PROPOSED COMMERCIAL AQUACULTURE FACILITIES

prepared by

FSH 507 Students

Instructor

Dr. J. E. Lannan

Summer 1974

C O N T E N T S

I N T R O D U C T I O N

The theory and philosophy of marine aquaculture will be considered in an integrated series of lectures, discussions, and student projects. The projects will serve as the matrix for the entire course. Lectures and discussions will, hopefully, fill many of the voids within the matrix.

Every student participating in the course will complete a project. The project will consist of developing a proposal for a commercial aquaculture enterprise. In developing the proposal, students may utilize any format they desire. The proposals may be in outline form, supplemented with narrative as required. Verbosity is discouraged. Typing of the proposals is not required so long as they are legible.

A draft of each students proposal is due on Wednesday, July 31. Each proposal will then be subjected to biological, engineering, legal, and economic evaluations accomplished by different students. Each student will have the opportunity to modify his or her proposal prior to submitting a final draft at the end of the quarter.

Each proposal must address, but need not be limited to species selection; biological parameters; proposed culture methods; proposed culture facilities; water utilization and management; permits required; and financial estimates, including capital and operating costs, and income and profit estimates.

A PROPOSED FACILITY FOR THE CULTURE OF TWO SPECIES OF CARP UTILIZING WASTE GROWN ALGAE AS A FOOD RESOURCE

Introduction

The science of resource management is commanding greater attention with each passing day. Minimum pollution and maximum productivity are cries heard often, but with equal frequency many of our valuable resources are wasted or even destroyed.

In order to attain maximum productivity, minimum pollution and the friendship of both conservationists and economists alike new concepts and techniques must be researched and practiced so as to gain productivity from what was previously considered waste. It is bearing this in mind that the following aquaculture facility is proposed.

Objectives

Aquatic Foods Inc. (AFI) is designed to serve as an efficient sewage treatment/aquaculture facility. Algal culture will be stimulated by the input of nutrients from a sewage treatment plant and will serve as a principle food resource for the production of *Hypophthalmichthys molitrix* (silver carp) and *Hypophthalmichthys nobilis* (bighead carp). As carp are warm water fish growth in the colder Oregon waters will accelerate by utilization of heated power plant effluent. In keeping with the nature of the project this proposal is divided into two sections, Part 1 considers the mechanics of pond treatment and phytoplankton production, while Part 2 dwells upon the subject of fish protein production and the economic feasibility of such a venture.

PART 1

Oxidation or Waste Stabilization Pond Theory

Oxidation ponds or lagoons are being increasingly used by cities and industries alike as an efficient means of BOD and suspended solid removal. Reasons are largely economic in nature - ponds are cheap to build, require little maintenance and if properly designed are as efficient as the sophisticated and expensive treatment systems.

The stabilization process is very simply a mutually beneficial interaction between bacteria and algae. Bacteria oxidize and consume the organic matter, producing CO_2 and ammonia, and the algae through photosynthesis utilize these waste products themselves producing oxygen. A simplified diagram of the process may be found in Figure 4.

Smooth operation and efficient BOD removal in the pond process is dependent upon a sufficient supply of oxygen. Oxygen may be supplied by surface aeration, algal photosynthesis or compounds such as nitrates, sulfates and phosphates. Should these natural sources fail to supply oxygen in sufficient quantities artificial introduction must be initiated through use of mechanical mixing or aeration devices.

Because stabilization depends very highly on photosynthetic activity, light is also an indispensable resource. Pond construction will vary regionally depending upon the relative intensity of solar radiation. Light penetration is also very dependent upon algae concentrations present at any given time. Concentrations of Euglena have been observed in a three inch thick layer beneath the water surface (Bartsch and Taft, 1956) resulting in anaerobic conditions occuring at the pond bottom.

Temperature although not altering the nature of the processes will have a great effect on the rate of stabilization. Seasonal or other causes of temperature fluctuation will influence the BOD reaction, algal respiration and dissolved oxygen saturation level. Stabilization rate is a linear function of temperature when the range is 13°C - 30°C. Bartsch and Taft (1956) found that loading could be increased 1.5 times as a result of a temperature increase from 20°C to 30°C.

Despite the great number of different wastes treated by the pond method, algal diversity seems to remain fairly constant. Concentrations vary depending upon the type of waste treated and temperature, but Chlorella, Scenedesmus, Euglena, Ankistrodesmus, Chlamydomonas and Micractinum seem to be present in nearly all circumstances.

Of all wastes presently being treated by stabilization pond procedures sewage is the most suitable for use as an algal culture medium. As carbon nitrogen and phosphorus are the principally found nutrients in sewage information on their percent composition in algae and uptake is of primary importance in the design of stabilization ponds. Oswald (72) has summarized very adequately the work on carbon, nitrogen and phosphorus so far completed in this regard as follows:

Carbon:	125 mg/1 C converted to algae containing 40 to 60% carbon - potential yield, from 208 to 312 mg/1.
Nitrogen:	40 mg/1 N converted to algae containing 5.5 to 12.5% nitrogen - potential yield, from 320 to 730 mg/1.
Phosphorus:	1 mg/1 of P converted to algae containing 0.5 to 1.5% phosphorus - potential yield, from 730 to 2,200 mg/1.
Note:	Temperature and light conditions were such that full assimilation of C, N, P was possible.

