2003

Effluent characterization of flow-through aquaculture operations in West Virginia

James H. Cunningham
West Virginia University

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Recommended Citation

Cunningham, James H., "Effluent characterization of flow-through aquaculture operations in West Virginia" (2003). *Graduate Theses, Dissertations, and Problem Reports*. 1344.
<https://researchrepository.wvu.edu/etd/1344>

This Thesis is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Thesis has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

Effluent Characterization of Flow-Through
Aquaculture Operations in West Virginia

James H. Cunningham

Thesis submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Civil and Environmental Engineering

Roger C. Viadero, Jr., Ph.D., Chair
Ronald H. Fortney, Ph.D.
Kenneth J. Semmens, Ph.D.

Department of Civil and Environmental Engineering

Morgantown, West Virginia
2003

Keywords: Aquaculture Effluent, Water Quality, Rainbow Trout,
Production Potential
Copyright 2003 James H. Cunningham

ABSTRACT

Effluent Characterization of Flow-Through Aquaculture Operations in West Virginia

James H. Cunningham

In order to reduce pollutant loading nationwide, the USEPA working in conjunction with the USDA, is in the process of developing effluent management guidelines and standards for private and public aquaculture operations. The purpose of this study is to provide industry, State, and Federal stakeholders with baseline effluent water quality data specific to West Virginia flow-through facilities, in an effort to help concerned parties make informed decisions regarding impending regulations and to examine the potential to increase production, based on effluent pollutant load and permit limitations.

WVU-CEE researchers examined both large and small-scale facilities in this project with varying water sources, rearing capacities, and effluent treatment methods. All facilities reared *Oncorhynchus mykiss* (rainbow trout). The influent and effluent of the six anonymous facilities were monitored approximately every six weeks for flow, temperature, conductivity, dissolved oxygen, turbidity, biochemical oxygen demand, total suspended solids, total ammonia nitrogen, nitrite, nitrate, and total phosphorus. Using flow rate and pollutant concentrations, mass loadings were then calculated for each constituent.

Average concentrations and mass loadings of regulated parameters were within acceptable ranges as well as anticipated regulatory limits. Potential for increased production exist at each facility based on effluent pollutant load and permit limitation.

TABLE OF CONTENTS

TITLE PAGE.....	i
ABSTRACT.....	ii
TABLE OF CONTENTS.....	iii
LIST OF TABLES.....	xii
LIST OF FIGURES.....	xiv
CHAPTER 1. INTRODUCTION.....	1
1.1 Problem Statement.....	1
1.2 Objectives.....	1
CHAPTER 2. BACKGROUND.....	2
2.1 Overview of Aquaculture in West Virginia.....	2
2.2 Culture Systems.....	2
2.2.1 Linear Units.....	2
2.2.2 Circular Units.....	3
2.3 Water Resources.....	4
2.3.1 Groundwater.....	4
2.3.2 Surface Water.....	5
2.4 Water Quality Criteria for Rainbow Trout.....	5
2.4.1 Ammonia Nitrogen.....	5
2.4.2 Carbon Dioxide.....	6
2.4.3 Nitrate.....	6
2.4.4 Nitrite.....	6
2.4.5 pH.....	6

2.4.6 Phosphorus.....	7
2.4.7 Total Suspended Solids.....	7
2.4.8 Total Alkalinity.....	7
2.4.9 Temperature.....	7
2.5 Aquaculture Effluent Pollutants.....	7
2.5.1 Organic Pollutants.....	8
2.5.2 Nutrient Pollutants.....	8
2.5.2.1 Nitrogen.....	9
2.5.2.2 Phosphorus.....	9
2.6 Regulation.....	10
2.6.1 Federal Regulation.....	10
2.6.2 State Regulation.....	10
2.7 Effluent Management.....	10
2.7.1 Dissolved Pollutant Management.....	10
2.7.2 Suspended Pollutant Management.....	11
CHAPTER 3. INVESTIGATIVE APPROACH.....	11
3.1 Experimental Design.....	11
3.1.1 Site Selection.....	11
3.1.1.1 Water Source.....	12
3.1.1.2 Facility Size.....	12
3.1.1.3 Effluent Treatment.....	13
3.1.1.4 Operator Feeding Practices.....	13
3.1.2 Description of Research Sites.....	13

3.1.2.1 Facility A.....	13
3.1.2.2 Facility B.....	16
3.1.2.3 Facility C.....	18
3.1.2.4 Facility D.....	19
3.1.2.5 Facility E.....	21
3.1.2.6 Facility F.....	23
3.1.3 Sampling Sites.....	25
3.1.4 Sampling Regime.....	25
3.1.5 Field Monitoring and Grab Samples.....	26
3.2 Methods.....	26
3.2.1 Field Monitoring.....	26
3.2.2 Grab Sample Analysis.....	28
3.2.2.1 Nutrients.....	28
3.2.2.2 Biochemical Oxygen Demand.....	28
3.2.2.3 Solids.....	28
3.3 Quality Assurance and Quality Control.....	29
3.3.1 External Laboratory Analyses.....	29
3.3.2 In-house Laboratory Analyses.....	29
3.3.2.1 Solids.....	29
3.3.2.2 Biochemical Oxygen Demand.....	29
3.3.2.3 Field Meters.....	30
3.4 Statistical Analyses.....	30
3.4.1 Paired t-Test.....	30

3.4.1 Wilcoxon Signed Rank Test.....	32
CHAPTER 4. RESULTS.....	32
4.1 Facility A.....	32
4.1.1 Field Monitoring.....	32
4.1.1.1 Flow.....	33
4.1.1.2 pH.....	33
4.1.1.3 Specific Conductance.....	33
4.1.1.4 Temperature.....	33
4.1.1.5 Dissolved Oxygen.....	34
4.1.1.6 Turbidity.....	34
4.1.2 Grab Samples.....	34
4.1.2.1 Total Suspended Solids (TSS).....	35
4.1.2.2 Five Day Biochemical Oxygen Demand (BOD ₅).....	35
4.1.2.3 Total Ammonia Nitrogen (TAN).....	36
4.1.2.4 Nitrate (NO ₃ ⁻).....	36
4.1.2.5 Total Phosphorus (TP).....	36
4.1.2.6 Nitrite (NO ₂).....	36
4.1.3 Statistical Analysis.....	37
4.2 Facility B.....	37
4.2.1 Field Monitoring.....	37
4.2.1.1 Flow.....	38
4.2.1.2 pH.....	38
4.2.1.3 Specific Conductance.....	38

4.2.1.4 Temperature.....	38
4.2.1.5 Dissolved Oxygen.....	39
4.2.1.6 Turbidity.....	39
4.2.2 Grab Samples.....	39
4.2.2.1 Total Suspended Solids (TSS).....	40
4.2.2.2 Five Day Biochemical Oxygen Demand (BOD ₅).....	40
4.1.2.3 Total Ammonia Nitrogen (TAN).....	40
4.2.2.4 Nitrate (NO ₃ ⁻).....	41
4.2.2.5 Total Phosphorus (TP).....	41
4.2.2.6 Nitrite (NO ₂).....	41
4.2.3 Statistical Analysis.....	41
4.3 Facility C.....	42
4.3.1 Field Monitoring.....	42
4.3.1.1 Flow.....	43
4.3.1.2 pH.....	43
4.3.1.3 Specific Conductance.....	43
4.3.1.4 Temperature.....	43
4.3.1.5 Dissolved Oxygen.....	43
4.3.1.6 Turbidity.....	44
4.3.2 Grab Samples.....	44
4.3.2.1 Total Suspended Solids (TSS).....	44
4.3.2.2 Five Day Biochemical Oxygen Demand (BOD ₅).....	45
4.3.2.3 Total Ammonia Nitrogen (TAN).....	45

4.3.2.4 Nitrate (NO_3^-).....	45
4.3.2.5 Total Phosphorus (TP).....	45
4.3.2.6 Nitrite (NO_2).....	46
4.3.3 Statistical Analysis.....	46
4.4 Facility D.....	47
4.4.1 Field Monitoring.....	47
4.4.1.1 Flow.....	47
4.4.1.2 pH.....	48
4.4.1.3 Specific Conductance.....	48
4.4.1.4 Temperature.....	48
4.4.1.5 Dissolved Oxygen.....	48
4.4.1.6 Turbidity.....	49
4.4.2 Grab Samples.....	49
4.4.2.1 Total Suspended Solids (TSS).....	49
4.4.2.2 Five Day Biochemical Oxygen Demand (BOD_5).....	50
4.4.2.3 Total Ammonia Nitrogen (TAN).....	50
4.4.2.4 Nitrate (NO_3^-).....	50
4.4.2.5 Total Phosphorus (TP).....	50
4.4.2.6 Nitrite (NO_2).....	51
4.4.3 Statistical Analysis.....	51
4.5 Facility E.....	52
4.5.1 Field Monitoring.....	52
4.5.1.1 Flow.....	52

4.5.1.2 pH.....	52
4.5.1.3 Specific Conductance.....	53
4.5.1.4 Temperature.....	53
4.5.1.5 Dissolved Oxygen.....	53
4.5.1.6 Turbidity.....	53
4.5.2 Grab Samples.....	54
4.5.2.1 Total Suspended Solids (TSS).....	54
4.5.2.2 Five Day Biochemical Oxygen Demand (BOD ₅).....	55
4.5.2.3 Total Ammonia Nitrogen (TAN).....	55
4.5.2.4 Nitrate (NO ₃ ⁻).....	55
4.5.2.5 Total Phosphorus (TP).....	56
4.5.2.6 Nitrite (NO ₂).....	56
4.5.3 Statistical Analysis.....	56
4.6 Facility F.....	58
4.6.1 Field Monitoring.....	58
4.6.1.1 Flow.....	58
4.6.1.2 pH.....	58
4.6.1.3 Specific Conductance.....	58
4.6.1.4 Temperature.....	59
4.6.1.5 Dissolved Oxygen.....	59
4.6.1.6 Turbidity.....	59
4.6.2 Grab Samples.....	59
4.6.2.1 Total Suspended Solids (TSS).....	60

4.6.2.2 Five Day Biochemical Oxygen Demand (BOD ₅).....	60
4.6.2.3 Total Ammonia Nitrogen (TAN).....	60
4.6.2.4 Nitrate (NO ₃ ⁻).....	61
4.6.2.5 Total Phosphorus (TP).....	61
4.6.2.6 Nitrite (NO ₂).....	61
4.6.3 Statistical Analysis.....	61
CHAPTER 5. DISCUSSION.....	62
5.1 Field Measurements.....	62
5.1.1 pH.....	63
5.1.2 Dissolved Oxygen.....	64
5.2 Grab Samples.....	68
5.2.1 Un-ionized Ammonia Nitrogen.....	70
5.3 Pollutant Spikes.....	72
5.4 BOD ₅ vs. Turbidity.....	72
5.5 Increased Production Potential.....	74
CHAPTER 6. SUMMARY AND CONCLUSIONS.....	78
6.1 Summary.....	78
6.1.1 Site Visits.....	78
6.1.2 Data Analysis.....	78
6.2 Conclusions.....	79
6.2.1 Effluent Characteristic.....	79
6.2.2 Production Potential.....	80
6.2.3 Further Research.....	80

CHAPTER 7. REFERENCES.....	80
APPENDIX A.....	85
APPENDIX B.....	88
APPENDIX C.....	91
APPENDIX D.....	94
APPENDIX E.....	97
APPENDIX F.....	102

LIST OF TABLES

TABLE		PAGE
Table 2.4.1	Water Quality Criteria for Salmonid Production (IDEQ, 1998)	5
Table 3.1	Site characteristics of the six facilities.	12
Table 3.1.1.1.1	NPDES Permit Requirements for Facility A.	16
Table 3.1.2.2.1	NPDES Permit Requirements for Facility B.	18
Table 3.2.1.1	Instruments Employed in Field Monitoring.	26
Table 3.2.2.2	Location and Methods of Flow Determination at Study Sites.	28
Table 3.2.2.1	Analytical Methods Used in Assays Performed by the NRCCE.	28
Table 4.1.1.1	Field Monitoring Results of Facility A.	33
Table 4.1.2.1	Grab Sample Results of Facility A.	35
Table 4.1.3.1	Facility A Water Quality Monitoring Statistical Analysis Results.	37
Table 4.2.1.1	Field Monitoring Results of Facility B	38
Table 4.2.2.1	Grab Sample Results of Facility B	40
Table 4.2.3.1	Facility B Water Quality Monitoring Statistical Analysis Results.	42
Table 4.3.1.1	Field Monitoring Results of Facility C.	42
Table 4.3.2.1	Grab Sample Results of Facility C.	42
Table 4.3.3.1	Facility C Water Quality Monitoring Statistical Analysis Results.	47
Table 4.4.1.1	Field Monitoring Results of Facility D.	45
Table 4.4.2.1	Grab Sample Results of Facility D.	47
Table 4.4.3.1	Facility D Water Quality Monitoring Statistical Analysis Results.	50
Table 4.5.1.1	Field Monitoring Results of Facility E.	51
Table 4.5.2.1	Grab Sample Results of Facility E.	53
Table 4.5.3.1	Facility E Effluent Water Quality Monitoring Statistical Analysis Results.	56
Table 4.5.3.2	Facility E OLS Pond Effluent Water Quality Monitoring Statistical Analysis Results.	56
Table 4.6.1.1	Field Monitoring Results of Facility F.	57
Table 4.6.2.1	Grab Sample Results of Facility F.	59
Table 4.6.3.1	Facility F Water Quality Monitoring Statistical Analysis Results.	61

Table 5.1	Average Change in Measured Parameters from Influent to Effluent.	62
Table 5.1	Normal Ranges of Pollutant Concentration Increase Reported by Hinshaw, 2002.	67
Table 5.2.2	Average Changes in Pollutant Concentrations and Mass Loading from Influent to Effluent for All Participating Facilities.	69
Table 5.2.1.1	Calculated Un-ionized Ammonia Concentrations, Mass Loads, and Production Output of Participating Facilities.	71
Table 5.5.1	Production Impacts of Various TSS Effluent Limitations.	75
Table 5.5.2	Production Impacts of Two TAN Effluent Limitations.	76
Table 5.5.3	Production Impacts of BOD ₅ Effluent Limitation.	76
Table 5.5.4	Production Impacts at two TP Effluent Limitations.	77

LIST OF FIGURES

Figure		Page
Figure 2.2.1.1.	Schematic of typical linear fish culture unit.	3
Figure 2.2.2.1.	Schematic of typical circular fish culture unit.	4
Figure 2.5.2.1	Fate of feed nitrogen (N) and phosphorus (P).	9
Figure 3.1.1	Process Flow Diagram of Facility A.	14
Figure 3.1.2	Photograph of Granular Media Filters of Facility A.	15
Figure 3.1.3	Photograph of Aspirator System for Aeration at Facility A.	15
Figure 3.1.4	Process Flow Diagram of Facility B.	16
Figure 3.1.5	A Photograph of the Sedimentation Basin and Granular Media Filters of Facility B.	17
Figure 3.1.6	Process Flow Diagram of Facility C.	18
Figure 3.1.7	Photograph of Raceway System at Facility C.	19
Figure 3.1.8	Process Flow Diagram of Facility D.	20
Figure 3.1.9	Photograph of Surface Aerators at Facility D.	21
Figure 3.1.10	Process Flow Diagram of Facility E.	21
Figure 3.1.11	Packed Aeration Column	22
Figure 3.1.12	Liquid Oxygen Tanks of Facility E.	23
Figure 3.1.13	Process Flow Diagram of Facility F.	24
Figure 3.1.14	Photograph of the Circular Tanks at Facility F.	25
Figure 5.1.1.1	Average Effluent pH of Each Facility and Permit Limitations.	
Figure 5.1.2.1.	Influent and Effluent DO Concentrations of Facility A.	63
Figure 5.1.2.2.	Influent and Effluent DO Concentrations of Facility D.	63
Figure 5.1.2.3.	Influent and Effluent DO Concentrations of Facility F.	64
Figure 5.1.2.4.	Influent and Effluent DO Concentrations of Facility B.	65

Figure 5.1.2.5.	Influent and Effluent DO Concentrations of Facility C.	65
Figure 5.1.2.6.	Influent and Effluent DO Concentrations of Facility E.	65
Figure 5.2.1.1	Ammonia Speciation as a Function of pH.	71
Figure 5.4.1.	Turbidity vs. BOD ₅ for Facility A.	72
Figure 5.4.2.	Turbidity vs. BOD ₅ for Facility E.	73
Figure 5.4.3.	Turbidity vs. BOD ₅ for Facilities A and E.	73

CHAPTER 1. INTRODUCTION

1.1 Problem Statement

In order to reduce pollutant loadings nationwide, the U.S. Environmental Protection Agency (EPA), working in conjunction with the U.S. Department of Agriculture (USDA), are developing effluent management guidelines and standards for private and public aquaculture operations. Close proximity to eastern markets and an abundance of water resources gives the aquaculture industry in West Virginia tremendous potential for growth. Existing facilities must maximize their production to meet demands, compete with new operations, and be compliant with anticipated effluent standards.

1.2 Objectives

The objectives of this research were to (1) provide industry, State, and Federal stakeholders with baseline effluent water quality data specific to West Virginia facilities, in an effort to help concerned parties make informed decisions regarding impending regulations and (2) examine the potential to increase productivity based on effluent pollutant load and permit limitations. To attain these objectives, a water quality characterization was conducted at six anonymous facilities using flow-through design, rearing mostly rainbow trout (*Oncorhynchus mykiss*), that were selected based on various water sources, operation, size, and effluent treatment. Pollutant load for each facility was compared with permit limitations to determine regulation impacts on production.

CHAPTER 2. BACKGROUND

2.1 Overview of Aquaculture in West Virginia

Aquaculture is a growing industry both locally and nationwide for both recreation and food fish. An abundance of water resources, topography, and close proximity to eastern markets give West Virginia a unique opportunity for growth. Due to an abundance of groundwater sources, trout are the predominantly grown cool water fish in West Virginia. Nationally, commercial trout farms produce nearly 700,000 pounds annually (USDA, 1998).

2.2 Culture Systems

2.2.1 Linear Units

Raceways are linear fish culture units that have continuous flow for enhanced fish production and solids removal. Raceways are usually constructed of reinforced concrete, however earth, plastic, and metal are also used. Some additional characteristics of raceways include length:width ratio of 10:1, with a maximum depth of 0.61 m (2 ft.), water exchange rate of 4 exchanges per hour, and a linear water velocity of 0.033 m/sec (Soderberg, 1995). The appropriate water velocity allows solids to settle at the rear of the culture units for easier cleaning.

Raceways are constructed in series or tiers and the number to tiers are based on dissolved oxygen (DO) and the accumulation of fish metabolic waste products (e.g. solids, dissolved nutrients, and dissolved gases). Clean-out plugs are usually located at the end of each culture unit for the removal of solids to a settling pond.

Presented in Figure 2.2.1.1 is a schematic of a typical raceway unit that has laminar flow for even solids distribution in the quiescent zones.

Figure 2.2.1.1. Schematic of typical linear fish culture unit.

2.2.2 Circular Units

Presented in Figure 2.2.2.1 is a schematic of a typical circular fish production unit. Circular fish rearing units are typically 0.61 – 0.91 m (2 - 3 ft.) in depth and 0.91 – 15.2 m (3 - 50 ft.) in diameter (Soderberg, 1995). Water enters the unit under pressure at one location along the edge of the unit and drains out the bottom. The injection of water causes a circular pattern flow of water in which velocity decreases near the center, resulting in the accumulation of solids at the bottom-center of the tank that produces a self-cleaning action. Circular units typically have velocities five to ten times higher than linear units, but exchange rates are usually only 2 exchanges per hour, limiting fish density (Colt and Tomasso, 2001).

Figure 2.2.2.1. Schematic of typical circular fish culture unit.

2.3 Water Resources

The most important factor in successful fish production is the source water. Adequate quantity and quality of water are critical for fish culture operation and can be supplied by ground or surface sources (Colt and Tomasso, 2001).

2.3.1 Groundwater

Groundwater is the most desirable water source for trout production in West Virginia and the primary sources utilized are springs and mine waters. Groundwater is ideal for trout production because of both its quantity and quality.

West Virginia has 249 springs discharging 0.38 – 37.4 m³/min. (100 - 9870 gal./min.), with a total discharge of 727 m³/min (192,000 gal./min.) (McColloch, 1986). Springs provide high quality water with relatively constant temperature and flow, but can be supersaturated with nitrogen and carbon dioxide gases that need removed before use (Wedemyer, 2001).

Jenkins *et al.* (1995) investigated the use of discharge water from active and abandoned coal mines for the rearing of trout. Like traditional groundwater sources, mine waters have relatively constant year-round temperature and with acceptable water quality, can provide an important water source for trout production. Jenkins *et al.* (1995) concluded that 238 m³/min (63,000 gal./min.) were adequate for trout production when pretreatment of water was not necessary.

2.3.2 Surface Water

Surface water is surface runoff as a direct result of precipitation and base flow from groundwater sources. In areas where precipitation is heavy and regular, surface water can be utilized for trout culture. However, high variability in precipitation can limit the utilization of surface waters for trout production due to variations in quantity and quality.

2.4 Water Quality Criteria for Rainbow Trout

Presented in Table 2.4.1 are the water quality criteria, relevant to this study, for rearing salmonids.

Table 2.4.1. Water Quality Criteria for Salmonid Production.

Parameter	Upper limits for Continuous Exposure and/or Tolerance Ranges	Reference
Ammonia (NH ₃)	0.0125 mg/L (un-ionized form)	Soderberg, 1995
Carbon dioxide	0 to 10 mg/L	Meade, 1989
Nitrate (NO ₃ ⁻)	0 to 3.0 mg/L	Meade, 1989
Nitrite (NO ₂ ⁻)	0.1 mg/L in soft water 0.2 mg/L in hard water (0.03 to 0.06 mg/L nitrite-nitrogen)	Meade, 1989 IDEQ, 1998
pH	6.5 to 8.0	Meade, 1989
Phosphorus	0.01 to 3.0 mg/L	IDEQ, 1998
Total Suspended Solids (TSS)	< 80.0 mg/L	IDEQ, 1998
Total Alkalinity (as CaCO ₃)	10 to 400 mg/L	Meade, 1989
Temperature	0.5 to 25.5 C (tolerance range) 10.0 to 15.5 C (optimal range)	Piper, <i>et al.</i> , 1982

2.4.1 Ammonia Nitrogen

Ammonia is the primary nitrogenous waste production from fish metabolism and is toxic to fish in its un-ionized form. Ammonia is a gas that dissolves into water and forms either ammonium ion (NH_4^+) or un-ionized ammonia (NH_3). The form of ammonia varies with pH, temperature, and salinity, with increases in the toxic un-ionized form coinciding with increases in pH and temperature and decreases with increased salinity (Soderburg, 1995).

