2045-20

V-C-213

UTILIZATION OF WASTE HEAT FROM POWER PLANTS BY SEQUENTIAL CULTURE OF WARM AND COLD WEATHER SPECIES

C. R. Guerra, B. L. Godfriaux and C. J. Sheahan
Public Service Electric and Gas Company
Newark, New Jersey U.S.A.

ABSTRACT

Aquaculture operations utilizing thermal discharges from power plants may significantly contribute to energy conservation and food production in the future. Commercialization of this technology will however, require the development of aquaculture schemes which do not interfere with the principal functions of the power plant but still operate reliably and economically under varying environmental conditions.

For the past three years, field experiments at a power generating station along the Delaware River have successfully demonstrated the concept of sequential (diseasonal) aquaculture. This process involves growing warm weather species during the warm months of the year and cold weather species during the cold season. The research, under the sponsorship of NSF/RANN, has recently been expanded to a proof-of-concept scale. The principal project objectives include the evaluation of the commercial feasibility of the concept, in particular, the overall process reliability, reproducibility of results and aquaculture product acceptability.

A pilot aquaculture facility is being used to rear freshwater shrimp, Macrobrachium rosenbergii, and rainbow trout, Salmo gairdneri, utilizing the thermal discharges from the Mercer Generating Station (Trenton, New Jersey). Delaware River water on passing through condensers of two 300 MW turbines gains thermal energy (up to 6°C) and provides two thermal regimes, of semi-annual frequency, in the plant effluents: one suited for shrimp and the other for trout. This diseasonal aquaculture scheme causes minimal interference with power plant operation and no modifications of the condenser operation or thermal discharge pattern.

Adult shrimp are conditioned for spawning and the hatched larvae reared indoors during winter and early spring. Juvenile shrimp are transferred to raceways and ponds by May. Marketable adult shrimp (greater than 11 cm) are harvested in the fall. Rainbow trout fingerlings are stocked in November, grown outdoors during the colder months and harvested by May (28 cm size).

The research is being carried out at the power plant facilities equipped to rear all stages of the shrimp life cycle and with flow capabilities to maintain up to 36,000 kg of trout. Supporting research is being conducted at Trenton State College and Rutgers University laboratories. Long Island Oyster Farms and the NJ Department of Agriculture are also participating in the project.

Experiments are being conducted to increase the shrimp stacking density by increasing the effective surface area of tanks, ponds and raceway, using various designs of submerged substrates. The trout experiments are designed to test increasing trout stacking densities in the untreated thermal effluent. Methods for waste heat dissipation are also being studied to better control the temperature regimes for shrimp and for trout. Tests for product quality control and market acceptance have been satisfactory.

A summary of the results to date and a description of the plans for the proof-of-concept evaluation are the subject of this report.

INTRODUCTION

For every unit of coal or oil burned in an electric generating plant, about one-third of the energy is converted to electricity. The other two-thirds of this energy is released to the environment as waste heat in the plant condenser cooling water and in stack gases.

Aquaculture research to determine whether the giant Malaysian freshwater shrimp species, Macrobrachium rosenbergii, and rainbow trout, Salmo gairdneri, could be successfully reared in the Mercer Generating Station heated discharge water during the warmer and colder months, respectively, was begun in August 1973.

Public Service Electric and Gas Company (PSE&G) provided the aquaculture site and the initial capital to build the original pilot aquaculture facility and initiate the research. Starting in July 1974, the National Science Foundation, Research Applied to National Needs Program (NSF/RANN) awarded PSE&G two grants to cover most of the pilot research expenses to November 1976. In November 1976, NSF/RANN provided a proof-of-concept grant to enlarge the present aquaculture facilities and to continue the research program.

The pilot aquaculture research project was conducted by PSE&G jointly with Trenton State College; Rutgers, The State University and Long Island Oyster Farms, Inc. Trenton State College operated the aquaculture facility at the Mercer Generating Station and conducted all testing at the site. Rutgers University ran the laboratory experiments to determine the physiological limits of various environmental parameters and nutritional requirements of the two species chosen for culture in the Mercer discharge water. Long Island Oyster Farms provided aquaculture expertise and a number of juvenile and adult shrimp required by the project.

The proof-of-concept project will involve the same organizations mentioned above. In addition, Buchart-Horn Inc. will perform the design and engineering of the aquaculture facilities, and the NJ Department of Agriculture will supply a farm cooperator to rear rainbow trout fingerlings for stocking the grow-out facilities at the power plant.

