The Biological Implications of Pond Cleaning on Hatchery Reared Salmon

Julie Peel

Salmonid Enhancement Program
Department of Fisheries and Oceans
1090 West Pender Street
Vancouver, B.C. V6E 2P1

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ABSTRACT

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The nitrogen cycle is very active within a fish hatchery environment. It is suspected that the interaction between two of its components, ammonia and nitrite with suspended particulate matter precipitates certain fish diseases including bacterial gill disease. This study was undertaken to investigate the factors leading to a toxic environment for hatchery reared salmonids and the relationship to fish culture techniques, pond design and equipment use.

A program of research visits to six salmonid hatcheries to examine their facilities and interview the fish culturists was conducted over a four month period. Data on pond types and sizes, species of fish, loading densities, flow rate, water quality, feeding, pond cleaning techniques and disease history was recorded.

In addition, a study of food decomposition was conducted at the Puntledge River facility laboratory. The inflow and outflow of a rearing channel and three isolated water environments were monitored for water quality over five days. Dissolved oxygen, temperature, pH, ammonia and nitrite measurements were made. Analysis of the samples from the three isolated environments revealed degradation of the water quality through increased turbidity and changes in the pH, ammonia and nitrite levels.

Résumé

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Dans les établissements piscicoles, le cycle de l'azote est très actif. On croit que l'interaction entre deux de ses composés, soit l'ammoniaque et le nitrite, et des particules de matière en suspension accélère le développement de certaines maladies, dont la maladie bactérienne des ouïes. La présente étude vise à examiner les facteurs responsables de l'intoxication du milieu d'élevage des salmonidés et à déterminer leur incidence sur les techniques d'élevage, la conception des étangs et l'utilisation de l'équipement.

Dans le cadre d'un programme de recherche d'une durée de quatre mois, on a visité six établissements de salmoniculture; on a ainsi pu examiner les installations et interroger les pisciculteurs. On a recueilli des données sur le genre et la grosseur des étangs, les espèces de poisson, les densités de chargement, le débit, la qualité de l'eau, la nourriture, les techniques de nettoyage des étangs et les cas de maladies antérieures.

Par ailleurs, une étude sur la décomposition de la nourriture a été effectuée au laboratoire de la piscifacture de la rivière Puntledge. On a étudié pendant cinq jours la qualité de l'eau d'alimentation et d'évacuation d'un canal d'élevage et trois bassins isolés. On a mesuré la quantité d'oxygène dissous, la température, le PH, de même que la concentration d'ammoniaque et de nitrite. Les analyses des échantillons prélevés dans les trois bassins isolés ont montré une dégradation de la qualité de l'eau due à une augmentation de la turbidité ainsi qu'à des changements du PH et des niveaux d'ammoniaque et de nitrite.

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INTRODUCTION

Fish are aquatic and poikilothermic creatures whose existence and performance are dependent on the quality of their environment. Chemical and physical variability exists within the freshwater environment while ocean conditions remain relatively uniform, however smaller bodies of water such as hatchery ponds, are subject to a greater magnitude of environmental change. Water quality management in the culture of salmonids has, therefore, become a topic of major concern and study.

Water quality during intensive fish rearing depends on three factors: quality of source water, fish food and water flow. Based on practicality, the latter two factors become of primary concern to the fish culturist. The high loading densities practiced at fish hatcheries makes the control of these elements vital to the production of healthy fish. Fish weight and water temperature related feed schedules (Stauffer's Formula OMP schedule - see Appendix 1) provide a physiological maximum feed ration guide, yet it appears inevitable that some food will remain uneaten. Water flow serves to exercise the fish, prevent the attack of external parasites and provide the fish with dissolved oxygen in addition to flushing away a portion of the waste food and fish excrement. Water flow sufficient to flush out all wastes may also be sufficiently powerful to divert energy normally directed towards fish growth into vigorous current swimming. In an attempt to maintain possible maximum growth and production, flow must be limited. The result is an increase in suspended particulate matter and a gradual accumulation of sludge (feces and uneaten food) two potentially hazardous situations for salmonids. In attempting to restore a healthy growth environment, ponds are often cleaned.

There are several advantages to pond cleaning done regularly, the task never becomes terribly onerous, good water quality is maintained, mortalities can be easily counted, disease treatment can be made effectively and the ponds remain attractive. Pond cleaning can also be detrimental to hatchery fish.

This paper is an attempt to summarize information on the nitrogen pathways operating within the hatchery pond and the knowledge of the effects of pond cleaning in reaching and understanding of why certain diseases, Bacterial Gill disease for example can be precipitated by their interaction. The relationship to fish culture techniques, pond design and equipment use is also discussed.

DISCUSSION

Once adequate dissolved oxygen levels are maintained, the single most limiting water quality parameter in a culture system is the toxicity of nitrogen compounds (Colt et al, 1979). Nitrogen is present in aquatic system in several forms, the most common of which are ammonia (NH_2), ammonium (NH_4), nitrate (NO_3), nitrite (NO_2), nitrogen gas (N_2), amino acids and proteins. Conversion between forms may occur due to simple chemical reactions but are more frequently the result of biological activities (Figure 1 - Wheaton, 1978).

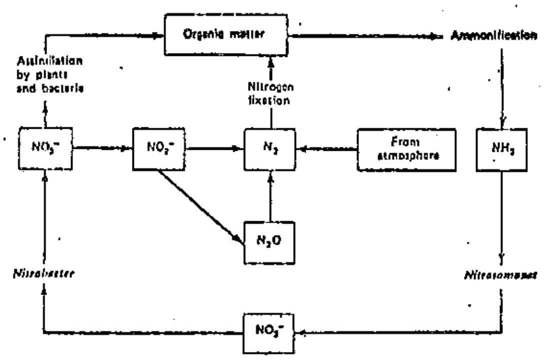

Figure 1. The Nitrogen Cycle (Wheaton, 1977)

There are three nitrogen sources related to a fish culture system. First, nitrogen contained in the water supply; second, nitrogen produced by the fish through their metabolism of food; and third, nitrogen generated through bacterial decomposition of sludge (waste food and fish excrement). Nitrogen compounds produced within the culture system, by fish metabolism and bacterial decomposition, constitutes the major source of nitrogen and are a result of fish food protein utilization (Figure 2).

The amount of nitrogen entering a pond through fish food such as Oregon Moist Pellet (OMP) can be calculated from the fact that the food is 35% protein (wet weight) and this protein is 16% nitrogen by weight.

(Eg.) Nitrogen in 1 lb. O M P = 1 lb. x .35 x .16 = .056 lb.N

A portion of the nitrogen found in food proteins is converted into fish mass while the remainder is released through the kidneys and gill tissue as

