS DATA (Continued)

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**Notes**

- avg. of 3 LB samples
- 50ug/L CK STD
- 125ug/L CK STD

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### TOTAL PHOSPHORUS DATA (Continued)

**May 18, 19, 20 (Continued)**

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**Jun. 16**

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**Jul. 14**

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203
### TOTAL PHOSPHORUS DATA (Continued)

#### Jul. 14 (Continued)

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#### Aug. 11

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**P9-1-FR** 11-Aug AM 12-Aug 0.256 0.232 80.155
**SM2-1-LR** 11-Aug AM 12-Aug 0.403 0.379 132.505
**P9-1-LR** 11-Aug AM 12-Aug 0.241 0.217 74.814
**SM2-1-SP** 11-Aug AM 12-Aug 0.490 0.466 163.487
**P9-1-SP** 11-Aug AM 12-Aug 0.358 0.334 116.479
**J1-1** 11-Aug AM 12-Aug 0.216 0.192 65.911
**SM2-1** 11-Aug AM 12-Aug 0.392 0.368 128.587
**J3-1** 11-Aug AM 12-Aug 0.201 0.177 60.569
**J4-1** 11-Aug AM 12-Aug 0.210 0.186 63.774
**J5-1** 11-Aug AM 12-Aug 0.208 0.184 63.062
### TOTAL PHOSPHORUS DATA (Continued)

#### Aug. 11 (Continued)

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APPENDIX H (FECAL COLIFORM DATA)

Fecal Coliform Analytical Results

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### APPENDIX I (BOD DATA)

#### BOD Analytical Results

**Jun. 16**

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Seed in Samples (ml): 2
Seed in Correction (ml): 10

Diluted 500/1000
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**Seed in Samples (ml): 2**
**Seed in Correction (ml): 10**

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**Seed in Samples (ml): 2**
**Seed in Correction (ml): 10**

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### APPENDIX J (1996 FIELD MEASUREMENTS AND WATER CHEMISTRY DATA)

#### Dec. 18 (AM), 1995

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<th>pH</th>
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<th>FLOW (cfs)</th>
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<th>NH₃ (ug N/L)</th>
<th>NH₄ (ug N/L)</th>
<th>ORG N (ug N/L)</th>
<th>T N (ug N/L)</th>
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## 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

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### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

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2 1 3

1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)


### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

#### Jan. 22, 1996

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (%) sat. | TURB. (ntu) | FLOW (cfs) | NO\textsubscript{2}+NO\textsubscript{3} (ug N/L) | N\textsubscript{H}\textsubscript{3} (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC BOD\textsubscript{5} (mg/L) |
|------|--------------|-----------|------------------|----|-----------|------------|------------|-----------|-----------------|----------------|----------------|--------------|--------------|--------------|--------------|--------------|-----------------|
| J1   | 1.1          | 0         | 0                | 7.3| 9.5       | 68         | 0          | 61.6      | 5921            | 85             | 0.137         | 347          | 6353         | *             | *             | *             | 159            |
| SM2  | 4.1          | 110       | 177              | 7.2| 9.4       | 72         | 0          | 7.7       | *               | *              | *             | *            | *             | *             | *             | *             |
| J3   | 0.8          | 110       | 177              | 7.2| 8.7       | 62         | 0          | 65.2      | *               | *              | *             | *            | *             | *             | *             | *             |
| J4   | 1.1          | 130       | 210              | 7.0| 8.4       | 60         | 0          | 51.7      | *               | *              | *             | *            | *             | *             | *             | *             |
| J5   | 1.5          | 120       | 194              | 7.4| 9.4       | 68         | 8          | 62.3      | *               | *              | *             | *            | *             | *             | *             | *             |
| J6   | 2.2          | 140       | 226              | 7.0| 10.1      | 74         | 2          | 37.5      | 6453            | 381            | 0.381         | 1704         | 8538         | *             | 215           | *             |
| CB7  | 5.6          | 240       | 387              | 6.9| 4.3       | 33         | 4          | 1.0       | *               | *              | *             | *            | *             | *             | *             | *             |
| J8   | 2.0          | 140       | 226              | 7.2| 11.1      | 81         | 2          | 53.6      | *               | *              | *             | *            | *             | *             | *             | *             |
| P9   | 3.7          | 140       | 226              | 7.2| 12.2      | 92         | 0          | 6.1       | *               | *              | *             | *            | *             | *             | *             | *             |
| P10  | 3.2          | 130       | 210              | 6.5| 7.4       | 55         | 0          | 9.7       | *               | *              | *             | *            | *             | *             | *             | *             |
| SQ11 | 0.6          | 100       | 161              | 7.0| 13.1      | 93         | 30         | 13.2      | *               | *              | *             | *            | *             | *             | *             | *             |
| SQ12 | 0.3          | 110       | 177              | 6.8| 12.6      | 89         | 0          | 5.5       | *               | *              | *             | *            | *             | *             | *             | *             |
| J13  | 0.9          | 160       | 258              | 6.9| 8.5       | 61         | 22         | 8.5       | 5746            | 494            | 0.301         | 1057         | 7287         | *             | 248           | *             |
| J14  | 0.2          | 190       | 306              | 6.7| 5.6       | 39         | 0          | 0.6       | *               | *              | *             | *            | *             | *             | *             | *             |
| D15  | *            | *         | *                | *  | *         | *          | *          | *         | *               | *              | *             | *            | *             | *             | *             | *             |

#### Feb. 10, 1996

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (%) sat. | TURB. (ntu) | FLOW (cfs) | NO\textsubscript{2}+NO\textsubscript{3} (ug N/L) | N\textsubscript{H}\textsubscript{3} (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC BOD\textsubscript{5} (mg/L) |
|------|--------------|-----------|------------------|----|-----------|------------|------------|-----------|-----------------|----------------|----------------|--------------|--------------|--------------|--------------|--------------|-----------------|
| J1   | 3.5          | 100       | 161              | 7.8| 7.0       | 52         | 10         | 183.7     | 4631            | 393            | 2.921          | 1597         | 6980         | 272          | 168          | 440            |
| SM2  | 4.3          | 100       | 161              | 7.9| 7.8       | 59         | 6          | 12.2      | *               | *              | *             | *            | *             | *             | *             | *             |
| J3   | 3.5          | 100       | 161              | 7.9| 6.8       | 51         | 10         | 144.9     | *               | *              | *             | *            | *             | *             | *             | *             |
| J4   | 3.5          | 100       | 161              | 7.8| 7.3       | 55         | 10         | 121.7     | *               | *              | *             | *            | *             | *             | *             | *             |
| J5   | 3.8          | 110       | 177              | 7.9| 8.3       | 63         | 12         | 110.9     | *               | *              | *             | *            | *             | *             | *             | *             |
| J6   | 5.2          | 110       | 177              | 7.8| 8.5       | 68         | 11         | 110.4     | 5069            | 1127           | 9.958          | 1423         | 7618         | 195          | 255          | 450            |
| CB7  | 6.1          | 180       | 290              | 7.8| 4.2       | 33         | 11         | 1.4       | *               | *              | *             | *            | *             | *             | *             | *             |
| J8   | 4.3          | 110       | 177              | 7.9| 9.7       | 74         | 9          | 100.0     | *               | *              | *             | *            | *             | *             | *             | *             |
| P9   | 5.2          | 100       | 181              | 7.9| 11.1      | 86         | 1          | 15.4      | *               | *              | *             | *            | *             | *             | *             | *             |
| P10  | 5.0          | 90        | 145              | 7.7| 6.6       | 51         | 1          | 16.7      | *               | *              | *             | *            | *             | *             | *             | *             |
| SQ11 | 4.5          | 80        | 129              | 7.8| 10.7      | 82         | 3          | 28.0      | *               | *              | *             | *            | *             | *             | *             | *             |
| SQ12 | 5.8          | 110       | 177              | 7.9| 10.2      | 81         | 2          | 14.3      | *               | *              | *             | *            | *             | *             | *             | *             |
| J13  | 5.0          | 120       | 194              | 7.9| 8.6       | 67         | 20         | 62.0      | 5052            | 943            | 10.277         | 1056         | 7050         | 220          | 326          | 547            |
| J14  | 4.3          | 150       | 242              | 7.9| 4.5       | 35         | 13         | 1.0       | *               | *              | *             | *            | *             | *             | *             | *             |
| D15  | *            | *         | *                | *  | *         | *          | *          | *         | *               | *              | *             | *            | *             | *             | *             | *             |
### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