From the above data depicting an algal growth potential for domestic sewage it is evident that both carbon and nitrogen are present in concentrations inhibitory to maximum algal growth. It is apparent then that for optimum algal production to persist either addition of carbon and nitrogen or removal of nitrogen and phosphorus is obligatory. Until recently action taken in this regard was very costly and difficult largely due to the inefficient means of removing nitrogen. However a new and inexpensive method of nitrogen subtraction has been developed utilizing the deep faculative pond concept. Through this procedure it is now possible to convert 60% of the incoming nitrogen to nitrogen gas. From this discussion then it seems a combination system involving nutrient subtraction and nutrient assimilation is the most economically feasible.

Facility Design

Pond Layout and Design: AFI will maintain four ponds for waste treatment, each designed to fulfill a certain need. Water will be pumped from the aerated cultivation ponds into a 1.5 acre faculative pond. Surface flow will lead to the aerated 3 acre algal cultivation pond at which point algae will be harvested. Ponds 3 and 4 will be deep water ponds as is pond 1 and will aid in final clarification and purification.

The first or faculative pond will be 3.3 m deep and will effectively reduce BOD by 84%, carbon by 51% and nitrogen by 34%. Water will be pumped from the cultivation ponds into a center bottom discharge thereby bringing the waste warmth into the fermentation zone and permitting a 360° contact of sewage with the ponds contents.

The second, third and fourth ponds will further reduce BOD, COD, carbon, nitrogen and phosphorus levels. Pond 2 will be 3 acres in area and three feet deep thus permitting extensive nutrient uptake through rapid algal cultivation. Upon harvesting algae may be either bagged and shipped to various sources of demand or further processed and reintroduced to the raceway to serve as a food resource to young fishes. Pond 3 and pond 4 will be 8 feet in depth and serve sedimentation and maturation functions. Pond 3 will be 2.5 acres in area, pond 4 will be 3 acres. Turnover rates of each pond are represented in Figure 1.

Algal Harvesting Procedure

The processing of algae involves three steps: initial concentration, dewatering and final drying. Due to the size, specific gravity and morphology of algal cells large scale harvesting of algae as a foodstuff has so far not been practical. There are however, many techniques which may be used to extract algae from pond effluent. Centrifugation, ion exchange precipitation, chemical precipitation and various flocculants may be used to concentrate the algae into an algal slurry at which point various methods of dewatering and drying may be utilized. Golueke and Oswald (1965) have reviewed the methods available, the efficiencies of these methods and the relative costs of each. When considering these various alternatives choice must depend not only upon cost of equipment and operation but also upon the quality of the product desired.

AFI will utilize centrifugation for both the concentration and dewatering steps and drum drying for the final processing. This procedure will, although higher in cost than alternative methods, provide a high grade produce, low space requirements and less handling. Primary centrifugation will increase algal solids concentration from pond concentration to 1-2% of the slurry. The solids content will then be raised to 10-15% after primary centrifugation and to 85% upon final drying.

The facility will have a maximum harvesting capacity of 7 million gallons per day or 4 thousand gallons per minute. Operating volume will, however, likely be much less depending upon algal concentrations, sewage inflows and demand for processed algae. Assuming a 7 mgd operating capacity high quality algae could be produced by the above method approximately $80.00 per ton. At an algal concentration of 200 mg/l about 1.2 million gallons of pond effluent are required to produce one ton of algae. Therefore, close to 6 tons of dry algae may be produced per day at full operating capacity. Market price estimates are vague as the market is at present small, however feed experts predict prices similar to soybean oil meal or between $75.00 and $85.00 per ton. It then appears that algae harvesting is not a profitable venture, however, one must also consider the monetary benefit gained from BOD and nutrient removal. Also as previously mentioned much of the processed algae will not be sold, but will be ground and used for fish feed at a price much less than that of commercially available feeds.

PART 2

General Characteristics of Carp

Carp are the principal farmed Cyprinid in the world. They are a warm water species requiring a very minimum temperature of 5°C. Spawning will take place in temperatures between 18-20°C and optimum growth occurs between 20-28°C.

Many species are cultured with many food preference variations present among them. Greatest advantage is taken of this variability in China where the polyculture of five species is practiced with great success and efficiency. In this proposed facility the plankton feeding section of the above trophic scheme will be utilized - silver carp being phytoplankton feeders and big head carp being zooplankton consumers.

Hatchery Operation

The hatchery portion of AFI will consist of two spawning ponds, two rearing ponds, a brood stock holding pond and a brood stock conditioning pond. Pond area and volume figures may be found in Figure 1. The facility will receive heated water from an adjacent steam electric station at a flow rate of 0-4 million gallons per day. That water which does not flow through the hatchery (4 million-hatchery flow) will enter the main intake canal and the raceway system. Also, should the S.E.S. curtail operation for maintenance purposes, an axilliary pumping unit will be available so as to maintain sufficient flow.