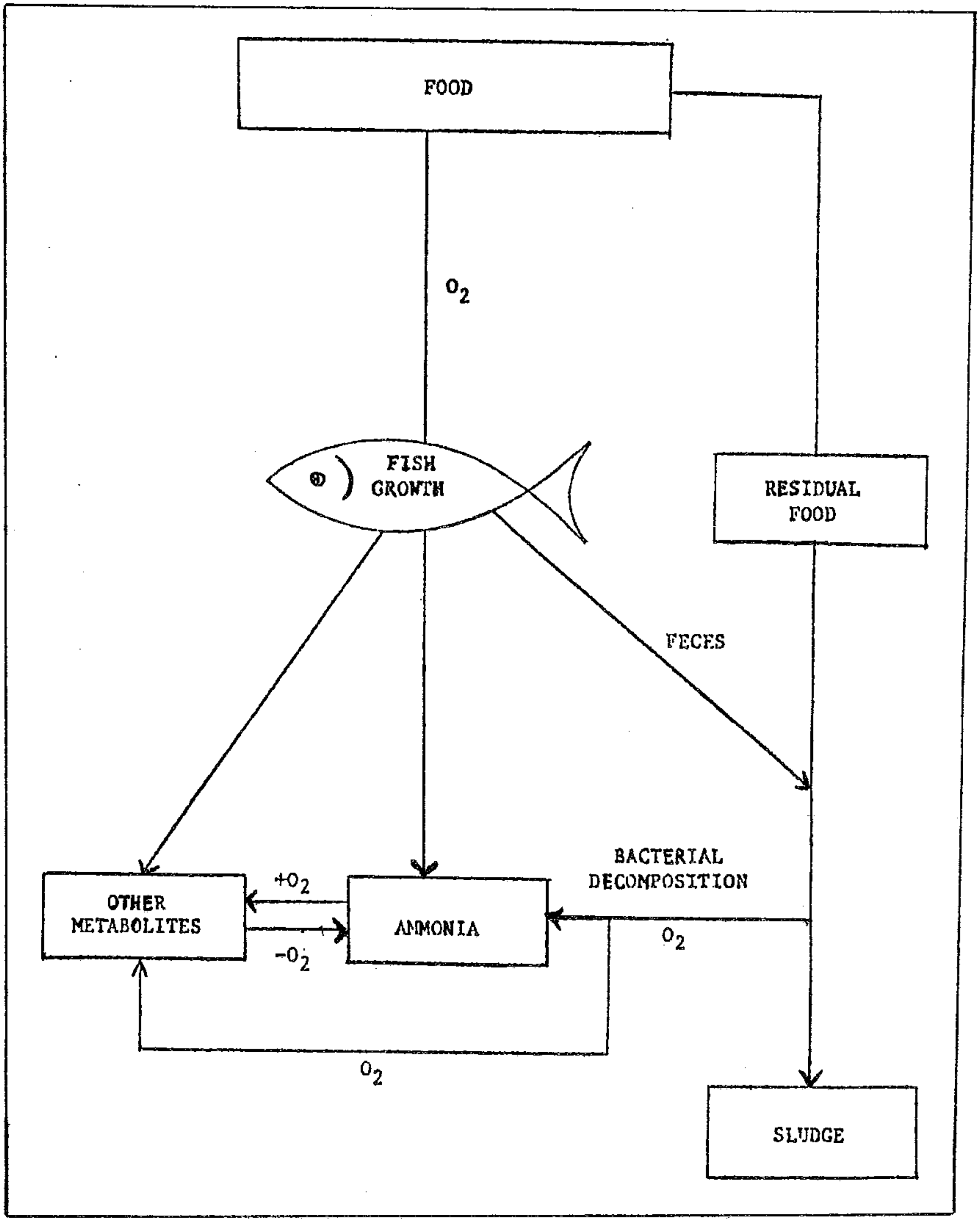

Figure 2. Fish Food Utilization (Liao, 1972)

mainly urea and ammonia. Due to its low toxicity to fishes and its quick conversion to ammonia and carbon dioxide, urea never becomes a serious hazard to culture systems (Colt and Tchobanoglous, 1978). Ammonia, however, is toxic to fish, even at very low concentrations (Burrows, 1964). Ammonia (NH_3) and the ammonium ion (NH_4) exist together in an equilibrium system. Data from several sources (Brockway, 1950; Lloyd, 1961; Burrows, 1964; Liao & Mayo, 1972) indicated that it is the unionized form (NH_3) that is toxic to fish.

Ammonia

Due to its neutral form, NH_3 is readily soluble in the lipid segments of the cell membrane and passes through without need of active transport. The ammonium ion cannot readily pass through the charge lined micropores of the hydrophobic membrane components due to its larger size and electrical charge (Hampson, 1976). Ammonia toxicity therefore, relies heavily on the water conditions that effect the equilibrium.

$$NH_3\ (g) + nH_2O = NH_3\ .\ nH_2O\ (aq) = NH_4^+ + OH^- + (n - 1)\ H_2O$$

The percentage of each form in an aqueous system is pH and temperature dependent. Table 1 gives the concentration of un-ionized ammonia as a function of pH and temperature in aqueous ammonia solution. As the pH and temperature rise, there is proportionately more toxic ammonia. Toxicity is affected to a lesser extent by dissolved oxygen concentrations (Wuhrmann, 1952; Downing & Hoskins, 1955; Lloyd, 1961), bicarbonate alkalinity (Lloyd, 1961) and the free carbon dioxide content in the water (Lloyd & Herbert, 1960).

Table 1. Percentage of un-ionized ammonia in aqueous ammonia solution at different pH's and temperatures.

pH	(C) 10 (F) 50.0	11 51.8	12 53.6	13 55.4	14 57.2	15 59.0	16 60.8	17 62.6	18 64.4	19 66.2	20 68.0
7.0	.19	.20	.21	.24	.25	.27	.29	.31	.34	.37	.40
7.1	.23	.26	.27	.30	.32	.34	.37	.39	.42	.46	.50
7.2	.29	.32	.34	.37	.40	.43	.46	.50	.53	.58	.63
7.3	.37	.40	.43	.47	.51	.54	.58	.62	.67	.73	.79
7.4	.47	.51	.54	.59	.64	.68	.73	.78	.84	.91	.99
7.5	.59	.64	.68	.74	.80	.85	.92	.98	1.06	1.15	1.24
7.6	.74	.80	.85	.93	1.00	1.07	1.16	1.24	1.33	1.44	1.56
7.7	.92	1.01	1.07	1.17	1.26	1.35	1.45	1.55	1.67	1.81	1.96
7.8	1.16	1.27	1.35	1.46	1.58	1.69	1.82	1.95	2.09	2.26	2.45
7.9	1.46	1.59	1.69	1.83	1.98	2.12	2.29	2.44	2.62	2.83	3.06
8.0	1.83	2.10	2.12	2.30	2.48	2.65	2.86	3.05	3.28	3.54	3.83
8.1	2.29	2.50	2.65	2.88	3.11	3.32	3.58	3.81	4.09	4.42	4.77
8.2	2.86	3.12	3.32	3.59	3.88	4.14	4.46	4.75	5.10	5.50	5.94
8.3	3.58	3.90	4.14	4.48	4.84	5.16	5.55	5.90	6.33	6.82	7.36
8.4	4.46	4.87	5.15	5.58	6.01	6.41	6.89	7.32	7.84	8.44	9.09
8.5	5.55	6.05	6.40	6.92	7.45	7.98	8.52	9.04	9.68	10.40	11.18

Source: Journal Fisheries Research Board of Canada, Vol. 29, No. 10, 1972, page 1506, by R. P. Trussell

Fish excretory mechanisms and the bacterial action in the pond water produce an increase in the ammonia level of the ambient water. A decrease in ammonia excretion follows, forcing the ammonia level in the blood and tissue of the fish to increase (Colt et al, 1979). Serious effects on the physiology of the fish may result, depending on the duration of exposure.

As excretion of ammonia becomes more difficult, there may be a reduction or cessation of feeding to reduce the production of metabolic ammonia. Over a continuous period of time, ammonia toxicity results in a reduction of growth rate and stamina and produces widespread hyperplasia of the gill epithelia. Blood hemoglobin then loses its ability to liberate carbon dioxide or to unite with oxygen, forcing the fish into a state of suffocation (Brockway, 1950; Burrows, 1964; Colt et al, 1979).

A summary of work done on the effects of un-ionized ammonia on four species of fish is presented in Table 2 (Hampson, 1971). Sublethal effects are shown to adversely affect fish growth and performance to an increasing extent as the ammonia concentration rises and weakens fish resistancy to disease infection. Ammonia will kill fish at relatively low concentration, hence a permissible upper concentration limit was proposed by Sigma Resource Consultants (1979) at 2 ug/l un-ionized NH_3.

Symptoms of ammonia toxicity within a hatchery environment are as follows:

- fish appear lethargic
- fish may refuse food
- loss of fish equilibrium
- increased or labored gill activity and jaw spasms
- pale and dying fish

Ammonia is the principle toxic metabolic by-product causing difficulty in rearing ponds, however, nitrite may also occur at toxic levels (Burrows, 1964; Colt et al, 1979).

Table 2. Toxic and growth inhibiting concentrations of un-ionized ammonia affecting four species of fish (Hampson, 1976).

Species	Effect on fish	Concentration of un-ionized ammonia ammonia ppm N	Source
Rainbow trout (Salmo gairdnerii Richardson)	Acute toxic thresholds taken in this report (LC_{50} in 500 min.)	0.3	Lloyd and Herbert (1960), here
	Incipient LC_{50} in 500 min. - generally accepted	0.41	Lloyd and Herbert (1960), Alderson (1976)
	EIFAC recommendation (acute and chronic toxic effects - probably includung a margin for error)	0.025	EIFAC (1970)
	Upper tolerance limit	0.05	Scott and Gillespie (1972)
	LC_{50} in 500 min	0.45	Schulze-Weihenbrauck (1974)
	Just did not affect growth	0.13	Schulze-Weihenbrauck (1974)
	Harmless	0.10	
	LC_{50} in 500 min	0.39	Lloyd and Orr (1969)
	Harmless	0.047	Lloyd and Orr (1969)
Chinook salmon (Oncorhynchus Ishaituytaho)	Complete consolidation of gill epithelium in 6 weeks	0.016 for 24 h/day	Burrows (1964)
	Fish can tolerate with impunity for 6 weeks	0.016 for 1 h/day	Burrows (1964)
	Growth rate reduced (6 weeks exposure)	0.002 for 12 h/day	Burrows (1964)
	Reduction in stamina and decreased resistance to infection (6 weeks exposure)	0.002 for 24 h/day	Burrows (1964)
	Extensive hyperplasia of gill epithelium in 6 weeks	0.006 for 24 h/day	Burrows (1964)
	Upper tolerance limit	0.005 for 24 h/day	Schulze-Weihenbrauck (1974)
Dover sole (Microstomus pacificus)	Fish just completely stopped feeding. Nil growth.	0.75	Alderson (1976)
	Growth at 13% of the rate when ammonia concentration approaches zero (pH 8)	0.41	Alderson (1976)
	No effect on growth	0.042	Alderson (1976)
Turbot (Atheresthes stomias)	No effect on growth	0.09	Alderson (1976)

Nitrite

Nitrite (NO_2) is formed in the nitrogen cycle (Figure 1) by two processes. Nitrifying bacteria, such as Nitrosomonas sp. attack ammonia and release nitrite:

$$2NH_3 + 3.5\ O_2\ \text{(nitrosomonas)}\ 2NO_2 + 3H_2O$$

Bacteria use the energy produced by this oxidation to build carbohydrates. The second process involves the reduction of nitrate (NO_3) to nitrite and is facilitated by specific diatoms and algae:

$$NO_3\ \text{(diatoms/algae)}\ NO2 + 1/2\ O_2$$

The final step in the decomposition of nitrogenous material is the oxidation of nitrite by nitrobacter sp.

$$NO_2 + O_2\ \text{(nitrobacter)}\ NO_3$$

While nitrates are not toxic, they do act as growth promoters for plants and bacteria, a condition undesirable in a closed system for fish culture (Wheaton, 1978; Pettigrew et al, 1978; Colt et al, 1979).