The aquaculture facilities are located at PSE&G's Mercer Generating Station four miles south of Trenton, New Jersey, on the Delaware River (Fig. 1). The station, which is coal-fired, generates some 600 MW of power and discharges approximately 450,000 gpm of heated discharge water at a maximum of 6°C above the ambient Delaware River water temperature. The thermal discharges derive from two condensers coupled to a twin set of 300 MW steam driven turbines. The power generating units are of base load (continuous) operation. Chlorine is used for condenser biofouling control. Godfriaux et al. (1975) has described the pilot aquaculture facilities.

SUMMARY OF PILOT STUDY RESULTS

The main purpose of the pilot study was to evaluate the biological feasibility of sequentially rearing the freshwater shrimp *Macrobrachium rosenbergii* (de Man) and rainbow trout *Salmo gairdneri* (Richardson) in the thermal effluent of a fossil fueled generating station using river water. Secondary objectives were to make preliminary evaluations of the engineering and economic feasibility of rearing the above mentioned species in thermal effluents and to make some preliminary assessments of product quality.

1. Biological Feasibility

Large, natural, seasonal temperature fluctuation of surface water (6°C to 30°C) between the warmer and colder months of the year occur in many areas of the nation. Power plant discharges add an approximately constant thermal increment

(6°C to 15°C) with the resulting aquatic environment being thermally distinct and suited for culture of a cold and warm weather species on a semiannual basis. This new aquaculture concept is called "diseasonal aquaculture" and has been found to be operationally feasible for rainbow trout and freshwater shrimp at Mercer Station.

Both species responded well to the thermal effluent environment. Growth and food conversion rates were equal to the better growth and food conversion rates cited in the literature for both species. There were no serious disease outbreaks for either species. The use of vertical draped netting in a pond and raceway, to increase submerged surface area, increased shrimp production threefold relative to the production from existing operations elsewhere. Temperature limits in the thermal effluent acceptable for Macrobrachium rosenbergii and rainbow trout culture were 15°C to 37.5°C and 0.4°C to 26.5°C, respectively. There was a temperature-dissolved oxygen interaction at the upper thermal limit for both species, which tended to depress the temperature limits.

Some difficulties were encountered in rearing the larval stages of Macrobrachium rosenbergii. Success was dependent on having available suitable quantities of brine shrimp (Artemia) larvae for the feeding of Macrobrachium rosenbergii larvae. Non-Artemia larvae diets did not allow Macrobrachium larvae to complete their growth through their larval stages. Only two mishaps occurred which caused significant mortalities. Rainbow trout were found to be very sensitive to the chlorine residual in the station effluent during periods of generating station chlorination, and the shrimp suffered when there was a combination of momentary high temperature water (35°C) and low dissolved oxygen in the raceway water.

2. Engineering Feasibility

The basic attitude taken during the experimentation was that aquaculture operations must adapt to the operating characteristics of an electric generating station. Any substantial modifications of an existing electric generating station could probably never be paid for by the additional profits derived from the aquaculture operations.

Experience has indicated that three generating units would be preferable at an electric generating station, if a continuous supply of heated effluent is desired. This feature becomes more important the higher a particular generating unit raises the water temperature above ambient.

Certain operating problems were countered with simple, inexpensive solutions. The sensitivity that rainbow trout showed to chlorine residuals during station chlorination of its cooling waters, was solved by automatically shutting down the aquaculture facility intake pumps and aerating the rearing raceways and ponds. When the temperature of the station thermal effluent was approaching upper thermal limits of trout or shrimp, water was sprayed into the ponds or raceway to lower the water temperature a few degrees.

An inexpensive telephone alarm system was installed to alert project personnel when water temperature, dissolved oxygen or pressure were recorded outside permissible values. These were the only engineering problems encountered in the study.

3. Economic Feasibility

Intensive, waste heat aquaculture which employs the use of high water flow rates appears to be an attractive investment (9 to 55% return on investment). Although both shrimp and rainbow trout are biologically feasible for culture in the Mercer Generating Station thermal effluent, recent projections indicate rainbow trout would provide between 77 percent and 95 percent of the total yearly revenues with present technology.

Since only about four hectares of land are available for a commercial aquaculture facility at the Mercer Generating Station, and the production of both shrimp and trout is almost tripled per unit area of raceway when raceway depth is increased (from 0.9 m to 2.4 m), the most efficient production unit appears to be the deeper raceway. The deeper raceway requires increased water flow rates or a supplemental water aeration/oxygen injection system to maintain desired levels of dissolved oxygen and minimize the build-up of metabolic wastes.