Due to the stringent spawning requirements of carp techniques of artificial propogation will be practiced. The procedure for obtaining, spawning, hatching and rearing will be as follows: (Bardach, 1972)

a. Permits allowing introduction of silver and bighead carp must first be secured after which time pairs of carp, (3/4 silver 1/4 bighead) will be imported from Taiwan. The brood stock will be selected on the basis of favorable response to stress conditions.

b. Brood stock are held in the brood stock holding pond until gonadal maturity is attained, at which point they are transferred to a conditioning pond which is artificially maintained at the desired temperature.

c. Stock are removed and subjected to injections of 2 to 3 mg dried cyprinid pituitary. Timing is very important in this step as estrualization must be completed at time of maturation.

d. Spawners are immediately placed in the spawning ponds (23-29°C) in a ratio of 2:1 males to females. Spawning occurs within 14 hours after which time the pond is drained and eggs are collected with a fine mesh net placed at the outlet. Spawners are returned to the conditioning pond for recuperation.

e. Eggs are placed in hatching nets provided with baffels to direct water flow upward. A hatching rate of 90% may be maintained with a water flow of 20 l/min at concentrations of 3,000 eggs/l.

f. Hatching occurs in 30-32 hours at a temperature of 25°C. The yolk sac is absorbed within 3-6 days.

g. Upon absorption of the yolk sac fry are transferred to rearing ponds. Within 2-4 weeks sizes of 30 mm are attained at which point transfer to cultivating systems occurs.

<u>Cultivation and Harvesting</u>

Fish will be stocked in the raceway at a density of 6 lb/ft^3 or 2,500 fry per enclosure. Cultivation ponds will be stocked at a rate of 15,000/acre or 225,000 per total pond area. The total system will therefore have a capacity of 262,000 fry. Growth to harvesting size (3 kg) requires a maximum of three years and as a yearly harvest is desired initial stocking density will be approximately 1/3 of the total capacity. Modification of the proposed procedure may be possible, however, should there be a demand for small size immature fish by either fishmeal or fertilizer industries. Profit from such ventures will be considered extra and not tallied on the balance sheet.

Assuming a harvest size per year (beginning the third year) of 87,000 fish at a price of 50¢ per pound and a weight of 6 pounds a fish, a total revenue of $261,000.00 per year may be realized. Assuming a predicted variable cost of $97,000.00 gross profits will be $164,000.00. After taxes net profit would still be approximately $90,000.00 giving, at worst, a return on investment of 9%.

Harvesting will be carried out once a year during the spring with the aid of nets and part-time unskilled labor. Fish will be cleaned, brined and cold stored on the site (30 ton capacity). Transportation of fish to market will be provided by the individual food chains purchasing the fish.

Disease Management

Considerations of disease management are of particular importance to AFI due to the nature of the influent. Although the influent sewage has received both primary and secondary treatment thereby increasing greatly the chemical quality of the water, bacterial quality is not necessarily improved. It is true that the coliform count may be greatly reduced in treated sewage but pathogenic bacteria have in some cases been greatly stimulated by the treatment process (Skiezko, 1974). As but one example the incidence of Aeromona has been observed to increase a million fold in the presence of sewage (Skiezko, 1974). In this case the slime lining in the pipes apparently serves as a very efficient culture medium for the bacteria.

Due to the above circumstances and resultant high chance of pathogenic attach, AFI will expose the incoming sewage to oxidation pond treatment before it may enter the pond cultivation system. Pond volume will be approximately 17 million ft^3 yielding a detention time of 41 days at a maximum flow of three million gallons per day.

Data on the pathogenic potential of sewage such as that discussed above is strongly lacking. Recent studies (Slanetz, Bartley, Metcalf and Nesman, 1972; Little, Conell, Gentry, 1972) however, have suggested that treatment of oxidizing ponds will yield a 95% to 99% die-off of coliforms and certain pathogenic bacteria. It was also found that when ponds were operated in a series of four ponds, counts as low as two per ml were frequent. Viral concentrations were also reduced greatly in these studies but isolations were made indicating that 100% die-off had not been realized. Also it should be noted that the bacteria and enteric pathogen isolations were appreciably higher in the winter than in the summer.

As mentioned above AFI will subject water flow to treatment before it is exposed to the fish cultivation area. Presently only the one large pond is planned, however, upon commencement of operation water samples will be taken frequently and subjected to bacterial analysis. Should pathogenic organisms be present in harmful concentrations construction of other ponds will be considered. Also should the concentrations of algae rise to harvestable quantities processing for feed use purposes will be considered.

Despite these precautionary measures diseases may and most likely will occur in at least small portions of the fish population. Should the need for large scale treatment arise many chemicals may be utilized. As an example of such conditions some of the common diseases of carp are mentioned with workable or recognized treatments below:

Disease or Parasite	Pesticide	Concentration
Colummaris (Davis 65)	malichite green	---
	sulfadiazine	---
	sulfamerazine	---
Aeromonas (Meyer 66)	acriflavin	---
	chloramphenicol	---
	oxytetracycline	---
	chlortetracycline	---
	penicillin	---
	streptomycin	---
Argulus sp. (Sarig 71)	lindane	.02
	malathion	.25
	dipterex	.25
	D.D.V.R.	.25
	bromex	.12
Lernaea (Sarig 71)	$KMNO_4$	25.00
	dipterix	.25
	D.D.V.P.	.12
	bromex	.25
Eragasilus ichthyophthyius (Sarig 71)	bromex	.15

Other common parasites of carp are Ichthyophthirinus nuttifilus, Chilodonella sp. and Saprolegnia sp. (Sarig 71).