Nitrite is extremely toxic to fish because of its effects on oxygen transport and tissue damage. Exposure to nitrite results in methemoglobinemia, the conversion of hemoglobin to methemoglobin, because the methemoglobin pigment cannot transport oxygen, the fish become weakened and mortalities may occur as a result of anoxia (Liao & Mayo, 1972; Russo et al, 1974).

The lethal effect of nitrite on fish vary with the water chemistry. Wedemeyer and Yasutake (1978) and Russo and Thurston (1977), show that the addition of calcium can increase the tolerance of salmonids by up to sixty times since calcium ions may compete with nitrite for transport across the gill and reduce the effect of nitrite. Russo and Thurston (1977) also found that pH had no effect on nitrite tolerance while Wedemeyer and Yasutake (1978) reported that there was a distinct relationship between pH and nitrite toxicity. It appears that further work is needed to clarify the parameters affecting nitrite toxicity.

The Environmental Protection Agency (1976) concluded on the basis of the work done by Russo et al (1974) and Russo and Thurston (1975) that a nitrite nitrogen level at or below 0.06 mg/l should be sufficient to protect salmonid fishes.

The ammonia and nitrite components of the bacterial nitrification reaction NH_3 ----> NO_3 ----> NO_3 are continually present in an active culture system. Their concentration is dependent on several factors such as pond temperature feed rate, water chemistry, load rate and the diurnal variations in ammonia excretion of fish all of which greatly alter the total toxic nitrogen compounds present in a system (Burrows, 1974; Mclean & Fraser, 1974; Wedemeyer et al, 1976). In addition, hatchery disturbances such as fish removal, transport and pond cleaning can cause a significant rise in the concentration of nitrogen wastes.

McLean and Fraser (1974) studied the effect of a fish removal on a coho pond and recorded the diurnal ammonia pulses on three occasions within a seven day period. The results show an immediate response to the disturbance and a long-lasting effect, indicated by the continuance of high ammonia levels (Figure 3). During transport, ammonia levels rise as the fish respond to the disturbance and changes in water quality resulting from inadequate water exchange and temperature regulation.

Pond cleaning causes a disturbance which necessarily results in an increase in the ammonia excretion rate of the fish. Furthermore, agitation of the pond bottom causes an increase in suspended particulate matter. These particulates consist of waste food and feces in varying stages of bacterial decomposition. Thus, disturbance of the pond bottom results in both an increase in suspended solids and an increase in nitrogenous compounds throughout the pond. The effects of distributing the type of solids found on rearing pond surfaces throughout the water column deserves special attention.

Suspended Solids

Suspended particulate matter can seriously injure or kill fish by causing abrasive wounds, clogging the gills and lessening the resistance to infection.

The degree of damage appears to depend on the shape of the particle, the duration of exposure, the age of the fish (the older, the more resistant) and the interaction of the particles with certain chemicals (G. Hoskins). Research done by Hymes (1958) showed that healthy fish may swim through heavy solid suspensions without significant damage. In the presence of even low concentration toxic substances, however, fish may become so weakened that the abrasive and clogging action of suspended solids becomes even more effective (Ellis, 1939). The lack of knowledge of the effects of particle shapes and the interaction between toxic substances such as ammonia and nitrite, and particle types, on the degree of damage caused by suspended particles has made the attainment of comprehensive turbidity guidelines impossible. Further research is needed to clarify the role of suspended solids in aggravating gill tissue and increasing the susceptibility of salmonids to gill diseases.

IMPLICATION OF POND CLEANING

When pond sludge is disturbed during cleaning, the resultant suspended solids function not only as chemical and physical gill irritants but as carriers of discharged pathogens as well. Bacteria previously confined to the pond bottom are able to circulate freely among the fish, greatly increasing the threat of infection. These radical changes in water quality, in conjunction with the commotion of the pond cleaning, create an additional detriment for salmonids, a stress reaction.

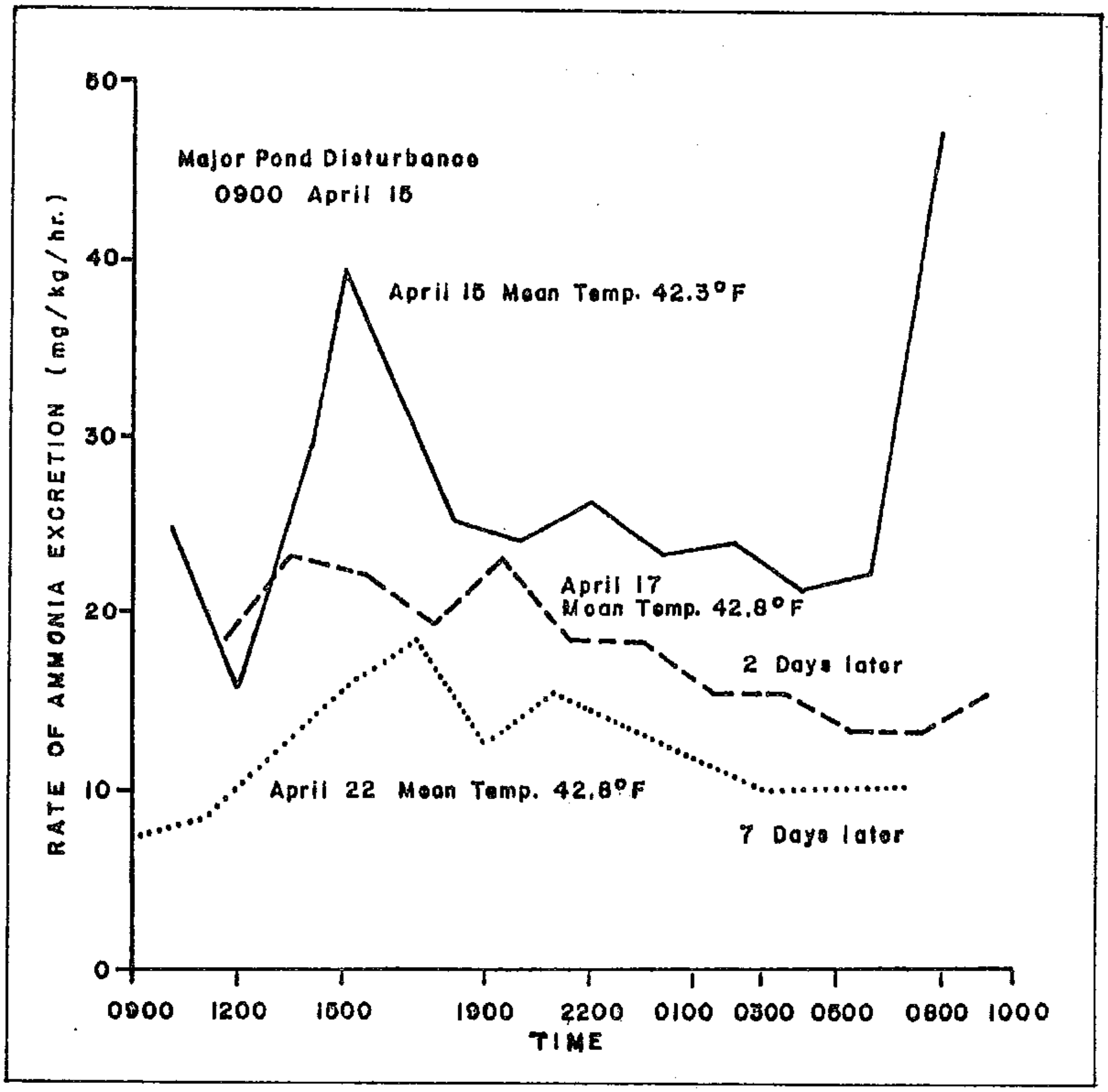

Figure 3. Ammonia Production by coho salmon following the April 15 pond disturbance. (McLean & Fraser, 1974)

In general, a stress is any change from what is an optimal condition for a fish. Chemical, environmental and biological stress factors will reduce the innate resistance of a fish to disease. The mechanism by which this occurs is probably hormonal, effecting a reduction in antibody and phagocytic responses (G. Hoskins, personal communication; Brown, 1980). The debilitated fish becomes increasingly unable to fight the bacteria that, during pond cleaning, becomes increasingly virulent.

