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IDAHO NATIONAL ENGINEERING LABORATORY

FISH CULTURE UTILIZATION OF GEOTHERMAL ENERGY

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Fish Biologist

PREPARED FOR THE

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AEROJET NUCLEAR COMPANY

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ABSTRACT

Geothermal water and energy are suitable resources for fish farmers to use to raise large quantities of high-protein fish. Water quality and the domestication of new species of fish are areas where considerable research is indicated. This report indicates how geothermal resources could be utilized to supply the various environmental requirements for fish.

PREFACE

The work included in this report was performed by Paul A. Roberts, Private Consultant on Fish Biology, and was coordinated by the Geothermal Projects Branch of Aerojet Nuclear Company, prime contractor to the Energy Research and Development Administration at the Idaho National Engineering Laboratory.

Financial support for this work was supplied from funds assigned to Aerojet Nuclear Company by the Energy Research and Development Administration to evaluate various potential non-electric uses of geothermal energy.

The information presented in this report has been made an integral part of the "National Program Definition Study for the Non-Electrical Utilization of Geothermal Energy", Report ANCR 1214 prepared by the Geothermal Projects Branch of Aerojet Nuclear Company.

This report is being issued separately since it contains data that is thought to be valuable to many Government and non-Government enterprises engaged in geothermal activities.

The staff of Aerojet Nuclear Company Geothermal Projects Branch wishes to thank Mr. Paul Roberts for his fine work in assembling the data contained in this report.

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FISH CULTURE UTILIZATION OF GEOTHERMAL ENERGY

Fish culture is the environmental control of fish habitat for man's benefit. This means providing food, oxygen, waste removal, predation control and physical habitat in a system that will yield an economically significant advantage over nature. The art and science of fish culture trys to do this by compounding artificial or low cost ingredients to equal or surpass the natural food, maintain sufficient oxygen by aeration, removing waste products by various means, controlling predation by various barriers and isolation methods and by providing a suitable habitat by building an appropriate facility or fish farm.

This report will show how geothermal energy and its byproducts can be used to supply the various environmental requirements of fish.

The main limiting factor in locating a fish farm is sufficient suitable water. Suitable water for the desired species means, proper ionic, gaseous and mineral content as well as temperature. There are of course trade offs among the other limiting factors, such as: land area versus water flow with the interaction of temperature control, which means there is no one best way to raise fish. Using the available resources calls for astute judgement on the part of the fish farmer.

METHODS OF UTILIZATION

Geothermal energy yields four products or byproducts that are of direct use in fish culture. These are:

1. Water flow
2. Heat
3. Mineral Content
4. Convertible energy (static head and electricity)

1. WATER FLOW

The main limiting factor in fish culture is water. For pond culture the water flow requirement is minimal but the total static volume and land area is high. Intensive fish culture, as in raceways, requires large amounts of water but little static volume and land area. Closed cycle systems or modifications of it are similar to intensive culture in water needs but require large amounts of convertible energy.

The various cultural systems of fish culture vary mainly in the methods of oxygen input and metabolic waste disposal.

Extensive Culture or pond culture utilizes the large water surface area primarily for oxygen input with supplementation from evaporation replacement inflow and photosynthesis. Photosynthesis can be as much a liability for oxygen during darkness as it is a source during day-light. Waste disposal is by septic means within the pond. Nutrient build-up is removed by periodic draining and trophic utilization (harvesting the end result of the food chain).

Intensive Culture is based on using a large flow of water to bring in oxygen and carry out wastes. The first limiting factor in obtaining greater yields is oxygen, which is easily replaced by aeration. Aeration is accomplished by various devices but the principle is the same; increase the surface area of the water by producing bubbles and/or droplets. A casual way of estimating the effectiveness is to ask, How noisy is it? The louder it is means the more effective it is. For example, compare a water fall to a flat stream. All such devices require convertible energy to operate them. Gravity or water falling from a static head is nominally free provided the topography of the site has the fall necessary. Methods using other forms of convertible energy become quite expensive in capital, operating and fail safe costs. Oxygen can be directly injected into the water from external sources such as liquid oxygen at a cost competitive with mechanical means.

The second limiting factor to increasing production in intensive culture is waste accumulation. Ammonia is the primary waste and is the main form of excreted nitrogenous waste in fish. The toxic NH_3 form in solution varies considerably in toxicity depending upon pH and temperature.

Ammonia can be removed from water by several means. The first means is aeration at a level that can overcome the 95%:5% ratio of ammonia's attraction to water over air. Because of the high energy cost, capital, fail safe costs and potential air pollution this system is impractical on a large scale.

The second means of ammonia removal is with the use of foam with aeration, which is reasonably effective. The ammonia and other wastes seem to adhere to the bubble-water interface and are carried off with foam removal. The lost mucus and other excretions of fish will foam with aeration if the concentration is high enough. However, this generally does not occur in tanks or raceways but only in transport tanks where fish are confined for relatively long periods in oxygenated but static water. The addition of a foamant has yet to be developed commercially for fish culture.

The third means is selective absorption of ammonia by certain zeolites. This has potential but the operation costs and regeneration of the zeolite do present problems.

The fourth means is the chlorination of water which converts the ammonia to amines which escape to the atmosphere and may be a possible air pollutant. The chlorine must be removed by charcoal beds which must be regenerated. This method is feasible but like the other means the costs of treatment and the resultant production increase do not make them competitive at the present time with large flows of water and no treatment but limited fish production. A potential use is in cooling water used for fish culture prior to use in a condensor or heat exchanger. If the chlorine is injected and the amines removed the residual chlorine will prevent fouling organisms from building up in the apparatus.

The natural method of ammonia removal uses bacteria with the addition of energy and oxygen to convert ammonia to nitrite which is toxic to fish at less than .5 ppm. Then the nitrite is converted to nitrate which is non-toxic. The main requirements for this process to take place are first an oxygen level in the water of at least 3-5 ppm and second a sufficient surface area of a hard substrate for the bacteria to grow upon. There are several state and federal fish hatcheries (mostly salmon) presently using this method in a semi-closed system. The capital costs and operating cost are entirely out of proportion for commercial usage. About one mile of stream bed will accomplish the same effect at a commercially feasible cost but with some loss of temperature control.

The solid waste and nitrate are a significant problem in that they are defined by the EPA as nutrient enrichers for receiving waters and thus are pollutants. The capital investment and design problems of the removal of nitrates and solid waste are; first the extremely dilute concentrations, and second, the nature of the solid waste. The solid waste is nearly the specific gravity of water and easily broken up.

The technology for sewer treatment plants is not particularly applicable since the effluent at its worst from a fish hatchery is better than the effluent of a tertiary sewer treatment plant. A good proportion of the solid wastes will settle out within an hour but must be removed almost continuously or anaerobic decomposition sets in generating more ammonia and other gases. Still after most of the settleable solids are removed there remains suspended solids and the soluble nutrients (mostly nitrogen forms).

Thus the ultimate solution to effluent water quality is some form of trophic utilization to remove the nitrogen and other nutrients.

A great variety and not very predictable assortment of photosynthetic algae, moss, phytoplankton and bacteria, such as the bacteria in the ammonia nitrate cycle and fungus will be found in the effluent waters and ditches of a fish hatchery. The removal of nuisance fouling algae and moss will remove some of the nitrogen from the water. Some of the nutrients will be captured in the bacterial sludge on the bottom of the ponds. There is a possibility of utilization of the protein of the sludge organisms for fish or animal feed. Recovery and drying difficulties are the principal deterrents. The art of water plant culture is in its infancy. However, some water plants and algae vary from 5% protein to 60% on a dry weight basis, averaging 10-15%. More research is highly indicated and work is being done.

The use of a balanced population of various herbiverous fish, filter feeding plankton eating fish and various mollusks work well in pond culture utilizing nutrients in the water by eating elemental life forms. The Chinese have developed this to quite an art but the fish used are not native to North America and only two have been introduced here. None are universally popular as food fish in the United states. No comparable polyculture has been worked out using North American fish.

Semi-Intensive Culture is an intermediate system between extensive and intensive cultures and utilizes the balanced raceway. Oxygen is replenished by aeration as in intensive culture but wastes are disposed of by natural action in the earthen ponds, themselves, which are of a sufficient size and are stocked appropriately light with fish.

