AQUACULTURE TECHNIQUES:
A PRODUCTION FORECASTING MODEL FOR AQUACULTURE SYSTEMS

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AQUACULTURE TECHNIQUES: A PRODUCTION FORECASTING MODEL FOR AQUACULTURE SYSTEMS

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PREFACE

This report is the fourth of the Aquaculture Technique series, a collection of Office of Water Resource and Technology (OWRT)-sponsored research projects addressing water use in aquaculture. These reports, which include water use and discharge (Klontz et al. 1978), oxygen requirements (Downey and Klontz 1981), and an aquaculture teaching model (McNair, McArthur, and Klontz 1982), have provided new technical information for increasing aquaculture systems' productivity. The computerized simulation model has been developed based on techniques reported in these publications.

The analysis and significant findings contained herein are largely condensed from a Doctoral dissertation by Downey (1981).

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ABSTRACT

Computer implementation of the mathematical models of quantitative relationships in aquaculture systems is a dynamic process which provides a conceptual framework for understanding systems behavior. These models can provide useful information on variable significance to systems functioning, thereby directing research resources into areas which will most benefit further understanding of the system. Furthermore, as aquaculture systems research progresses, the composite model can be modified to incorporate new technology. Modeling, therefore, is a cyclic process--a means for understanding the system, for evaluating the system, and for using the model to incorporate the new technology.

This computer-implemented mathematical model addresses one of the significant limitations of aquaculture systems management, namely, production forecasting, by providing a method of using current technology to predict Allowable Growth Rate (AGR). The use of the model in aquaculture operations could aid production forecasting, resulting in more efficient water usage and profitable aquaculture systems operations.

I. INTRODUCTION

Facilities employing intensive aquaculture technologies produce millions of pounds of food and game fish annually the world over. The most abundant group of fish raised is the salmonids; i.e., trout, charr, and Pacific salmon. The channel catfish industry in the United States is rapidly becoming an intensive aquaculture industry, having been a semi-intensive process since its inception in the 1960's.

Among the identifiable constraints to productivity, water use and growth forecasting need concerted attention. The increasing production costs and loss of production potential through infectious and noninfectious diseases are often the effect of suboptimum practices of water use and growth forecasting. Thus, use of validated methods and mathematical models to optimize water use and production forecasting could reduce production costs by decreasing the loss of production potential.

Several mathematical and/or computer models have been developed for aquaculture, particularly salmonids (Rasch 1972; Johnson 1974; Jorgensen 1976; Kerr 1971a,b,c), but for the most part, none is either sufficiently comprehensive or flexible to accomplish the goal of being a tool both for production forecasting and/or for hatchery design.

Downey (1981) developed a quantitative computerized model which reflects the interrelationships among major variables in aquaculture systems. Although the conceptual framework was derived from facilities rearing rainbow trout (*Salmo gairdneri*), the general approach and concepts developed are applicable to *all* aquaculture systems.

II. AQUACULTURE SYSTEMS CONCEPTS

The opinion that no two finfish-culture facilities are physically alike is held by most knowledgeable aquaculture professionals. However, in theory, they are similar qualitatively, and dissimilar only quantitatively. Klontz et al. (1979) have identified 56 interacting factors, dependent and independent, biotic and abiotic, which constitute a functional aquaculture system. For the sake of simplifying system complexity, the 56 factors have been grouped into five major components: Fish, Water, Nutrition, Pond, and Management (Table 1).

The majority of the factors intrinsic to an aquaculture system, and particularly those impinging on productivity, can be arranged into qualitatively ordered cause and effect relationships to define the system (Figure 1). In such a system, a quantitative change in any factor can cause sequential changes through the system which cannot be altered unless another change is introduced (Downey 1978; Klontz et al. 1979; Downey 1982). The result of this "domino-effect" is a change in fish growth rate. Predictability of growth in terms of nutrition, water, fish, pond, and management constraints is necessary for forecasting systems behavior.

Table 1. Factors affecting the productivity of trout and salmon raising facilities (Klontz et al. 1979).

A. Fish Associated	
1. Ammonia-nitrogen	7. Infectious disease history
2. Behavior	8. Length-weight relationship
3. Nutritional requirements	9. Cannibalism
4. Environmental requirements	10. Oxygen uptake
a. physical	11. Oxygen demand
b. chemical	12. Fecal solids
5. Product definition	13. CO_2
6. Growth Rate Potential	
B. Water Associated	
1. Dissolved oxygen	12. Municipal contaminants
2. Nitrite-nitrogen	13. Natural contaminants
3. Alkalinity	a. N_2
4. pH	b. CO_2
5. Inflow	c. H_2S
6. Suspended solids	14. Utilization
7. Settleable solids	15. Salinity
8. Temperature	16. Hardness (Ca^{++})
9. Carrying capacity	17. B.O.D.
10. Agricultural contaminants	18. Viscosity
11. Industrial contaminants	
C. Container Associated	
1. Water volume	5. Water replacement time
2. Water velocity	6. Outfall design
3. Composition	7. Shape
4. Water flow pattern	
D. Nutrition Associated	
1. Feeding rate	4. Nutritional quality
2. Feed efficiency	a. proximate analysis
3. Feed style	b. metabolizable energy
	5. Feed Storage
E. Management Associated	
1. Fish sampling techniques	5. Pond cleaning
2. Feeding frequency	6. Fish size grading techniques
3. Feeding techniques	7. Management programming
4. Record keeping	8. Management objectives

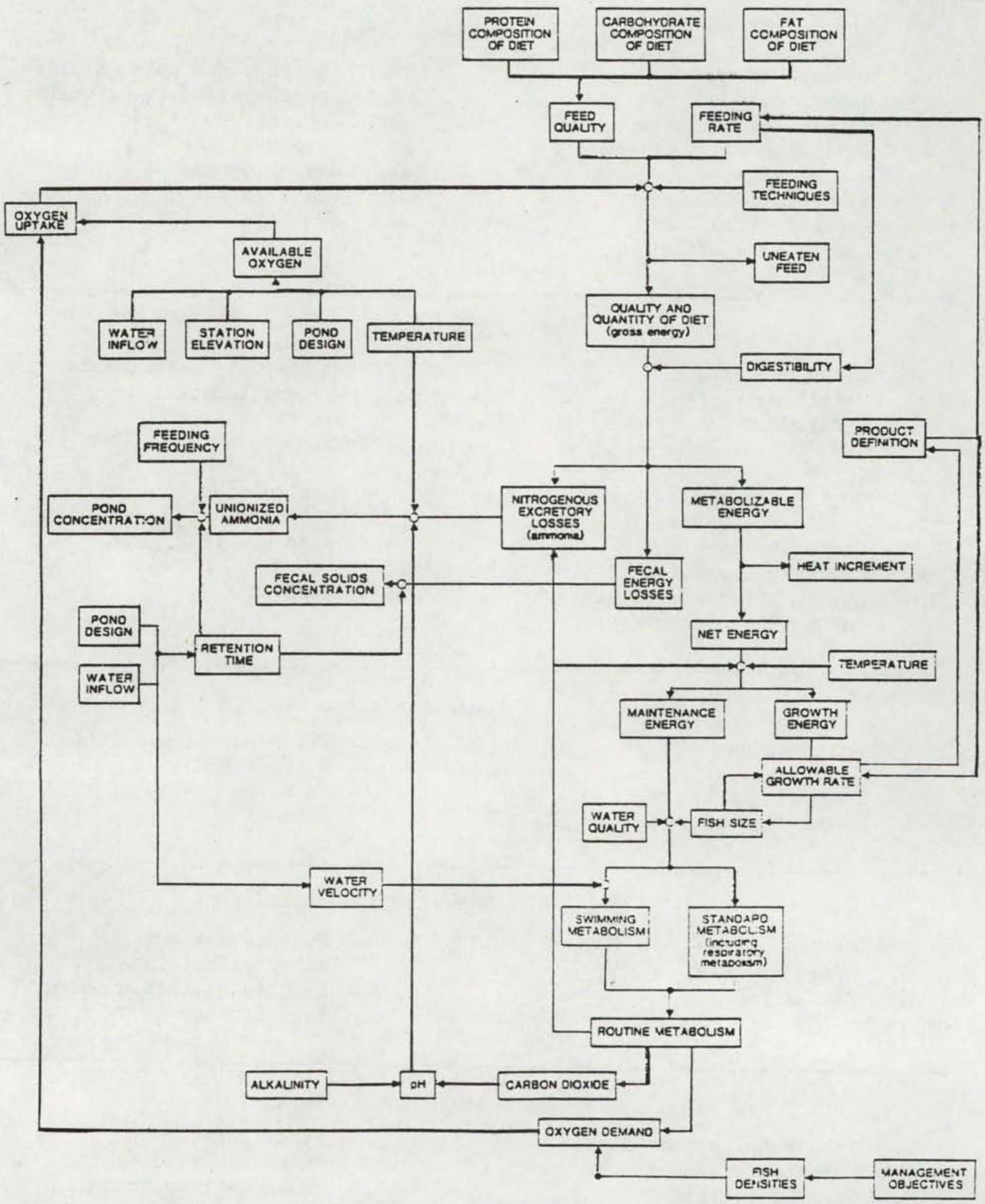

Figure 1. Factors and their interactions considered by the aquaculture systems model (Downey, 1981).

III. NUTRITION

The quality and quantity of food fed to fish in an aquaculture system are the main variables of the system, dictating the rate of growth and overall production. Virtually all the energy in intensive or semi-intensive aquaculture systems is derived from the ration presented.

Diet quality has a profound impact on dietary efficiency and fish health. Phillips and Brockway (1959) reported that the elaboration of one pound weight gain by brook trout (Salvelinus fontinalis) required more than twice the dietary protein in prepared diet (300 g) than in a natural diet (143 g). Growth differences were attributed to the essential dietary amino acids being contained in the natural diet in their necessary proportions.

Excessive levels of dietary fat or carbohydrates can alter the general state of fish health by causing fatty infiltration of the liver and excess glycogen reserves in the viscera, respectively. As a result of these findings, the general dietary composition of commercially prepared diets is 30-55% protein, 7-17% fat, and 9-23% carbohydrate (Halver 1972).

A. ENERGY CONTENT

The dietary energy sources; i.e., protein, carbohydrate, and fat, and the feeding rate, determine the total energy the system receives. The amount of energy consumed by fish, regardless of whether the energy can be utilized by the fish for growth or metabolism, is the gross energy (GE) of the diet. The GE of a diet is the sum of the three dietary energy components. Crude protein contains 5.65 Kcal/g, lipids contain 9.4 Kcal/g, and carbohydrates contain 4.16 Kcal/g (Phillips and Brockway 1959).

Although the GE content of a diet provides a general picture of its nutritive value, an estimate of the energy available for growth and metabolism is necessary for energetic studies of fish (Figure 2). The digestible energy (DE) and metabolizable energy (ME) of a diet depend upon the digestibility of each of the three individual energy components of the diet. In addition, the ME also reflects the energy lost due to nitrogenous excretory products.

B. DIET COMPOSITION

Fish feed is manufactured commercially in different pellet sizes in order to be palatable for the fish. Generally, there are three groups of feed sizes: fry fines, crumbles, and pellets. Fish fry (1-2") are fed the fry fines, fingerlings (2-4") are fed crumbles and small pellets, and the subadults-adults (4-15") are fed larger pellets. Feed composition of this diet changes with pellet sizes (Tables 2, 3, 4). Fry fines contain the highest protein and total energy content, while the crumbles contain intermediate amounts, and pellets the lowest protein and total energy content. Thus, feed efficiencies would be expected to be lower in pellets than in fry fines.

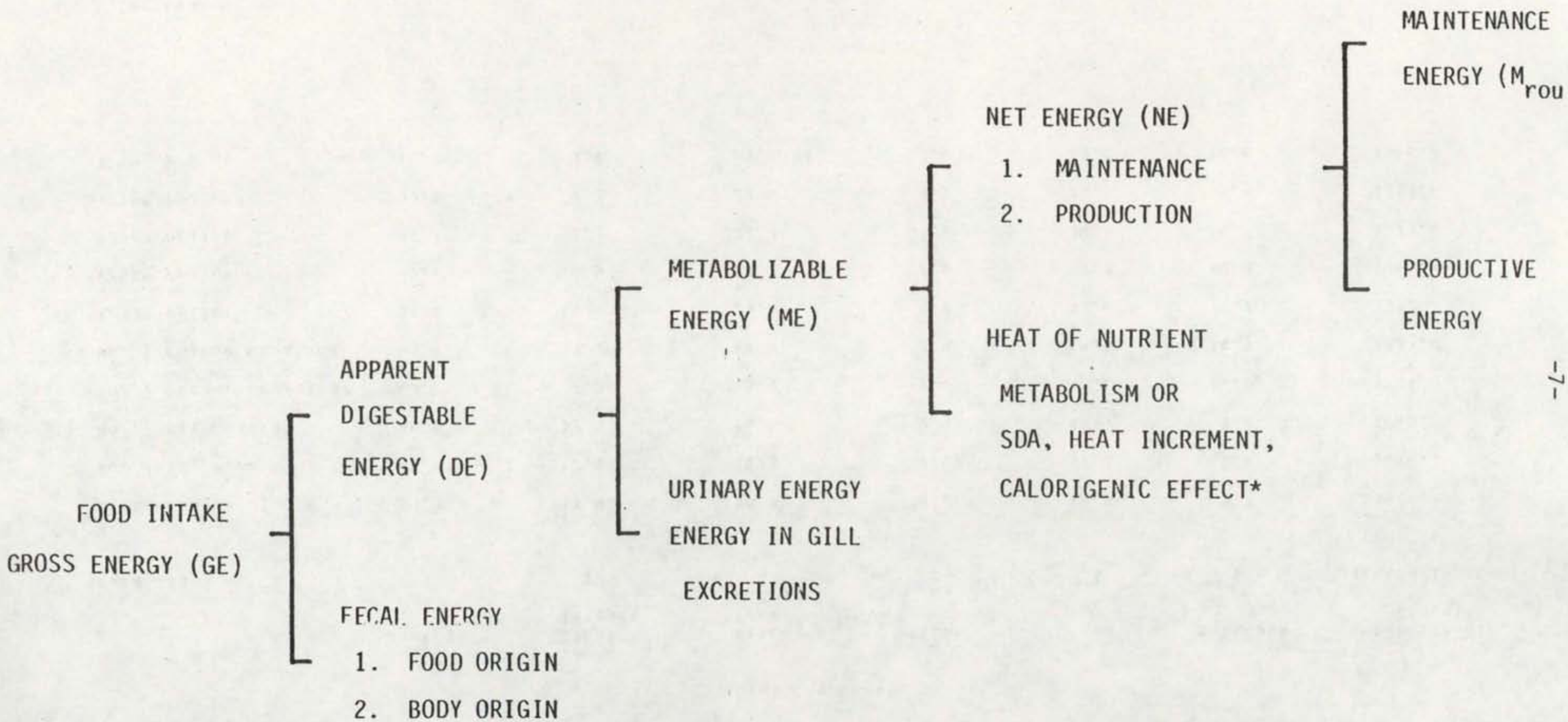

Figure 2. Energy flow in an aquaculture system (modified from Smith 1976).