4. Product Quality

Heavy metal and arsenic analyses were conducted at various times for *Macrobrachium rosenbergii* reared at the Mercer Aquaculture Facility and overseas locations. There was little difference between these shrimp sources. Mercer rainbow trout were also examined for heavy metals and arsenic, and both Mercer shrimp and rainbow trout were analyzed for polychlorinated biphenyls (PCBs). All results were within permissible levels.

Restaurant evaluation of the shrimp were favorable with respect to flavor, color and texture. The Department of Food Science, Rutgers University did note on one occasion, a slight "earthy" flavor in a taste test on Mercer reared rainbow trout. However, in most taste trials, the trout was found to be quite tasty. Small volumes of trout were sold at a local fish market and the shrimp served at a local restaurant.

PROOF-OF-CONCEPT AQUACULTURE RESEARCH PLANS

1. Layout of Facility

The general layout of the proof-of-concept aquaculture facilities is shown in Figure 2. It includes two laboratory nurseries and grow out facilities.

The two laboratories are Lord and Burnham "Gro-Mar" greenhouse units 6.7 m X 14.6 m. Laboratory I (Fig. 3) is used as a hatchery for *Macrobrachium rosenbergii*. It has special tanks for brood stock, for culturing the early and late larval stages of shrimp and for hatching of brine shrimp eggs. It also serves as a holding area for post-larvae and early juvenile shrimp until they are placed in the covered, outdoor, heated, nursery raceways.

There are six early larval rearing tanks. Each tank measures 56 cm in diameter and is basically cone shaped. The tanks are made of a fiberglass reinforced polyester resin with an FDA approved gelcoat on the interior surface. Also located in Laboratory I are twenty-one late larval brood stock and post-larval rearing tanks which are low cost, concrete, cemetery vaults (2.2 m X 0.8 m X 0.7 m). They were painted on the inside with an FDA approved epoxy paint to achieve watertightness.

Laboratory II serves as the rainbow trout hatchery and fry rearing building (Fig. 4). It contains two, eight tray, salmonid battery incubation units; eight 3 m X 0.9 m X 0.6 m trout fry/fingerling rearing troughs and five 2 m square rearing tanks with round corners. The heat exchanger which will be described in a later section is also located here.

Figure 2 shows five main grow-out raceways. One is an existing 50 m X 2.4 m X 0.9 m V-shaped, liner raceway. The other four raceways will be of concrete. Two will be 3.6 m wide and the other two 2.4 m wide. One two-unit raceway set will be 2.4 m deep and the other two-unit set will be 0.9 m deep. All four raceways will be 30 m in length.

The facilities include six 12.2 m X 1.8 m X 0.9 m nursery raceways (Fig. 2). These raceways will be covered with a low cost plastic sheet structure to reduce water heat loss during the colder months of shrimp juvenile rearing. The plastic walls will be rolled down during hot weather (trout fingerling rearing).

Two other elements of the pilot facility will be retained. One is Pond I which is a 27.5 m X 7.6 m X 0.9 m PVC liner lined pond. The other is Pond II (15 m X 15 m X 1.8 m) which is similarly liner lined and will be modified into a temperature equalization pond. Both ponds are shown in Figure 2.

Other features of the facilities include a PVC liner lined dual lagoon type waste treatment system consisting of aeration and settling lagoons (6.1 m X 6.1 m X 2.4 m each) and a food storage/workshop building.

2. Pumps and Piping System

There are three sources of water for use in the proof-of-concept aquaculture facility: generating station heated effluent, Delaware River ambient water and well water. TABLE I lists the maximum flow of each water source available to each aquaculture facility process unit, and Figure 5 shows a schematic of the process water flow to the various units within the aquaculture facility.

Well water is supplied to each process unit, except Laboratory I, and is individually valved for control. Tempered water from the temperature moderation pond (which mixes ambient river and station discharge canal water) is also supplied to each process unit. The six nursery raceways are supplied ambient river water and waste, heat exchanger water from Laboratory I, in addition to tempered water and well water for a wider range of water temperature control. The temperature moderation pond is supplied with water from all three sources for blending purposes. Raceway cleanings are taken by underflow piping or pumped directly to the waste treatment facility for settling and aeration prior to discharge to the power station discharge canal.

There are four station discharge canal water intake pumps: two rated for 3,000 liter/minute and two 5,700 liter/minute. There are two 1,900 liter/minute ambient river water intake pumps and two new 7,600 liter/minute temperature moderation pond pumps for tempered water distribution to the process units. There are also two 1,900 liter/minute well pumps. In the event of a temperature moderation pond breakdown of the pumps or pond itself, discharge canal and river ambient water can bypass the temperature moderation pond and go directly to the process units. The piping system incorporates no lead base materials and to avoid problems with pluggage of the pump inlet strainer, back flushing by gravity is used.