The water from a geothermal source could be utilized in the following manner for total utilization of the water:

1. Intensive culture in tanks or raceways of hard construction, such as fiberglass, metal or concrete until ammonia levels get too high.
2. Treatment to remove solids and ammonia
3. More intensive culture (earthen or hard construction)
4. More treatment, etc.
5. Semi-intensive culture (earthen construction)
6. Extensive Culture
7. Wild Life habitat or irrigation

The land area required for 10 cfs of water used for fish culture in the above concept are:

1. 4 acres
2. 4 acres
3. 8 acres

4. 8 acres

5. 16 acres)dependent on local soil permeability and
)
6. 64 acres)net evaporation

7. Up to 320 acres irrigation depending on evaporation and seepage loss in ponds and much more with off season storage.

The best quality water should be used where quality can be exploited, in high density intensive culture. Poor quality water should be used where compensating factors such as less crowding, natural feed production and lower investment will counter-balance the less production per unit flow of water. A linear flow through without recirculation is simpler, less energy consuming and much easier to control disease.

The design of a fish farm and water utilization must be planned and designed with specific fish production goals and marketing outlets in mind. Early and close coordination between the fish culturist and power plant engineers is essential if the water is to be successfully used by a fish farm.

2. HEAT

Fish are cold blooded animals having the same body temperature as their surrounding water. Their metabolic rate is not constant as in mammals but varies with temperatures. The rate of metabolism of fish in general follows this rule of thumb. A doubling of the metabolic action for each 10 degrees F rise in temperature over about 20 - 30 degrees F range, which is specific to each species. Trout and salmon are in the 40 - 70 degree F range and catfish and other warm water fish are in the 70 - 90 degree F range.

Intensive fish culture gains an important management tool when temperature can be controlled or at least there is a constant temperature. With constant temperature feeding growth and stocking rates can be simplified and planned for. A sudden rise in temperature means the fish will need more food and oxygen. Less oxygen will be available, thus a crisis will develop.

A sudden drop in temperature could mean over feeding unless corrected, and a delay in marketing. With temperature under the control of management, timing of marketing, off season spawning, optimal temperature research and many other profitable controls can be exercised.

Below are some examples of how various temperatures can be utilized for profitable fish farming or research.

TROUT AND SIMILAR COLD WATER FISH

32-40 degrees F	Prechilling and holding of fish prior to processing. Egg incubation to delay hatching time. Cooling water for refrigeration.
40-50 degrees F	Egg incubation to delay hatching time. Cooling water for refrigeration, spawn taking, holding back fingerlings for stocking time, holding back of marketing of food fish.
50-60 degrees F	Egg incubation to delay hatching time. Cooling water for refrigeration, spawn taking, holding back for marketing, fingerlings for stocking production, food fish production, spawning time adjustment, spawner replacement production.
60-70 degrees F	Cooling water for refrigeration, food fish production, spawner replacement production, spawning timing adjustment, fast growth production, disease control as natural immunity only becomes effective above 60 degrees F, research into high temperature production problems.
70-up degrees F	Experimental only, at present. Selective breeding for temperature tolerance. With super saturation of oxygen, production experimentation.

160-up degrees F	Building heating, snow removal.
212-up degrees F	Steam for cleaning and sterilizing.

WARM WATER FISH (CATFISH, etc.)

40-50 degrees F	Non-productive holding to delay marketing. Prechilling before processing for food. Hatchery building air cooling. Cooling water for refrigeration.
50-60 degrees F	Wintering spawners to induce spawning with temperature rise. Holding back for market timing, hatchery building air cooling, cooling water for refrigeration.
60-70 degrees F	Slow production, fingerling production.
70-80 degrees F	Spawning, egg incubation, food fish production, fingerling production, spawner production.
80-90 degrees F	Spawning, food fish production, spawner production, fast growth production.
90-up degrees F	Experimental, selective breeding for temperature tolerance, research into high temperature survival.
160-up degrees F	Building heating, snow removal.
212-up degrees F	Steam cleaning, sterilizing.

Sources of different temperature waters for fish culture from geothermal sources.

40-50 degrees F	Spring or ground water for condensor cooling before use in cooling (Surface waters generally suitable for intensive commercial fish culture).

50-60 degrees F	Spring or ground water for condensor cooling before use in cooling. Cooler water warmed with hotter water.
60-70 degrees F	Spring or ground water for condensor cooling before use in cooling. Cooler water mixed with hotter water. Heated waters of condensors.
70-80 degrees F	Some geothermal waters. Heated waters off condensors, cooler water mixed with hotter.
80-90 degrees F	Some geothermal waters. Heated water off condensors, cooler water mixed with warmer water, water cooled by evaporation from natural sources up to 150 degrees F, cooled geothermal waters over 150 degrees F from flash residual, condensate or cooling waters.

Other species of fish will have similar patterns of temperature usage but at different temperatures.

To best utilize the warm water of geothermal origin or byproducts, temperature regulation is of prime importance. A constant temperature water supply of suitable temperature leads to simplified management of fish production. Temperature regulation and multiple water temperature give the fish farmer management tools that can be exploited to expand production and marketing opportunities.

Raising the temperature of water lowers the saturation levels of dissolved gases. Consequently, heated water is supersaturated and is deleterious to the fish. Removal of the excess gases, particularly nitrogen, is by the same method as aeration to replace oxygen.

To obtain the maximum benefits possible from geothermal heat for fish culture new and creative concepts and designs must be employed in geothermal power plant engineering. A fish culturist should be associated with the design team of a geothermal power plant.

3. MINERAL CONTENT

The mineral content of geothermal waters is its biggest liability to fish culture. However, some geothermal waters have mineral content with potential for unique fish production programs economically feasible, perhaps, nowhere else. No water is "ideal" for fish culture, some waters are better than others and some must be improved to be useful. The basic rule is to put some fish of the desired species in the water under question and see what happens. Extensive tests of the inflowing water will give minimal guidance as to what is happening to a production lot of fish in that water. The real determinant of fish production suitability is the interaction of the fish metabolism and the water as altered by fish metabolism.

Surface waters naturally harboring fish are well analyzed and described in literature. The mineral content of geothermal waters has to a degree been analyzed but only a few pure geothermal waters naturally harbor fish. Warm springs in Nevada harbor fish found nowhere else. A handful of fish production facilities are presently using partially or totally geothermal water for fish culture. Thus the suitability of geothermal water for fish culture can only be guessed at using a few postulated guidelines, until fish are used in a fish cultural similation bioassay.

Some postulated guide lines for geothermal water suitability for fish culture are as follows:

1. Water is free from toxic substances from the plumbing and apparatus of the power plant such as metals and chlorine.

2. Water is similar in mineral content to water known to be suitable for fish culture.

3. Water is buffered with carbonate, if not limestone is available nearby.

4. If water is highly mineralized, it is similar in mineral content ratios to sea water. (Na, Cl predominate and are about equal).

5. If water does contain any obvious toxic substances, they can be removed.

6. The water can be discharged into public waters.

If all the guidelines or nearly all the guidelines are met by the waters, there is a good possibility that the water is suitable.

Some specifics on various dissolved substances and their effects on fish culture are listed below:

Al	Aluminum	Unknown, potentially harmful at high concentrations. Proper alloys suitable for fittings or fish tanks.
Sb	Antimony	Unknown, may be concentrated in fish up to an unsafe level for human consumption.
Ar	Argon and inert gases	Displace oxygen from water. Removable.
As	Arsenic	Toxic, unknown, may be concentrated in fish up to an unsafe level for human consumption.
B	Boron	Unknown, high levels may restrict discharge.
Br	Bromine	Harmful if as a gas is at .1 ppm or less. Ionic forms probably not harmful if not in excess of chloride.
Cd	Cadmium	Very toxic to fish in soft water. In hard water it can be concentrated to unsafe levels for human consumption. No cadmium fittings.
Ca	Calcium	Essential to fish growth, fish obtain considerable amounts of the calcium from the water. Should be the most abundant anion.
Cl	Chlorine	Gas harmful at .1 ppm. Ionic form essential
Cr	Chromium	Toxic and concentratable.
Cu	Copper	Toxic in soft water. At low levels used therapeutically. Pipe and fittings to be avoided for soft water.