2.4.2 Carbon Dioxide

Carbon dioxide can occur naturally in some water sources used for fish production and can be added to water by fish respiration. Increased levels of carbon dioxide in culture water can lead to increased levels in the fish blood, resulting in carbonic acid production which can lower blood pH. Systems with high environmental carbon dioxide levels require degassing before use in fish culturing (Hargreaves and Brunson, 1996).

2.4.3 Nitrate

Nitrate is produced by the bacterially-mediated oxidation of nitrite and is not considered toxic to fish in levels anticipated in aquaculture operations (Colt and Tomasso, 2001).

2.4.4 Nitrite

Nitrite is produced by the bacterially-mediated oxidation of ammonia. Typically, nitrite is further oxidized to nitrate, but in situations where ammonia oxidation exceeds nitrite oxidation, nitrite concentrations can become elevated to toxic levels.

2.4.5 pH

pH of culture waters influences the toxicity of ammonia, hydrogen sulfide, and metals and extremes can affect production negatively.

2.4.6 Phosphorus

Although little is known on the effects of dissolved phosphorus on aquatic animals, its impact in the environment is understood quite well. Phosphorus discharged from aquaculture operations can increase plant growth in the receiving waterbody and lead to advanced eutrophication; thus degrading water quality (Meade, 1989).

2.4.7 Total Suspended Solids

Suspended solids in aquaculture operations primarily consist of uneaten feed and fish fecal matter (biosolids). Suspended solids can harbor opportunistic pathogens, are associated with certain induced diseases, and can cause fin rot and gill damage (Wedemyer, 2001).

2.4.8 Total Alkalinity

Alkalinity is a measure of the capacity of water to neutralize a strong acid (Snoeyink and Jenkins, 1980). It impacts the initial pH of water and pH change due to carbon dioxide release by fish and the effects of photosynthesis, as well as ammonia toxicity.

2.4.9 Temperature

Temperature is one of the most important water characteristics in aquaculture operations, due to its affect on fish metabolism, DO concentration, ionization of ammonia, decomposition, and photosynthesis. Temperatures outside the optimum range for a particular fish species can result in stress, decreased production efficiency, and possibly death (Colt and Tomasso, 2001)

2.5 Aquaculture Effluent Pollutants

Feed addition in aquaculture operations is the primary source of pollutants in process waters (Meade, 1989). Therefore, large facilities with more fish apply more feed, and thus have

higher pollutant concentration in process waters before treatment. Uneaten feed and fish fecal matter are the two predominant results of the feed addition to operation waters, resulting in both dissolved and suspended waste. Both dissolved and suspended wastes contain organic (BOD₅) and nutrient (nitrogen and phosphorus) pollutants.

2.5.1 Organic Pollutants

Organic pollutants result from undigested feed and fish biosolids and can be in the dissolved or suspended state. The most common parameter associated with organic pollutants in aquaculture effluents is the 5-day biochemical oxygen demand (BOD₅), which is a measure of the oxygen demand of microorganisms to degrade organic matter.

2.5.2 Nutrient Pollutants

The two primary nutrient pollutants in aquaculture waters are nitrogen (N) and phosphorus (P) and are of concern because of their detrimental impacts on the environment. An abundance of N and P in waters can lead to eutrophication (Selong and Helfrich, 1998). Like all other aquaculture pollutants, the source of nutrients is feed and its metabolic residuals. Figure 2.5.2.1 illustrates the fate of N and P as they enter an aquaculture operation in the form of feed.

**Figure 2.5.2.1. Fate of feed nitrogen (N) and phosphorus (P).
Adapted from Ramseyer and Garling, 1997.**

2.5.2.1 Nitrogen

Nitrogen in feed is primarily in the form of amino acids, the building blocks of proteins. The sources of nitrogen excreted by fish include undigested and unabsorbed dietary protein, sloughed intestinal cells, amino acids absorbed in amounts greater than the fish can utilize, and degraded metabolic products (Ramseyer and Garling, 1997). Only 30% of consumed feed nitrogen is retained by the fish, while the remaining 70% is excreted by the lungs as ammonia gas and as biosolids. Of excreted nitrogen, 87% is in the dissolved form of gaseous ammonia, while only 13% is in the suspended form, which makes N difficult to remove from wastewaters (Ramseyer and Garling, 1997).

2.5.2.2 Phosphorus

Phosphorus availability in fish feeds depends greatly upon the source, with rice bran and blood meal ranging from 19 to 81%, respectively. Feeds that contain highly available forms of phosphorus will excrete less to the environment. Only 32% of consumed feed phosphorus is

retained by the fish, while the remaining 68% is excreted in dissolved and suspended forms. Of excreted phosphorus, 10-40% is in the dissolved form, while 60-90% is in the suspended form, making phosphorus more easily controlled with proper solids management (Ramseyer and Garling, 1997).

2.6 Regulation

2.6.1 Federal Regulation

Since aquaculture wastewaters are discharged into receiving waterbodies, they are regulated by the Federal Clean Water Act (CWA) of 1977. Federal regulation is primarily enforced by the U.S. Environmental Protection Agency (EPA). As in many states, West Virginia is delegated to regulate aquaculture discharges, through the West Virginia Department of Environmental Protection (WVDEP).

2.6.2 State Regulation

Current West Virginia regulation requires a National Pollutant Discharge Elimination System (NPDES) permit for coldwater aquatic animals that discharge more than 30 days per year or produce above 9,072 kg (20,000 lbs.) per year (Ewart, 1995). Facilities that meet this criterion are classified as concentrated animal feeding operations (CAFO).

2.7 Effluent Management

The control of pollutants in aquaculture effluents requires reducing the amount of dissolved and suspended waste produced in the system. Dissolved pollutants are primarily controlled through diet optimization and to a lesser extent proper solids management. Suspended pollutants in aquaculture effluents are controlled through the use of various sedimentation and filtration processes.

2.7.1 Dissolved Pollutant Management

Ingredients in fish feed that are easily digested is the primary treatment for dissolved pollutants. Cho (1997), reported the use of a highly digestible, nutrient-dense (HND) diet yielded outputs less than 190 kg solid waste and 3 kg phosphorus per metric ton of salmonid fish produced, while a conventional diet yielded 240 and 4 kg, respectively.

2.7.2 Suspended Pollutant Management

Rapid and permanent removal of suspended solids from process waters is essential to reduce pollutant load and to prevent leaching of pollutants to the dissolved state. Sedimentation for the removal of suspended waste from aquaculture effluent is the most common and economical method in the United States (Hinshaw, 2002). There are three primary types of settling basins used to treat aquaculture effluent: quiescent zones, off-line settling (OLS) basins, and full-flow settling basins.

Quiescent zones are areas at the end of each raceway that are barred from fish and allow solids to settle, where they can be removed by the use of a stand pipe to an OLS basin.

OLS basins are settling areas that receive a small fraction of the total system flow and contain concentrated amounts of suspended waste. Most circular tank systems employ OLS basins as their suspended pollutant treatment method.

Full-flow settling basins receive the total flow of the aquaculture operation and are generally used for flow less than 283 L/sec (Hinshaw, 2002).

CHAPTER 3. INVESTIGATIVE APPROACH

3.1 Experimental Design

3.1.1 Site Selection

In order to provide effluent data on a broad range of operations, six (6) West Virginia aquaculture facilities were selected for participation in the study. The identity of all participants remained anonymous. To enable inter-facility comparison, all participating facilities were of flow-through design and reared primarily rainbow trout (*Oncorhynchus mykiss*); however, limited numbers of brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) were also raised at all but two (2) facilities. Site selection was based on water source, facility size, effluent treatment, and operator feeding practices.

Table 3.1. Site characteristics of the six facilities.

Characteristic	Facility					
	A	B	C	D	E	F
Water Source	Spring	Spring	Spring	Spring	Mine	Mine
Annual Feed Mass	>18,144 Kg	< 9,072 Kg	< 9,072 Kg	< 9,072 Kg	> 18,144 Kg	9,072 to 18,144 Kg
Annual Fish Production	90,718 Kg	13,608 Kg	13,608 Kg	< 9,000 Kg	57,000 Kg	36,000 Kg
Fish lbs./gpm	153	39.3	93.8	39.4	68.9	67.7
Effluent Treatment	Sediment Pond	Sediment Basin	Sediment Pond	None	OLS Pond	OLS Pond
Feeding Practice	Hand (measured)	Hand (measured)	Automated (pull string)	Automated (pull string)	Hand (measured)	Hand (measured)
Feed Type (CP/F)	38/11	40/23	40/23	42/16	38/11	38/11

3.1.1.1 Water Source

Facilities were selected for inclusion in this study to encompass a range of water sources for trout production. Water sources utilized at the selected sites included natural springs and mine pool waters.

3.1.1.2 Facility Size

National Pollutant Discharge Elimination System (NPDES) Permits have been issued to facilities based on the annual rate of feed applied, therefore, facility “size” was based on this criterion. Three (3) sizes of facilities were selected for this study:

1. Facilities applying > 40,000 lbs (18,144 kg). feed annually.
2. Facilities applying 20,000 to 40,000 lbs. (9,072 to 18,144 kg) feed annually.
3. Facilities applying < 20,000 lbs.(9,072 kg) feed annually (Ewart *et al.* 1995).

3.1.1.3 Effluent Treatment

Given varying water resources employed, size, and economic viability of the selected operations, a wide range of effluent treatment options were observed. Treatment strategies ranged from direct discharge into receiving water bodies to more complex designs involving sedimentation and biofiltration. The wide range of treatment options at study facilities enabled an assessment of the benefits of additional treatment methods on production and effluent quality.

3.1.1.4 Operator Feeding Practices

Facilities were also characterized according to the type of feed, quantity of feed, and feeding mechanism employed. The type of feed utilized was either conventional or “high yield”, while the feeding mechanism was either automatic or manual.

3.1.2 Description of Research Sites

3.1.2.1 Facility A

A schematic of Facility A is presented in the following process flow diagram (PFD).

Figure 3.1.1 Process Flow Diagram of Facility A.

Note: Facility has 40 raceways.

The facility was a West Virginia State owned hatchery that supplied ~ 90,000 kg of trout for stocking of State waters.

Water was pumped from a nearby spring that had an average flow of 4,542 liters per minute. The facility had forty (40) concrete raceways (30.5 m x 2.44 m x 0.762 m) in which fingerlings through brood stock resided. Approximately 2,268 m³ of production volume was available. Quiescent zones at the end of each raceway were employed to remove settleable solids from the process water. Stand pipes in the quiescent zones allowed solids removal to the sedimentation pond for treatment. Six (6) furnace-slag granular media filters (15.3 m x 4.65 m) were used to re-circulate 75 – 80% of the total flow into the head-works of the facility. A photograph of the granular media filters of Facility A is presented in Figure 3.1.2. Recirculation water was aerated by an aspirator system, presented in Figure 3.1.3. Water from the quiescent zones and backwash from periodic cleaning of the granular media filters passed through an effluent sedimentation pond before being discharged into the receiving water body.

Figure 3.1.2 Photograph of Granular Media Filters of Facility A.

Figure 3.1.3 Photograph of Aspirator System for Aeration at Facility A.

A summary of water quality parameters and regulatory limits required by the NPDES Permit for Facility A are presented in Table 3.2. The facility's effluent was regulated by an NPDES Permit, which called for the monitoring of flow rate, five-day biochemical oxygen demand (BOD₅), total suspended solids (TSS), ammonia nitrogen (NH₃), settleable solids (SS), pH, and dissolved oxygen (DO). The BOD₅, TSS, and NH₃ were monitored once per month by

composite samples, while pH, DO, and SS were monitored through grab sample analysis. Flow rates were estimated.

Table 3.2 NPDES Permit Requirements for Facility A.

Parameter	(Mass Load) Kg/day		(Concentration) mg/L	
	Avg Monthly	Max Daily	Avg Monthly	Max Daily
BOD ₅	432.35 (196.11 lbs/day)	864.70 (392.2 lbs/day)	30	60
TSS	432.35 (196.11 lbs/day)	864.70 (392.2 lbs/day)	30	60
TAN	N/A	150.55 (62.3 lbs/day)	N/A	10.44 [†]
SS	N/A	N/A	N/A	0.2
DO	N/A	N/A	Minimum 6.0	Minimum 6.0
pH	N/A	N/A	6 – 9	6 – 9
Flow	N/A	N/A	N/A	Monitor mgd

[†] - Based on NH₃ water quality standard (WQS) of 20 µg/L, 18.9 °C, and pH of 6.55.

3.1.2.2 Facility B

A schematic of Facility B is presented in the following process flow diagram.

Figure 3.1.4 Process Flow Diagram of Facility B.

The facility produced ~ 13,608 kg of primarily rainbow trout, with a small amount of brook and brown trout. High yield feeds were administered manually one [1] to two [2] times daily. The primary market for this facility was private stocking for game fishing.

Water flowed from the spring under gravity into the facility headbox, where it was split into eight [8] concrete raceways (2.44 m x 13.7 m x 0.61 m) and three [3] earthen raceways (2 @

4.57 m x 13.7 m x 0.61 m and 1 @ 3.05 m x 30.5 m x 0.61 m). Facility B had an approximate production volume of 296m³. Water then flowed through a concrete sedimentation basin (13.9 m x 4.92 m x 1.22 m) for solids removal. Two [2] crusher-run limestone granular media filters (10.7 m x 13.9 m x 1.22 m) were operated 3 – 6 months per year and able to create 4,361 m³/day for recirculation. A photograph of the sedimentation basin and granular media filters of Facility B is presented in Figure 3.1.5. During operation of the granular media filter, the operator had the option to incorporate liquid oxygen into the recirculation water.

Figure 3.1.5 A Photograph of the Sedimentation Basin and Granular Media Filters of Facility B.

A summary of water quality parameters and regulatory limits required by the NPDES Permit for Facility B are presented in Table 3.2. The facility's effluent was also regulated by an NPDES Permit, which called for the semi-annual monitoring of flow rate, BOD₅, TSS, NH₃, SS,

pH, and DO. The BOD₅, TSS, and NH₃ were monitored once per month by composite samples, while pH, DO, and SS were monitored by grab samples. Flow rates were estimated.

Table 3.3 NPDES Permit Requirements for Facility B.

Parameter	(Mass Load) lbs/day		(Concentration) mg/L	
	Avg Monthly	Max Daily	Avg Monthly	Max Daily
BOD ₅	Monitor Only	Monitor Only	Monitor Only	Monitor Only
TSS	Monitor Only	Monitor Only	Monitor Only	Monitor Only
NH ₃	N/A	Monitor Only	N/A	Monitor Only
SS	N/A	N/A	N/A	Monitor Only
DO	N/A	N/A	Monitor Only	Monitor Only
pH	N/A	N/A	Monitor Only	Monitor Only
Flow	N/A	N/A	N/A	Monitor mgd

3.1.2.3 Facility C

A schematic of facility C is presented in the following process flow diagram.

Figure 3.1.6 Process Flow Diagram of Facility C.

The operation was gravity fed by spring water, and the headloss of the site allowed for gravity reaeration between raceways. High yield feeds were administered both mechanically (pull string) and manually (hand measured) one [1] to two [2] times daily. The facility produced ~13,608 kg of rainbow, brook, and brown trout, with rainbow being the predominant species. The primary market for this facility was an adjacent fee fishing operation.

Water flowed by gravity from the spring to a headbox where it was spit into two [2] parallel raceway systems consisting of two [2] (9.0 m x 1.83 m x 0.53 m), two [2] (15.3 m x 1.83 m x 0.53 m), two [2] (16.7 m x 1.83 m x 0.53 m), and two [2] (11.9 m x 1.83 m x 0.53 m) concrete raceways, totaling eight [8], with quiescent zones at the end of each for solids removal. A photograph of the raceway system at Facility C is presented in Figure 3.1.7. The facility had a production volume of 102.5 m³ in the raceway system and 6,170 m³ in the sedimentation / fee fish pond. Headloss at the site enabled considerable reoxygenation between production units ($h_L \sim 1.0$ m). Water from the raceway system was then passed through a sedimentation pond before being discharged into an adjacent vegetated discharge ditch that carried the effluent to the receiving water body. Solids from the quiescent zones were periodically removed through stand pipes and discharged into the vegetated discharge ditch. Facility C is not regulated by an NPDES Permit.

Figure 3.1.7 Photograph of Raceway System at Facility C.

3.1.2.4 Facility D

A schematic of facility C is presented in the following process flow diagram.

Figure 3.1.8 Process Flow Diagram of Facility D.

Note: Facility has 5 containment areas.

Facility D used the existing stream channel as raceways, with holding areas separated by gates. High yield feed was delivered mechanically (pull string) and manually (hand measured) one [1] to two [2] times daily. The facility produced < 9,000 kg of rainbow, brook, and brown trout, with rainbow being the predominant species. The market for Facility D was private stocking for game fishing.

Water from an adjacent spring was collected in a culvert pipe and discharged into the earthen raceway system. Five [5] holding areas were separated by gates where oxygen was increased minimally by gravity aeration, due to small head loss. Floating impeller aerators were employed to increase dissolved oxygen during low-flow conditions. A photograph of the floating impeller aerators is presented in Figure 3.1.9. There was no effluent treatment in the operation; hence effluent from the facility flowed directly into the receiving water body. Facility D is not regulated by an NPDES Permit.

Figure 3.1.9 Photograph of Surface Aerators at Facility D.

3.1.2.5 Facility E

A schematic of facility E is presented in the following process flow diagram.

Figure 3.1.10 Process Flow Diagram of Facility E.

Note: Facility has multiple tanks of each size.

The operation was gravity fed water from a deep mine pool that needed to be de-gassed to remove excess carbon dioxide (CO_2) and increase the DO concentration. High yield feeds were administered manually (hand measured) three [3] times daily. The facility produced approximately 57,000 kg rainbow trout annually. The primary market for facility E was human consumption, with restaurants being the main purchaser.

Water from the deep mine drain flowed by gravity to a packed column to remove CO_2 and increase DO. A photograph of the packed column is presented in Figure 3.1.11.

Figure 3.1.11 Packed Aeration Column

Water was then distributed through parallel delivery piping to 24 – 1.4 m^3 , 48 – 2.8 m^3 , 10 – 37.9 m^3 , and 12 – 75.8 m^3 circular tanks. Liquid oxygen was fed in the influent of each tank to increase DO levels. A photograph of the liquid oxygen tanks is presented in Figure 3.1.12. The

discharge from all the tanks was then distributed to a parallel raceway system where trout were held for final grow-out and distribution. Water from the raceway system was then discharged to the receiving water body. Stand pipes in each tank in the system drained to an off-line sedimentation (OLS) pond, in which solids were settled. The supernatant was discharged to the receiving water body. The facility did not have an NPDES Permit.

Figure 3.1.12 Liquid Oxygen Tanks of Facility E.

3.1.2.6 Facility F

A schematic of facility F is presented in the following process flow diagram.

Figure 3.1.13 Process Flow Diagram of Facility F.

Note: Facility has multiple tanks of each size.

The operation was gravity fed water from a deep mine pool that needed to be de-gassed to remove excess carbon dioxide (CO_2) and increased DO concentration. The facility produced approximately 36,000 kg rainbow trout annually. The primary market for this facility was human consumption, with restaurants being the main purchaser.

Water from a deep mine drain flowed by gravity to a packed column to remove CO_2 and increase the DO (see Figure 3.1.11). Water was then distributed through parallel delivery piping to 2 – 10.0 m^3 , 5 – 37.9 m^3 , and 4 – 75.8 m^3 circular tanks. A photograph of the circular tanks is presented in Figure 3.1.14. Liquid oxygen was fed to the influent of each tank to increase DO concentrations. Water from the tanks was then discharged to a drainage ditch to transfer the effluent to the receiving water body. Stand pipes in each tank in the system drained to an off-line sedimentation (OLS) pond, in which solids settled and the supernate discharged to the

vegetated ditch and then into the receiving water body. The facility did not have an NPDES Permit.

Figure 3.1.14 Photograph of the Circular Tanks at Facility F.

3.1.3 Sampling Sites

In order to perform a “cause and effect” comparison of production, influent and effluent were monitored to ascertain the net effects of the hatchery on water quality. Facility E had an additional effluent site from the OLS pond that was also monitored in conjunction with the effluent from the primary system.

3.1.4 Sampling Regime

Each facility was visited approximately every six weeks for one year and then approximately once per quarter for an additional year. Each site visit included field monitoring and the collection of grab samples for analysis.

3.1.5 Field Monitoring and Grab Samples

Field monitoring consisted of measuring flow, water temperature, pH, DO, specific conductance, and turbidity. Grab sampling was conducted during each site visit and samples were collected for BOD₅, TSS, SS, TAN, NO₂⁻, and NO₃⁻ analysis.

3.2 Methods

3.2.1 Field Monitoring

Instruments used for field monitoring are presented in Table 3.2.1.1. Measurements were taken using *YSI* portable meters, a *Hach* turbidimeter, and a *Marsh-McBirney Inc.* FLO-MATE flow meter.

Table 3.2.1.1 Instruments Employed in Field Monitoring.

Parameter(s) Measured	Manufacturer	Model	Type of Instrument
pH/Conductivity/Temp.	<i>YSI</i>	63	Electrode
DO, % Saturation, Temp.	<i>YSI</i>	95	Electrode
Turbidity	<i>Hach</i>	2100P	Spectrophotometer
Flowrate	<i>Marsh-McBirney</i>	2000	Electromagnetic

The *YSI* 63 pH meter was calibrated prior to each use. Following the manufacturer's instructions, a two point calibration was performed using pH 7 and pH 10 buffers. The *YSI* 95 DO meter was calibrated with each use per manufacturer's instructions employing percent saturation according to elevation in one-hundred foot increments. The *Hach* turbidimeter was checked for accuracy each use with standards of 5.57 NTU, 56.1 NTU, and 550 NTU. When the calibration procedures were completed and documented, field measurements of influent and effluent waters were made.