3. Air Supply System

The air supply for all aquaculture facilities is taken from the 21 kgs/cm^2 power plant air system. Air filters were installed upstream of the air pressure regulator to prevent oil traces from the plant centifugal air compressors from entering the culture tanks and ponds. The station air pressure was reduced to 0.4 kgs/cm^2 for its use within the aquaculture facility. To prevent water build up and possible upstream freezing of the air line or oil carry over, the air filters are bled off on a continuous basis. A portable air compressor will be rented if required to maintain dissolved oxygen levels in the main rearing units during the months of March through May when the trout biomass will be at its highest.

4. Heat Exchanger System

The heat exchanger is used to heat the Mercer discharge canal water being supplied to Laboratory I where the shrimp are kept during the colder months of the year. The heat exchanger system is part of a closed loop heating system. The system is located in Laboratory II and supplies heated station discharge water to Laboratory I. A 3 hp, 2,550 rpm centrifugal pump feeds city water to two RUDD, industrial type, gas-fired heaters. The heaters are rated at a total output of 1×10^9 joules/hr and input of 1.3×10^9 joules/hr. The hot water heaters are capable of raising 115 liters/minute of water 22°C above ambient on a continuous basis. The heaters are thermostatically controlled to shut off at a predetermined temperature.

The heated water output from the RUDD heaters is supplied to a single plate type heat exchanger. The heat exchanger is rated at 0.95×10^9 joules/hr at about 115 liters/minute. The heat exchanger plates are made of titanium. A plate type heat exchanger was selected due to the limited space available as well as for ease of cleaning. A back flush system is incorporated on the heat exchanger which utilizes 6 kgs/cm^2 city water. With this method the flow is reversed on the canal water side of the exchanger, and this removes any debris build up. The exchanger has operated according to design since installation. Internal inspections have found the exchanger clean.

5. Water Monitoring and Alarm System

An alarm system is used to provide notifications to the aquaculture project manager, the generating station control operator (in the power plant control room), and outside aquaculture personnel in the event of any abnormal environmental conditions in the project. The various parameters being monitored (water temperature, water pressure, dissolved oxygen and air pressure) are sensed by appropriate primary elements which activate electrical switching devices. The electrical output of these devices is sent to a common control relay. This relay is used to initiate an electronic telephone dialer system. The telephone dialer uses a pre-recorded magnetic tape cartridge that contains telephone numbers and a message. It is used to call and inform outside people that an alarm condition exists. The dialer system is a modification of a commercially available system made by Dytron, Inc. for fire and security uses in residential and industrial applications.

6. Aquaculture Waste Water Treatment

As stipulated in the EPA Draft Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Fish Hatcheries and Farms - by Schneider (1974), process water flow may be discharged directly back into the water source. However, water used for raceway cleaning should be settled (sediment removed) before effluent is returned to receiving waters.

7. Chlorine Control System

The Fisher-Porter chlorine control equipment has been modified to include an electrical interlock with the heated discharge water intake pumps. The operation of the interlock system depends on the opening of the chlorine dilution water valve. Upon activation of the control relay for the dilution water valve, an auxiliary relay causes the heated discharge water pump contactor to open thereby stopping the pumps. An additional feature of this system is the ability to operate only one pump at a time or to override the system completely in the manual mode.

8. Water Chemistry and Bacteriology

Bacterial counts in the Delaware River and Mercer discharge canal are highest during the summer and early fall. This also coincides with periods of greater total chlorine occurring in the Delaware River. Total chlorine concentrations of up to 0.1 ppm were recorded before passage through the Mercer

Generating Station. This is believed to be the result of discharges of local sewage treatment plants further up river which encourage bacterial blooms due to the high temperatures of the Delaware River. The sewage treatment plants try to suppress these bacterial blooms by increasing the amount of chlorine added to the sewage discharges.

9. Sequence of Culture Operations - Shrimp and Trout

Figure 6 shows the sequence of shrimp and trout culture operations through the year. In Laboratory I, shrimp (*Macrobrachium rosenbergii*) brood stock are spawned in late December early January, and the resulting fertilized eggs are hatched by the beginning of February. The shrimp larval cycle is completed some time in early March, in Laboratory I, and then the post-larvae are transferred to the covered nursery raceways where they are grown to 3-5 cm juveniles by mid-May. At this time, the juvenile shrimp are transferred to the outdoor pond or raceways where they are kept until they reach a length of 12-15 cm (September-October) when they are harvested.