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### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY

**Feb. 24, 1996**

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**Feb. 25, 1996**

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### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

#### Feb. 26, 1996

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (npu) | FLOW (cfs) | NO₂⁺NO₃ (mg/L) | T NH₃ (ug N/L) | NH₄⁺ (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SRP (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC (ug P/L) | BOD₅ (mg/L) |
|------|---------------|-----------|-----------------|----|-----------|------------|------------|-----------|--------------|----------------|--------------|----------------|--------------|--------------|---------------|--------------|--------------|-------------|-------------|
| J1   | 4.2           | 130       | 210             | 8.4| 8.0       | 61         | 0          | 62.3      | 5797         | 36             | 1.173        | 529           | 6363         | 92           | 54            | 147          |             |             |
| SM2  | 5.4           | 120       | 194             | 8.2| 9.1       | 71         | 0          | 7.6       |              |               |              |               |              |              |              |              |             |             |
| J3   | 4.1           | 120       | 194             | 8.0| 7.6       | 58         | 0          | 58.3      |              |               |              |               |              |              |              |              |             |             |
| J4   | 4.2           | 120       | 226             | 8.1| 7.8       | 60         | 0          | 72.7      |              |               |              |               |              |              |              |              |             |             |
| J5   | 4.2           | 120       | 210             | 8.0| 8.9       | 68         | 0          | 42.6      |              |               |              |               |              |              |              |              |             |             |
| J6   | 4.5           | 130       | 210             | 7.9| 9.7       | 74         | 2          | 25.1      | 6234         | 479            | 4.974        | 1002          | 7715         | 78           | 78            | 156          |             |             |
| CB7  | 7.3           | 200       | 323             | 7.9| 5.3       | 43         | 2          | 0.9       |              |               |              |               |              |              |              |              |             |             |
| J8   | 4.8           | 130       | 210             | 8.0| 10.3      | 80         | 0          | 21.5      |              |               |              |               |              |              |              |              |             |             |
| P9   | 5.9           | 130       | 210             | 8.0| 11.5      | 91         | 0          | 9.1       |              |               |              |               |              |              |              |              |             |             |
| P10  | 5.8           | 130       | 210             | 8.0| 7.1       | 56         | 0          | 11.8      |              |               |              |               |              |              |              |              |             |             |
| SQ11 | 4.9           | 110       | 177             | 7.9| 11.5      | 89         | 30         | 15.0      |              |               |              |               |              |              |              |              |             |             |
| SQ12 | 5.7           | 120       | 194             | 7.9| 11.6      | 91         | 0          | 6.3       |              |               |              |               |              |              |              |              |             |             |
| J13  | 4.9           | 140       | 226             | 7.8| 8.3       | 64         | 0          | 14.3      | 4474         | 785            | 6.748C       | 1507          | 6765         | 73           | 136          | 209          |             |             |
| J14  | 6.6           | 200       | 323             | 7.9| 7.0       | 56         | 0          | 0.6       |              |               |              |               |              |              |              |              |             |             |
| D15  | *             | *         | *               | *  | *         | *          | *          | *         |              |               |              |               |              |              |              |              |             |             |

#### Mar. 9, 1996

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# 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

### Apr. 14, 1996

| SITE | TEMP. | TDS | COND. | pH | DO | DO | TURB. | FLOW | NO$_2$+NO$_3$ | T NH$_3$ | NH$_3$ | ORG N | T N | SR P | ORG P | T P | FC | BOD$_5$ |
|------|------|----|------|----|----|----|------|------|-------------|---------|-------|-------|------|----|-----|------|----|----|--------|
| J1   | 11.4 | 100 | 161  | 7.0 | 7.5 | 67 | 0    | 55.7 | 4685        | 49      | 0.111 | 631 | 5425 | 99 | 75 | 174 | 44 |
| SM2  | 10.7 | 100 | 161  | 7.4 | 8.5 | 75 | 0    | 6.1  | 4622        | 94      | 0.507 | 670 | 5368 | 143 | 65 | 209 |    |
| J3   | 11.4 | 110 | 177  | 7.3 | 7.7 | 69 | 0    | 45.6 | 4799        | 41      | 0.185 | 646 | 5486 | 93  | 71 | 164 |    |
| J4   | 11.2 | 130 | 210  | 7.3 | 7.9 | 71 | 0    | 51.7 | 4849        | 45      | 0.199 | 1099 | 5983 | 94  | 60 | 154 |    |
| J5   | 10.9 | 120 | 194  | 7.5 | 8.9 | 79 | 0    | 35.6 | 4969        | 71      | 0.491 | 886 | 5926 | 78  | 76 | 154 |    |
| J6   | 11.0 | 130 | 210  | 7.3 | 10.1| 89 | 0    | 32.8 | 5487        | 157     | 0.690 | 833 | 6477 | 99  | 83 | 182 | 58 |
| CB7  | 12.4 | 200 | 323  | 7.2 | 7.8 | 72 | 2    | 0.6  | 1389        | 780     | 2.987 | 265 | 2434 | 17  | 341| 358 |    |
| J8   | 11.3 | 120 | 194  | 7.2 | 10.6| 94 | 0    | 38.3 | 5967        | 89      | 0.315 | 745 | 6800 | 111 | 75 | 186 |    |
| P9   | 11.5 | 100 | 161  | 7.1 | 11.0| 99 | 0    | 7.5  | 9010        | 36      | 0.102 | 1240 | 10286| 266 | 53 | 319 |    |
| P10  | 11.3 | 100 | 161  | 6.9 | 9.7 | 87 | 0    | 13.2 | 9288        | 81      | 0.145 | 1123 | 10492| 336 | 94 | 430 |    |
| SQ11 | 12.0 | 110 | 177  | 7.2 | 11.8| 107| 6    | 10.1 | 5512        | 37      | 0.139 | 760 | 6310 | 23  | 45 | 69  |    |
| SQ12 | 11.4 | 90  | 145  | 7.3 | 10.9| 98 | 0    | 6.3  | 6301        | 35      | 0.156 | 475 | 6811 | 16  | 40 | 57  |    |
| J13  | 12.3 | 150 | 242  | 7.4 | 12.1| 111| 2    | 10.5 | 4073        | 264     | 1.712 | 912 | 5269 | 59  | 139| 198 | 230|
| J14  | 14.3 | 180 | 290  | 7.2 | 19.7| 190| 6    | 0.6  | 2911        | 27      | 0.118 | 1579 | 4517 | 70  | 169| 238 |    |
| D15  | 13.4 | 150 | 242  | 7.4 | 14.6| 137| 10   | 2.4  | 6226        | 139     | 0.903 | 1332 | 7697 | 36  | 144| 180 |    |