Sites and methods for flow measurements were taken at each site based on an assessment of facility layout and design. Determination using one of three approaches are detailed below.

Water height over outlet weirs was measured and flowrate was determined using a rectangular streamlined weir equation (EQN. 3.1) (Lin, 2001)

$$Q = 1.705LH^{3/2} \quad (\text{EQN. 3.1})$$

where Q = flow rate, m³/s
 L = weir length, m
 H = head on weir, m

Stream velocity and cross-sectional were also measured and placed into a open-channel flow equation (EQN. 3.2) (Lin, 2001).

$$Q = VA \quad (\text{EQN. 3.2})$$

where Q = flow rate, m³/s
 V = average velocity, m/s
 A = cross-sectional area, m

The timed volumetric method was also used to determine flowrate, and is presented in equation (EQN. 3.3).

$$Q = Vol./t \quad (\text{EQN. 3.3})$$

where Q = flow rate, m³/s
 $Vol.$ = know volume, m
 t = time, s

Presented in Table 3.2.1.2 are the site locations and methods for flow measurement at each facility.

Table 3.2.1.2 Location and Methods of Flow Determination at Study Sites

Facility	Location	Method
A	Influent Pipe	Eq. 3.3
B	Effluent Structure	Eq. 3.1
C	End of Raceways	Eq. 3.1
D	Earthen Raceways	Eq. 3.2
E	Influent Pipes	Eq. 3.3
F	Discharge Ditch	Eq. 2

3.2.2 Grab Sample Analysis

3.2.2.1 Nutrients

Samples were collected in high density polyethylene (HDPE) bottles with zero headspace, pH adjusted to < 2 standard units with H₂SO₄, and stored at 4°C until analysis. Nutrients were analyzed by the *National Research Center for Coal and Energy* (NRCCE), a WVDEP certified laboratory. Analytical methods used in assays performed by the NRCCE are presented in Table 3.2.2.1.

Table 3.2.2.1 Analytical Methods Used in Assays Performed by the NRCCE.

Assay	EPA Method
Nitrite, NO ²⁻	353.2
Nitrate, NO ³⁻	353.2
Total Ammonia Nitrogen, (TAN)	350.1
Total Phosphorus, (TP)	200.7

3.2.2.2 Biochemical Oxygen Demand

Samples were collected in HDPE bottles with zero headspace and stored at 4°C until analysis (hold time 48 hours). Researchers at the *West Virginia University* Department of Civil and Environmental Engineering (WVU-CEE) conducted BOD₅ measurements following EPA method number 405.1.

3.2.2.3 Solids

Samples were collected in HDPE bottles with zero headspace and stored at 4°C until analysis (hold time 7 days). WVU-CEE researchers conducted non-filterable solids (TSS) measurements following EPA method number 160.2.

3.3 Quality Assurance and Quality Control

3.3.1 External Laboratory Analyses

A field triplicate (one sample split into three) was taken during each sampling excursion. Each individual analyte was measured in each of the triplicate samples by the external laboratory. Triplicate sample analyses were used to assess the analytical precision of the laboratory. Suspected “outliers” were subjected to the Dixon’s Extreme Value test for statistical analysis before their removal (US EPA, 1998).

3.3.2 In-house Laboratory Analyses

3.3.2.1 Solids

A triplicate sample was taken and analyzed during each sampling excursion to measure the precision of the analytical procedure. For TSS, sample blanks and replicates were analyzed on at least 10% of all samples in the batch.

3.3.2.2 Biochemical Oxygen Demand

Quality analysis/quality control procedures of BOD₅ included field triplicates, seed controls, dilution water blanks, and glucose-glutamic acid checks.

To ensure populations of microorganisms were present and capable of oxidizing biodegradable or organic matter in the sample, the sample was seeded with *Polyseed*TM. Dilution water blanks check the quality of dilution water and can detect the development of nitrifying bacteria in the dilution water. Glucose-glutamic acid checks serve as a “standard” check and measure the accuracy of the procedure.

3.3.2.3 Field Meters

YSI field meters were calibrated per manufacturer's instructions at the beginning of each sampling visit as outlined previously in Section 3.5.1. In addition, the DO and conductivity / pH probes were cleaned, calibrated, and the DO membrane cap replaced when needed. Accuracy of the *Hach* turbidimeter was verified at the start of each sampling event using *gelex*TM standards and calibrated in the laboratory using *stablcal formazin*TM standards per manufacturer's instructions.

3.4 Statistical Analyses

3.4.1 Paired *t*-Test

The paired *t*-test is a parametric statistical method that assumes the observed treatment effects are normally distributed and used when you want to determine if a treatment on one individual is significant (SPSS, 1997). For this research, a comparison of facility influent and effluent were compared to determine if the water quality had significantly changed through the process.

Examining the changes rather than the values observed before and after the intervention removes the differences due to individual responses, producing a more sensitive, or powerful, test (Hayter, 1996). The paired *t*-test is a parametric statistical method, and thus is only used when the observed treatment effects are consistent with a normally distributed population (data set), and the populations have equal variance (SPSS, 1997). In a normally distributed data set 67% of all data falls within two standard deviations of the mean, if the positive deviation is equal to the negative deviation, then the data set has equal variance. *Sigma Stat* software, a program by SPSS (1997), was used to determine the *t*-test statistic using a 95 percent level of confidence, $\alpha = 0.05$, and $P = 0.05$.

The value of the t -test statistic is indicative of whether or not a statistically significant difference exists between the two sets of data used for the paired t -test and was computed using equation 3.7.1.1.

$$t = \frac{\text{mean difference of the data sets}}{\text{standard error of the mean difference}} \quad (\text{EQN 3.7.1.1})$$

Statistically significant differences existed when the absolute value of the paired t -test statistic was large ($|t| \geq 2$), which meant that the difference in the two data sets was larger than what could be otherwise attributed to random variability, alone. For absolute values of the t -test statistic close to zero, one assumes there is no significant difference between the two data sets (SPSS, 1997). The *Sigma Stat* software was programmed to recognize an absolute value of two as the boundary for statistically significant differences, that is, for t -test statistic values greater than $|2|$, one could conclude there existed a statistically significant difference. Likewise, for t -test statistic values less than $|2|$, one could conclude no statistically significant difference existed.

Confidence intervals were calculated using the paired t -test data. If the confidence interval included zero, one could conclude a statistically significant difference did not exist (Hogg and Ledolter, 1992, SPSS, 1997). The level of confidence, reported as a percentage, is the level to which one could assume the data fell within the confidence interval. In this instance, one could be 95% confident that the difference of the population means fell within the confidence interval for each specific test run (Hogg and Ledolter, 1992).

Alpha was the acceptable probability of incorrectly concluding that there was a statistically significant difference between the influent and effluent (SPSS, 1997). Using $\alpha = 0.05$, a chance of error equal to 5% was acceptable. Larger values of α expanded the requirements of concluding there was a significant difference, but also increased the risk of incorrectly concluding there was a statistically significant difference.

Finally, the P value was the probability of wrongly concluding that there was a significant effect (SPSS, 1997). For values of $P < 0.05$, one can assume that a statistically significant difference did exist.

3.4.2 Wilcoxon Signed Rank Test.

When analyzed data is nonparametric, the *Wilcoxon Signed Rank Test* was used to assess the effect of facility production on process waters from influent to effluent. This test analyzes the paired differences of the influent and effluent data. Under the null hypothesis of no differences between influent and effluent data, you would expect half of the differences between pairs to be negative and half positive, that is the average being $n/2$ [where n is the number of pairs] (Hogg and Ledolter, 1992). The observed treatment differences are ranked without regard to sign and then signs are added to each pair. The ranks are then summed and compared. If the ranks tend to have the same sign, there is a statistically significant difference between the influent and effluent data (SPSS, 1997).

CHAPTER 4. RESULTS

4.1 Facility A

4.1.1 Field Monitoring

Field monitoring results for Facility A from January 2001 to October 2002 are presented in Table 4.1.1.1. Averages and ranges of concentrations are presented to show extremes due to seasonal variations and impacts of production activities, however the exact cause of those extremes was not thoroughly investigated.

Table 4.1.1.1. Field Monitoring Results of Facility A.

Site	pH, Std. Units average [range]	Temperature, °C average [range]	Spc. Cond., µS/cm average [range]	DO, mg/L average [range]	Turbidity, NTU average [range]
Influent	7.17 [6.57-7.57]	10.76 [7.3-12.8]	185.8 [148.7-233.6]	9.16 [8.27-11.1]	1.61 [0.54-4.81]
Effluent	7.08 [6.71-7.49]	11.62 [5.8-16.3]	195.1 [144.1-245.4]	7.25 [5.92-9.55]	4.21 [1.88-8.91]

4.1.1.1 Flow

Facility A had a built-in electronic flow meter; however, it was not in working condition during the entire study. The average flow recorded was 7,142 m³/sec. (1,310 GPM) and was consistent with the NPDES permitted amount of 7,631 m³/sec. [1,400 GPM] (WVDEP, 1993). Fluctuations were seasonally influenced by the production of the adjacent groundwater spring.

4.1.1.2 pH

Measured pH values are summarized in Table 4.1.1.1 and presented fully in Table A.1. Influent pH values ranged from 6.57 to 7.57 standard units and averaged 7.17. Effluent pH values ranged from 6.71 to 7.49 and averaged 7.08. All measured values were within the permitted range between 6 – 9 standard units (WVDEP, 1993).

4.1.1.3 Specific Conductance

Specific conductance values summarized in Table 4.1.1.1 are presented fully in Table A.2. Influent specific conductance values ranged from 148.7 to 233.6 µS/cm and averaged 185.8 µS/cm. Effluent specific conductance values ranged from 144.1 to 245.4 µS/cm and averaged 195.1 µS/cm.

4.1.1.4 Temperature

Temperature, summarized in Table 4.1.1.1 and presented fully in Table A.1, ranged from 7.3 to 12.8 °C (45 to 55 °F) with an average of 10.8 °C (51 °F) in the influent and effluent

temperatures ranged from 5.8 to 16.3 °C (42 to 61 °F) with an average of 11.6 °C (53 °F). Monitored temperatures were in acceptable ranges for the survival of rainbow trout (Meade, 1989). Temperature was not a regulated parameter in the facility's NPDES Permit.

4.1.1.5 Dissolved Oxygen

Dissolved oxygen concentrations summarized in Table 4.1.1.1, are presented fully in Table A.2. Typically, DO concentrations remained relatively constant in the facility's influent, ranging from 8.27 to 11.06 mg/L, averaged 9.16 mg/L, and were within the acceptable range for salmonid production (5 mg/L to saturation; Heinen 1996). Effluent DO concentrations ranged from 5.92 to 9.55 mg/L and average 7.25 mg/L. The facility operated floating-surface aerators in the sedimentation pond to increase DO concentrations above the lower NPDES regulated limit of 6 mg/L, however one measurement failed to meet this limitation (WVDEP, 1993).

4.1.1.6 Turbidity

Turbidity values are summarized in Table 4.1.1.1 and presented fully in Table A.2. Influent turbidity ranged from 0.54 to 4.81 NTU and averaged 1.61 NTU. Effluent turbidity ranged from 1.88 to 8.91 NTU and averaged 4.21 NTU.

4.1.2 Grab Samples

Grab sample results from January 2001 to October 2002 are summarized in Table 4.1.2.1 and presented fully in Table A.3. Averages and ranges of concentration and loading are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.1.2.1 Grab Sample Results of Facility A.

Site	TSS average [range]	BOD ₅ average [range]	NH ₃ average [range]	NO ₃ ⁻ average [range]	TP average [range]
Influent concentration, mg/L	5.8 [1.0-32.0]	1.43 [†] [1.43]	0.07 [†] [0.005 [†] -0.15]	0.76 [0.46-1.53]	0.009 [†] [0.005 [†] -0.04]
Effluent concentration, mg/L	11.5 [4.5-17.5]	4.70 [†] [1.43 [†] -11.96]	0.31 [0.14-0.53]	1.28 [0.85-1.92]	0.50 [0.22-1.24]
Effluent loading, kg/d	78.1 [18.5-148.4]	34.5 [†] [10.5 [†] -101.4]	2.02 [0.06-5.34]	8.60 [6.52-11.04]	3.58 [1.20-10.52]

[†] Presented value was calculated by $\frac{\text{MDL}}{2}$

4.1.2.1 Total Suspended Solids (TSS)

Concentration and mass loading of effluent TSS were below the acceptable limit of the facility's NPDES permit (30 mg/L average monthly and 60 mg/L maximum daily). TSS concentrations are summarized in Table 4.1.2.1 and presented in full in Tables A.3 to A.6. Influent TSS concentrations ranged from 1.0 mg/L to 32 mg/L and averaged 5.78 mg/L. Effluent TSS concentrations ranged from 4.50 mg/L to 17.5 mg/L and averaged 11.5 mg/L. TSS loadings ranged from 18.49 to 148.41 kg/d and averaged 78.12 kg/day.

4.1.2.2 Five Day Biochemical Oxygen Demand (BOD₅)

Concentration and mass loading of effluent BOD₅ were below the NPDES permitted limit (30 mg/L average monthly and 60 mg/L maximum daily). All influent grab samples taken and analyzed for BOD₅ were below the MDL of 2.86 mg/L. Effluent concentrations of BOD₅ ranged from 1.43 to 11.96 mg/L and averaged 4.70 mg/L. Effluent mass loadings of BOD₅ ranged from 10.5 to 101.4 kg/d and averaged 34.5 kg/d. Results are summarized in Table 4.1.2.1 and presented fully in Table A.6.

4.1.2.3 Total Ammonia Nitrogen (TAN)

Total ammonia nitrogen concentrations and mass loadings are summarized in Table 4.1.2.1 and presented fully in Table A.4. Influent TAN concentrations ranged from 0.005 to 0.15 mg/L and averaged 0.07 mg/L. Effluent NH_3 concentrations ranged from 0.14 to 0.53 mg/L and averaged 0.31 mg/L. Effluent mass loadings ranged between 0.06 to 5.34 kg/d and averaged 2.02 kg/d. Concentration and mass loading of effluent NH_3 were below the allowable limit of the facility's NPDES permit (10.44 mg/L maximum daily).

4.1.2.4 Nitrate (NO_3^-)

Nitrate concentrations and mass loadings are summarized in Table 4.1.2.1 and presented fully in Tables A.4 and A.5. Nitrate is not regulated under the facility's existing NPDES permit. Influent nitrate concentrations ranged from 0.46 to 1.53 mg/L and averaged 0.76 mg/L. Effluent nitrate concentrations ranged from 0.85 to 1.92 mg/L and averaged 1.28 mg/L. Effluent mass loadings ranged between 6.52 to 11.04 kg/d and averaged 8.60 kg/d.

4.1.2.5 Total Phosphorus (TP)

Total phosphorus concentrations and mass loadings are summarized in Table 4.1.2.1 and presented fully in Tables A.5 and A.6. Influent total phosphorus concentrations ranged from 0.001 to 0.04 mg/L and averaged 0.009 mg/L. Effluent total phosphorus concentrations ranged from 0.22 to 1.24 mg/L and averaged 0.50 mg/L. Effluent mass loadings ranged between 1.20 to 10.52 kg/d and averaged 3.58 kg/d. Total phosphorus is not regulated under the facility's existing NPDES permit.

4.1.2.6 Nitrite (NO_2^-)

All influent grab samples had nitrite concentrations less than the MDL of 0.01 mg/L. All but two of the effluent grab samples had nitrite concentrations less than the MDL; with those

concentrations being 0.023 and 0.024 mg/L. The resulting mass loadings were 0.13 and 0.10 kg/d. These results are presented fully in Table A.5.

4.1.3 Statistical Analysis

The Paired *t*-Test and *Wilcoxon Signed Rank Test* were used to determine if any significance difference existed between influent and effluent monitored parameters. The Paired *t*-Test was used when observed treatment effects were normally distributed, while the *Wilcoxon Signed Rank Test* was employed with non-normal distribution. The Summaries of the statistical analysis results are presented in Table 4.1.3.1.

Table 4.1.3.1 Facility A Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired t-test	0.262	N
Temperature	Y	Paired t-test	0.135	N
Dissolved Oxygen	Y	Paired t-test	0.005	Y
Spc. Cond.	Y	Paired t-test	0.007	Y
Turbidity	Y	Paired t-test	0.009	Y
TSS	Y	Paired t-test	< 0.001	Y
Ammonia	Y	Paired t-test	< 0.001	Y
Nitrate	Y	Paired t-test	0.020	Y
Total P	Y	Paired t-test	0.002	Y
BOD ₅	Y	Paired t-test	0.011	Y
Nitrite	N	Wilcoxon Signed Rank Test	0.500	N

4.2 Facility B

4.2.1 Field Monitoring

Field monitoring results for Facility B from November 2000 to October 2002 are presented in Table 4.2.1.1. Averages and ranges of concentrations are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.2.1.1. Field Monitoring Results of Facility B.

Site	pH, Std. Units average [range]	Temperature, °C average [range]	Sp. Cond., µS/cm average [range]	DO, mg/L average [range]	Turbidity, NTU average [range]
Influent	7.41 [6.88-7.92]	11.81 [9.30-13.40]	307.6 [166.5-360.0]	9.33 [8.28-10.1]	1.67 [0.54-5.92]
Effluent	7.48 [7.04-8.08]	13.81 [10.90-19.70]	328.9 [313.7-357.1]	10.23 [7.80-12.7]	1.80 [0.39-1.80]

4.2.1.1 Flow

Measured flow rates, presented fully in Table B.1, ranged from 1,139 to 8,399 m³/day and averaged 4,166 m³/day (209, 1541, and 764 GPM).

4.2.1.2 pH

Measured pH values are summarized in Table 4.2.1.1 and presented fully in Table B.1. Influent pH values ranged from 6.88 to 7.92 standard units and averaged 7.41. Effluent pH values ranged from 7.04 to 8.08 and averaged 7.48.

4.2.1.3 Specific Conductance

Specific conductance values summarized in Table 4.2.1.1 are presented fully in Table B.2. Influent specific conductance values ranged from 166.5 to 360.0 µS/cm and averaged 307.6 µS/cm. Effluent specific conductance values ranged from 313.7 to 357.1 µS/cm and averaged 328.9 µS/cm.

4.2.1.4 Temperature

Temperature values, summarized in Table 4.2.1.1, are presented fully in Table B.1. Influent temperatures ranged from 9.30 to 13.4 °C (48.7 to 56.1 °F) and averaged 11.81 °C (53.3 °F). Effluent temperatures ranged from 10.9 to 19.7 °C (51.6 to 53.5 °F) and averaged 13.8 °C (56.9 °F). Monitored temperatures were within acceptable ranges for the survival of rainbow trout (Meade, 1989).

4.2.1.5 Dissolved Oxygen

Dissolved oxygen concentrations summarized in Table 4.2.1.1, are presented fully in Table B.2. Typically, DO concentrations remained relatively constant in the facility's influent, ranging from 8.28 to 10.06 mg/L, with an average of 9.33 mg/L, and were within the acceptable range for salmonid production (5 mg/L to saturation; Heinen 1996). Effluent DO concentrations ranged from 7.80 to 12.67 mg/L and average 10.23 mg/L.

4.2.1.6 Turbidity

Turbidity values are summarized in Table 4.2.1.1 and presented fully in Table B.2. Influent turbidity ranged from 0.54 to 5.92 NTU and averaged 1.67 NTU. Effluent turbidity ranged from 0.39 to 6.41 NTU and averaged 1.80 NTU.

4.2.2 Grab Samples

Grab sample results from November 2000 to October 2002 are summarized in Table 4.2.2.1 and presented fully in Table B.3 to B.6. Averages and ranges of concentration and loading are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.2.2.1 Grab Sample Results of Facility B.

Site	TSS average [range]	BOD ₅ average [range]	NH ₃ average [range]	NO ₃ ⁻ average [range]	TP average [range]
Influent concentration, mg/L	1.75 [†] [0.50 [†] -4.0]	1.43 [†] [1.43 [†]]	0.07 [†] [0.01 [†] -0.16]	0.76 [0.47-2.03]	0.02 [†] [0.005 [†] -0.05]
Effluent concentration, mg/L	3.60 [2.0-6.0]	1.43 [†] [1.43 [†]]	0.10 [†] [0.01 [†] -0.21]	0.65 [0.50-0.96]	0.03 [†] [0.005 [†] -0.09]
Effluent loading, kg/d	14.09 [5.23-25.2]	5.96 [1.63 [†] -12.0 [†]]	0.36 [†] [0.02 [†] -0.66]	2.70 [0.58-4.70]	0.12 [†] [0.005 [†] -0.27]

[†] Presented valued was calculated by: $\frac{MDL}{2}$.

4.2.2.1 Total Suspended Solids (TSS)

TSS concentrations are summarized in Table 4.2.2.1 and presented fully in Table B.3. Influent TSS concentrations ranged from 0.50 to 4.0 mg/L and averaged 1.75 mg/L. Effluent TSS concentrations ranged from 2.0 to 6.0 mg/L and averaged 3.60 mg/L. TSS loadings ranged from 5.23 to 25.20 kg/d and averaged 14.09 kg/day.

4.2.2.2 Five Day Biochemical Oxygen Demand (BOD₅)

All influent and effluent grab samples taken and analyzed for BOD₅ were below the MDL. Effluent mass loadings of BOD₅ ranged from 1.63 to 12.0 kg/d and averaged 5.96 kg/d. Results are summarized in Table 4.2.2.1 and presented fully in Table B.6.

4.1.2.3 Total Ammonia Nitrogen (TAN)

Ammonia concentrations and mass loadings are summarized in Table 4.2.2.1 and presented fully in Tables B.3 and B.4. Influent NH₃ concentrations ranged from 0.01 to 0.16 mg/L and averaged 0.07 mg/L. Effluent NH₃ concentrations ranged from 0.01 to 0.21 mg/L and

averaged 0.10 mg/L. Effluent mass loadings ranged from 0.02 to 0.66 kg/d and averaged 0.36 kg/d.

4.2.2.4 Nitrate (NO_3^-)

Nitrate concentrations and mass loadings are summarized in Table 4.2.2.1 and presented fully in Tables B.4 and B.5. Influent nitrate concentrations ranged from 0.47 to 2.03 mg/L and averaged 0.76 mg/L. Effluent nitrate concentrations ranged from 0.50 to 0.96 mg/L and averaged 0.65 mg/L. Effluent mass loadings ranged from 0.58 to 4.70 kg/d and averaged 2.70 kg/d.

