CHARACTERIZATION, TREATMENT, AND IMPROVEMENT OF AQUACULTURAL EFFLUENTS

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(ABSTRACT)

Based on in-stream surveys, the Virginia Department of Environmental Quality (VDEQ) concluded that the discharges from aquacultural facilities could impact benthic macroinvertebrate populations. In response to this finding, the VDEQ awarded researchers at Virginia Tech a grant, under the auspices of the 604(b) Water Quality Management Planning Grant Program, to characterize the effluents at various trout farms and to investigate means for improving the quality of the receiving waters.

Studies were conducted at four trout farms, which will hereafter be referred to as Farms A through D. The project was divided into three main components. Water quality and sludge characterization, water and sludge treatability options, and waste reduction strategies were the three phases of the project. Waste reduction was studied via alternative feed and improvement of feeding practices with the efforts of Justin Nyland. Studies were conducted at Farms C and D and results will be presented in a separate thesis titled, "Use of a High Energy Feed for the Improvement of Aquacultural Effluents", by the above-referenced author. The scope of this thesis will cover "water quality and sludge characterization" and "water and sludge treatability options", presenting results from farms A, B, and C.

During the water quality and sludge characterization phase, average effluent quality over the course of a day was not found to be impaired during a 7-month sampling and monitoring study at the three trout farms. However, effluent quality was found to change significantly during times of high farm activity (i.e. feeding, harvesting, cleaning, etc.). Normalized Total Suspended Solids (TSS) concentrations were found to be as high as 115 mg/l during harvesting and 63 mg/l during feeding. Solids characterization studies proved farm waste solids degrade over time and that their particle size distributions are a function of the feed size and activity of a

certain raceway. Waste solids accumulation studies proved that the solids removal efficiency of farm sediment traps were very low, and after a certain period of time, they reached capacity due to particle scouring.

A pilot plant was constructed in the water and sludge treatability phase to prove a baffled settling scheme was sufficient to treat average and peak TSS concentrations during a normal workweek. The study found optimal TSS removals at detention times of 15-20 minutes, and overflow rates of 77.4 – 48.9 $m^3/m^2 \cdot d$. Given economic, spatial, and operational constraints, sedimentation was found to be the most feasible treatment technology for raceway-system trout farms.

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1.0 Literature Review

Background

It has been well documented in recent years that the aquaculture industry is undergoing rapid growth (Goldburg and Triplett, 1997; Ewart *et al*., 1995). The growth is in part due to a rising world population, a trend towards lower fat, lower cholesterol foods, and a wild stock that can no longer keep up with the demands of today's marketplace. Due to the development of this industry, production facilities have been receiving more attention from state and federal environmental regulators. While water consumption is an important issue, solids and nutrient discharges from aquaculture facilities have received the most attention. Even though most fish farms in the U.S. are not regulated for the discharge of nitrogen and phosphorus, aquaculture production facilities in Europe (Bergheim and Cripps, 1998), and most recently, trout farms in Northern Idaho (MacMillan, 1991), now have nutrient discharge limits. Also, recent legislation has given states the authority to establish Total Maximum Daily Loads (TMDLs) in aquacultural facility discharge permits, rather than the more common concentration-based permits. These trends provide a glimpse of what other fish farms will likely face in the near future.

Raceway System Farms

Of the many types of aquaculture production facilities in-use today, flow-through systems are expected to receive the largest impact from any future regulations. Sedgwick (1995), Stickney (1994), and Brown and Gratzek (1980) provide background on the operation and maintenance of such farms. These systems (e.g. raceways) have high, single-pass flows, low 24-hour pollutant concentrations, and little if any treatment before the effluent is discharged to their respective receiving stream. Treatment options are often limited due to economical and spatial constraints; however, sediment ponds (Mudrak, 1981; Henderson & Bromage, 1988), sediment traps (Axler *et al.*, 1997; MacMillan, 1991), microscreen filtration (Summerfelt, in press; Bergheim *et al.*, 1993), and wetlands (Shwartz and Boyd, 1995; Adler *et al.*, 1996, Massingill *et al.*, 1998) have been implemented or studied in the past. Although the flow-through systems produce effluent concentrations that are generally well within the standards of their permit, the high flows that are encountered result in significant loadings of many of the constituents which promote eutrophication (Folke *et al.*, 1994; Cripps, 1995), toxicity to the benthic community (Loch *et al.*, 1996), and/or fish diseases (Chapman *et al.*, 1987). This low concentration, high flow effluent is much more difficult to treat in comparison to some of the low flow, high concentration effluents found in other aquacultural systems (Summerfelt, 1998a).

Aquacultural Effluent Treatment

Settling Ponds

Settling ponds are considered to be the most popular treatment alternative for aquacultural facilities. They are easy to operate and maintain, have relatively good TSS removal efficiencies, and are the most economical to construct.

Henderson and Bromage (1988) and Mudrak (1981) have published settling pond designs for aquacultural wastes. Efficiency of settling ponds will be specific to the size and operation of the farm. Reported retention times have ranged as low as 3 minutes (Mudrak, 1981) to as high as 3 days (Liao, 1970); however, typical recommended retention times are from 30 – 120 minutes. Assuming a 0.9 m depth, the corresponding surface overflow rates would be 40.7 $m^3/m^2 \cdot day$ – 10.2 $m^3/m^2 \cdot day$. Stechey (1998) suggests surface loading rates of 46.8 – 77.3 $m^3/m^2 \cdot day$. Since depths in settling ponds may vary depending on the site, surface loading rate is the parameter that will dictate the area required for proper settling. Low overflow rates are the most critical disadvantage when evaluating treatment options for aquacultural facilities, especially for single-pass, raceway-style fish farms (Summerfelt, 1997, in press).

Another major disadvantage is the difficulty in removing the accumulated solids. Since most settling ponds will be large in size, it will be difficult for the operators to clean the ponds regularly. Some systems may incorporate an automatic sludge removal mechanism (Mudrak, 1981), but this will add considerable capital and maintenance costs. Most operations will allow solids to settle out and remain in the pond for long periods of time. This will allow for degradation of the settled solids allowing a reduction in particle size and a release of nutrients. If fish or waterfowl (Mudrak, 1981) find a way to get into the pond, the chance for resuspension is high due to the reduced particle size and high accumulation. Algae growth may also flourish due the slow velocity, dead areas, and nutrient content of the water.

Sediment Traps

Sediment traps, or "quiescent zones", are also a popular treatment device implemented at aquacultural facilities. They are placed at the end of a raceway, or set of raceways, and provide an area of quiescence to allow coarse solids to settle out. Screens and weirs make the boundaries of the sediment trap. Whether they are solely meant for retaining fish and controlling flow, or if they are designed to remove solids, sediment traps have been proven to be effective in the removal of waste solids (Axler et al., 1997). With their small size and simple design, they are easy to clean and maintain. The attractiveness of this option has caused some farms to redesign their facilities (MacMillan, 1991).

Tube and Plate Settlers

Tube and plate settlers have been used successfully in the drinking water (Smethurst, 1979) and wastewater (Mendis, 1980) treatment industries. Some aquacultural facilities have also used the settlers (Warren-Hansen, 1982; Libey, 1993). Their success in solids removal can be attributed to the high surface area and shallow settling depth provided within the plates or tubes. They do not require a lot of space, and they have high efficiencies compared to typical sedimentation basins. Yao (1970) and Metcalf and Eddy (1991) have published information on theory and design of these units.

Disadvantages include high capital costs and frequent backwashing (Summerfelt, 1997, in press) due to biological growth. Like the other sedimentation alternatives, if upkeep is not provided, smaller particles and a release of nutrients can occur.

Microscreens

Microscreens are a popular treatment option for aquacultural facilities, and applications have been documented in flow-through systems (Summerfelt, 1997, in press) and recirculating systems (Bergheim *et al*., 1993). Summerfelt (1997, in press) provides an excellent summary of the types of microscreens and theory behind the operation, along with the advantages and disadvantages in implementing such a treatment scheme. The screens are designed to remove a certain sized particle (and larger) based on the size of the openings. They are usually attached to a rotating device (e.g. drum or disc) where they are constantly immersed into the facilities effluent. Particles are removed from the screens by high-pressure water or air suction (Summerfelt, 1997, in press). Screens are typically sized based on the desired removal, hydraulic capacity, backwash conditions, and various other farm-specific characteristics. Many studies (Bergheim *et al*., 1993; Kelly *et al*., 1997; Summerfelt, 1997, in press) have reported excellent average solids removal efficiencies, some as high as 80%.

In addition to improved solids removal efficiencies, nutrient removals have also been reported to be significant because of their correlation with solids concentration (Cripps, 1992;

Schwartz and Boyd, 1994). With the requirement of frequent rinsing or vacuuming, solids are not retained for long periods of time, preventing degradation of the particles and release of nutrients. This is a considerable advantage over sedimentation technologies, where particles have been shown to degrade, release nutrients, and perhaps resuspend into the effluent. Other reported advantages include easy installation and small space and head requirements (Summerfelt, 1997, in press).

Disadvantages of this system include high capital costs, frequent maintenance, and little removal for particles smaller than 40 μm (Summerfelt, 1997, in press). Wade *et al.* (1996) performed analyses on capital and operating costs of various types of microscreen filters. Although it was determined that treating large flows was more economical than treating small flows, capital and operating costs were still very high. Based on information provided by Summerfelt (1996), 60 μm units will range in cost from $1,000 - $4,000 for every 380 L/min. These costs do not include backwashing and sludge removal costs, which also may be significant.

Filter Beds

Filter beds are one of the oldest treatments for water and wastewater facilities. Granular media filters can remove particles by settling, straining, interception, absorption, and biological growth (Metcalf and Eddy, 1991). The technology is also implemented at aquacultural facilities, with sand and plastic beads being the most common media used. The systems have the ability to remove small particles, large particles, ammonia, phosphorus, and pathogens within the pore spaces of the media. There are many disadvantages, however, as outlined by Summerfelt (1997 in press). Among them are: moderate head requirement, need for a sophisticated backwashing system, considerable capital costs, high maintenance costs, and inability to treat large flows.

Although Kristiansen and Cripps (1996) found that sand filters could be used for treatment of aquaculture wastewater for up to 2 -3 months before maintenance was needed, the release of nutrients was not well defined and will probably be site specific, depending on the organic and nutrient content of the effluent. Some farms may not have the available head to operate the system; others may not have the manpower for proper maintenance; and, most raceway-system farms have large flows that would require multiple beds.

Flotation

Flotation is a unit process that uses gas bubbles to facilitate solid/liquid separation. Bubbles are able to attach to solids to bring them to the surface based on the new specific gravity of the component (less than water). Dissolved air flotation (DAF) is a common flotation method where pressurized air is introduced into a water column. The bubbles quickly migrate to the surface carrying to the surface. Although it seems to be the opposite of sedimentation, the key to both systems is the difference of specific gravity between the particle and the water. A very heavy particle will easily settle, while a light particle will be easier to float. Thus, the inability of small particles to settle, is an advantage for DAF. Although DAF installations have performed well in fish processing industries (Marti *et al*., 1994; Genovese and Gonzalez, 1994) for removing grease, fats, solids, and other organics, very little data have been published on the feasibility of such installations for aquacultural effluent treatment.

Foam fractionation is another flotation process that uses dispersed air, or any other gas, to achieve a specific gravity difference between the solids and the water. Bubbles rise to the surface, adsorbing particulate and dissolved constituents, such as surfactants, along the way. Studies have proven this to be a successful technology in recirculating systems (Chen *et al*., 1993; Weeks *et al*., 1992) removing fine particles, nutrients, proteins, and other organics. Like

DAF, foam fractionation will remove small particles well (< 30 μm), particles that are typically missed by other conventional treatment processes (Chen *et al*., 1993).

Although flotation methods have been reported to be moderate in cost (Summerfelt, 1997, in press), the design and proper operation of such a system can be complex, and would only be shown to be efficient if used in conjunction with another conventional solids removal process (i.e. sedimentation). Since space and manpower is limiting at many farms, a combination of flotation and sedimentation would not be feasible. Another reason for caution would be the fact that most installations have been made at recirculating systems. Additional data and cost information are needed for high flow, single-pass systems in order for this process to be considered feasible.

Raceway Baffles

Baffle usage in hatchery raceways has proven to be successful for controlling waste solids (Boersen and Westers, 1986; Westers, 1991, and Kindschi *et al*., 1991). In these systems, baffles are placed along the raceway at various points. Baffles extend from above the water surface to some point above the bottom of the raceway. The theory behind the design is to space the baffles so they may cause the water flowing beneath the baffles to have a velocity great enough to cause solids to be carried downstream, rather than settling within the raceway. Once the solids reach the end of the raceway, a quiescent zone is used to allow sedimentation of the particles. This provides for a clean raceway and reduced nutrient releases. Capital costs are low and there is little headloss. Rainbow trout have been among the many cold water species that can tolerate these conditions (Boersen and Westers, 1986).

Disadvantages include a biological growth on the baffles that must be closely monitored. Although the growth may utilize some of the dissolved compounds found in the farm's effluent, the growth should be monitored to ensure flocs do not shear and get entrained in the effluent. The most important disadvantage is the difficulty placed on operations. To harvest fish, or to maintain a raceway, baffles must be taken out (IDEQ, 1998). Boersen and Westers (1986) note that “use of baffles in dirt raceways does not seem practical and has not been attempted”. Since many trout farms have earthen raceways; most have busy schedules for harvesting and transferring fish; and, few have efficient solids removal units to take advantage of the concentration of solids, baffles would not be practical for many farms.

Ozone

Ozone is used in the water and wastewater treatment industry for disinfection and odor control (Metcalf and Eddy, 1991). Ozone has been used in recirculating systems. Ozone can be added to the water in recirculating facilities to improve its quality, and to lower the amount of make-up water required (Summerfelt, 1997, in press). Its oxidizing capability is specifically helpful in the reduction of fine solids, nitrite, nonbiodegradable organics, and pathogens in the facility’s effluent. Other useful advantages for ozone is its rapid reaction rate and eventual production of oxygen. Disadvantages include its harmful nature to humans, on-site generation requirement, and high capital and operating costs (Summerfelt and Hochheimer, 1997). Ozone has been proven to work well in combination with other treatment processes such as microscreens (Summerfelt *et al.*, 1996), however, the level of treatment ozone provides acts more as a polishing step for water that will be reused. The high capital and operating costs, along with the level of treatment obtained, would not make this a feasible treatment option for many single-pass, raceway systems.

Wetlands

Constructed wetlands have also been considered for the treatment of aquacultural effluents (Massingill *et al*., 1998; Schwartz and Boyd, 1995; and Adler *et al*., 1996). Advantages of implementing constructed wetlands as a treatment scheme for an aquacultural facility include: low capital and operating costs, good nutrient uptake and solids removal, and a better plant and animal community. A variety of processes occur within wetlands that make them excellent treatment options for aquacultural facilities. Sedimentation, filtration, adsorption, plant uptake, and a variety of microbial processes that may reduce the organic and nitrogen content of the effluent have been cited as the main mechanisms for pollutant removal (Schwartz and Boyd, 1995). However, wetlands require a long detention time for proper effluent treatment, resulting in very large land requirements. Harvesting of mature plants is also required to prevent them from dying and releasing the nutrients that were previously bound. Another disadvantage is the inconsistent data that are available. Phosphorus uptake is heavily dependent on the plants, soils, composition of the effluent, and the lifetime of the system. The site-specific requirements of such a system, along with the large land area requirement, makes such a system infeasible for most large flow, single-pass systems.

Swirl Separators

Swirl separators are centrifuges that force solids to the walls, while the entire unit is spinning. In aquacultural settings, they are typically used to concentrate the solids in a smaller underflow (Warren-Hansen, 1982), where it is subsequently treated via filtration or sedimentation. Units such as these are more effective when treating particles that have high specific gravities, such as grit in the wastewater treatment. Villeneuve and Gaume (1994) found that the swirl separator was ineffective in removing pollutants from combined sewers. It was successful in removing sand and other heavy particles, but the fines and the pollutants that are commonly associated with them, escaped to downstream processes. Since particles in aquacultural effluent are known to be small and light, the efficiency of such a system is difficult to predict. Capital costs are relatively high (Warren-Hansen, 1982) and proper control of hydraulics is critical (Summerfelt, 1997, in press).

Aquacultural Sludge Treatment and Disposal

Landfills

Landfills are one of the least common methods to dispose of aquacultural waste solids because of high costs. Some facilities are forced to take their sludge to a landfill where states regulate the waste as industrial, rather than agricultural. When on-site space or local cropland is not available for disposal, aquacultural facilities may again be forced to take their waste to a landfill. When this is the case, most landfills will require the sludge to be thickened before disposal. Thus, on-site thickening of aquacultural sludge would be necessary, but disposal and transportation costs would be lowered significantly (Summerfelt, 1997, in press). Since Virginia permits aquacultural facilities to land apply their sludge, in addition to the fact that many trout farms are located in rural areas with plenty of available cropland, landfilling may not be necessary, nor economical.

Land Application

Land application of aquacultural sludges is the easiest and most common method of waste solids disposal for fish farms (IDEQ, 1998). Regulations vary state to state, but most allow aquacultural sludge to be land applied because of minimal concentrations of metals, pathogens, and toxics within the sludge. To evaluate the feasibility for a given farm, the distance to the land application site, in addition to how quickly the sludge accumulates at the farm, should be considered.

The rate which sludge may be applied to land is dependent on a variety of factors. Soil type, plant type, odor issues and sludge nutrient content are the major factors that govern the application rate and land area required for proper application. Table 1 includes data taken from Metcalf and Eddy (1991) which indicates the nutrient uptake rates of various crops and forests.

Table1. Nutrient uptake rates for selected crops and forests (adapted from Metcalf and Eddy, 1991).