### Apr. 15, 1996

<p>| SITE | TEMP. | TDS | COND. | pH | DO | DO | TURB. | FLOW | NO$_2$+NO$_3$ | T NH$_3$ | NH$_3$ | ORG N | T N | SR P | ORG P | T P | FC | BOD$_5$ |
|------|------|----|------|----|----|----|------|------|-------------|---------|-------|-------|------|----|-----|------|----|----|--------|
| J1   | 11.8 | 130 | 210  | 7.5 | 7.4 | 67 | 0    | 58.7 | 4489        | 56      | 0.408 | 1080 | 5625 | 97  | 70 | 167 |    |
| SM2  | 11.0 | 100 | 161  | 7.4 | 9.0 | 80 | 0    | 6.4  |             |         |        |       |      |     |    |     |    |
| J3   | 11.8 | 110 | 177  | 7.3 | 7.4 | 67 | 0    | 45.8 |             |         |        |       |      |     |    |     |    |
| J4   | 11.8 | 110 | 177  | 7.4 | 7.9 | 72 | 0    | 49.2 |             |         |        |       |      |     |    |     |    |
| J5   | 11.6 | 120 | 194  | 7.5 | 8.4 | 75 | 0    | 34.7 |             |         |        |       |      |     |    |     |    |
| J6   | 11.8 | 140 | 226  | 7.4 | 10.3| 94 | 0    | 33.7 | 5525        | 144     | 0.837 | 503 | 6171 | 97  | 77 | 174 |    |
| CB7  | 12.8 | 200 | 323  | 7.2 | 7.4 | 89 | 2    | 0.6  |             |         |        |       |      |     |    |     |    |
| J8   | 11.6 | 120 | 194  | 7.3 | 10.0| 90 | 0    | 38.1 |             |         |        |       |      |     |    |     |    |
| P9   | 11.7 | 100 | 161  | 7.1 | 10.9| 98 | 0    | 6.9  |             |         |        |       |      |     |    |     |    |
| P10  | 11.6 | 100 | 161  | 6.9 | 9.6 | 86 | 0    | 12.2 |             |         |        |       |      |     |    |     |    |
| SQ11 | 12.3 | 100 | 151  | 7.2 | 11.5| 106| 4    | 9.6  |             |         |        |       |      |     |    |     |    |
| SQ12 | 11.8 | 90  | 145  | 7.3 | 11.0| 100| 0    | 6.4  |             |         |        |       |      |     |    |     |    |
| J13  | 12.0 | 150 | 242  | 7.3 | 11.1| 101| 2    | 12.7 | 3833        | 278     | 1.306 | 980 | 5091 | 58  | 126| 184 |    |
| J14  | 13.0 | 170 | 274  | 7.3 | 16.3| 152| 4    | 0.6  |             |         |        |       |      |     |    |     |    |
| D15  |      |    |      |    |    |    |      |      |             |         |        |       |      |     |    |     |    |</p>
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**1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)**

**Apr. 27, 1996**

**Apr. 28, 1996**
### 1996 Field Measurements and Water Chemistry (Continued)

**Apr. 29, 1996**

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**May 19, 1996**

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**May 20, 1996**

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### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO<sub>3</sub>+NO<sub>2</sub> (ug N/L) | T NH<sub>3</sub> (ug N/L) | NH<sub>3</sub> (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SRP (ug P/L) | ORG P (ug P/L) | TP (ug P/L) | FC (mg/L) | BOD<sub>5</sub> (mg/L) |
|------|--------------|-----------|------------------|----|------------|------------|------------|----------|-----------------|----------------|---------------|--------------|-------------|-------------|---------|---------|---------|---------|--------|
| J1   | 13.1         | 100       | 161              | 7.0| 6.9        | 65         | 2          | 40.9     | 4996            | 24             | 0.052        | 167         | 5187        | 54         | 85        | 119     | 320     | <2      |
| J2   | 10.9         | 100       | 161              | 7.2| 7.9        | 70         | 2          | 4.8      | 4830            | 28             | 0.098        | 312         | 5170        | 93         | 62        | 156     | 140     | <2      |
| J3   | 13.6         | 140       | 226              | 6.4| 6.4        | 60         | 4          | 26.0     | 5013            | 31             | 0.021        | 215         | 5260        | 52         | 66        | 118     | *       | <2      |
| J4   | 13.2         | 120       | 194              | 6.9| 6.8        | 63         | 10         | 28.0     | 5202            | 31             | 0.054        | 420         | 5653        | 47         | 72        | 119     | *       | *       |
| J5   | 12.9         | 120       | 194              | 6.9| 7.9        | 73         | 6          | 19.0     | 5448            | 37             | 0.073        | 500         | 5985        | 46         | 71        | 117     | *       | *       |
| J6   | 12.4         | 110       | 177              | 7.0| 8.6        | 79         | 4          | 17.2     | 6370            | 94             | 0.226        | 897         | 7361        | 48         | 82        | 130     | 240     | 2.6     |
| CB7  | 15.9         | 170       | 274              | 7.0| 3.7        | 37         | 44         | 1.0      | 267             | 951            | 2.893        | 51          | 983         | 10        | 288       | 299     | 110     | 4.6     |
| J8   | 12.6         | 110       | 177              | 7.3| 8.8        | 81         | 8          | 14.0     | 7039            | 52             | 0.256        | 1046        | 8137        | 66         | 51        | 117     | 2.7     |
| P9   | 12.6         | 120       | 194              | 7.1| 9.9        | 91         | 2          | 4.4      | 10234           | 24             | 0.074        | 1205        | 11463       | 95         | 32        | 128     | 350     | <2      |
| P10  | 12.6         | 140       | 228              | 7.1| 7.8        | 72         | 2          | 7.8      | 11115           | 54             | 0.164        | 1240        | 12408       | 114        | 30        | 145     | *       | *       |
| SQ11 | 13.3         | 120       | 194              | 6.9| 11.9       | 112        | 4          | 3.9      | 6879            | 18             | 0.037        | 1060        | 7957        | 15         | 21        | 36      | 100     | <2      |
| SQ12 | 11.3         | 120       | 194              | 7.1| 9.9        | 89         | 2          | 1.6      | 7535            | 18             | 0.505        | 450         | 8103        | 8          | 20        | 28      | *       | *       |
| J13  | 18.3         | 180       | 290              | 7.1| 8.3        | 89         | 20         | 3.7      | 1338           | 394            | 1.766        | 505         | 2237        | 150        | 233       | 383     | 740     | 2.5     |
| J14  | 17.1         | 270       | 435              | 6.9| 1.6        | 17         | 12         | 0.3      | 0               | 2839           | 8.905        | 514         | 3153        | 22         | 209       | 231     | *       | *       |
| D15  | 15.3         | 190       | 306              | 7.0| 7.3        | 73         | 22         | 0.1      | 1659           | 616            | 1.802        | 1408        | 3883        | 6         | 396       | 394     | *       | *       |