4.2.2.5 Total Phosphorus (TP)

Total phosphorus concentrations and mass loadings are summarized in Table 4.2.2.1 and presented fully in Table B.6. Influent total phosphorus concentrations ranged from 0.005 to 0.05 mg/L and averaged 0.02 mg/L. Effluent total phosphorus concentrations ranged from 0.005 to 0.09 mg/L and averaged 0.03 mg/L. Effluent mass loadings ranged from 0.001 to 0.27 kg/d and averaged 0.12 kg/d.

4.2.2.6 Nitrite (NO_2)

All influent and effluent grab samples had nitrite concentrations less than the MDL. The resulting mass loadings ranged from 0.01 to 0.08 kg/d and averaged 0.04 kg/d. These results are presented fully in Table B.5.

4.2.3 Statistical Analysis

The Paired *t*-Test and *Wilcoxon Signed Rank Test* was used to determine if any significance difference existed between influent and effluent monitored parameters. The Paired *t*-Test was used when observed treatment effects were normally distributed, while the *Wilcoxon*

Signed Rank Test was employed with non-normal distribution. The Summaries of the statistical analysis results are presented in Table 4.2.3.1.

Table 4.2.3.1 Facility B Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired <i>t</i> -Test	0.365	N
Temperature	N	Wilcoxon Signed Rank Test	0.027	Y
Dissolved Oxygen	Y	Paired <i>t</i> -Test	0.101	N
Spc. Cond.	N	Wilcoxon Signed Rank Test	0.846	
Turbidity	Y	Paired <i>t</i> -Test	0.439	N
TSS	Y	Paired <i>t</i> -Test	0.001	Y
Ammonia	Y	Paired <i>t</i> -Test	0.007	Y
Nitrate	N	Wilcoxon signed rank test	0.25	N
Total P	Y	Paired <i>t</i> -Test	0.026	Y
BOD ₅	Y	Paired <i>t</i> -Test	1.000	N
Nitrite	N	Wilcoxon signed rank test	1.000	N

4.3 Facility C

4.3.1 Field Monitoring

Field monitoring results for Facility C from November 2000 to October 2002 are presented in Table 4.3.1.1. Averages and ranges of concentrations are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.3.1.1. Field Monitoring Results of Facility C.

Site	pH, Std. Units average [range]	Temperature, °C average [range]	Spc. Cond., µS/cm average [range]	DO, mg/L average [range]	Turbidity, NTU average [range]
Influent	7.81 [7.24-8.41]	14.48 [11.2-16.3]	190.2 [143.2-200.0]	9.43 [8.39-10.6]	0.90 [0.46-2.21]
Effluent	8.03 [6.86-8.84]	15.27 [11.4-19.7]	193.9 [168.7-204.2]	10.42 [6.01-12.7]	5.07 [0.96-15.8]

4.3.1.1 Flow

Measured flow rates, presented fully in Table C.1, ranged from 1,057 to 2,616 m³/day and averaged 1,745 m³/day (194, 480, and 320 GPM).

4.3.1.2 pH

Measured pH values are summarized in Table 4.3.1.1 and presented fully in Table C.1. Influent pH values ranged from 7.24 to 8.41 standard units and averaged 7.81. Effluent pH values ranged from 6.86 to 8.84 and averaged 8.03.

4.3.1.3 Specific Conductance

Specific conductance values summarized in Table 4.3.1.1 are presented fully in Table C.2. Influent specific conductance values ranged from 143.2 to 200.0 µS/cm and averaged 190.2 µS/cm. Effluent specific conductance values ranged from 168.7 to 204.2 µS/cm and averaged 193.9 µS/cm.

4.3.1.4 Temperature

Temperature values, summarized in Table 4.3.1.1, are presented fully in Table C.1. Influent temperatures ranged from 11.2 to 16.3 °C (52.2 to 61.3 °F) and averaged 14.5 °C (58.1 °F). Effluent temperatures ranged from 11.4 to 19.7 °C (52.5 to 67.5 °F) and averaged 15.3 °C (60.0 °F). Monitored temperatures were in acceptable ranges for the survival of rainbow trout (Meade, 1989).

4.3.1.5 Dissolved Oxygen

Dissolved oxygen concentrations summarized in Table 4.3.1.1, are presented fully in Table C.2. Typically, DO concentrations remained relatively constant in the facility's influent, ranging from 8.39 to 10.6 mg/L, with an average of 9.43 mg/L, and were within the acceptable

range for salmonid production (5 mg/L to saturation; Heinen 1996). Effluent DO concentrations ranged from 6.01 to 12.7 mg/L and average 10.4 mg/L.

4.3.1.6 Turbidity

Turbidity values are summarized in Table 4.3.1.1 and presented fully in Table C.2. Influent turbidity ranged from 0.46 to 2.21 NTU and averaged 0.90 NTU. Effluent turbidity ranged from 0.96 to 15.8 NTU and averaged 5.07 NTU.

4.3.2 Grab Samples

Grab sample results from November 2000 to October 2002 are summarized in Table 4.3.2.1 and presented fully in Table C.3 to C.6. Averages and ranges of concentration and loading are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.3.2.1 Grab Sample Results of Facility C.

Site	TSS average [range]	BOD ₅ average [range]	NH ₃ average [range]	NO ₃ ⁻ average [range]	TP average [range]
Influent concentration, mg/L	2.67 [2.0-6.0]	1.43 [†] [1.43 [†]]	0.09 [†] [0.01 [†] -0.18]	0.14 [†] [0.01 [†] -0.55]	0.05 [†] [0.005 [†] -0.16]
Effluent concentration, mg/L	6.87 [2.0-14.0]	1.71 [†] [1.43 [†] -4.27]	0.21 [0.08-0.45]	0.07 [0.02-0.15]	0.09 [†] [0.005 [†] -0.26]
Effluent loading, kg/d	12.3 [2.11-25.0]	2.96 [†] [1.51 [†] -7.03]	0.37 [0.12-0.74]	0.12 [0.03-0.27]	0.15 [†] [0.001 [†] -0.49]

[†] Presented valued was calculated by: $\frac{\text{MDL}}{2}$.

4.3.2.1 Total Suspended Solids (TSS)

TSS concentrations are summarized in Table 4.3.2.1 and presented fully in Table C.3. Influent TSS concentrations ranged from 2.0 to 6.0 mg/L and averaged 2.67 mg/L. Effluent TSS concentrations ranged from 2.0 to 14.0 mg/L and averaged 6.87 mg/L. TSS loadings ranged from 2.11 to 25.0 kg/d and averaged 12.34 kg/day.

4.3.2.2 Five Day Biochemical Oxygen Demand (BOD₅)

All influent grab samples analyzed for BOD₅ were below the MDL. Effluent BOD₅ concentrations ranged from 1.43 to 4.27 mg/L and averaged 1.71 mg/L. Mass loadings of BOD₅ ranged from 1.51 to 7.03 kg/d and averaged 2.96 kg/d. Results are summarized in Table 4.3.2.1 and presented fully in Table C.6.

4.1.2.3 Total Ammonia Nitrogen (TAN)

Ammonia concentrations and mass loadings are summarized in Table 4.3.2.1 and presented fully in Table C.3 and C.4. Influent NH₃ concentrations ranged from 0.01 to 0.18 mg/L and averaged 0.09 mg/L. Effluent NH₃ concentrations ranged from 0.08 to 0.45 mg/L and averaged 0.21 mg/L. Effluent mass loadings ranged from 0.12 to 0.74 kg/d and averaged 0.37 kg/d.

4.3.2.4 Nitrate (NO₃⁻)

Nitrate concentrations and mass loadings are summarized in Table 4.3.2.1 and presented fully in Table C.4 and C.5. Influent nitrate concentrations ranged from 0.01 to 0.55 mg/L and averaged 0.14 mg/L. Effluent nitrate concentrations ranged from 0.02 to 0.15 mg/L and averaged 0.07 mg/L. Effluent mass loadings ranged from 0.03 to 0.27 kg/d and averaged 0.12 kg/d.

4.3.2.5 Total Phosphorus (TP)

Total phosphorus concentrations and mass loadings are summarized in Table 4.3.2.1 and presented fully in Table C.6. Influent total phosphorus concentrations ranged from 0.005 to 0.16 mg/L and averaged 0.05 mg/L. Effluent total phosphorus concentrations ranged from 0.005 to 0.26 mg/L and averaged 0.09 mg/L. Effluent mass loadings ranged from 0.001 to 0.49 kg/d and averaged 0.15 kg/d.

4.3.2.6 Nitrite (NO_2^-)

All influent and effluent grab samples had nitrite concentrations less than the MDL. The resulting mass loadings ranged from 0.01 to 0.03 kg/d and averaged 0.02 kg/d. These results are presented fully in Table C.5.

4.3.3 Statistical Analysis

The Paired *t*-Test and *Wilcoxon Signed Rank Test* was used to determine if any significance difference existed between influent and effluent monitored parameters. The Paired *t*-Test was used when observed treatment effects were normally distributed, while the *Wilcoxon Signed Rank Test* was employed with non-normal distribution. The Summaries of the statistical analysis results are presented in Table 4.3.3.1.

Table 4.3.3.1 Facility C Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired <i>t</i> -Test	0.321	N
Temperature	Y	Paired <i>t</i> -Test	0.149	N
Dissolved Oxygen	Y	Paired <i>t</i> -Test	0.152	N
Spc. Cond.	N	Wilcoxon Signed Rank Test	0.275	N
Turbidity	Y	Paired <i>t</i> -Test	0.017	Y
TSS	Y	Paired <i>t</i> -Test	0.018	Y
Ammonia	Y	Paired <i>t</i> -Test	0.021	Y
Nitrate	N	Wilcoxon signed rank test	0.275	N
Total P	Y	Paired <i>t</i> -Test	0.009	Y
BOD ₅	N	Wilcoxon Signed Rank Test	1.000	N
Nitrite	N	Wilcoxon Signed Rank Test	1.000	N

4.4 Facility D

4.4.1 Field Monitoring

Field monitoring results for Facility D from January 2001 to June 2002 are presented in Table 4.4.1.1. Averages and ranges of concentrations are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.4.1.1. Field Monitoring Results of Facility D.

Site	pH, Std. Units average [range]	Temperature, °C average [range]	Spc. Cond., µS/cm average [range]	DO, mg/L average [range]	Turbidity, NTU average [range]
Influent	7.69 [7.25-8.06]	11.3 [9.30-13.0]	271.2 [193.6-323.0]	9.33 [6.48-11.19]	3.28 [1.03-7.47]
Effluent	7.81 [7.26-8.48]	12.2 [10.3-13.3]	293.4 [222.1-336.1]	8.07 [5.96-10.16]	4.45 [2.02-8.13]

4.4.1.1 Flow

Measured flow rates, presented fully in Table D.1, ranged from 932 to 5,178 m³/day and averaged 2,741 m³/day (171, 950, and 503 GPM).

4.4.1.2 pH

Measured pH values are summarized in Table 4.4.1.1 and presented fully in Table D.1. Influent pH values ranged from 7.25 to 8.06 standard units and averaged 7.69. Effluent pH values ranged from 7.26 to 8.48 and averaged 7.81.

4.4.1.3 Specific Conductance

Specific conductance values summarized in Table 4.4.1.1 are presented fully in Table D.2. Influent specific conductance values ranged from 193.6 to 323.0 µS/cm and averaged 271.2 µS/cm. Effluent specific conductance values ranged from 222.1 to 336.1 µS/cm and averaged 293.4 µS/cm.

4.4.1.4 Temperature

Temperature values, summarized in Table 4.4.1.1, are presented fully in Table D.1. Influent temperatures ranged from 9.3 to 13.0 °C (48.7 to 55.4 °F) and averaged 11.3 °C (52.3 °F). Effluent temperatures ranged from 10.3 to 13.3 °C (50.5 to 56.0 °F) and averaged 12.2 °C (54.0 °F). Monitored temperatures were in acceptable ranges for the survival of rainbow trout (Meade, 1989).

4.4.1.5 Dissolved Oxygen

Dissolved oxygen concentrations summarized in Table 4.4.1.1, are presented fully in Table D.2. Typically, DO concentrations remained relatively constant in the facility's influent, ranging from 6.48 to 11.19 mg/L, with an average of 9.33 mg/L, and were within the acceptable range for salmonid production (5 mg/L to saturation; Heinen 1996). Effluent DO concentrations ranged from 5.96 to 10.16 mg/L and average 8.07 mg/L.

4.4.1.6 Turbidity

Turbidity values are summarized in Table 4.4.1.1 and presented fully in Table D.2. Influent turbidity ranged from 1.03 to 7.47 NTU and averaged 3.28 NTU. Effluent turbidity ranged from 2.02 to 8.13 NTU and averaged 4.45 NTU.

4.4.2 Grab Samples

Grab sample results from January 2001 to June 2002 are summarized in Table 4.4.2.1 and presented fully in Table D.3 to D.6. Averages and ranges of concentration and loading are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.4.2.1 Grab Sample Results of Facility D.

Site	TSS average [range]	BOD ₅ average [range]	NH ₃ average [range]	NO ₃ ⁻ average [range]	TP average [range]
Influent concentration, mg/L	3.00 [†] [0.5 [†] -8.0]	1.43 [†] [1.43 [†]]	0.05 [†] [0.01 [†] -0.15]	1.00 [0.10-1.37]	0.02 [†] [0.005 [†] -0.039]
Effluent concentration, mg/L	10.88 [5.50-25.0]	2.42 [†] [1.43 [†] -4.96]	0.23 [0.10-0.59]	1.00 [0.12-1.44]	0.19 [0.03-0.37]
Effluent loading, kg/d	36.1 [6.79-110]	6.29 [†] [1.33 [†] -18.4]	0.52 [0.10-1.02]	2.77 [0.25-5.16]	0.46 [0.11-1.44]

[†] Presented valued was calculated by: $\frac{\text{MDL}}{2}$.

4.4.2.1 Total Suspended Solids (TSS)

TSS concentrations are summarized in Table 4.4.2.1 and presented fully in Table D.3. Influent TSS concentrations ranged from 0.5 to 8.0 mg/L and averaged 3.00 mg/L. Effluent TSS concentrations ranged from 5.50 to 25.0 mg/L and averaged 10.88 mg/L. TSS loadings ranged from 6.79 to 110 kg/d and averaged 36.1 kg/day.

4.4.2.2 Five Day Biochemical Oxygen Demand (BOD₅)

All influent grab samples analyzed for BOD₅ were below the MDL. Effluent BOD₅ concentrations ranged from 1.43 to 4.96 mg/L and averaged 2.42 mg/L. Mass loadings of BOD₅ ranged from 1.33 to 18.4 kg/d and averaged 6.29 kg/d. Results are summarized in Table 4.4.2.1 and presented fully in Table D.6.

4.4.2.3 Total Ammonia Nitrogen (TAN)

Ammonia concentrations and mass loadings are summarized in Table 4.4.2.1 and presented fully in Tables D.3 and D.4. Influent NH₃ concentrations ranged from 0.01 to 0.15 mg/L and averaged 0.05 mg/L. Effluent NH₃ concentrations ranged from 0.10 to 0.59 mg/L and averaged 0.23 mg/L. Effluent mass loadings ranged from 0.10 to 1.02 kg/d and averaged 0.52 kg/d.

4.4.2.4 Nitrate (NO₃⁻)

Nitrate concentrations and mass loadings are summarized in Table 4.4.2.1 and presented fully in Tables D.4 and D.5. Influent nitrate concentrations ranged from 0.10 to 1.37 mg/L and averaged 1.00 mg/L. Effluent nitrate concentrations ranged from 0.12 to 1.44 mg/L and averaged 1.00 mg/L. Effluent mass loadings ranged from 0.25 to 5.16 kg/d and averaged 2.77 kg/d.

4.4.2.5 Total Phosphorus (TP)

Total phosphorus concentrations and mass loadings are summarized in Table 4.4.2.1 and presented fully in Table D.6. Influent total phosphorus concentrations ranged from 0.005 to 0.039 mg/L and averaged 0.02 mg/L. Effluent total phosphorus concentrations ranged from 0.03 to 0.37 mg/L and averaged 0.19 mg/L. Effluent mass loadings ranged from 0.11 to 1.44 kg/d and averaged 0.46 kg/d.

4.4.2.6 Nitrite (NO_2^-)

All influent and effluent grab samples had nitrite concentrations less than the MDL. The resulting mass loadings ranged from 0.01 to 0.05 kg/d and averaged 0.03 kg/d. These results are presented fully in Table D.5.

4.4.3 Statistical Analysis

The Paired *t*-Test and *Wilcoxon Signed Rank Test* was used to determine if any significance difference existed between influent and effluent monitored parameters. The Paired *t*-Test was used when observed treatment effects were normally distributed, while the *Wilcoxon Signed Rank Test* was employed with non-normal distribution. The Summaries of the statistical analysis results are presented in Table 4.4.3.1.

Table 4.4.3.1 Facility D Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired <i>t</i> -Test	0.298	N
Temperature	Y	Paired <i>t</i> -Test	0.009	Y
Dissolved Oxygen	Y	Paired <i>t</i> -Test	0.026	Y
Spc. Cond.	N	Wilcoxon Signed Rank Test	0.031	Y
Turbidity	Y	Paired <i>t</i> -Test	0.007	Y
TSS	Y	Paired <i>t</i> -Test	0.017	Y
Ammonia	Y	Paired <i>t</i> -Test	0.025	Y
Nitrate	N	Wilcoxon signed rank test	0.945	N
Total P	Y	Paired <i>t</i> -Test	0.008	Y
BOD ₅	N	Wilcoxon Signed Rank Test	0.250	N
Nitrite	N	Wilcoxon Signed Rank Test	1.000	N

4.5 Facility E

4.5.1 Field Monitoring

Field monitoring results for Facility E from January 2001 to June 2002 are presented in Table 4.5.1.1. Averages and ranges of concentrations are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.5.1.1. Field Monitoring Results of Facility E.

Site	pH, Std. Units average [range]	Temperature, °C average [range]	Sp. Cond., µS/cm average [range]	DO, mg/L average [range]	Turbidity, NTU average [range]
Influent	6.90 [6.33-7.20]	13.5 [13.1-13.7]	467.1 [391.2-545.0]	6.14 [5.82-6.97]	4.55 [3.99-5.28]
Effluent	7.43 [6.86-7.81]	13.7 [12.9-14.1]	499.4 [430.0-548.0]	7.66 [5.74-8.88]	5.64 [3.63-8.32]
OLS Pond Effluent	7.41 [6.85-7.90]	14.6 [11.8-16.5]	507.3 [237.0-840.0]	9.22 [7.92-12.5]	5.05 [3.63-7.50]

4.5.1.1 Flow

Measured effluent flow rates, presented fully in Tables E.1 and E.7, ranged from 5,374 to 16,084 m³/day and averaged 10,068 m³/day (986, 2,951, and 1,825 GPM). OLS Pond flow rates ranged from 343 to 3063 m³/day and averaged 2,276 m³/day (63, 562, and 418 GPM).

4.5.1.2 pH

Measured pH values are summarized in Table 4.5.1.1 and presented fully in Tables E.1 and E.7. Influent pH values ranged from 6.33 to 7.20 standard units and averaged 6.90. Effluent pH values ranged from 6.86 to 7.81 and averaged 7.43. OLS Pond effluent pH values ranged from 6.85 to 7.90 standard units and averaged 7.41.

4.5.1.3 Specific Conductance

Specific conductance values summarized in Table 4.5.1.1 are presented fully in Tables E.2 and E.8. Influent specific conductance values ranged from 391.2 to 545.0 $\mu\text{S}/\text{cm}$ and averaged 467.1 $\mu\text{S}/\text{cm}$. Effluent specific conductance values ranged from 430.0 to 548.0 $\mu\text{S}/\text{cm}$ and averaged 499.4 $\mu\text{S}/\text{cm}$. OLS Pond effluent specific conductance values ranged from 237.0 to 840.0 $\mu\text{S}/\text{cm}$ and averaged 507.3

4.5.1.4 Temperature

Temperature values, summarized in Table 4.5.1.1, are presented fully in Tables E.1 and E.7. Influent temperatures ranged from 13.1 to 13.7 $^{\circ}\text{C}$ (55.6 to 56.7 $^{\circ}\text{F}$) and averaged 13.5 $^{\circ}\text{C}$ (56.3 $^{\circ}\text{F}$). Effluent temperatures ranged from 12.9 to 14.1 $^{\circ}\text{C}$ (55.2 to 57.4 $^{\circ}\text{F}$) and averaged 13.7 $^{\circ}\text{C}$ (56.7 $^{\circ}\text{F}$). OLS Pond effluent temperatures ranged from 11.8 to 16.5 $^{\circ}\text{C}$ (53.2 to 61.7 $^{\circ}\text{F}$) and averaged 14.6 $^{\circ}\text{C}$ (58.3 $^{\circ}\text{F}$). Monitored temperatures were in acceptable ranges for the survival of rainbow trout (Meade, 1989).

4.5.1.5 Dissolved Oxygen

Dissolved oxygen concentrations summarized in Table 4.5.1.1, are presented fully in Tables E.2 and E.7. Typically, DO concentrations remained relatively constant in the facility's influent, ranging from 5.82 to 6.97 mg/L, with an average of 6.14 mg/L, and were within the acceptable range for salmonid production (5 mg/L to saturation; Heinen 1996). Effluent DO concentrations ranged from 5.74 to 8.88 mg/L and average 7.66 mg/L. OLS Pond effluent DO concentrations ranged from 7.92 to 12.5 mg/L and average 9.22 mg/L

4.5.1.6 Turbidity

Turbidity values are summarized in Table 4.5.1.1 and presented fully in Table E.2 and E.7. Influent turbidity ranged from 3.99 to 5.28 NTU and averaged 4.55 NTU. Effluent

turbidity ranged from 3.63 to 8.32 NTU and averaged 5.64 NTU. OLS Pond effluent turbidity ranged from 3.63 to 7.50 NTU and averaged 5.05 NTU

4.5.2 Grab Samples

Grab sample results from January 2001 to June 2002 are summarized in Table 4.5.2.1 and presented fully in Tables E.3 to E.6 and E.8 to E.9. Averages and ranges of concentration and loading are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.5.2.1 Grab Sample Results of Facility E.