Land Use	Nitrogen Uptake (kg/ha·yr)	Phosphorus Uptake (kg/ha·yr)
Bermuda	392 - 672	33.6 – 44.8
Kentucky Bluegrass	202 - 269	44.8
Tall Fescue	151 - 325	29.1
Corn	174 - 193	19 – 28
Cotton	74 - 112	13.4
Wheat	56 – 90.7	16.8
Hardwood Forest (Eastern)	218	-
Red Pine Forest (Eastern)	112	-

Although phosphorus is usually the limiting nutrient for plant growth, nitrogen is frequently used to set sludge application rates because of possible leaching to the groundwater table. Depending on the type of crop, the land requirement may be altered one way or the other. If sludge is found to accumulate at a high rate (which would be expected after implementation of a treatment scheme), if the disposal site is far from the farm, and/or if the farm experiences climates that would prevent land application, on-site thickening may be considered. Studies (Naylor *et al.*) have shown that there are measures that can be taken to prevent excessive runoff during winter months. Other studies (Bruggeman and Mostaghimi, 1993) have demonstrated that the surface application of sludge actually helped reduce sediment and nutrient losses for no-till and conventional-till croplands.

Composting

Composting is another popular sludge treatment alternative used in the aquacultural industry. When large land areas are not available for land application, or if transportation and disposal costs are high, composting can be an attractive alternative (IDEQ, 1998). Aerated stack piles are the most common method (Summerfelt, 1997, in press), and they require a bulking agent, aeration source, and frequent turning and mixing. Although there has not been many studies published on the effectiveness of composting waste solids, there have been good results for composting processing wastes and mortalities (Shelton *et al*., 1998). Waste solids are thought to compost in much the same manner (IDEQ, 1998; Summerfelt, 1997, in press). There is considerable capital investment for the equipment, and operating such a system will also require extra money and manpower. However, composting may be feasible if there is a market for the rich compost, or if other alternatives are found to be infeasible or uneconomical (IDEQ, 1998). Although land application is the easiest and most common method of sludge treatment/disposal, it may still be worthwhile to investigate composting to take full advantage of the marketability of the high-nutrient sludge.

Sludge drying beds

Sludge drying beds are one of the most common on-site sludge handling processes implemented for aquacultural waste solids. Sand drying beds, paved drying beds, lagoons, and wetlands are among the types of sludge handling processes that can be implemented at aquacultural facilities. Vertical flow wetlands (Summerfelt *et al*., 1996) have been shown to have to have significant TSS, COD, and nutrient removal. Plant uptake allows wetlands to thicken sludge to as high as 7% solids, and have useful lifetimes of up to ten years (Reed *et al*., 1995). Similar results were found for activated sludge (Lienard *et al*., 1995). Lagoons rely on evaporation as the main method for thickening sludge, but some removal is also accomplished by percolation. Lagoons are effective in areas where evaporation is high, and they usually have cycles from several months to several years. After decanting the supernatant, sludge is usually removed at a solids content of 25 - 30% (Metcalf and Eddy, 1991). A detailed design of lagoons for aquacultural sludges is given by IDEQ (1998).

2.0 Water Quality and Sludge Characterization at Raceway-System Trout Farms

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Abstract

Studies were conducted to characterize effluent quality and the waste solids within the waters of three raceway-style trout farms. No significant differences were noticed in effluent quality between the three farms during seven months of periodic grab sampling. Average effluent quality over the course of a day was not found to be impaired during a sampling and monitoring study. However, effluent quality was found to change significantly during times of feeding and harvesting. Normalized Total Suspended Solids (TSS) concentrations were as high as 115 mg/l for an effluent under the influence of an intensive harvest. Feeding was also seen to cause spikes in TSS concentrations (as high as 63 mg/l). Total Kjeldahl Nitrogen (TKN) and Ortho-Phosphate (OP) concentrations were also seen to rise during feeding and harvesting activities.

Through batch studies and particle counting techniques, aquacultural waste solids were found to degrade over time. Distribution of particles in the 5 – 20 µm range were found to increase from 57% to 85% in a period of six days. Particle size distributions in aquacultural effluents were also found to be a function of the fish and feed size, and time of day.

Waste solids accumulation in quiescent zones (sediment traps) was monitored in a field experiment to quantify the capacity and trapping efficiency of the units. Solids were found to accumulate at a rapid rate; however, the trapping efficiency of the units was found to be extremely low when taking into account the feed conversion ratios (FCRs) and typical utilization rates of production fish. High overflow rates, particle degradation, flow spikes, and high sludge banks lead to scouring of waste solids and a point of maximum capacity for the sediment trap.

All findings may be useful for future treatment evaluations and suggestions for best management practices (BMPs) for similar aquacultural facilities.

Keywords: Solids; Nutrients; Sludge; Scouring; Raceway; Trout; Particle distribution; Sediment traps

2.1 Introduction

Recently, the Virginia Department of Environmental Quality (VDEQ) performed benthic surveys in many of the receiving streams that were under the influence of trout farm discharges. The results indicated that many of the trout facilities had an adverse effect on receiving waters and associated aquatic organisms. Due to the rising state and federal concern over aquacultural effluents, VDEQ provided Virginia Tech researchers with funding to identify and assess viable treatment options for suspended matter in fish culture effluents. Background on the operations of such facilities are covered by Sedgwick (1995), Stickney (1994), and Brown and Gratzek (1980).

The purpose of this study was to characterize the effluents from three raceway-style trout farms in Virginia and to relate how the constituents within these waters can dictate treatment process selection and design. Site characterization, water quality monitoring, waste solids characterization, and various other laboratory and field experiments were the tools used to accomplish this objective. Special attention was given to the nature of the suspended and settled (sludge) waste solids generated within the farms. Suspended matter is of most concern because of the loadings observed within trout farms, along with the fact that other pollutants (nutrients) have been seen to be associated with elevated TSS levels (Cripps, 1992; Schwartz and Boyd, 1994).

2.2 Methods and Materials

2.2.1 Site Selection

As mentioned previously, three trout farms were selected for this study. Two of the three facilities (Farm A and Farm B) are private companies, while the third (Farm C) is state-owned. The base for choosing the three farms included: (1) they were the subject of the benthic surveys conducted by the State, (2) they were willing to participate in the project, and (3) they were thought to be good representations of the raceway-style fish farms present in the Commonwealth of Virginia. Site characteristics are provided in Table 1. Sketches of the three facilities are shown in the Appendix.

Table 1. Site characteristics of the three trout farms.

Characteristic	FARM		
	A	B	C
Average Production (kg/yr)	27,200 – 36,300	27,200	79,400 – 113,400
Fish Type	Rainbow and Brook	Rainbow	Rainbow, Brook, Brown and Stripers
# Raceways in Use (Total #)	3 (7)	14 (14)	24 (31)
Feeding Practice	Automated (pull string)	Hand (measured)	Hand (measured)
Reported Feed Conversion Ratios (FCRs)	1.6	1.6 - 2	1.2 – 1.8
Concrete/Earthen Lined	Concrete	Concrete & Earthen	Concrete & Earthen
Water Source	Spring	Spring	Spring
Manpower	1 person	1 person	4 – 6 people
Pollutants regulated	TSS, NH_3-N, & SS	TSS, BOD_5 & SS	TSS, BOD_5, NH_3-N & SS
Treatments	Sediment traps	None	Sediment traps

2.2.2 Sampling and Monitoring

Waters within the farms and at the outfall of the facilities were sampled and monitored from September of 1997 to April of 1998. Although laboratory and field studies were being performed concurrently, general sampling and monitoring was performed on a bi-monthly basis. Among the parameters measured were temperature, dissolved oxygen (DO), total suspended solids (TSS), settleable solids (SS), volatile suspended solids (VSS), dissolved organic carbon (DOC), five-day biochemical oxygen demand (BOD_5), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), total phosphorus (TP), orthophosphate (OP), and flow. Grab samples were taken at the inlet, at the end of each active raceway, and at the facility outfall. Periodic composite samples were collected to obtain 24-hour samples at the various farms and raceways. Facility records were also kept regarding kilograms fed, kilograms of fish gained, number of fish per kilogram, number of fish moved (in or out), and number/pounds of fish harvested from each raceway.

A five-day intensive effluent monitoring study was performed in April at Farm C. The main purpose of this study was to identify peaks in effluent concentrations during a full workweek of farm activities. Three raceways within this farm were targeted for the study based on differences in size, fish density, and harvesting activity. Series of grab samples were taken at the head and end of each raceway and analyzed for TSS. The time between samples was 2 to 120 minutes, depending on the level of activity of the farm, with the daily monitoring occurring from 7am - 4pm. Periodic samples were also taken to measure nutrients (TKN, TP, and OP), DOC, SS, and particle size. Twenty-four hour composite samples were also taken at the end of the raceways for TSS measurement. Times of feeding and harvesting were closely recorded for subsequent correlation with effluent quality.

2.2.3 Water Quality Parameters

TSS, VSS, SS, TP, OP, TKN, NH_4-N, BOD_5, and DOC were performed in accordance with Standards Methods (1995). DO and temperature were measured using a YSI Model 57 Oxygen Meter. Flow was measured with a Swoffler velocity meter, in combination with weir equations (Evett and Liu, 1987). Due to low velocities within the raceways, the Swoffler velocity meter was not sensitive enough to measure flow within a farm's raceway. The meter cannot detect velocities below 3 cm/sec, and can induce errors when the velocity decreases below 46 cm/sec. Although flow-through trout farms have high flows, the immense surface area of a farm causes typical raceway velocities to be approximately 0.05 – 0.10 cm/sec (Stechey, 1998). Velocities at certain locations in earthen-walled raceways will be even lower due to short-circuiting and deadspots. Farms B and C, however, have inlet channels that bring water from a spring and distribute the flow equally among each train of raceways. These channels have high enough velocities to allow for precise measurement of flow. Because of the need to measure the distribution of flow within the farms, water height over the outlet weirs was measured and subsequently used in a sharp-crested, contracted, rectangular weir equation (Eq. 1):

$$Q\left(m^3/\text{sec}\right) = CL^{1.02}H^{1.47} \qquad (1)$$

where C = 1.69, L = weir length (m), and H = water height (m)

Using the experimental coefficients and factors, a flow was determined. Because weir equations are largely empirical, a comparison was made at Farm B between the total inflow (using the Swoffler velocity meter) and the sum of the flows passing over the first weir in each train of raceways (using weir equations). This study was performed twice at Farm B on separate occasions. Both studies proved that measuring the water height passing over the outlet weir was within 2.5% of the total flow coming into the farm. This provided the project team with confidence in measuring raceway flows using weir equations. Since weirs at Farms A and C are constructed and used in the same manner as they are at Farm B, inter-farm flows at all facilities were calculated using Equation 1. Flows were measured periodically at all three facilities.

2.2.4 Particle Size Analysis

Particle size analyses can give an indication of the number, mass, and/or volume of particles within specified size ranges. Limited studies have been published on the particle size distribution of solids in aquacultural effluents. Those that were performed (Chen *et al*., 1993; Kelly *et al*., 1997: Cripps, 1995; Chapman *et al*., 1987), however, were helpful in identifying typical size distributions and for subsequent comparison with the data obtained in this study.

Particle Counts and TSS distributions were performed on various effluents and sludges encountered at the three farms to provide preliminary information on the applicability of certain treatment alternatives. TSS distributions were obtained by passing the filtrate of a known volume of sample through a series of macroporous filters (larger to smaller) and determining the retained solids on each. Filter sizes included 1.5, 30, 70, 105, and 210 microns (μm). Although the TSS distributions provided information regarding the size ranges that contributed the most toward the overall TSS, they did not provide data for the number distribution or volume of the particles.

Particle counting was performed with a HIAC Model PC-320 Automatic Particle Size Analyzer with a 300 μm sensor. The sensor was calibrated by Pacific Scientific in December of 1997. This instrument has the capability of counting particles in twelve, user-selected size ranges. An inherent assumption of the device is that all particles are assumed to be perfect spheres. Chen et al. (1993) conducted a study with a similar instrument and concluded that particles could indeed be approximated as spheres. Particle counts were performed on various effluents and sludges from the farms and samples generated in the laboratory. All samples were filtered through a 210 μm macroporous filter to prevent repeated clogging of the sensor. After filtering, samples were diluted (if needed), and carefully split into sampling jars. Dilutions of the filtrate were often necessary before splitting to bring the total number of particles to be counted below 12,000. The analyzer would extract 10 ml of sample from the jar and would count and display the number of particles in each size range. To verify the jar was being completely mixed during the sampling process, the procedure was repeated four times to obtain 5 total data sets within each jar. Initially, four replicates of each sample were also analyzed to ensure proper splitting of the sample; however, due to good replication and the duration of the process, the number of replicates was decreased to three, and, toward the end of the project, to two. Because of the sensitivity of the particle counting process, all glassware and equipment were thoroughly rinsed with Nanopure water. Between samples, Nanopure water was flushed through the sensor until particle counts in all size ranges approached zero.

2.2.5 Batch Study

Batch studies were performed in the laboratory in an attempt to measure particle degradation as a function of time. In terms of this paper, degradation is defined as particle breakdown as a result of physical and biological processes. Studies were performed for various durations and sampling intervals. The batch study discussed in this paper was performed for 8 days, with sampling occurring every two days. The reactor consisted of a 110-liter cylindrical tank in which fresh trout farm effluent was added on Day 0. The reactor was held at a constant temperature of 26 °C and was continuously aerated to maintain a DO concentration similar as to what was found in the field. At the time of sampling, the reactor was mechanically mixed for approximately 10 minutes using a Graham ¼ hp, 3450 rpm (multiple speed), single-phase, alternating current motor with two, 23-cm impellers, providing for a well-mixed sample to analyze TSS, particle size distribution, TSS distribution, nutrients, and DOC. The mixer was quickly turned off following initial sampling to allow the remaining particles to settle and degrade in much the same fashion as what occurs at the bottom of the raceways.

2.2.6 Sludge Accumulation

Due to observations made in the eight months of sampling and monitoring, in addition to what was observed during the five-day, intensive effluent sampling and monitoring performed at Farm C, a study was undertaken to measure the accumulation of solids in sediment traps. Sediment traps, or “quiescent zones”, are a popular treatment device implemented at aquacultural facilities. They are placed at the end of a raceway, or set of raceways, and provide an area of quiescence to allow coarse solids to settle out. Screens and weirs usually make the boundaries of the sediment trap. Whether they are solely meant for retaining fish and controlling flow, or if they are designed to remove solids, sediment traps have been proven to be effective in the removal of waste solids (Axler et al., 1997). In addition to measuring solids accumulation in the traps, data concerning the settling efficiency, nutrient content, and particle size distribution were also obtained.

A raceway was chosen at Farm C to be the target of this study. It was one of the larger raceways in the farm, with dual sediment traps, a high feeding rate (22.7 kg/day), 6.3 mm screens, and periodic harvests during the study. The dual sediment traps allowed for accumulation measurement on one trap, with sample withdrawal from the other trap. In this way, one trap remained undisturbed throughout the study. Since previous measurements indicated that flow was evenly distributed between the two sediment traps, solids were assumed to accumulate in same manner for each trap, allowing an accumulation rate to be calculated based on the entire raceway. On Day 0, both sediment traps were completely cleaned of any settled solids. The site was then visited on days 6, 10, 14, and 22 to measure accumulation and to extract a sludge sample for nutrients, TSS, VSS, bulk density, and particle size. Accumulation was obtained by splitting the sediment trap into a grid (Figure 1) and measuring the depth of sludge at each coordinate.

All data were entered into Sigma Plot, where three-dimensional plots and total sludge volume calculations were developed. Based on the bulk density and percent moisture of the sludge, and the time between site visits, an accumulation rate (volume/time or mass/time) was

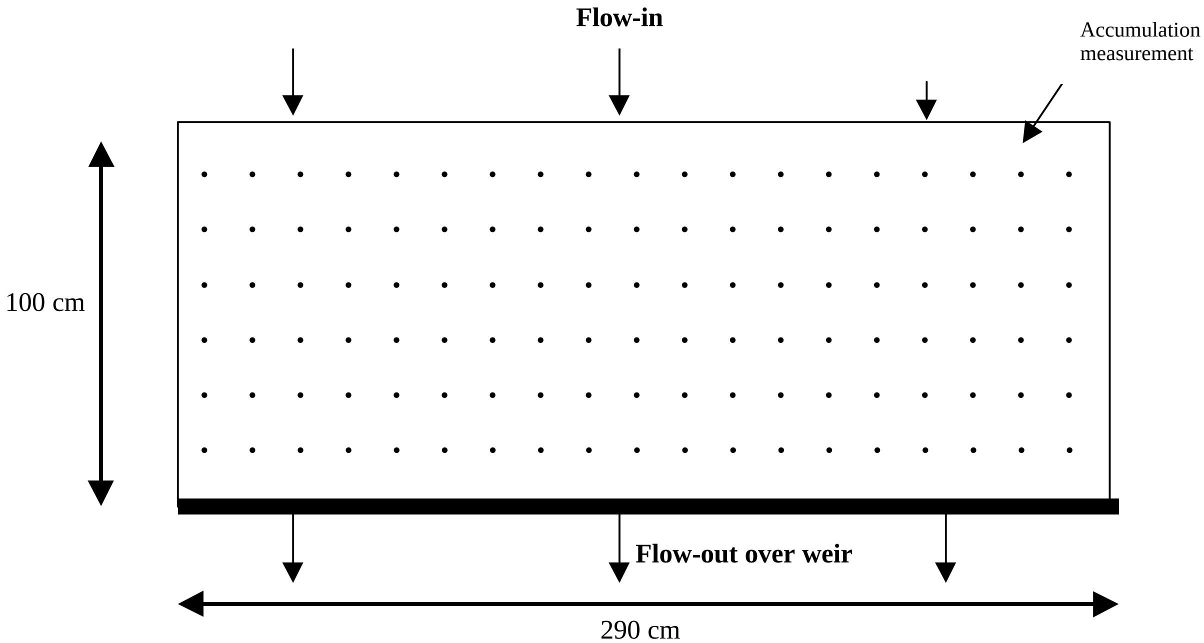

Fig. 1. Example of grid system used at Farm C for one of the sediment traps in the observed raceway.

calculated. Fish densities and feed rates were also closely monitored for additional correlations. Samples from the other trap were never taken from the same spot to ensure a fresh sample was taken each time. A 60-liter Shop Vac, Model QL50D was used for trap cleaning and sample withdrawal. Flow rates were assumed to be equal across each sediment trap, although measurements were taken on each sampling day to check the validity of the assumption.