Disease

Bacterial infection do not arise spontaneously; they require an interaction of various factors (Figure 4) which, within a culture system, are very delicately balanced between three factors; pathogen, host and environment.

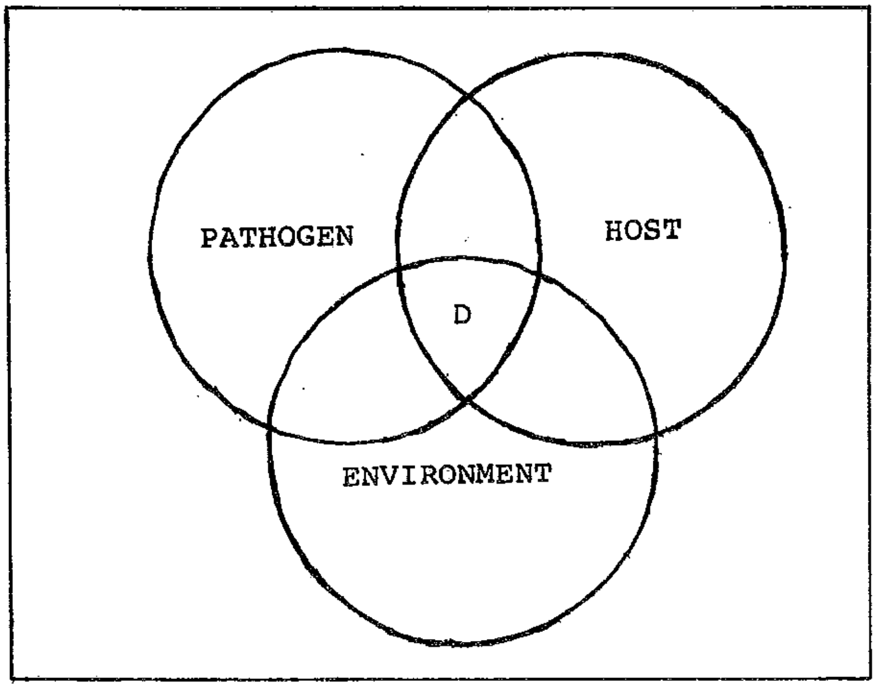

Figure 4. Interaction of Factors leading to a disease outbreak

Fish (host) can thrive in the presence of limited bacteria (pathogens) provided environmental stress is minimal.

Although documentation is scarce, it is reasonable to expect that gill irritation resulting from increased levels of ammonia, nitrite and/or suspended solids, in conjunction with the depressed immune response caused by stress, allows bacteria to gain a foothold on the gills and in the bloodstream. Burrows (1964) proposed that the extensive hyperplasia of the gill epithelium, caused by ammonia, is a predisposing factor to bacterial gill disease, one of the most common diseases of hatchery-reared salmonids. Bacterial gill disease is a superficial infection of the gills by large numbers of myxobacteria which causes fusing and clubbing of the gill filaments. Distress and death are caused by the inability of the fish to obtain oxygen and eliminate carbon dioxide and ammonia (Wood, 1968). The United States Fish and Wildlife Service (1980) and Wood (1968) suggest that some irritant, possibly a metabolic product, is responsible for addition, Wood (1968) noted that infected fish moved from a diseased water source to fresh water in the early stages of infection, recovered spontaneously.

Bacterial Gill Disease

Fish infected can be recognized by the following symptoms:

- lethargy
- pale colour
- swimming at the pond surface

- loss of appetite
- widened gill covers
- labored gill activity
- excess mucous around the gills
- clubbing of the gills (Davis, 1961; Wood, 1968; U.S.A. Fish & Wildlife, 1980)

Enteric Red-Mouth Disease

An additional bacterial disease ostensibly precursed by ammonia, nitrite and/or suspended solids irritation, is Red-mouth.

The bacteria enters the blood and tissues, causing a breakdown of the capillaries in the body wall and visceral organs. Progression of the disease involves hemorrhaging of the intestinal walls at the base of the pectoral and pelvic fins and the branchiostegal region.

Symptoms of infection:

- loss of appetite
- listlessness
- externally visible hemorrhaging (Wood, 1968)

Wood (1968) outlines the ideal conditions for an epidemic, provided the bacteria Aeromonas liquefaciens is present:

- several months accumulation of pond sludge
- mortalities removed infrequently
- substantial increases in bacteria levels resulting from sludge and dead fish accumulation
- intimate exposure of fish to high levels of bacteria and sludge during pond cleaning
- stress caused by handling and/or pond cleaning activities.

Further research is needed to end speculation and distinguish the role of pond cleaning products (ammonia, nitrite and suspended solids) in instigating such infections as bacterial gill disease, enteric red-mouth and conceivably others.

CRITERIA FOR CONTROL

Disease control at hatcheries depends primarily on prophylaxis rather than chemical treatment, hence the vital need for good fish culture techniques. Maintenance of large fish populations requires effective and efficient management, emphasizing water quality, nutrition and reduction of stresses. While considerable discord exists among fish culturists on the subject of pond sludge removal, several guidelines have been established to control its detrimental effects.

Minimizing Sludge Build-up

- maintain adequate water flows
- feed carefully to avoid waste food collecting on the pond bottom
- refrain from overcrowding fish
- pick mortalities frequently
- clean ponds regularly to prevent the necessity of major cleaning

Pond Cleaning

- attempt to maintain proper environmental conditions
- cease feeding during and immediately following pond cleaning to alleviate ammonia build-up (in a single pass system this may not be necessary)
- disinfect equipment transferred between ponds to prevent the spread of infection
- handle equipment carefully and gently, stirring up as little sludge as possible and attempting to minimize stress on the fish
- if a disease is known to occur at a particular time, schedule all pond activities well in advance or after the event

Adherence to these policies helps maintain a healthy balance between pathogens, host and environment during a potentially hazardous activity. In addition, a comprehensive knowledge of the unique characteristics of different rearing facilities is essential to sustaining a healthy environment.

POND DESIGN

Pond design can significantly influence fish health and productivity. Two basic categories of rearing ponds have developed; the flow-through ponds and the circulating ponds. In principal, all flow-through ponds establish a very distinct water quality gradient (O_2 levels & metabolic wastes) from intake to outlet. In contrast, circulating ponds achieve a homogeneous environment by mixing the incoming water with used water. Major design and operating characteristics of specific rearing facilities are discussed below.

"Flow-Through" Pond

Rearing Trough

A standard hatchery rearing trough is constructed of aluminum or fiberglass and has length, width, depth measurements of 21 ft. x 2.5 ft x 1.5 ft., although some variations exist. The troughs feature a rounded bottom and are mounted on supporting framework with the upper end slightly higher than the foot to allow proper drainage. A wire jump screen is usually placed across the trough at the inflow and a similar screen positioned at the foot end to prevent fish from escaping with the outflow. The rate of flow into the trough is regulated by a faucet or similar device at the head end and the troughs are usually arranged in pairs, one below the other, so that the same water is used in both troughs. Separate drainage outlets are maintained to allow independent emptying which is essential to prevent excrement and wastes from contaminating the lower trough when the upper trough is cleaned.

General Operating Characteristics:

- size convenient for fish culturists to work around
- easy to view fish
- easy to remove fish
- size makes disease treatment simple
- possible to have high loading densities
- smooth sides reduce fin erosion
- size necessitates hand feeding
- can be painted with algicide
- baffles can be installed to increase bottom velocity to accomplish self-cleaning and exercise the fish
- cleaning is time consuming due to number of troughs used
- cleaned either by suction vacuuming or pulling end pipe and brushing sludge to end as trough is flushed. (stressful)

Opinions on the effectiveness of rearing troughs are numerous and varied. Some fish culturists maintain that fish perform well in troughs during initiation of feeding and early rearing stages. Others insist that troughs were designed primarily for the convenience of the narrow and shallow container dimensions. To alleviate the stress of the fish at being conspicuous, some innovations have arisen. Troughs painted dark colours and troughs with partial caps allow fish culturists to continue their activities while controlling stress. In general, the success of rearing troughs depends on the species of fish cultured, the duration of time spent in the rearing trough and particularly the quality of culture techniques (fish culturists, personal communications; Sinclair, 1976; Westers et al, 1977).

Raceway

The raceway is simply a greatly enlarged, flat-bottomed trough with a stream of water flowing into one end and out the other. Relative dimensions vary but a length:width:depth ratio of 30:3:1 is acceptable. Inlet and outlet usually cover the full width of the pond. Inlet structures vary from single surface pipes, upwelling standpipes and horizontal jet bars. Dead water "hot spots" can be avoided by use of upwelling floor diffusers or ledge spillways extending the full pond width at the inlet. These features prevent waste food and excrement from collecting. Normally there are two slots in the wall on each side of the opening, one for dam boards to regulate the depth of water and the other for insertion of a wire screen to prevent the fish from escaping. A similar screening device is used at the head of the raceway to prevent the fish from leaping at the inflow water.