In December, rainbow trout eyed eggs are placed in battery incubation trays in Laboratory II. Egg hatching is completed by the end of December. The yolk-sac fry are then placed in rearing troughs also located in Laboratory II and are grown to a length of 9 cm by mid-May when the trout fingerlings are transferred to the outdoor nursery raceways. The fingerlings are held in the nursery raceways until mid-November when they should be approximately 20 cm long. They are then transferred to the outdoor production raceways and harvested at approximately 30 cm in length at the beginning of May.

10. Production Capabilities for Shrimp and Trout

TABLE II summarizes the projected production capacity of the proof-of-concept facilities. The production capacities for rainbow trout could be greatly increased in the two 2.4 m deep raceways by increasing the trout stocking densities higher than indicated in TABLE II. These rearing units will then be available for the rearing of alternate species.

CONCLUSIONS

Our experience thus far has indicated that sequential rearing of the freshwater shrimp, *Macrobrachium rosenbergii*, and rainbow trout, *Salmo gairdneri*, is a promising aquaculture alternative to use the heated effluent from the Mercer Generating Station. Chlorination of the cooling water in the plant steam condensers has caused some problems in rearing a chlorine sensitive species such as rainbow trout, but this problem has been avoided by shutting down the aquaculture intake pumps during the chlorination periods.

Increasing the trout stocking densities results in dissolved oxygen becoming the limiting factor during the water intake shutdowns. This situation is expected to be resolved by water aeration, recirculation and oxygenation as required. Shrimp production is dependent on high culture densities which we hope to achieve by submerged substrates and separated habitats in deeper raceways.

ACKNOWLEDGMENTS

This research is being funded by NSF/RANN Grants AEN 74-14079 ENV 76-19854 A01 and GI-43925, and PSE&G Authorizations RD-378 and RD-443. Other contributions to the project have been made by Long Island Oyster Farms, Trenton State College, Rutgers University and the New Jersey Department of Agriculture.

Many persons from outside the project have provided valuable suggestions and help to this work. We would like to acknowledge in particular the help provided by: Dr. E. H. Bryan (Program Manager, Environmental Systems and Resources, NSF/RANN), and Mr. J. Steinsieck (Superintendent, Mercer Station, PSE&G). We would also like to thank personnel in both Production and Engineering Departments of PSE&G for their assistance and cooperation in this project.

REFERENCES

1. Godfriaux, B. L., H. J. Valkenburg, A. Van Riper and C. R. Guerra 1975: Power plant heated water use in aquaculture: pp. 233-250. In Proceedings of the Third Annual Pollution Control Conference of the Water and Wastewater Equipment Manufacturers Association (Ed. V. W. Langworthy). 915 pp.

2. Schneider, R. F. 1974: Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Fish Hatcheries and Farms (Draft). Environmental Protection Agency, Office of Enforcement, National Field Investigations Center, Denver, Colorado. 237 pp.