2.3 Results and Discussion

2.3.1 Sampling and Monitoring

Sampling and monitoring data for the three trout farms are summarized in Table 2. As seen from the data, there does not seem to be a significant effect on water quality from the point of entry ("inlet") to the point of discharge ("outlet"). Small differences in DO (10.6 vs. 8.5 mg/l, 10.5 vs. 7.9 mg/l, and 10.5 vs. 8.1 mg/l), TSS (0.2 vs. 3.2 mg/l, 0.5 vs. 3.9 mg/l, and 0.3 vs. 6.1 mg/l), and BOD_5 (0.7 vs. 1.3 mg/l, 0.5 vs. 1.2 mg/l, and 1.1 vs. 1.3 mg/l) can be seen between the inlets and outlets of Farms A, B, and C, respectively. These differences, in terms of water quality and permit requirements, do not seem to pose a significant threat to the environment. All

Table 2. Water quality data for trout farms A, B, and C. "Within Farm" relates to data obtained from the end of all active raceways in each farm. Parenthesis ( ) indicates the mean of the data.

Parameter	FARM A			FARM B			FARM C		
	Inlet	Within Farm	Outlet	Inlet	Within Farm	Outlet	Inlet	Within Farm	Outlet
Flow (m3/min)	2.70– 4.05 (3.10)			11.2 – 24.8 (16.8)			25.6 – 28.9 (27.7)		
DO (mg/l)	9.2 - 14.2 (10.6)	3.2 – 13.3 (7.0)	5.7 – 9.5 (8.5)	8.2 – 11.5 (10.5)	5.8 – 10.8 (8.6)	6.8 – 9.6 (7.9)	9.4 – 10.6 (10.5)	4.8 – 9.7 (7.6)	7.2 – 9.4 (8.1)
Temp (°C)	10.5 – 13 (12.2)	11.5 – 15 (13)	11 – 15.5 (12.9)	6 – 12.5 (9.7)	6 – 14 (9.1)	5 – 16.5 (11.4)	8.5 – 13.5 (10.5)	8 – 14 (11.0)	8.5 – 14 (10.4)
pH	7.1 – 7.4 (7.3)	7.0 – 7.4 (7.2)	7.3 – 7.8 (7.5)	7.3 – 7.6 (7.5)	7.2 – 7.6 (7.4)	6.9	7.3	7.1 – 7.6 (7.3)	7.8
TSS (mg/l)	0 – 1.1 (0.2)	0 – 30.4 (3.9)	0.8 – 6 (3.2)	0 – 1.8 (0.5)	0 – 43.7 (5.3)	1.5 – 7.5 (3.9)	0 – 1.5 (0.3)	0 – 28 (7.1)	4.1 – 62 (6.1)*
SS (ml/l)	0		0 - .04 (.02)	0		0.01 - .08 (0.04)	0		0.04 – 0.08 (0.07)
BOD_5 (mg/l)	0 – 1.25 (0.7)	0.5 – 3.9 (1.5)	0.96 – 1.9 (1.3)	0 – 1.4 (0.5)	0.3 – 7.2 (2.1)	0.6 – 2.4 (1.2)	0 – 2.0 (1.1)	0.4 – 7.5 (2.5)	0.5 – 1.8 (1.3)
DOC (mg/l)	0.93 – 4.11 (2.1)	0.9 – 7.9 (2.9)	1.5 – 2.4 (1.9)	0.91 – 2.56 (1.6)	1.2 – 8.1 (2.7)	1.2 – 3.1 (1.9)	1.1 – 2.7 (2.0)	1.1 – 11.1 (2.4)	1.5 – 3.8 (2.3)
NH_3-N (mg/l)	0.6	0.2 – 1.1 (0.5)	0.5 – 0.6 (0.6)	0.2	0.06 – 1.1 (0.5)	0.45	.03	.03 – 2.2 (0.4)	0.02 – 0.17 (0.1)

* - Two outliers thrown out for calculation of mean

mean concentrations of the regulated parameters (DO, BOD_5, TSS, SS, and NH_4-N) are well below the average discharge concentration standards stated in each farm's permit. There were very few instances (Farm A DO and Farm C TSS) where the upper or lower range would have caused a violation of the permit.

Measurements within active raceways, however, generate a bit more concern. There were many instances at all three trout farms when water quality passing through a given raceway was impaired, especially for DO and TSS. Many TSS spikes, for example, were seen to be as high as 30 or 40 mg/l, a concentration that could have significant impacts on water quality and aquatic life of the receiving streams. In virtually all instances, however, the effluent quality was able to recover before discharge. Recovery could be due to settling within the lower raceways or by dilution with the rest of the farm's flow. Spikes at the outfall could also have been missed due to the periodic nature of the sampling process. These "inter-farm" spikes cannot be overlooked as they provide an idea of how severe effluent quality can be affected depending on the farm activities and location of the raceway in question.

Flows in the three farms were higher than expected. However, sampling dates coincided with the rainy season, September to March. Thus, low flows during the late spring and summer were not measured and included in the farm averages. Because flow data are on the conservative side, pollutant concentrations are probably lower than would be expected if summer flow data were considered. While flows tend to decrease during the hot months of the year, the loading of pollutants remains the same, resulting in a more concentrated effluent that may impact water quality. Also, inflow measurements were assumed to accurately represent outflow. However, some of each farm’s total flow is probably lost due to evaporation, infiltration, or by some other means of diversion; estimating such occurrences was beyond the scope of this project.

Many of the samples that were high in TSS seemed to coincide with feeding, cleaning, or time when fish were excited. Although none of the samples taken coincided with a farm harvest, such practices were observed at Farms B and C. By having employees walking in the water, and by corralling the fish into a small area (an area which usually has many settled solids on the raceway bottom), significant TSS spikes (“shock loadings”) were observed. Since feeding usually does not occur during or close to the same time as the harvest, most, if not all solids present in the water column can be attributed to the resuspension of bottom deposits. After consulting literature on water quality effects of harvesting, feeding, cleaning, and other farm activities (Parjala, 1984; Schwartz and Boyd, 1994; Kelly *et al*., 1997), more attention was focused on these issues. A five-day intensive effluent monitoring study was performed as a result of the above observations. Characteristics of the three raceways can be seen in Table 3.

Table 3. Characteristics for three raceways at Farm C subjected to intensive monitoring study. Study performed 3/28/98 – 4/3/98.

CHARACTERISTIC	RACEWAY		
	I	II	III
Feed Rate (kg/day)	0/22.7[a]	22.7	45.4
Quantity of Fish (kg)	453	1360	10,400
Fish Density (kg/m^3)	6.47	15.2	72.8
Raceway Dimensions (l x w x d); m	61 x 3.7 x 0.30	60 x 4.4 x 0.33	58 x 8.0 x 0.30
Flow (m^3/min)	5.0 – 5.5 (5.1)[b]	5.0 – 5.5 (5.1)[b]	9.5 – 10 (9.8)
Harvesting (y/n)?	No	Yes	No

[a]Feed rate changed from 0 lbs to 22.7 kg on 4/1/98.

[b]Raceway I flows directly into II. Thus, equal flows are assumed.

As seen from Table 3, the three selected raceways were different in terms of size, flow, fish density, and harvesting activity, providing a good variety of raceway conditions for the study. TSS fluctuations were given the most attention. Many samples were collected in raceways II and III due to the high feed rates and/or harvesting activity of the raceways. Due to the large number of samples projected for the study, it was decided raceway II would only be sampled intensively on days 1-3 (one day for baseline, two days of harvests) and raceway II would be sampled for the entire week. Samples were not taken on Day 4 due to a delay in the arrival of the recently ordered sample bottles. Figures 2 and 3 provide an illustration of changes in TSS concentrations during various days of the study for raceways II and III.

The reason for plotting the difference between the inlet and outlet of the experimental raceways in Figures 2 and 3, was to give an indication of how severely water quality can be impaired due to one event. As seen from the figures, TSS concentration varies greatly in a given work day, especially when harvesting occurred (days 2 and 3 for raceway II). Peaks were seen to be as high as 115 mg/l and 72 mg/l. Although these are large spikes, the events occur very quickly (10-25 min), and end up being diluted, or completely missed when collecting 24-hr composite samples.

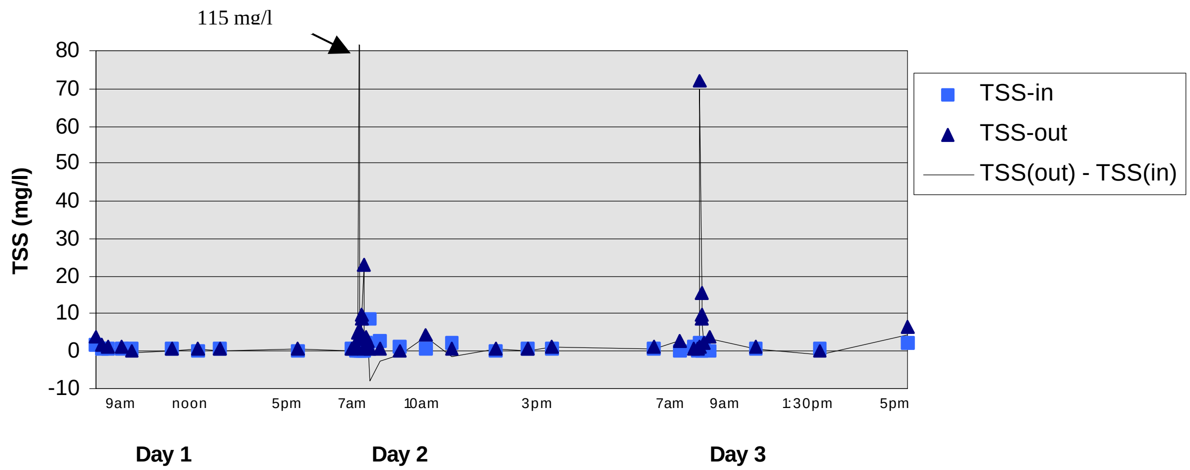

Fig. 2. TSS Concentrations for Raceway II during days 1-3 of a 1-week intensive sampling study.

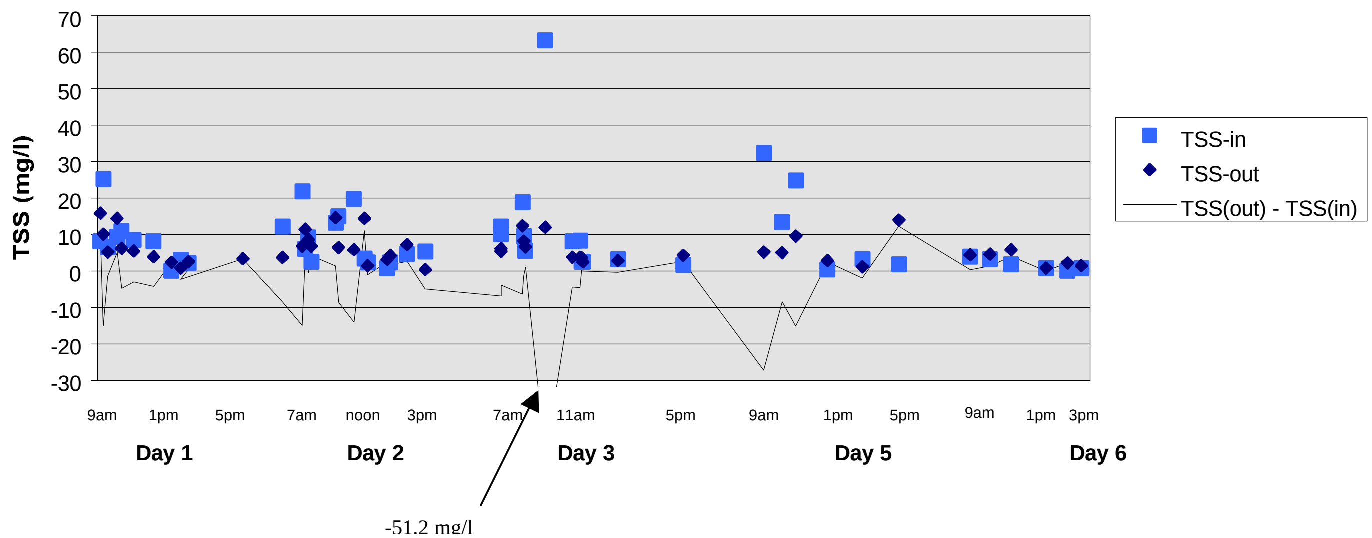

Fig. 3. TSS Concentrations for Raceway III during days 1-3, 5-6 of a 1-week intensive sampling study.

Effects of feeding are apparent when analyzing Figure 3. Raceway III was not harvested during the study; however, it did have a high fish density, and thus a high feeding rate (11.4 kg/feed, 4 feeds/day). Concentrations are seen to fluctuate more than what is seen in raceway II. Fluctuations are not only due to more feeds per day, but it is also due to the water quality of the upstream raceways. Several times during the five days of monitoring, the water quality coming into raceway III was highly impaired, masking the effects of feeding. The raceway upstream of II was virtually empty at the time of this study, enabling easy isolation of the events in raceway II. When a series of raceways are active and feed rates are high, water quality can be impaired for longer periods of time. Table 4 can help with this analysis by illustrating the range and mean concentration of solids for the inlet and outlet of Raceways II and III.

Table 4. Range and mean ( ) TSS concentrations for Raceways II and III.

ACTIVITY	TSS (mg/l)			
	RACEWAY II		RACEWAY III*	
	IN	OUT	IN	OUT
Feeding	0.7 – 1.7 (1.0)	1.3 – 3.7 (2.2)	0.8 – 63.2 (16.2)	3.2 – 15.8 (10.7)
Harvesting	0 – 2.4 (0.7)	0.6 – 115 (16.1)	-	-
No Activity	0 – 2.2 (0.7)	0 – 6.6 (1.4)	0 – 19.8 (5.0)	0.4 – 14 (4.0)

*- Raceway III not harvested

As seen in Table 4, TSS concentrations entering raceway II were low for every sample (max of 2.4 mg/l) during every event. Thus, the high spikes seen in Figure 2 can be completely attributed to harvesting. Water quality entering raceway III was impaired much of the time, however. TSS concentrations as high as 63.2 mg/l enter the raceway during the feeding process. This is because two to five workers feed simultaneously, causing each upstream raceway to have an effect on the lower raceways. This high inlet TSS contribution makes it difficult to assess feeding effects of one raceway. These high inlet concentrations (e.g. 63.2 mg/l) also indicate that the feed is not being utilized efficiently in the upstream raceways. Many studies have confirmed such wastage during manual feeding practices (Schwartz, 1994; Summerfelt, 1998; Michelson, 1991).

Other water quality parameters during harvesting can be seen in Table 5. TKN is seen to remain fairly steady, while OP is seen to increase significantly with high TSS loads. These results make sense, as previous studies (Braaten, 1991; Heinen *et al.*, 1996) have found 50-85% of the phosphorus is in particulate form, while over 85% of the nitrogen is in solution.

Table 5. Other water quality data taken during harvests*.

PARAMETER	RACEWAY II	
	Inlet	Outlet
Settleable Solids (ml/l)	0	0.1 – 1.5 (0.8)
DOC (mg/l)	1.2 – 2.1 (1.7)	1.8 – 3.1 (2.6)
TKN (mg/l)	0 – 3.3 (1.6)	4.4 – 6.4 (5.4)
Ortho-Phosphate (µg/l)	24 – 42 (33)	53 – 320 (190)

* - Mean based on two sampling events (Days 2 and 3)

2.3.2 Particle Size Analysis

Particle size analyses were performed via filtration for various effluents and sludges to arrive at an estimate of TSS distributions. The data will allow for proper solids treatment evaluations and designs. Examples of the filtration results can be seen in Figures 4 and 5. Size ranges are in microns (µm), while their magnitude is represented as percent contribution of total TSS.

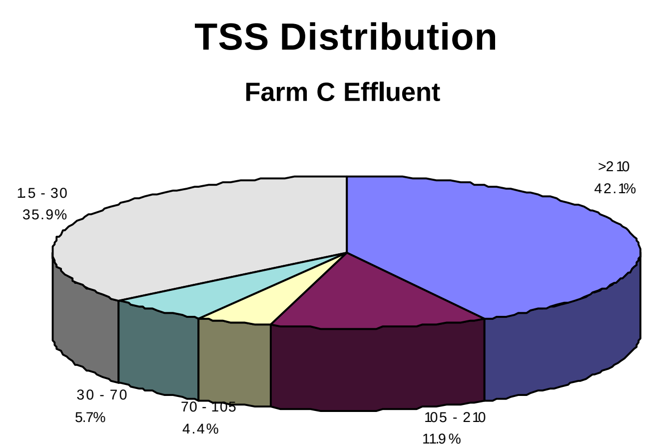

Fig. 4. TSS distribution of Farm C effluent.

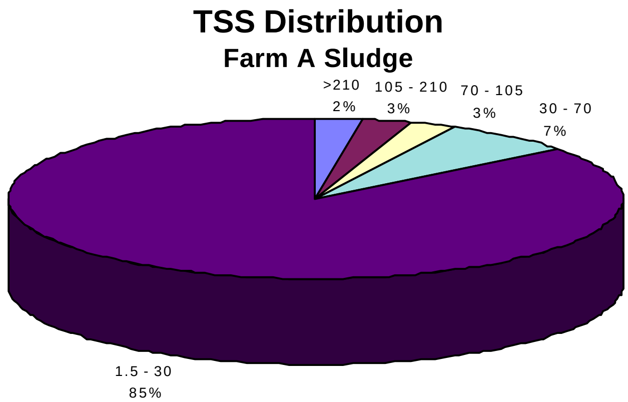

Fig. 5. TSS distribution of Farm A sludge.

The examples in Figures 4 and 5 are representative of the results found throughout the facilities over the course of the project. Although the mass of solids in the 1.5 – 30 µm range is a bit higher in Farm A's sludge sample than others, more than 50% of the solids in the remaining sludges were in this range. This information, especially for the effluents, verifies the results of previous studies (Chen *et al*., 1993; Kelly *et al*., 1997; Cripps, 1995) in that a high portion of the solids present in aquacultural facilities is in these lower size ranges. These results indicate that high percentages of the effluent TSS are in size ranges that are not typically easy and economical to treat. Many filter screens, for example, have optimum removal efficiencies for particles larger than 80 µm (Chen *et al.*, 1993; Summerfelt, 1998a).