As a final aspect of disease management one must look at the problem of stress upon the fish population. When placed among any unnatural circumstances or position such as is the case in any aquaculture facility stress will be greater than that found in nature. This is simply because for an aquaculture venture to be feasible stocking rates greater than those found in natural conditions are required. It is therefore important to realize as a closing comment on disease management that concentrations of pathogenic organisms which are tolerated by species in the wild may readily infect and be lethal to that same species in an aquaculture situation.

Legal Considerations

The following steps must be taken to make AFI an operational enterprise:

a. A permit must be obtained allowing the introduction of silver carp and bighead carp into the U.S. for aquaculture purposes.

b. Contracts must be signed pertaining to the purchase of AFI land.

c. A building permit must be obtained.

d. A permit must be obtained from the FDA authorizing sale of the product.

e. AFI must come to agreement with the nearby municipality on the subject of sewage utilization and construction responsibilities.

f. AFI must obtain written permission to utilize S.E.S. effluent.

g. A water rights permit must be obtained authorizing the following appropriations of water:

  1. Full utilization of S.E.S. effluent for the purpose of fish cultivation.
  2. Use of all sewage from the nearby treatment facility.
  3. Use and return of up to four million gpd from the adjacent river in the event of S.E.S. shutdown.

h. A license to incorporate must be granted.

i. A discharge permit must be obtained from the EPA.

Economic Considerations

Economically speaking aquaculture in any form must be considered a high risk operation. In intensive culture situations fixed cost expenditures are very great, variable costs usually high and production uncertain as biological reacitons to artificial environments are never totally predictable. A lower risk situation may prevail where extensive culture methods are practiced, but even when conditions approach those of nature the unexpected may arise.

Most all authors agree that aquaculture in the Northwest may be feasible only when considering high priced luxury market fish and shellfish. Trout, salmon, shrimp and oysters would fall into this category and are considered delicacy foods by most Americans. These opinions are largely valid but value should be given not only to those species comprising the present market but also to the lower priced species which maintain economic vitality in other regions of the country and world. The channel catfish of the southern United States and the Chinese carp upon which this proposal is centered would be two principle candidates for the future market.

When considering Chinese carp market demand information was non-existent as the product was unavailable. This coupled with the high risk of aquaculture in general would seem to make consideration of carp culture a foolish and even profound venture. However based on the following analysis of consumer demand it appears evident that a potential market does exist for a limited number of suppliers.

a. 25,000 lbs of carp (3/4 silver and 1/4 bighead) were imported from Japan at a harvesting price of 35¢ a lb.

b. Including import duty, handling and transportation, total cost of delivery to retail market was 70¢ a lb.

c. Fish were distributed to safeway stores along the west coast and were sold at 90¢ a lb - all were sold.

d. Accompanying each purchase was a questionaire requesting consumer information regarding quality of the product and the ability of the product to serve as a substitute for established fish foods. A 60% return was recorded or roughly 11,000 questionaires.

Market Analysis: Carp vs. Salmon

From Fig. 4 showing indifference curve analysis for carp vs. salmon, the following conclusions may be drawn:

a. Consumption of carp will be greatest at middle income levels, however, consumers in the low income bracket will spend a greater proportion of their income on carp than consumers in the middle or high income brackets.

b. Salmon at this time is the more desired species for use as a food resource, however, realization of desires is limited by income.

c. The higher income group although preferring salmon find equal satisfaction when the ratio of carp/salmon is 4/6.5.

Market Analysis: Carp vs. Sole

From Fig. 4 showing I.C. analysis for carp vs. sole the following may be concluded:

a. Consumer preference is exhibited at all income levels for carp over sole.

b. Carp may be considered a closer substitute for sole than for salmon.

c. The lower price of carp and it's acceptable taste will tend to shift demand away from sole and towards carp should the supply be great enough.

General Discussion

The above relationships represent but two studies in consumer behavior. For a precise analysis of market demand for carp not only other seafood products require consideration but also nonseafood proteins which could be considered substitutes. It is apparent, however, that consumers will adopt the taste of carp into their diet and although not considering it a substitute for salmon will look upon it as a tasty low cost protein source.