General Operating Characteristics

- easy to work around
- good visibility of fish
- relatively easy to remove fish
- facilitates automatic feeders (manpower savings)
- fish tend to congregate at head end

- high water exchange rates allow maximum loading capacity
- greater water demand than circulating ponds
- if water quality is good, raceways can be arranged in series
- seldom attain sufficient water velocity for self-cleaning
- water exchange is minimal in corners, leading to "hot spots"
- baffles can be installed to increased bottom velocity to aid in cleaning and exercise the fish
- can be painted with an algicide
- rough concrete can promote fin erosion

Raceway culture is widely used in hatcheries because the associated water flow minimizes the concentration of metabolites, maintains high oxygen levels and exercises the fish. Ideal plug flow, where all elements of water move with identical horizontal velocity, will not exist in a raceway so attempts should be made to prevent the settling out of solids, by establishing a minimum of four exchanges per hour. Figure 5 illustrates the vertical velocity profile within an active raceway. Raceways are not self-cleaning at operating water flows and must be vacuumed regularly and scrubbed down at the end of the rearing period (Fish Culturist, personal communications; Sinclair, 1976; Wester et al, 1978).

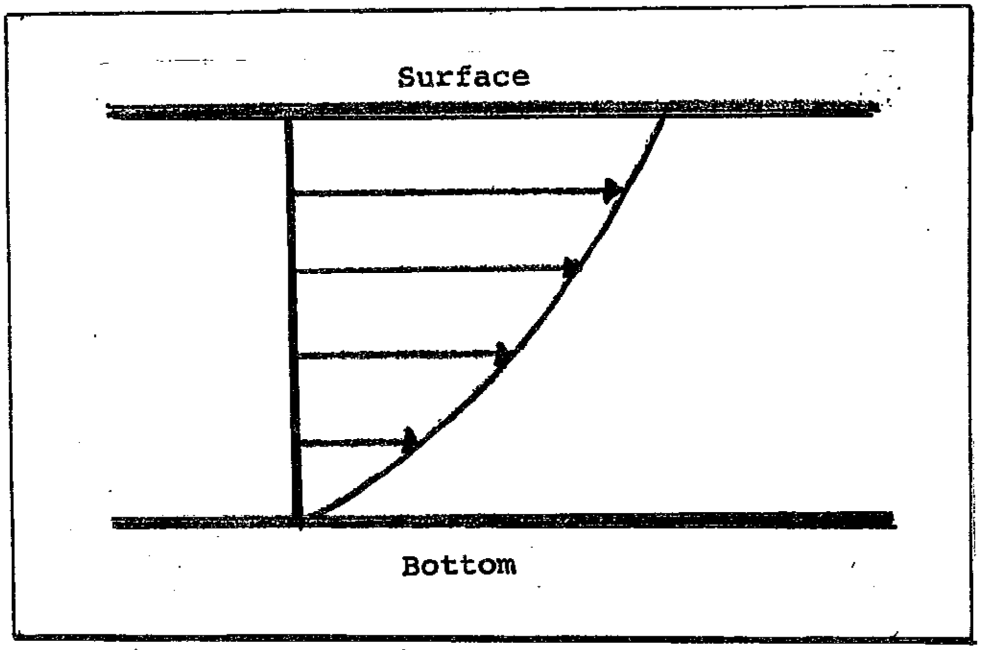

Figure 5. Vertical velocity profile in a raceway (taken from Wheaton, 1977)

Rearing Channel

The rearing channel incorporated some of the features of the raceway with characteristics of an earthen pond. It is constructed on gently sloping land and characterized by gravel sides and bottom. While lengths may vary substantially, the width and depth measurements remain fairly uniform at 25 ft. x 4 ft. (at the centre). The water flow characteristics are similar to those of a raceway.

General Operating Characteristics:

- cheaper to build and operate than a concrete raceway
- bank errosion can be a problem
- good capacity for self-purification

- fish get natural food supplements (small organisms and insects)
- predation can be significant
- stock inventories difficult to achieve
- can't see (or remove) mortalities
- fish removals difficult
- disease treatment difficult
- sterilization to eliminate disease is virtually impossible
- water demand is high for greatest efficiency
- cleaned after rearing by flushing out, hosing down and drying out.

Water quality appears to remain high in rearing channels, probably a function of flow rates, lower densities, and the recycling of wastes into benthic organisms. Fish culturists agree that salmonids can benefit from the natural environment, however this must be weighed against the difficulties in management and disease treatment as well as lower loading densities (Fish Culturists, personal communication; Sinclair, 1976; Westers, 1977).

Earthen Pond

An earthen pond consists of a simple earth excavation of variable size and shape, with dirt sides and gravel bottom. Ponds should be equipped with screens to prevent fish jumping at the inflow or escaping at the outlet. A concrete outlet complete with dam boards is used to regulate water depth.

General Operating Characteristics:

- low cost installation
- have little or no pollution problems - self-purifying
- fish get natural food supplements
- predation can be significant
- difficult to maintain accurate stock inventory records
- difficult to remove mortalities
- fish removal difficult
- treatment for disease and pond sterilization impractical
- lower circulation and flushing rates creates dead spots
- loading capacity less than a raceway
- subject to extreme temperature fluctuation
- cleaned annually after release by flushing, hosing and drying out.

Increasing interest in earthen ponds is due to low cost expansion and improved quality of fry (Sinclair, 1976). Because of the large surface areas involved, the flow to volume ratio required for raceway efficiency is never achieved and loading capacity is considerably less. The most practical application of earth ponds appears to be as low-maintenance natural-release ponds (Fish Culturists; Sinclair, 1976).

Circulating Ponds

Burrows Pond

The basic design of the rectangular circulating pond is a rectangle with a centre wall partly dividing the pond into two equal sections water is forced, under pressure into the pond at opposite ends. The pond can be equipped with turning vanes at each corner to aid in hydraulic stability, and providing a smooth laminar flow throughout the pond, with relatively high velocities along the outer edge, diminishing towards the centre wall. Water leaves the pond through two bottom screens located near the centre wall and at opposite ends of it. Water depth is controlled by a removable standpipe in the waste pipe of the outlet sump. In operation, the water flows in a path parallel to the outside walls but gradually moves towards the centre wall, leaving the pond through the perforated plates on the bottom. The rectangular pond operates well at a length of 50 feet, width of 17 feet and water depth of 30 to 36 inches (Burrows et al, 1970).

General Operating Characteristics

- costly to construct
- no major eddies or "hot spots" created
- self-cleaning (to a degree)
- critical drain size for maintaining self-cleaning velocity is hazardous for small fry

- increased flushing rate to permit higher densities defeat hydraulic design characteristics
- circulating characteristics is a problem for effective disease treatment
- fish distributed evenly
- facilitates food distribution
- fine food particles do not flush away in a raceway
- fish get choice of water velocity and get more exercise than in a raceway (Burrows et al, 1970)
- algal growth can be a significant problem, particularly on vanes
- vanes can make pond cleaning difficult and dangerous
- ponds can be painted with an algicide.

The Burrows pond performs well under ideal conditions and is especially useful where water is limited. Supplementary cleaning during the rearing period is usually required and facilitated by vacuuming daily. After release, ponds are scrubbed down, hosed off, and dried in preparation for subsequent ponding. While the advantages to using a Burrows pond are numerous, considerable debate exists over whether or not fish raised in an "average" environment end up mediocre quality (fish culturists, personal communication; Burrows et al, 1970; Sinclair, 1976; Westers et al, 1977).

Circular Tub

The most common circular tub is of fiberglass construction and comes preassembled. Pond dimensions are numerous, varying greatly in diameter and depth, the ratio of which significantly alter the hydraulic characteristics and consequently the fish rearing efficiency. Water enters at one side of the tub and leaves through an outlet pipe in the centre. The water supply may be in the form of a single pipe projecting from the side, a vertical pipe with several jet headers on the side wall, or a horizontal jet spray bar extending between the side and the centre, spraying water on the surface. In all cases the water is directed in a circulating flow around the circumference of the tank. Depending on the species and size of fish, a jump barrier may be required about the circumference.

General Operating Characteristics:

- complete and uniform circulation of water
- efficient self-cleaning
- loading capacities cannot be increased by increasing the water exchange due to the fish velocity barrier
- water velocity barrier limits capacity for smaller fish
- uniform fish distribution
- good food distribution
- fines tend to circulate without flushing away
- difficult to do flush treatment for disease
- difficult to remove fish
- smooth sides reduce the risk of fin erosion
- can be painted with algicide
- supplementary cleaning done regularly by lifting standpipe and flushing out wastes. Scrubbing down and dried at release.

Circular tubs provide an economic and efficient use of a limited water supply and are a convenient size for use in selective breeding, food experiments and other research projects.

There is a great diversity of opinions concerning the relative merits of different pond design, which can often be attributed to even slight variations in the water supply, hatchery program or operating procedures. To improve fry quality and subsequent return rates, fish culturists must adapt their methods in response to these changes. Innovations in equipment and techniques can substantially alter the quality of rearing water and hence the success of a hatchery program. Following is a discussion of various innovations applicable for use in fish hatchery pond cleaning.