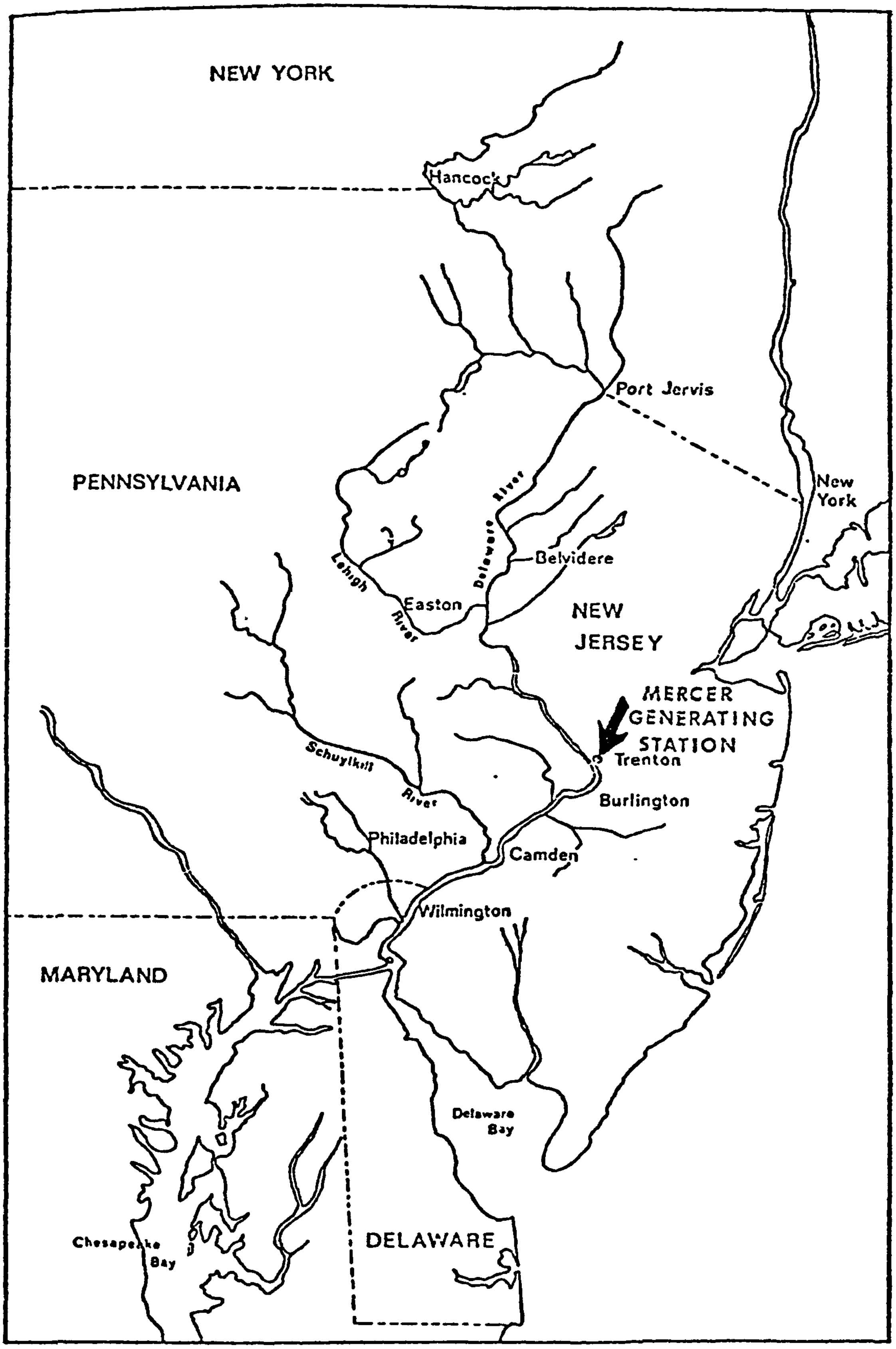


Figure 1. Map of the Delaware River Drainage Basin Showing the Location of the Mercer Generating Station