Table 2. Diet composition of various sized Moore-Clark dry diet trout feeds. Data presented are actual values determined by proximate analysis except where noted.

	Diet Component						
	Protein	Ether Extract	Nitrogen Free Extract	Fiber	Ash	Moisture	Metabolizable Energy[1]
Feed Size	%	%	%	%	%	%	(Kcals/lb feed)
Chinook Mash	53.1	11.8	10.7	1.6	15.9	7.7	1524.7
No. 1 Fry Fine	46.6	12.5	15.5	2.9	14.7	7.8	1460.2
No. 2 Fry Coarse[2]	46.6	12.5	15.5	2.9	14.7	7.8	1460.2
No. 3 Grower Crumbles[3]	43.2	7.2	18.4	2.4	14.6	14.0	1231.0
No. 4 Coarse Crumbles	43.2	7.2	18.4	2.4	14.6	14.0	1231.0
3/32" Pellet	39.8	11.9	21.6	5.9	13.6	7.2	1352.2
4/32" Pellet	45.6	9.5	20.2	2.5	12.2	10.1	1366.3
5/32" Pellet	37.3	9.3	22.1	7.2	14.8	9.4	1213.6
3/16" Pellet[3]	37.3	9.3	22.1	7.2	14.8	9.4	1213.6
1/4" Pellet	45.8	8.4	21.1	1.4	12.8	10.6	1366.7

[1] See text.

[2] Estimated from data collected on No. 1 Fry Fine feed.

[3] Estimated from data collected on Coarse Crumbles.

[4] Estimated from data collected on 5/32" pellets.

Table 3. Diet composition of various sized Silvercup dry diet trout feeds. Data presented are actual values determined by proximate analysis except where noted.

	Diet Component						
Feed Size	Protein %	Ether Extract %	Nitrogen Free Extract %	Fiber %	Ash %	Moisture %	Metabolizable Energy[1] (Kcals/lb feed)
Starter	54.4	15.8	10.7	0.1	11.9	8.7	1649.8
No. 1 Fry Fine[2]	52.2	13.1	10.7	*	*	*	1555.0
No. 2 Fry Coarse[2]	52.2	13.1	10.7	*	*	*	1555.0
No. 3 Fine Crumbles	48.3	9.3	18.3	0.3	11.4	11.9	1397.0
No. 4 Coarse Crumbles[3]	48.3	9.3	18.3	0.3	11.4	11.9	1397.0
3/32" Pellet[4]	44.6	9.4	21.6	2.7	11.6	10.0	1353.6
1/8" Pellet[4]	44.6	9.4	21.6	2.7	11.6	10.0	1353.6
5/32" Pellet	44.6	9.4	21.6	2.7	11.6	10.0	1353.6
3/16" Pellet[4]	44.6	9.4	21.6	2.7	11.6	10.0	1353.6
1/4" Pellet[4]	44.6	9.4	21.6	2.7	11.6	10.0	1353.6

[1] See text.

[2] Estimated from data provided by the manufacturer.

[3] Estimated from data collected on No. 3 Fine Crumbles.

[4] Estimated from data collected on 5/32" Pellet.

Table 4. Diet composition of various sized Oregon Moist pellet feeds. Data presented are actual values determined by proximate analysis except where noted.

	Diet Component						
Feed Size	Protein %	Ether Extract %	Nitrogen Free Extract %	Fiber %	Ash %	Moisture %	Metabolizable Energy[1] (Kcals/lb feed)
Fry Start	38.3	12.6	10.3	1.8	10.6	26.4	1266.9
Fry Meal	35.0	13.0	12.0	2.1	8.8	29.1	1230.4
1/32" Pellet	38.6	12.1	10.4	0.9	10.4	27.5	1255.2
3/64" Pellet[2]	39.4	12.0	11.1	1.4	10.4	25.7	1270.2
1/16" Pellet	39.0	12.1	9.7	1.4	10.4	27.4	1257.8
3/32" Pellet	36.3	12.5	9.8	1.6	9.6	30.2	1221.2
1/8" pellet	36.7	13.4	9.8	1.7	9.9	28.5	1261.6
5/32" Pellet[3]	36.7	13.4	9.8	1.7	9.9	28.5	1261.6

[1]See text.

[2]Represents an average of duplicate samples.

[3]Estimated from data collected on 1/8" Pellet.

IV. WATER IN AQUACULTURE SYSTEMS

A. OXYGEN

A significant production-limiting constraint in aquaculture systems is low dissolved oxygen levels which affect various species of fish by serving: to reduce fish growth, to decrease feed efficiency, to alter feeding behavior, and to decrease survival (Davis 1975). Even though scientists have documented these qualitative effects of dissolved oxygen in aquaculture systems, they have yet to define lower limits of dissolved oxygen which foster healthy conditions.

Many investigators have attempted to define the limiting levels of oxygen in the aquatic environment. Ellis et al. (1948) reported that a good mixed fish fauna exists only if the dissolved oxygen concentration is in excess of 5 mg/l. The key word in the foregoing recommendation is "exists", with no reference made to growth. Leitritz and Lewis (1976) stated that the lowest safe level of dissolved oxygen for trout is 5 mg/l but recommended that 7 mg/l dissolved oxygen would be a preferable minimum. Westers and Pratt (1977) and Westers (1979) recommended 5 mg/l as being the minimum dissolved oxygen content of water exiting hatchery ponds. Piper (1972) determined that when oxygen concentrations of water exiting experimental hatchery ponds average less than 5 mg/l, growth of trout in the ponds was limited by oxygen. Wedemeyer and Wood (1974) recommended oxygen levels for salmon on the basis of water temperature. They concluded that increases in water temperature require higher dissolved oxygen levels to meet the physiological needs of salmon.

Others have attempted to define oxygen levels using environmental partial pressures of oxygen (pO_2). Jones et al. (1970) analyzed optimum oxygen transfer across the gill membranes and determined that a pO_2 of 118 mmHg was necessary to maintain a proper gradient for oxygen uptake. Randall (1970) calculated that the external-internal dissolved oxygen gradient should be 20 mmHg pO_2. Cameron (1971) reported that rainbow trout blood remains nearly 100% saturated with oxygen until the pO_2 drops below 80 mmHg. Itazawa (1970) reported that rainbow trout blood remains saturated with oxygen until the pO_2 is less than 100 mmHg. Others have indicated equally equivocal and contradictory data (Davis 1975). Nonetheless, oxygen requirements for aquaculture systems should be based upon the oxygen partial pressure. The reasons for the use of partial pressures are two-fold; physical characteristics of oxygen in aquaculture systems and the physiological requirements of fish (Downey and Klontz 1981).

B. TEMPERATURE

In aquaculture systems, water temperature affects the system by directly adjusting the rates of system variables such as environmental partial pressure of oxygen, dissociation of ammonia, and the metabolic and growth rates of the fish. By altering these variables directly, temperature indirectly affects virtually every other variable in the system, thus affecting the overall systems rate of operation.

Each species of fish (and sometimes strains within the same species) have preferred water temperatures at which growth and metabolism are optimal. This temperature has been designated as the Standard Environmental Temperature (SET) (Klontz et al. 1979).

The general relationship between growth rates of a specific sized fish and temperature is parabolic with the maximum growth occurring at the SETs (Brett et al. 1969; Shelbourn et al. 1973; Elliott 1967a,b).

Several investigators attempted to model the effects of temperature on growth. Haskell (1959) noted that trout growth basically ceased at 38.6F (4C). From this concept, he defined the Temperature Unit (TU) for trout as the average daily water temperature of the system minus 38.6F. Thus, growth of fish at any water temperature could be estimated using this TU concept.

C. OTHER ENVIRONMENTAL REQUIREMENTS

Other water quality variables, such as pH, alkalinity, and water hardness, can also affect metabolism and constrain growth if present in high or low concentration extremes. These variables increase metabolism by requiring the fish to expend more energy for ionic regulation in their body.

V. FISH IN AQUACULTURE SYSTEMS

A. GROWTH

Growth of fish is the ultimate product of an aquaculture system. The entire system operation is directed towards this end. Fish growth is typically measured as an increase in length (Haskell 1959; Klontz et al. 1978), wet or dry weight gain (Brett and Shelbourn 1975; Stauffer 1973), protein utilization (Nightingale 1974), or as an increase in energy content in the fish (Warren and Davis 1968; Elliott 1976b; Staples and Nomura 1976). Although many of these measures are interrelated, growth in the context of this discussion is defined as an increase in the energy content of the fish.

Models of fish growth and metabolism have been either descriptive mathematical models, or analysis of the energy components of growth, commonly referred to as the bioenergetics approach (Warren and Davis 1968; Fry 1971; Kerr 1971a,b,c,; Elliott 1976a,b; 1977; Bond 1979). Using descriptive models to project growth means researchers must collect empirical data on fish growth and then, using statistical and mathematical techniques, fit a mathematical equation to the data which best describes the relationship. A bioenergetics approach to growth modeling assumes that all energy in a fish system can be accounted for as retained (= fish growth), as used to maintain the fish (= fish metabolism), or as lost from the system (waste).

The potential growth rate of fish in aquaculture systems considers the biotic capacity of the fish. The biotic potential of fish is hypothesized in an "ideal" system with no constraints to growth, and is a function of the genetic composition of the fish. Since growth in this "ideal" system is not readily quantifiable, a realistic working definition for growth potential must be established. In the context of the systems approach, fish growth potential is the expected growth in which the diet quantity and quality, fish species, and life support are specified without constraints (Figure 3).

Constraints in aquaculture systems can and do reduce the growth rates of fish in the system. Two growth constraints, pond design and management, modify environmental quality, thus dictating metabolic costs to the fish and their growth potential. This impact can be seen in water concentrations of ammonia, the chief excretory product of protein metabolism, permitted to exceed 0.0125 mg/l due to high retention times (pond design) or high densities of fish (management). Defining the pond design and management constraints which impact growth rates yields a reduced potential growth rate, termed the Allowable Growth Rate (AGR). Production forecasting depends upon the ability to predict AGR, the rate of fish growth in a specified system in which constraints are functional.

B. METABOLISM

Metabolism has the greatest intrinsic influence on growth, energy, and rate of energy consumption through the system. Energy requirements for metabolism must be met before growth can occur. In addition, environmental parameters indirectly affect growth through the alteration of metabolic energy needs of the fish.