Particle counting was then implemented to back up the filtration results, and also to derive a better idea of particle distribution. Initial particle count measurements on effluents indicated that as high as 85% of the particles were less than 20 µm in diameter. Sludge samples had an even higher percentage of particles in this same size range. Although particle count measurements were seen to vary in these smaller size ranges, there was never an instance when particles from 80 – 210 µm resulted in a contribution of more than 5% (solids > 210 µm were excluded by sample preparation procedure), contrary to results from TSS distribution. A linear relation between the number distribution and the TSS distribution was not found for the effluents mainly because of the vast difference in volume between the smaller particles and larger particles. For example, it would take 1,600, 5-micron particles to achieve the same volume as one, 200-micron particle. Since it is inherent that the smaller size ranges will always have more particles, it is difficult to make correlations with mass within specified size ranges. If there are instances when TSS and number distributions are similar, it more than likely occurred by chance, and not because number distributions are a good tool for prediction of mass distributions. Number distributions are helpful, however, for determining trends in the number distribution. For example, from TSS distributions and particle counts, there was an apparent difference in particle sizes between the effluents and sludges found at the farms. These findings prove that particles may degrade in the raceway bottoms and sediment traps. A controlled batch study was performed to attempt to monitor particle degradation over time. Results from the batch study can be seen in Table 6 and Figure 6.

Table 6. Particle count data* from batch study for days 2, 4, 6, and 8. Particle counts expressed as percent of total number.

Day	Size Range (µm)											
	5-10	10-15	15-20	20-25	25-30	30-40	40-50	50-60	60-80	80-100	100-120	120-210
2	25.4	19.2	12.7	9.9	8.1	12.7	5.3	2.8	2.4	0.8	0.3	0.5
4	35.8	24.1	14.2	8.8	5.7	7.7	1.3	0.9	0.8	0.3	0.2	0.3
6	42.2	25.2	12.7	6.9	4.1	4.7	1.6	0.9	0.8	0.4	0.2	0.3
8	48.8	25.2	11.4	5.4	2.9	3.3	1.2	0.6	0.6	0.3	0.1	0.2

Table 6 presents the raw data obtained from the batch study, while Figure 6 groups the data into three main size ranges for graphical representation. The bar chart shows that particle degradation does occur, and that it may occur relatively quickly. Although it was difficult to prove in the laboratory, the significance of these findings is that degradation may lead to reduced settling efficiency and the release of additional nutrients that were previously bound (Summerfelt, 1998a; Summerfelt 1998b).

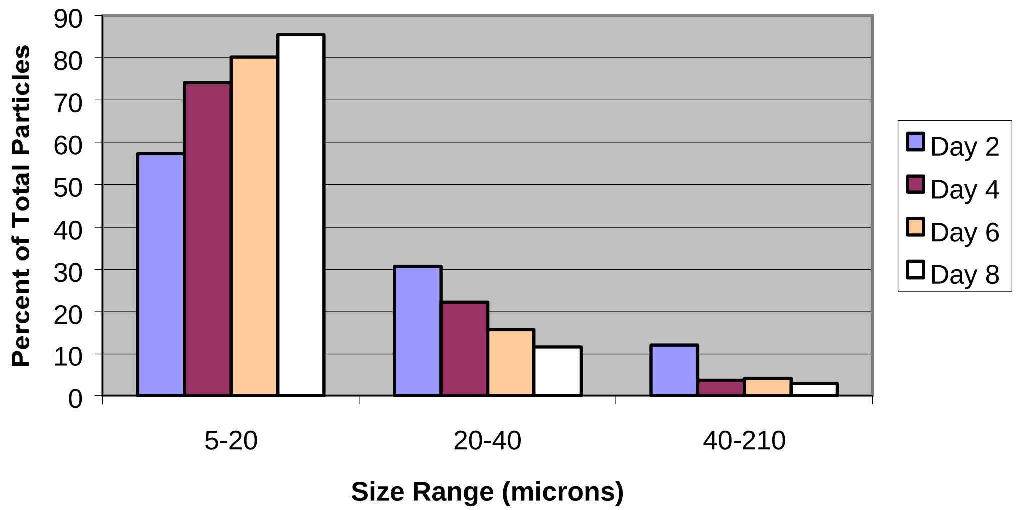

Fig. 6. Change in particle count distribution during batch study.

The particle size distributions are also seen to vary according to the size of fish and time of day. Table 7 summarizes the same three particle size ranges according to fish size and farm activity.

Table 7. Particle size distribution for three different sized fish, during three different times of the day.

Fish/kg	Percent of Total Number								
	During Feeding			In-Between Feeds			After Work Day		
	5-20µm	20-40µm	40-210µm	5-20µm	20-40µm	40-210µm	5-20µm	20-40µm	40-210µm
100	82.2	12.2	5.6	84.3	10.6	5.2	73.8	18.1	7.9
22.7	74.2	16.1	9.6	73.9	15.9	10.1	69.1	17.3	13.5
4.20	64.7	19.3	16	73.5	17.4	9.1	69.1	17.3	13.5

The fish were fed a feed type according to their size. Feeds according to decreasing fish weight consisted of pellet sizes 4.76 mm, 3.17 mm, and "Number 3" which is a very fine pellet, much smaller than the 3.17 mm feed. Dramatic differences are not seen in the data, but small correlations can be made. As expected, smaller fish with smaller feeds, produced smaller particles. On every occasion, the 100 fish/kg (largest) group produced more particles in the 5 – 20 μm range than the other two fish sizes. The differences in particle size distributions were most apparent during feeding. Distributions for the 100 fish/kg group during feeding were 82.2, 12.2, and 5.6 % respectively for each of the three size ranges, while 64.7, 19.3, and 16% were the distributions for the largest group of fish (4.20 fish/kg). These differences can be attributed to larger pieces of food getting wasted or partially uneaten by the larger fish. Considering the range of FCRs reported earlier, the fish seem to be getting overfed, leading to a surplus of larger-sized solids in the raceway's effluent.

In the category of "In-Between Feeds", differences are again seen in particle size distribution and fish size, although they are not as apparent as the results obtained "During Feeding". Since the samples taken for this time range were at least 1-2 hours after feeding, it would be difficult to attribute the differences directly to feed size. One possibility is the larger feed particles settled out within the raceway and periodically get resuspended when the fish get excited. If a certain raceway has more larger-sized solids in its effluent than another raceway, then one would expect more larger particles to settle to the bottom of the raceways. Due to high fish density, workers/visitors walking close to the raceways, or seemingly no reason, fish may get excited and suspend settled solids. Since the samples were taken well after feeding took place, waste products could also have had a contribution towards any differences in particle size distributions. Some studies (Warrer-Hansen, 1991) have been performed which indicated that there was a difference in size and settling efficiency of feces of different sized fish. Although the magnitude of this contribution is not known, waste products and solids resuspension are the two most likely candidates for the particle size differences in this category.

After the last feed of the day, particle size distributions were seen to approach one another. Significant differences are not seen in size ranges according to fish size. This was expected because waste feed and waste products in the effluent are at a minimum during this time of the day (at least 4 hours after last feed). Additionally, since there were no workers present, fish excitement was greatly reduced.

2.3.3 Sludge Accumulation and Characterization

To properly characterize trout farm sludges and to assess the effectiveness of sediment traps for solids removal, a field test was conducted at Farm C. This field test provided data regarding the rate of accumulation that could be later used to determine the efficiency of sediment traps as a sole treatment option. Laboratory scale analyses of samples taken during the test provided information regarding particle size distribution, nutrient content, and solids content of the farm's sludge.

On each day of measurement, deposition of solids was highest at the point just on the other side of the inlet screen. From there, the accumulation sloped steeply to almost no accumulation at the inside wall of the weir.

After 14 days, for example, the sludge blanket was as high as 14 cm (water depth was 43.1 cm). Sedimentation of the solids on the remaining days occurred in much the same manner. These findings were similar to what was predicted by Westers (1991). This settling phenomenon indicates that the presence of screens is helpful in producing a quiescent area within the trap, optimizing the settling potential of the suspended solids. As high flows approach the screen of the sediment trap, the openings of the screen (6.3 cm) "break up" the water and allow particle separation and subsequent settling to occur, rather than allowing the solids to remain entrained in the flow. The height of the weir also has a contribution to the overall effectiveness of the sediment trap to catch particles. Since the height of the weir (38 cm) was similar to the average height of the water (43.2 cm), weir overflow was low, limiting turbulence within the trap.

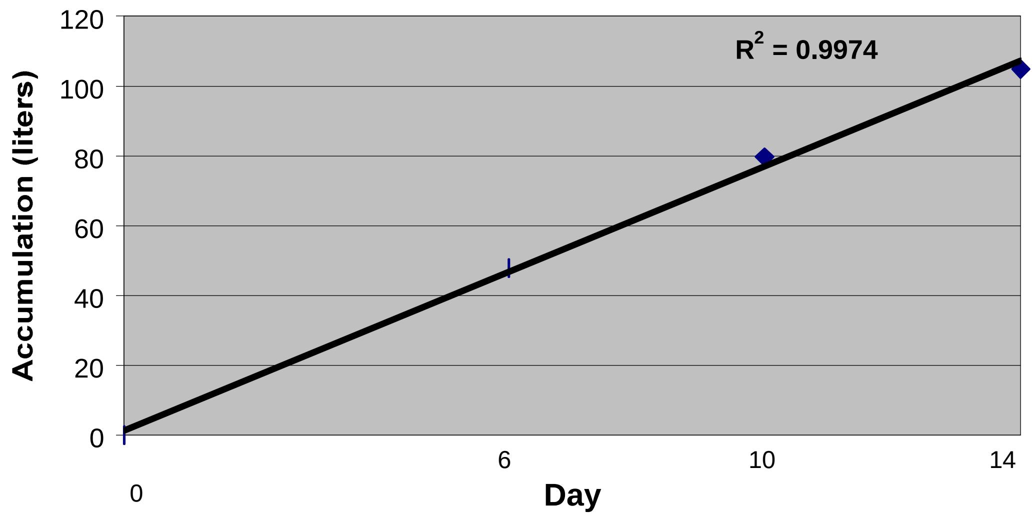

Figure 7. Sludge accumulation at Farm C as a function of time for days 0 – 14.

Figure 7 illustrates accumulation of solids as a function of time for the first three sampling days (Days 6, 10, and 14). As can be seen from the figure, there seems to be a linear trend (R^2 = .9974) relating sludge accumulation to time. Based on an measured bulk density of 1.006 g/cm^3, the sludge was found to accumulate at a rate of 7.86 kg/day in the trap. Assuming equal solids deposition between the two traps, a total accumulation rate of 15.7 kg/day was measured for the experimental raceway. Based on a 3% solids content of the sludge, the accumulation rate can be expressed as 0.45 dry kg/day. Since the raceway was being fed 22.7 kg/day of a feed with a 12% moisture content, a total dry input of 20 kg/day occurred in the experimental raceway. Since Farm C FCRs are from 1.2-1.8 (ratio of mass fed to mass gained), and the fact that previous studies mentioned have concluded 1-30% of fish feed goes uneaten

(Summerfelt, 1998a) and 25 – 60 % of the feed results in TSS (Summerfelt, 1998a; Maugle, 1998; Singh, 1998; Ziegler, 1998), there seems to be very little solids accumulation occurring within the traps. Taking into consideration waste products, resuspension of settled material due to feeding, harvesting, and other excitable events, the amount of solids that may be passing through the raceway far exceeds what was found in the traps.

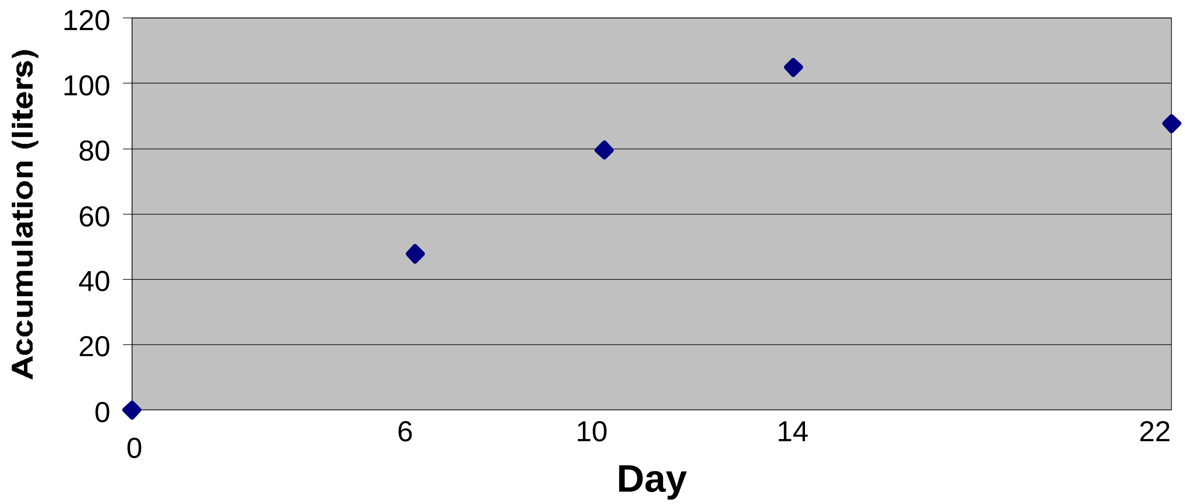

Fig. 8. Sludge accumulation at Farm C as a function of time for days 0 – 22.

Figure 8 shows the same accumulation data as what was presented in Figure 7, except for the addition of the “Day 22” data point. The reason for isolating this data point was to show that a sediment trap has a limited capacity for collecting material, and when that was exceeded, very little, if any, solids removal occurred. For example, no significant removal occurred between Day 14 and Day 22. In fact, there seemed to actually be an output of solids from the sediment trap due to scouring. Camp (1936) developed an expression that related scouring potential to the size and specific gravity of a particle. This “potential” was defined in terms of a scouring velocity, thus, any flow-through velocity exceeding this scouring velocity would cause the defined particle (or smaller) to scour. Equation (2) defines this expression.

$$V_{scour} = \left[\frac{8k\left(SG_{solids} - 1\right)gd}{f} \right]^{1/2} \quad (2)$$

where, k = experimental constant based on material, f = Darcy-Weisbach friction factor, g = acceleration due to gravity

Three things may have contributed to particle scouring during the field experiment. One, a spike in flow could have caused an increase in velocity through the trap. This increase in velocity may have exceeded the scouring velocity of the settled particles, causing them to be introduced into the effluent. Two, degradation of particles occurred within the trap (as proven from batch study results), causing a smaller particle size distribution which results in a lower scouring velocity. Three, the sludge bank increased to a height where it could not withstand the flow-through velocity. Velocity is known to change as a function of stream depth, with an overall maximum occurring approximately 6/10 (60%) of the depth below the surface. Thus, particles on top of a 10 cm pile may not scour, but they may when they are in a pile 20 cm. This may well have happened during this experiment because the depth of accumulation after Day 14 was as high as 20 cm, or 65% below the surface. The slightest increase in height of the sludge bank could have caused a scouring situation. All of these reasons, in addition to any artificial disturbances within the trap that may have caused the settled solids to be stirred-up (escaped fish, workers, equipment, etc.), can be used to explain the leveling-off of the accumulation. These results provide important information for treatability options and suggestions for best management practices (BMPs).

Particle size data are shown in Table 8. There seems to be very few trends in the data as a function of time, therefore making it difficult to show degradation led to particle scouring. The overall distribution is weighted heavily at the lower end, thus it seems that many of the particles within a sediment trap are susceptible to scouring. Since the particle size did not change significantly, it seems either a surge of flow or a rise in the sludge bank prevented accumulation, or an input of particles. Lack of large particles in these distributions can be attributed to the difference in size and specific gravities of the organics and inorganics. It may take thousands of small, organic particles to match the weight of one large, inorganic particle, so the previous observations for the organic content of the sludge may still be valid, depending on the size and weight of the inorganics. If the inorganics were larger than 210 μm, then they were filtered from the sample before counting and did not contribute to the size distributions shown below.

Table 8. Particle size distribution of Farm C sludge during 3-week sludge experiment.

Day	Size Range (μm)											
	5-10	10-15	15-20	20-25	25-30	30-40	40-50	50-60	60-80	80-100	100-120	120-210
6	53	24.4	10.6	4.9	2.6	2.6	0.8	0.4	0.4	0.1	0.1	0.1
10	50.4	25.6	12.6	5.4	2.3	2	0.7	0.4	0.3	0.1	0.1	0.1
14	51.3	25.1	11.9	5	2.4	2.3	0.9	0.4	0.4	0.1	0.1	0.1
22	51.3	24.3	11.3	5.2	2.7	2.9	0.9	0.5	0.5	0.2	0.1	0.1
avg	51.5	24.8	11.6	5.1	2.5	2.4	0.82	0.42	0.4	0.12	0.1	0.1

Results of the laboratory analyses on the sludge, along with relevant farm conditions are shown in Table 9. Very little change in feed rate and fish density occurred during the 22-day experiment, giving confidence that a constant load of solids were being produced in the targeted raceway. Flow rates were also seen to be relatively steady throughout the 22-day experiment, although peak events may have been missed due to the interval of monitoring. By taking water depth measurements within the trap, detention times were able to be calculated based on flow and the surface area of the sediment trap. As seen from the results, the settling time within these traps is extremely low (average = 23.9 seconds) compared to what is allowed for typical primary sedimentation in wastewater treatment processes (120 minutes), making it suprising that any accumulation occurred at all. The accumulation can be a testament to the usefulness of the screens and weirs as described earlier.

Table 9. Measured sludge characteristics and farm conditions during 3-week sludge monitoring study.