Site	TSS average [range]	BOD ₅ average [range]	NH ₃ average [range]	NO ₃ ⁻ average [range]	TP average [range]
Influent concentration, mg/L	2.38 [1.00-4.00]	1.43 [†] [1.43 [†]]	0.24 [0.05-1.23]	0.10 [†] [0.01 [†] -0.22]	0.02 [†] [0.005 [†] -0.07]
Effluent concentration, mg/L	7.90 [5.00-10.0]	4.36 [†] [1.43 [†] -6.04]	0.31 [0.15-0.48]	0.18 [0.03-0.27]	0.19 [0.005 [†] -0.29]
Effluent loading, kg/d	81.2 [32.2-161]	46.9 [†] [7.68 [†] -76.9]	3.06 [1.13-5.21]	1.79 [0.33-2.88]	1.35 [†] [0.01 [†] -2.76]
OLS Pond effluent concentration, mg/L	5.69 [†] [0.5-8.00]	1.70 [†] [1.43 [†] -3.56]	0.30 [0.13-0.54]	0.16 [0.10-0.19]	0.06 [†] [0.005 [†] -0.10]
OLS Pond effluent loading, kg/d	12.6 [†] [1.72-21.0]	4.07 [†] [0.49 [†] -10.9]	0.68 [0.14-1.65]	0.34 [0.06-0.57]	0.20 [†] [0.02-0.55 [†]]

[†] Presented valued was calculated by: $\frac{MDL}{2}$.

4.5.2.1 Total Suspended Solids (TSS)

TSS concentrations are summarized in Table 4.5.2.1 and presented fully in Tables E.3 and E.8. Influent TSS concentrations ranged from 1.00 to 4.00 mg/L and averaged 2.38 mg/L.

Effluent TSS concentrations ranged from 5.00 to 10.0 mg/L and averaged 7.90 mg/L. TSS effluent loadings ranged from 32.2 to 161 kg/d and averaged 81.2 kg/day. OLS Pond effluent TSS concentrations ranged from 0.50 to 8.00 mg/L and averaged 5.69 mg/L. OLS Pond effluent loadings ranged from 1.72 to 21.0 kg/d and averaged 12.6 kg/day.

4.5.2.2 Five Day Biochemical Oxygen Demand (BOD₅)

All influent grab samples analyzed for BOD₅ were below the MDL. Effluent BOD₅ concentrations ranged from 1.43 to 6.04 mg/L and averaged 4.36 mg/L. Mass loadings of BOD₅ ranged from 7.68 to 76.9 kg/d and averaged 46.9 kg/d. OLS Pond effluent BOD₅ concentrations ranged from 1.43 to 3.56 mg/L and averaged 1.70 mg/L. OLS Pond mass loadings of BOD₅ ranged from 0.49 to 10.9 kg/d and averaged 4.07 kg/d. Results are summarized in Table 4.5.2.1 and presented fully in Tables E.6 and E.9.

4.5.2.3 Total Ammonia Nitrogen (TAN)

Ammonia concentrations and mass loadings are summarized in Table 4.5.2.1 and presented fully in Tables E.3, E.4, and E.8. Influent NH₃ concentrations ranged from 0.05 to 0.123 mg/L and averaged 0.24 mg/L. Effluent NH₃ concentrations ranged from 0.15 to 0.48 mg/L and averaged 0.31 mg/L. Effluent mass loadings ranged from 1.13 to 5.21 kg/d and averaged 3.06 kg/d. OLS Pond effluent NH₃ concentrations ranged from 0.13 to 0.54 mg/L and averaged 0.30 mg/L. OLS Pond mass loadings of NH₃ ranged from 0.14 to 1.65 kg/d and averaged 0.68 kg/d.

4.5.2.4 Nitrate (NO₃⁻)

Nitrate concentrations and mass loadings are summarized in Table 4.5.2.1 and presented fully in Tables E.4, E.5, E.8, and E.9. Influent nitrate concentrations ranged from 0.01 to 0.22 mg/L and averaged 0.10 mg/L. Effluent nitrate concentrations ranged from 0.03 to 0.27 mg/L

and averaged 0.18 mg/L. Effluent mass loadings ranged from 0.33 to 2.88 kg/d and averaged 1.79 kg/d. OLS Pond effluent nitrate concentrations ranged from 0.10 to 0.19 mg/L and averaged 0.16 mg/L. OLS Pond mass loadings of nitrate ranged from 0.06 to 0.57 kg/d and averaged 0.34 kg/d.

4.5.2.5 Total Phosphorus (TP)

Total phosphorus concentrations and mass loadings are summarized in Table 4.5.2.1 and presented fully in Tables E.6 and E.9. Influent total phosphorus concentrations ranged from 0.005 to 0.07 mg/L and averaged 0.02 mg/L. Effluent total phosphorus concentrations ranged from 0.005 to 0.29 mg/L and averaged 0.15 mg/L. Effluent mass loadings ranged from 0.01 to 2.76 kg/d and averaged 1.35 kg/d. OLS Pond effluent total phosphorus concentrations ranged from 0.005 to 0.10 mg/L and averaged 0.06 mg/L. OLS Pond mass loadings of total phosphorus ranged from 0.02 to 0.55 kg/d and averaged 0.20 kg/d.

4.5.2.6 Nitrite (NO₂⁻)

All influent and effluent grab samples had nitrite concentrations less than the MDL. The resulting mass loadings ranged from 0.05 to 0.16 kg/d and averaged 0.10 kg/d. OLS Pond effluent mass loadings ranged from 0.003 to 0.03 kg/d and averaged 0.02 kg/d. These results are presented fully in Table E.5 and E.9.

4.5.3 Statistical Analysis

The Paired *t*-Test and *Wilcoxon Signed Rank Test* was used to determine if any significance difference existed between influent and effluent monitored parameters. The Paired *t*-Test was used when observed treatment effects were normally distributed, while the *Wilcoxon Signed Rank Test* was employed with non-normal distribution. The Summaries of the statistical analysis results are presented in Table 4.5.3.1. and 4.5.3.2.

Table 4.5.3.1 Facility E Effluent Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired <i>t</i> -Test	< 0.001	Y
Temperature	Y	Paired <i>t</i> -Test	0.279	N
Dissolved Oxygen	Y	Paired <i>t</i> -Test	0.001	Y
Spc. Cond.	N	Wilcoxon Signed Rank Test	0.016	Y
Turbidity	Y	Paired <i>t</i> -Test	0.087	N
TSS	Y	Paired <i>t</i> -Test	< 0.001	Y
Ammonia	Y	Paired <i>t</i> -Test	0.001	Y
Nitrate	Y	Paired <i>t</i> -Test	0.015	Y
Total P	Y	Paired <i>t</i> -Test	0.004	Y
BOD ₅	Y	Paired <i>t</i> -Test	< 0.001	Y
Nitrite	N	Wilcoxon Signed Rank Test	1.000	N

Table 4.5.3.2 Facility E OLS Pond Effluent Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired <i>t</i> -Test	< 0.001	Y
Temperature	Y	Paired <i>t</i> -Test	0.082	N
Dissolved Oxygen	Y	Paired <i>t</i> -Test	< 0.001	Y
Spc. Cond.	N	Paired <i>t</i> -Test	0.55	N
Turbidity	Y	Paired <i>t</i> -Test	0.287	N
TSS	Y	Paired <i>t</i> -Test	0.006	Y
Ammonia	N	Wilcoxon Signed Rank Test	0.195	N
Nitrate	Y	Paired <i>t</i> -Test	0.083	N
Total P	Y	Paired <i>t</i> -Test	0.003	Y
BOD ₅	N	Wilcoxon Signed Rank Test	1.000	N
Nitrite	N	Wilcoxon Signed Rank Test	1.000	N

4.6 Facility F

4.6.1 Field Monitoring

Field monitoring results for Facility F from January 2001 to June 2002 are presented in Table 4.6.1.1. Averages and ranges of concentrations are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.6.1.1. Field Monitoring Results of Facility F.

Site	pH, Std. Units average [range]	Temperature, °C average [range]	Sp. Cond., µS/cm average [range]	DO, mg/L average [range]	Turbidity, NTU average [range]
Influent	7.47 [7.13-7.82]	12.8 [12.1-13.1]	524.4 [500.0-539.0]	9.93 [8.19-11.32]	1.80 [0.62-3.13]
Effluent	7.35 [7.09-7.56]	12.9 [12.0-13.6]	535.8 [500.0-565.9]	8.25 [6.98-9.52]	3.11 [1.00-6.62]

4.6.1.1 Flow

Measured flow rates, presented fully in Table F.1, ranged from 3,036 to 11,571 m³/day and averaged 6,387 m³/day (557, 2,123, and 1,172 GPM).

4.6.1.2 pH

Measured pH values are summarized in Table 4.6.1.1 and presented fully in Table F.1. Influent pH values ranged from 7.13 to 7.82 standard units and averaged 7.47. Effluent pH values ranged from 7.09 to 7.56 and averaged 7.35.

4.6.1.3 Specific Conductance

Specific conductance values summarized in Table 4.6.1.1 are presented fully in Table F.2. Influent specific conductance values ranged from 500.0 to 539.0 µS/cm and averaged 524.4 µS/cm. Effluent specific conductance values ranged from 500.0 to 565.9 µS/cm and averaged 535.8 µS/cm.

4.6.1.4 Temperature

Temperature values, summarized in Table 4.6.1.1, are presented fully in Table F.1. Influent temperatures ranged from 12.1 to 13.1 °C (53.8 to 55.6 °F) and averaged 12.8 °C (55.0 °F). Effluent temperatures ranged from 12.0 to 13.6 °C (53.6 to 56.5 °F) and averaged 12.9 °C (55.2 °F). Monitored temperatures were in acceptable ranges for the survival of rainbow trout (Meade, 1989).

4.6.1.5 Dissolved Oxygen

Dissolved oxygen concentrations summarized in Table 4.6.1.1, are presented fully in Table F.2. Typically, DO concentrations remained relatively constant in the facility's influent, ranging from 8.19 to 11.32 mg/L, with an average of 9.93 mg/L, and were within the acceptable range for salmonid production (5 mg/L to saturation; Heinen 1996). Effluent DO concentrations ranged from 6.98 to 9.52 mg/L and average 8.25 mg/L.

4.6.1.6 Turbidity

Turbidity values are summarized in Table 4.6.1.1 and presented fully in Table F.2. Influent turbidity ranged from 0.62 to 3.13 NTU and averaged 1.80 NTU. Effluent turbidity ranged from 1.00 to 6.62 NTU and averaged 3.11 NTU.

4.6.2 Grab Samples

Grab sample results from January 2001 to June 2002 are summarized in Table 4.6.2.1 and presented fully in Tables F.3 to F.6. Averages and ranges of concentration and loading are presented to show extremes due to seasonal variations and impacts of production activities.

Table 4.6.2.1 Grab Sample Results of Facility F.

Site	TSS average [range]	BOD ₅ average [range]	NH ₃ average [range]	NO ₃ ⁻ average [range]	TP average [range]
Influent concentration, mg/L	2.36 [1.00-3.00]	1.43 [†] [1.43 [†]]	0.03 [†] [0.01 [†] -0.06]	0.15 [0.08-0.24]	0.02 [†] [0.005 [†] -0.07]
Effluent concentration, mg/L	6.43 [3.00-10.0]	2.75 [†] [1.43 [†] -5.60]	0.36 [0.13-0.65]	0.18 [0.11-0.29]	0.10 [0.005 [†] -0.19]
Effluent loading, kg/d	37.4 [17.0-57.9]	18.6 [†] [4.34 [†] -46.3]	2.15 [0.65-3.57]	1.20 [0.53-2.48]	0.62 [†] [0.003-1.52]

[†] Presented valued was calculated by: $\frac{\text{MDL}}{2}$.

4.4.2.1 Total Suspended Solids (TSS)

TSS concentrations are summarized in Table 4.6.2.1 and presented fully in Table F.3. Influent TSS concentrations ranged from 1.00 to 3.00 mg/L and averaged 2.36 mg/L. Effluent TSS concentrations ranged from 3.00 to 10.0 mg/L and averaged 6.43 mg/L. TSS loadings ranged from 17.0 to 57.9 kg/d and averaged 37.4 kg/day.

4.6.2.2 Five Day Biochemical Oxygen Demand (BOD₅)

All influent grab samples analyzed for BOD₅ were below the MDL. Effluent BOD₅ concentrations ranged from 1.43 to 5.60 mg/L and averaged 2.75 mg/L. Mass loadings of BOD₅ ranged from 4.34 to 46.3 kg/d and averaged 18.6 kg/d. Results are summarized in Table 4.6.2.1 and presented fully in Table F.6.

4.6.2.3 Total Ammonia Nitrogen (TAN)

Ammonia concentrations and mass loadings are summarized in Table 4.6.2.1 and presented fully in Tables F.3 and F.4. Influent NH₃ concentrations ranged from 0.01 to 0.06

mg/L and averaged 0.03 mg/L. Effluent NH_3 concentrations ranged from 0.10 to 0.59 mg/L and averaged 0.36 mg/L. Effluent mass loadings ranged from 0.65 to 3.57 kg/d and averaged 2.15 kg/d.

4.6.2.4 Nitrate (NO_3^-)

Nitrate concentrations and mass loadings are summarized in Table 4.6.2.1 and presented fully in Tables F.4 and F.5. Influent nitrate concentrations ranged from 0.08 to 0.24 mg/L and averaged 0.15 mg/L. Effluent nitrate concentrations ranged from 0.11 to 0.29 mg/L and averaged 0.18 mg/L. Effluent mass loadings ranged from 0.53 to 2.48 kg/d and averaged 1.20 kg/d.

4.6.2.5 Total Phosphorus (TP)

Total phosphorus concentrations and mass loadings are summarized in Table 4.6.2.1 and presented fully in Table F.6. Influent total phosphorus concentrations ranged from 0.005 to 0.07 mg/L and averaged 0.02 mg/L. Effluent total phosphorus concentrations ranged from 0.005 to 0.19 mg/L and averaged 0.10 mg/L. Effluent mass loadings ranged from 0.003 to 1.52 kg/d and averaged 0.62 kg/d.

4.6.2.6 Nitrite (NO_2^-)

All influent and effluent grab samples had nitrite concentrations less than the MDL. The resulting mass loadings ranged from 0.03 to 0.12 kg/d and averaged 0.06 kg/d. These results are presented fully in Table F.5.

4.6.3 Statistical Analysis

The Paired *t*-Test and *Wilcoxon Signed Rank Test* was used to determine if any significance difference existed between influent and effluent monitored parameters. The Paired *t*-Test was used when observed treatment effects were normally distributed, while the *Wilcoxon*

Signed Rank Test was employed with non-normal distribution. The Summaries of the statistical analysis results are presented in Table 4.6.3.1.

Table 4.6.3.1 Facility F Water Quality Monitoring Statistical Analysis Results.

Parameter	Normality Test Passed? (Y/N)	Test Used	P	Statistically Significant Difference? (Y/N; P<0.05)
pH	Y	Paired <i>t</i> -Test	0.018	Y
Temperature	Y	Paired <i>t</i> -Test	0.747	N
Dissolved Oxygen	Y	Paired <i>t</i> -Test	0.047	Y
Spc. Cond.	Y	Paired <i>t</i> -Test	0.096	N
Turbidity	Y	Paired <i>t</i> -Test	0.044	Y
TSS	Y	Paired <i>t</i> -Test	0.007	Y
Ammonia	Y	Paired <i>t</i> -Test	0.004	Y
Nitrate	N	Paired <i>t</i> -Test	0.084	N
Total P	Y	Paired <i>t</i> -Test	0.002	Y
BOD ₅	Y	Paired <i>t</i> -Test	0.091	N
Nitrite	N	Wilcoxon Signed Rank Test	1.000	N

CHAPTER 5. DISCUSSION

5.1 Field Measurements

Presented in Table 5.1 are the average changes in field monitoring results from influent and effluent for all facilities. In general, small increases in water temperature, turbidity, and specific conductance were observed and attributed to atmospheric exposure and the addition of fish production waste. Reductions in DO were attributed to fish respiration and the biological decomposition of fish biosolids.

Table 5.1 Average change in measured parameters from influent to effluent.

Facility	Temperature, °C	pH, Std. Units	DO, mg/L	Turbidity, NTU	Specific Conductance, $\mu\text{S}/\text{cm}$
A	0.86	-0.09	-1.91 [†]	2.60 [†]	9.29 [†]
B	2.00	0.07	0.90	0.13	12.2
C	0.79	0.22	0.99	4.17 [†]	3.68
D	0.90 [†]	0.12	-1.26 [†]	1.17 [†]	22.24 [†]
E (Outlet)	0.18	0.53 [†]	1.52 [†]	1.09	32.30 [†]
E (OLS Pond)	1.13	0.51 [†]	3.08 [†]	0.50	40.23
F	0.05	-0.12 [†]	-1.68 [†]	1.31 [†]	11.40

†: Indicates a statistically significant change.

5.1.1 pH

Measurements of pH were relatively constant from influent to effluent for facilities A, B, C, D and not statistically different. Facilities E and F both had statistically significant increases in pH from influent to effluent as a result of the CO₂ stripping. Equations 5.1.1 and 5.1.2 represent the equilibrium relationships between CO_{2(g)}, CO_{2(aq)}, H₂O, H₂CO₃ (carbonic acid), H⁺ (pH), HCO₃⁻ (carbonate), and CO₃⁻² (carbonate) (Snoeyink and Jenkins, 1980).

When CO₂ is removed from the systems with the use of packed aeration columns (PAC), the concentration of H⁺ is reduced; this results in an increase in pH.

Average effluent pH values of all facilities were with the regulated range of 6 – 9 standard units. Presented in Figure 5.1.1.1 is the average effluent pH for each facility and the permitted limitations.

Figure 5.1.1.1 Average effluent pH of each facility and permit limitations.

5.1.2 Dissolved Oxygen

Three facilities had slight reductions in DO concentration from influent to effluent while the other three had slight increases in DO concentration. DO concentration reductions in facilities A, D, and E were attributed to fish metabolic requirements and the biological decomposition of organic matter in fish production waste (Hinshaw, 2002). Presented in Figures 5.1.2.1, 5.1.2.2, and 5.1.2.3 are plots of influent and effluent DO concentrations of facilities A, D, and E over the study period.

Figure 5.1.2.1. Influent and Effluent DO Concentrations of Facility A.

Figure 5.1.2.2. Influent and Effluent DO Concentrations of Facility D.

Figure 5.1.2.3. Influent and Effluent DO Concentrations of Facility E.

Facilities A, D, and E each had one occurrence of effluent DO below the regulated limit of 6 mg/L; however, average concentrations of all facilities were within the acceptable range. The low DO measurements of facility A effluent was most likely the result of the aerobic biological decomposition of organic waste in the sedimentation pond. Equations 5.1.2.2, 5.1.2.3, and 5.1.2.4 represent three primary biologically mediated reactions that can reduce dissolved oxygen concentrations in water. COHNS represents carbon, oxygen, hydrogen, nitrogen, and sulfur of the organic material and $C_5H_7NO_2$ represents cell tissue (Metcalf & Eddy, 2003).

Oxidation:

Synthesis:

Endogenous respiration:

DO depression at facility D were the result of two main problems, oxygen consumption through biological decomposition of organic material (see equations 5.1.2.2, 5.1.2.3, and 5.1.2.4) and low reaeration efficiency between raceways. Lack of effective solids removal led to solids accumulation in the earthen raceways and subsequent decomposition. Aeration in facility D was accomplished through the intermittent use of floating surface aerators and simple weir cascade aeration between containment areas. Low DO levels were most likely due to an inadequate number of mechanical aerators and the low reaeration efficiencies of simple weirs. Soderberg (1995) reported simple weir reaeration efficiencies of 6.2, 9.3, and 12.4% for head losses of 22.9, 30.5, and 61.0 cm, respectively. All the simple weir head losses at facility D were less than 61.0cm.

Low DO concentrations in the effluent of facility E were most likely a result of high fish density and thus high O₂ consumption in a containment area located immediately before discharge to the receiving stream. Market-size fish were held in the containment area for shipment to the processing facility

Increases in DO concentration in facilities B, C, and E were attributed to efficient reaeration in combination with low fish demand, photosynthetic activity of aquatic plants, and liquid oxygen supplementation. Equation 5.1.2.1 represents the formula for photosynthesis by

green plants, bryophytes, and algae that results in O₂ production (Smith, 1996). Photosynthesis involves the reduction of six moles of CO₂ to one mole of sugar (CH₂O) and results in the removal of six moles of H₂O and the production of six moles of O₂.

Presented in Figures 5.1.2.4, 5.1.2.5, and 5.1.2.6 are the influent and effluent DO concentrations of facilities B, C, and F over the study period.

Figure 5.1.2.4. Influent and Effluent DO Concentrations of Facility B.

Figure 5.1.2.5. Influent and Effluent DO Concentrations of Facility C.

Figure 5.1.2.6. Influent and Effluent DO Concentrations of Facility F.

5.2 Grab Samples

Presented in Table 5.2.1 are the normal ranges of pollutant concentration increase reported by four studies as reported by Hinshaw (2002). In general, small increases in pollutant concentrations were observed in the process water from influent to effluent as a result of production activities. Concentrations of measured pollutants were within acceptable ranges of anticipated limits for all facilities and compared relatively well to reported data.

Table 5.2.1 Normal ranges of pollutant concentration increase reported by Hinshaw, 2002.

Study No.	TSS, mg/L	BOD ₅ , mg/L	TAN, mg/L	NO ₃ ⁻ , mg/L	TP, mg/L
1	0-55	5.36	0.53	1.68	*
2	3.7	4.0	0.49	0-0.17	*
3	0-2.8	0	0.01-0.18	0-0.017	0-0.13
4	4.36	1.5	0.172	0.036	0.038

* No data reported in study.

Table 5.2.2 Average Changes in Pollutant Concentrations and Mass Loading from Influent to Effluent for All Participating Facilities.