C. WASTE PRODUCTS

1. Ammonia

Ammonia is a metabolic by-product resulting from protein anabolism and catabolism, and is the main nitrogenous excretory product of teleost fish

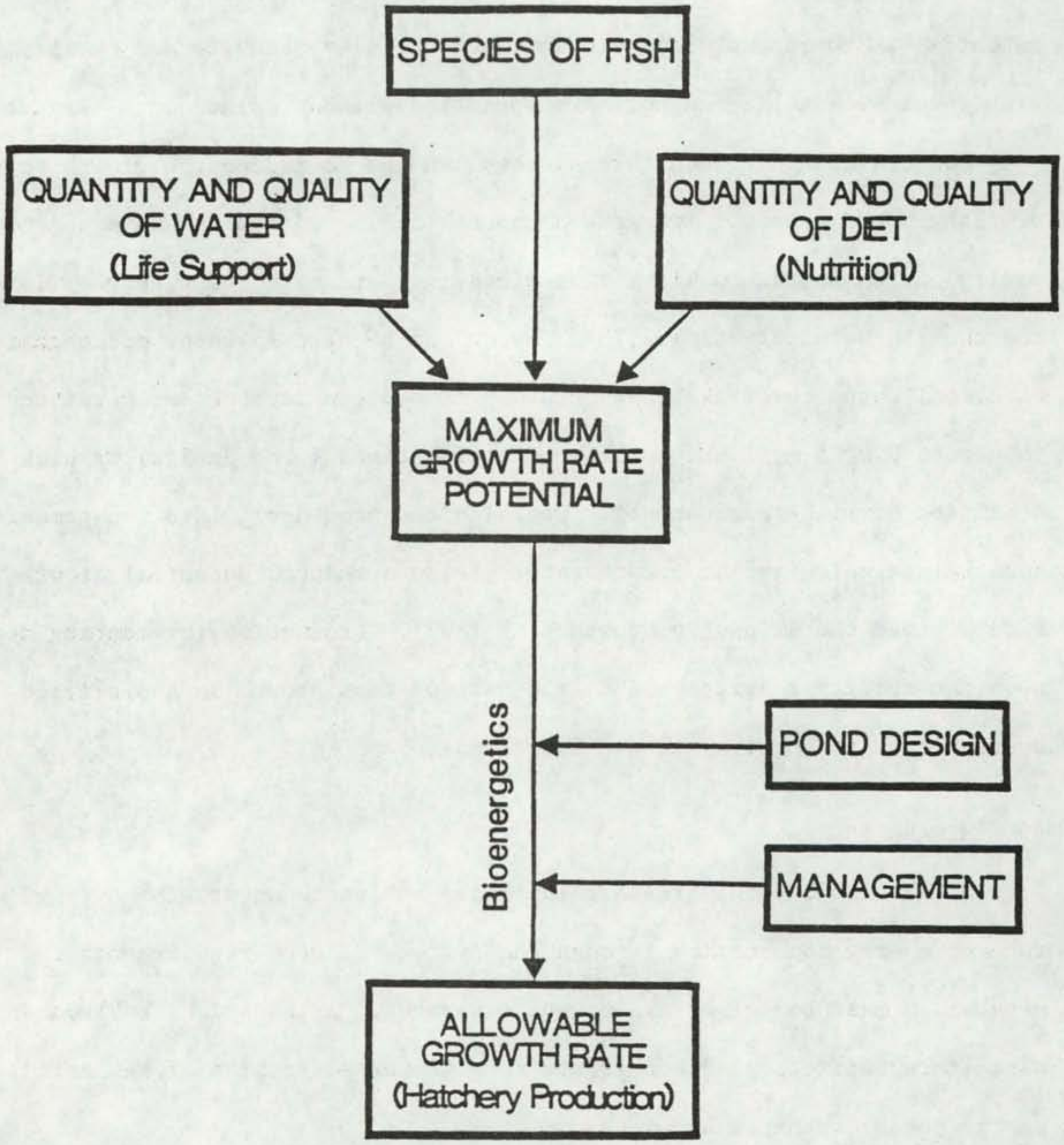

Figure 3. Relationships of major components defining allowable growth (Downey, 1981).

(Burrows 1964; Forster and Goldstein 1969). Ammonia is primarily excreted across the gills in exchange for sodium (Na^+). In aquatic systems, ammonia dissociates into unionized and ionized forms. Although much of the ammonia in the aquatic environment is in the form of ionized ammonia, many studies have shown that the unionized fraction of ammonia is toxic to fish (Burrows 1964; Smith and Piper 1975; Larmoyeux and Piper 1973). High environmental concentration of ammonia (NH_3) can cause gill hypertrophy or hyperplasia (Burrows 1964; Smith 1972), reduce fish growth (Brockway 1950; Burrows 1964; Larmoyeux and Piper 1973), or cause death (Smart 1976; 1978). Total ammonia ($NH_3 + NH_4^+$) in aquaculture systems should be maintained below 0.5 ppm in order not to impair the general health of the fish (Smith and Piper 1975). Ammonia (NH_3) limits in aquaculture systems have been set at a maximum of 0.0125 mg/l (Smith and Piper 1975). Ammonia dissociation in water is pH and temperature dependent. Increases in temperature and/or pH decrease dissociation (shift the reaction to the left) (Trussell 1972; Thurston et al. 1975).

Maximum limits (no-effect levels) of ammonia have been determined for continuous fish exposure in the aquaculture systems, but the effects of exposure to varying concentrations of ammonia have received little attention (Smith and Piper 1975). Burrows (1964) reported the differences in fish health as a result of varying the ammonia exposure pattern. These observations indicated that duration of exposure of fish to ammonia is at least as important as the ammonia concentration. Furthermore, a spiked (peaked) exposure of fish to high concentrations of unionized ammonia did not adversely affect the health of the fish as much as continuous exposure to lower levels of unionized ammonia. The pattern of exposure of fish to unionized ammonia is directly related to the total ammonia production (TAP) and its retention time in the rearing pond.

Other environmental variables altering susceptibility of fish to the effects of unionized ammonia are high carbon dioxide concentrations (Lloyd and Herbert, 1960) and low dissolved oxygen tensions (Merkens and Downing 1957; Downing and Merkens 1955). Both observations support the hypothesis that many environmental constraints affect growth and metabolism by altering oxygen uptake rates for fish.

Previous models of TAP by trout (Liao 1971; Willoughby et al. 1972; Speece 1973; Meade 1974; Paulson 1980) were developed from Haskell's supposition (Haskell 1959); "The amount of metabolic products generated is proportional to the amount of food fed." These models linearly relate the TAP to the amount of food fed.

TAP by fish can be partitioned into two recognizable fractions; endogenous ammonia production (EAP) and exogenous ammonia production (EXAP). Endogenous ammonia excreted by fish is a waste product generated as a result of normal cellular catabolism. Exogenous ammonia excreted by fish is a waste product formed due to the breakdown of absorbed dietary nitrogen (protein) compounds which are not synthesized into body protein (Maynard et al. 1975).

Models which consider the fractional components of TAP have been proposed by Downey (1981).

2. Feces

Fecal products excreted by fish are largely a composite of waste products from undigested feed residues and metabolic waste products. In aquaculture systems the undigested feed residue contributing to the feces is directly related to the quantity (= feeding rate) and quality of the diet.

Metabolic waste products, on the other hand, are end-products of fish metabolism. Both components must be considered singly or collectively when analyzing total feces production (TFP).

Analysis of TFP has been estimated by a model developed from empirical observations (Willoughby et al. 1972; Liao and Mayo 1974) or in laboratory digestibility studies (Phillips and Brockway 1959; Klontz et al. 1978). In these digestibility studies, the apparent digestibility (which differs from the actual digestibility) of various feed components is determined by calculating the difference in total component concentration (determined by proximate analysis) in the diet and the feces. This method of assessing apparent digestibility provides an estimate of the composite fecal production, which includes both the endogenous and exogenous components of the fecal material. Digestibility coefficients developed by these methods in the laboratory can be utilized in the analysis of fecal production of fish. With the bioenergetics systems approach, effects of feed composition are incorporated into the prediction of TFP (Downey 1981).

3. Carbon Dioxide Production:

Carbon dioxide in aquaculture systems is a direct result of fish metabolism. High levels of CO_2 in the system can alter both the hemoglobin oxygen affinity (Bohr effect) and carrying capacity of the blood (Root effect), and correspondingly can reduce oxygen uptake. This results in reduced system productivity. High carbon dioxide levels can also affect the toxicity of ammonia in aquaculture systems by altering the system's pH (Lloyd and Herbert 1960).

The rate of CO_2 production by fish can be related to the amount of oxygen consumed by the respiratory quotient (RQ) (Gordon et al. 1972).

The RQ depends upon the composition of the materials metabolized by the fish. The RQ has a value of 1.0 for carbohydrates, 0.8 for proteins, and 0.71 for fats (Gordon et al. 1972). Average RQ values for salmonids have ranged from 0.8 (Brett 1973) to 0.9 (Kutty 1968; Brett and Groves 1980).

VI. POND DESIGN IN AQUACULTURE SYSTEMS

A. WATER FLOW PATTERNS

Aquaculture ponds are classified into two types on the basis of water flow characteristics: noncirculating and circulating. Noncirculating ponds, or raceways, are linear ponds in which water enters at one end of the pond and exits at the other. Water flow is laminar; there is relatively little mixing of incoming and existing water. Many width-length-depth ratios are used in raceway designs, but hydraulically, and on the basis of productivity, ponds of 1:10:0.3 relative width:length:depth dimensions appear to be best (Burrows and Chenoweth 1955).

Raceway ponds are arranged as single systems or in series. In series (= linear reuse) systems, water exiting the upper pond is reused in succeeding ponds in the series before being discharged. Thus, water quality entering the reuse pond depends upon the quality of water exiting the previous pond.

Circulating ponds are rearing ponds in which the incoming water mixes with existing pond water, resulting in a homogeneous (or near homogeneous) water mass (Burrows and Chenoweth 1955: Burrows and Combs 1969; Burrows and Chenoweth 1970; Westers and Pratt 1977).

Some of the more common circulating pond designs are the Burrows pond, Circular pond, modified Mayhall or Thayer-Ellis pond, Rathbun pond, and Foster- Lucas pond. Circulating water flows are also common in large dirt ponds (.3-10 acres), are used in semi-intensive and extensive aquaculture, and are found in rectangular-shaped ponds which deviate appreciably from the standard 1:10:0.3 dimensions.

The differences of water flow in circulating and noncirculating ponds provide different physical and psychological environments for fish. These differences are categorized into velocity, retention time, and oxygenation.

B. WATER VELOCITY

Water velocity is important to the self-cleaning qualities of a pond. Burrows and Chenoweth (1970) state that a velocity of 6.1 cm/s (0.2 fps) is required along the center wall of a Burrows pond in order to maintain its self-cleaning properties. Jensen (1972) also stated that velocity is an important factor in determining whether fecal material will settle or remain suspended in raceways.

Pond water velocity also influences the metabolic rate and general condition of the fish. High velocities (9-12 cm/s) can increase the metabolic rate 2.3 times that of standard metabolism (Brett and Glass 1973). This increased metabolic rate produces high oxygen consumption by fish, increases ammonia production rates, and decreases dietary efficiency. These changes in metabolism, coupled with other hydraulic characteristics (i.e., retention time), can cause reduced fish production. Leitritz and Lewis (1976) provided a model for determining average water velocities in noncirculating ponds.

Water velocity in circulating ponds must be determined empirically as no model takes into account the wide varieties of pond design and water inflow.

C. OXYGENATION

Again, oxygen is one of the more important constraints in hatchery operations. Low oxygen levels reduce growth rates of fish, which limit overall productivity. The amount of oxygen available for fish in a pond depends primarily upon the solubility and partial pressure of the water supply and upon pond aeration efficiency.

Oxygen tensions in water entering single-use, noncirculating ponds is usually 95-100% of saturation. As the incoming water progresses through the pond, oxygen levels in the water decrease, reaching the lowest tensions at or before the outfall. This reduction, which is proportional to the amount and size of fish in the pond, can be so significant that water exiting a noncirculating pond has oxygen tensions at or near limiting oxygen levels.

In reuse noncirculating systems, ponds receive inflow water from the previous pond(s). Water generally flows out of the previous pond over a weir (damboards) and into the head end of the reuse pond. Oxygen tensions of the water entering the head of the reuse pond depend upon the oxygen tensions of the water exiting the previous pond, the height of the waterfall between the two ponds, and the oxygen saturation of the water. Efficiency of reoxygenation of water is higher in low-oxygen waters than in water with high oxygen tension, and therefore, reaeration efficiency (on a percent basis) would be higher when the water exiting the previous pond is low in oxygen.

Reaeration of oxygen in the water is seldom complete and is related to the distance the water falls through the air (Haskell et al. 1960). Oxygen transfer across an air/water interface follows a simple first-order rate equation (McLean and Boreham 1980; Downey 1981).

On the basis of available oxygen, the circular pond has a potential for greater oxygen concentrations and carrying capacity (biomass which an aquaculture system will support) than noncirculating ponds (Larmoyeux and Piper 1973). This greater potential for circulating ponds is directly related to the oxygen concentrations of exisitng water in the pond. In noncirculating ponds, the oxygen content of the water constantly decreases towards the pond outfall. Although the overall average oxygen concentration in the pond is above minimum oxygen tensions, about half of the pond has less than this average concentration, with a significant amount of the pond containing water with oxygen tensions at or near minimum oxygen requirements of trout. However, circulating ponds have oxygen concentrations in the pond that are the same throughout (assuming completely homogeneous mixing), and these levels also are overall average tensions. Therefore, theoretically, the load in a circulating pond can be increased to the point where the average oxygen tension (which is also the content throughout the pond) is near minimum oxygen tensions, without impairing growth. If pond loads in noncirculating ponds were increased in order to obtain average oxygen tensions near the minimum levels, oxygen tensions in about half of the pond would be below the minimum oxygen requirements for optimum growth and metabolism, and therefore, growth would decrease.

D. RETENTION TIME

Retention time denotes the length of time a substance, such as a metabolite or added chemical remains in the system. Retention time, detention time, replacement time, filling time, and water replacements per hour are interrelated hydraulic parameters. The retention time (= detention time) and replacement time of a pond are complementary. Replacement time measures the rate of loss of a substance from a pond, therefore, 99% replacement is equal to 1% retention. The term "replacements per hour" equals 60 divided into the 100% replacement time.

Calculation of retention time in noncirculating ponds generally has been estimated with models used to estimate filling time (Klontz 1979).

Hydraulically, circulating ponds differ considerably from noncirculating ponds. The objective of using circulating ponds in fish culture is to provide a homogeneous water mass (Westers and Pratt 1977). In a homogeneous system, the loss of a substance from the pond is directly related to the concentration of the substance in the pond. Loss of substances is by molecular displacement (rather than molecular replacement) in noncirculating ponds and is logarithmic (Downey 1981). However, mixing does not always produce an "ideal" homogeneous system, and incomplete mixing, which depends upon the amount of short circulating of new water, often occurs in circulating ponds (Burrows and Chenoweth 1955; Burrows and Combs 1969). In circular ponds the amount of mixing is related to the inflow angle, which can be designated by an empirical mixing coefficient (Downey 1981).