Parameter	Units	Range	Average
Feed Rate	kg/day	22.7	22.7
Fish Density	kg/m^3	55.8 - 73	65.6
Flow	m^3/min	3.1 – 3.3	3.2
Detention Time	sec	23.4 – 24.2	23.9
Percent Solids*	%	2.4 – 2.9	2.6
Percent Volatile Solids	%	44 – 62.7	56.1
Bulk Density	g/cm^3	1.004 – 1.008	1.006
TKN	mg/l	639 – 852	735 (2.9% by wt)
OP	mg/l	73.9 – 272	133 (0.5% by wt.)
Overflow rate	$m^3/m^2\cdot day$	1510 - 1620	1570

*- Dependent on pump/vacuum

"Percent solids" is an indication of the moisture content of the sludge and is highly dependent on the withdrawal process used. The wet-vac used in this study was able to achieve a solids content of around 2.6%; however, larger pump and vacuum systems have been known to yield a solids content as high as 5% for sludge. This increased efficiency can lower disposal costs, require less land area for sludge spreading, and allow for quicker drying in sludge drying beds.

Volatile suspended solids (VSS) content gives an indication of the distribution of organic versus inorganic particles. In the sludges analyzed, volatile solids content were a bit lower than expected (62.7, 61.1, 56.8, and 44%, respectively for the four monitoring days). Untreated municipal sludges have been known to have a VSS content of 60-80% (Metcalf and Eddy, 1991), and considering the amount of organics introduced into the water from the feeds, along with the low bulk densities measured, the percentages were expected to be higher. An explanation might be that the earthen walls and bottoms make a high inorganic contribution. Although sand and silt are expected to settle within the raceway, the activity of the fish may move the particles slowly toward the sediment trap where they will remain due to their high specific gravity. Since the organics from the feed and feces are very small and light, they will not have as high of a mass contribution as the inorganic particles on a per-particle basis. The steady drop in %VSS throughout the study, although a small decrease, may be attributed to inorganics taking the place of organic particles. Since there is such a large difference in specific gravity between an organic particle and an inorganic particle, sand and silt may find their way to the bottom of the sludge bank. While the inorganic particles are steadily accumulating, the lighter organic particles find themselves closer to the surface, and more susceptible to scour, decreasing their overall mass contribution to the sludge. Due to the apparent loss of organics within the trap over time, these findings may be helpful in determining best management practices within the farms.

TKN and OP data give an indication of the nutritional value of the sludge. Because of its non-toxic nature, and its high organic and nutrient content, alternative uses may be investigated for the sludge. Although the slurry would need to be dewatered for beneficial use, the potential is apparent. If the sludge is to be land applied, the nutrient content will dictate the area, crop type, and soil type for proper assimilation.

2.4 Conclusions

Effluent quality for three trout farms in Virginia was characterized based on grab and composite samples. The effluent concentrations of regulated parameters were within compliance of each farm's discharge permit. Periodic spikes in solids concentration during feeding, harvesting, cleaning, and other raceway disturbance activities need to be considered when evaluating best management practices and treatment alternatives. The solids spikes during feeding and harvesting, in particular, were found to be much greater than 24-hr composite measurements. Since these events are infrequent, and have durations of less than 20 - 30 minutes, they tend to be masked when evaluating overall water quality. Grab sampling may miss these events, while composite sampling dilutes the effect of the events.

Particle size analyses indicated that the size distribution for solids in aquacultural effluents are weighted heavily towards the 5 - 20 μm range. These solids are not only very small, but also very light, and are therefore very difficult to remove. Although the majority of the solids will reside in this range, effluent particle size distributions may vary according to fish size, feed type, time of day, and degradation time. This information will be important when predicting removal efficiencies of proposed treatments or practices.

Solids accumulation within sediment traps was found to occur at a rapid rate; however, when compared to the amount of solids passing through a raceway, the accumulating amount was found to be insignificant. Based on the flowrates measured, detention times within these traps were approximately 24 seconds. Although this is far less than what would be suggested for typical treatment applications, the removal that did occur was higher than expected, attributable to the quiescent area produced by the screen and weir. Although much accumulation occurs within sediment traps, there is a point when their capacity is exceeded due to scouring. Flow spikes, increases in sludge banks, and/or particle degradation can lead to resuspension of the particles. These findings may be useful when suggesting best management practices to combat the solids loading discharged by the facilities. Any sludge that is withdrawn from sediment traps, or elsewhere in the farm, contains relatively high organic matter and nutrients, and thus could be used as a beneficial and marketable product.

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3.0 Water and Sludge Treatability Options for Raceway-System Trout Farms

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Abstract

Aquacultural effluent and sludge treatment options were investigated for single-pass, raceway-style trout farms. Investigations consisted of literature reviews, laboratory and pilot scale experiments, and interaction with operators, superintendents, and professionals in the aquacultural production business.

Sedimentation was deemed the most technically and economically feasible treatment alternative for single-pass trout farms. A pilot plant was constructed at a trout farm to optimize design of a settling unit that would provide high TSS removals, reduce the opportunity for particle resuspension and/or degradation, minimize capital and operating costs, require little space, and minimize the effect on farm productivity. Three trials were conducted with the pilot unit at different detention times and overflow rates. The results indicated that a settling basin, with appropriate baffles, weirs, and screens, will effect high TSS removals at only 15-20 minutes of detention time and overflow rates of 77.4 and 48.9 $m^3/m^2 \cdot d$.

Annual sludge accumulations and land application requirements were estimated for three trout farms. Based on conservative assumptions, including a sludge nitrogen level of 3%, land requirements ranged from 15-30 hectares. Although maintenance costs will be relatively high for proper cleaning of settling units, TSS loading in the farm effluent should be significantly lower.

Keywords: Overflow rate, effluent treatment, sludge, land application, nutrients, solids, sediment traps, plug flow

3.1 Introduction

Regulatory pressure is developing within the aquaculture industry. This is not only due to an increasing demand for fresh fish, but also because in-stream, macroinvertebrate studies have been performed indicating that facility effluents have had adverse effects on receiving waters. New regulations are expected which will change many concentration-based guidelines to loading-based guidelines, where the controlling parameters will be in terms of mass/time, rather than mass/volume. These Total Maximum Daily Loads (TMDLs) are expected to have a significant impact on many aquacultural facilities that have high water consumption and high production rates. In addition to TMDLs, nitrogen and phosphorus limits are expected to be implemented in the near future, as they are in Europe (Bergheim and Cripps, 1998) and Idaho (MacMillan, 1991). Therefore, treatment processes will need to be implemented at many facilities.

The key to treatment implementation is to develop a treatment scheme that will be economical, relatively easy to operate and maintain, fit in the space and operation schedule of the farm, and most importantly, perform at its designed efficiency. Since there are many types of aquacultural production facilities, there in turn will be different treatment alternatives available for each type of facility. For each type of facility, treatment options may again be different based on the budget, manpower, and space available for each farm. Therefore, it is important that treatment recommendations be farm-specific, taking into consideration all of the above factors. Following a "general" recommendation might not only prove to be costly to a farm, but the treatment performance may not be sufficient.

There are many effluent treatment alternatives being used or proposed in the aquacultural industry. The most common alternative is sedimentation, either by large settling ponds (Mudrak, 1981; Henderson and Bromage, 1988), small quiescent zones (i.e. sediment traps) (Axler *et al*., 1997; MacMillan, 1998), or tube and plate settlers (Summerfelt, 1997, in press). Another one of the most common alternatives is filtration, using microscreens (Bergheim *et al*., 1993; Kelly *et al*., 1997) or filter beds (Kristiansen and Cripps, 1996). Other options include flotation (Marti *et al*., 1994; Genovese and Gonzalez, 1994), foam fractionation (Chen *et al*., 1993; Weeks *et al*., 1992), wetlands (Massingill, 1998; Schwartz and Boyd, 1995; Adler *et al*., 1996), cyclones (Warren-Hansen, 1982), ozone (Summerfelt and Hochheimer, 1997), raceway baffles (Boersen and Westers, 1986; Westers, 1991; and Kindschi *et al*., 1991), and waste reduction. One should keep in mind that many of the above alternatives can be used in combination with others (i.e. settling ponds and microscreens, baffles and sediment traps, foam fractionation and ozone); however, all have specific advantages and disadvantages. The most universal and efficient alternative is waste reduction, and it should be practiced in combination with any proposed alternative. A joint study (Nyland and Boardman, 1998) focused on this issue by studying the effects of alternative feed implementation on facility effluents. Sludge treatment options usually consist of land application (IDEQ, 1998) and/or on-site thickening (Summerfelt *et al*., 1996; Reed *et al*., 1995). Composting (Shelton, 1998; IDEQ, 1998) and wetlands (Summerfelt *et al*., 1996) have also been used to treat and dispose of sludge.

The Virginia Department of Environmental Quality (VDEQ) provided Virginia Tech researchers with funding to identify and assess viable treatment options for suspended matter in fish culture effluents. Water quality and sludge characterizations were also performed (Maillard *et al.*, 1998), and used to aid in the assessment of many of the above treatability options. Although this paper will focus on the effectiveness of sedimentation and land application for waste solids removal and disposal, the reader is encouraged to review the full report submitted to

VDEQ (Boardman *et al.*, 1998) which discusses the feasibility of many other treatment options available to the aquaculture industry.

Therefore, the purpose of this study was to identify and evaluate aquacultural effluent and sludge treatment options, and to propose technically and economically feasible alternatives for the three farms. Laboratory and pilot scale experiments, in addition to the data gathered during the water quality and sludge characterization studies (Maillard *et al.*, 1998), were used to analyze the efficiency of the selected alternatives.

3.2 Methods and Materials

3.2.1 Water Quality Parameters

Total Suspended Solids (TSS), volatile suspended solids (VSS), settleable solids (SS), dissolved organic carbon (DOC), total Kjeldahl nitrogen (TKN), and orthophosphate (OP) were measured in this study according to Standard Methods (1995). DO and temperature were measured using a YSI Model 57 Oxygen Meter.

Flow was measured using weir equations developed by Evett and Liu (1987). The relationship was proved valid using a Swoffler velocity meter as described in the water quality and sludge characterization studies (Maillard *et al.*, 1998).

3.2.2 Particle Size Analysis

Procedures and assumptions used during the water and sludge treatability study (Maillard *et al.*, 1998) for particle counting were used in this phase of the work. Replicates of each sample were again counted.

3.2.3 Type II Settling

Type II settling refers to the settling of particles in relatively dilute solutions by interaction with other particles (Reynolds and Richards, 1996). Performing such tests provides data that will aid in choosing overflow rates and basin depths of settling basins based on a desired removal.

Type II settling tests were performed on various effluents from the individual trout farms. A 1.8-meter tall, 15.2-cm diameter settling column with sample withdrawal ports every 0.3 meters was constructed for these experiments. Although the column had six ports, it was decided to use the first, third, and fifth ports only, due to the number of samples needed and the amount of water available in the column. Effluent was introduced into the column in a well-mixed state and was poured as quickly as possible (5-10 seconds) into the column to prevent settling before the start of the test. As soon as the column was filled with a farm's effluent, a timer was started and samples were withdrawn from the ports at 5, 10, 20, 30, 45, 60, and 90 minutes. Three samples were taken from the effluent source to accurately measure the initial TSS concentration. All samples were analyzed for TSS, while VSS, nutrients and particle size were periodically measured. Effluent used for the 8-Day batch study was withdrawn from Farm C during an elevated event.

3.2.4 Type III Settling

Type III settling refers to the settling of particles that are so concentrated and close together that they remain in a fixed position, slowly settling as a "zone" (Reynolds and Richards, 1996). This test is usually performed with highly concentrated samples, such as sludge, and like the Type II settling test, data obtained can be used for design purposes. Removal of TSS, overflow rate, basin size, and detention time can all be obtained as a result of this test.

Type III tests were performed on various trout farm sludges that were withdrawn directly from a raceway, or more often, from a sediment trap at the end of a raceway. These tests were performed in one-liter graduated cylinders. A well-mixed sludge sample was introduced into the graduated cylinder as quickly as possible. The solid/liquid interface was then measured as a function of time. Sampling times varied according to how well the sludge began to settle; but, for the most part, measurements were taken at 0, 3, 5, 7, 10, 15, 20, 25, 30, 40, 50, 60, 75, 90, and 120 minutes. When settling rate began to level out (after 30 – 60 minutes), a sample of supernatant was taken and analyzed for nutrients and DOC. Initial TSS samples were also measured in duplicate.

Results from particle size analyses and settling tests (Type II and Type III) were utilized for solids characterization and treatment potential. Particle size distributions can provide data for trends in size distributions, while settling tests can provide overflow rate data that can later be used for settling basin designs. Particles size analyses (Chen *et al*., 1993; Kelly *et al*., 1997; Cripps, 1995; Chapman *et al*., 1987) and Type II settling tests (Stechey, 1998) have proven to be useful in other related treatment research efforts.

3.2.5 Pilot Plant Study

From the findings of the sludge accumulation and characterization study (Maillard *et al.*, 1998), it was determined that the sediment traps located at the bottom of raceways of some farms seemed to work well at trapping suspended solids. By creating a quiescent zone with screens and weirs, solids had an opportunity to settle out before getting transported downstream. However, based on the amount of feed added to the water and reported utilization rates (i.e. 30-60% of feed results in TSS), this accumulation seemed to be extremely small. These results were believable because the sediment trap was found to only provide a detention time of approximately 24 seconds (surface loading = 1570 $m^3/m^2 \cdot day$). This indicated that although significant accumulation occurs within the traps, many solids will pass through the raceways.

To catch more solids, and to prevent resuspension from high flows, fish excitement, particle degradation, and/or other farm activities, a more efficient settling basin design was considered. This design would use a combination of the current sediment trap design (weirs, screens) and typical wastewater treatment sedimentation theory (plug flow, detention time, surface loading, and scouring). Preliminary calculations were made to determine how much detention time could be increased (or surface loading decreased) and how well the unit could provide for plug-flow (using baffles). After seeing some designs could be made without unrealistic demands for space on the farms, a pilot-scale settling tank at Farm C was constructed in much the same manner as would be proposed for the trout farms. The unit contained screens and baffles, and provided for proper water depths and velocities. Because of the difficulty in identifying the level of treatment required at a given facility, the pilot plant was operated at three detention times (10, 20 and 30 minutes) and samples multiple times a day, for five days per detention time. Although overflow rate is the true determining factor for sedimentation, detention time was also used as a design parameter. Water depths in the pilot plant were similar to what was found in raceways at some of the facilities.

A schematic of the pilot unit is shown in Figure 1. As can be seen from the figure, this tank contained screens (0.6 cm) and a baffle (Plexiglas) to provide for optimal settling and to encourage plug-flow. The tank was concrete, contained approximately 3400 liters of capacity and was manufactured by Concrete Casting Company (Roanoke, VA). The unit was placed on an access road adjacent to a raceway so as not to interfere with regular farm activities. The raceway was chosen after taking into consideration fish densities, harvesting schedule, feed rates, and ease of operation. A pump was placed in the raceway to transfer water from the raceway into the pilot via 7.6-cm diameter PVC pipe. A 4.4 liters/s Sta-Rite submersible pump with 1.1-

kW Franklin Electric motor was purchased from Ferguson Enterprises (Blacksburg, VA). Using a pump allowed for easy regulation of flow and the ability to change detention times. The pump ran continuously for the duration of the study. Outflow was provided by a 10-cm corrugated pipe that fed the next lower raceway to prevent introduction of treated effluent into the tank inlet.

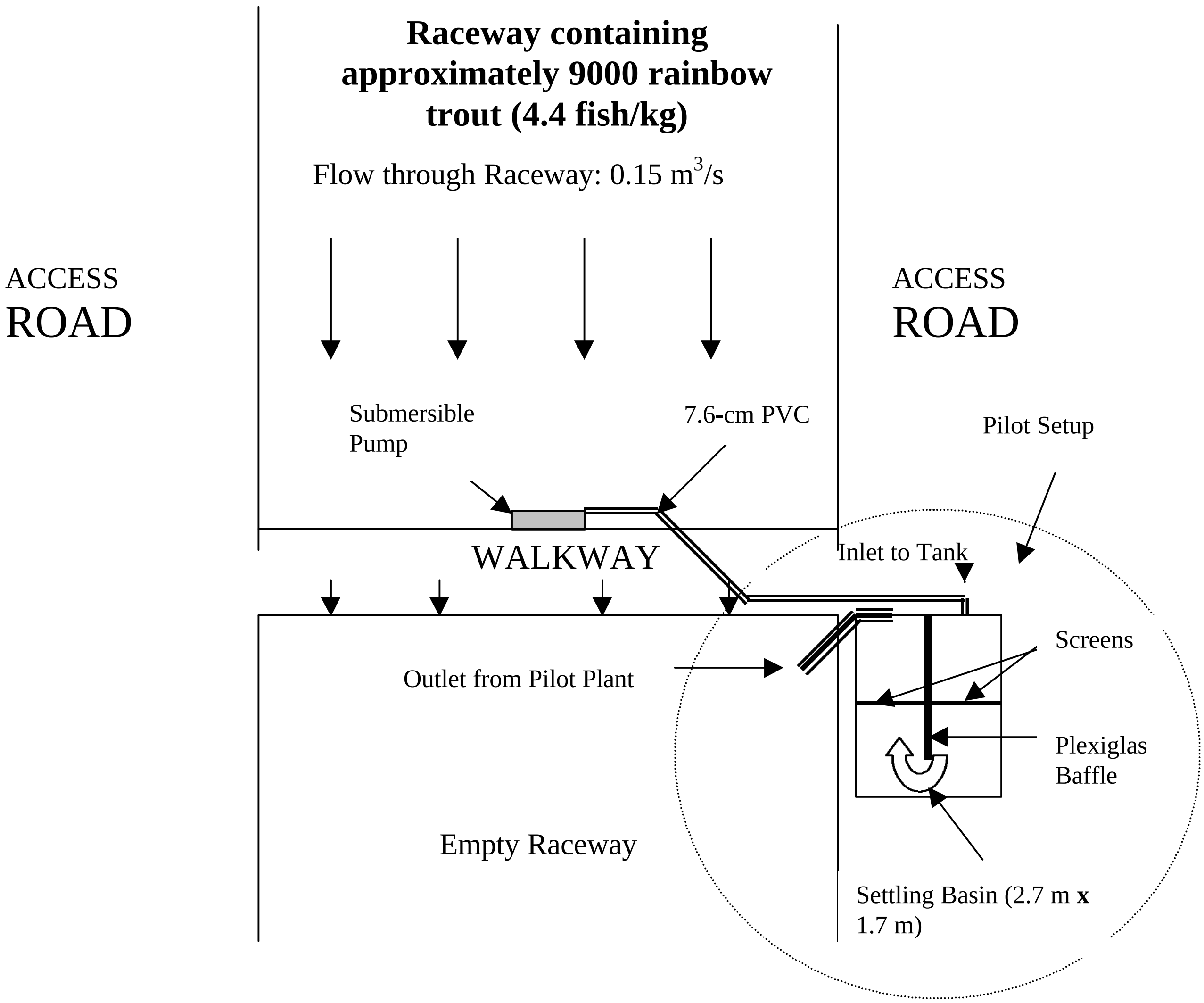

Figure 1. Pilot plant layout at Farm C.