Cost Analysis

Fixed Costs

Land @ $2,000.00 per acre - 40 acres	$	80,000.00
Hatching facility		
building - aluminum frame and siding	$	16,000.00
brood stock holding pond @ $1,000.00 per acre		500.00
brood stock conditioning pond		4,000.00
spawning ponds @ $1,500.00 each		3,000.00
rearing ponds @ $3,000.00 each		6,000.00
hatching nets, troughs, hypophysation equip.		1,000.00
Raceway cultivation system		
cement enclosures @ $6,000.00 per enclosure	$	90,000.00
Pond cultivation system		
15 acres @ $1,500.00 per acre	$	22,500.00
Pond clarification system		
faculative pond - 1.5 acres @ $1,500.00 per acre	$	2,250.00
algal growth pond - 3 acres @ $1,000.00 per acre		3,000.00
sedimentation pond - 2.5 acres @ $1,500.00 per acre		3,750.00
maturation pond - 3 acres @ $1,500.00 per acre		4,500.00

Algae harvesting facility	
building aluminum frame and siding	$ 6,000.00
centrifugation equipment	150,000.00
drum drying equipment	6,000.00
packaging equipment	1,000.00
Fish harvesting facility	
building cost - aluminum frame and siding	$ 6,000.00
harvesting equipment	2,000.00
brining and storage (cold)	30,000.00
Pumping equipment	
main intake	$ 5,000.00
hatchery intake	1,500.00
Canal system	
sewage inflow pipe	$ 10,000.00
hatchery facility intake	8,000.00
main intake	11,000.00
final outflow	1,000.00
Land preparation costs	
general clearing	$ 30,000.00
slope preparation	20,000.00
Legal costs and fees	
hatchery permit	$ 100.00
incorporation	100.00
road easement	500.00
lawyer	2,000.00
water rights	50.00
consultant engineer	30,000.00
Transportation costs	
1 1/2-ton pickup	$ 5,000.00
Total Fixed Cost	$ 560,250.00

<u>Variable Costs</u>

Labor	
foreman	$ 10,000.00
accountant	10,000.00
secretary	6,000.00
unskilled labor	12,000.00
part-time harvesting help	2,000.00
Depreciation and repairs - 10% of fixed cost	$ 39,725.00

Public utilities		$ 2,000.00

Taxes: (may be tallied only after income is realized)
corporate income tax - 30% on first $25,000.00
52% on remainder
investment credit - subtract 7% total taxes & 1/4 remainder

Total Variable Costs		$ 81,725.00
Total Cost (at end of first year - taxes)		$ 641,975.00

<u>Additional Costs</u>

Housing facility	$ 30,000.00	
Fence enclosure	30,000.00	
Lab equipment	40,000.00	
Trained Pathologist	15,000.00	a year
Parking lot and access road	100,000.00	
Primary oxidation pond	9,000.00	
Additional pond const. costs	10,500.00	
Revised Total Cost	$867,475.00	

Private Investment Required until harvest $1,060,925.00

<u>Water Volume and Flow Information</u>

	Volume
Hatchery Facility:	
spawning ponds (15'x15'x3')	675 ft^3/pond
rearing ponds (15'x45'x3')	2,025 cu ft/pond
brood stock holding pond (.5 acres x 4.5')	1,570,500 cu ft/pond
brood stock cond. pond (115'x45'x4.5')	3,038 cu ft/pond
Raceway System:	
15 enclosures x 3,600 cu ft/enclosure	54,000 cu ft

water flow through raceway;
= 4 million gallons per day (heated effluent)
= 162,000 gallons per hour
= 21,600 cu ft per hour

$$\frac{\text{volume}}{\text{flow}} = 2.5$$

detention time = 7 hours

Pond Cultivation System: (15 acres total x 4.5 ft deep)
volume = 3,165,000 cu ft/acre
= 47,475,000 cu ft/pond area

assume a flow of 7 million gpd - detention time = 51 days

Waste Water Treatment System:

Pond	Volume	Detention Time
1	10,470,000 ft^3	11.3 days
2	6,278,000 ft^3	9.0 days
3	13,960,000 ft^3	15.1 days
4	16,879,000 ft^3	18.1 days

Closing Comments and Suggestions

Upon careful evaluation of the proposal by myself and critism of others it appears that technical improvements could be made in many areas thereby increasing the economic feasibility and efficiency of the system. These modifications will be considered seriously before any final preparations for construction are made. Among the suggestions are the following:

a. There appears to be a threat of pathogenic contamination to the system. To alleviate this problem sewage must flow directly into the waste treatment facility where upon it is used as a culture medium for algae which could be then harvested and re-introduced as a food resource to fish stocks. Drum drying would kill any bacteria present.

b. Product variability could be greatly extended by the installation of a fish reduction plant yielding a high protein concentrate. Should acceptance of carp as a fillet fish be less than expected a product of this nature would make continuation of production possible.

c. At present stocking densities, land costs and construction costs, the use of raceway culture seems wasteful. Pond construction is much cheaper yielding many more fish per capital invested. Experimentation with greatly increased raceway stocking densities may, however, negate this suggestion.

d. Algal harvest methods seem unnecessarily expensive. Chemical flocculants and gravity filtration devices are much less expensive and although yielding a slightly less pure product, may be found much more feasible.

AFI feels that with incorporation of the above suggestions an enterprise of the type proposed would be both economically feasible and community serving.

References Cited

Bardach, Rhyther and McLarney (1972). Aquaculture. Wiley & Sons, New York. 868 pp.

Bartsch, A.F. and Taft, R.A. (1956). Biological and Chemical Aspects of Organic Waste Lagoons. Reprinted from "Land Disposal of Liquid Waste", A collection of papers presented at the University of Wisconsin Engineering Institute on Industrial Wastes, 1956, U.S. Department of Health, Education, and Welfare - Public Helath Service.