Facility	TSS, mg/L (kg/day)	BOD ₅ , mg/L (kg/day)	TAN, mg/L (kg/day)	NO ₃ ⁻ , mg/L (kg/day)	TP, mg/L (kg/day)
A	5.74 [†] (44.2)	3.27 [†] (24.4)	0.24 [†] (1.55)	0.52 [†] (3.02)	0.49 [†] (3.52)
B	1.85 [†] (8.20)	0.00 (0.00)	0.03 [†] (0.13)	0.03 (0.32)	0.01 [†] (0.06)
C	4.22 [†] (7.70)	0.28 (0.46)	0.12 [†] (0.21)	-0.07 ^A (-0.10)	0.04 [†] (0.06)
D	7.88 [†] (27.3)	0.99 (3.00)	0.18 [†] (0.35)	0.00 (0.00)	0.17 [†] (0.42)
E (outlet)	5.52 [†] (58.1)	2.93 [†] (32.5)	0.07 [†] (0.56)	0.08 [†] (0.72)	0.13 [†] (1.22)
E (OLS Pond)	3.31 [†] (-10.6) ^B	0.27 (-10.3) ^B	0.06 (-1.82) ^B	0.06 (-0.73) ^B	0.04 [†] (0.07) ^B
F	4.07 [†] (23.6)	1.32 (9.43)	0.33 [†] (1.92)	0.03 (0.14)	0.08 [†] (0.53)

A: Overall reduction in concentration and mass load from influent to effluent.

B: Overall reduction in mass load due to partial flow of the facility.

†: Statistically significant change.

Typically, the generation of pollutants correlated with fish production; operations with larger fish production had higher pollutant concentrations and mass loads. The order of fish production, from highest to lowest was A, E, F, C, D, and B, while order of mass load TSS production was E, A, D, F, B, and C. Facility D had the highest average concentration increase in TSS, but this was attributed to the lack of effluent treatment for solids removal and the use of earthen raceways which could contribute solids by stream bank erosion. Additionally, facility D had similar fish production to that of B and C, but discharged higher concentrations and mass loadings for all monitored parameters.

Facility C had an average reduction in nitrate concentration from influent to effluent. Nitrate reduction could be contributed to uptake by aquatic plants in the operation's sedimentation pond. Redding *et al.* (1997) observed decreases in nitrate concentrations in aquaculture wastewaters as it passed through ponds containing aquatic plants.

5.2.1 Un-ionized Ammonia Nitrogen

Ammonia is the primary nitrogenous by-product of fish metabolism and is a concern for aquaculture because it is toxic in its un-ionized form (NH_3) (Wedenmyer, 2001). In water, ammonia nitrogen exists as either the ammonium (NH_4^+) or un-ionized ammonia (NH_3) ions, and their concentrations are regulated by pH. Equations 5.2.1.1 and 5.2.1.2 present the equilibrium reactions which governs ammonia nitrogen speciation.

Grab sample measurements of TAN include both NH_3 and NH_4^+ concentrations and thus, concentration of un-ionized ammonia is not explicitly represented as TAN. However, Soderberg (1995) presented the following equation for un-ionized ammonia nitrogen calculation.

$$\text{Un-ionized ammonia (NH}_3\text{) mg/L} = \frac{\text{TAN(mg/L)}}{1 + 10^{(\text{pka}-\text{pH})}} \quad (\text{EQN 5.2.1.2})$$

where,

pka = negative log of the acid dissociation constant.

$$\text{pka} = 0.09018 + \frac{2729.92}{T + 273.15} \quad (\text{EQN 5.2.1.2})$$

where,

T = temperature in °C.

Presented in Figure 5.2.1.1 is a distribution plot of ammonia (NH_3) and ammonium (NH_4^+) as a function of pH.

Figure 5.2.1.1 Ammonia Speciation as a Function of pH.

Presented in Table 5.2.1.1 are the calculated un-ionized ammonia concentrations and mass loadings of all participating facilities.

Table 5.2.1.1. Calculated Un-ionized Ammonia Concentrations, Mass Loads, and Production Output of Participating Facilities.

Facility	Average influent un-ionized ammonia, mg/L (range)	Average effluent un-ionized ammonia, mg/L (range)	Average un-ionized ammonia production [effluent – influent] mg/L
A	1.7×10^{-4} (2.0×10^{-5} - 6.6×10^{-4})	9.1×10^{-4} (2.8×10^{-4} - 3.24×10^{-3})	7.4×10^{-4}
B	4.5×10^{-4} (2.0×10^{-5} - 2.28×10^{-3})	1.08×10^{-3} (2.0×10^{-4} - 4.47×10^{-3})	6.3×10^{-4}
C	1.58×10^{-3} (1.3×10^{-4} - 8.86×10^{-3})	8.01×10^{-3} (5.4×10^{-4} - 1.893×10^{-2})	6.43×10^{-3}
D	5.4×10^{-4} (5.0×10^{-5} - 2.07×10^{-3})	3.41×10^{-3} (1.12×10^{-3} - 6.74×10^{-3})	2.87×10^{-3}
E	2.9×10^{-4} (1.0×10^{-4} - 6.4×10^{-4})	2.54×10^{-3} (7.6×10^{-4} - 6.26×10^{-3})	2.25×10^{-3}
E (OLS Pond)	2.9×10^{-4} (1.0×10^{-4} - 6.4×10^{-4})	2.57×10^{-3} (4.1×10^{-4} - 4.52×10^{-3})	2.28×10^{-3}
F	2.4×10^{-4} (4.0×10^{-5} - 4.9×10^{-4})	1.91×10^{-3} (4.7×10^{-4} - 3.28×10^{-3})	1.67×10^{-3}

The U.S. Environmental Protection Agency has established acceptable concentration of NH_3 not to exceed 0.016 mg/L for aquatic organisms. Reduced growth rates of rainbow trout were reported at 0.0166 mg/L NH_3 , but not at 0.0125 mg/L by Larmoyeaux and Piper (1973). All facility effluents were below the toxic threshold of 0.016 mg/L and thus could be further utilized for production.

5.3 Pollutant Spikes

Due to the long distance between the WVU campus and the study sites, it was difficult to plan sampling events to coincide with plant activities that could influence effluent water quality such as time of day, feeding, cleaning, and harvesting. Clark *et al.* (1985) and Boardman *et al.* (1998) reported increases in nutrients and solids throughout the day and concentration peaks during raceway cleaning and harvesting. The data from this study were derived by random grab sampling and may not include pollutant spikes. However, pollutant spikes cannot be overlooked when addressing the quality of water discharged from a facility and should be further investigated to determine the magnitude and occurrences of such events.

5.4 BOD₅ vs. Turbidity

In an effort to provide a real-time monitor of pollutant concentration, the relationship between turbidity and BOD₅ was examined. The potential exists for operators with an inexpensive turbidity meter to estimate BOD₅ concentration. To determine the existence of a correlation, turbidity measurements were considered the independent and BOD₅ concentrations the dependent variables. The results were plotted for each individual site due to variability in raw water quality. Facilities A and E were the only two facilities that had consistent BOD₅ measurements greater than the MDL (2.86 mg/L). Field measurements and sampling during

times of high BOD₅ discharge would give additional data and improve the results of this investigation.

Presented in Figure 5.4.1 is the turbidity vs. BOD₅ plot for facility A. A R^2 value of 0.7101 was calculated, however a majority of the measurements were taken at low turbidity and BOD₅ concentrations.

Figure 5.4.1. Turbidity vs. BOD₅ for Facility A.

Presented in Figure 5.4.2 is the turbidity vs. BOD₅ plot for facility E. A R^2 value of 0.0002 was calculated for this facility, but the low value was attributed to low turbidity and BOD₅ measurements.

Figure 5.4.2. Turbidity vs. BOD₅ for Facility E.

Presented in Figure 5.4.3 is a plot of turbidity and BOD₅ for both facilities A and E. A R² value of 0.5345 was calculated; however the low result was attributed to low measurements for both variables.

Figure 5.4.3. Turbidity vs. BOD₅ for Facilities A and E.

Although low R² values were calculated for the respective facilities, a relationship existed between turbidity and BOD₅. Sampling and analysis of facilities with higher fish densities or during production operations such as cleaning and harvesting may have resulted in higher turbidity and BOD₅ measurements and thus a higher R² values.

5.5 Increased Production Potential

The presented production numbers are based strictly on effluent pollutant load and discharge limitations and do not address the metabolic requirements of fish nor the capacity of the existing operations. Average discharge concentrations of regulated parameters (TSS, TAN, and BOD₅) for each facility were compared to existing West Virginia discharge limitations. There exist the potential for increased production at each facility based on current permit limitations. Additionally, average discharge concentrations of TP for each facility were compared to discharge limitations in other States reported by Wedemeyer (2001). The difference between the pollutant limitation and discharge concentration represent a “freeboard” of potential

increase in fish production. Using the calculated freeboard for each pollutant and the average discharge for each facility, the mass load freeboard was then calculated. The mass load of each pollutant was used to calculate an equivalent amount of feed and extrapolated to the fish production value of the feed (IDEQ, 1998). The species dependent calculating factors were based on a dry feed with 10% moisture, digestibility of 80% and a feed conversion of 1.2.

Presented in Table 5.5.1 are the production impacts of effluent TSS limitation of 30, 20, 10, and 5 mg/L. The current West Virginia NPDES limitation for average TSS concentration is 30 mg/L. However, Wedemeyer (2001) reported average TSS limitations at Idaho, Washington, and Michigan facilities as 5, 5, and 4 mg/L, respectively.

Table 5.5.1 Production impacts of various TSS effluent limitations.

Facility	30 mg/L Limitation		20 mg/L Limitation		10 mg/L Limitation		5 mg/L Limitation	
	Change in Production, kg/year	Percent Change	Change in Production, kg/year	Percent Change	Change in Production, kg/year	Percent Change	Change in Production, kg/year	Percent Change
A	133,555	147	61,285	68	-10,985	-12	-47,120	-52
B	111,510	819	69,271	509	27,033	199	5,913	43
C	40,922	301	23,230	171	5,538	41	-3,308	-24
D	53,136	390	25,345	186	-2,446	-18	-16,341	-120
E	225,593	392	123,515	215	21,436	37	-29,603	-51
F	152,632	421	87,875	242	23,118	64	-9,260	-26

As seen in Table 5.5.1, current West Virginia limitations would enable all facilities to increase production from 147 to 819%, while a 5 mg/L limitation would result in reduced production at five facilities from 24 to 120% and an increase at one facility of 43%.

Presented in Table 5.5.2 are the production impacts by an effluent TAN limitation of 10.44 and 5 mg/L. The current West Virginia average discharge limitation for TAN is 10.44 mg/L.

Table 5.5.2 Production impacts of two TAN effluent limitations.

Facility	10.44 mg/L		5 mg/L	
	Additional Production, kg/year	Percent Change	Additional Production, kg/year	Percent Change
A	573,443	632	265,493	293
B	342,100	2,514	162,117	1,191
C	141,770	1,042	66,381	488
D	222,253	1,633	103,834	763
E	809,964	1,407	374,998	651
F	511,294	1,410	235,357	649

As seen in Table 5.5.2, the current West Virginia limitation for TAN would enable all facilities to increase production from 632 to 2,514%, while a 5 mg/L limitation would allow 293 to 1,191% increase in production

Presented in Table 5.5.3 are the production impacts of an effluent BOD₅ limitation of 30 mg/L, the current West Virginia discharge limit.

Table 5.5.3 Production impacts of BOD₅ effluent limitation.

Facility	30 mg/L	
	Additional Production, kg/year	Percent Change
A	182,843	202
B	120,676	887
C	50,052	368
D	76,647	563
E	261,729	455
F	176,463	487

As seen in Table 5.5.3, the current West Virginia limitation for BOD₅ would allow all facilities to increase production from 202 to 887%.

Presented in Table 5.5.4 are the production impacts of an effluent TP limitation of 0.1 and 1.0 mg/L. Wedemeyer (2001) reported NPDES average effluent limits for TP as 0.1 mg/L at an Idaho hatchery. There is currently no effluent discharge limitation for TP at permitted West Virginia facilities.

Table 5.5.4 Production impacts at two TP effluent limitations.

Facility	0.1 mg/L	Percent Change	1.0 mg/L	Percent Change
	Additional Production, kg/year		Additional Production, kg/year	
A	-22,643	-25	28,304	31
B	2,647	19	32,423	238
C	139	1	12,611	93
D	-1,959	-14	17,632	130
E	-3,998	-7	67,963	118
F	0	0	45,651	126

As seen in Table 5.5.4, if a TP limitation of 0.1 mg/L was instituted at each facility, production would have to decrease from 7 to 25% for three facilities, could increase 1 and 19% at two facilities, while no change in production would be possible at the final site.

Based on the minimum amount of freeboard, the limiting factor for increased production at each facility was TSS, with increases ranging from 147 to 819 percent.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1 Summary

Close proximity to eastern markets and an abundance of water resources gives the aquaculture industry in West Virginia tremendous potential for growth. However, existing facilities must maximize their production to meet market demands, compete with new operations, and continue to meet effluent pollutant limitations. The purpose of this study was to provide industry, State, and Federal stakeholders with baseline water quality data specific to West Virginia facilities, in an effort to help concerned parties make informed decisions regarding impending regulations. Another objective of this research was to examine the potential for increases in production at each facility, based on effluent pollutant discharge requirements.

6.1.1 Site Visits

Each facility was visited and engineering process assessments were conducted through interviews and observations to establish PFDs, production techniques, and management practices. Influent and effluent field measurements of flowrate, pH, temperature, DO, turbidity, and specific conductance were taken at each facility to establish baseline conditions and for comparison with water quality criteria for trout production and effluent regulatory limits. Similarly, grab samples of influent and effluent at each facility were taken and measured for TSS, BOD₅, TAN, NO₂⁻, NO₃⁻, and TP concentrations to establish baseline conditions and for comparison with water quality criteria for trout production and effluent regulatory limits.

6.1.2 Data Analysis

Flowrate and effluent pollutant concentrations were used to calculate mass loadings for comparison with current and anticipated regulatory limits. Water temperature, pH, and TAN concentrations were used to calculate un-ionized ammonia concentrations for comparison with

the known concentration toxic to trout. In order to provide operators with an inexpensive real-time indicator of pollutant discharge, turbidity and BOD₅ measurements were examined to determine if a predictable relationship could be established. Additionally, average effluent pollutant concentration at each facility was used to calculate the potential to increase productivity, based on effluent regulatory limits.

6.2 Conclusions

6.2.1 Effluent Characteristics

Field measurements of influent and effluent at each facility were within acceptable ranges for trout production. Average effluent values of regulated field measurements of pH and DO were within current limitations. However, facilities A, D, and E each had one occurrence of DO concentration less than the regulatory limit of 6 mg/L. The low DO measurements were attributed to the biological decomposition of organic matter, poor reaeration efficiency, and high fish density prior to discharge. Low DO occurrences could be corrected by the implementation of various reaeration techniques such as diffusion, mechanical aeration, and pure oxygen addition. Additionally, better management of fish biosolids (quick and permanent removal) to prevent over-accumulation would reduce DO depletion as organic matter decomposes.

Regulated parameters (TSS, BOD₅, and TAN) were below current limitations in terms of concentration and mass load for all facilities. Concentration of grab sample pollutants (*e.g.*, TSS, BOD₅, TAN, NO₂⁻, NO₃⁻, and TP), in general, had small increases from influent to effluent for all facilities, as a result of fish production. Generally, effluent pollutant concentrations were proportional to fish production, higher production equated higher pollutant concentration. However, facility D had low production numbers and relatively high pollutant concentration increases, which were attributed to the lack of effluent treatment.

6.2.2 Production Potential

All participating facilities had the potential to increase production based on effluent pollutant concentration, mass load, and current effluent regulatory limits. Based on current limitations, the limiting factor for increased production at all facilities was TSS, though a minimum increase in production potential of 147% was attainable.

6.2.3 Further Research

Further study is warranted to examine effluent pollutant spikes during various hours of the day and during different management practices (*e.g.*, feeding, harvesting, and raceway cleaning), to determine more accurately the extent that existing water resources at each facility can be utilized to increase production, reaeration efficiencies of each facility, and the effectiveness of various treatment methods to enable further productivity while maintaining regulatory compliance.

CHAPTER 7. REFERENCES

- APHA (American Public Health Association). 1985. *Standard Methods for the Examination of Water and Wastewater*, 16th Edition. Washington, D.C.
- Axler, R.P., Tikkanen, C., Henneck J., Schuldt, J., and McDonald, M.E. 1997. "Characteristics of Effluent and Sludge from Two Commercial Rainbow Trout Farms in Minnesota." *The Progressive Fish-Culturist* 59: 161-172.
- Boaventura, R., Pedro, A.M., Coimbra, J., and Lencastre, E. 1997. "Trout Farm Effluents: Characterization and Impacts on the Receiving Streams." *Environmental Pollution* 95: 379-387.
- Boardman, G.D., Maillard, V., Nyland, J., Flick, G.J., and Libey, G.S. 1998. The Characterization, Treatment and Improvement of Aquaculture Effluents. Virginia Polytechnical Institute, Blacksburg, Virginia.
- Buttner, J.K., Soderberg, R.W., and Terlizzi, D.E. 1993. "An Introduction to Water Chemistry in Freshwater Aquaculture." *Northeastern Regional Aquaculture Center Factsheet* 170.
- Cho, C.Y. 1997. "Reduction of Waste Output from Salmonid Aquaculture through Feeds and Feeding." *The Progressive Fish-Culturist* 59: 155-160.
- Colt, J.E. and Tomasso, J.R. 2001. "Hatchery Water Supply and Treatment." Wedemeyer, G. (Ed.), Fish Hatchery Management, 2nd Edition (pp 91-186). American Fisheries Society, Bethesda, Maryland.
- Davis, J.T. 1993. "Survey of Aquaculture Effluent Permitting and 1993 Standards in the South." *Southern Regional Aquaculture Center Publication No. 465*.
- Enell, M. 1995. "Environmental Impact of Nutrients from Nordic Fish Farming." *Water Science and Technology* 31: 61-71.
- Eqart, J.W., Hankins, J., and Bullock, D. 1995. "State Policies for Aquaculture Effluents and Solid Wastes in the Northeast Region." *Northeastern Regional Aquaculture Center Bulletin No. 300*.
- Gatlin, D.M., III, and Hardy, R.W. 2002. "Manipulations of Diets and Feeding to Reduce Losses of Nutrients in Intensive Aquaculture." *Aquaculture and the Environment in the United States*, U.S. Aquaculture Society, Baton Rouge, Louisiana.
- Hargreaves and Brunson. 1996. "Carbon Dioxide in Fish Ponds." *Southern Regional Aquaculture Center. Publication No. 468*.
- Heinen, J.M. 1996. "Water Quality Criteria, Uptake, Bioaccumulation, and Public Health Considerations for Chemicals of Possible Concern in West Virginia Mine Waters Used for

Culture of Rainbow Trout.” The Conservation Fund’s Freshwater Institute, Shepherdstown, West Virginia.

Hinshaw, J. 2000. “Trout Farming: Carrying Capacity and Inventory Management.” Southern Regional Aquaculture Center Publication No. 222.

Hinshaw, J.M., and Fornshell, G. 2002. “Effluents from Raceways.” Aquaculture and the Environment in the United States, U.S. Aquaculture Society, Baton Rouge, Louisiana.

IDEQ (Idaho Division of Environmental Quality). 1998. Idaho Waste Management Guidelines for Aquaculture Operations. Idaho Department of Health and Welfare, Division of Environmental Quality, Twin Falls, Idaho.

Isco, Inc. 1988. Open Channel Flow Measurement Handbook. 2nd Edition. Lincoln, Nebraska.

Klontz, G.W. 1995. Quantitative Methods for Intensive Aquaculture. University of Idaho, Moscow, Idaho.

Kolsäter, L. 1995. “Feed Management and Reduction of Aquaculture Wastes.” Water Science and Technology 31: 213-218.

Lanari, D, D’Agaro, E., and Ballestrazzi, R. 1995. “Dietary N and P Levels, Effluent Water Characteristics and Performance in Rainbow Trout.” Water Science and Technology 31:157-165.

Lin, S.D. 2001. Water and Wastewater Calculations Manual. McGraw-Hill, New York, New York.

Mayer, I., and McLean, E. 1995. “Bioengineering and Biotechnological Strategies for Reduced Waste Aquaculture.” Water Science and Technology 31: 85-102.

Mazik, P.M. and Parker, N.C. 2001. “Semicontrolled Systems.” Wedemeyer, G. (Ed.), Fish Hatchery Management, 2nd Edition (pp 241-284). American Fisheries Society, Bethesda, Maryland.

Meade, J.W. 1989. Aquaculture Management. Van Nostrand Reinhold, New York.

Médale, F., Brauge, C., Vallée, F., and Kaushik, S.J. 1995. “Effects of Dietary Protein/Energy Ratio, Ration Size, Dietary Energy Source and Water Temperature on Nitrogen Excretion in Rainbow Trout.” Water Science and Technology 31: 185-194.

Metcalf & Eddy, Inc. 2003. Wastewater Engineering: Treatment and Reuse. McGraw-Hill, New York, New York.

Mugg, J., Serrano, A., Liberti, A, and Rice, M.A. "Aquaculture Effluents: A Guide for Water Quality Regulators and Aquaculturist" Northeastern Regional Aquaculture Center Bulletin No. 00-003.

Naylor, S.J., Moccia, R.D., and Durant, G.M. 1999. "The Chemical Composition of Settleable Solid Fish Waste (Manure) from Commercial Rainbow Trout Farms in Ontario, Canada." North American Journal of Aquaculture 61:21-26.

Piper, R.G., McElwain, I.B., Orme, L.E., McCraren, J.P., Fowler, L.G., and Leonard, J.R. 1982. "Fish Hatchery Management." U.S. Fish and Wildlife Service, Washington, D.C.

Ramseyer, L.J. and Garling, D.L. 1997. "Fish Nutrition and Aquaculture Waste Management." Proceedings of the 1997 North Central Aquaculture Conference, Indianapolis, IN. Illinois-Indiana Sea Grant Program, Publication CES-305 57-62.

Redding, T., Todd, S., and Midlen, A. 1997. "The Treatment of Aquaculture Wastewaters – A Botanical Approach." Journal of Environmental Management 50: 283-299.

Rodrigues, A.M.P. 1995. "Biological and Nutritional Approach to the Environmental Impact of Trout Culture in Portugal." Water Science and Technology 31: 239-248.