POND CLEANING INNOVATIONS

Vacuum Heads

One of the most important tools used by the fish culturist, in the attempt to control sludge build-up is the vacuum. While pump and hose efficiency is vital, it is the vacuum head attachment that determines the success of the apparatus. Numerous attachments have been developed by trial and error methods, a portion of which are illustrated in Figure 6. The vacuum head dimensions, material of construction, and the effectiveness of the device, in collecting sludge without clogging, minimizing suspended solids and preventing excessive fish stress. There appears to be no universally acceptable attachment due to the variation in jobs. Repeated attempts at design, usually results in success.

"Kreepy Krawly" Automatic Pond Cleaner

A recent development in swimming pool technology, may also have considerable potential for use in fish hatchery pond cleaning. The "Kreepy Krawly" automatic pond cleaner is distributed through Aquatime Leisure Products in Burnaby, at an approximate cost of $749 dollars per unit. It operates unattended and continuously off a swimming pool filter pump, cleaning the walls of the pool by hydraulic action. Apparently there is only one moveable part, making the unit virtually maintenance free. Should "Kreepy Krawly" be adapted for hatchery use, the potential benefits would be:

- continuous cleaning to eliminate sludge accumulation
- reduction in fish stress caused by manual cleaning, as fish would probably acclimatize to a continuously operating unit
- manpower savings

Preliminary testing of the "Kreepy Krawly" unit, to calculate its effectiveness, is scheduled to take place at the Capilano Hatchery.

Baffles

Additional automatic pond cleaners of considerably less cost, are the plywood baffles that can be set up in Capilano troughs. Baffles are cut to fit the inside of the troughs with several inches clearance at the bottom. The baffles create a high water velocity along the bottom of the trough, which helps sweep the settling wastes down to the outflow. Mike Wolfe, a fish culturist at the Robertson Creek hatchery, found that a series of three plywood baffles in a Capilano trough, operating 24 hours/day, achieved a high degree of self-cleaning. The fish, consequently, experienced less stress from the higher velocity flow. Because of the similarities in water flow characteristics, baffles may have additional application in raceways and rearing channels.

Chevron Industrial Membrane (CIM)

The green algicide paint currently employed at hatcheries to reduce algal growth, has several shortcomings. Not only is it expensive, but it flakes off easily, necessitating regular repainting and it is suspected of causing low level poisoning at some hatcheries. Chevron has developed a new membrane system that may replace algicide currently used in rearing ponds.

Chevron Industrial Membrane is a black elastomer which fully cures in twenty-four hours to form a monolithic, highly impermeable membrane system.

Specific Characteristics Include:

- spray or squeegee application
- thickness of up to 1/4" without sagging
- adheres to concrete, metal, glass, fiberglass and wood (may need bonding agent)
- smooth surface

- flexible (stretches two times its length)
- durable
- serviceable temperature range -51°C to 121°C
- abrasion resistant
- ultra-violet stable
- can be used in direct contact with most chemicals
- non-toxic to fish
- can be painted
- can be made skid resistant

CIM can be used on ponds for easier cleaning, reducing fin abrasion, eliminating low level poisoning and serving as a sealant. Chevron guarantees the membrane for five years, provided it is applied by a licensed applicator. The life of a CIM membrane, however, is considered to be closer to 25 years. Approximate costs based on a 50 mil thickness are:

$2.00/sq. ft. on concrete

$2.80/sq. ft. on prepared earth

(Information on CIM was supplied by York Painting Ltd., Victoria)

Spray Wash Wand

A Ford BTC 150 spray wash wand is currently in use at the Big Qualicum River Salmon Hatchery and has achieved some good results. The unit is powerful and easy to manage and has the convenience of a wash and rinse setting, facilitating both disinfection and rinsing. The spray wand performed well in cleaning Heath trays. The trays were pulled out from the stacks one at a time, cleaned and replaced. It was found that this method of cleaning saved considerable time and manpower. The spray wand was also used on the concrete raceway after fry release, again with good results. The initial costs of the machine was approximately $1400.00, however, several breakdowns have necessitated further expenditure for repairs.

Liquid Live Micro-Organisms (LLMO)

Liquid Live Micro-organisms is a product manufactured by the General Environmental Science Corporation of Cleveland, Ohio, to solve organic waste problems and consequently may be of some use to fish hatcheries. Live bacterial cultures are grown to maturity and then suspended in a dormant state until the culture is diluted and comes in contact with suitable nutrients. LLMO contains seven different strains of saprophytic bacteria; some aerobic, some anaerobic, which are touted to prevent problems arising from bacterial decomposition.

According to its procedures LLMO is:

- 100% live micro-organisms
- non-toxic
- non-pathogenic
- non-irritating
- in easy-to-use liquid form

In Addition, LLMO:

- eliminates noxious odors
- reduces B.O.D., C.O.D. and suspended solids
- lives off all organic waste material
- nitrifies and denitrifies
- maintains total ammonia levels at 0.25 mg/l or lower in a hatchery culture system, where the control of ammonia and nitrite concentrations and suspended solids is essential, LLMO may be of service. Maintaining water quality in this way, rather than manual pond cleaning, may reduce the stress fish are subjected to. To investigate the properties of LLMO, it was included in a lab study investigating food decomposition.

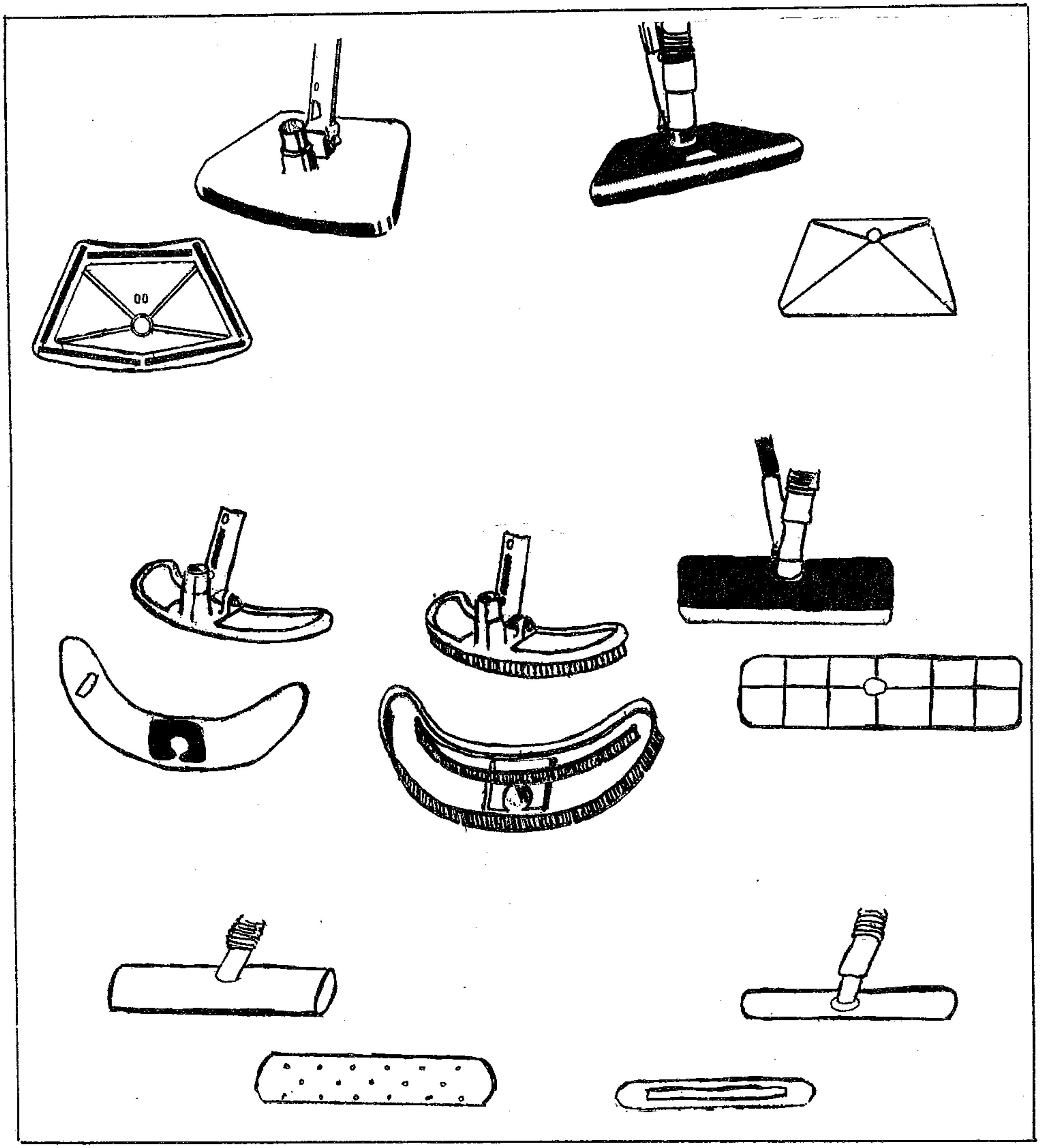

Figure 6. Vacuum Head Attachments

FOOD DECOMPOSITION STUDY

A study of food decomposition (see Figure 7) was conducted at the Puntledge River Hatchery between August 9 and 13, 1982. To investigate the breakdown of Oregon Moist Pellet fish food, a control plus two food and water environments were established in 20 liter plastic pails with lids. These systems were set up as follows:

Pail #1 - 15 liters rearing channel outflow water

Pail #2 - 15 liters rearing channel outflow water
+ 50 (g) O.M.P. (3/64" pellet)

Pail #3 - 15 liters rearing channel outflow water
+ 50 (g) O.M.P. (3/64" pellet) + 0.05 ml
Liquid Live Micro-organisms.