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## 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO$_2$+NO$_3$ (ug N/L) | T NH$_3$ (ug N/L) | NH$_3$ (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC (mg/L) | BOD$_5$ (mg/L) |
|------|--------------|-----------|------------------|----|-----------|-----------|------------|----------|----------------------|---------------|---------------|---------------|--------------|--------------|---------------|---------------|-------------|---------|--------------|
| J1   | 15.6         | 120       | 194              | 6.5| 5.9       | 59        | 0          | 21.7     | 4384                  | 37            | 0.035         | 321           | 4742         | 39           | 50            | 89            | 130         | <2       |
| SM2  | 12.9         | 120       | 194              | 7.0| 7.1       | 66        | 0          | 4.3      | 5329                  | 47            | 0.117         | 710           | 6086         | 51           | 41            | 92            | 220         | 2.8     |
| J3   | 16.3         | 120       | 194              | 7.1| 4.8       | 49        | 2          | 17.0     | 4201                  | 35            | 0.138         | 547           | 4753         | 32           | 51            | 83            | *          | 2.0     |
| J4   | 15.3         | 130       | 210              | 6.8| 5.5       | 54        | 0          | 15.2     | 4514                  | 45            | 0.083         | 564           | 5123         | 41           | 49            | 90            | *          | *       |
| J5   | 14.8         | 130       | 210              | 7.1| 6.5       | 64        | 0          | 12.4     | 4596                  | 47            | 0.166         | 290           | 4933         | 17           | 64            | 80            | *          | *       |
| J6   | 15.0         | 140       | 226              | 7.0| 7.3       | 71        | 2          | 9.7      | 5913                  | 97            | 0.278         | 1019          | 7029         | 14           | 66            | 80            | 210         | 2.9     |
| CB7  | 17.1         | 180       | 290              | 7.0| 2.7       | 28        | 20         | 0.6      | 32                    | 688           | 2.857         | 20            | 920          | 10           | 238           | 248           | 350         | 4.0     |
| J8   | 14.4         | 130       | 210              | 7.3| 8.0       | 77        | 2          | 6.3      | 6409                  | 34            | 0.185         | 534           | 6977         | 33           | 37            | 70            | *          | <2      |
| P9   | 13.9         | 120       | 194              | 7.7| 9.9       | 95        | 6          | 1.3      | 12438                 | 21            | 0.279         | 1250          | 13709        | 57           | 66            | 123           | 2500        | 4.5     |
| P10  | 13.0         | 160       | 258              | 6.9| 7.7       | 72        | 2          | 2.7      | 15621                 | 25            | 0.049         | 1545          | 17191        | 85           | 34            | 119           | *          | *       |
| SQ11 | 14.5         | 130       | 210              | 7.1| 9.4       | 91        | 6          | 1.3      | 6687                  | 40            | 0.139         | 632           | 7359         | 13           | 20            | 34            | 420         | 4.8     |
| SQ12 | 14.3         | 110       | 177              | 7.7| 10.0      | 97        | 2          | 1.0      | 7301                  | 24            | 0.327         | 12530         | 8523         | 7            | 19            | 26            | *          | *       |
| J13  | 19.0         | 180       | 290              | 7.4| 3.3       | 36        | 22         | 0.7      | 3770                  | 101           | 0.945         | 3009          | 6880         | 28           | 554           | 582           | 400         | 12.6    |
| J14  | 18.2         | 230       | 371              | 7.1| 1.1       | 11        | 10         | 0.0      | 56                    | 1811          | 8.062        | 815           | 2862         | 2            | 174           | 176           | *          | *       |
| D15  | 19.8         | 180       | 290              | 7.6| 4.8       | 54        | 18         | 0.0      | 3894                  | 384           | 5.954         | 1618          | 5896         | 81           | 276           | 357           | *          | *       |

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO$_2$+NO$_3$ (ug N/L) | T NH$_3$ (ug N/L) | NH$_3$ (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC (mg/L) | BOD$_5$ (mg/L) |
|------|--------------|-----------|------------------|----|-----------|-----------|------------|----------|----------------------|---------------|---------------|---------------|--------------|--------------|---------------|---------------|-------------|---------|--------------|
| J1   | 17.8         | 120       | 194              | 7.5| 8.4       | 89        | 2          | 21.7     | 4319                  | 19            | 0.203         | 440           | 4778         | 41           | 47            | 88            | *          | *       |
| J6   | 17.9         | 130       | 210              | 7.6| 8.3       | 88        | 0          | 9.7      | 6905                  | 92            | 0.842         | 1154          | 8121         | 37           | 44            | 81            | *          | *       |
| J13  | 19.4         | 190       | 306              | 7.5| 3.4       | 38        | 2          | 0.7      | 3746                  | 87            | 0.808         | 1295          | 5108         | 63           | 85            | 148           | *          | *       |
### 1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)

**Aug. 11 (AM), 1996**

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO$_3$+NO$_2$ (ug N/L) | T NH$_3$ (ug N/L) | NH$_3$ (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC (%) | BOD$_5$ (mg/L) |
|------|---------------|------------|------------------|----|-----------|------------|-------------|-------------|-----------------|-----------------|---------------|--------------|-------------|-------------|--------------|-------------|-------------|--------|---------------|
| J1   | 14.7          | 130        | 210              | 7.2| 5.4       | 53         | 2           | 25.5        | 4000            | 24              | 0.107         | 205          | 4229        | 31          | 35          | 66          | 300        | 4.5     |
| SM2  | 12.8          | 120        | 194              | 7.0| 6.5       | 60         | 2           | 3.5         | 5414            | 63              | 0.156         | 1057         | 6534        | 51          | 77          | 129         | 290        | 5.9     |
| J3   | 15.2          | 130        | 210              | 6.9| 4.4       | 44         | 0           | 13.0        | 3923            | 24              | 0.056         | 518          | 4465        | 25          | 35          | 61          | *          | <2      |
| J4   | 14.7          | 130        | 210              | 7.1| 4.5       | 43         | 0           | 6.8         | 4066            | 35              | 0.123         | 704          | 4805        | 29          | 35          | 64          | *          | *       |
| J5   | 13.9          | 120        | 194              | 7.3| 6.1       | 58         | 0           | 6.9         | 4088            | 25              | 0.130         | 127          | 4240        | 31          | 32          | 63          | *          | *       |
| J6   | 15.0          | 150        | 242              | 7.2| 4.7       | 46         | 0           | 7.0         | 4486            | 55              | 0.249         | 825          | 5368        | 28          | 37          | 65          | 300        | 2.2     |
| CB7  | 15.9          | 200        | 323              | 7.0| 3.4       | 35         | 10          | 0.5         | 61              | 829             | 2.522         | 360          | 1250        | 14          | 211         | 226         | 1700       | 8.0     |
| J8   | 13.4          | 130        | 210              | 7.2| 6.1       | 57         | 0           | 4.0         | 4597            | 30              | 0.124         | 776          | 5403        | 30          | 32          | 62          | *          | 3.4     |
| P9   | 12.9          | 130        | 210              | 7.1| 9.8       | 91         | 0           | 0.8         | 8420            | 22              | 0.070         | 1623         | 10065       | 52          | 24          | 76          | 340        | 2.7     |
| P10  | 13.0          | 160        | 258              | 7.1| 5.2       | 48         | 0           | 1.8         | 13254           | 41              | 0.131         | 1856         | 15251       | 73          | 54          | 127         | *          | *       |
| SQ11 | 15.0          | 140        | 226              | 7.1| 7.0       | 69         | 8           | 0.8         | 4961            | 47              | 0.169         | 1088         | 6094        | 12          | 40          | 53          | 420        | <2      |
| SQ12 | 13.9          | 140        | 226              | 7.1| 10.1      | 96         | 0           | 0.6         | 6315            | 20              | 0.068         | 1042         | 7377        | 11          | 20          | 31          | *          | *       |
| J13  | 15.9          | 190        | 306              | 7.3| 2.3       | 23         | 2           | 0.2         | 398             | 41              | 0.249         | 1197         | 1636        | 36          | 87          | 124         | 430        | 5.4     |
| J14  | 16.2          | 180        | 290              | 7.4| 0.8       | 6          | 4           | 0.0         | 315             | 508             | 3.946         | 757          | 1580        | 5           | 105         | 110         | *          | *       |
| D15  | 15.7          | 230        | 371              | 7.3| 3.3       | 33         | 8           | 0.0         | 4602            | 132             | 0.790         | 1580         | 6314        | 227         | 264         | 491         | *          | *       |