Davis, H.S. (1965). Culture and Diseases of Game Fishes. University of California Press, Berkely and Los Angeles. 332 pp.

Golueke, C.G. and Oswald, W.J. Harvesting and Processing Sewage Grown Planktonic Algae. Jour. Water Pollution Control Fed., 37, 471-498 April 1965.

Little, J.A., Carroll, B.J. and Gentry, R.E. Bacteria Removal in Oxidation Ponds. pgs. 141-151 in 2nd International Symposium for Waste Treatment Lagoons, 217 Nuclear Reactor Center, University of Kansas, Lawrence, Kansas 66044 (1970).

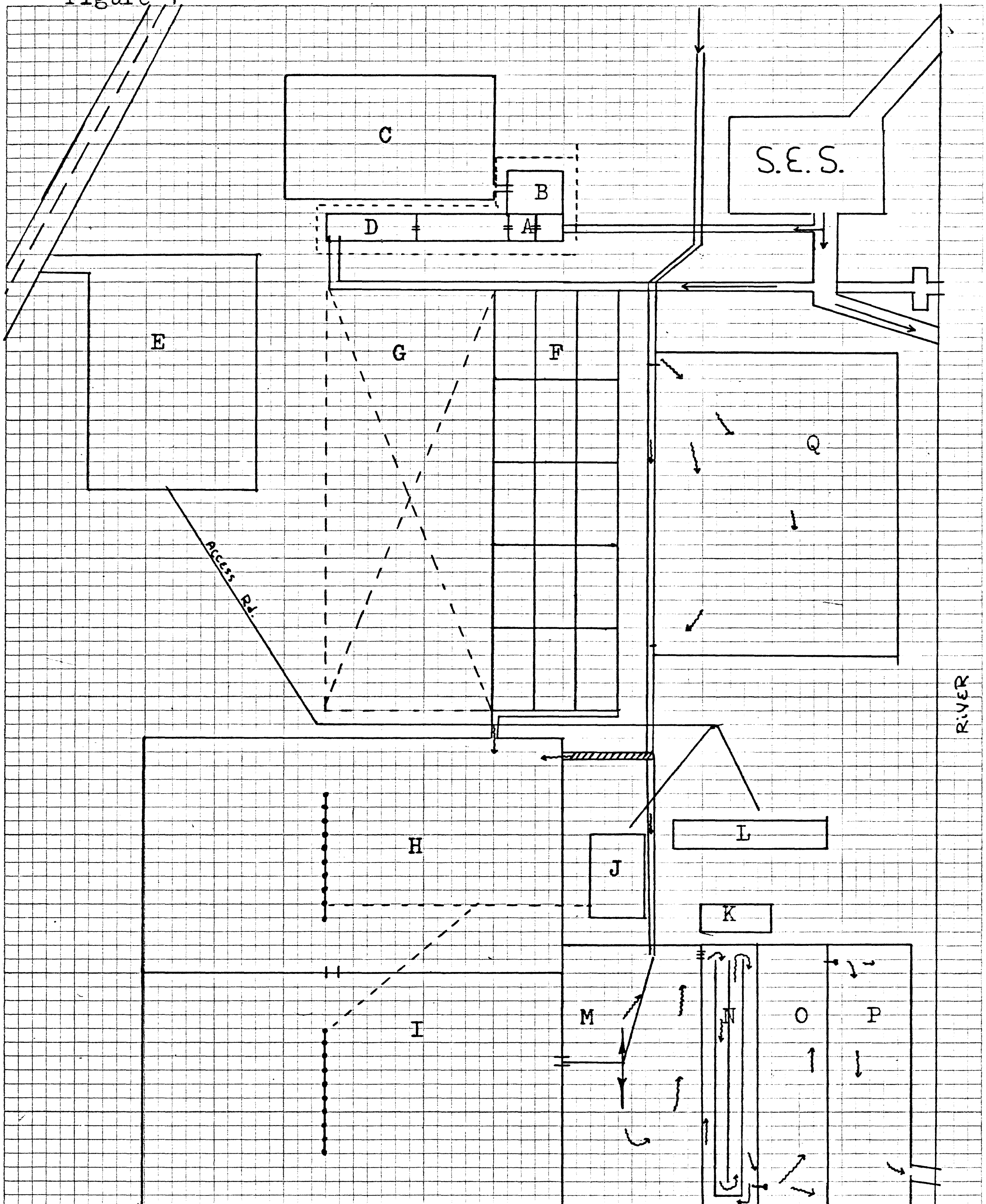
Meyer, Fred P. (1968). A Review of the Parasites and Diseases of Fishes in Warm-Water Ponds in North America; U.S. Department of the Interior Fish Farming Experimental Station Stuttgart, Arkansas, U.S.A. Presented at FAO World Symposium on Warm-Water Pond Fish Culture Rome. 1968.

Oswald, W.J., Meron, A. and Zabat, M.D. Designing Waste Ponds to Meet Water Quality Criteria. pgs 186-194 in 2nd International Symposium for Waste Treatment Lagoons, 217 Nuclear Reactor Center, University of Kansas, Lawrence, Kansas 66044 (1970).