VII. MANAGEMENT OF AQUACULTURE SYSTEMS

Conceptually, the entire systems operation and production are under the complete control of facility management. Management personnel can control system variables and interactions and therefore can directly and indirectly affect systems operation through manipulation of input variables to assure an optimum environment for production. Management activities consist of defining management goals and objectives of the system (= product definition) and the manipulation of system variables and interactions to meet management objectives (production).

A. PRODUCT DEFINITION

One of the underlying principles of a properly managed aquaculture system simply states: "The ends prescribe the means." That is, the type of fish to be produced by the system (product definition) dictates the methods used to attain this product (Klontz et al. 1979). Therefore, it is necessary to have a complete product definition (PD) of the system before actual production commences.

A PD consists of setting criteria which define the goal(s) of the system. The PD criteria include the species, number, quality, and size of fish to be produced, and the date the product is to be harvested. The size fish will be at the start of the rearing process and the starting data for that process are also specified (Downey 1981).

Every aquaculture system has these objectives inherent in its product definition. However, these objectives are not the same quantitatively for all aquaculture systems. Commercial aquaculture systems strive to produce substantial numbers of market-sized fish for market when the demand and price are the highest, thus resulting in maximum economic return. Conservation aquaculture systems raise fish of predetermined sizes and numbers for release at a specific time into specified waters.

With the PD established (the ends), systems management considerations (the means), such as growth rates, feeding rates, space and water requirements, are defined within narrow limits. This process of defining management objectives and systems operation is called production forecasting.

B. PRODUCTION

Conceptually, production consists of the following individual activities: spawn-taking, egg incubation, fry feeding, fingerling feeding, grow-out feeding, and processing or distribution (Figure 4). Each activity has its own intrinsic set of criteria and problems. There are no established, routine methods by which each activity is to be accomplished. At least two routine fish culture activities should be standardized, becuase of their impact, if inaccurately done, on the entire process. These are the inventory techniques grading and record keeping. Each will be discussed separately.

1. Inventory Techniques: The most common method of growth assessment consists of estimating the number of fish per pound (or kilogram) and/or the average length of fish in the population. These data are then expanded as representative of the entire population. The numbers of samples per lot vary from 3-5 with the mean of the samples constituting the mean of the population. There is high potential for variation and error if statistical validity is not considered.

One method found to be highly reliable is the "5-by-5" inventory technique described by Klontz et al. (1978). The method has been severely tested under

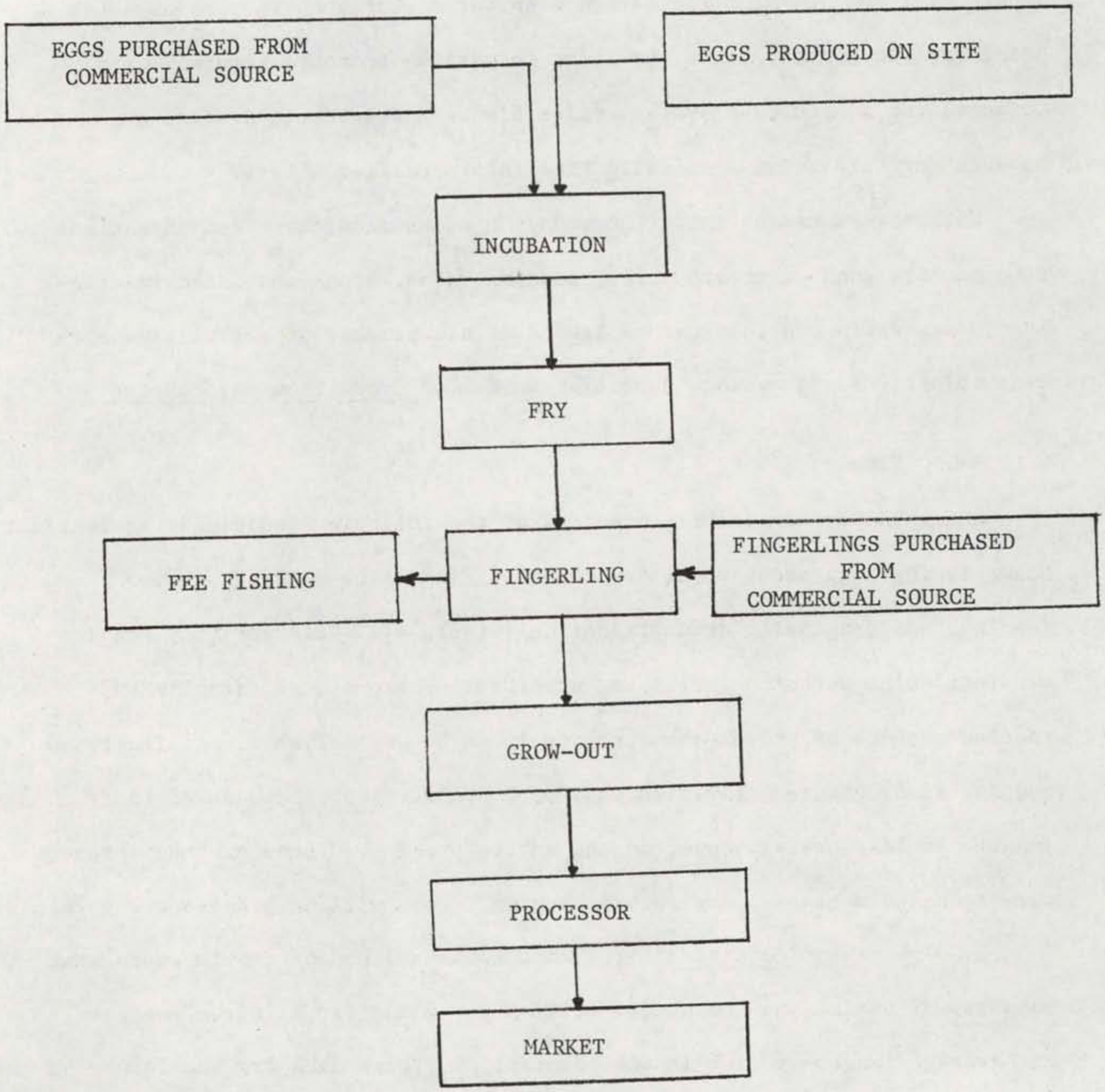

Figure 4. A schematic flow of activities and segments in freshwater food fish production.

both laboratory and field conditions and has proved to be statistically valid.

The inventory process begins with the fish not having been fed for a time sufficient to result in an empty gastrointestinal tract. Latent bacterial and viral infections are frequently activated by physical stress. Fish having empty gastrointensinal tracts are less predisposed to the adverse effects of physical stress (Wedemeyer and Wood 1974).

The fish are crowded to the inflow end of the pond and restrained there with a movable screen. In this process, the crowding should be the point where the density of the fish obscures the bottom of the screen. Next, five randomly selected samples of fish are netted and placed into a live-box. One sample is netted from the live-box, weighed, and counted back into the downstream side of the pond. The fish remaining in the live-box are released to the downstream portion of the pond and the process is repeated four more times. Thus, the origin of the term, "5-by-5" (Figure 5).

In addition to the subsamples being weighed and counted, one subsample is anesthetized and measured to the nearest mm. These data are used to establish a length frequency distribution within the population. The validity of the sample being representative of the population can be established by comparing the mean length with the median length. From these data one can visualize the range of sizes within the population and make some qualitative and quantitative judgments about the necessity for grading the population.

2. Record keeping: Implicit in the process of fish production, for whatever purpose, is the necessity for keeping detailed records of feed consumption, water flow, biomass in ponds, mortalities (including assessments of cause), water temperature, and numbers of fish on hand. Without such

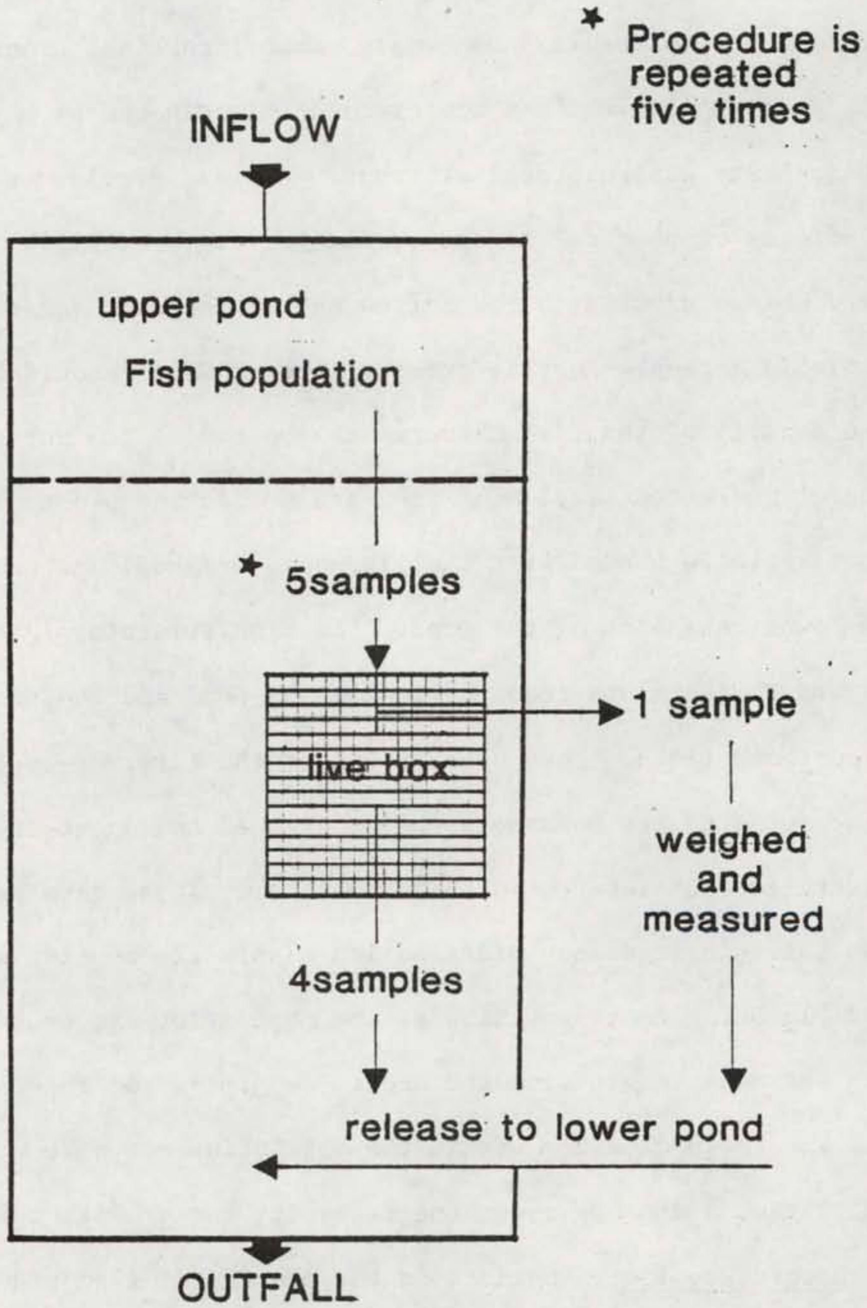

Figure 5. Schematic of activities in the "5-by-5" fish inventory process.

records, the application of production forecasting techniques is not feasible, and nearly impossible. Further substantiation of the needs for adequate records of daily activities is reflected in reduced costs of production, according to those who employ record-keeping practices.

3. Feeding Rates

Feeding rates (i.e., amount of food fed per time) can be modified to meet specific management needs for fish growth and systems productivity. If system productivity falls behind projected rates, management can increase feeding rates (if feeding rates are below allowable) to increase productivity. A reduction in feeding rates reduces productivity, and can bring a system which is ahead of projected productivity back on schedule.

Feeding rates for fish in aquaculture systems have received considerable attention (Schaeperclaus 1933; Deuel et al. 1952; Phillips and Brockway 1959; Freeman et al. 1967; Phillips 1972; Klontz et al. 1979). Downey (1981) developed feeding rate calculations which incorporate the energy gain of the fish and routine metabolic rates of fish. The amount of food fed during a specified period must contain enough metabolizable energy to satisfy all of these energy requirements of the fish for growth and metabolism.

4. Carrying Capacities

Physiological carrying capacities are indices usually based directly and indirectly upon the available oxygen of the system (Haskell 1955; Willoughby 1968; Elliott 1969; Westers 1970; Piper 1970; Liao 1970; Klontz et al. 1978) but which also can consider metabolite concentrations (Westers and Pratt 1977). The available oxygen and metabolite concentrations are functions of pond design; therefore, physiological carrying capacities differ among pond designs.

In serial reuse systems, oxygen levels are reduced and metabolite concentrations are higher than in single use pond. The reduction in available oxygen in reuse noncirculating systems is the result of extraction of oxygen by fish in the previous pond system(s) and the fact that reaeration between ponds is seldom sufficient to obtain saturation (Haskell et al. 1960). Generally, carrying capacity for noncirculating ponds, based on oxygen available, are calculated. However, the determination of available oxygen for a reuse system is determined by the amount of recharge occurring rather than oxygen saturation.

Unionized ammonia concentrations in noncirculating reuse pond systems can increase to detrimental levels and reduce fish growth and carrying capacity of the system (Larmoyeux and Piper 1973; Westers and Pratt 1977). The unionized ammonia concentrations in noncirculating reuse ponds sum the ammonia produced by fish in previous ponds and the ammonia produced by fish in the particular reuse pond (Downey 1981).

Physiological carrying capacities of circulating ponds, based upon available oxygen, are superior to noncirculating ponds (Larmoyeux et al. 1973). This higher carrying capacity is attributed to increased aeration efficiency and to the relatively homogeneous (oxygen) environment of circulating ponds.