**Aug. 11 (PM), 1996**

| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO$_3$+NO$_2$ (ug N/L) | T NH$_3$ (ug N/L) | NH$_3$ (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC (%) | BOD$_5$ (mg/L) |
|------|---------------|------------|------------------|----|-----------|------------|-------------|-------------|-----------------|-----------------|---------------|--------------|-------------|-------------|--------------|-------------|-------------|--------|---------------|
| J1   | 15.3          | 120        | 194              | 7.5| 8.0       | 79         | 2           | 24.0        | 4238            | 26              | 0.242         | 840          | 5104        | 34          | 29          | 63          | *          | *       |
| J6   | 15.5          | 130        | 210              | 7.5| 8.2       | 81         | 0           | 7.0          | 4204            | 48              | 0.446         | 873          | 5125        | 26          | 34          | 60          | *          | *       |
| J13  | 16.8          | 180        | 290              | 7.5| 2.2       | 22         | 1           | 0.2          | 381             | 49              | 0.495         | 1148         | 1578        | 40          | 53          | 93          | *          | *       |
| SITE | TEMP. (deg C) | TDS (ppm) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat) | TURB. (NTU) | FLOW (cfs) | NO₃+NO₂ (ug N/L) | T NH₃ (ug N/L) | NH₃ (ug N/L) | ORG N (ug N/L) | T N (ug N/L) | SR P (ug P/L) | ORG P (ug P/L) | T P (ug P/L) | FC (%) | BOD₅ (mg/L) |
|------|---------------|-----------|-----------------|----|-----------|------------|-------------|-----------|----------------|----------------|-------------|---------------|--------------|------------|--------------|--------------|--------------|--------|------------|
| J1   | 12.2          | 120       | 194             | 7.2| 5.0       | 46         | 0           | 27.9      | 4084           | 25             | 0.094       | 193           | 4282         | 39          | 34           | 73           | 1400         | <2     |
| SM2  | 10.8          | 140       | 226             | 7.2| 6.8       | 60         | 0           | 7.0       | 5144           | 43             | 0.146       | 544           | 5731         | 28          | 28           | 84           | 3400         | <2     |
| J3   | 12.5          | 140       | 226             | 7.1| 3.4       | 31         | 0           | 18.0      | 4049           | 18             | 0.054       | 903           | 4970         | 26          | 25           | 51           | *            | <2     |
| J4   | 12.1          | 130       | 210             | 7.2| 4.6       | 42         | 2           | 10.3      | 4399           | 32             | 0.120       | 689           | 5030         | 37          | 26           | 63           | *            | *      |
| J5   | 11.8          | 140       | 226             | 6.8| 5.6       | 50         | 0           | 11.2      | 4604           | 24             | 0.035       | 582           | 5210         | 34          | 25           | 59           | *            | *      |
| J6   | 12.2          | 130       | 210             | 7.0| 4.2       | 39         | 0           | 9.5       | 5382           | 50             | 0.119       | 1201          | 6613         | 42          | 38           | 60           | 610          | 5.9    |
| CB7  | 12.2          | 150       | 242             | 6.8| 3.6       | 33         | 50          | 0.6       | 133            | 684            | 1.032       | 960           | 1777         | 30          | 639          | 669          | 3700         | 12.1   |
| J8   | 11.6          | 140       | 226             | 7.0| 5.6       | 51         | 0           | 4.5       | 4562           | 26             | 0.059       | 749           | 5337         | 32          | 33           | 66           | *            | 3.3    |
| P9   | 10.9          | 140       | 226             | 7.1| 10.1      | 90         | 0           | 1.5       | 9018           | 12             | 0.033       | 547           | 9577         | 44          | 15           | 59           | 800          | 3.0    |
| P10  | 11.2          | 170       | 274             | 7.0| 6.7       | 60         | 0           | 3.2       | 13285          | 20             | 0.044       | 1160          | 14465        | 75          | 19           | 94           | *            | *      |
| SQ11 | 12.4          | 140       | 226             | 7.1| 6.3       | 58         | 1           | 2.3       | 4821           | 41             | 0.126       | 1183          | 6045         | 25          | 33           | 58           | 400          | 3.9    |
| SQ12 | 11.3          | 150       | 242             | 7.1| 10.0      | 90         | 0           | 1.0       | 5579           | 19             | 0.054       | 808           | 6406         | 13          | 21           | 34           | *            | *      |
| J13  | 13.0          | 200       | 323             | 7.2| 1.3       | 12         | 4           | 0.6       | 0              | 354            | 1.412       | 1090          | 1444         | 29          | 302          | 331          | 180          | 5.5    |
| J14  | 14.0          | 250       | 403             | 7.1| 1.0       | 9          | 2           | 0.0       | 42             | 1382           | 4.610       | 1630          | 3034         | 3           | 259          | 281          | *            | *      |
| D15  | 13.0          | 100       | 161             | 7.2| 3.8       | 35         | 8           | 0.0       | 2428           | 379            | 1.510       | 1328          | 4135         | 214         | 147          | 361          | *            | *      |

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1996 FIELD MEASUREMENTS AND WATER CHEMISTRY (Continued)
# APPENDIX K (1980/1981 OVERDORFF STUDY DATA)

**Oct. 21, 1980**

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**Nov. 23, 1980**

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### 1980/1981 OVERDORFF STUDY DATA (continued)

#### Apr. 19, 1981

| Site | # | Temp (°C) | Cond (mhos/cm) | pH | DO (mg/L) | DO (% sat) | Turb (ntu) | Flow (cfs) | NO₂ (ug N/L) | NO₂+NO₃ (ug N/L) | TNH₃ (ug N/L) | NH₃ (ug N/L) | ORTHO P (ug P/L) | TP (ug P/L) | FC (ug P/L) | COD (mg/L) |
|------|---|-----------|----------------|----|-----------|------------|------------|------------|-------------|----------------|----------------|--------------|----------------|----------------|-------------|-------------|-----------|
| J1   | #1 | 11.0      | 140            | 7.3 | 7.5       | 67         | 4          | 43.5       | 50          | 2750           | 90             | 0.396        | 70             | 90            | 470         | 38         |
| J3   | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J4   | #2 | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J5   | #3 | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J6   | #4 | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| CB7  | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J8   | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| *    | #5 | 12.0      | 160            | 7.2 | 8.0       | 73         | 2          | 19.5       | 50          | 1750           | 60             | 0.224        | 30             | 50            | 110         | 27         |
| P9   | #6 | 11.5      | 130            | 7.3 | 9.5       | 85         | 2          | 8.2        | 50          | 4550           | 40             | 0.182        | 90             | 150           | 1400        | 21         |
| P10  | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| *    | #7 | 11.5      | 130            | 6.5 | 6.5       | 58         | 1          | 5.7        | 50          | 4750           | 70             | 0.051        | 120            | 160           | 35          | 34         |
| SQ11 | #10| 12.0      | 140            | 7.3 | 11.1      | 101        | 4          | *          | 50          | 2950           | 130            | 0.610        | 10             | 30            | 48          | 15         |
| *    | #11| 13.5      | 140            | 7.4 | 10.7      | 101        | 3          | *          | 50          | 3450           | 90             | 0.586        | 10             | 50            | 67          | 8          |
| SQ12 | #12| 13.0      | 130            | 7.2 | 6.8       | 63         | 4          | 4.3        | 50          | 3050           | 80             | 0.319        | 10             | 30            | 12          | 25         |
| *    | #12| 12.0      | 110            | 6.9 | 8.7       | 79         | 1          | *          | 50          | 4350           | 50             | 0.094        | 10             | 20            | 55          | 4          |
| J13  | #9 | 12.5      | 210            | 7.1 | 4.4       | 41         | 2          | *          | 50          | 1150           | 110            | 0.337        | 60             | 90            | 140         | 23         |