Sawyer, C.N., McCarty, P.L., and Parkin, G.F. 1994. Chemistry for Environmental Engineering, 4th Edition, McGraw-Hill, Inc., New York, New York.

Selong, J.H., and Helfrich, L.A. 1998. "Impacts of Trout Culture Effluent of Water Quality and Biotic Communities in Virginia Headwater Streams." The Progressive Fish-Culturist 60:247-262.

Smearman, S.C., D'Souza, G.E., and Norton, V.J. 1997. "External Costs of Aquaculture Production in West Virginia." Environmental and Resource Economics 10: 167-175.

Snoeyink, V.L. and Jenkins, D. 1980. Water Chemistry. John Wiley & Sons, Inc., New York, New York.

Soderberg, R.W. 1995. Flowing Water Fish Culture. Lewis Publishers, Boca Raton, Florida.

Summerfelt, S., Bebak-Williams, J., and Tsukuda, S. 2001. "Controlled Systems: Water Reuse and Recirculation." Wedemeyer, G. (Ed.), Fish Hatchery Management, 2nd Edition (pp 285-395). American Fisheries Society, Bethesda, Maryland.

Stumm, W. and Morgan, J.J. 1996. Aquatic Chemistry. John Wiley & Sons, Inc., New York, New York.

United States Department of Agriculture. Electronic Outlook Report from the Economic Research Service. National Agriculture Statistics Service, LDP=AQS-15. 2002.

USEPA, 1998. "Guidance for Data Quality Assessment, Practical Methods for Data Analysis." EPA 600-R-96-084, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

USEPA. 1982. "Handbook for Sampling and Sample Preservation of Water and Wastewater." EPA 600/4-82-029, U.S. Environmental Protection Agency, Washington, D.C.

USEPA. 1997. "Volunteer Stream Monitoring: A Methods Manual." EPA 841-B-97-003, U.S. Environmental Protection Agency, Washington, D.C.

USEPA. 1999. "Methods and Guidance for Analysis of Water." EPA 821-C-99-001, U.S. Environmental Protection Agency, Washington, D.C.

Westers, H. 1984. Principles of Intensive Fish Culture. Michigan Department of Natural Resources, Lansing, Michigan.

West Virginia Department of Environmental Protection. National Pollutant Discharge Elimination System. Permit No. WV0111821. Charleston, West Virginia, 1993.

Westers, H. 2001. "Production." Wedemeyer, G. (Ed.), Fish Hatchery Management, 2nd Edition (pp 31-89). American Fisheries Society, Bethesda, Maryland.

Wurts, W.A. and Durborow, R.M. 1992. "Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds." Southern Regional Aquaculture Center Publication No. 464.

APPENDIX A

Table A.1. Facility A Flow, pH, and Temperature.

Date	Flow, gal./min.	Flow, m3/day	Influent pH	pH	Influent Temperature, °C	Temperature, °C
1/4/01	1344	7325.34	7.46	7.03	7.3	5.8
3/26/01	1056	5755.62	7.08	7.19	7.3	7
5/16/01	1508	8219.20	7.11	6.82	10.4	10.9
7/5/01	1556	8480.82	6.57	6.71	12.2	14.1
8/8/01	1850	10083.24	7.57	7.31	12.8	16.3
9/25/01	1276	6954.71	7.37	7.2	11.7	13.2
11/19/01	754	4109.60	7.50	7.49	11.4	10.5
6/6/02	1409	7679.61	6.92	6.89	11.6	13.2
10/13/02	1017	5543.06	6.91	7.08	12.1	13.6
Min.	754.00	4109.60	6.57	6.71	7.30	5.80
Max.	1850.00	10083.24	7.57	7.49	12.80	16.30
Avg.	1307.78	7127.91	7.17	7.08	10.76	11.62

Table A.2. Facility A DO, Turbidity, and Specific Conductance.

Date	Influent Dissolved Oxygen, mg/L	Dissolved Oxygen, mg/L	Influent Turbidity, NTU	Turbidity, NTU	Influent Specific Conductance, µS/cm	Specific Conductance, µS/cm
1/4/01	8.53	8.52	1.08	1.88	157.4	156.9
3/26/01	9.25	9.55	4.81	8.35	150.6	144.1
5/16/01	8.44	7.82	0.69	3.01	161.8	170.4
7/5/01	9.25	6.33	1.31	8.91	185.3	198.3
8/8/01	9.27	5.94	1.73	2.84	174.6	192.2
9/25/01	11.06	7.16	0.54	4.71	229.5	245.4
11/19/01	8.86	7.16	0.57	2.69	233.6	245.3
6/6/02	9.48	6.84	1.84	2.13	148.7	160.5
10/13/02	8.27	5.92	1.95	3.36	230.5	242.5
Min.	8.27	5.92	0.54	1.88	148.70	144.10
Max.	11.06	9.55	4.81	8.91	233.60	245.40
Avg.	9.16	7.25	1.61	4.21	185.78	195.07

Table A.3. Facility A TSS and TAN.

Date	Influent Total Suspended Solids (TSS), mg/L	Influent Total Suspended Solids (TSS), kg/day	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Influent Ammonia Nitrogen (TAN), mg/L	Influent Ammonia Nitrogen (TAN), kg/day
1/4/01	32*		14	102.55	0.153	1.121
3/26/01	2	11.51	14	80.58	0.01	0.058
5/16/01	1	8.22	15	123.29	0.04	0.329
7/5/01	2.5	21.20	17.5	148.41	0.125	1.060
8/8/01	2	20.17	10	100.83	0.010	0.101
9/25/01	4	27.82	8.7	60.51	0.005	0.035
11/19/01	3	12.33	4.5	18.49	0.03	0.107
6/6/02	2.5	19.20	11	84.48	0.08	0.614
10/13/02	3	16.63	9	49.89	0.14	0.776
Min.	1.00	8.22	4.50	18.49	0.01	0.03
Max.	4.00	27.82	17.50	148.41	0.15	1.12
Avg.	2.50	17.13	11.52	85.45	0.07	0.47

Table A.4. Facility A NH₃, TAN, and NO₃.

Date	Influent Unionized Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (TAN), mg/L	Ammonia Nitrogen (TAN), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), kg/day	Nitrate Nitrogen (NO ₃), mg/L
1/4/01	0.00066	0.4	2.93	0.00057	0.514	3.765	1.507
3/26/01	0.00002	0.357	2.05	0.00081	0.893	5.140	1.63
5/16/01	0.00010	0.212	1.74	0.00028	0.542	4.455	1.09
7/5/01	0.00010	0.459	3.89	0.00060	0.613	5.199	0.954
8/8/01	0.00008	0.53	5.34	0.00324	1.530	15.427	0.901
9/25/01	0.00002	0.15	1.04	0.00056	0.7139	4.965	0.937
11/19/01	0.00017	0.14	0.58	0.00083	0.5397	2.218	1.75
6/6/02	0.00014	0.25	1.92	0.00046	0.4600	3.533	0.85
10/13/02	0.00025	0.3	1.66	0.00088	1.0000	5.543	1.92
Min.	0.00002	0.14	0.58	0.00028	0.46	2.22	0.85
Max.	0.00066	0.53	5.34	0.00324	1.53	15.43	1.92
Avg.	0.00017	0.31	2.35	0.00091	0.76	5.58	1.28

Table A.5. Facility A NO₃, NO₂, and TP.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Influent Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Influent Total Phosphorus (TP), mg/L	Influent Total Phosphorus (TP), kg/day
1/4/01	11.04	0.01	0.01	0.07	0.0005	0.004
3/26/01	9.38	0.01	0.023	0.13	0.0005	0.003
5/16/01	8.96	0.01	0.01	0.08	0.0005	0.004
7/5/01	8.09	0.01	0.01	0.08	0.0093	0.079
8/8/01	9.08	0.01	0.01	0.10	0.0005	0.005
9/25/01	6.52	0.01	0.01	0.07	0.0180	0.125
11/19/01	7.19	0.01	0.024	0.10	0.03500	0.144
6/6/02	6.53	0.01	0.01	0.08	0.018	0.138
10/13/02	10.64	0.01	0.01	0.06	0.001	0.003
Min.	6.52	0.01	0.01	0.06	0.0005	0.0028
Max.	11.04	0.01	0.02	0.13	0.0350	0.1438
Avg.	8.60	0.01	0.01	0.09	0.0092	0.0561

Table A.6. Facility A TP, and BOD₅.

Date	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
1/4/01	0.279	2.04	1.43	10.4752	1.43	10.48
3/26/01	0.413	2.38	1.43	8.23054	6.22	35.80
5/16/01	0.233	1.92	1.43	11.7535	3.98	32.71
7/5/01	1.24	10.52	1.43	12.1276	11.96	101.43
8/8/01	0.221	2.23	1.43	14.419	3.61	36.40
9/25/01	0.622	4.33	1.43	9.94524	3.97	27.61
11/19/01	0.292	1.20	1.43	5.87673	3.6	14.79
6/6/02	0.408	3.13	1.43	10.8	4.6	35.33
10/13/02	0.81	4.49	1.43	7.92657	2.95	16.35
Min.	0.22	1.20	1.43	5.88	1.43	10.48
Max.	1.24	10.52	1.43	14.42	11.96	101.43
Avg.	0.50	3.58	1.43	10.19	4.70	34.54

APPENDIX B

Table B.1. Facility B Flow, pH, and Temperature.

Date	Flow, gal./min.	Flow, m3/day	Influent pH	pH	Influent Temperature, °C	Temperature, °C
11/10/00	209	1139.13	7.51	7.64	12.2	12
1/4/01	634	3455.55	7.92	8.08	9.9	10.9
3/26/01	896	4883.56	7.55	7.27	9.3	13.2
5/16/01	1541	8399.07	6.88	7.35	11.2	12
7/5/01	824	4491.13	7.22	7.04	12.3	11.4
8/8/01	1347	7341.69	7.60	7.8	13.4	14.6
9/25/01	822	4480.23	7.25	7.26	12.6	18.7
11/19/01	480	2616.19	7.70	7.56	12.2	19.7
6/6/02	332	1809.53	7.29	7.29	11.9	12.2
10/13/02	558	3041.32	7.16	7.5	13.1	13.4
Min.	209.00	1139.13	6.88	7.04	9.30	10.90
Max.	1541.00	8399.07	7.92	8.08	13.40	19.70
Avg.	764.30	4165.74	7.41	7.48	11.81	13.81

Table B.2. Facility B DO, Turbidity, and Specific Conductance.

Date	Influent Dissolved Oxygen, mg/L	Dissolved Oxygen, mg/L	Influent Turbidity, NTU	Turbidity, NTU	Influent Specific Conductance, µS/cm	Specific Conductance, µS/cm
11/10/00	8.88	7.8	1.17	1.22	343.8	347.6
1/4/01	9.76	9.87	1.03	0.39	312.4	326.8
3/26/01	9.86	12.15	5.92	6.14	270.4	232.6
5/16/01	9.42	10.35	0.86	0.95	312.7	309.7
7/5/01	9.85	12.13	1.29	1.23	320.6	320.3
8/8/01	9.04	12.67	1.62	2.2	343.2	340.1
9/25/01	10.06	10.36	1.27	1.28	333.6	336.2
11/19/01	8.59	10.42	0.54	1.66	166.5	313.7
6/6/02	9.53	8.42	1.26	1.66	312.7	313.8
10/13/02	8.28	8.17	1.71	1.23	360	357.1
Min.	8.28	7.80	0.54	0.39	166.50	232.60
Max.	10.06	12.67	5.92	6.14	360.00	357.10
Avg.	9.33	10.23	1.67	1.80	307.59	319.79

Table B.3. Facility B TSS and TAN.

Date	Influent Total Suspended Solids (TSS), mg/L	Influent Total Suspended Solids (TSS), kg/day	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Influent Ammonia Nitrogen (TAN), mg/L	Influent Ammonia Nitrogen (TAN), kg/day
11/10/00	4	4.56	6	6.83	0.099	0.113
1/4/01	2.5	8.64	2.5	8.64	0.151	0.522
3/26/01	0.5	2.44	2	9.77	0.005	0.024
5/16/01	0.5	4.20	3	25.20	0.035	0.294
7/5/01	1	4.49	5	22.46	0.156	0.701
8/8/01	2	14.68	3	22.03	0.020	0.147
9/25/01	1	4.48	4.5	20.16	0.005	0.022
11/19/01	1	2.62	2	5.23	0.005	0.013
6/6/02	2	3.62	3	5.43	0.04	0.072
10/13/02	3	9.12	5	15.21	0.14	0.426
Min.	0.50	2.44	2.00	5.23	0.01	0.01
Max.	4.00	14.68	6.00	25.20	0.16	0.70
Avg.	1.75	5.89	3.60	14.09	0.07	0.23

Table B.4. Facility B NH₃, TAN, and NO₃.

Date	Influent Unionized Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (TAN), mg/L	Ammonia Nitrogen (TAN), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), kg/day	Nitrate Nitrogen (NO ₃), mg/L
11/10/00	0.00070	0.172	0.20	0.00161	0.476	0.542	0.5102
1/4/01	0.00228	0.191	0.66	0.00447	0.65	2.246	0.715
3/26/01	0.00003	0.005	0.02	0.00002	0.937	4.576	0.942
5/16/01	0.00005	0.063	0.53	0.00030	0.492	4.132	0.503
7/5/01	0.00057	0.136	0.61	0.00031	0.473	2.124	0.514
8/8/01	0.00019	0.08	0.59	0.00131	2.03*		0.64
9/25/01	0.00002	0.005	0.02	0.00003	0.6249	2.800	0.6097
11/19/01	0.00005	0.05	0.13	0.00069	0.4884	1.278	0.5871
6/6/02	0.00017	0.11	0.20	0.00047	0.5200	0.941	0.5200
10/13/02	0.00048	0.21	0.64	0.00159	0.9000	2.737	0.96
Min.	0.00002	0.01	0.02	0.00002	0.47	0.54	0.50
Max.	0.00228	0.21	0.66	0.00447	0.94	4.58	0.96
Avg.	0.00045	0.10	0.36	0.00108	0.62	2.38	0.65

Table B.5. Facility B NO₃, NO₂, and TP.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Influent Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Influent Total Phosphorus (TP), mg/L	Influent Total Phosphorus (TP), kg/day
11/10/00	0.58	0.01	0.01	0.01	0.0005	0.001
1/4/01	2.47	0.01	0.01	0.03	0.0005	0.002
3/26/01	4.60	0.01	0.01	0.05	0.0005	0.002
5/16/01	4.22	0.01	0.01	0.08	0.00501	0.042
7/5/01	2.31	0.01	0.01	0.04	0.0085	0.038
8/8/01	4.70	0.01	0.01	0.07	0.00929	0.068
9/25/01	2.73	0.01	0.01	0.04	0.0250	0.112
11/19/01	1.54	0.01	0.01	0.03	0.03700	0.097
6/6/02	0.94	0.01	0.01	0.02	0.03	0.051
10/13/02	2.92	0.01	0.01	0.03	0.046	0.140
Min.	0.58	0.01	0.01	0.01	0.00	0.00
Max.	4.70	0.01	0.01	0.08	0.05	0.14
Avg.	2.70	0.01	0.01	0.04	0.02	0.06

Table B.6. Facility B TP, and BOD₅.

Date	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
11/10/00	0.0005	0.001	1.43	1.43	1.63
1/4/01	0.0005	0.002	1.43	1.43	4.94
3/26/01	0.0005	0.002	1.43	1.43	6.98
5/16/01	0.0132	0.11	1.43	1.43	12.01
7/5/01	0.0121	0.05	1.43	1.43	6.42
8/8/01	0.02217	0.16	1.43	1.43	10.50
9/25/01	0.061	0.27	1.43	1.43	6.41
11/19/01	0.092	0.24	1.43	1.43	3.74
6/6/02	0.041	0.07	1.43	1.43	2.59
10/13/02	0.088	0.27	1.43	1.43	4.35
Min.	0.001	0.001	1.43	1.43	1.63
Max.	0.09	0.27	1.43	1.43	12.01
Avg.	0.03	0.12	1.43	1.43	5.96

APPENDIX C

Table C.1. Facility C Flow, pH, and Temperature.

Date	Flow, gal./min.	Flow, m3/day	Influent pH	pH	Influent Temperature, °C	Temperature, °C
11/9/00	480	2616.19	7.24	8.84	14.3	13.2
1/4/01	223	1215.44	8.41	8.6	11.2	12
3/26/01	302	1646.02	8.15	8.69	11.9	11.4
5/16/01	337	1836.78	7.80	8.36	14.5	14.6
7/5/01	361	1967.59	7.68	7.96	16	18.7
8/8/01	194	1057.38	7.98	8.26	16.3	19.7
9/25/01	333	1814.98	7.93	8.14	14.9	15.9
11/19/01	303	1651.47	8.02	7.55	14.5	13.2
6/6/02	317	1727.78	7.66	7.02	15.6	17.8
10/13/02	353	1923.99	7.27	6.86	15.6	16.2
Min.	194.00	1057.38	7.24	6.86	11.20	11.40
Max.	480.00	2616.19	8.41	8.84	16.30	19.70
Avg.	320.30	1745.76	7.81	8.03	14.48	15.27

Table C.2. Facility C DO, Turbidity, and Specific Conductance.

Date	Influent Dissolved Oxygen, mg/L	Dissolved Oxygen, mg/L	Influent Turbidity, NTU	Turbidity, NTU	Influent Specific Conductance, µS/cm	Specific Conductance, µS/cm
11/9/00	9.15	12.15	0.46	15.8	143.2	189
1/4/01	10.61	10.35	0.74	2.66	194.6	195
3/26/01	9.38	12.13	1.12	6.52	189.7	168.7
5/16/01	9.52	12.67	0.68	2.26	191.5	189.7
7/5/01	9.42	10.36	0.5	8.33	192.4	195
8/8/01	8.93	10.42	0.66	4.64	195.2	194.6
9/25/01	9.99	11.9	1	2.73	197.2	197.4
11/19/01	9.6	10.27	2.21	4.7	198.6	202.8
6/6/02	9.34	6.01	0.86	0.96	200	204.2
10/13/02	8.39	7.89	0.77	2.06	200	202.8
Min.	8.39	6.01	0.46	0.96	143.20	168.70
Max.	10.61	12.67	2.21	15.80	200.00	204.20
Avg.	9.43	10.42	0.90	5.07	190.24	193.92

Table C.3. Facility C TSS and TAN.

Date	Influent Total Suspended Solids (TSS), mg/L	Influent Total Suspended Solids (TSS), kg/day	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Influent Ammonia Nitrogen (TAN), mg/L	Influent Ammonia Nitrogen (TAN), kg/day
11/9/00	2	5.23	8	20.93	0.158	0.413
1/4/01	2.5	3.04	10	12.15	0.178	0.216
3/26/01	3	4.94	14	23.04	0.005	0.008
5/16/01	2	3.67	6	11.02	0.041	0.075
7/5/01	2	3.94	12.7	24.99	0.153	0.301
8/8/01	2	2.11	2	2.11	0.01	0.011
9/25/01	6	10.89	3.5	6.35	0.01	0.018
11/19/01	2	3.30	2	3.30	0.005	0.008
6/6/02	2	3.46	3.5	6.05	0.14	0.242
10/13/02	3	5.77	7	13.47	0.17	0.327
Min.	2.00	2.11	2.00	2.11	0.01	0.01
Max.	6.00	10.89	14.00	24.99	0.18	0.41
Avg.	2.65	4.64	6.87	12.34	0.09	0.16

Table C.4. Facility C NH₃, TAN, and NO₃.

Date	Influent Unionized Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (TAN), mg/L	Ammonia Nitrogen (TAN), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), kg/day	Nitrate Nitrogen (NO ₃), mg/L
11/9/00	0.00071	0.134	0.35	0.01893	0.069	0.181	0.051
1/4/01	0.00886	0.184	0.22	0.01462	0.107	0.130	0.116
3/26/01	0.00015	0.075	0.12	0.00690	0.05	0.087	0.02
5/16/01	0.00067	0.109	0.20	0.00623	0.047	0.086	0.031
7/5/01	0.00212	0.21	0.41	0.00667	0.01	0.020	0.03
8/8/01	0.00028	0.15	0.16	0.00987	0.265	0.280	0.029
9/25/01	0.00023	0.3	0.54	0.01162	0.1411	0.256	0.1479
11/19/01	0.00013	0.45	0.74	0.00377	0.5455	0.901	0.1108
6/6/02	0.00180	0.26	0.45	0.00091	0.05	0.086	0.07
10/13/02	0.00090	0.25	0.48	0.00054	0.08	0.154	0.07
Min.	0.00013	0.08	0.12	0.00054	0.01	0.02	0.02
Max.	0.00886	0.45	0.74	0.01893	0.55	0.90	0.15
Avg.	0.00158	0.21	0.37	0.00801	0.14	0.22	0.07

Table C.5. Facility C NO₃, NO₂, and TP.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Influent Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Influent Total Phosphorus (TP), mg/L	Influent Total Phosphorus (TP), kg/day
11/9/00	0.13	0.01	0.01	0.03	0.0005	0.001
1/4/01	0.14	0.01	0.01	0.01	0.0005	0.001
3/26/01	0.03	0.01	0.01	0.02	0.0189	0.031
5/16/01	0.06	0.01	0.01	0.02	0.05240	0.096
7/5/01	0.06	0.01	0.01	0.02	0.0376	0.074
8/8/01	0.03	0.01	0.01	0.01	0.05258	0.056
9/25/01	0.27	0.01	0.01	0.02	0.07	0.131
11/19/01	0.18	0.01	0.01	0.02	0.082	0.135
6/6/02	0.12	0.01	0.01	0.02	0.038	0.066
10/13/02	0.13	0.01	0.01	0.02	0.162	0.312
Min.	0.03	0.01	0.01	0.01	0.00	0.00
Max.	0.27	0.01	0.01	0.03	0.16	0.31
Avg.	0.12	0.01	0.01	0.02	0.05	0.09

Table C.6. Facility C TP, and BOD₅.