F	Fluorine	Essential in low levels. Fish can tolerate levels unsuited for livestock or human consumption. Tolerated to 10 ppm. Gas very toxic.
I	Iodine	Essential. Supplemented in fish feed. Iodine disinfectants are toxic.
Fe	Iron	Not particularly toxic. Does precipitate and iron bacteria can suffocate eggs. Also, often present in waters with negative oxygen tension but can be aerated to an oxide which precipitates. Stainless steel is generally safe unless water is highly saline.
Pb	Lead	Some salts toxic but is safe to use in sea water.
Li	Lithium	Some is normal. Potentially toxic in high concentrations.
Mg	Magnesium	Some essential, but too much is toxic.
Hg	Mercury	Concentrated by fish to levels unsafe for human consumption.
P	Phosphorus	Some is essential but high levels are toxic.
K	Potassium	Some is essential. Excess over sodium or calcium is questionable.
Si	Silicon	Precipitates of silicates can suffocate eggs.
Na	Sodium	Essential for metabolism and respiration. High levels tolerated well.
S	Sulfur	Sulfur oxides change pH of soft water drastically.
H_2S	Hydrogen Sulfide	Very toxic to fish in parts per billion. Easily removed with aeration but comes back if pond bottoms become anaerobic.
Hydrocarbon gases		Mostly insoluble and not much of a problem. May be captured for fuel.
Plastic monomers		Potentially toxic

Chlorinated hydrocarbons	Toxic or concentratable to unsafe levels for human consumption.
SO_4 Sulphate	Some is essential. Is toxic when waters are considered epsom salt waters.
Carbonate CO_2, CO_3^-, CO_4^-, etc.	Essential for growth and needed for buffering to control pH. Can be added by running water over limestone or oyster shells.
NO_2 Nitrite	Highly toxic to fish. Binds hemoglobin and causes anoxia.
NO_3 Nitrate	Non toxic to fish even beyond nondischargeable levels.
pH	The generally desired range is 6.5 to 9.5 and it should be stable from buffering.

This list is not exhaustive of potentially toxic substances. Research is needed both from an academic approach and a practical approach. A fish is one of the most sensitive bioassay organisms available and by far the best agent for deciding the fish production suitability of water. Because the gills carry much of the load of maintaining osmotic balance and the excretion of ions, fish are capable of living in water that is unsafe for other uses. Concentration by fish of toxic substances, such as metals and pesticides, make it necessary to analyze the fish for the substance in question. This is particularly true after long term exposure to the water.

Water classified by salinity is as follows:

1. Distilled water is 0 to 1 parts per million salinity.
2. Fresh water is 1 to 100 ppm in soft water and 100 to 1000 ppm in hard water.
3. Brackish water is 1000 ppm or 1 part per thousand (ppt) or o/oo to 20 ppt.

4. Sea water is 20 to 35 ppt.

5. Salt sea water or brines are 35 to 250 ppt.

6. Saturated or super saturated brines are 250 ppt and up.

7. "Saline" waters are in the range of 1 to 35 ppm.

Most surface saline water (Estuarine and Sea Water) has so much life in it that fish culture is hampered by fouling organisms and disease causing organisms. Suitable geothermal saline water or any deep ground water source is essentially sterile and free from most deleterious life forms. As a result marine forms could be raised inland in pure water, free from the endemic problems of disease and fouling organisms. Of course careful isolation and introduction of production fish or shellfish must be made to prevent the introduction of unwanted forms.

Caution must be observed in the choice of plumbing and fittings, particularly with shellfish, because of the toxic nature of the metallic ions in saline water.

Distilled water such as condensed steam from a geothermal power plant is not habitable by fish. Fish do need some mineral in the water in order to live. Limestone, oyster shells or other easily soluble mineral sources to treat the water are reasonably inexpensive and fairly effective.

After a complete water analysis geothermal waters intended to be used for fish culture must be tested by fish in a simulated production situation. In addition materials for power plant and fish facilities must be tested for durability and subjected to a fish bioassay.

4. CONVERTIBLE ENERGY

Fish production uses energy. The main use of convertible energy is in aeration. The spilling of water over splash boards to aerate it, costs energy either in the form of pumping to lift the water in the first place or energy not recovered by water wheels to do other forms of work.

Pumping water of the quantities necessary for fish culture is quite expensive and when a competitor raises fish without pumping water some significant breakthroughs in production cost control must be made to stay profitable. The greater the static head or pressure of water received by a fish farm and the greater the fall until ultimate disposal the greater the fish production potential, or profit, using free energy.

Without sloping topography some form of convertible energy must be used for aeration. A geothermal power plant should select a site on a hillside so that fish culture can be economically pursued. Gravity sprinkler irrigation should also be considered. The recharging of sloping alluvial aquifers is another reason for the hillside location of geothermal wells.

FISH CULTURE'S CONTRIBUTION

Fish suitable for commercial culture must not only be biologically amenable to fish farming but must be high enough in value to be reared profitably. Because of the high capital investment and land costs, cheap protein will not be the output of commercial fish farms in North America. The return per acre of land in pond culture with supplemental feeding is about competitive with food crops such as soybeans and rice. Natural feed utilization will not produce sufficient fish to make the investment attractive to fish farm investors. Some fish are highly efficient under artifical culture but there is insufficient market demand, competion from wild fish or just low prices, which make these fish unsuited for fish farming.

North American commercial fish farmings contribution to global food resources and the national economy is as follows:

1. Utilization of protein sources unsuitable directly for human consumption.
   - Grain byproducts from milling and fermentation
   - Meat processing: cutting scraps, rejected carcasses, meat meal rendering
   - Milk processing: whey
   - Oilseed meals, soybean and cottonseed

Ocean fisheries: scrap fish, processing wastes, small fish, and species abundant but not harvested for human food, such as anchovy and menhaden.

2. Providing high quality protein fish for human consumption to supplement or replace natural fish populations depleted by over fishing the population or ecological change.

3. To provide employment for people engaged in growing, processing and distributing fish or fish feed.

4. Investment return to fish farmers and financiers, that will yield economic development and employment elsewhere.

5. Recreation for Americans and employment and investment returns in the recreation industry.

6. Employment and investment return to the building industry.

7. Utilize resources for man's benefit that may otherwise not be fully exploited. In this category geothermal water makes its main contribution. The water, heat and mineral content of geothermal energy would only be partly utilized if power generation were its only product. Fish culture can utilize this resource after power generation and geothermal waters too cold for power generation.

FISH TO RAISE

Many fish and acquatic organisms are desirable for food and of high enough value to be considered for commercial culture. The following will summarize some of the opportunities to utilize the water associated with geothermal development:

CHANNEL CATFISH <u>Ictaluras Punctatus</u> (Rafinesque)

This catfish is the most widely cultured fish in the United States and is the first choice to utilize geothermal water. The marketing is established and production methods fairly well known.

Channel catfish can survive in a great range of environments and in different methods of fish culture. Their best growth is at about 85 degrees F, however, they can survive 95 degrees F if there is sufficient oxygen available.

They cease to feed at about 60 degrees F and can over winter at 38 degrees F. Commercial production is feasible from 75 to 90 degrees F. Spawning and egg incubation are best at about 78 degrees F. They are sensitive to rapid changes of temperature so the fish farm design and the water from a geothermal power plant must be able to maintain a reasonably stable temperature. Spawners may fail to spawn if the temperature drops 10 to 15 degrees during the spawning season.

Spawning will take place at up to 3 ppt salinity, while production can be done up to 10 ppt. This is in dilute sea water. Catfish are being reared successfully in geothermal water that is fairly soft and high in sodium.

The usual market size is about one to one and one-fourth pounds live weight. Certain regions of the country prefer one-half pound live weight, in addition portions and steaks can be marketed from catfish three pounds and up.

Catfish sell FOB at the fish farm from the record low of twenty-eight cents to a high of sixty-five cents per pound. The current and expected range is forty-five to fifty-five cents a pound. They are also widely marketed for stocking of private waters at from eighty cents a pound to one dollar ten cents per pound. Eggs cost about five dollars per thousand and started fry about ten dollars per thousand. A completely dressed out catfish yields about 50% marketable product. The product will then cost about one dollar per pound. To this are added 5 to 10 cents commissions, 15 to 20 cents processing and 20-40 cents overhead and profit, yielding a wholesale cost of about $1.40 to $1.65 per pound. However, actual prices may vary considerably from this due to marketing conditions. Current food fish sales total about 20 million pounds per year with additional live stocking sales.

Catfish are fed a pelleted feed of from 25 to 40% protein. In pond culture an incomplete low protein feed, costing 8 to 12 cents a pound is given. This is supplemented by the natural feed of the pond. In raceway and tank culture a complete feed of 35 to 40% protein is required at a cost of 14 to 17 cents per pound. In the 85 degree F range catfish are better able to use vegetable origin protein.

Most catfish are raised in ponds. The economic advantages of year around growth, harvesting and capital investment utilization clearly indicate basing usage of geothermal water for catfish farming or intensive culture in tanks or raceways.