#### May 25, 1981

<p>| Site | # | Temp (°C) | Cond (mhos/cm) | pH | DO (mg/L) | DO (% sat) | Turb (ntu) | Flow (cfs) | NO₂ (ug N/L) | NO₂+NO₃ (ug N/L) | TNH₃ (ug N/L) | NH₃ (ug N/L) | ORTHO P (ug P/L) | TP (ug P/L) | FC (ug P/L) | COD (mg/L) |
|------|---|-----------|----------------|----|-----------|------------|------------|------------|-------------|----------------|----------------|--------------|----------------|----------------|-------------|-------------|-----------|
| J1   | #1 | 12.5      | 160            | 7.3 | 6.5       | 60         | 7          | 38.5       | 10          | 2510           | 210            | 1.019        | 110            | 140           | 10000       | 27         |
| SM2  | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J3   | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J4   | #2 | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J5   | #3 | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J6   | #4 | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| CB7  | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| J8   | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| *    | #5 | 13.0      | 170            | 7.1 | 5.3       | 49         | 6          | 20.5       | 20          | 1520           | 170            | 0.539        | 120            | 150           | 4300        | 29         |
| P9   | #6 | 11.0      | 150            | 7.3 | 8.0       | 71         | 3          | 8.5        | 20          | 5320           | 800            | 2.632        | 150            | 220           | 37000       | 43         |
| P10  | *  | *         | *              | *  | *         | *          | *          | *          | *           | *               | *              | *            | *              | *             | *           | *          |
| *    | #7 | 11.5      | 150            | 6.5 | 4.5       | 40         | 2          | 6.0        | 10          | 6110           | 220            | 0.159        | 220            | 260           | 120         | 47         |
| SQ11 | #10| 14.0      | 150            | 7.1 | 7.0       | 67         | 13         | 20         | 2620         | 220            | 0.744        | 70             | 150            | 300          | 45         |
| *    | #11| 14.0      | 150            | 7.2 | 8.0       | 77         | 8          | *          | 20          | 2620           | 220            | 0.936        | 70             | 130           | 300         | 49         |
| SQ12 | #8 | 13.0      | 155            | 7.2 | 8.5       | 79         | 7          | 5.0        | 30          | 3330           | 570            | 2.272        | 50             | 110           | 120         | 37         |
| *    | #12| 11.0      | 115            | 6.8 | 7.0       | 62         | 1          | *          | 10          | 4310           | 130            | 0.181        | 20             | 40            | 1000        | 18         |
| J13  | #9 | 14.5      | 295            | 7.0 | 1.0       | 10         | 22         | *          | 50          | 200            | 2700           | 7.502        | 700            | 840           | TNTC        | 120        |</p>
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**Note:** This table contains data for the years 1980 and 1981, with columns for temperature, pH, dissolved oxygen (DO), turbidity (TURB.), conductivity (COND.), nitrite (NO₂⁻), nitrate (NO₃⁻), sulfate (SO₄²⁻), phosphate (PO₄³⁻), ammonium (NH₄⁺), orthophosphate (ORTHO-P), total phosphorus (TP), and chemical oxygen demand (COD). The data are organized by site and date.
### 1980/1981 OVERDORFF STUDY DATA (continued)

#### Aug. 23, 1981

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### APPENDIX L (1988/1989 ECOLOGY STUDY DATA)

#### Sep. 13, 1988

| SITE | TEMP. (deg C) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat.) | TURB. (nru) | FLOW (cfs) | NO$_3$+NO$_2$ (ug NL) | TNH$_3$ (ug NL) | NH$_3$ (ug NL) | TIN (ug P/L) | TP (ug/mL) | FC (mg/L) | COD (mg/L) | BOD$_5$ (mg/L) |
|------|---------------|------------------|----|----------|-------------|------------|----------|-----------------|--------------|--------------|------------|-------------|-----------|-----------|-----------|-------------|
| J1   | 10.5          | 240              | 7.2| 8.69     | 78          | 1          | 11.4     | 3100            | 30           | 0.092        | 3130        | 40          | 63         | 10        | 3          |
| SM2  | 9.6           | 250              | 7.2| 9.18     | 81          | 2          | 1.5      | 5500            | 30           | 0.082        | 5530        | 40          | 310        | 11        |
| J3   | 10.7          | 240              | 7.2| 7.77     | 70          | 1          | *        | *               | *            | *            | *           | *          | 100       |
| J4   | 10.9          | 230              | 7.0| 8.26     | 75          | 1          | *        | *               | *            | *            | *           | *          | 100       |
| J5   | 10.7          | 230              | 7.0| 7.70     | 70          | 1          | *        | *               | *            | *            | *           | *          | 1100      |
| J6   | 11.7          | 250              | 6.8| 4.54     | 42          | 1          | *        | *               | *            | *            | *           | *          | 2         |
| CB7  |              | CB               |    |          |             |            |          |                 |              |              |             |            |
| J8   | 11.8          | 250              | 6.1| 4.74     | 44          | 1          | *        | *               | *            | *            | *           | *          | 530       |
| P9   | 13.5          | 270              | 6.9| 6.02     | 83          | 1          | 0.4      | 8300            | 30           | 0.064        | 8330        | 100         | 440       |
| P10  | 12.5          | 290              | 6.4| 4.80     | 45          | 1          | *        | *               | *            | *            | *           | *          | 2900      |
| SQ11 | 12.7          | 250              | 6.9| 6.70     | 64          | 1          | 0.4      | 2300            | 10           | 0.016        | 2310        | 40          | 92        |
| SQ12 | 16.0          | 250              | 6.7| 7.96     | 81          | 1          | *        | *               | *            | *            | *           | *          | 270       |
| J13  | 11.6          | 480              | 6.6| 3.23     | 30          | 1          | *        | *               | 20           | 0.452        | 610         | 330         | 110       |

#### Oct. 11, 1988

| SITE | TEMP. (deg C) | COND. (umhos/cm) | pH | DO (mg/L) | DO (% sat.) | TURB. (nru) | FLOW (cfs) | NO$_3$+NO$_2$ (ug NL) | TNH$_3$ (ug NL) | NH$_3$ (ug NL) | TIN (ug P/L) | TP (ug/mL) | FC (mg/L) | COD (mg/L) | BOD$_5$ (mg/L) |
|------|---------------|------------------|----|----------|-------------|------------|----------|-----------------|--------------|--------------|------------|-------------|-----------|-----------|-----------|-------------|
| J1   | 11.0          | 248              | 7.2| 6.30     | 57          | 1          | 13.2     | 3600            | 20           | 0.068        | 3620        | 70          | 110       |
| SM2  | 9.9           | 254              | 7.3| 9.30     | 83          | 2          | 3.5      | 5500            | 30           | 0.110        | 5530        | 50          | 150       |
| J3   | 11.0          | 246              | 7.2| 8.60     | 60          | 1          | *        | *               | *            | *            | *           | *          | 160       |
| J4   | 10.9          | 241              | 7.2| 7.70     | 70          | 1          | *        | *               | 3200         | 10           | 0.033      | 3210        | 40         |
| J6   | 10.8          | 242              | 7.1| 7.30     | 68          | 1          | 9.4      | 3500            | 10           | 0.024        | 3510        | 50          | 240       |
| J8   | 11.0          | 267              | 7.0| 4.90     | 40          | 1          | *        | *               | 290          | *            | *           | *          | 2900      |
| CB7  |              | CB               |    |          |             |            |          |                 |              |              |             |            |
| J8   | 10.9          | 262              | 7.0| 5.50     | 50          | 1          | *        | *               | *            | *            | *           | *          | 320       |
| P9   | 11.4          | 292              | 7.3| 10.20    | 94          | 1          | 1.3      | 8100            | 10           | 0.044        | 8110        | 180         | 520       |
| P10  | 11.0          | 294              | 7.0| 8.20     | 75          | 1          | *        | *               | *            | *            | *           | *          | 350       |
| *    | 11.2          | 292              | 6.7| 5.70     | 52          | 1          | 1.3      | 11000           | 10           | 0.005        | 11010       | 200         | 410       |
| SQ11 | 11.5          | 268              | 7.0| 6.40     | 59          | 1          | 0.5      | 3500            | 10           | 0.023        | 3510        | 40          | 110       |
| SQ12 | 10.5          | 258              | 7.4| 11.20    | 101         | 1          | 0.4      | 3100            | 70           | 0.372        | 3170        | 10          | 200       |
| *    | 10.6          | 210              | 7.0| 8.90     | 82          | 1          | *        | *               | 5300         | 10           | 0.021      | 5310        | 20         |
| J13  | 11.2          | 470              | 6.6| 0.40     | 4           | 110        | *        | 10              | 670          | 0.584        | 680         | 590        | 92        |