Date	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Influent Biochemical Oxygen Demand (BOD ₅), kg/day	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
11/9/00	0.0005	0.001	1.43	3.74	1.43	3.74
1/4/01	0.0005	0.001	1.43	1.74	1.43	1.74
3/26/01	0.069	0.11	1.43	2.35	4.27	7.03
5/16/01	0.0684	0.13	1.43	2.63	1.43	2.63
7/5/01	0.05258	0.10	1.43	2.81	1.43	2.81
8/8/01	0.06287	0.07	1.43	1.51	1.43	1.51
9/25/01	0.104	0.19	1.43	2.60	1.43	2.60
11/19/01	0.127	0.21	1.43	2.36	1.43	2.36
6/6/02	0.118	0.20	1.43	2.47	1.43	2.47
10/13/02	0.256	0.49	1.43	2.75	1.43	2.75
Min.	0.00	0.00	1.43	1.51	1.43	1.51
Max.	0.26	0.49	1.43	3.74	4.27	7.03
Avg.	0.09	0.15	1.43	2.50	1.71	2.96

APPENDIX D

Table D.1. Facility D Flow, pH, and Temperature.

Date	Flow, gal./min.	Flow, m3/day	Influent pH	pH	Influent Temperature, °C	Temperature, °C
1/17/01	171	932.02	7.92	7.83	9.3	10.9
2/22/01	412	2245.56	8.06	7.92	9.8	10.3
5/14/01	751	4093.25	7.45	7.46	11.1	12.7
7/2/01	808	4403.92	7.81	8.06	11.8	13.3
8/6/01	950	5177.88	7.68	8.48	13	13.1
10/2/01	378	2060.25	7.70	7.72	12.1	12.7
12/4/01	178	970.17	7.65	7.74	11.7	11.6
6/26/02	376	2049.35	7.25	7.26	11.8	13.2
Min.	171.00	932.02	7.25	7.26	9.30	10.30
Max.	950.00	5177.88	8.06	8.48	13.00	13.30
Avg.	503.00	2741.55	7.69	7.81	11.33	12.23

Table D.2. Facility D DO, Turbidity, and Specific Conductance.

Date	Influent Dissolved Oxygen, mg/L	Dissolved Oxygen, mg/L	Influent Turbidity, NTU	Turbidity, NTU	Influent Specific Conductance, µS/cm	Specific Conductance, µS/cm
1/17/01	6.48	6.22	3.81	3.81	300	300
2/22/01	9.15	9.07	1.03	2.02	222.7	222.1
5/14/01	9.6	7.57	3.05	3.87	283.2	285.6
7/2/01	9.95	9.12	2.75	5.11	302	306.4
8/6/01	9.86	10.16	7.47	8.13	193.6	260.7
10/2/01	9.48	8.17	4.08	5.37	323	325.2
12/4/01	8.95	5.96	2.19	4.75	238.7	336.1
6/26/02	11.19	8.28	1.82	2.54	306.3	311.3
Min.	6.48	5.96	1.03	2.02	193.60	222.10
Max.	11.19	10.16	7.47	8.13	323.00	336.10
Avg.	9.33	8.07	3.28	4.45	271.19	293.43

Table D.3. Facility D TSS and TAN.

Date	Influent Total Suspended Solids (TSS), mg/L	Influent Total Suspended Solids (TSS), kg/day	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Influent Ammonia Nitrogen (TAN), mg/L	Influent Ammonia Nitrogen (TAN), kg/day
1/17/01	3	2.796	9	8.39	0.025	0.0233
2/22/01	2	4.491	7	15.72	0.035	0.0786
5/14/01	1	4.093	11	45.03	0.041	0.1678
7/2/01	0.5	2.202	25	110.10	0.152	0.6694
8/6/01	8	41.423	14.5	75.08	0.02	0.1036
10/2/01	2	4.121	8	16.48	0.01	0.0206
12/4/01	4	3.881	7	6.79	0.005	0.0049
6/26/02	3.5	7.173	5.5	11.27	0.1384	0.2836
Min.	0.50	2.20	5.50	6.79	0.005	0.005
Max.	8.00	41.42	25.00	110.10	0.15	0.67
Avg.	3.00	8.77	10.88	36.11	0.05	0.17

Table D.4. Facility D NH₃, TAN, and NO₃.

Date	Influent Unionized Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (TAN), mg/L	Ammonia Nitrogen (TAN), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), kg/day	Nitrate Nitrogen (NO ₃), mg/L
1/17/01	0.00036	0.11	0.10	0.00146	1.02	0.951	1.44
2/22/01	0.00072	0.102	0.23	0.00159	1.37	3.076	1.36
5/14/01	0.00023	0.17	0.70	0.00111	1.09	4.462	1.10
7/2/01	0.00207	0.232	1.02	0.00621	1.04	4.580	1.06
8/6/01	0.00022	0.1	0.52	0.00665	1.01	5.230	0.996
10/2/01	0.00011	0.17	0.35	0.00202	1.2548	2.585	1.2055
12/4/01	0.00005	0.59	0.57	0.00674	1.1428	1.109	0.7167
6/26/02	0.00052	0.3411	0.70	0.00147	0.10	0.205	0.12
Min.	0.000047	0.10	0.10	0.001115	0.10	0.20	0.12
Max.	0.002067	0.59	1.02	0.006739	1.37	5.23	1.44
Avg.	0.000535	0.23	0.52	0.003407	1.00	2.77	1.00

Table D.5. Facility D NO₃, NO₂, and TP.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Influent Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Influent Total Phosphorus (TP), mg/L	Influent Total Phosphorus (TP), kg/day
1/17/01	1.34	0.01	0.01	0.01	0.0005	0.0005
2/22/01	3.05	0.01	0.01	0.02	0.0005	0.0011
5/14/01	4.50	0.01	0.01	0.04	0.00988	0.0404
7/2/01	4.67	0.01	0.01	0.04	0.00999	0.0440
8/6/01	5.16	0.01	0.01	0.05	0.01343	0.0695
10/2/01	2.48	0.01	0.01	0.02	0.039	0.0803
12/4/01	0.70	0.01	0.01	0.01	0.029	0.0281
6/26/02	0.25	0.01	0.01	0.02	0.024	0.0492
Min.	0.25	0.01	0.01	0.01	0.0005	0.0005
Max.	5.16	0.01	0.01	0.05	0.039	0.080
Avg.	2.77	0.01	0.01	0.03	0.016	0.039

Table D.6. Facility D TP, and BOD₅.

Date	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Influent Biochemical Oxygen Demand (BOD ₅), kg/day	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
1/17/01	0.119	0.11	1.43	1.33	1.43	1.33
2/22/01	0.0499	0.11	1.43	3.21	1.43	3.21
5/14/01	0.0962	0.39	1.43	5.85	1.43	5.85
7/2/01	0.328	1.44	1.43	6.30	4.18	18.41
8/6/01	0.03187	0.17	1.43	7.40	1.43	7.40
10/2/01	0.179	0.37	1.43	2.95	1.43	2.95
12/4/01	0.371	0.36	1.43	1.39	4.96	4.81
6/26/02	0.368	0.75	1.43	2.93	3.09	6.33
Min.	0.03	0.11	1.43	1.33	1.43	1.33
Max.	0.37	1.44	1.43	7.40	4.96	18.41
Avg.	0.19	0.46	1.43	3.92	2.42	6.29

APPENDIX E

Table E.1. Facility E Flow, pH, and Temperature.

Date	Flow, gal./min.	Flow, m3/day	Influent Ph	pH	Influent Temperature, °C	Temperature, °C
1/17/01	986	5374.09	7.05	7.65	13.5	13.1
3/1/01	2314	12612.23	6.82	7.23	13.1	12.9
5/14/01	2951	16084.13	6.72	7.38	13.7	14
7/2/01	1450	7903.08	7.05	7.68	13.5	14
8/6/01	2346	12786.64	7.20	7.81	13.3	14
10/2/01	1500	8175.60	6.94	7.37	13.5	13.9
12/4/01	1230	6703.99	7.06	7.45	13.7	13.3
6/26/02	2000	10900.80	6.33	6.86	13.5	14.1
Min.	986	5374.09	6.33	6.86	13.10	12.90
Max.	2951	16084.13	7.20	7.81	13.70	14.10
Avg.	1825	10067.57	6.90	7.43	13.48	13.66

Table E.2. Facility E DO, Turbidity, and Specific Conductance.

Date	Influent Dissolved Oxygen, mg/L	Dissolved Oxygen, mg/L	Influent Turbidity, NTU	Turbidity, NTU	Influent Specific Conductance, µS/cm	Specific Conductance, µS/cm
1/17/01	5.93	7.24	4.61	8.32	500	500
3/1/01	6.21	8.2	5.11	5.44	443.6	489
5/14/01	5.96	7.98	4.02	3.63	458.8	537
7/2/01	5.91	7.93	3.99	6.9	472.2	477
8/6/01	6.22	7.98	5.28	7.12	422.8	430
10/2/01	5.82	7.34	4.58	4.81	391.2	505
12/4/01	6.09	5.74	4.44	3.98	545	548
6/26/02	6.97	8.88	4.34	4.92	503	509
Min.	5.82	5.74	3.99	3.63	391.20	430.00
Max.	6.97	8.88	5.28	8.32	545.00	548.00
Avg.	6.14	7.66	4.55	5.64	467.08	499.38

Table E.3. Facility E TSS and TAN.

Date	Influent Total Suspended Solids (TSS), mg/L	Influent Total Suspended Solids (TSS), kg/day	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Influent Ammonia Nitrogen (TAN), mg/L	Influent Ammonia Nitrogen (TAN), kg/day
1/17/01	2	10.75	6	32.24	0.08	0.44
3/1/01	1	12.61	5	63.06	0.09	1.14
5/14/01	1	16.08	10	160.84	0.078	1.25
7/2/01	2	15.81	6.2	49.00	0.22	1.72
8/6/01	4	51.15	10	127.87	0.09	1.15
10/2/01	2.5	20.44	9	73.58	0.05	0.41
12/4/01	3	20.11	10	67.04	0.07	0.47
6/26/02	3.5	38.15	7	76.31	1.2278	13.38
Min.	1.00	10.75	5.00	32.24	0.05	0.41
Max.	4.00	51.15	10.00	160.84	1.23	13.38
Avg.	2.38	23.14	7.90	81.24	0.24	2.50

Table E.4. Facility E NH₃, TAN, and NO₃.

Date	Influent Unionized Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (TAN), mg/L	Ammonia Nitrogen (TAN), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), kg/day	Nitrate Nitrogen (NO ₃), mg/L
1/17/01	0.00022	0.211	1.13	0.00220	0.01	0.05	0.174
3/1/01	0.00014	0.194	2.45	0.00076	0.105	1.32	0.196
5/14/01	0.00010	0.187	3.01	0.00113	0.135	2.17	0.153
7/2/01	0.00059	0.428	3.38	0.00512	0.105	0.83	0.168
8/6/01	0.00034	0.39	4.99	0.00626	0.172	2.20	0.225
10/2/01	0.00011	0.15	1.23	0.00088	0.2173	1.78	0.2717
12/4/01	0.00020	0.46	3.08	0.00309	0.01	0.07	0.2525
6/26/02	0.00064	0.478	5.21	0.00088	0.01	0.11	0.03
Min.	0.00010	0.15	1.13	0.00076	0.01	0.05	0.03
Max.	0.00064	0.48	5.21	0.00626	0.22	2.20	0.27
Avg.	0.00029	0.31	3.06	0.00254	0.10	1.07	0.18

Table E.5. Facility E NO₃, NO₂, and TP.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Influent Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Influent Total Phosphorus (TP), mg/L	Influent Total Phosphorus (TP), kg/day
1/17/01	0.94	0.01	0.01	0.05	0.012	0.064
3/1/01	2.47	0.01	0.01	0.13	0.0005	0.006
5/14/01	2.46	0.01	0.01	0.16	0.0005	0.008
7/2/01	1.33	0.01	0.01	0.08	0.00919	0.073
8/6/01	2.88	0.01	0.01	0.13	0.0064	0.082
10/2/01	2.22	0.01	0.01	0.08	0.026	0.213
12/4/01	1.69	0.01	0.01	0.07	0.065	0.436
6/26/02	0.33	0.01	0.01	0.11	0.018	0.196
Min.	0.33	0.01	0.01	0.05	0.00	0.01
Max.	2.88	0.01	0.01	0.16	0.07	0.44
Avg.	1.79	0.01	0.01	0.10	0.02	0.13

Table E.6. Facility E TP, and BOD₅.

Date	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Influent Biochemical Oxygen Demand (BOD ₅), kg/day	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
1/17/01	0.098	0.53	1.43	7.68	1.43	7.68
3/1/01	0.0005	0.01	1.43	18.04	6.04	76.18
5/14/01	0.043	0.69	1.43	23.00	4.78	76.88
7/2/01	0.139	1.10	1.43	11.30	4.34	34.30
8/6/01	0.198	2.53	1.43	18.28	4.4	56.26
10/2/01	0.148	1.21	1.43	11.69	4.55	37.20
12/4/01	0.29	1.94	1.43	9.59	3.58	24.00
6/26/02	0.253	2.76	1.43	15.59	5.75	62.68
Min.	0.00	0.01	1.43	7.68	1.43	7.68
Max.	0.29	2.76	1.43	23.00	6.04	76.88
Avg.	0.15	1.35	1.43	14.40	4.36	46.90

Table E.7. Facility E OLS Pond Flow, pH, Temperature, DO, and Turbidity.

Date	Flow, gal./min.	Flow, m3/day	pH	Temperature, °C	Dissolved Oxygen, mg/L	Turbidity, NTU
1/17/01	63	343.38	7.63	11.8	9.01	5.44
3/1/01	562	3063.12	7.55	13.2	8.82	7.5
5/14/01	265	1444.36	7.27	16.5	12.48	3.63
7/2/01	550	2997.72	7.55	15.8	8.47	6.24
8/6/01	550	2997.72	7.9	16.4	9.63	4.39
10/2/01	500	2725.20	7.21	14.5	7.92	4.43
12/4/01	400	2180.16	7.3	14.1	8.82	4.06
6/26/02	450	2452.68	6.85	14.6	8.63	4.71
Min.	63.00	343.38	6.85	11.80	7.92	3.63
Max.	562.00	3063.12	7.90	16.50	12.48	7.50
Avg.	417.50	2275.54	7.41	14.61	9.22	5.05

Table E.8. Facility E Specific Conductance, TSS, TAN, NH₃, and NO₃.

Date	Specific Conductance, μS/cm	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (NH ₃), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Nitrate Nitrogen (NO ₃), mg/L
1/17/01	500	5	1.72	0.421	0.14	0.00380	0.184
3/1/01	446.7	4	12.25	0.54	1.65	0.00452	0.186
5/14/01	466.8	8	11.55	0.263	0.38	0.00149	0.193
7/2/01	237	0.5	3.00	0.378	1.13	0.00385	0.101
8/6/01	840	7	20.98	0.19	0.57	0.00447	0.162
10/2/01	506	7	19.08	0.13	0.35	0.00055	0.1462
12/4/01	555	8	17.44	0.29	0.63	0.00147	0.172
6/26/02	507	6	14.72	0.22	0.54	0.00041	0.113
Min.	237.00	0.50	1.72	0.13	0.14	0.00041	0.10
Max.	840.00	8.00	20.98	0.54	1.65	0.00452	0.19
Avg.	507.31	5.69	12.59	0.30	0.68	0.00257	0.16

Table E.9. Facility E NO₃, NO₂, TP, and BOD₅.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
1/17/01	0.06	0.01	0.00	0.065	0.02	1.43	0.49
3/1/01	0.57	0.01	0.03	0.0005	0.55	3.56	10.90
5/14/01	0.28	0.01	0.01	0.082	0.12	1.43	2.07
7/2/01	0.30	0.01	0.03	0.07	0.21	1.43	4.29
8/6/01	0.49	0.01	0.03	0.016	0.05	1.43	4.29
10/2/01	0.40	0.01	0.03	0.09	0.25	1.43	3.90
12/4/01	0.37	0.01	0.02	0.101	0.22	1.43	3.12
6/26/02	0.28	0.01	0.02	0.08	0.20	1.43	3.51
Min.	0.06	0.01	0.003	0.0005	0.02	1.43	0.49
Max.	0.57	0.01	0.03	0.10	0.55	3.56	10.90
Avg.	0.34	0.01	0.02	0.06	0.20	1.70	4.07

APPENDIX F

Table F.1. Facility F Flow, pH, and Temperature.

Date	Flow, gal./min.	Flow, m3/day	Influent pH	pH	Influent Temperature, °C	Temperature, °C
1/17/01	1212	6605.88	7.58	7.45	12.1	12
3/1/01	1009	5499.45	7.13	7.09	12.4	12.2
5/14/01	1338	7292.64	7.21	7.17	12.9	13
7/2/01	1042	5679.32	7.58	7.53	13.1	13.3
8/6/01	2123	11571.20	7.82	7.56	13.1	13.6
10/2/01	922	5025.27	7.43	7.38	13	13.3
12/4/01	557	3035.87	7.52	7.3	13.1	12.6
Min.	557	3035.87	7.13	7.09	12.10	12.00
Max.	2123	11571.20	7.82	7.56	13.10	13.60
Avg.	1172	6387.09	7.47	7.35	12.81	12.86

Table F.2. Facility F DO, Turbidity, and Specific Conductance.

Date	Influent Dissolved Oxygen, mg/L	Dissolved Oxygen, mg/L	Influent Turbidity, NTU	Turbidity, NTU	Influent Specific Conductance, µS/cm	Specific Conductance, µS/cm
1/17/01	11.32	8.32	3.13	6.62	500	500
3/1/01	8.19	9.52	2.22	5.11	528	526
5/14/01	9.81	8.65	0.62	1	515	522
7/2/01	10.2	6.98	0.63	1.51	529	550
8/6/01	10.2	7.01	2.28	1.94	539	544
10/2/01	10.77	8.29	1.87	2.71	536	543
12/4/01	9.02	8.97	1.82	2.91	524.1	565.9
Min.	8.19	6.98	0.62	1.00	500.00	500.00
Max.	11.32	9.52	3.13	6.62	539.00	565.90
Avg.	9.93	8.25	1.80	3.11	524.44	535.84

Table F.3. Facility F TSS and TAN.

Date	Influent Total Suspended Solids (TSS), mg/L	Influent Total Suspended Solids (TSS), kg/day	Total Suspended Solids (TSS), mg/L	Total Suspended Solids (TSS), kg/day	Influent Ammonia Nitrogen (TAN), mg/L	Influent Ammonia Nitrogen (TAN), kg/day
1/17/01	2	13.21	6	39.64	0.040	0.264
3/1/01	3	16.50	9	49.50	0.057	0.313
5/14/01	3	21.88	3	21.88	0.042	0.306
7/2/01	2	11.36	3	17.04	0.055	0.312
8/6/01	1	11.57	5	57.86	0.030	0.347
10/2/01	2.5	12.56	9	45.23	0.010	0.050
12/4/01	3	9.11	10	30.36	0.005	0.015
Min.	1.00	9.11	3.00	17.04	0.01	0.02
Max.	3.00	21.88	10.00	57.86	0.06	0.35
Avg.	2.36	13.74	6.43	37.36	0.03	0.23

Table F.4. Facility F NH₃, TAN, and NO₃.

Date	Influent Unionized Ammonia Nitrogen (NH ₃), mg/L	Ammonia Nitrogen (TAN), mg/L	Ammonia Nitrogen (TAN), Kg/day	Unionized Ammonia Nitrogen (NH ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), mg/L	Influent Nitrate Nitrogen (NO ₃), kg/day	Nitrate Nitrogen (NO ₃), mg/L
1/17/01	0.00033	0.54	3.57	0.00328	0.198	1.308	0.212
3/1/01	0.00017	0.65	3.57	0.00176	0.235	1.292	0.289
5/14/01	0.00016	0.135	0.98	0.00047	0.118	0.861	0.145
7/2/01	0.00049	0.352	2.00	0.00284	0.096	0.545	0.113
8/6/01	0.00046	0.25	2.89	0.00221	0.208	2.407	0.214
10/2/01	0.00006	0.13	0.65	0.00074	0.1479	0.743	0.1339
12/4/01	0.00004	0.46	1.40	0.00208	0.0775	0.235	0.1755
Min.	0.00004	0.13	0.65	0.00047	0.08	0.24	0.11
Max.	0.00049	0.65	3.57	0.00328	0.24	2.41	0.29
Avg.	0.00024	0.36	2.15	0.00191	0.15	1.06	0.18

Table F.5. Facility F NO₃, NO₂, and TP.

Date	Nitrate Nitrogen (NO ₃), Kg/day	Influent Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), mg/L	Nitrite Nitrogen (NO ₂), Kg/day	Influent Total Phosphorus (TP), mg/L	Influent Total Phosphorus (TP), kg/day
1/17/01	1.40	0.01	0.01	0.07	0.0005	0.0033
3/1/01	1.59	0.01	0.01	0.05	0.0005	0.0027
5/14/01	1.06	0.01	0.01	0.07	0.0005	0.0036
7/2/01	0.64	0.01	0.01	0.06	0.0097	0.0551
8/6/01	2.48	0.01	0.01	0.12	0.01144	0.1324
10/2/01	0.67	0.01	0.01	0.05	0.044	0.2211
12/4/01	0.53	0.01	0.01	0.03	0.065	0.1973
Min.	0.53	0.01	0.01	0.03	0.00	0.00
Max.	2.48	0.01	0.01	0.12	0.07	0.22
Avg.	1.20	0.01	0.01	0.06	0.02	0.09

Table F.6. Facility F TP, and BOD₅.

Date	Total Phosphorus (TP), mg/L	Total Phosphorus (TP), Kg/day	Influent Biochemical Oxygen Demand (BOD ₅), mg/L	Influent Biochemical Oxygen Demand (BOD ₅), kg/day	Biochemical Oxygen Demand (BOD ₅), mg/L	Biochemical Oxygen Demand (BOD ₅), Kg/day
1/17/01	0.084	0.55	1.43	9.45	1.43	9.45
3/1/01	0.0005	0.003	1.43	7.86	1.43	7.86
5/14/01	0.06	0.44	1.43	10.43	1.43	10.43
7/2/01	0.096	0.55	1.43	8.12	5.6	31.80
8/6/01	0.131	1.52	1.43	16.55	4	46.28
10/2/01	0.145	0.73	1.43	7.19	3.93	19.75
12/4/01	0.186	0.56	1.43	4.34	1.43	4.34
Min.	0.00	0.00	1.43	4.34	1.43	4.34
Max.	0.19	1.52	1.43	16.55	5.60	46.28
Avg.	0.10	0.62	1.43	9.13	2.75	18.56