Although oxygen tensions are not normally limiting in circulating ponds, ammonia concentrations can increase to levels which affect productivity. These higher ammonia concentrations are primarily attributed to the longer retention times of circulating ponds.

5. Population Densities

In addition to the life support or physiological carrying capacity of a fish rearing unit, each species and perhaps strain of fish has its psychological limits of population density (lb/ft^3 or kg/m^3). If these limits are exceeded, the growth rate potential of the system is reduced measurably.

Psychological carrying capacities are density indices which balance the fish, water, container, and management component interactions in order to satisfy the innate behavioral requirements of the fish. These indices are expressed in $lbs/ft^3/in$ or $kg/m^3/cm$ of fish (Piper 1972; Klontz et al. 1978). Density indices are independent of pond design and, therefore, can be used for any pond design.

VIII. PRODUCTION FORECASTING COMPUTER MODEL

From the foregoing systems concepts, an interactive computer production forecasting model was developed. The computer model is located in the Conversation Monitoring System (CMS) at the University of Idaho, Moscow, Idaho, and can be accessed from virtually any location in the world, providing the user has a remote terminal, a telephone, and the proper accounting information. The computer system is extremely fast in its operation. One run of the program requires 5 minutes for execution.

A. COMPUTER SYSTEM

The CMS System is a time-sharing interactive computer system. An interactive computer system requires the user to communicate directly with the computer via a terminal. For users not on a direct link with the central computer system, the user can connect with the computer via the telephone and a remote terminal. Recording data and executing the program can then begin.

In a time-sharing computer system, for example (Figure 6), while one user is answering a question, the computer is either calculating values for other equations or is requesting data from other users. When it is the "user's turn" again (a matter of a fraction of a second), the computer recognizes the input data and will proceed to execute the program. The time-sharing system allows for maximum utilization of computer resources and reduced costs for the user.

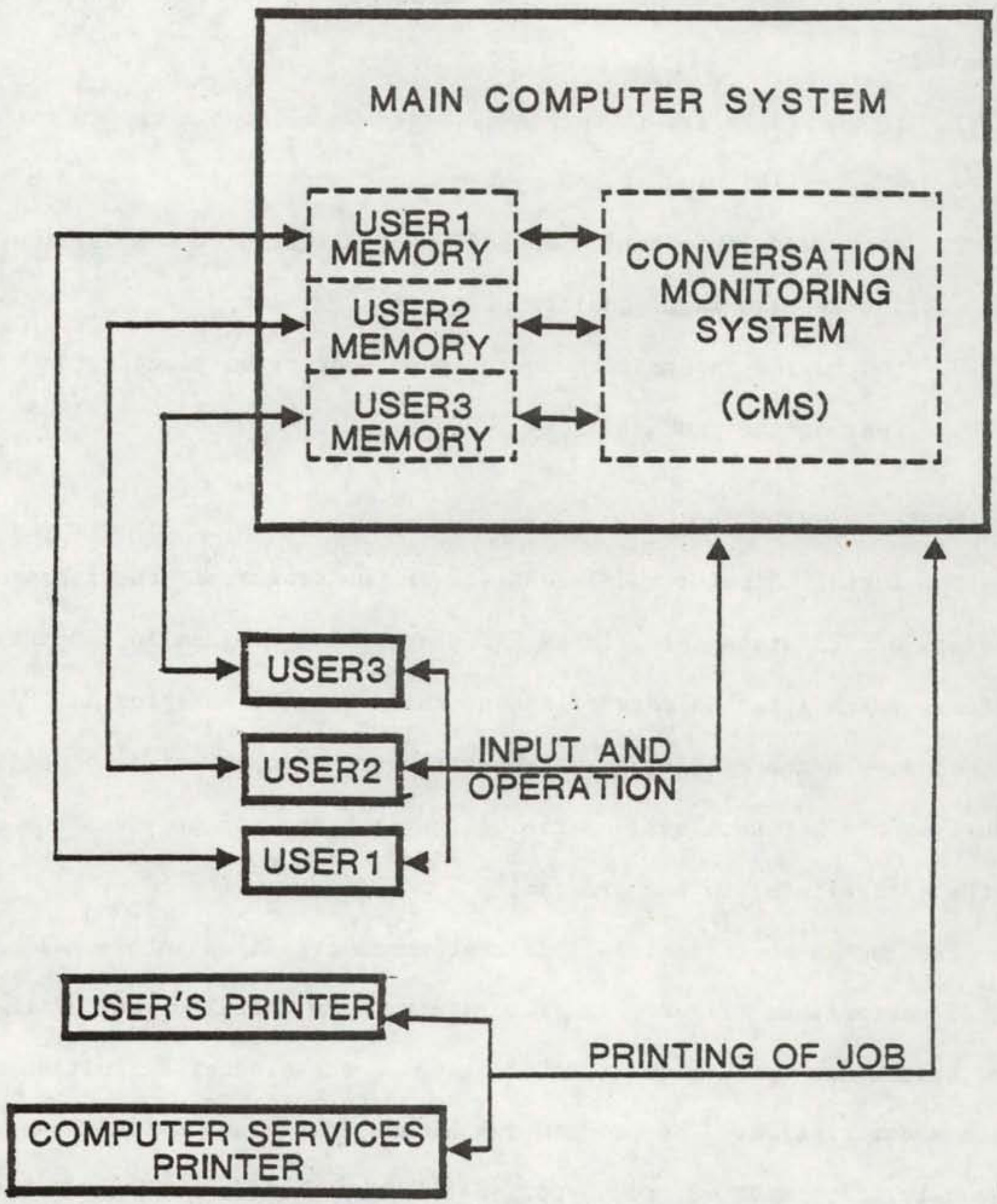

Figure 6. Interactive Conversation Monitoring Computer System (CMS) (Downey, 1981).

B. COMPUTER MODEL

The forecasting model, written in IBM WATFIV fortran, requires 520K of storage and takes approximately 7.5 seconds of CPU time to execute completely on a 4341 IBM Central Processor. There are three purposes of the model:

1. to provide a growth forecast, based on allowable growth for a specified product and systems configuration;
2. to provide information on pond hydraulics, diet composition, and average water quality of the system; and,
3. to provide information on the pond space requirements for rearing the product.

C. MODEL DESCRIPTION

The actual computer model consists of two programs: the first program consists of 228 statements, is an EXEC, a special program in IBM interactive systems, which attaches data files and calls the FORTRAN program, PRELIM for execution. In the EXEC program the user has the opportunity to obtain a manual at his/her terminal describing the program, and provides the name(s) of the data file(s) to the program.

PRELIM has approximately 1525 statements organized into a main program and 25 subroutines (Figure 7). The main program contains many of the input read statements which request information on the product definition and systems description. The program can handle 15 product definitions simultaneously, each with 40 growth periods (15 day periods) per product definition. When all input information is acquired, specific subroutines are called depending upon the stated product definition.

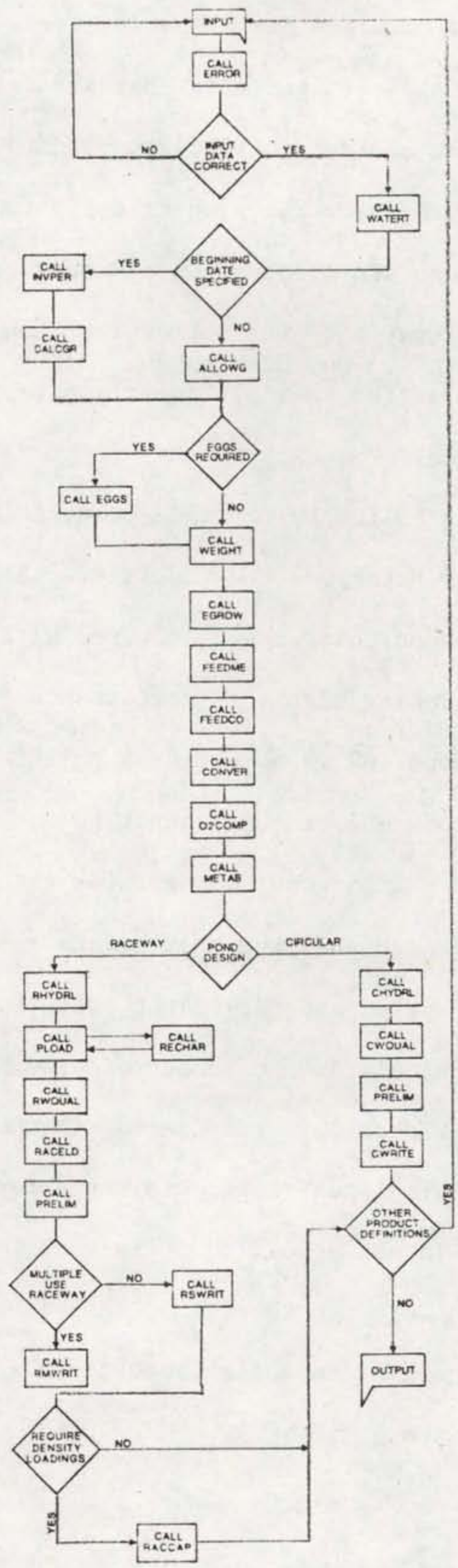

Figure 7. Flow diagram of the production forecasting model, PRELIM.

Subroutine ERROR checks the input data to ensure the data entered are reasonable. If input data are unreasonable, i.e., a 13 is entered for month, this subroutine alerts the user that the data has been improperly entered. Program control is then returned to the main program and the user is asked to re-enter the product definitions(s).

Subroutine WATERT requests information on the water temperature profile, water pH, and facility elevation. The subroutine then calculates the water temperature for each day of the year by linearly interpolating values from the given temperature data.

Subroutine CALCGR is called by the main program if the user specifies when fish will arrive (or hatch) on the facility. The AGR of the fish for the particular system are calculated and compared with the required growth rate (end size minus beginning size). A performance factor is calculated (= required/allowable), and AGR is adjusted by this factor. If the performance factor is greater than one, the PD cannot be met within the constraints of the system. If the required growth is greater than allowable growth, the computer prints a message that the growth rate and productivity are not within the means of the system and terminates execution.

Subroutine INVPER calculates the number of growth or inventory periods and approximate dates for each inventory period in the growth forecast.

Subroutine ALLOWG calculates the growth rates for each inventory period when the beginning date is not specified. The number of inventory periods and the inventory period date are determined in this subroutine. Growth rates are determined according to water temperature and are considered to be allowable for the system.

Subroutine WEIGHT calculates total poundage and total number of fish at each inventory period.

Subroutine FEEDME reads the diet file containing proximate analysis information and calculates the metabolizable energy and net energy of each pellet size. Average wastage (%), based upon nutritional components (protein, lipids, fiber, carbohydrates) is also calculated. This subroutine calls another subroutine, FEEDCO.

Subroutine FEEDCO creates an array, COLLAT, which contains the variables corresponding to the diet size required for each fish size, and collates the diet size and quality with specific inventory periods.

Subroutine EGROW calculates the body energy content and fish growth in terms of energy in the body of one fish at each inventory period.

Subroutine CONVER determines total energy requirements for an individual fish for each inventory period. Feed conversions (wet weight) and feed requirements for the entire product are also calculated.

Subroutine O2COMP reads in data files containing the saturation values of oxygen (mg/l) and minimum oxygen levels (mg/l) for various temperatures and elevations. These values, in conjunction with oxygen consumption, are used to calculate carrying capacities for each pond and inventory period.

Subroutine METAB computes the daily ammonia and feces production.

If the fish are reared in raceways, subroutine RHYDRL is called from the main program, and the hydraulic components, volume, retention time, and water velocity of a raceway pond are determined.

If the fish are reared in circulating ponds, subroutine CHYDRYL is executed, determining circulating pond hydraulic components, volume, retention time, and water velocity.

Subroutine PCCAP calculates the maximum density index of the pond. This maximum density carrying capacity is compared with the oxygen carrying capacity, and the lesser of the two indices is stored as a value of another variable. If the system is a multiple-use raceway, this subroutine calls subroutine RECHAR to determine carrying capacities in reuse ponds. Subroutine RECHAR determines the recharge of oxygen occurring in the reuse ponds of the raceway system and uses these values to determine oxygen carrying capacity.

Subroutine RWQUAL computes the unionized ammonia concentration in a raceway pond generated by a full pond of fish (determined from the lesser of the two carrying capacities of PCCAP). If this concentration exceeds 0.0125 mg/k in the pond (or reuse pond), carrying capacities are adjusted to maintain unionized ammonia concentration at or below 0.0125 mg/1. Once maximum poundage is calculated, average water quality, unionized ammonia concentration, average fecal solids concentration, and starting and ending densities, based on maximum carrying capacities, are recalculated.

Subroutine RACELD calculates the total pounds of fish, total pond, and water flow requirements for each inventory period.

Subroutine CWQUAL determines the carrying capacity of circular ponds. It determines which carrying capacity, density or oxygen, is lower and then uses these densities to calculate average unionized ammonia concentrations in the pond. If the average unionized ammonia concentration exceeds 0.0125 mg/1, the maximum poundage is reduced to produce an average concentration of 0.0125 mg/1. Average fecal solids concentrations are then calculated.

Subroutine PRELIM contains the "write" statements for the preliminary growth program.

Subroutine RSWRIT writes the summary of the pond, diet, and water quality characteristics if a single-use raceway system is employed.

Subroutine RMWRIT writes the summary of the pond, diet, and water quality characteristics for a multiple-use raceway system.

Subroutine RACCAP writes the beginning and ending fish densities for a completely loaded raceway. This output has to be specifically requested.