235
### 1988/1989 ECOLOGY STUDY DATA (continued)

#### Dec. 6, 1988

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#### Jan. 18, 1989

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236
| SITE | TEMP. (deg C) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO₃⁺NO₂ (µg N/L) | TNH₃ (µg N/L) | NH₃ (µg N/L) | TIN (µg P/L) | TP (µg P/L) | FC (µg P/L) | COD (mg/L) | BOD₅ (mg/L) |
|------|--------------|----|-----------|------------|-------------|------------|------------------|---------------|--------------|------------|-------------|-----------|------------|-----------|-----------|
| J1   | 3.5          | 6.5| 7.50      | 56         | 9           | 118.9      | 4730             | 1140          | 0.490        | 5670       | 720         | 5100      | 55         | 11        |
| SM2  | 3.7          | 6.5| 7.80      | 59         | 18          | 18.2       | 3750             | 3440          | 1.280 C      | 7190       | 4230        | 4300      | 80         | 30        |
| J3   | 3.2          | 6.9| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| J4   | 3.1          | 6.9| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| J5   | 3.0          | 6.9| 6.80      | 51         | 7           | 93.5       | 6590             | 1460          | 1.230 C      | 8050       | 530         | 2700      | 53         | 45        |
| J6   | 2.3          | 6.5| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| CB7  | *            | *  | *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| J8   | 2.0          | 6.9| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| P9   | 5.4          | 7.0| 10.10     | 80         | 3           | 19.5       | 7540             | 2530          | 3.169 C      | 10080      | 3090        | 1500      | 64         | 30        |
| P10  | 5.1          | 6.7| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| SQ11 | 1.8          | 185| 9.20      | 66         | 8           | 27.7       | 3710             | 3480          | 3.119 C      | 7160       | 590         | 3800      | 66         | 50        |
| SQ12 | 3.2          | 200| 9.30      | 69         | 6           | 16.5       | 4280             | 1470          | 0.502 C      | 5740       | 430         | 1000      | 56         | 70        |
| S4   | 6.5          | 195| 6.8       | *          | *           | 2          | 6650             | 1080          | 0.907        | 8020       | 450         | 2000      | 35         | 10        |
| J7   | 2.0          | 7.0| 7.10      | 51         | 14          | 93.1       | 3820             | 3570          | 3.107 C      | 7390       | 340         | 2700      | 69         | 64        |
| J13  | 1.8          | 6.9| 5.20      | 37         | 28          | *          | *                | *             | 1450         | 0.986      | 6040        | 520       | 2900       | 64        |

**Mar 28, 1989**

| SITE | TEMP. (deg C) | pH | DO (mg/L) | DO (% sat) | TURB. (ntu) | FLOW (cfs) | NO₃⁺NO₂ (µg N/L) | TNH₃ (µg N/L) | NH₃ (µg N/L) | TIN (µg P/L) | TP (µg P/L) | FC (µg P/L) | COD (mg/L) | BOD₅ (mg/L) |
|------|--------------|----|-----------|------------|-------------|------------|------------------|---------------|--------------|------------|-------------|-----------|------------|-----------|-----------|
| J1   | 6.8          | 7.1| 6.50      | 53         | 5           | 125.5      | 4700             | 330           | 0.560        | 5300       | 300         | 5000      | 53         | 4         |
| SM2  | 7.1          | 7.0| 6.30      | 52         | 6           | 10.5       | 4000             | 960           | 1.556        | 4960       | 570         | 800       | 52         | *         |
| J3   | 7.1          | 255| 7.2       | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| J4   | 7.1          | 265| 7.2       | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| J5   | 7.6          | 265| 7.2       | 6.80       | 57         | 86.0       | 4700             | 280           | 0.822        | 4980       | 260         | 400       | 48         | *         |
| J6   | 8.6          | 255| 7.2       | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| CB7  | *            | *  | *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| J8   | 8.2          | 7.3| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| P9   | 8.5          | 7.7| 9.80      | 64         | 1           | 15.1       | 8200             | 40            | 0.345        | 8240       | 500         | 46        | 41         | *         |
| P10  | 8.4          | 6.9| *         | *          | *           | *          | *                | *             | *            | *          | *           | *         | *          | *         |
| P9   | 8.4          | 239| 6.9       | *          | *           | 91         | 9000             | 90            | 0.105        | 9090       | 580         | 100       | 53         | *         |
| S4   | 9.0          | 215| 7.0       | *          | *           | 1          | 8300             | 10            | 0.016        | 8310       | 60          | 3         | 16         | *         |
| J7   | 7.8          | 255| 7.3       | 8.10       | 68         | 70.3       | 4600             | 100           | 0.304        | 4700       | 220         | 77        | 38         | *         |
| J13  | 7.4          | 308| 7.1       | *          | *           | 6          | 4900             | 230           | 0.459        | 5130       | 360         | 230       | 40         | 3         |
**1988/1989 ECOLOGY STUDY DATA** (continued)

**May 23, 1989**

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APPENDIX M (NITROGEN MODELING RESULTS)

Predicted Ammonia Transport
Jan. 21, 1996

Ammonia Loading
Jan. 21, 1996
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Jan. 21, 1996

Nitrite + Nitrate Loading
Jan. 21, 1996
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
Feb. 11, 1996

Ammonia Loading
Feb. 11, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Feb. 11, 1996

Nitrite + Nitrate Loading
Feb. 11, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
Feb. 25, 1996

Ammonia Loading
Feb. 25, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Feb. 25, 1996

Nitrite + Nitrate Loading
Feb. 25, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
Mar. 10, 1996

Ammonia Loading
Mar. 10, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
**NITROGEN MODELING RESULTS (Continued)**

**Predicted Ammonia Transport**  
Mar. 24, 1996

- **Graph**
  - Title: Predicted Ammonia Transport
  - Date: Mar. 24, 1996
  - Graph shows predicted values of ammonia transport along the Sumas River from 0 to 10 river miles.
  - Data points indicate observed values at various locations.

**Ammonia Loading**  
Mar. 24, 1996

- **Graph**
  - Title: Ammonia Loading
  - Date: Mar. 24, 1996
  - Graph illustrates ammonia loading from Sumas River to North Ditch at 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 river miles.
  - Inset details dispersed loading and tributary point loading.

*Note:* The diagrams accurately represent the nitrogen modeling results for the Sumas River on Mar. 24, 1996, including predicted transport and ammonia loading at various river miles.
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Apr. 14, 1996

Nitrite + Nitrate Loading
Apr. 14, 1996
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Apr. 28, 1996

Nitrite + Nitrate Loading
Apr. 28, 1996
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
May 19, 1996

Ammonia Loading
May 19, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
May 19, 1996

Nitrite + Nitrate Loading
May 19, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
Jun. 16, 1996

Ammonia Loading
Jun. 16, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Jun. 16, 1996

Nitrite + Nitrate Loading
Jun. 16, 1996

Dispersed Loading (Kg N/day/0.1 miles)

Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS  (Continued)

Predicted Ammonia Transport
Jul. 14, 1996

Ammonia Loading
Jul. 14, 1996
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
Aug. 11, 1996

Ammonia Loading
Aug. 11, 1996

Dispersed Loading (Kg N/day/0.1 miles)
Tributary Point Loading (Kg N/day)
NITROGEN MODELING RESULTS (Continued)

Predicted Ammonia Transport
Sep. 4, 1996

Ammonia Loading
Sep. 4, 1996
NITROGEN MODELING RESULTS (Continued)

Predicted Nitrite + Nitrate Transport
Sep. 4, 1996

Nitrite + Nitrate Loading
Sep. 4, 1996
APPENDIX N (PHOSPHOROUS MODELING RESULTS)

Predicted Total Phosphorous Transport
Jan. 21, 1996

Total Phosphorous Loading
Jan. 21, 1996
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Feb. 11, 1996

Total Phosphorous Loading
Feb. 11, 1996
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Feb. 25, 1996

Total Phosphorous Loading
Feb. 25, 1996

Dispersed Loading (Kg P/day/0.1 miles)
Tributary Point Loading (Kg P/day)
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Mar. 10, 1996

![Graph showing predicted total phosphorous transport with river mile axis and observed data points marked with red dots.]