Serig, S. (1971) Diseases of Fishes-Book 3: The Prevention and Treatment of Diseases of Warmwater Fishes under Subtropical Conditions, with Special Emphasis on Intensive Fish Farming. T.F.H. Publications, Inc. Ltd., Hong Kong.

Slanetz, L.W., Bartley, Clara H., Metcalf, T.G. and Nesman, R. Survival of Enteric Bacteria and Viruses in Municipal Sewage Lagoons. pgs 132-141 in 2nd International Symposium for Waste Treatment Lagoons, 217 Nuclear Reactor Center, University of Kansas, Lawerence, Kansas 66044 (1970).

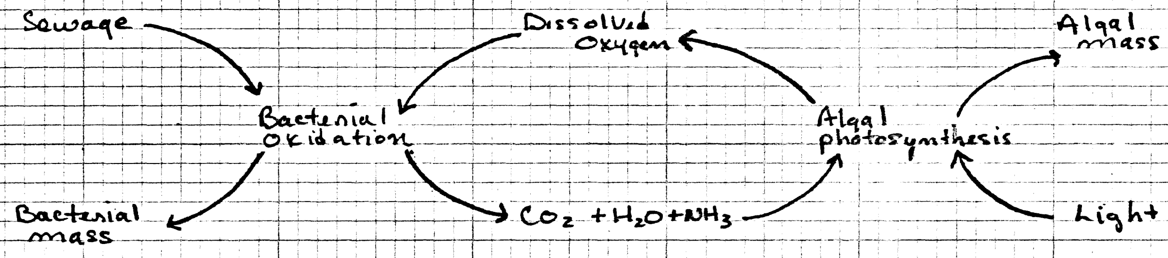
Figure 1



KEY

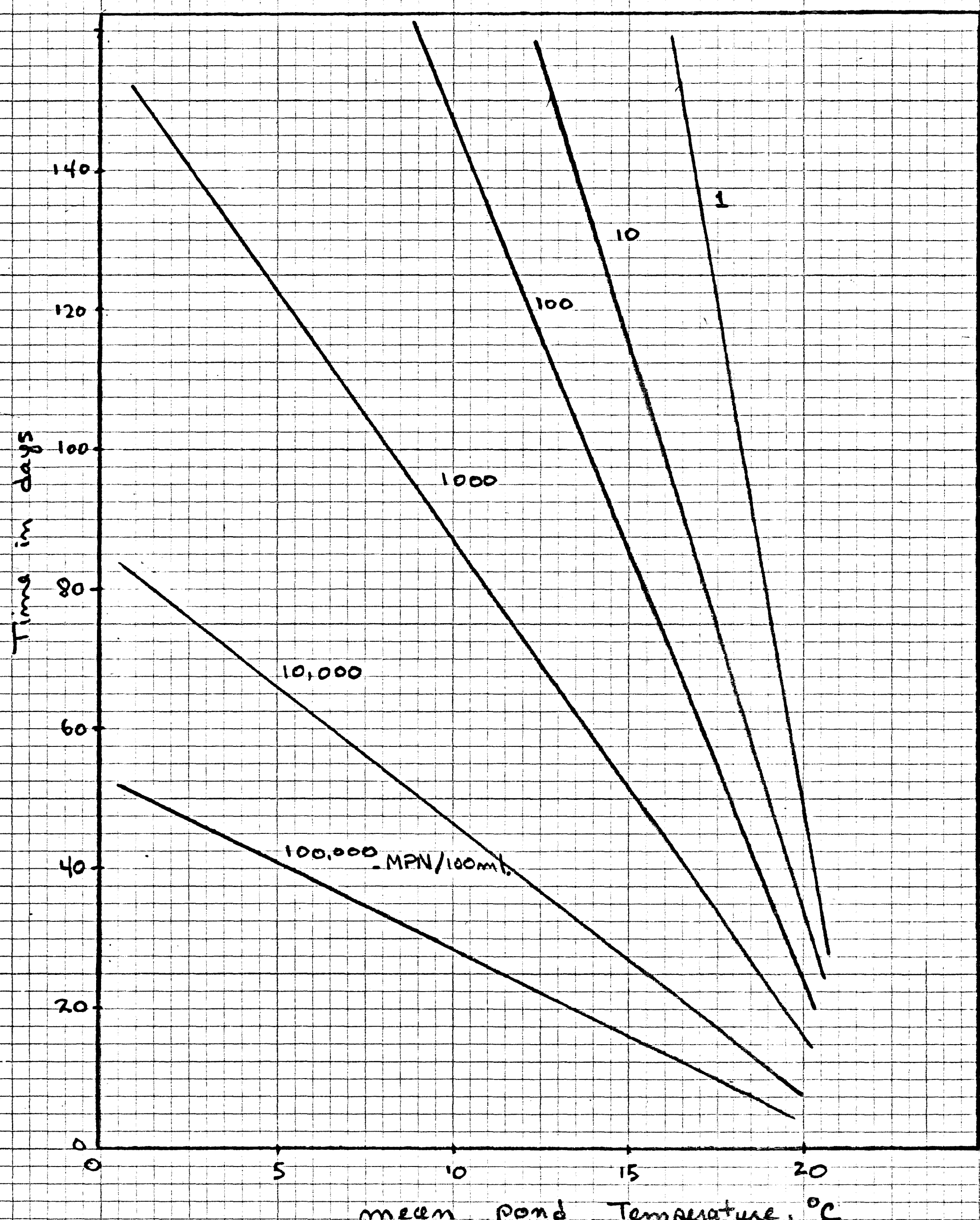
A-spawning ponds
B-conditioning pond
C-holding pond
D-hatching and rearing ponds
E-parking lot
F-raceway cultivation system
G-future raceway site
H-I-cultivation ponds
j-fish harvest facility
K-algae harvest facility
L-cold storage
M-N-O-P-treatment ponds
Q-primary oxidation pond