The sampling scheme was mainly focused on TSS removal. As a result, many grab samples were taken each day at the inlet, middle, and outlet of the tank. Samples were taken during a wide range of farm activities (feeding, harvesting, artificial stir-ups, and no activity).

TKN, OP, DOC, particle size, and SS samples were taken periodically along with a daily measurement of temperature. Fish densities, flow, feeding rates, and harvesting schedules were also closely monitored during the study. Since solids loading to the pilot unit was much lower per m^2 of settling area than what was seen under field conditions, accumulation was not significant enough to measure. However, qualitative observations of the accumulation were made. Box plots of the TSS data collected were generated using Sigma Plot software.

3.3 Results and Discussion

3.3.1 Type II Settling

Type II Settling results from the 8-day batch test performed in the water quality and sludge characterization study are shown in Figure 2 and Table 1. As can be seen from the figure, removal steeply increases in the first 20 – 30 minutes, and begins to level off thereafter. The

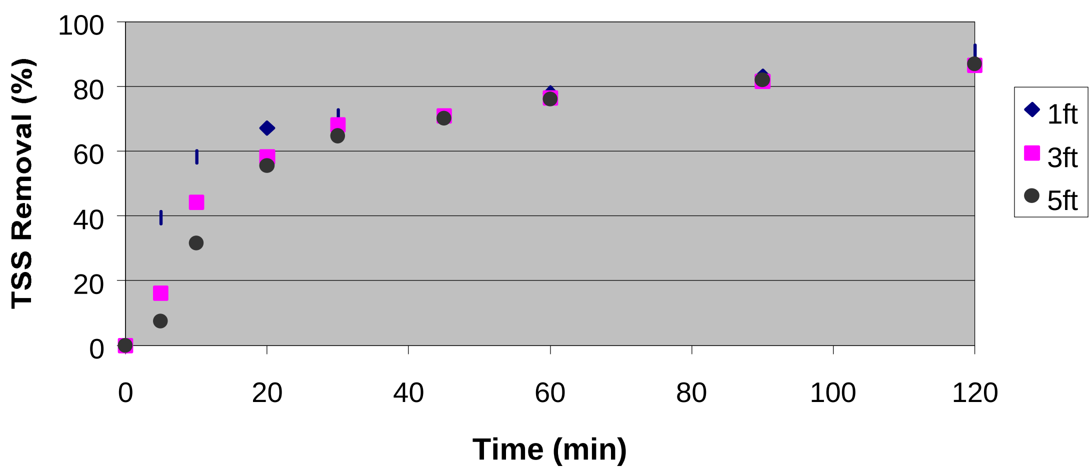

Figure 2. Type II settling results using average values from the 8-Day batch study.

data are significant when determining the required area for efficient solids removal. From the figure, one might expect good removal in a 0.9 m settling basin after 30 minutes; however, if this detention time is tripled (which in turn triples the required land area), little improvement will occur. In some instances the extra removal may be needed for regulatory compliance, such as during harvesting or feeding when TSS levels are elevated. Average TSS data used to establish the plot are shown in Table 1. As can be seen from the table, the average initial TSS concentration was approximately 40 mg/l. This is representative of a peak event such as feeding or harvesting. Although some TSS spikes were found to be over 100 mg/l during a 3-week intensive sampling and monitoring study (Maillard *et al*., 1998), this concentration would be representative of the highest feeding peak, and of most harvests peaks. The data from the table indicate that it is difficult to achieve an effluent concentration of less than 5 - 10 mg/l. This confirms studies by Henderson and Bromage (1988), which concludes efficient effluent TSS concentrations of less than 6 mg/l are difficult to attain. To do so would require 60 - 90 minutes of detention time, and an overflow rate of 14.4 – 21.6 $m^3/m^2 \cdot day$. These required overflow rates are low, but comparable to Mudrak (1981) and Liao (1970).

Table 1. Summary of Type II settling results from the 8-Day batch study.

Time (min)	Depth = 0.305m		Depth = 0.9m		Depth = 1.5m	
	TSS (mg/l)	TSS Removal (%)	TSS (mg/l)	TSS Removal (%)	TSS (mg/l)	TSS Removal (%)
0	39.3	0	39.3	0	39.3	0
5	23.8	39.5	32.9	16.3	36.3	7.5
10	16.4	58.3	21.9	44.2	26.8	31.7
20	12.9	67.2	16.4	58.2	17.5	55.4
30	11.4	70.9	12.5	68.1	13.9	64.6
45	11.5	70.7	11.5	70.8	11.8	70
60	8.7	77.9	9.2	76.5	9.4	76
90	6.6	83.1	7.2	81.6	7.1	82
120	3.6	90.9	5.3	86.5	5.2	86.9

Because of the many uncertainties involved in scaling up laboratory-based results to full-scale applications, caution should be taken when using the above data, or any other published data, for final design decisions. A successful sedimentation design will be highly dependent on the field conditions of the farm in question. Temperature, wind, TSS concentration, solids characterization, and variation in flow are just a few of the factors that could cause deviation from a purely laboratory-based design.

3.3.2 Type III Settling

Type III settling results from the sludge accumulation experiment (Maillard *et al*., 1998) are shown in Figure 3. The plot presents data for four different sludges at Farm C. Reynolds and Richards (1996) and Metcalf and Eddy (1991) have detailed procedures for utilizing Type III data for final clarifier design. This information is also useful for the design of sludge drying beds or sludge stabilization lagoons. Analysis of Figure 3 reveals that the sludge from Farm C can be thickened by approximately 65% after only 60 minutes of settling time. Additional thickening will occur, but at a very slow rate, once the asymptote is reached. The performance

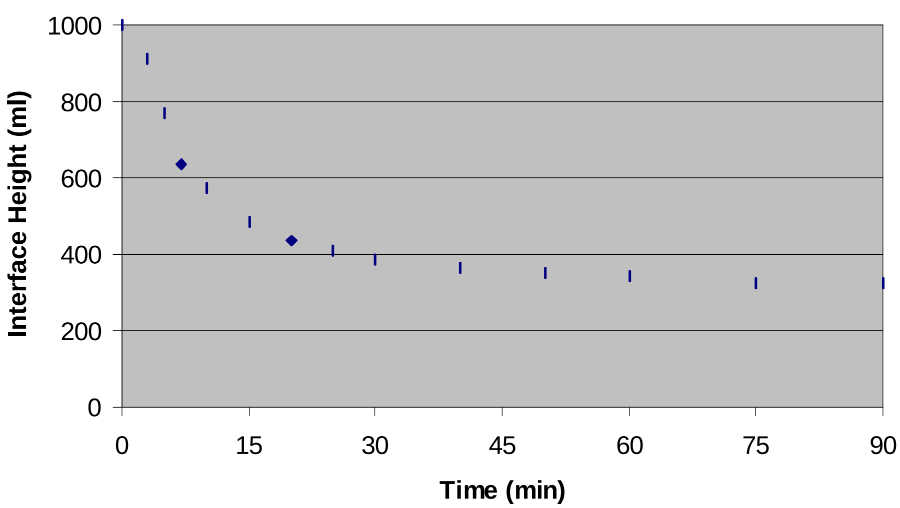

Figure 3. Type III settling results for sludges encountered during 3-week sludge accumulation experiment (average initial TSS = 25,400 mg/l).

of the sludge after this 60-minute settling period is not critical because most farms allow many days to pass before sludge is withdrawn. The hydraulic loading of the sludge is, of course, much less than that of the farm's effluent. Thus, spatial requirements for sludge settling are not as significant as they are for effluent solids.

Although the supernatant had some residual fines, most of the initial mass of 25,400 mg TSS was contained in the lower third of the solution after 60 minutes of settling time. The newly thickened sludge therefore had a TSS concentration of 74,000 mg/l. If aquacultural facilities choose to use ponds or lagoons for their sludge treatment, the ponds may need to be decanted to enable sludge withdrawal. The decant should be recycled through the treatment scheme, sent to another stabilization pond, or land applied, because the TSS concentration associated with it will more than likely be in violation of the facility's discharge permit (IDEQ, 1998). The amount of nutrients that may have been released during the thickening process could also be significant. Once dewatered, the sludge may be thickened additionally by allowing for evaporation.

3.3.3 Pilot Plant Study

As mentioned in the "Methods and Materials" section, the pilot plant operated at three detention times (10, 20, and 30 minutes) for five days per detention time. Table 2 lists the flow characteristics of the pilot unit during the three trials.

Table 2. Flow and overflow rates during pilot plant trials.

	10 minutes	20 minutes	30 minutes
Flow (liters/sec)	4.7	2.17	1.32
Overflow Rate ($m^3/m^2 \cdot d$)	106	48.9	29.8

Results of TSS grab samples taken during the three trials, in addition to 24-hr composite samples at each detention time, are shown in Table 3. As seen in Table 3, TSS concentrations varied greatly among the grab samples taken during each trial. Many grab samples resulted in TSS concentrations of less than 1 mg/l; however, there were spikes as high as 326 mg/l. Significant inlet TSS concentrations (79.5, 326, and 90.8 mg/l, respectively, for the three trials) were seen in all trials. Spikes of this magnitude were not seen when sampling from the middle of the settling tank, or at the outlet, giving an indication that removal occurred within the tank and that the tank could dampen shock loads.

Table 3. TSS data for three pilot plant trials.

	10 minutes			20 minutes			30 minutes		
	Inlet	Middle	Outlet	Inlet	Middle	Outlet	Inlet	Middle	Outlet
Grab TSS Range (mg/l)	0- 79.5	0 - 8.4	0 - 6.4	0 - 326	0 - 4.4	0 - 3.8	0.2 - 90.8	0- 2.0	0 - 2.0
Avg. TSS (mg/l)	7.0	3.2	2.4	22.4	1.9	1.1	13.1	0.87	0.85
TSS Removal			65.7			95			93.5
Number samples	33	27	31	25	22	31	29	23	32
Composite TSS Range (mg/l)	0 - 2.2	-	-	1.2 - 5.5	-	-	1.5 - 44	-	-
Avg. TSS (mg/l)	1.28	-	-	2.26	-	-	2.5	-	-
Number samples	3	-	-	5	-	-	3	-	-

The TSS removals in Table 3 were calculated using the average inlet and outlet concentrations for each trial. Due to the wide range of average inlet concentrations (7.0, 22.4, and 13.1 mg/l), it is difficult to be highly confident in the calculated TSS removals. It is therefore difficult to suggest an optimal detention time, or overflow rate. Although average inlet TSS concentrations varied for each time trial, it is worth noting that the middle and outlet concentrations were found to decrease with increasing detention times. From this, it may be said that the performance of the pilot was more dependent on the settling time/area, rather than the inlet concentration.

Composite samples were taken to prove that although high activity may occur in a given raceway, with high effluent TSS peaks (i.e. inlet of pilot unit), the overall TSS concentration on a 24-hr basis was relatively small (1.2 - 2.5 mg/l). Thus, even though the experimental raceway was harvested five times during the study, received 22.7 kg of feed every day, and underwent other periodic disturbances, the effects on effluent quality were masked when averaged by composite sampling over the course of a day.

Due to the number of TSS grab samples taken, and the uncertainty of where optimal removal may occur, the data were statistically analyzed using box plots. Box plots for the 10, 20, and 30 minute detention times are shown in Figures 4, 5, and 6. Data between the 25th and 75th percentile are grouped in the box. The whiskers extend from the 10th to the 90th percentile, while the solid and dotted lines represent the median and mean, respectively.

Looking at Figure 4, the width of the boxes for the inlet, middle, and outlet samples are not seen to change significantly. This gives an indication that the concentration of most of the samples is not changing. Although the whiskers tend to approach the median when traveling through the tank (inlet-middle-outlet), samples in the 25th-75th percentile did not decrease in TSS concentration. This is also evident by the means and medians at each sampling location. The mean is seen to drop at each location; however, there is no such trend for the median. Thus, it can be inferred that a 10-minute detention time (106 $m^3/m^2 \cdot d$ overflow rate) will be capable of absorbing a shock loading, but will not cause a reduction in TSS during average periods. This makes sense because shock loadings usually consist of large particles, either uneaten or partially eaten food, or resuspended particles that were previously heavy enough to settle out. For a shock loading of heavy particles, the detention time would not have to be high. Since these shock loadings are probably at the far end of the whiskers, one can see that a decrease in whisker range

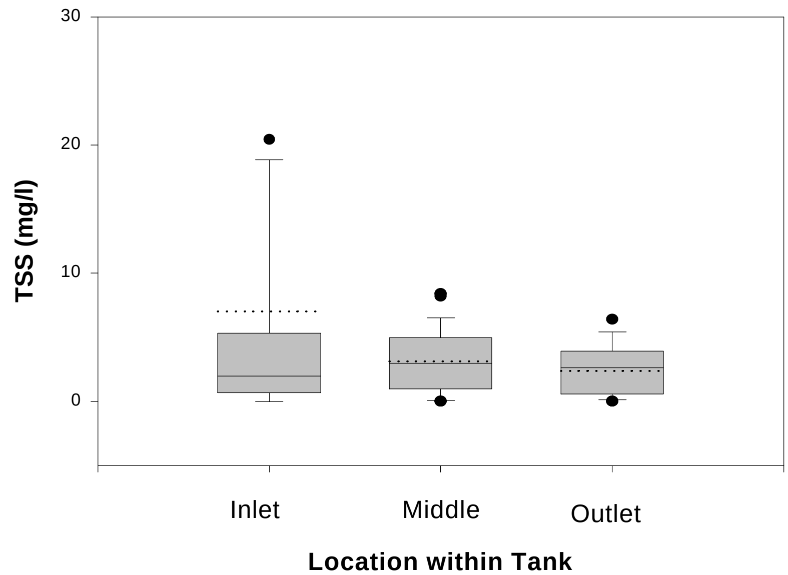

Figure 4. Pilot TSS data during 10-minute detention time trial. Note: Two inlet samples are off scale (39.4 and 79.5 mg/l).

will represent removal of the shock loadings. The boxes (25^{th} – 75^{th} percentile) would not be expected to decrease in concentration, mainly because they are already at a low range of concentrations, but they are capable of being reduced in width. Maillard *et al.* (1998) proved that particle size was dependent on the type of activity that was occurring in the raceway. Particle size during average periods of activity, or during no activity, were found highly weighted at the smaller size ranges. The number of particles in these small size ranges was much lower during times of high activity. Since a detention time of 10 minutes is not sufficient to settle out these small particles, little removal, and thus little narrowing of the boxes occurred. Since shock loadings had little effect on the overall 24-hr effluent TSS concentration, then the same can be said for any removal that may occur during these events. Although it is important to treat these events efficiently, treating shock loadings alone is not sufficient.

Figure 5 illustrates data from the 20-minute detention time trial. Here, a distinguishable difference can be made in solids removal between the inlet, middle, and outlet of the settling tank. The box, whiskers, mean, and median are all seen to decrease when moving from the inlet to the middle, and from the middle to the outlet of the tank. The first advantage that can be seen from doubling the detention time is the ability to absorb significant shock loadings. As stated earlier, detention time does not need to be great when attempting to remove solids from shock loadings. The earlier trial proved that shock loadings could be removed at 10 minutes of settling. This was confirmed by the 20-minute trial, which had more and higher shock loadings than the

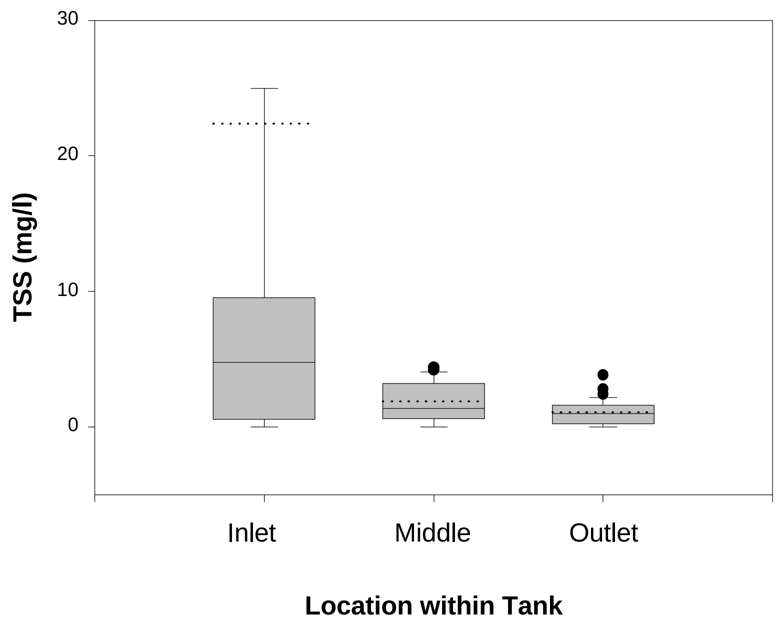

Figure 5. Pilot TSS data during 20-minute detention time trial. Note: Two inlet samples are off the scale (106 and 326 mg/l).

10-minute trial; however, the middle of the tank (theoretically one-half of the detention time or 10 minutes) never had TSS concentration higher than 5 mg/l. Thus, results from the 10-minute and 20-minute detention time trials showed that 10 minutes of detention time (106 $m^3/m^2 \cdot day$) is sufficient for solids removal during peak events. Since sediment traps were found to have overflow rates of approximately 1570 $m^3/m^2 \cdot day$, it is apparent that the traps will only catch a fraction of the peak events.