Fingerlings from pond culture are not recommended to be grown out in raceways or tanks. At less cost and with better over all results catfish should be raised from hatching to market in intensive culture. Pond culture at a geothermal site would be supplemental or incidental to other water usage or treatment.

BLUE CATFISH <u>Ictaluras Furcatus</u> (LeSueur)

The Blue Catfish is not reared as much as Channel Catfish but for production has some highly desirable features. Blues yield 10 to 20% more meat per fish. They are native to clear waters (Channel Catfish are native to opaque waters) and have a light reflecting blue pigmentation. Thus they do not develop so much melanin (blackness) as channel catfish when reared in clear water. Their environmental requirements are about the same as channel catfish. Blue Catfish are easier to capture but are more delicate and difficult to handle and dipnet.

Other Catfish and Bullheads

Those of appropriate size would be suitable if they have an economic or marketing value superior to channel or blue catfish. Only experimentation will show any advantages.

Catfish environmental requirements are for warm water that can be fairly poor quality. The oxygen level in the ponds should be above 3 to 4 ppm but can for short periods drop below 2 ppm. Catfish are very ammonia tolerant and not going off of feed till 32 ppm at suitable pH. Trout show severe gill damage at 1 ppm. Nitrate levels to 400 ppm do not seem to harm the catfish. Thus intensive culture of catfish can be very productive per unit of water.

BASS (Centrarcids) genus Mictopterus (Largemouth, Smallmouth, spotted and some other bass)

These fish have been raised successfully in pond culture by providing forage fish as food. Some beginnings have been made in raceway rearing and the use of artificial feed. There is a potential market for large bass to be stocked in ponds overcrowded with stunted sunfish. Food marketing has yet to be established but they are a high quality food. They are considered the sportiest fresh water fish so their production for fee fishing has a great promise.

The environmental requirements are in the main similar to other warm water fish and catfish. Bass are excellent jumpers and can jump out of tanks unless they are covered. Cannibalism is also a problem. Survival of bass during transportation is a problem that needs research. Bass then are quite suitable for rearing in connection with geothermal power.

Bass and several other game fish suitable for fish culture are in many states the exclusive right of the state to buy, propagate, own, stock and do anything with except catch them. Thus there are legal barriers to the sale or production of bass and many other fish in some states. These laws are antiquated, provincial and not in the best interest of the fish consuming public.

SUNFISHES (Centrarcids) genus Pomoxis and Lepomis and others

The sunfish or bream are all excellent food fish provided they are large enough. In pond culture they often over-reproduce and become small stunted fish. There has been enough work to show that sunfish can be trained to eat artificial food. Intensive culture may solve some of the problems of the culture of these fish but it is an unknown enterprise, but one with promise.

PERCH

YELLOW PERCH Perca flavescens

WALLEYE Stizostendion vitreum

SAUGER Stizostendion canadense

These are excellent food fish with the native populations either unharvestable or polluted. Yellow Perch can be raised in captivity. The big problems are in providing feed for the tiny fry, preventing cannibalism and with Yellow Perch preventing population stunting. Water of trout quality in the 70's would be suitable for these fish. Research and development in rearing Perch to marketable size is needed.

BASS (SERRANDAE) genus Roccus and Morone White Bass, Yellow Bass, White Perch and Striped Bass

These are excellent sport and food fish. Some are anadromous, living in the sea and returning to fresh water to spawn. However, they can spend their entire lives in fresh water. There is an excellent start towards the commercial culture of these fish. They are quite sensitive to bad environments and sudden changes of temperature or salinity.

Their large size and the sportiness of the Striped Bass make it desirable to attempt to rear these fish in saline geothermal water of 3 to 10 ppt salinity. Major research is needed to develop these promising fish commercially.

MINOR FISH Gambusia and Silversides, etc.

These fish are suitable for brackish water and find market in mosquito control and possible as bait or meal fish.

BAIT FISH Minnow family

Various members of the minnow family are reared for use as bait in the Midwest and South in ponds under conditions similar to catfish. Their potential in connection with geothermal water would be as forage fish to to feed other more valuable fish.

SUCKERS Buffalo fish genus Ictiobus

These fish are reared commercially in pond culture and widely fish commercially in rivers. The wholesale price is so low (10 to 15 cents per pound) that the per acre return is much less than catfish. They, however, are filter feeders, eating plankton that other species do not use. Thus, they are of potential value for trophic utilization in ponds receiving water from intensive culture. They are excellent tasting but do have a lot of bones.

CARP Cyprinus Carpio

There is a large market, of over 20 million pound per year, for carp among Jewish, East European and Asian peoples in the United States. However, the price is very low. Fishermen get about three cents per pound and these fish retail at 20-40 cents per pound. With the high cost of land and fish farm construction, carp culture under the present price structure in the United States will remain about nil. Carp have been bred more for fish culture suitability than any other fish. They are able to survive in a bad environment and they grow at stupendous rates if given enough feed. If special marketing opportunities exist, carp are the ideal fish to rear in connection with geothermal power. Considerable Israeli Carp, a special fast growing strain, are imported at high enough prices to justify their culture here.

PIKE genus Esox

These are predatory fish, good eating and very sporty. Their natural production cannot meet the demand for these fish. Pond culture of these fish to produce fingerlings has been carried on for many years but does not meet demands. Overcoming cannibalism and legal barriers may allow these fine fish to be reared commercially.

GOLD FISH AND DECORATIVE CARP (KOI)

These forms of carp have sufficient value to warrant artificial culture. Marketing is controlled by a few brokers, who work with specialist gold fish farmers. Gold fish also find a market as bait fish and as forage fish. Effort goes into maintaining a brood stock, successful spawning and fingerling hatching. Most are sold as one inch fingerlings. Speculative production and a changeable buying public instill great uncertainties into new enterprises.

TROPICAL FISH

The multitude of tropical fish represent the highest money value fish culture industry in the United States. Most tropical fish farms are in northern Florida. They use small ponds but pump water from considerable depths. There is a highly developed marketing system, which also handles gold fish.

Speculative production and fluctuating market, with considerable hobby production entering the market indicate contract production as the only way to market from new operations. One large geothermal based tropical fish farm could completely upset marketing and lead to gross over-production. The value per pound is high, but the handling and sorting of small lots runs the cost up.

TILAPIA

This Asian, African and South American fish family, similar to the sunfish, are being cultured in many places in the world. The main production problem is one of stunting from over-reproduction. They are mouth brooders so the young have an excellent chance of maturing. Reproduction takes place at an early age and several times a year.

There is a great variety of tilapia, some are herbivorous, others are omnivorous. As a part of the population in a trophic utilization pond, Tilapia could make a considerable contribution to removing nutrients. They like water above 80 to 85 degrees F and are killed by cold water. They also have promise as fish for raceway production since they are excellent eating, can be crowded and are able to survive in very poor water.

WHITE AMUR <u>Ctenopharyngopon idellus</u>

This large, fast growing fish, recently imported from China is herbivorous, eating tremendous amounts of aquatic vegetation and of land plants if fed to them. But it utilizes very little of its feed so other herbivorous fish should be stocked with it. It is excellent food but does have bones like others of the carp family and minnow family. There is considerable controversy concerning the introduction of this fish since it can eat and destroy the habitat of many desirable game species. Many states have outlawed its introduction but others are stocking it in certain waters.

There are many fresh water fish of tropical areas that may be suitable for production in fish farms based on geothermal water. Little is known of these fish and the desirability of importing them is questionable.

SHRIMP

There is a great deal of enthusiasm for and research concerning the rearing of shrimp in captivity. The demand cannot be met even at an extremely high price per pound by the ocean fishery. There are some shrimp farms now in the experimental stage. The problem of food is reasonably near solution but cannibalism and captive reproduction are more elusive. Cannibalism can be controlled by rearing shrimp in individual compartments. However, two or three million compartments for a major shrimp farm is a severe management and capital problem.

There are several large tropical shrimp that live entirely in fresh water. The difficulty in obtaining fresh water shrimp and getting them to reproduce is the reason more has not been done.

Most attention has been focused on shrimp that migrate between fresh and salt water. Schemes proposing the use of a completely closed water system utilizing artificial sea water are in the experimental stage. Geothermal water and/or its heat have been included in some plans. Idaho is considered to have ideal sites and/or water for such ventures.

Shrimp culture must be considered a valid potential use of geothermal water, if not currently usable, at least within 5 to 10 years.

CRAYFISH

Crayfish have considerable demand though current methods of culture are not amenable to production in a high capital investment facility.