Figure 2



Stabilization mechanism

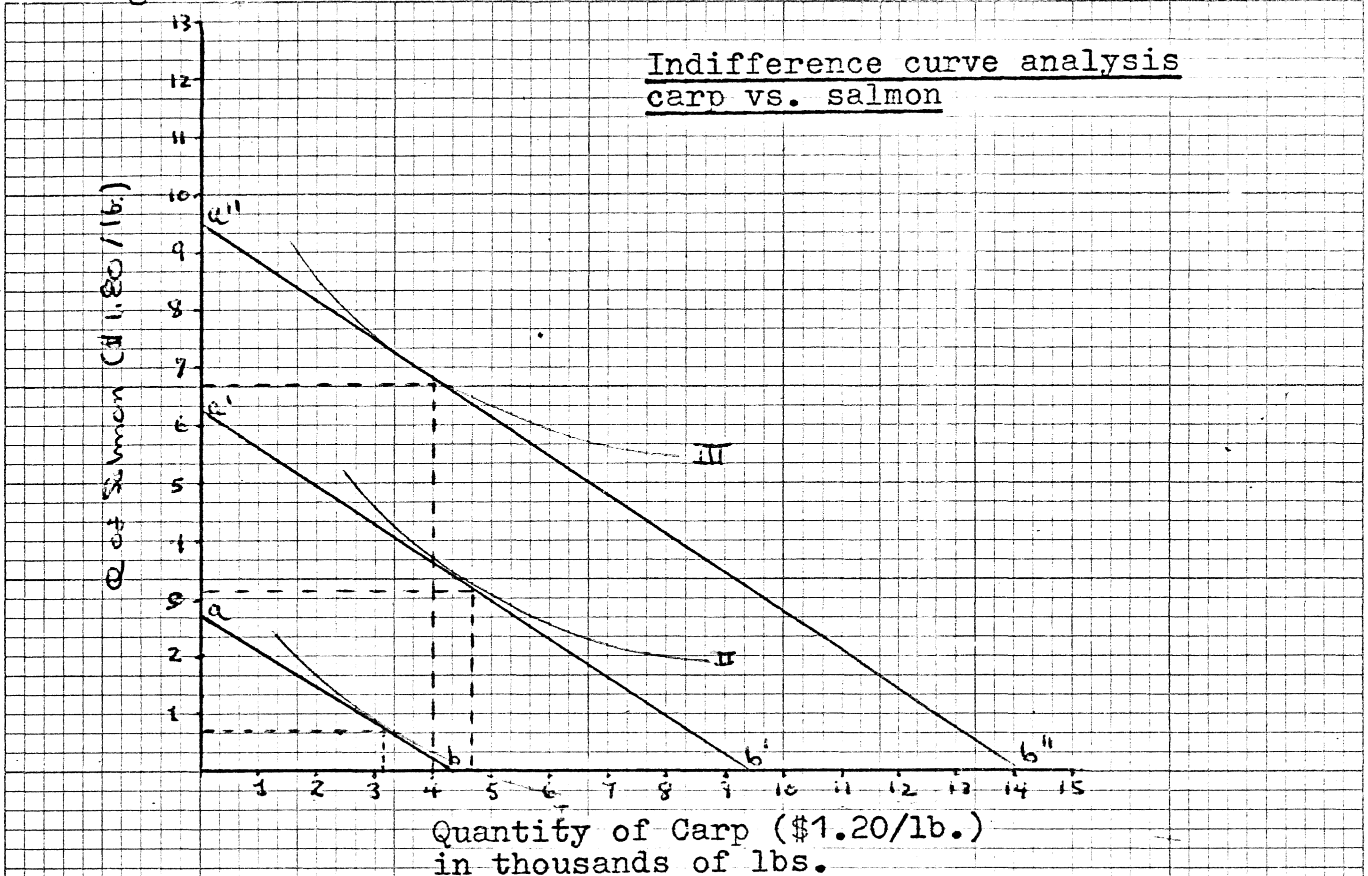
fig. 3



From Oswald, Heron and Zabat(70)

initial MPN 10^8/100ml.

Figure 4



Low income = budget line ab - $2000-$8000/year
Middle income = budget line a b - $8000-$14000/year
High income = budget line a b -$14000-$20000/year
Note: budget lines are determined from average Y. Also the consumer may only spend Y on salmon or carp-there are no other goods in the market.