Subroutine CWRITE writes the summary of the pond, diet, and water quality characteristics for a circular pond system.

D. MODEL OUTPUT

The production forecasting model generates, depending on pond design, three forecasting schedules (Appendix I).

The first schedule printed by the program is a preliminary production forecast. The number of eggs needed for the product definition (if the fish are reared from eggs) and the days required for egg incubation are specified. Incubation times are based on temperature units and data obtained from Leitritz and Lewis (1976).

The main output of the preliminary forecast schedule consists of nine columns of information. The inventory period column contains approximate dates of pond inventory. The density capacity and oxygen capacity columns provide a maximum poundage of fish, according to fish size and pond design, permitted in the pond without exceeding pond capacities. The fish size, number of fish, total pounds of fish, and number per pound, which reflect summary statistics at the beginning of the period, are presented for each inventory period. The total pounds of food fed provides an estimate of food required <u>during the inventory period</u> to obtain the desired fish size (predicted size at the beginning of the next period) and growth rate. The feed size column, obtained from industry recommendations, presents the recommended size of feed fed to the lot of fish for each inventory. In using this schedule, the user must keep in mind that the end of one inventory period is the beginning of the next inventory period and so on.

The second schedule generated by the program is a summary of the pond system components. Information on the pond hydraulics, diet composition, water quality, and management of the system are summarized in this schedule. Pond hydraulics include water inflow per pond, pond dimensions, mean retention time, and water velocity. The diet composition records the average diet makeup (protein, lipid, and carbohydrates) and calculated metabolizable energy of each feed size for the specified diet. The pond water quality summarizes overall water pH and alkalinity, water temperature, oxygen saturations, minimum oxygen levels ($pO2 > 90.0$ mmHg), ammonia and feces production, and average concentrations.

Summary statistics for multiple-use raceway systems also include fish densities and metabolite concentrations for each pond in the reuse system and total concentrations for the entire reuse system.

The second schedule management component presents pond and water requirements for each product definition. If the system is a multiple-use raceway, minimum and maximum space and water requirements are printed to accommodate the many strategies of fish distribution in the multiple-use pond. Fish can be loaded into all ponds (upper deck, first reuse, etc.) of the raceway system, resulting in maximum water reuse and minimizing water requirements. Another strategy is to load fish only into the first pond of the raceway (upper pond) and operate these raceway systems as a single-use system, resulting in maximum water use requirements. Any other loading method employed would result in water requirements between the minimum and maximum water usage. Since there are many ways in which ponds of reuse systems can (and are) utilized, the provision of information on minimum and maximum water requirements are an aid to forecasting and particular management strategy. Therefore, the management component of multiple-pond raceway systems contains minimum and maximum water and space requirements for the product definition.

Schedule three of the program provides starting and ending densities of a completely loaded raceway. This schedule, created at the request of the user, is only available for raceway systems. This schedule contains estimates, based on growth rate and fish mortality, of the maximum starting and ending densities of a completely loaded raceway for each inventory period. Pond loadings are based upon the assumption that at the end of the inventory period the poundage in the pond will equal the carrying capacity of the pond system (calculated according to the lowest carrying capacity). Maximum poundages at the beginning (and end) of the inventory period provide a relative measure for determining water and space requirements for the particular loading strategies employed.

E. MODEL APPLICATION

The computer model is a flexible model which can enhance the management, design, and evaluation of aquaculture systems through applications included below.

1. Provide long-range production forecasting information for more effective management of aquaculture systems.

   The output of this program provides a long range production forecasting model which can be used to meet market demands and increase productivity through effective planning.

2. Test alternate strategies to determine the least costly processes for rearing fish.

   Alternate strategies can be evaluated with the computer model by changing input variables, i.e., diet, water flows, and weir heights, and obtaining the output requirements of growth rates, feed requirements, pond requirements, and water requirements. The assignment of actual costs and profits to these components permits an economic analysis of the various management strategies.

3. An aid in designing new facilities and/or renovating existing facilities.

   The use of the model for designing hatcheries is an extension of the model usage for evaluating management strategies. In addition to varying input variables mentioned above, the design engineer can alter pond design to observe how growth rates, feed requirements, pond requirements, and water requirements change. Again, by assigning costs to the individual factors, an economic analysis of alternate pond designs can be conducted.

4. Assessment of hatchery effluents and water treatment facility requirements necessary for meeting present and future EPA regulations.

   One of the outputs of the program is the prediction of production and concentration of waste products. This information, coupled with performance efficiencies of waste treatment facilities such as settling ponds and biofilters, can be used to determine the waste treatment facilities required at present or proposed facilities to meet water quality standards.

5. A teaching tool for training fish culturists at the middle and upper managerial levels.

   The model can be used as a teaching tool by providing a mechanism for managers to immediately evaluate a proposed management solution to an aquaculture systems problem. An added benefit of using this model is that the application of the solution (a management strategy) does not result in an involvement of fish if a wrong solution is chosen. Therefore, one can learn valuable lessons without risking fish and money.

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Appendix I. An example of the input required and summary tables generated by the PRELIM computer program.

THE PRELIMINARY PROGRAM IS A LONG RANGE FORECASTING MODEL. IT IS DESIGNED TO ALLOW THE USER TO PROGRAM HIS FACILITY'S PRODUCTION BY PROVIDING QUANTITATIVE INFORMATION ON GROWTH RATES, FEED SCHEDULES, WATER AND POND REQUIREMENTS, AND SUGGESTED LOADING AND SPLITTING DENSITIES. DETAILS OF THE PROGRAM'S OPERATION AND THE GENERAL USE OF COMPUTERS FOR GROWTH FORECASTING ARE EXPLAINED IN TWO MANUALS PRINTED AT THE UNIVERSITY OF IDAHO ("USING THE PRELIMINARY GROWTH PROGRAM", BY PHILIP C. DOWNEY AND GEORGE W. KLONTZ, AND "USING THE CMS INTERACTIVE COMPUTER SYSTEM FOR GROWTH PROGRAMMING", BY PHILIP C. DOWNEY AND GEORGE W. KLONTZ. WOULD YOU LIKE A COPY OF EITHER THE CMS MANUAL (ENTER CMS) OR THE PRELIMINARY GROWTH PROGRAM (ENTER PRE) OR BOTH MANUALS (ENTER BOTH)? IF NOT, ENTER NO.)
no

THE PRELIMINARY PROGRAM REQUIRES THE USER TO INPUT INFORMATION IN ORDER TO OPERATE THE PROGRAM AND CALCULATE THE FACILITY'S POTENTIAL. PROVIDING THIS INFORMATION TO THE COMPUTER CAN BE ACCOMPLISHED BY ENTERING THE DATA IN AN INTERACTIVE MODE OR BY PROVIDING THE COMPUTER WITH DATA FILES CONTAINING THE INPUT DATA.

DO YOU WANT TO INPUT THE DATA IN THE INTERACTIVE MODE (ENTER INTER) OR USING DATA FILES (ENTER DATA)?
inter
EACH TIME INFORMATION IS NECESSARY THE COMPUTER WILL PRINT A MESSAGE EXPLAINING WHAT TYPE(S) OF INFORMATION ARE REQUIRED. UPON COMPLETION OF THE COMPUTER MESSAGE YOU WILL INPUT THE DESIRED INFORMATION.

WHAT BRAND OF FEED WILL BE FED?

```
    OREGON MOIST PELLET  (ENTER OMP)
    SILVERCUP            (ENTER SIL)
    MOORE-CLARK          (ENTER MC)
  * A SPECIFIC DIET      (ENTER NAME)
```

*NOTE:
THE USER OF THIS PROGRAM MAY SPECIFY A SPECIFIC DIET HE/SHE WISHES TO USE. THE DIET INFORMATION MUST BE STORED IN A DATA FILE AND GIVEN A NAME (ANY 8 CHARACTER NAME) AND FOLLOW A SPECIFIC FORMAT. IF YOU LIKE TO USE A SPECIFIC DIET FOR PRODUCTION, CONSULT THE USER'S MANUAL FOR INSTRUCTIONS ON FORMING THE DIET DATA FILE.
sil

```
EXECUTION BEGINS . . .
 HOW MANY DIFFERENT PRODUCT DEFINITIONS DOES THE FACILITY HAVE
?
1
 ENTER THE PRODUCT DEFINITIONS, ONE DEFINITION PER LINE - AFTER EACH QUESTION MARK.


 A COMPLETE PRODUCT DEFINITION CONSISTS OF:

  (1)  THE SPECIES OF FISH (CODE IS 1--RAINBOW TROUT)
  (2)  THE MONTH, DAY AND YEAR THE PRODUCT IS TO BE READY (1.E.,4,15,0).
  (3)  THE SIZE OF THE FISH ON THE DAY THEY ARE TO BE READY FOR MARKET OR STOCKING:
       ENTER BOTH THE NUMBER PER POUND AND THE TOTAL LENGTH IN INCHES
  (4)  THE SIZE (IN INCHES) AND THE DATE AT THE BEGINNING OF THE GROWTH PROGRAM;
       A)  IF THEY ARE TO BE EGGS AT THE BEGINNING, ENTER 0 FOR SIZE
       B)  IF THE SIZE OF THE FISH (EGGS, 1",2", ETC.) ARE AVAILABLE YEAR ROUND, YOU CAN ENTER 0 FOR THE DATE
           AND THE COMPUTER WILL CALCULATE THE DATE WHEN EGGS SHOULD BE TAKEN.
  (5)  Enter THE MAXIMUM DENSITY INDEX.

   AN EXAMPLE OF HOW TO ENTER THE DATA:

    THE PRODUCT DEFINITION IS:

1000000 RAINBOW TROUT 1.4 PER POUND SIZE (SIZE = 12 INCHES) ARE NEEDED ON APRIL 1.
THEY WILL BE RAISED FROM EGGS WHICH CAN BE OBTAINED THROUGHOUT THE YEAR.
MAXIMUM DENSITIES ARE NOT TO EXCEED 0.5 LBS/CUF1/INCH.

   THE ENTRY WOULD APPEAR AS:

1,4,1,0,1.4,12,1000000,0,0,0,.5

?
1,4,1,0,1.4,12,1000000,0,0,0,.5
 WHAT TYPE OF POND WILL BE USED TO WEAR THIS PRODUCT DEFINITION?
 ENTER 1 FOR RACEWAY PONDS AND 2 FOR CIRCULATING PONDS.
?
1
 ENTER THE AMOUNT OF WATER (IN CFS) ENTERING EACH RACEWAY AND THE WATER USE;
  (THE CODE FOR WATER USAGE IS:  1 FOR SINGLE USE, 2 FOR 1 REUSE, 3 FOR 2 REUSES.)
?
2,1,1
 ENTER THE AVERAGE LENGTH, WIDTH, AND DEPTH OF A SINGLE POND IN THE
 RACEWAY SYSTEM.
?
100,10,3
 WHAT IS THE WATER PH, ALKALINITY, AND THE ELEVATION OF THE STATION?
?
```

```
7,6,190,1000
 HOW MANY DIFFERENT WATER TEMPERATURE VALUES ARE RECORDED AND WHAT IS THE MEASUREMENT SCALE
 (ENTER 1 FOR FAHRENHEIT OR 0 FOR CENTIGRADE)
?
2,1
 ENTER THE MONTH AND DAY THE TEMPERATURE WAS RECORDED,
 AND THE WATER TEMPERATURE SCALE (0 FOR CENTIGRADE, 1 FOR FAHRENHEIT)
?
1,1,54
?
6,1,59
```

*** PRELIMINARY PROGRAM FOR RAINBOW TROUT***

THE EGGS SHOULD BE OBTAINED ON APRIL 22 AND WILL
REQUIRE 40 DAYS TO REACH 1.90 ON JUNE 01

INVENTORY PERIOD		DENSITY CAPACITY (LBS/POND)	OXYGEN CAPACITY (LBS/POND)	FISH SIZE (IN INCHES)	NUMBER OF FISH	NUMBER PER LB	TOTAL LBS OF FISH	FEED CONVERSION	TOTAL LBS FEED FED PER INVENTORY	FEED SIZE
JUNE	01	2852.0	1032.6	1.90	1093935.	351.955	3108.16	1.317	5628.77	#2 FRY COARSE
JUNE	15	3811.1	1455.9	2.54	1089035.	147.504	7383.10	1.458	10005.66	#3 FINE CRUMBL
JULY	01	4751.9	1907.1	1.17	1084158.	76.091	14247.88	1.446	14369.04	#4 COARSE CRUM
JULY	15	5676.8	2375.4	3.78	1079302.	44.631	24182.75	1.488	19864.37	3/32" PELLET
AUGUST	01	6582.3	2876.2	4.39	1074468.	28.629	37530.36	1.477	25293.85	3/32" PELLET
AUGUST	15	7471.9	3385.3	4.98	1069654.	19.573	54649.71	1.476	31097.64	1/8" PELLET
SEPTEMBER	01	8142.1	4027.3	5.56	1064864.	14.064	75713.44	1.506	36433.56	1/8" PELLET
SEPTEMBER	15	9163.5	4570.8	6.11	1060094.	10.611	99903.94	1.505	42268.54	1/8" PELLET
OCTOBER	01	9967.4	5148.3	6.64	1055346.	8.245	127994.94	1.539	47275.52	5/32" PELLET
OCTOBER	15	10724.4	5710.7	7.15	1050619.	6.620	158714.94	1.540	52760.11	5/32" PELLET
NOVEMBER	01	11463.5	6319.4	7.64	1045914.	5.420	192976.81	1.576	57038.66	3/16" PELLET
NOVEMBER	15	12157.8	7063.9	8.11	1041229.	4.543	229171.87	1.576	61982.56	3/16" PELLET
DECEMBER	01	12835.9	7698.1	8.56	1036566.	3.861	268489.44	1.571	66716.06	3/16" PELLET
DECEMBER	15	13499.9	8326.7	9.00	1031922.	3.319	310950.00	1.621	69967.56	3/16" PELLET