CLAMS AND MUSSELS

There is an excellent use of fresh water clams and mussels in effluent treatment ponds. They are filter feeders and are highly effective in removing nutrients from the water. There is as yet little market for these efficient mollusks. They are of a high nutritional value. They can be made into a high quality meal for use in fish feed or feed for other animals. If salinity is at or near sea water concentrations, oysters and other saleable mollusks can be reared.

EELS

The Asian and European demand for eel is not being met by eel farming or commercial fishing. The big obstacle to expansion is the lack of elvers (fry). Pollution and environmental deterioration have severely cut back eel populations. Eel culture is based on capturing the elvers as they ascend rivers from the sea, where they were born under, as yet, unknown circumstances. Until captive reproduction or additional elver production are achieved, contemplation of eel culture expansion is perhaps unwarranted.

ALIGATORS, CROCIDILES AND CAYMEN

The artificial culture of these reptiles has been achieved in Australia and in Japan, where geothermal water is used. At Miracle Hot Springs near Buhl, Idaho, several aligators have been kept for several years, but as yet none of the eggs laid have hatched. These reptiles in captivity have been fed very low price scrap fish. If the demand for their leather makes their artificial rearing financially feasible the methods will be fairly easy to develop.

MEAL FISH

The growth of fish in effluent treatment ponds for use in fish meal has only a marginal potential for financial success. But an available protein source for emergency fish feed might be a wise investment.

TROUT AND SALMON

If ground water from 40-65 degrees F is pumped for use in condensor cooling, trout culture could be carried out in the water before it enters the condensors. Trout are best raised in raceways or tanks and require high quality water. Oxygen must be above 5 ppm in the ponds and ammonia must remain below .5 ppm for a good safety margin. Trout are marketed at sixty-five cents live to processing plants but they cost $2.75 per pound retail. Live stocking for recreational uses and in private waters accounts for much of the production outside of the Snake River Valley in Idaho.

MARINE FISH

There are many more species of salt water fish valued for food than fresh water fish. In addition, the growth rate and retail price of some salt water fish are superior to fresh water fish. The Japanese have a large industry raising the Yellowtail, a member of the tuna family. At geothermal sites with saline water of ocean salinity and of mineral ratios similar to sea water, the culture of marine fish should be considered.

The previous is not exhaustive, so a creative enterpreneur will probably find other species to farm commercially.

To establish a fish for commercial fish farming, one only need to show that there is a market for the fish at a high enough price to make a profit for an investor. Once the basics are learned by academic type research, the lure of profits will find solutions to the problems. Fish brokers and wholesale buyers can sell any fish as long as they can be assured of a year around supply of high quality and in sufficient quantity. Fish buyers talk in terms of 10,000 pounds per month or more. Thus the fish farmers problem is keeping costs less than sale price.

Fish farmers need to unite and gain allies if legal barriers to fish culture are to ever be removed. Government agencies and the private sector are often in direct opposition on legislation and policies. Increased trust and understanding must be developed.

The food fish marketing system in the United States is very poor. Each fish farmer developing a major new fish farm finds it necessary to build a processing plant and develop nationwide marketing.

DESIGN OF FISH FARMS

Anything that will hold water and in which the fish can be confined and then harvested later would qualify as a fish production pond. The refinements and compromises necessary for economical construction, suitable for fish habitat, security against fish loss and ease of harvest have produced many designs of fish ponds.

Basically there are four classes in fish ponds: linear flow, circular flow, vertical flow and static ponds.

The linear flow or raceway is the most common form of fish pond. Oxygen is replenished by spilling over dam boards, which separate the different sections of a raceway. Construction is of either a hard material such as fiberglass, aluminum, stainless steel, concrete or wood or they may be of earthen construction with natural sloping sides or with retention walls. Size varies from a one to two cubic foot hatchery and experimental tank to an 80 by 300 by 5 feet deep earthen raceway section. Concrete raceways generally have a 1:5 to 1:10 width to length ratio and are 3 to 4 feet deep. Water flow velocities range from .05 feet per second to .4 feet per second in hard surface tanks. Harvest ease depends upon how well the ponds are designed, constructed and maintained. A properly designed and built array of concrete raceways can raise a million pounds of fish in a 10 acre area with a work force of about 4 men.

Earthen ponds being much lower in initial investment have a higher upkeep cost. They should be dry for one month or more a year and have a labor liability greater than twice that of a good concrete fish farm. Velocities and fish stocking densities should be much lower in earthen raceways than in concrete raceways so at least 3 or 4 times as much land is required.

Management of raceways is based on adjusting the variable parameters or tolerance levels in accordance with the fixed parameters to a predetermined standard, set by judgement of the manager. The following are parameters that may be variable or fixed and generally the remaining parameters can be derived from other parameters:

Water velocity, depth, width, length, flow
Fish weight per volume
Fish number per volume
Fish weight per pond
Fish size
Fish number per surface area
Fish weight per surface area
Feeding rate
Feed efficiency
Growth rate
Oxygen consumption
Ammonia concentration

This report is not the place for a complete treatise on fish farm design and management. The mathematics of the inter-relationship between the various parameters are in the literature. Of course there are as many opinions on what the parameter values should be as there are fish culturists. Most of these values are a continuum between fail safe and sure failure. However, compromise must be made because the fail safe values may be financially impossible.

One cubic foot per second flow of water through a fish production pond will lose one part per million oxygen and gain .1 to .2 ppm ammonia for each 20 pounds of fish food fed per day. How many pounds of fish 1 cfs of waterflow will support is dependent for the most part on the size of the fish, temperature, and oxygen inflow level and how low the oxygen level in the outflow may be tolerated by that particular species.

In linear raceways the oxygen level drops along the length of a section as it is used by the fish. Then is boosted by spilling over the day boards. The water in a raceway section contains only the oxygen that entered. Reaeration does not take place until the next spill. The lower the oxygen level in the water the easier it is to increase the level. As a consequence, jetting or spraying oxygen saturated inflow water into the first section of a raceway does not appreciably increase the oxygen levels available to the fish. Effort should be directed at fully aerating depleted water as it is spilling to the next pond.

In spite of its water use inefficiencies, linear raceways are the most popular design for intensive culture in commercial fish farms. The advantages of rectangular tanks lies in their ease of construction, efficient fish handling and harvest and efficient land utilization. The raceway is the best form of fish rearing design, where the inflow water has little or no head pressure and the site slopes six inches to ten feet for each 100 feet horizontally.

The circular flow type of fish tank can be cylindrical or rectangular. The unifying feature is that the water in the tank recirculates around in the tank passing the inflow water several times before being discharged. Present rectangular recirculating designs, such as Burrows Ponds and other older designs are not significantly more efficient in water utilization than linear raceways and require considerable pumping of water for operation. Their value lies in having water velocity, with its attendant stamina increase in fish destined for survival in the wild such as salmon.

Cylindrical forms of fish tanks, though more difficult to harvest than linear raceways, are much more efficient in using water. Oxygen depleted water flows past the inflow, then by jetting the inflow water so that it carries with it considerable air, the air bubbles can then affect aeration of the water in the tanks.

Careful attention must be paid to the geometry of the water in letting and tank dimensions to give a uniform environment without dead areas. A head pressure above 30 psi is necessary if circular tank water efficiencies are to be of an advantage. For ammonia tolerant species such as catfish, circular tanks may show an economic advantage over linear raceways even with pumping costs because of the higher fish densities that can be maintained at a high oxygen level with minimal water flow. This means more total production possible and less capital investment per pound of fish because of the smaller amount of tank per fish.

Where the site is flat and or where pumping is required circular tanks have advantages. Direct oxygen injection is most efficient in circular tanks as are mechanical agitators. Otherwise, circular tanks are the choice at sites with considerable slope.

Circular tanks are managed for fish production according to the same mathematics as linear raceways with some variation. With inflow jetting, oxygen levels can be maintained at or near saturation throughout the tank so oxygen "consumption" need not be figured as long as the level in the tank is adequate. Ammonia concentration then becomes the limiting factor to productive capacity. For each species and water supply the tolerance level will have to be found by testing at the site with the desired species of fish.

Circular tanks properly operated are self-cleaning but suspended solids from fish feces and uneaten food can cloud the water to a deleterious degree even if the oxygen and ammonia levels are satisfactory. The cure is to increase the water flow, perhaps without jetting the additional water.

The vertical flow fish tank or silo is of interest and has application in certain locations. As to water efficiency silos are really just raceways turned on end. If direct oxygen injection is used they are very efficient in water use. Greater densities can be held in silos than in raceways because of the increased water velocity supplying oxygen and carrying off wastes. This velocity does not cause the weak fish to lay against the outlet as they would under similar velocities in raceways. Water velocity does cost feed efficienty, since the fish must swim harder and consume energy instead of growing.