Total Phosphorous Loading
Mar. 10, 1996

![Graph showing total phosphorous loading with river mile axis and tributary point loading marked in blue.]

Dispersed Loading (Kg P/day/0.1 miles)
Tributary Point Loading (Kg P/day)
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Mar. 24, 1996

Total Phosphorous Loading
Mar. 24, 1996
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Apr. 14, 1996

Total Phosphorous Loading
Apr. 14, 1996

Dispersed Loading (Kg P/day/0.1 miles)
Tributary Point Loading (Kg P/day)
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Apr. 28, 1996

Total Phosphorous Loading
Apr. 28, 1996
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Jun. 16, 1996

Total Phosphorous Loading
Jun. 16, 1996
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Jul. 14, 1996

Total Phosphorous Loading
Jul. 14, 1996
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Aug. 11, 1996

Total Phosphorous Loading
Aug. 11, 1996

Dispersed Loading (Kg P/day/0.1 miles)
Tributary Point Loading (Kg P/day)
PHOSPHOROUS MODELING RESULTS (Continued)

Predicted Total Phosphorous Transport
Sep. 4, 1996

Total Phosphorous Loading
Sep. 4, 1996

Dispersed Loading (Kg P/day/0.1 miles)
Tributary Point Loading (Kg P/day)
APPENDIX O (DISSOLVED OXYGEN MODELING RESULTS)

Predicted Disolved Oxygen and Biochemical Oxygen Demand Transport
Jun. 16, 1996

Biochemical Oxygen Demand Loading
Jun. 16, 1996
DISSOLVED OXYGEN MODELING RESULTS (Continued)

Predicted Dissolved Oxygen and Biochemical Oxygen Demand Transport
Jul. 14, 1996

Biochemical Oxygen Demand Loading
Jul. 14, 1996
DISSOLVED OXYGEN MODELING RESULTS (Continued)

**Predicted Disolved Oxygen and Biochemical Oxygen Demand Transport**
*Aug. 11, 1996*

**Biochemical Oxygen Demand Loading**
*Aug. 11, 1996*
DISSOLVED OXYGEN MODELING RESULTS (Continued)

Predicted Dissolved Oxygen and Biochemical Oxygen Demand Transport
Sep. 4, 1996

Biochemical Oxygen Demand Loading
Sep. 4, 1996
QUAL2E is a comprehensive and versatile stream water quality model designed by the Environmental Research Laboratory to simulate a variety of water quality constituents in any combination desired by the user. The model is programmed in ANSI FORTRAN 77, and is applicable to any well mixed dendritic stream system. It assumes that the major transport mechanisms are significant only along the longitudinal axis of the stream and is limited hydraulically, to the simulation of time periods during which both the stream flow and input waste loads are essentially constant. QUAL2E can be used to simulate the following constituents:

1. Dissolved Oxygen
2. Biochemical Oxygen Demand
3. Temperature
4. Algae as Chlorophyll a
5. Organic Nitrogen as N
6. Ammonia as N
7. Nitrite as N
8. Nitrate as N
9. Organic Phosphorus as P
10. Dissolved Phosphorous as P
11. Coliforms
12. One Arbitrary Nonconservative Constituent
13. Three Conservative Constituents

Figure P-1 shows all of the major constituent Interactions within the model.

For the current project, a number of the differential equations used in the QUAL2E model to govern constituent transformation, were borrowed and partially modified to fit project needs. Following is a description of these equations as programmed in the QUAL2E model:

Ammonia Nitrogen
\[ \frac{dN_i}{dt} = \beta_i N_t - \beta \frac{N_i}{\sigma_i} + \frac{F_i}{d} \alpha_i u A \]
where
\[
F_1 = P_N N_i/(P_N N_i+(1-P_N)N_3)
\]

- \(N_i\) = the concentration of ammonia nitrogen, mg-N/L
- \(N_3\) = the concentration of nitrate nitrogen, mg-N/L
- \(N_4\) = the concentration of organic nitrogen, mg-N/L
- \(\beta_1\) = rate constant for the biological oxidation of ammonia nitrogen, temperature dependent, day\(^{-1}\)
- \(\beta_3\) = organic nitrogen hydrolysis rate, day\(^{-1}\)
- \(\alpha_1\) = fraction of algal biomass which is nitrogen, mg-N/mg-A
- \(\sigma_3\) = the benthos source rate for ammonia nitrogen, mg-N/ft\(^2\)-day
- \(d\) = mean depth of flow, ft
- \(F_1\) = fraction of algal nitrogen uptake from ammonia pool
- \(\mu\) = the local specific growth rate of algae, day\(^{-1}\)
- \(A\) = algal biomass concentration, mg-A/L
- \(P_N\) = preference factor for ammonia nitrogen (0 to 1.0)

**Nitrite Nitrogen**
\[
dN_2/dt = \beta_1 N_1 - \beta_2 N_2
\]
where
- \(N_1\) = the concentration of ammonia nitrogen, mg-N/L
- \(N_2\) = the concentration of nitrite nitrogen, mg-N/L
- \(\beta_1\) = rate constant for the oxidation of ammonia nitrogen, temperature dependent, day\(^{-1}\)
- \(\beta_2\) = rate constant for the oxidation of nitrite nitrogen, temperature dependent, day\(^{-1}\)

**Nitrate Nitrogen**
\[
dN_3/dt = \beta_2 N_2 - (1-F)\alpha_1 \mu A
\]
where
- \(F\) = fraction of algal nitrogen taken from ammonia pool, as described for ammonia nitrogen
- \(\alpha_1\) = fraction of algal biomass that is nitrogen, mg-N/mg-A
- \(\mu\) = local specific growth rate of algae, day\(^{-1}\)
Figure P-1. Major Constituent Interactions in QUAL2E
Dissolved Oxygen
\[
dO/dt = K_2(O^*-O) + (\alpha_3\mu - \alpha_4\rho)A - K_4L - K_4/d - \alpha_5\beta_1N_1 - \alpha_6\beta_2N_2
\]
where
- \(O\) = the concentration of dissolved oxygen, mg/L.
- \(O^*\) = the saturation concentration of dissolved oxygen at the local temperature and pressure, mg/L.
- \(\alpha_3\) = the rate of oxygen production per unit of algal photosynthesis, mg-O/mg-A.
- \(\alpha_4\) = the rate of oxygen uptake per unit of algae respired, mg-O/mg-A.
- \(\alpha_5\) = the rate of oxygen uptake per unit of ammonia nitrogen oxidation, mg-O/mg-N.
- \(\alpha_6\) = the rate of oxygen uptake per unit of nitrite nitrogen oxidation, mg-O/mg-N.
- \(\mu\) = algal growth rate, temperature dependent, day\(^{-1}\).
- \(\rho\) = algal respiration rate, temperature dependent, day\(^{-1}\).
- \(A\) = algal biomass concentration, mg-A/L.
- \(L\) = concentration of ultimate carbonaceous BOD, mg/L.
- \(d\) = mean stream depth, ft.
- \(K_1\) = carbonaceous BOD deoxygenation rate, temperature dependent, day\(^{-1}\).
- \(K_2\) = the reaeration rate in accordance with the Fickian diffusion analogy, temperature dependent, day\(^{-1}\).
- \(K_4\) = sediment oxygen demand rate, temperature dependent, g/ft\(^2\)-day.