Water samples were collected by hand from the three pails and from the inflow and outflow of the rearing channel (Appendix 2). Samples were suction filtered immediately and monitored for water quality according to the following parameters.

TEST PARAMETERS

Temperature

Water temperatures were measured at each of the five sampling points at each sampling time.

Dissolved Oxygen (D.O.)

Dissolved oxygen levels were measured at each of the five sampling stations at each sampling time using a YSI model 57 oxygen meter with a YSI model 5739 probe. Results are expressed in ppm.

pH

pH was measured using a Fischer accumet model 292 pH meter.

Ammonia Nitrogen

The method of Zadorojny et al (1973) was used for determination of ammonia nitrogen. This is a phenyl-hypochlorite method for determining low-level ammonia in water using sodium nitroprusside as a catalyst. Results are expressed as mg/l and represent the sum of ionized and un-ionized ammonia present in the sample. Colour measurements were made at 640 nm using a Bausch and Lomb Spectronic Mini 20 Spectophotometer. Reagent blanks and standards were also tested to ensure accuracy.

Nitrite

Nitrite analyses were made by measuring the colour produced by a diazotization reaction between sulfanilamide, the nitrite in the sample and N-(1-hapthyl) ethylene - diamine in hydrochloric acid solution. Colour measurements were made at 530 nm using the Bausch and Lomb Spectronic Mini 20 Spectrophotometer. Standards and reagent blanks were tested to ensure nitrite analysis was yielding accurate nitrite nitrogen values.

Results of Observations

(Detailed test results and calculations are presented in Appendix 3). Initial experiment design was revised following the second day of testing in response to unacceptable low oxygen levels in all three pails. The experiment resumed on the third day after provisions to aerate the pails, while maintaining satisfactory water temperatures were made. Subsequent water samples were tested for nitrite. Although the experiment had to be redesigned and repeated, some significant information was acquired from the initial errors and the water quality testing:

- 50 g of 3/64" O.M.P. pellets and 15 litres of water mixed by inversion twice resulted in an immediate breakdown of the pellet structure and substantial turbidity
- particles remained in suspension - a relatively small amount of the food settled out over time
- at constant temperatures, the pH's of pail #2 and #3 were at least 3.5% lower than the pH's of the control
- there was significant ammonia production (up to 2.8 mg/l) in the pails with food and water
- when the food and water were mixed, there was an initial rise in ammonia concentration levels that slowly dropped over a 20-minute settling period

- ammonia levels in pails #2 and #3 increased over the first two hours and then gradually decrease
- nitrite concentrations were very low throughout the experiment
- as the ammonia concentration lessened, the nitrite level increased
- there appeared to be no difference in results between pails #2 and #3. This may be because: a) the bacteria needed more time to activate, or b) the bottle of LLMO had exceeded its shelf life (no expiry date was given).

On the basis of these observations, it appears that initial food decomposition favours the ammonia pathway and that over time, the ammonia concentrations begin to decrease and the nitrite pathway becomes more active. The experiment also showed that an increase in suspended solids was always accompanied by a rise in ammonia concentration levels. Ammonia concentration values ranged from 1.08 mg/l to 2.0 mg/l over the course of the experiment. The total nitrogen theoretically possible in pail #2 and #3 was 2800 mg/l. This means that 99.9% of the total nitrogen was in forms other than ammonia or nitrite. In the rearing channel, the calculated rate of nitrogen production was 17.7 mg N/Kg Hr (see Appendix 3). An estimate of the actual amount of NH_4 - N produced in the rearing channel was calculated to be:

4040 mg. NH_4-N/Kg of food hr

This figure is based on the action of fish, food and water. In comparison, the amount of NH_4-N produced as a result of only food and water was calculated to be 405 mg NH_4 mg/Kg of food x hr. Ammonia production where fish food and water are present is ten times greater than the ammonia production caused by food and water alone, in a period of two hours. Fish are, therefore, the major sources of ammonia nitrogen entering a fish culture system.

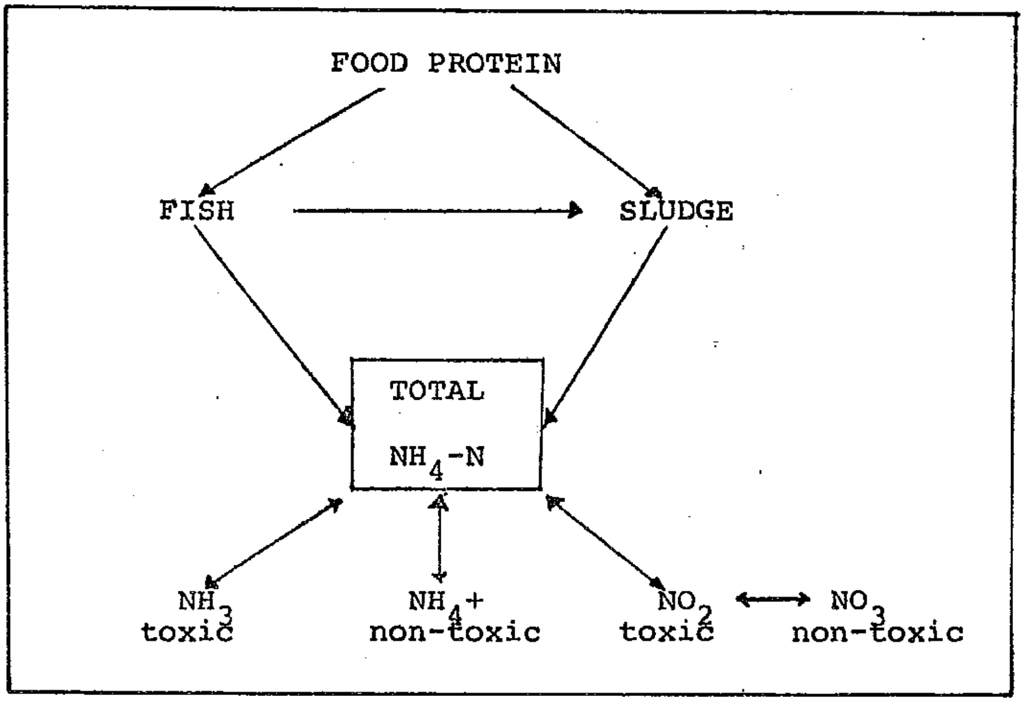

Figure 7. Food Decomposition Pathway in an Aquatic System

CONCLUSION

The effects of manual pond cleaning on hatchery reared salmonids are clear. Agitation of the pond sludge layer results in a degradation of water quality, thus exposing the fish intimately with chemical and physical gill irritants (NH_3, NO_2, suspended solids) and increasing levels of pathogens. These stresses augment an interaction of factors which weaken the innate resistance of the fish, leading to a bacterial disease infection.

The control of nitrogen toxicity in the culture of salmonids depends on a knowledge of the mechanisms of toxicity, the effect of each compound over the rearing period, and an understanding of the hydraulics of each culture system. Diligence on the part of fish culturists, in keeping informed of developments in research and culture techniques, in addition to evolving methods to meet their individual needs, is essential to maintaining a healthy growth environment for salmonids.

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APPENDIX I

O.M.P. MAXIMUM RATION (% BODY WEIGHT/DAY)
FISH WEIGHT (GRAMS)