Silos are ideal for sites of steep slopes, rugged terrain and very limited land area. Caution must be exercised, however, since certain soils are not able to support the weight per square foot that silos exert, especially if the ground becomes wet as often happens at fish farms.

Static water ponds are utilized in extensive style fish culture. Production per acre can be as low as 40 pounds per acre per year with natural food utilization in cold water ponds where trout are reared. However, production may be more than 10,000 pounds per acre per year such as in the Chinese warm water polyculture. Catfish production with artificial feed yields about 2000 pounds per acre.

Pond culture at geothermal sites would only be valid as a way of utilizing the nutrient rich effluent from intensive culture. In the Intermountain Region geothermal waters are found in climates that have too short of and too cold of a growing season for effective commercial warm water fish production in ponds. Irrigated cropland would return far more per acre.

All designs for fish tanks must deal with factors not evident in fish management mathematics. Fish do get sick and die, occasionally in large numbers. Outlet screens must be of sufficient area to allow considerable number of dead fish to accumulate before the screens become clogged. Anticipation and planning for harvesting and handling of the fish must be done. The simplistic idea of a pipe out the bottom of a pond direct to the processing plant is the best method, theoretically, for harvesting. But fish don't freely float out with the water, they fight the current even until they are on dry ground and stay in the pipes after the water is shut off. More importantly marketing realities seldom call for all of the fish in a pond, but for part of the number in a pond and often only a particular size fish is wanted. There is a need for considerable research and development in harvesting and handling of fish. But the expected sales for such a system are so low that commercial ventures shy away from such research. Control of fouling algae should be anticipated.

Fish farms must also have in addition to proper and safe ponds, several other capital items. Feed storage is needed for at least one month's supply of bagged and bulk feeds. Garage and repair space is needed for various equipment. Some of the equipment needed are lawn tractors, farm tractors, implements such as mowers, fish transport trucks, feeding vehicles, road, ditch and pond maintenance and construction equipment and pickup trucks. Processing plants are needed for any significant sized fish farms, which are located in a remote area away from other processing plants. A fish processing plant contains live holding tanks, facilities for eviscerating, deboning, skinning, breading, packaging, freezing and cold storage, as well as areas for employees. Administrative office areas must also be included. Construction and repair areas are needed to maintain the processing and fish production equipment. On-site housing for at least part of the crew would be required if the site was beyond commuting distance of an available labor force. Professional fish biologists and managerial personnel would, in all likelihood, be brought onto the site and they would need housing too. A landing strip would be valuable at sites remote from airports with air freight service.

Geothermal power plants producing the proper amounts, temperatures and qualities of water can contribute an immensely valuable resource to fish culture. Design compatibility between power generation, fish culture and any other geothermal resources users will call for significant studies. Studies in design, materials and methods to insure the productive operation of all users are needed.

Fish farms are readily subjected to fault tree analysis. An insurer of fish farming defines a casualty-loss as a 1% or greater loss of fish in one day. It is the experience of most fish farmers that chronic mortality from disease causes the biggest production loss. The biggest one time losses occur when the water supply is shut off. A casual fault tree analysis will quickly show the importance of a reliable water supply. A reliable water supply is important to prevent catastrophic losses, in addition the water must be manageable enough and reliable enough to prevent chronically poor fish environment, which leads to disease. A geothermal power plant that would instantly shut off all the water would be very incompatible with fish culture. If five to ten separate turbine-condensor units were individually controlled, then the fish farm could be operated using the water of all but one power unit, which could then be shut down. A properly managed fish farm should have a margin of safety on the farm of 10 to 25% extra water in use, thus allowing an emergency shut down of a second power unit.

The contractual and financial arrangement between the power plant and a fish farm should require security of the water supply to fish farm as to quantity, temperature, and quality. Financial compensation, notification of flow changes and liabilities must be clearly spelled out in such an agreement. Capital financing of fish farms is fairly difficult since so few fish farms have been financed through major money markets. It would be most advantageous to capitalize a fish farm as a rider on power plant financing. One power company could rear andromous fish (Salmon, Steelhead and Striped Bass) itself and then trade the fish to another power company that must mitigate fish losses from hydroelectric development for kilowatts of electricity. Rule of thumb estimates figure from fifty cents to $1.50 per pound of capital investment per pound of fish production per year as being compatible when paying off the mortgage on private fish farms.

RESEARCH PROGRAMS

There is no doubt that there are many unanswered questions concerning fish production, using geothermal waters. A collaborative effort between private fish farmers who want to raise fish and researchers in fish culture would produce output of immediate application. Basic research in the field is needed but finding cures for problems encountered on a day to day basis are found most often by the man on the scene thinking and puttering around with solutions.

These research programs are applicable to the national development of fish culture in association with geothermal development.

A. No limit 20 year program for both thermal and geothermal power plants.

1. Fully define water quality effects, toxicity, tolerances and treatments for all desirable cultivatable species. For each species the separate and combined effects of each of the substances present in geothermal water and as modified by fish production should be studied. A 10 to 20 million dollar lab with 30 to 50 workers plus several university researchers and an annual budget of 20 million dollars would be required to carry out this type of program.

2. Fish Culture Research.
Develop methods, techniques, feeds and breed domestic strains for several species. A greatly expanded program of fish cultural research as is being done with trout, salmon and catfish research oriented toward commercial production in intensive culture is needed. This plan would require two million dollar lab, 10 workers and a two million dollar a year budget for each group of fish.

3. Heat Use Engineering.
Develop methods to extract heat more efficiently from water by means of heat diodes or heat exchangers. Present technology is crude, grandiose and inefficient. This could yield more power generation and more proper temperature water for fish culture with less ecological impact. About 100 workers with a budget of 30 million dollars would be needed at various universities and thermal sites.

4. Fish Marketing.

   Improve systems of delivering fish to the ultimate customer without spoilage in acceptable forms (i.e. without bones, etc.). This project would require 10 university workers and 20 industrial workers with a budget of 40 million dollars per year.

5. Geological and environmental effects of geothermal water extraction.

   The ultimate fate of used water on the surface or reinjected to the original aquifer or dry zones with and without fish culture would be the main effort. About 15 workers with a budget of 10 million dollars per year would be needed.

B. Limited National Program

1. A warm water intensive fish culture program studying water quality and fish culture on an integrated basis. About a one million dollar laboratory with about five workers and an annual budget of one million dollars would be needed.
2. Demonstration fish culture projects at various sites.
3. A portable fish bioassay setup for testing geothermal waters for fish culture suitability. (See Below)
4. Fundings of university research, directly working to solve problems encountered and specific toxicity problems. Cost about one million per year.
5. Publication of progress, problems encountered and work by private fish farms at geothermal sites.

C. Raft River Demonstration Project

1. Testing geothermal water as soon as available to determine if it can be used for fish culture in a portable test set up. Use this opportunity to check out and improve tests and gear. Near surface water for cooling is suitable for fish before and after heating based on use of similar water for successful fish culture.

2. Develop alternative ways of cooling, mixing and heating water to obtain water of various temperatures to enable finding ideal water temperatures for various species. Then set these up in succession to find best method.

3. Set up commercial fish farm research station. 50 degrees F cooling water and some mixed water to yield 60 degree F water to be used for trout brood stock operation, specializing in summer eggs and Chum salmon production in the winter. 70-80 degree F water to be used for experimentation, catfish spawning and egg incubation. 85 degree F water to be used for major production of channel and blue catfish and research into other species. Provision should be made for shrimp culture. A reasonable amount of land should be put into ponds for extensive culture. Additionally a wildlife-public recreation pond and marsh area may be created as well as installing circular irrigation sprinkling systems.

4. Set up a laboratory with sufficient gear to check fish quality and to detect effects of water and changes to and caused by materials of the power plant and fish farm. This lab would be shared but only partially funded by the fish farm operation. An intensive monitoring of all waters should be carried out both in the power plant and the fish farm.

5. Publications and information programs. All research and development information generated by the fish farm is to be published in scientific and fish publications. Presentations should be made to fish farmer conventions and fish culture conferences. These presentations will include financial data.

6. A site and provision for contract research and development in the fish culture field will be included in hatchery plans.

7. New species investigation to be conducted in experimental and pilot project sizes in preparation for full scale demonstration and development at future geothermal power plants.

Much of the cost of the research could be underwritten by foundations. Also, sharing in the costs would be State and Federal agencies with interests related to water quality, environment, pollution, energy generation and use, food and fish production geology, hydrology and basic research.