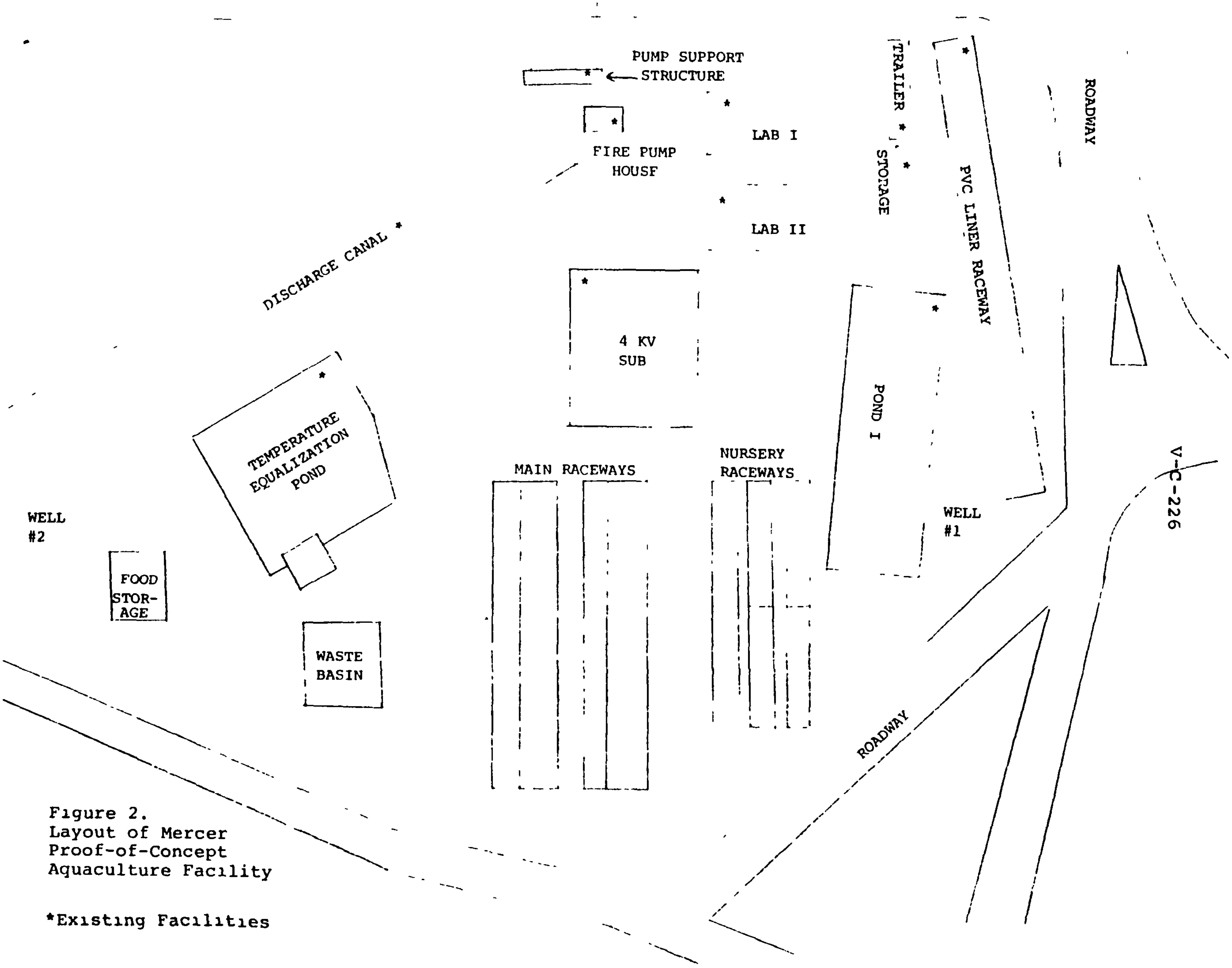


Figure 2.
Layout of Mercer
Proof-of-Concept
Aquaculture Facility

*Existing Facilities