The most important aspect of Figure 5 is the fact that the boxes are seen to get narrower when moving from location to location within the settling tank. This indicates that TSS concentrations in the 25th - 75th percentile were reduced when water was traveling around the settling tank. Doubling the detention time, therefore, allows for settling of the smaller particles that are so commonly associated with aquacultural effluents. Not only will a 20-minute detention time, or 48.9 $m^3/m^2 \cdot d$ overflow rate, absorb shock loadings, but it will also provide removal of solids during low to average activity. Since effluents under the influence of feeding and harvesting events are consolidated, and only consist of about 1 - 3 % of the total daily flow, it is important that a settling scheme provide removal during average farm activity.

Figure 6 contains box plots for the 30-minute detention time trial. Although the upper whisker for the inlet is off the plot due to many inlet TSS spikes, all were absorbed by the time the effluent reached the middle of the tank (theoretically 15 minutes). Again, this confirms the fact that solids within shock loadings will settle out relatively quickly. In addition to absorbing shock loadings within 15 minutes, the range of concentrations in the 25th - 75th percentile were seen to decrease to a significant degree, indicating that removal was occurring during low to average periods of activity. Looking at the box for the outlet, however, reveals that additional removal did not occur when doubling the detention time to 30 minutes. Box and whisker width,

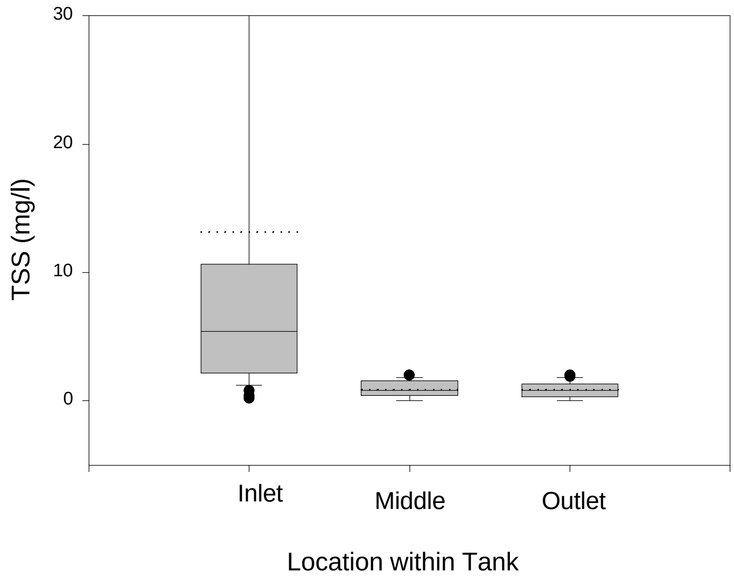

Figure 6. Pilot TSS data during 30-minute detention time trial. Note: Four inlet samples are off the scale (75.6, 90.8, 36.0, and 41.0 mg/l); also, upper whisker for inlet samples is off scale (39 mg/l).

along with the mean and median, are were not significantly different. In fact, the box containing TSS concentrations at the middle of the 30-minute trial is very similar to that for the outlet of the 20-minute detention trial, indicating that the maximum removal was reached between 15 and 20 minutes (77.4 and 48.9 $m^3/m^2 \cdot d$). This is an important conclusion because it shows that no additional removal will occur after 15 or 20 minutes, proving that typical detention times of 60 and 90 minutes are far more than required.

Nutrients (TKN and OP) were analyzed in samples associated with a TSS spike for each time trial. Although the parameters were not analyzed during other periods of time, the results give an indication of the potential removals when TSS concentrations are lower.

Table 4. Nutrient data for grab samples taken for each pilot plant trial.

	TSS (mg/l)			TKN (mg/l)			OP (µg/l)		
	inlet	outlet	% removal	inlet	outlet	% removal	inlet	outlet	% removal
10 min	79.5	3.0	96.2	4.1	0.16	96	314	14	95.5
20 min	106	4.2	96	4.8	0.16	96.6	357	13	96.4
30 min	36	0.8	97.8	2.5	0.5	80	338	24	92.9

Table 4 shows the potential of nutrient removal if shock loadings are efficiently managed. Studies were mentioned (Maillard *et al*., 1998) that showed a correlation between TSS removal and nutrient removal, especially phosphorus. TKN removal was suprisingly high, indicating that the amount of nitrogen bound to solids (mainly organic nitrogen) outweighs the contribution of nitrogen in solution (mainly ammonia) during peak TSS discharge events. Ortho-phosphate removal was expected to be high during high TSS removals, as it represents forms of phosphorus that are readily attached to particles. The above data illustrate that even a small amount of treatment can produce significant removals during peak events. Removing waste solids from an aquacultural effluent will not only reduce TSS loading, but can also aid in the reduction of nutrient loadings.

3.4 Conclusions

Effluent and sludge treatment options were investigated for raceway-style trout farms. Options were evaluated on the basis of performance, space, economics, manpower, and influence on productivity of the farms. Intensive literature reviews, lab and pilot scale studies, and interactions with operators and researchers through phone conversations, meetings, site visits, and conferences enabled the investigators to thoroughly evaluate current effluent and sludge treatment schemes used at aquacultural facilities.

Microscreens, ozone, flotation, foam fractionation, swirl separators, tube/plate settlers, and filter beds were all felt to be impractical due to high capital costs, difficulty in treating high flows, and/or space and maintenance requirements. Wetlands have proven to be effective and economical for aquacultural effluent treatment, but the space requirement is significant and not available for the three trout farms in the study. Sedimentation via settling ponds or sediment traps was found to be economical, easy to construct, and moderately effective for removing waste solids. Sediment traps (quiescent zones) are helpful for removing large solids, but their overall trapping efficiencies and capacities are limited. Efficiencies can be enhanced by placing baffles in upstream raceways, but the burden on operations and maintenance, along with the fact that they have only worked well in concrete-bottom raceways, made such a recommendation infeasible for the trout farms in this study. The idea does have merit if the farm has concrete bottoms, has low activity, can tolerate the added maintenance, and has a downstream settling unit. Nonetheless, overflow rates for sediment traps are extremely high, and the level of TSS removal is insignificant compared to the amount of waste solids that escape (Maillard *et al.*, 1998). Settling ponds yield low effluent TSS concentrations; however, space requirements, cleaning difficulties, and nutrient releases have been cited as disadvantages for implementation at aquacultural facilities.

Due to the results from the treatment survey, along with results from laboratory scale (Type II settling and particle size distributions) and field experiments (sludge accumulation) performed in the water quality and sludge characterization study (Maillard *et al.*, 1998), a pilot scale settling unit was set up at one of the trout farms. The design was based on a combination of concepts related to sediment traps and settling ponds, where screens, weirs, baffles, and a higher detention time/overflow rate were used to improve TSS removal. The pilot study revealed that all shock loadings could be treated to a high degree after a short period of time (10 minutes). However, TSS concentrations during low and average activities were not reduced due to insufficient settling time. Increasing the detention time of the settling unit to 15 - 20 minutes provided for increased TSS removal during all events. Since peak events were associated with only 1 - 3% of the total daily flow, the additional removal that is provided with the higher detention time is important in reducing overall TSS loadings discharged by the farms. Increasing the detention time and promoting plug-flow provided for high removals and low effluent concentrations. The design provided for efficient TSS reduction in a small amount of space. The added advantage of nutrient removal is also apparent when removing a large portion of the waste solids in an aquacultural effluent.

Any effluent treatment scheme that is aimed at solids removal will also need a rigorous sludge withdrawal, treatment and disposal plan. Pumps and vacuums connected to large, portable tanks is the most common way to extract the sludge. Land application is the most practical disposal alternative because of the low metal, high organic, and high nutrient content of the sludge, but space needs to be available to use this option. The traveling distance to the land application site and/or the amount of sludge withdrawn from the farm may make it necessary to consider on-site thickening of the sludge to reduce land disposal or land application hauling and disposal costs. Composting also has merit as a sludge treatment alternative and can be considered in some instances as a very good alternative, as it provides for a marketable product and can be operated cheaply. The capital costs can, in some instance, be high, and there is little available information on its success for aquacultural waste solids.

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4.0 Engineering Significance/Site Recommendations

4.1 Introduction

As mentioned in Chapters 2 and 3, there are a number of alternatives available for treatment of aquacultural effluents. Due to the wide range of aquacultural facilities, caution must be exercised in recommending a certain treatment scheme for a given farm. Flow rate, fish type, space, manpower, economics, performance, and influence on operations are a few of the parameters that need to be considered. Fewer alternatives for sludge treatment and disposal are available, and are usually dictated by space and hauling costs.

Farms A, B, and C are single-pass, raceway-system trout farms. As noted in Chapter 2 and 3, the three farms are quite different in terms of flow rates, manpower, production rates, and available space. All have economic constraints, however, and this, along with performance will be the driving factors for treatment decisions. Treatment and BMP recommendations are summarized below. It should be noted that waste minimization is the most important alternative that should be practiced. Waste minimization alone, however, will not be sufficient for proper TSS and nutrient removal. Due to the amount of solids that are introduced into the waters, and the routine activities of aquacultural facilities, additional treatment will be required.

4.2 Treatment Alternatives

4.2.1 Sediment Traps

Sediment traps were seen to remove a significant amount of waste solids in a sludge accumulation experiment performed in the water quality and sludge characterization study (Chapter 2). Capacity was reached after 14 days of accumulation, after which, new particles passed through, and some old particles were resuspended into the effluent. Sediment traps therefore serve a valuable role at the end of each raceway, but need to be cleaned regularly.

They should be constructed as wide as possible, and as long as the farm can comfortably provide without significant constraint on production. Overflow rates for these sediment traps at Farm C were 1510 – 1620 $m^3/m^2 \cdot day$. IDEQ (1998) states that quiescent zones should provide a velocity of 0.0094 m/s (816 $m^3/m^2 \cdot day$) to catch raceway biosolids. Any velocity below 0.0305 m/s (2630 $m^3/m^2 \cdot day$) should settle out partially eaten feed and fecal material. Screens (1/2 inch or 1/4 inch) should be used at the inlet side, with a broad-crested weir at the discharge end to provide for a quiescent environment in the trap.

As mentioned above, sediment traps have limited capacities, and a regular cleaning schedule will need to be implemented for the traps. Based on a feeding rate of 50 lbs/day, and a flow of approximately 1700 gpm, a dual sediment trap system reached capacity after 14 days of accumulation. Although it is difficult to extrapolate to other farms under other conditions, these results provide an indication of the cleaning schedule required. Two cleanings per month would be a good cleaning schedule to initiate, but this should be adjusted according to on-site conditions. Many methods are used to remove solids from the traps, some of which are described by IDEQ (1998). The method chosen should be capable of removing the solids at a high solids content, while at the same time, minimizing turbulence and resuspension of accumulated solids. Disturbances of water in the sediment traps during other normal operations should also be avoided. It is common for fish to escape into these units from the downstream raceway. If this occurs, fish should be removed as soon as possible. Leaving fish in the sediment traps will cause constant resuspension of accumulated waste solids (observed at Farms A and C).

Again, the importance of sediment traps is to remove easily settleable solids from the effluent, to prevent the particles from breaking into finer particles, and to prevent the release of nutrients. The traps are especially important during harvesting, when high TSS spikes, consisting of mostly large solids, are likely to occur in the effluent. Having a small-scale settling basin on-line when this event occurs will improve the efficiency of downstream processes and produce an overall better effluent quality.

4.2.2 *Settling Basins*

It is recommended that a settling basin be constructed at the end of each train of raceways at each farm (e.g., Farm A=1, Farm B=2, Farm C=4). An example unit is shown in Figure 1. An overflow rate of 48.9 $m^3/m^2 \cdot day$ should be provided. The unit should be as wide as the lowest raceway of each train, and span a length appropriate to achieve the required area for settling. Baffled walls should be installed in the settling basin to promote plug-flow and to provide access for cleaning. Since space is a critical parameter for the farms, adding baffles will help economize on the space available. Reynolds and Richards (1996) discuss a description of plug flow and its importance in sedimentation. The width of the baffles needs to be determined on a site-specific basis. If farm personnel prefer to clean settling units from the outside, or if they would like walking access around a settling unit, baffles should be about 3 feet wide. If the farmers prefer to enter the basin for cleaning, and would like to conserve as much space as possible, the baffles can be as narrow as the material will allow, considering the force of the water. The scouring velocity of the settled waste solids will restrict the number of baffles. The more baffles added, the narrower the channels become, thereby creating higher flow-through velocities. A target particle size of 5 - 20 µm is suggested for the design criteria based on particle size results from Chapter 3. Scouring velocity was defined in Chapter 3 and is a function of the specific gravity of the solids, diameter of the particle, and the Darcy-Weisbach friction factor. Spreadsheets are provided in Appendix B for each farm to calculate space requirements given a scouring velocity, number and size of baffles, and overflow rate. One can see that a compromise must be made between scouring velocity and good plug flow; i.e., the more baffles added, the more plug flow is encouraged. If too many baffles are added, however, the velocity will be too high and could cause scouring.

As with sediment traps, settling basins will also need to be cleaned on a regular basis. Because of the surface area provided for settling, cleaning will not be required as frequently as for the sediment traps. However, because of degradation and nutrient releases, a cleaning schedule that incorporates both the settling unit and sediment traps simultaneously may be more efficient and easier on operations.

Figure 1 shows a diversion channel that can be placed on either side of the settling unit. This diversion channel is designed to allow flow diversion during cleaning. As with any cleaning device, disturbance within the unit will be high, and will more than likely cause a large spike in effluent TSS concentration, especially if people are working in the tank. For example, the settling tank in Figure 1 provides an overflow rate of 48.9 $m^3/m^2 \cdot day$, and approximately 20 minutes of detention time. The unit can be considered as two equal sized pieces, both consisting of approximately half of the area and detention time needed for design TSS removal. This amount of area/time (10 minutes) was shown in Chapter 3 to be sufficient for removal of TSS spikes, but relatively non-effective during low or average activities. Thus, when cleaning takes place, operations will begin with the first part of the settling unit, allowing effluent to travel its normal path. Even though considerable resuspension will occur, the “second half” of the settling unit will provide for sufficient removal of the waste solids. When the time comes to clean the second half, flow must be shut-off upstream or diverted. Farm superintendents expressed concern over stopping flow if the time needed for cleaning was significant. Preventing fresh

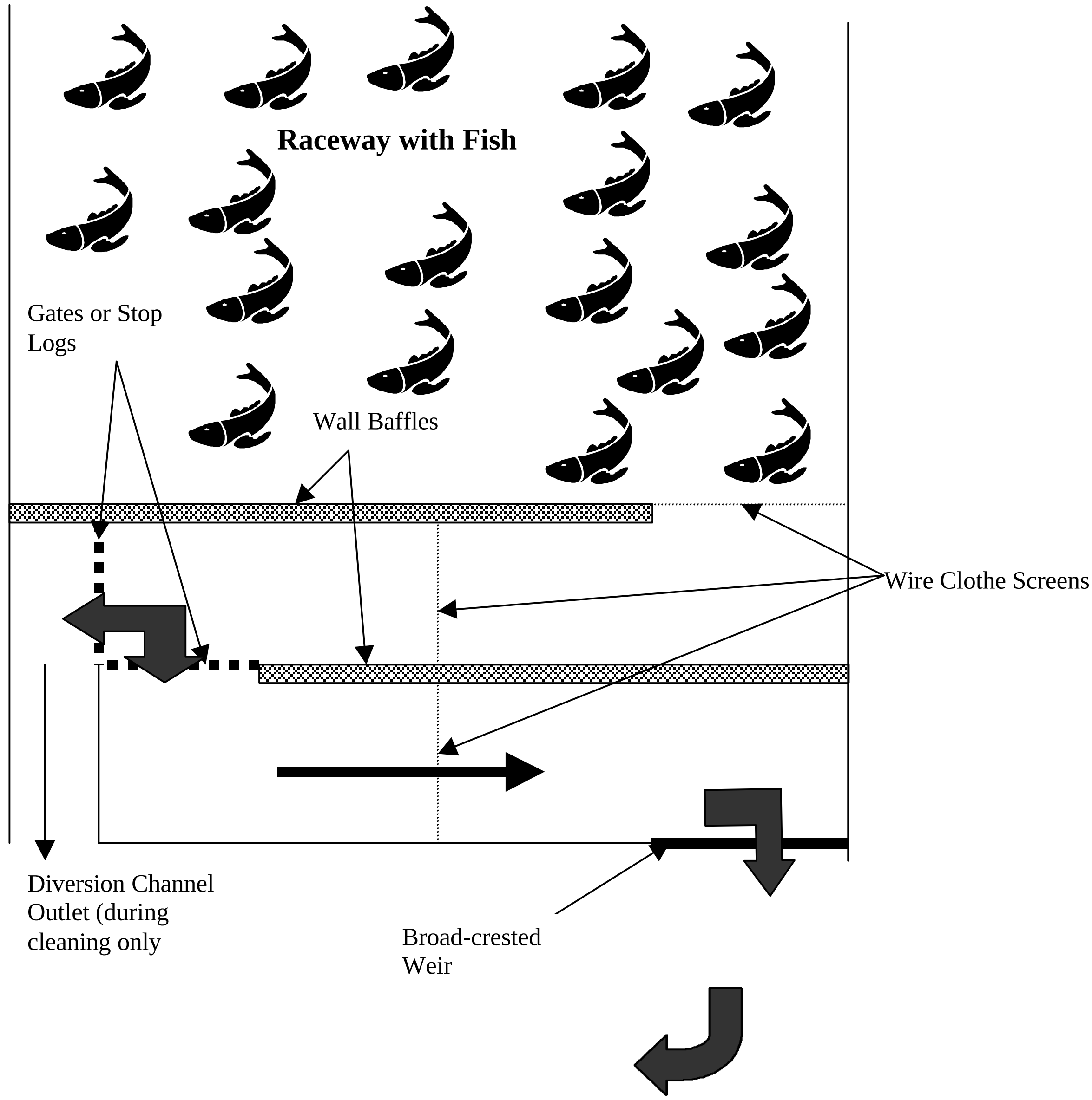

Fig. 1. Sample schematic of proposed treatment scheme (two baffles).

water from entering the raceways may result in disease problems, decrease in production, and overall poorer water quality. A diversion channel will combat this issue. Scouring of solids is not an issue for the diversion channel, so the main concern is to provide enough cross-sectional area for the flow. Removable gates or stop logs can be used to divert the incoming flow. Although solids will be suspended during cleaning, they will be allowed to settle once cleaning has ceased. As soon as farmers feel that the settling unit has returned to its normal state, flow can be returned to its normal path. Because farms lose half of the design settling capacity of the unit during times of cleaning, it is suggested that this practice take place at beginning or end of the workday, when TSS concentrations are typically low.