D. Portable fish culture suitability bioassay setup and program.

This setup is to be portable. It will require one goose neck trailer and one travel trailer for laboratory and living or office quarters. Also required would be two pickup trucks, one to haul the goose neck trailer and the other to haul the travel trailer and fish hauling tank. Other gear required would be several collapsible plastic swimming pools, pumps, pipe, valves, fittings, water heaters, aerators, and a large continuous service electric generator and water cooler. Test gear would include a microscope and staining setup, recording thermometers, water analysis gear to test exygen, ammonia, hydrogen sulfide, hardness, and pH, etc., scales and refrigerator-freezer. A two man team would operate this testing program.

Test Procedures

1. Obtain a complete laboratory water analysis.
2. Stock fish at a low level to see if water warrants further testing.
3. Three to six week study at low level to acclimatize fish to water and see if there are toxic problems.
4. Stocking fish at various densities to find maximum stocking level while monitoring water quality.
5. Vary the NH_3 level on a low level stocking and also vary the pH. Study fish for effects on gills and feed conversion.
6. Vary the oxygen level on low level stocking to find the chronic low tolerance level. Find length of time necessary to kill fish when water is shut off. Do this at various stocking levels.

7. Artifically simulate high stocking with low oxygen and high ammonia. Then compare the effect on fish to high level stocking.

8. Study buffering capacity of water with nitric acid, carbon dioxide and ammonia.

9. Long term rearing of at least four to six months to determine growth and rate and feed conversion as base line for possible fish farm development. Then test fish for toxic levels for human consumption of fluorine, cadmium, mercury and other heavy metals.

10. Induce stress in fish and observe for disease or excess losses.

11. Compile and report findings.

This set up could test at least two sites a year and if the result were favorable, it would insure the suitability of the water for fish culture. Most fish hatcheries have been built with hardly any water testing of this sort. The data amassed would be invaluable to a fish farmer utilizing that particular water source. Initial cost would be between 25 and 30 thousand dollars if all new equipment were purchased. If surplus, salvaged and used gear were used the cost could be halved or better. Total salaries would run 12 to 30 thousand dollars per year. Fuel and operating costs might run up to 10 thousand dollars. Up to 10,000 pounds of fish might be utilized in a years test schedule. This would cost about 15,000 dollars for the fish and the feed. With a useful life of five years the annual cost would run about 40 to 60 thousand dollars. A daily test fee of at least $250 to $300 would be required for contract work.

A research program should not be undertaken if there will not be some return of the effort and expense involved. About five percent of the fish consumed in the United States is of fresh water origin with less than half of that amount of fish being of commercial fish farm origin. By comparison China gets the majority of its fish from fresh water fish culture. As ocean fisheries decline and populations continue to increase, the demand for farm raised fish will grow. If the supply is to also expand new water sources and efficient methods of fish production must be found.

1000 cfs of geothermal water suitable for warm water fish culture would yield a minimum of 10 million pounds of fish, with a potential of 100 million pounds per year. The gross income would be 15 to 150 million dollars. Most of this income would be spent in sparsely populated rural areas for wages and agricultural feedstuffs while coming from outside sources. Fish culture has a high economic multiplier effect on the economy of a local farm area. Thus, a reasonable cost benefit ratio could be projected for a significant research program.

SUMMARY

Geothermal energy and water development will provide the resources that can be used by fish farmers to raise considerable amounts of high protein fish. Water quality and domesticating new species are the main problems for which research is indicated. The development of a fish culture industry based on geothermal water hinges on availability of proper quality water and a reasonable expectation of a profit on the part of the fish farmer.

APPENDIX I

FISH FOOD PRODUCTION ASSISTED BY GEOTHERMAL ENERGY

Fish feed is a unique feed in the animal industry. Since fish are cold blooded, energy is not needed to keep their bodies warm. In mammals and birds this energy for warmth is supplied in great part by carbohydrates. The metabolic and movement energy requirements of fish are met most efficiently by fats but proteins and carbohydrates are also used. Some fish, such as trout, have a low tolerance for carbohydrates and can be considered to be inborn diabetics. Fish also are not ruminants as are cattle and sheep. Thus, their bodily nitrogen needs can only be met by complete and balanced proteins. Herbiverous fish are able to digest vegetable matter by means of a long alkaline intestine and strong enzymes. These various factors then require that fish feed be made of high quality protein concentrates. Trout and salmon feeds have up to 53% protein, while catfish feed usually has about 25 to 35% protein. Such feeds require astute ingredient evaluation and purchase know how as well as skill in milling. Only a handfull of manufacturers remain in the fish feed business.

Present fish feed preparation methods do not require heat, in fact the feed must be cooled to prevent vitamin destruction and rancidity.

The preparation of ingredients offers somewhat of a use for geothermal heat. Usually fish meal, which is an important part of fish feed, is dried by the use of a direct flame dryer. The quality of the fish meal suffers as a consequence. Vacuum drying produces a much superior product since drying takes place at no more than 160 degrees F preserving vitamins, pigments and protein quality. The steam jacket of such a fish meal dryer could well be fired by geothermal steam.

A high quality feed ingredient can be prepared from fish by a process of enzyme digestion. By adjusting the pH and holding the temperature at about 140 degrees F for three hours fish are reduced almost to an amino acid broth. Either method of fish reduction could use geothermal heat. However, the raw ingredients of cheap fish are only available on the coast. Freshwater scrap fish are too expansive to compete with marine fish for reduction. The waste from the fish farm processing plant may be used but is of too low a quality and of such low volume to justify the expense of reduction. Many stocks of fresh-water fish such as carp have too high a level of chlorinated hydrocarbons and Mercury to be safely made into meal.

Drying aquatic vegetation for fish feed is an idea that merits study.

The culture of yeasts and other single cell sources of protein could benefit from geothermal heat. Such sources of protein can be effectively processed into a marketable and tasty protein food by growing fish with the product.

Some new concepts in fish feed production may come along in a few years and change the picture. For the present technology and fish feeds, geothermal energy has little that may be utilized.

APPENDIX II

PROTEIN BALANCE

A 100 gram hypothetical fish in its life time will have eaten about 100 grams of 50% protein feed or 200 grams of 25% protein feed. So our example fish will have eaten 50 grams of protein. A 100 gram fish is 75 grams water, 17.5 grams protein and the rest is fats, carbohydrates and ash. This means the fish is 70% protein on a dry weight basis.

The protein of a fish feed to be effective is a fully complete protein assembled from many sources. 100 grams of fish feed protein will produce about 35 grams of the highest quality protein (i.e. fish protein) on a dry weight basis.

So of the 50 grams of protein eaten, 32.5 grams of protein must not have been digested or was used for energy. Multiplying 32.5 grams by .16 (the conversion factor from protein to nitrogen) yields 5.2 grams of nitrogen. If all this was used by plants they would yield 32.5 grams of protein. Watercress has for example, 1.7 grams of protein per 100 grams of plant. Thus $\frac{32.5 \times 100}{1.7}$ = 191 grams of water cress. Efficiency may only be around 10%, however, so only 20 grams of water cress may be produced or 3.25 grams of recovered protein. Efficiency of aquatic plants to recover protein or to remove nitrogen enrichment, in other words, is an area of little knowledge, that needs considerable scientific study. Such information will not only be useful for fish hatcheries needing to remove enriching nutrients from their discharge water, but for sewer treatment technology and pollution abatement in general.

APPENDIX III

OPERATIONS USING GEOTHERMAL WATER FOR FISH CULTURE

1. Bozeman Fish Cultural Development Center, U.S. Fish and Wildlife Service, Bozeman, Montana.
   68 to 76 degree F spring water is mixed with an adjacent 44 degree F spring to yield 46 to 58 degree F water for trout production and research.

2. Royal Catfish, Twin Falls, Idaho.
   110 degree F artesian well water is mixed with 60 degree F spring water to yield 72 to 85 degree F water for catfish production and after flowing one mile, the water is re-used at 52 to 65 degree F for trout production during the winter.

3. Fish Breeders of Idaho, Buhl, Idaho.
   95 degree F artesian well water is mixed with 60 degree F spring water for catfish production at 85 degree F.

4. Calaqua, Paso Robels, California.
   117 degree F water cooled to 85 degrees F for catfish production.

Several hot spring resorts have or have expressed interest in placing fish or reptiles in their water. Starts have been made in Idaho with shrimp culture in or using the heat of geothermal water.