JANUARY	01	14118.6	8994.2	9.41	1027301.	2.901	354102.75	1.561	75526.69	3/16" PELLET
JANUARY	15	14756.5	9146.4	9.84	1022699.	2.541	402487.31	1.605	83182.50	3/16" PELLET
FEBRUARY	01	15387.5	9213.7	10.26	1018119.	2.241	454318.69	1.616	93170.62	3/16" PELLET
FEBRUARY	15	16036.8	9121.9	10.69	1013558.	1.980	511987.50	1.673	101636.75	1/4" PELLET
MARCH	01	16672.6	9221.9	11.12	1009019.	1.762	572748.37	1.678	112601.56	1/4" PELLET
MARCH	15	17325.7	9318.3	11.55	1004499.	1.570	639852.56	1.678	124897.75	1/4" PELLET
APRIL	01	18000.0	9348.6	12.00	1000000.	1.400	714285.87	0.0	0.0	------------

*** SUMMARY OF SINGLE USE RACEWAY COMPONENTS ***

POND HYDRAULICS

POND-SINGLE USE RACEWAY

INFLOW - 2.1 CFS

POND DIMENSIONS

POND LENGTH - 100.0 FEET
POND WIDTH - 10.0 FEET
POND DEPTH - 3.00 FEET
VOLUME - 3000.0 CUFT

MEAN RETENTION TIME 23.8 MINUTES

AVERAGE WATER VELOCITY - 0.0778 FPS

DIET COMPOSITION

FEED SIZE	PROTEIN (%)	LIPID (%)	CHO (%)	METABOLIZABLE ENERGY (KCAL/LB)
STARTER	54.4	15.8	10.7	1697.2
#1 FRY FINE	52.2	13.1	10.7	1557.1
#2 FRY COARSE	52.2	13.1	10.7	1557.1
#3 FINE CRUMBLES	48.3	9.3	18.3	1401.9
#4 COARSE CRUMBL	48.3	9.3	18.3	1401.9
3/32" PELLET	44.6	9.4	21.6	1359.5
1/8" PELLET	44.6	9.4	21.6	1359.5
5/32" PELLET	44.6	9.4	21.6	1359.5
3/16" PELLET	44.6	9.4	21.6	1359.5
1/4" PELLET	44.6	9.4	21.6	1359.5

WATER QUALITY PER POND SYSTEM

WATER PH = 7.6
ALKALINITY = 190.0

INVENTORY PERIOD		FISH DENSITIES (LBS)	WATER TEMPERATURE (F)	INFLOW OXYGEN (PPM)	OUTFALL OXYGEN (PPM)	DAILY AMMONIA PRODUCTION (MG/FISH/DAY)	AVERAGE UNIONIZED AMMONIA CONCENTRATION (PPM)	DAILY FECES PRODUCTION (MG/FISH/DAY)	AVERAGE FECAL CONCENTRATION (PPM)
JUNE	01	1032.6	59.0	10.3	5.9	3.14164	0.002385	28.94041	2.044818
JUNE	15	1455.9	58.7	10.3	5.9	5.82851	0.002579	64.67914	2.700239
JULY	01	1907.3	58.3	10.3	5.9	9.14380	0.002692	98.45935	2.777985
JULY	15	2375.4	58.0	10.3	5.9	12.64402	0.002682	163.41197	3.368002
AUGUST	01	2876.2	57.6	10.3	5.9	17.16086	0.002781	214.65712	3.436338
AUGUST	15	3385.3	57.2	10.3	5.9	22.36272	0.002877	270.73145	3.487426
SEPTEMBER	01	4027.3	56.9	10.5	6.0	27.87006	0.003014	325.36816	3.582793
SEPTEMBER	15	4570.8	56.5	10.5	6.0	33.98338	0.003104	384.15332	3.622224
OCTOBER	01	5148.3	56.1	10.5	6.0	40.20023	0.003163	438.12695	3.615583
OCTOBER	15	5710.7	55.8	10.5	6.0	46.96262	0.003246	495.77832	3.643508
NOVEMBER	01	6319.4	55.4	10.5	6.0	53.56314	0.003299	544.80176	3.627625
NOVEMBER	15	7063.9	55.1	10.8	6.2	60.75105	0.003458	598.99243	3.737373
DECEMBER	01	7698.1	54.7	10.8	6.2	68.22371	0.003539	651.83203	3.766201
DECEMBER	15	8326.7	54.4	10.8	6.2	75.35713	0.003585	693.60254	3.726077
JANUARY	01	8994.2	54.0	10.8	6.2	83.77879	0.003700	753.00073	3.819813
JANUARY	15	9146.4	54.5	10.8	6.2	94.39813	0.003787	836.77808	3.780689
FEBRUARY	01	9213.7	55.0	10.8	6.2	106.88470	0.003902	942.50659	3.783305
FEBRUARY	15	9121.9	55.5	10.5	6.0	119.39996	0.003887	1030.5088	3.644029
MARCH	01	9221.9	56.0	10.5	6.0	133.81546	0.003997	1176.0471	3.651708
MARCH	15	9318.3	56.4	10.5	6.0	149.96117	0.004113	1332.1179	3.665835
APRIL	01	9348.6	57.0	10.5	6.0	74.30809	0.001867	1332.1179	3.279742

MANAGEMENT COMPONENT

INVENTORY PERIOD		TOTAL PONDS REQUIRED	WATER REQUIREMENTS (IN CFS)
JUNE	01	6	12.60
JUNE	15	8	16.80
JULY	01	11	23.10
JULY	15	14	29.40
AUGUST	01	17	35.70
AUGUST	15	19	39.90
SEPTEMBER	01	22	46.20
SEPTEMBER	15	25	52.50
OCTOBER	01	28	58.80
OCTOBER	15	31	65.10
NOVEMBER	01	33	69.30
NOVEMBER	15	35	73.50
DECEMBER	01	38	79.80
DECEMBER	15	40	84.00
JANUARY	01	45	94.50
JANUARY	15	50	105.00
FEBRUARY	01	57	119.70
FEBRUARY	15	63	132.30
MARCH	01	69	144.90
MARCH	15	77	161.70

WOULD YOU LIKE STARTING AND ENDING DENSITIES FOR THE RACEWAY SYSTEM?
no

Table . An example of the summary tables generated by the PRELIM computer model for circular ponds.

*** PRODUCT DEFINITION 1 ***

THE EGGS SHOULD BE OBTAINED ON JULY 06 AND WILL REQUIRE 40 DAYS TO REACH 1.70 ON AUGUST 15.

INVENTORY		DENSITY CAPACITY (LBS/POND)	OXYGEN CAPACITY (LBS/POND)	FISH SIZE (IN INCHES)	NUMBER OF FISH	NUMBER PER LB	TOTAL LBS OT FISH	FEED CONVERSION	TOTAL LBS FEED FED PER INVENTORY	FEED SIZE
AUGUST	15	1491.9	340.0	1.70	106965.	502.759	212.76	1.597	519.03	3/64" PELLET
SEPTEMBER	01	2035.3	488.7	2.31	106486.	198.017	537.76	1.651	895.86	3/32" PELLET
SEPTEMBER	15	2572.1	643.4	2.92	106009.	98.110	1080.52	1.593	1282.61	1/8" PELLET
OCTOBER	01	3101.5	805.9	3.52	105535.	55.962	1885.82	1.585	1758.68	1/8" PELLET
OCTOBER	15	3624.2	972.9	4.12	105062.	35.071	2995.69	1.583	2289.50	5/32" PELLET
NOVEMBER	01	4139.0	1177.1	4.70	104591.	23.545	4442.16	1.575	2862.75	5/32" PELLET
NOVEMBER	15	4647.2	1359.5	5.28	104123.	16.634	6259.50	1.574	3479.82	5/32" PELLET
DECEMBER	01	5148.0	1550.4	5.85	103657.	12.237	8470.55	1.610	4055.20	5/32" PELLET
DECEMBER	15	5623.1	1737.0	6.39	103192.	9.390	10989.72	1.610	4688.97	5/32" PELLET
JANUARY	01	6090.6	1934.5	6.92	102730.	7.389	13902.35	1.618	5301.81	5/32" PELLET
JANUARY	15	6545.5	2061.6	7.44	102270.	5.953	17178.70	1.618	6162.81	5/32" PELLET
FEBRUARY	01	7007.9	2180.3	7.96	101812.	4.851	20987.84	1.670	6988.90	5/32" PELLET
FEBRUARY	15	7456.8	2298.2	8.47	101356.	4.026	25172.30	1.673	7961.94	5/32" PELLET
MARCH	01	7911.7	2414.7	8.99	100902.	3.371	29930.50	1.726	8850.89	5/32" PELLET

MARCH	15	8352.3	2462.7	9.49	100450.	2.865	35057.82	1.727	9942.97	5/32" PELLET
APRIL	01	8799.8	2558.7	10.00	100000.	2.450	40816.31	0.0	0.0	------------

*** SUMMARY OF CIRCULAR POND COMPONENTS ***

POND HYDRAULICS

POND-CIRCULAR

INFLOW - 0.75 CFS

MIXING COEFFICIENT - 1.83

POND DIMENSIONS
POND DIAMETER - 40.0 FEET
POND DEPTH - 1.8 FEET
VOLUME - 2200.0 CUFT.

MEAN RETENTION TIME 89.5 MINUTES

AVERAGE WATER VELOCITY - 0.5000 FPS

DIET COMPOSITION

FEED SIZE	PROTEIN (%)	LIPID (%)	CHO (%)	METABOLIZABLE ENERGY (KCAL/LB)
FRY START	38.3	12.6	10.3	1269.3
FRY MEAL	35.0	13.0	12.0	1233.3
1/32" PELLET	38.6	12.1	10.4	1257.7
3/64" PELLET	39.4	12.0	11.1	1274.7
1/16" PELLET	39.0	12.1	9.7	1260.0
3/32" PELLET	36.3	12.5	9.8	1223.5
1/8" PELLET	36.7	13.4	9.8	1263.8
5/32" PELLET	36.7	13.4	9.8	1263.8

WATER QUALITY PER POND SYSTEM

WATER PH = 7.3
ALKALINITY = 190.0

INVENTORY PERIOD		FISH DENSITIES (LBS)	WATER TEMPERATURE (F)	INFLOW OXYGEN (PPM)	DAILY AMMONIA PRODUCTION (MG/FISH/DAY)	AVERAGE UNIONIZED AMMONIA CONCENTRATION (PPM)	DAILY FECES PRODUCTION (MG/FISH/DAY)	AVERAGE FECAL CONCENTRATION (PPM)
AUGUST	15	1491.9	58.3	10.3	2.1754	0.010943	25.3729	24.3038
SEPTEMBER	01	2035.3	58.0	10.3	3.9766	0.010625	45.3484	23.3397
SEPTEMBER	15	2572.1	57.8	10.3	6.3615	0.010541	70.9403	22.8611
OCTOBER	01	3101.5	57.5	10.3	9.4320	0.010631	101.6138	22.5223
OCTOBER	15	3624.2	57.3	10.3	13.1400	0.010742	136.7503	22.1968
NOVEMBER	01	4139.0	57.0	10.5	17.4596	0.010815	175.4787	21.8385
NOVEMBER	15	4647.2	56.8	10.5	22.4503	0.010925	217.9942	21.5202
DECEMBER	01	5148.0	56.5	10.5	27.8079	0.010907	259.9197	20.9103
DECEMBER	15	5623.1	56.3	10.5	33.7789	0.010997	305.3408	20.5884
JANUARY	01	6090.6	56.0	10.5	40.1715	0.011017	350.5940	20.1500
JANUARY	15	6545.5	56.2	10.5	48.1993	0.011558	411.5977	20.4821
FEBRUARY	01	7007.9	56.5	10.5	56.8665	0.012039	473.1492	20.5407
FEBRUARY	15	7401.6	56.7	10.5	66.6954	0.012500	543.8691	20.6989
MARCH	01	7582.1	57.0	10.5	77.0059	0.012500	612.1882	19.9829
MARCH	15	7664.2	57.2	10.3	88.7604	0.012500	693.1016	19.4369
APRIL	01	8799.8	57.5	10.3	41.3896	0.005791	734.3451	20.1325

MANAGEMENT COMPONENT

INVENTORY PERIOD		TOTAL PONDS REQUIRED	WATER REQUIREMENTS (IN CFS)
AUGUST	15	1	0.75
SEPTEMBER	01	1	0.75
SEPTEMBER	15	1	0.75
OCTOBER	01	2	1.50
OCTOBER	15	2	1.50
NOVEMBER	01	2	1.50
NOVEMBER	15	2	1.50
DECEMBER	01	3	2.25
DECEMBER	15	3	2.25
JANUARY	01	3	2.25
JANUARY	15	4	3.00
FEBRUARY	01	4	3.00
FEBRUARY	15	5	3.75
MARCH	01	5	3.75
MARCH	15	5	3.75

Table . An example of the summary tables generated by the PRELIM computer model for multiple use raceways.

*** PRELIMINARY PROGRAM FOR RAINBOW TROUT ***

THE EGGS SHOULD BE OBTAINED ON SEPTEMBER 03 AND WILL REQUIRE 42 DAYS TO REACH 1.89 ON OCTOBER 15.