4.2.3 Sludge Disposal

Sludge disposal will be a time consuming process regardless of the choice of effluent treatment. IDEQ (1998) stated that over 25% of the labor costs are associated with handling and disposal of waste solids. Table 1 lists feed rates, reported FCRs, and calculated solids accumulation and land application requirements for Farms A-C.

Table 1. Predicted sludge accumulation and disposal requirements. Note: Feed assumed to be 12% moisture. Removal assumed to be 80% (average of 10 and 20 minute pilot trials). Percent solids of removed sludge assumed to be 3%. Nitrogen assumed to be 3% of waste solids (Chapter 2).

	FARM A	FARM B	FARM C
Feed rate (kg/yr)	42,730	41,000	227,300
FCR	1.6	1.6 - 2	1.2 – 1.8
TSS Produced* (kg/yr)	12,230	12,910	68,700
TSS Removal (kg/yr)	9780	10,330	55,000
Sludge Volume (m^3/yr)	324	342	1820
Nitrogen Produced (kg/yr)	293	310	1650
Land App. Requirements (hectare)			
Tall Fescue	0.9 – 1.9	1 – 2	5.1 – 11
Kentucky Bluegrass	1.1 – 1.4	1.1 – 1.5	15.1 – 20
Corn	1.6	1.7	22.2

***** Calculated from IDEQ (1998)

Although the calculations above are based on many assumptions, the sludge produced and required land area are expected to be close to what farms will be handling when the recommended BMPs and treatment schemes are implemented. If the volume of sludge collected results in excessive hauling costs, then on-site thickening should be considered. Land requirement will not change, assuming nutrients are not lost during thickening. If land area is of concern, composting should be investigated.

4.3 Supplemental BMPs

There are other site improvements and BMPs that can be implemented at the trout farms to improve effluent quality. Erosion control and concrete raceways are improvements that will not only improve effluent quality, but will improve production. Although these two options are not economical on the basis of pollutant reduction alone, they may be considered for improved production and easier operations. Both options will help to reduce the amount of inorganics and attached nutrients in effluents. Concrete-lined raceways will also reduce the amount of "dead spots" where a surplus of solids may accumulate and degrade.

Flow diversion should always be prevented unless flooding threatens the productivity of a farm. Diverting flow to adjacent streams or waterbodies will result in an untreated effluent discharged to the receiving stream. Once a settling unit is installed at a facility, all effluent should be directed towards this unit for full treatment. Diverted flows will mask the benefits of an installed settling unit.

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APPENDIX

FARM SCHEMATICS

FARM A

FOCUSED SAMPLING POINTS WITH PARAMETERS

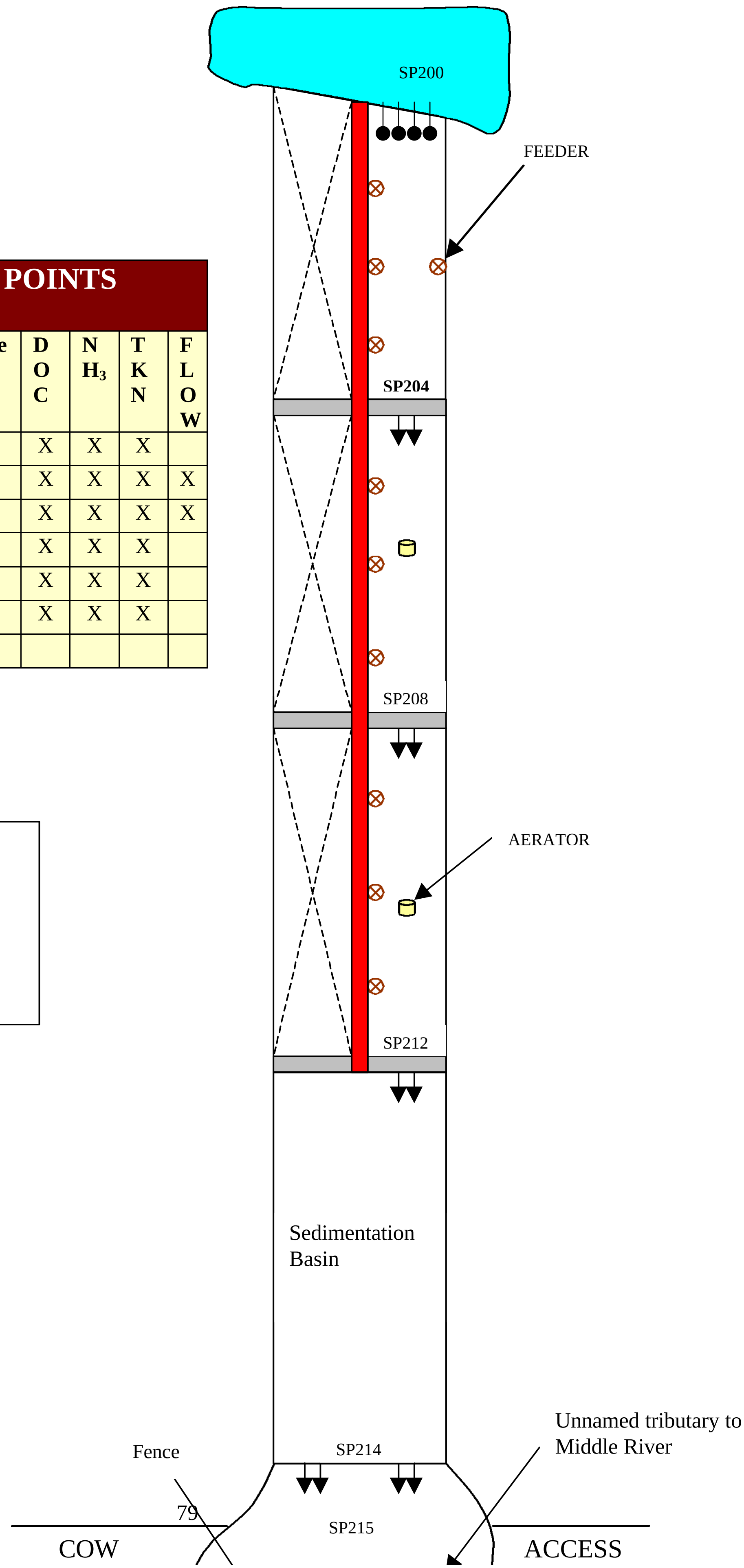
SP	DO	TEMP	BOD_5	TSS	Settleable Solids	DOC	NH_3	TKN	FLOW
200	X	X		X		X	X	X	
204	X	X	X	X		X	X	X	X
208	X	X	X	X		X	X	X	X
212	X	X	X	X		X	X	X	
214	X	X	X	X		X	X	X	
215	X	X	X	X	X	X	X	X	
216				X					

DESCRIPTIONS

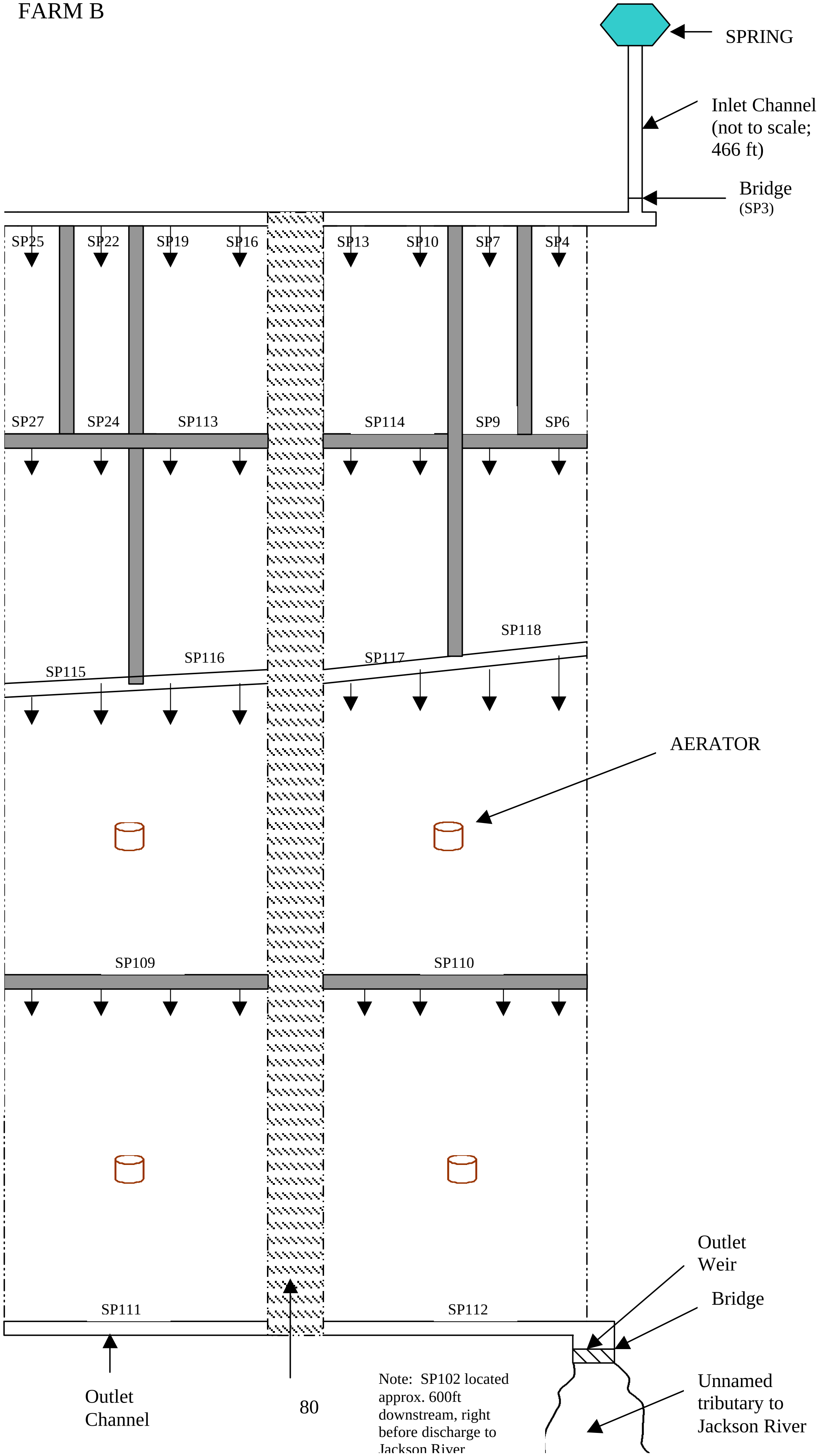
= **Weir Inlet**

= **Orifice Inlet**

Dashed "X" = Basins not in use



FARM B



USED SAMPLING POINTS ARAMETERS

	DO	TEMP	BOD5	TSS	SETT SOLIDS	DOC	NH3	TKN	FLOW
	X	X		X		X	X	X	X
									X
	X	X		X					
									X
	X	X		X					
									X
									X
									X
									X
									X
	X	X		X					
									X
	X	X		X					
	X	X	X	X	X	X	X	X	
	X	X	X	X		X	X	X	
	X	X	X	X		X	X	X	
	X	X	X	X		X	X	X	
	X	X	X	X		X	X	X	
	X	X		X					
	X	X		X					
	X	X		X					
	X	X		X					
	X	X		X					
	X	X		X					

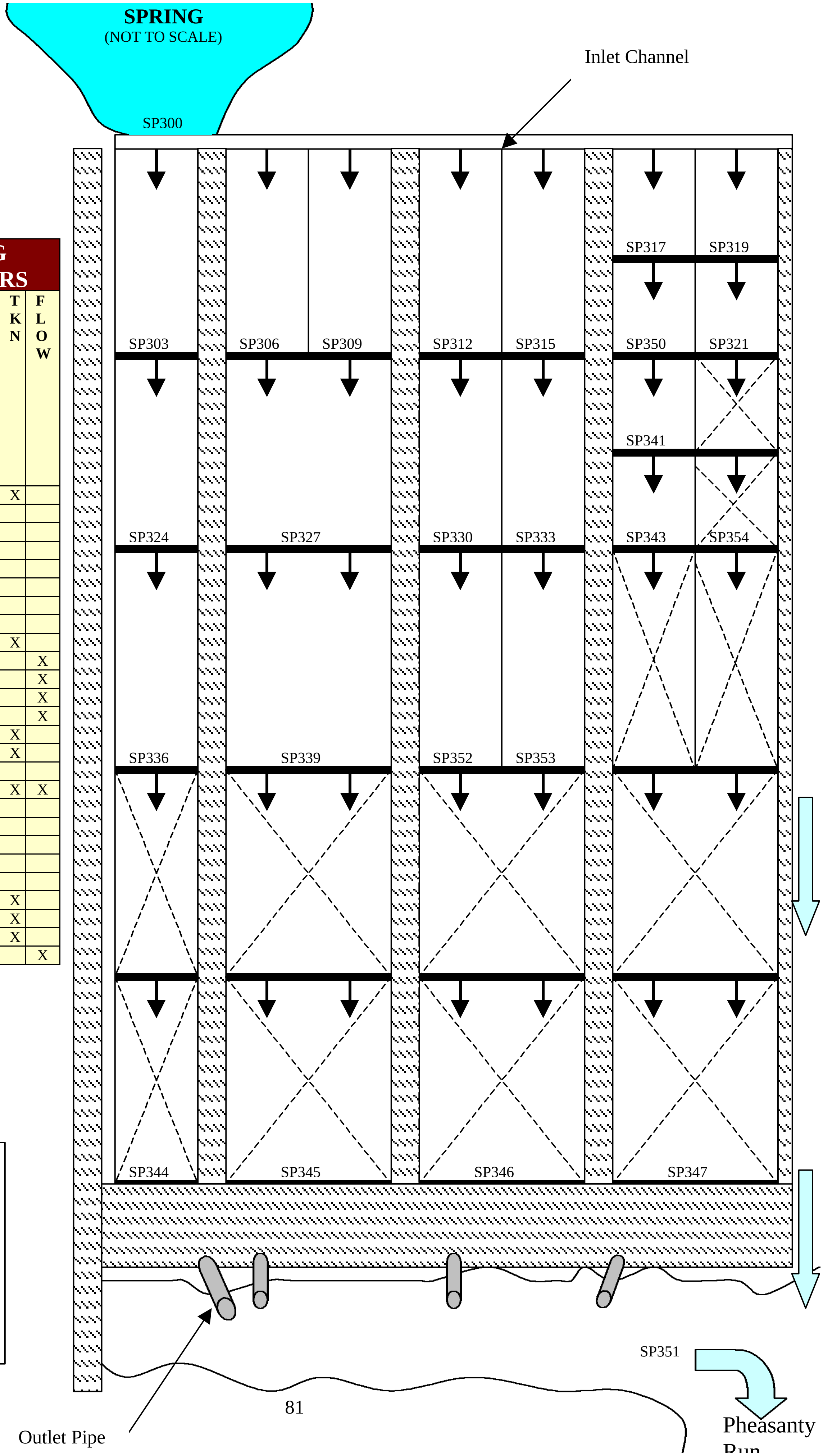
DESCRIPTIONS

otted-dashed line = urthen walls (erodible)

= Inlet Weir

= Truck Access

FARM C



FOCUSED SAMPLING POINTS W/PARAMETERS

SP	DO	TEMP	BOD5	TSS	SETT SOLIDS	DOC	NH3	TKN	FLOW
300	X	X		X		X	X	X	
303	X	X		X					
306	X	X		X					
309	X	X		X					
312	X	X		X					
315	X	X		X					
317	X	X		X					
319	X	X		X					
321	X	X	X	X		X	X	X	
324	X	X		X					X
327	X	X		X					X
330	X	X		X					X
333	X	X		X					X
336	X	X	X	X		X	X	X	
339	X	X	X	X		X	X	X	
341	X	X		X					
343	X	X	X	X		X	X	X	X
344				X					
345				X					
346				X					
347				X					
350	X	X		X					
351	X	X	X	X	X	X	X	X	
352	X	X	X	X		X	X	X	
353	X	X	X	X		X	X	X	
354									X

DESCRIPTIONS

Arrow = Weir Inlet

Dashed "X" = Basins not in use

= Truck Access

VITA

Vincent Maillard was born on May 25, 1973 in Taylor, Michigan and raised by his parents, Michael and Evelyn. He attended John F. Kennedy High School in the Downriver Detroit area, graduating in 1991 with academic and athletic honors. Upon graduation, Vince decided to enroll into an engineering transfer program with Central Michigan University (CMU) and Michigan Technological University (MTU). After studying 3 years at CMU, Vince transferred to MTU to study Environmental Engineering. While at MTU, Vince remained on the B.S. Environmental Engineering track, getting exposed many areas within environmental engineering. While at MTU, Vince was able to walk-on to the Varsity Tennis Team where he competed for two years on the Division II Intercollegiate level.

During Vince's senior year, his interest grew stronger in the process and design applications of water and wastewater treatment. Due to the general level of many of the classes in the program, and his increased interest in the field, Vince decided to pursue graduate study in environmental engineering. After many months of contact and investigation, he decided to attend Virginia Tech in the Fall of 1996. While at Virginia Tech, Vince was able to study and perform research in the area of water quality and wastewater treatment. He made many friends in the department while organizing many of the departments athletic activities.

Upon leaving Virginia Tech in August of 1998, Vince took an engineering position with Stearns & Wheler Environmental Engineers and Scientists in Bowie, Maryland. Although Vince had to leave Blacksburg before his thesis defense, he is proud to come back in December to fulfill the remaining portions of his degree requirements. Vince now resides in Annapolis where he continues his interest in sports.