APPENDIX IV

COSTS AND FISH MANAGEMENT CALCULATIONS

Fish production cost analysis, cash flow and fish growth projection are necessary for profitable management of a fish hatchery. However, such projections are subject to considerable variance due to the unpredictableness of fish, nature and marketing. Many fish projected to grow out in 12 months may actually vary 3 months either way. Individual fishes may be ready 4 months early or 5 months late of the time the average fish reaches market size.

Utilizing an intensive fish culture operation for maximum production requires that the total feed given per day be kept at or near a maximum limit year round. By obtaining eggs or fry year around and harvesting on an even continuous basis, much greater total production can be achieved than by starting fry and harvesting only once a year. This may be estimated by taking one-half of the single crop capacity and then determining how many times per year this weight of fish will double its weight the final time before harvest. Multiply the weight by the times per year for the maximum capacity.

Example I

In consideration of the limiting factors ,such as oxygen availability ammonia tolerance and water flow for the fish being raised, let's say that 300 pounds of food may be fed per day. The fish will eat 3% of their body weight per day. Thus 300 pounds per day will feed on the day before harvest 10,000 pounds of fish. This is the single crop annual production maximum. For simplicity let us assume a 1.0 conversion (pounds of fish feed per pounds of fish produces). This means the fish will gain 3% in weight per day. Compounding this rate for one month means the fish will double its weight. Thus, by use of our formula $\frac{10,000 \times 12}{2}$ = 120,000 pounds capacity per year with year around harvest.

Theoretically, by harvesting 600 pounds per day from the final production unit and replacing the harvested fish with 300 pounds of fish from the succeeding lot and replacing that with 150 pounds for the next lot and so on the annual capacity could be doubled. In practical terms only a part of this could be achieved. In fact, most fish farms get only about one-half or less the formula capacity production per year by daily harvesting and none of the replacement stocking multiplication takes place. Most trout farms seldom achieve production greater than 10,000 pounds per year per 1 cfs due to poor design and lack of full utilization.

When raising species for which eggs are available for only a short period of time per year, slightly different methods must be used to obtain daily harvest and maximum production. By controlling the temperature of different ponds the growth rate, which is temperature dependent may be varied, thus staggering the harvest dates. By grading the fish into fast growing and slow growing lots, the harvest of similar aged fish will be spread over a longer period of time. There is a narrow range between uneconomic underfeeding and overfeeding and within this range the growth of fish may be varied by adjusting the feeding rate. If all three of these methods just described are available and used, fish that normally would be ready for harvest in 11-13 months could be harvested in from 9 to 24 months. The main production costs in a fish farm are (1) labor, (2) feed, and (3) capital investment amortization. Labor costs are controlled by good management of skilled workers and mechanization but at the cost of capital. Feed costs are controlled by skilled fish management and disease control. Capital investment costs can be reduced by keeping construction costs at a minimum but not to the point of being unreliable or penalizing labor. These costs can also be reduced by maximizing production while preserving a suitable fish habitat. For a particular fish farm the maximum poundage production would be achieved with the fish that grows the fastest in the poorest water.

Example II

These projections are not to be considered as exact but rather they are being used to illustrate a method of analysis. Actual figures must be found by experience at the particular fish farm. In this example Rainbow Trout at 60 degrees F, Channel Catfish and Carp at 85 degrees F will be compared in raceways and circular tanks.

Raceways

The water size for one raceway receiving a flow of one cubic foot per second would be 25 feet long, 10 feet wide and 3 feet deep for each of four sections. There would be an inlet and outlet screen for each section. Between each section the water will spill 3 feet and the water level will be controlled by dam boards.

One important finding of this analysis is that the annual production for each species is not that different because of compensating factors.

In the raceway example above the catfish and carp will run out of oxygen before they will exceed their ammonia limit. To obtain maximum yield in a raceway for these species additional sections of raceway must be included. The trout would be exceeding their ammonia tolerance in the lower 3 sections of the raceway. Trout may tolerate such levels in the final days before harvest without great mortality. Production in this instance is probably too high. For the trout not to exceed the .5 ppm ammonia limit only 100 lbs. per day could be fed, which would yield a weight of 5,555 lbs in the raceway and an annual formula production of 16,662 pounds. For the catfish to reach the ammonia tolerance level seven sections of the raceway should be used and the carp should use nine sections. The new annual formula production would be 74,000 lbs of catfish and 131,280 of carp.

This example of a raceway production assumes that all fish growth takes place within the raceway. However, 4 sections will only hold 4 lots of fish at a time but the annual formula production assumes sufficient production units to separate the required number of lots of fish.

TABLE I

RACEWAYS

	TROUT	CATFISH	CARP
Temperature	60°F	85°F	85°F
Minimum Oxygen Concentration	5 ppm	3 ppm	1.5 ppm
Oxygen Consumption (saturation-O_2min)	9-5=4 ppm	6-3=3 ppm	6-1.5=4.5 ppm
Maximum Ammonia Concentration	.5 ppm	2 ppm	4 ppm
Ammonia production	1.6 ppm (exceeds safe limits)	1.2 ppm	1.8 ppm
Market size	.8 lbs 12 inches	1.2 lbs 17 inches	5 lbs 20 inches
Growth in inches per month	about 1	about 2	about 3
Time to market	about 11 months	about 8 months	about 7 months
Allowable feed per day-total of the 4 sections	320 lbs	240 lbs	360 lbs
% body weight of fish fed per day	1.8%	3%	6%
Weight of fish in the raceway	17,777 lbs	8,000 lbs	6,000 lbs
Pounds of fish per cu ft of water	6.1 lbs	2.79 lbs	2.07 lbs
Approximate time for final weight doubling	2 months	1 month	1/2 month
Annual formula production	53,328 lbs	48,000 lbs	72,000 lbs

Another lesson shown is that as the feed intake rate increases the pond length may be shortened to reduce the capital expense by increasing fish density.

Circular Tanks

In this example there will be 12 tanks each 10 feet in diameter and 3 feet 1 inch deep. This approximates the total volume of water in the raceway. Each tank would receive 1/12 of a cubic foot of water per minute, jetted in under sufficient pressure to maintain an oxygen drop of no more than 2 ppm. Thus the ammonia level will be the limiting factor to production.

This analysis of circular tanks clearly show the tremendous jump in production that can be achieved in circular tanks with ammonia tolerant species. This can take place when suitable oxygen levels are maintained either by getting the inflow water under higher pressure or if direct oxygen injection is used. If all the species had the same ammonia tolerance of 1 ppm the annual formula production would be 39,999 lbs. This level would be the same in a raceway situation but in a raceway the final pond is the only location where the maximum ammonia level is found. However, some of the fish in a raceway situation will be subject to low oxygen and high ammonia, which is more injurious than high ammonia and high oxygen levels. This sort of analysis points out the importance of knowing the ammonia tolerance for fish under production conditions in a particular water supply.

TABLE II

CIRCULAR TANKS

	TROUT	CATFISH	CARP
Temperature	60°F	85°F	85°F
Minimum Oxygen levels in the tanks (saturation 2 ppm)	9-2=7	6-2=4	6-2=4
Maximum Ammonia concentration	.7 ppm	10 ppm	10 ppm
Oxygen "consumption"	7 ppm	100 ppm	100 ppm
Allowable feed per day	140 lbs	2000 lbs	2000 lbs
% of body weight of fish fed per day	1.8%	3%	6%
Total weight of fish	7777 lbs	66,666 lbs	33,333 lbs
Pounds fish per cubic foot of water	2.65 lbs	21.5 lbs	10.75 lbs
Annual formula weight	23,328 lbs	399,996 lbs	399,996 lbs

TABLE III

Cost Analysis for Example II

	TROUT	CATFISH	CARP
Live sale price of fish per pound	.65	.50	.40
Cost of feed per pound that will give 1.0 conversion	.20	.18	.14
Difference	.45	.32	.26
Pounds of fish that must be raised to yield $30,000	66,666 lbs	93,750 lbs	115,384 lbs

The $30,000 figure includes all expenses other than food. With a labor cost of ten cents per pound of fish this amount of fish will allow a salary of $10,000 per year for operator of the fish farm. The remaining $20,000 is to be budgeted between operating costs, taxes, amortization of capital investment and profit. With the assumptions made in the previous tables, one cubic foot per second of water could yield enough fish production for a profitable operation with catfish or carp. Trout production would require five to ten times as much water to be profitable. The analysis for carp is only valid if a specialty market for carp were found that was willing to pay thirty cents per pound. Israeli carp do sell for at least that much but river carp sell for three cents per pound.

Knowing the fishes biological limits is the first and most important part of the analysis of the feasibility of a fish farm.

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