INVENTORY PERIOD		DENSITY CAPACITY (LBS/POND)	OXYGEN CAPACITY (LBS/POND)	FISH SIZE (IN INCHES)	NUMBER OF FISH	NUMBER PER LB	TOTAL LBS OF FISH	FEED CONVERSION	TOTAL LBS FEED FED PER INVENTORY	FEED SIZE
OCTOBER	15	2265.5	1090.2	1.89	112314.	364.087	308.48	1.383	512.64	FRY COARSE
NOVEMBER	01	2951.7	1506.8	2.46	111811.	164.621	679.20	1.636	935.54	GROWER CRUMBLE
NOVEMBER	15	3623.6	1939.2	3.02	111310.	88.976	1251.00	1.633	1306.35	COARSE CRUMBLE
DECEMBER	01	4279.2	2399.7	3.57	110811.	54.027	2051.05	1.466	1544.08	3/32" PELLET
DECEMBER	15	4920.6	2872.7	4.10	110315.	35.535	3104.37	1.467	1932.44	3/32" PELLET
JANUARY	01	5544.6	3461.7	4.62	109821.	24.837	4421.62	1.404	2358.68	4/32" PELLET
JANUARY	15	6182.2	3811.4	5.15	109329.	17.917	6101.85	1.402	2962.39	4/32" PELLET
FEBRUARY	01	6836.5	4040.1	5.70	108839.	13.250	8214.27	1.627	4052.21	5/32" PELLET
FEBRUARY	15	7478.6	4355.2	6.23	108352.	10.121	10705.20	1.631	4902.83	5/32" PELLET
MARCH	01	8134.0	4665.0	6.78	107867.	7.867	13711.41	1.680	5762.39	5/32" PELLET
MARCH	15	8775.7	4952.3	7.31	107383.	6.264	17142.17	1.680	6804.95	5/32" PELLET
APRIL	01	9432.7	5084.3	7.86	106902.	5.044	21192.37	1.739	7844.29	5/32" PELLET
APRIL	15	10074.4	5337.4	8.40	106424.	4.141	25702.77	1.742	9079.51	5/32" PELLET

MAY	01	10729.9	5566.6	8.94	105947.	3.427	30914.35	1.817	10223.74	5/32" PELLET
MAY	15	11361.9	5868.3	9.47	105472.	2.886	36540.93	1.818	11480.70	5/32" PELLET
JUNE	01	12000.0	6154.8	10.00	105000.	2.450	42857.13	0.0	0.0	------------

SUMMARY OF MULTIPLE USE RACEWAY COMPONENTS

POND HYDRAULICS

POND-MULTIPLE USE RACEWAY

INFLOW - 2.1 CFS

POND DIMENSIONS

POND LENGTH - 100.0 FEET
POND WIDTH - 10.0 FEET
POND DEPTH - 3.00 FEET
VOLUME - 3000.0 CUFT.

MEAN RETENTION TIME 23.8 MINUTES

AVERAGE WATER VELOCITY - 0.0778 FPS

FEED SIZE	PROTEIN (%)	LIPID (%)	CHO (%)	METABOLIZABLE ENERGY (KCAL/LB)
CHINOOK MASH	53.1	11.8	10.7	1527.3
FRY FINE	46.6	12.5	15.5	1464.1
FRY COARSE	46.6	12.5	15.5	1464.1
GROWER CRUMBLE	43.2	7.2	18.4	1228.7
COARSE CRUMBLE	43.2	7.2	18.4	1228.7
3/32" PELLET	39.8	11.9	21.6	1358.0
4/32" PELLET	45.6	9.5	20.2	1371.7
5/32" PELLET	37.3	9.3	22.1	1219.5
3/16" PELLET	37.3	9.3	22.1	1219.5
1/4" PELLET	45.8	8.4	21.1	1342.5

WATER QUALITY PER POND SYSTEM

WATER PH = 7.5
ALKALINITY = 150.0

INVENTORY PERIOD	POND REUSE	FISH DENSITIES (LBS)	WATER TEMPERATURE (F)	INFLOW OXYGEN (PPM)	OUTFALL OXYGEN (PPM)	DAILY AMMONIA PRODUCTION (MG/FISH/DAY)	AVERAGE UNIONIZED AMMONIA CONCENTRATION (PPM)	DAILY FECES PRODUCTION (MG/FISH/DAY)	AVERAGE FECAL CONCENTRATION (PPM)
OCTOBER 15	0	1090.2	57.0	10.1	6.0	2.6046	0.001584	34.9754	0.763677
	1	457.6		7.8	6.0		0.000664		1.131352
	2	457.6		7.8	6.0		0.0		0.0
OUTFALL AVERAGE		0.0					0.002247		1.895028
NOVEMBER 01	0	1506.8	56.6	10.1	6.0	4.8763	0.001818	69.1900	1.503974
	1	632.5		7.8	6.0		0.000763		1.399457
	2	632.5		7.8	6.0		0.000763		1.399457
OUTFALL AVERAGE		1264.0					0.003344		4.302888
NOVEMBER 15	0	1939.2	56.2	10.1	6.0	7.3990	0.001890	101.8794	2.204622
	1	814.0		7.8	6.0		0.000792		1.432734
	2	814.0		7.8	6.0		0.000792		1.432734
OUTFALL AVERAGE		1626.0					0.003475		5.070091
DECEMBER 01	0	2199.7	55.8	10.1	6.0	8.9031	0.001679	144.1580	3.105538
	1	1007.3		7.8	6.0		0.000704		1.524719
	2	1007.3		7.8	6.0		0.000704		1.524719
OUTFALL AVERAGE		2014.0					0.003088		6.154977
DECEMBER 15	0	2872.7	55.4	10.1	6.0	11.9055	0.001740	185.9077	3.689429
	1	1205.8		7.8	6.0		0.000730		1.547601
	2	1205.8		7.8	6.0		0.000730		1.547601
OUTFALL AVERAGE		2410.0					0.003201		6.784631

JANUARY	01	0	3461.7	55.0	10.4	6.2	17.0272	0.002057	197.9249	3.308335
		1	1453.1		7.9	6.2		0.000864		1.388620
		2	1453.1		7.9	6.2		0.000864		1.388620
OUTFALL AVERAGE			2906.0					0.003785		6.085576
JANUARY	15	0	3811.4	55.1	10.4	6.2	22.1952	0.002162	252.3626	3.350367
		1	1599.8		7.9	6.2		0.000907		1.405600
		2	1599.8		7.9	6.2		0.000907		1.405600
OUTFALL AVERAGE			3198.0					0.003976		6.161566
FEBRUARY	01	0	4040.1	55.8	10.1	6.0	26.4962	0.002060	433.2178	4.508469
		1	1695.8		7.8	6.0		0.000864		1.891503
		2	1695.8		7.8	6.0		0.000864		1.891503
OUTFALL AVERAGE			3390.0					0.003788		8.291475
FEBRUARY	15	0	4355.2	56.1	10.1	6.0	33.1644	0.002155	530.5967	4.547051
		1	1828.1		7.8	6.0		0.000904		1.908518
		2	1828.1		7.8	6.0		0.000904		1.908518
OUTFALL AVERAGE			3656.0					0.003963		8.364087
MARCH	01	0	4665.0	56.5	10.1	6.0	40.5997	0.002229	633.3560	4.518703
		1	1958.1		7.8	6.0		0.000935		1.896616
		2	1958.1		7.8	6.0		0.000915		1.896616
OUTFALL AVERAGE			3916.0					0.004100		8.311934
MARCH	15	0	4952.3	56.8	10.1	6.0	49.3499	0.002324	755.2798	4.555154
		1	2078.7		7.8	6.0		0.000975		1.911343
		2	2078.7		7.8	6.0		0.000975		1.911343
OUTFALL AVERAGE			4156.0					0.004274		8.377839
APRIL	01	0	5084.3	57.2	9.9	5.9	58.9984	0.002339	882.6404	4.400823
		1	2134.1		7.6	5.9		0.000981		1.847141
		2	2134.1		7.6	5.9		0.000981		1.847141
OUTFALL AVERAGE			4268.0					0.004301		8.095105
APRIL	15	0	5337.4	57.6	9.9	5.9	70.0844	0.002429	1030.5088	4.427429
		1	2240.4		7.6	5.9		0.001019		1.858111
		2	2240.4		7.6	5.9		0.001019		1.858111
OUTFALL AVERAGE			4480.0					0.004468		8.143652
MAY	01	0	5566.6	58.0	9.9	5.9	81.8338	0.002490	1176.0471	4.361670
		1	2336.6		7.6	5.9		0.001045		1.830373
		2	2336.6		7.6	5.9		0.001045		1.830373
OUTFALL AVERAGE			4672.0					0.004579		8.022415

MAY	15	0	5868.3	58.2	9.9	5.9	94.5578	0.002571	1332.1179	4.386629
		1	2463.2		7.6	5.9		0.001079		1.841113
		2	2463.2		7.6	5.9		0.001079		1.841113
OUTFALL AVERAGE			4926.0					0.004728		8.068855
JUNE	01	0	6154.8	58.3	9.9	5.9	100.1888	0.002444	1332.1179	3.905168
		1	2583.5		7.6	5.9		0.001025		1.638879
		2	2583.5		7.6	5.9		0.001025		1.638879
OUTFALL AVERAGE			5166.0					0.004495		7.182925

MANAGEMENT COMPONENT

INVENTORY PERIOD		TOTAL PONDS REQUIRED	MAXIMUM WATER REQUIREMENTS (IN CFS)	TOTAL NO OF RACEWAYS	MINIMUM TOTAL WATER REQUIRED (IN CFS)
OCTOBER	15	1	2.10	1	2.10
NOVEMBER	01	1	2.10	1	2.10
NOVEMBER	15	1	2.10	1	2.10
DECEMBER	01	2	4.20	1	2.10
DECEMBER	15	2	4.20	1	2.10
JANUARY	01	2	4.20	1	2.10
JANUARY	15	3	6.30	2	4.20
FEBRUARY	01	3	6.30	2	4.20
FEBRUARY	15	3	6.30	2	4.20
MARCH	01	4	8.40	2	4.20
MARCH	15	5	10.50	3	6.30
APRIL	01	5	10.50	3	6.30
APRIL	15	6	12.60	4	8.40
MAY	01	7	14.70	4	8.40
MAY	15	7	14.70	4	8.40

WOULD YOU LIKE STARTING AND ENDING DENSITIES FOR THE RACEWAY SYSTEM?
yes

*** STARTING-ENDING DENSITIES FOR EACH DECK IN A COMPLETELY LOADED RACEWAY ***

INVENTORY PERIOD		UPPER DECK STARTING-ENDING LBS	MID DECK STARTING-ENDING LBS	LOWER DECK STARTING-ENDING LBS	TOTAL LBS IN RACEWAY LBS
OCTOBER	15	308.48 - 679.20	287.04 - 632.00	287.04 - 632.00	882.57 - 1943.20
NOVEMBER	01	679.20 - 1251.00	441.40 - 813.00	441.40 - 813.00	1561.99 - 2877.00
NOVEMBER	15	1251.00 - 2051.05	614.20 - 1007.00	614.20 - 1007.00	2479.41 - 4065.05
DECEMBER	01	1897.97 - 2872.68	796.14 - 1205.00	796.14 - 1205.00	3490.25 - 5282.68
DECEMBER	15	2430.43 - 3461.72	1020.14 - 1453.00	1020.14 - 1453.00	4470.70 - 6367.71
JANUARY	01	2761.84 - 3811.35	1158.69 - 1599.00	1158.69 - 1599.00	5079.23 - 7009.35
JANUARY	15	3001.13 - 4040.10	1259.11 - 1695.00	1259.11 - 1695.00	5519.34 - 7430.09
FEBRUARY	01	3341.83 - 4355.22	1402.65 - 1828.00	1402.65 - 1828.00	6147.13 - 8011.22
FEBRUARY	15	3642.17 - 4664.95	1528.71 - 1958.00	1528.71 - 1958.00	6699.59 - 8580.95
MARCH	01	3961.19 - 4952.34	1662.12 - 2078.00	1662.12 - 2078.00	7285.42 - 9108.34
MARCH	15	4112.58 - 5084.27	1726.16 - 2134.00	1726.16 - 2134.00	7564.89 - 9352.27
APRIL	01	4400.75 - 5337.37	1846.92 - 2240.00	1846.92 - 2240.00	8094.59 - 9817.37
APRIL	15	4628.13 - 5566.55	1942.19 - 2336.00	1942.19 - 2336.00	8512.52 -10238.55
MAY	01	4964.73 - 5868.34	2083.75 - 2463.00	2083.75 - 2463.00	9112.22 -10794.34
MAY	15	5247.75 - 6154.84	2202.32 - 2583.00	2202.32 - 2583.00	9652.39 -11320.84

Selected Water Resources Abstracts

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16. Abstract

Computer implementation of the mathematical models of quantitative relationships in aquaculture systems is a dynamic process which provides a conceptual framework for understanding systems behavior. These models can provide useful information on variable significance to systems functioning, thereby directing research resources into areas which will most benefit further understanding of the system. Furthermore, as aquaculture systems research progresses, the composite model can be modified to incorporate new technology. Modeling, therefore, is a cyclic process--a means for understanding the system, for evaluating the system, and for using the model to incorporate the new techology.

This computer-implemented mathematical model addresses one of the significant limitations of aquaculture systems management, namely, production forecasting, by providing a method of using current technology to predict Allowable Growth Rate (AGR). The use of the model in aquaculture operations could aid production forecasting, resulting in more efficient water usage and profitable aquaculture systems operations.

17a. Descriptors

Instream flows, salmonids, rainbow trout, oxygen concentrations

17c. COWRR Field & Group

08I

18. Availability

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20. Security Class. (Page)

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