TEMP. °C	.20	.40	.60	.80	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0	25.0
3	2.81	2.23	1.95	1.77	1.64	1.30	1.14	1.04	.96	.90	.86	.82	.79	.76	.72	.68	.65	.63	.61	.56
4	4.04	3.21	2.80	2.55	2.36	1.88	1.64	1.49	1.38	1.30	1.24	1.18	1.14	1.10	1.03	.98	.94	.90	.87	.81
5	5.22	4.14	3.62	3.29	3.05	2.42	2.12	1.92	1.79	1.68	1.60	1.53	1.47	1.42	1.33	1.27	1.21	1.16	1.12	1.04
6	6.35	5.04	4.40	4.00	3.71	2.95	2.57	2.34	2.17	2.04	1.94	1.86	1.78	1.72	1.62	1.54	1.47	1.42	1.37	1.27
7	7.43	5.89	5.15	4.68	4.34	3.45	3.01	2.74	2.54	2.39	2.27	2.17	2.09	2.02	1.90	1.80	1.72	1.66	1.60	1.49
8	8.46	6.72	5.87	5.33	4.95	3.93	3.43	3.12	2.89	2.72	2.59	2.47	2.38	2.30	2.16	2.05	1.96	1.89	1.82	1.69
9	9.46	7.51	6.56	5.96	5.53	4.39	3.84	3.49	3.24	3.04	2.89	2.77	2.66	2.57	2.42	2.30	2.20	2.11	2.04	1.89
10	10.42	8.27	7.23	6.56	6.09	4.84	4.23	3.84	3.56	3.35	3.19	3.05	2.93	2.83	2.66	2.53	2.42	2.33	2.25	2.08
11	11.35	9.01	7.87	7.15	6.64	5.27	4.69	4.18	3.88	3.65	3.47	3.32	3.19	3.08	2.90	2.75	2.63	2.53	2.45	2.27
12	12.24	9.72	8.49	7.71	7.16	5.68	4.96	4.51	4.19	3.94	3.74	3.58	3.44	3.32	3.13	2.97	2.84	2.73	2.64	2.45
13	13.11	10.40	9.09	8.26	7.67	6.08	5.32	4.83	4.48	4.22	4.01	3.83	3.69	3.56	3.35	3.18	3.04	2.93	2.82	2.62
14	13.95	11.07	9.67	8.79	8.16	6.47	5.66	5.14	4.77	4.49	4.26	4.08	3.92	3.79	3.56	3.38	3.24	3.11	3.01	2.79
15	14.76	11.71	10.23	9.30	8.63	6.85	5.98	5.44	5.05	4.75	4.51	4.32	4.15	4.01	3.77	3.58	3.43	3.29	3.18	2.95
16	15.55	12.34	10.78	9.79	9.09	7.22	6.30	5.73	5.32	5.00	4.75	4.55	4.37	4.22	3.97	3.77	3.61	3.47	3.35	3.11
17	16.31	12.95	11.31	10.28	9.54	7.57	6.61	6.01	5.58	5.25	4.99	4.77	4.59	4.43	4.17	3.96	3.79	3.64	3.51	3.26
18	17.05	13.54	11.83	10.74	9.97	7.92	6.92	6.28	5.83	5.49	5.21	4.99	4.80	4.63	4.36	4.14	3.96	3.81	3.67	3.41
19	17.78	14.11	12.33	11.20	10.40	8.25	7.21	6.55	6.08	5.72	5.44	5.20	5.00	4.83	4.54	4.31	4.13	3.97	3.83	3.56
20	18.48	14.67	12.81	11.64	10.81	8.58	7.49	6.81	6.32	5.95	5.65	5.40	5.20	5.02	4.72	4.48	4.29	4.12	3.98	3.70

Maximum ration (%body weight/day) as a function of temperature and fish weight (Stauffers, 1973).
A moisture content of 30% has been assumed to express ration level in terms of O.M.P. (Oregon Moist Pellet).

APPENDIX II

Date	Time	Sample #	Temp. @ Sampling	O_2 Level (ppm)	Temp. @ Testing	NH_4-N (mg/l)	pH	NO_2-N (mg/l)	Comments
09/08/83	1545	1	18.5°C	/	23°C	.09	/	/	Samples stored overnite in cooler,
	(t=0)	2	18.5°C	/	23°C	.90	/	/	filtered. Immediate turbidity in pails
		3	18.5°C	/	23°C	.84	/	/	2 & 3, particles don't settle out.
10/08/83	815	1	17.6°C	/	23°C	.063	7.36	/	Samples stored in cooler for 1 1/2 hours,
	(t=16.5 hr)	2	17.6°C	/	23°C	1.04	7.12	/	filtered. Pails 2 & 3 very cloudy, some
		3	17.6°C	/	23°C	1.04	7.01	/	particles have settled out.
	1400	inflow	18.0°C	9.2	23°C	.01	/	/	O_2 level testing done after 4 inversion
	(t=41.25 hr)	1	18.0°C	6	23°C	.06	/	/	mixings with buckets. Anaerobre
		2	18.0°C	2.2	23°C	2.07	/	/	conditions in pails 2 & 3. High turbidity
		3	18.0°C	2.2	23°C	1.9	/	/	in pails 2 & 3. Buckets 2 & 3 saturated
		outflow	18.0°C	8.6	23°C	.052	/	/	with C_2 for 30 minutes.
11/08/83	900	inflow	17.5°C	9.8	23°C	.015	/	/	Buckets 2 & 3 smell awful, due to anaerobic
	(t=41.25 hr)	1	18.5°C	5 / 9	23°C	.06	/	/	condition. Two figures for O_2 level
		2	18.5°C	0 / 7	23°C	1.3	/	/	indicate before and after 15 minutes of
		3	18.5°C	.2 / 7	23°C	1.48	/	/	aeration. Samples stored in cooler 2 hours,
		outflow	17.5°C	9.0	23°C	.052	/	/	filtered. Contents of pails thrown out.
	1400	0 min	17.5°C	/	23°C	.92	/	/	50 grams 3/64 OMP + 15 L water to achieve
	(t=0)	10 min	17.5°C	/	23°C	.83	/	/	initial water quality samples at 0 min.,
		20 min	17.5°C	/	23°C	.80	/	/	10 min. and 20 min. Very turbid (2 & 3).
12/08/83	910	1	17.0°C	6	23°C	.037	/	/	New experiment begun. Constant aeration &
	(t=0)	2	17.0°C	5.4	23°C	.99	/	/	maintenance of temperature in pails by
		3	17.0°C	5.4	23°C	1.1	/	/	circulating river water. Initial turbidity.
	1100	1	17.0°C	9.2	23°C	.052	7.60	.0003	High concentration of suspended solids in
	(t=2 hr)	2	17.0°C	9.0	23°C	2.07	7.22	.0003	2 & 3.
		3	17.0°C	9.0	23°C	2.07	7.27	0	
	1300	1	17.0°C	9.0	23°C	.052	7.63	0	High concentration of suspended solids in
	(t=4 hr)	2	17.0°C	8.6	23°C	1.63	7.33	.0006	2 & 3. Scum forming on surface.
		3	17.0°C	8.6	23°C	1.78	7.35	.0006	
	1500	1	17.0°C	9.6	23°C	.044	7.56	0	High concentration of suspended solids in
	(t=6 hr)	2	17.0°C	9.0	23°C	1.08	7.23	.001	2 & 3. Surface covered frothy scum.
		3	17.0°C	9.1	23°C	1.26	7.24	.0006	

APPENDIX III

Weir Measurements at Puntledge River Hatchery Rearing Channel (rectangular weir):

Section	Depth	Length
#1	8.27 in	46.46 inch
#2	4.92 in	44.09 inch
#3	7.87 in	44.09 inch
#4	8.07 in	44.09 inch
#5	3.15 in	46.46 inch

Calculations

Flow by the Francis Formula Q = 3.33 H 3/2

∴ #1	1.90	x 3.87 ft.	=	7.35
2	.87	x 3.67 ft.	=	3.19
3	1.77	x 3.67 ft.	=	6.49
4	1.81	x 3.67 ft.	=	6.64
5	.445	x 3.87 ft.	=	1.72

Flow = 25.39 +/- 5 cfs
(or = 43137.6 l/min)

BIOMASS:

Section	Species	No.	Wt. per fish (g)
#1	Steelhead	56350	1.661 (+/- .486)
#2	Coho	420034	4.005 (+/- 1.343)
#3	Coho	372091	5.065 (+/- 1.166)
#4	Coho	371151	6.181 (+/- 1.391)

Total Biomass = 5954.6 kg

LOAD RATE:

load rate (L) = B/Q (biomass in kg ÷ flow in l/min) = 0.138 kg per l/min

Rate of Nitrogen Production In Rearing Channel "Rn":

$$Rn = \frac{(No-Ni)\ Q x.60}{Biomass} = \frac{(0.52\ mg/l - .0125\ mg/l) \times 43137.6\ l/m \times 60\ min}{5954.6\ kg}$$

Rn = 17.17 mg.N/kg hr

DAILY FEED TOTALS:

196.85	kg per day Coho
5.74	kg per day Steelhead
202.59	kg per day total

AMOUNT FED PER HOUR:

202.59 kg per day divided by 8 hours = 25.32 kg per hour

Theoretical Nitrogen Production in Rearing Channel:

25.32 Kg moist food = 17.72 kg dry food
or 8.86 kg protein
or 1.42 kg nitrogen

Theoretically, in one hour you could produce 1420.0 g of nitrogen per hour.

Measured Nitrogen Production in Rearing Channel:

5954.6 kg of fish x 17.17 mg N/kg hr = 102.24 g of nitrogen per hr

This can be expressed on a per kg of food basis as 4.04 g of N per kg of food per hr.

Ammonia Nitrogen Production "Rn" in an Isolated Environment of Food and Water Only:

$$Rn = \frac{VC}{Ft}$$

where:

F = weight of food (0.050 kg)
V = volume of test container (15 l)
t = duration of test (2 hr)
C = increase in ammonia N concentration (2.73 mg/l)

Substituting these values into the formula for Rn gives:

$$Rn = 0.410 \frac{\text{grams N}}{\text{kg of food hr}}$$

This compares with an ammonia N production rate in the rearing channel of 4.04 grams of N per kg of food hour. Ammonia nitrogen production where fish, food and water are present is ten times greater than the ammonia production caused by food and water alone in a period of two hours.