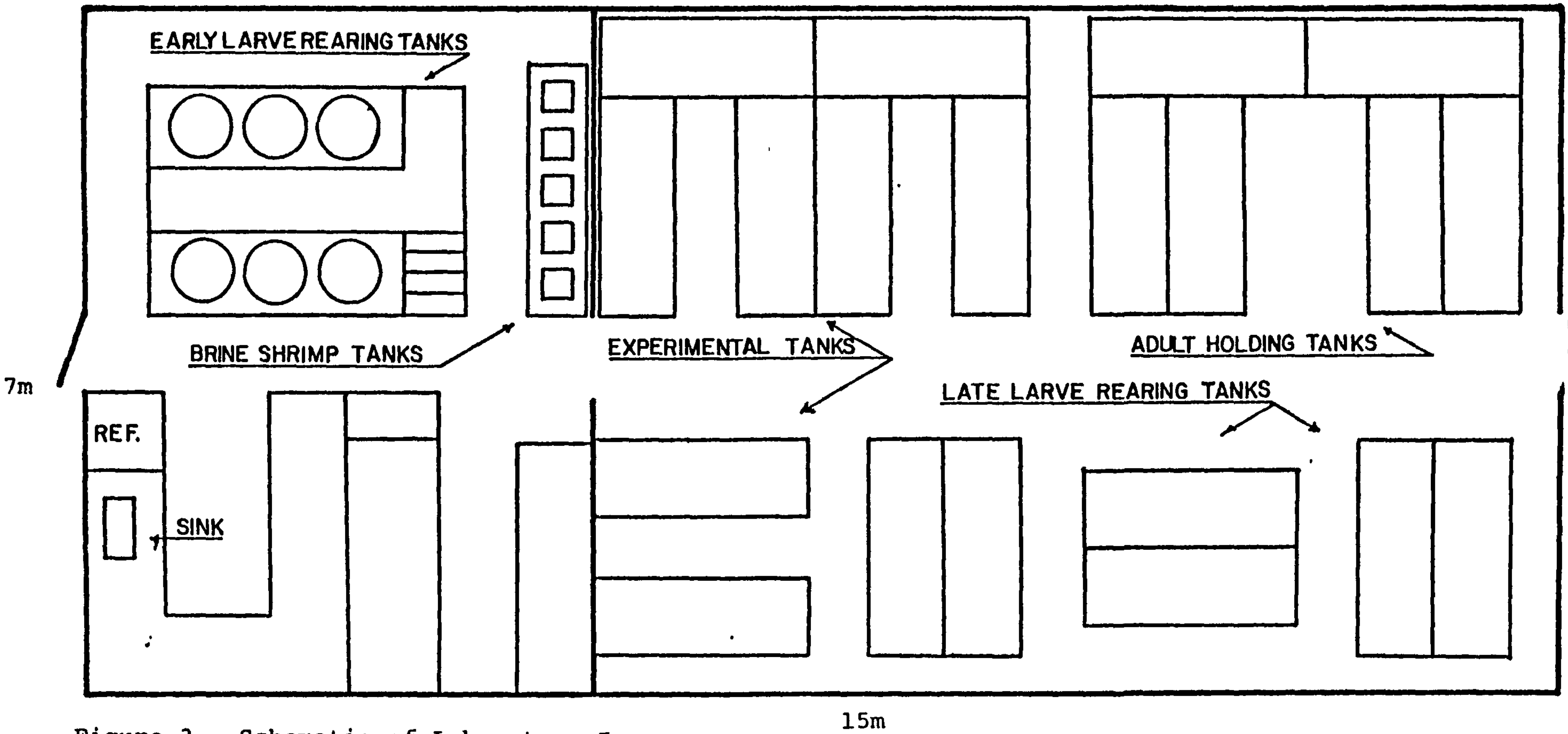


Figure 3. Schematic of Laboratory I

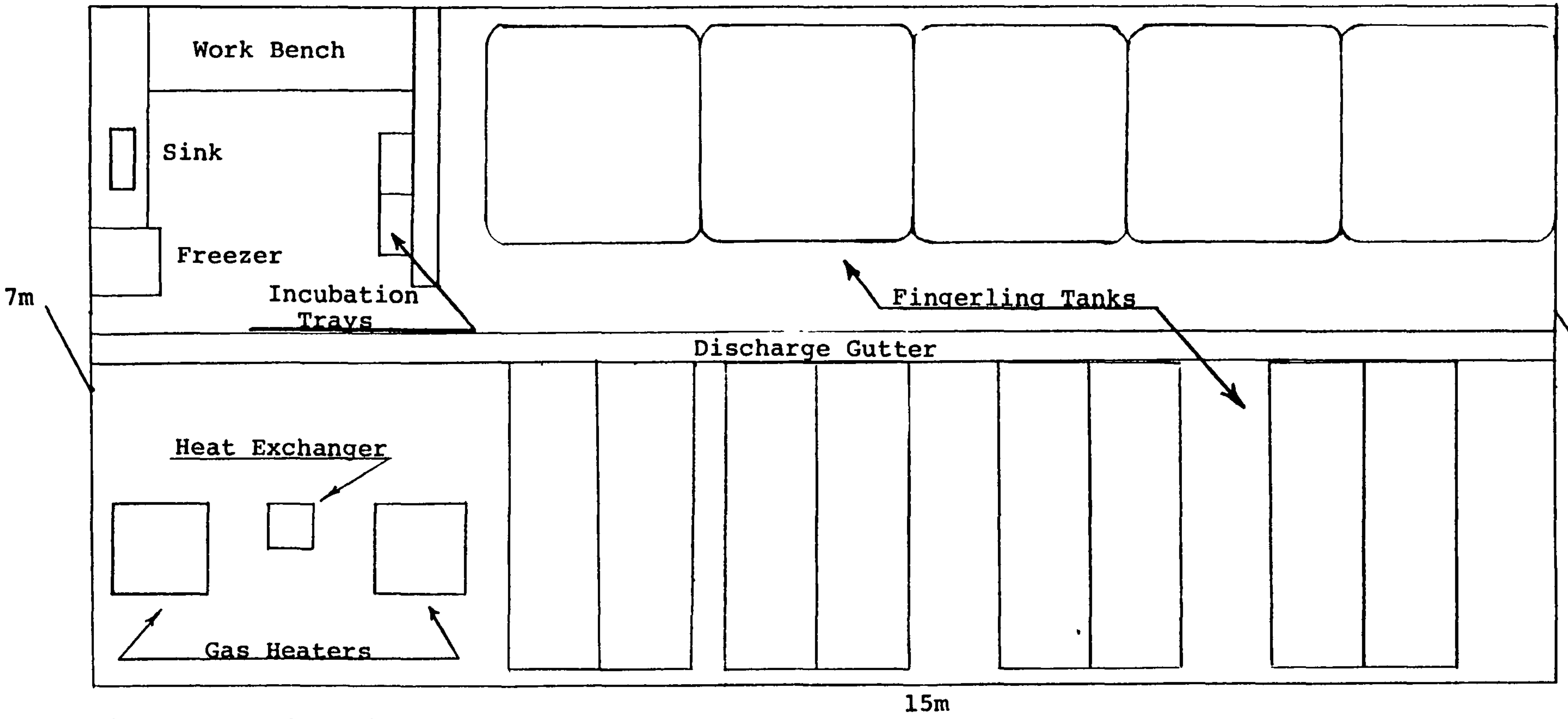


Figure 4. Schematic of Laboratory II

V-C-228

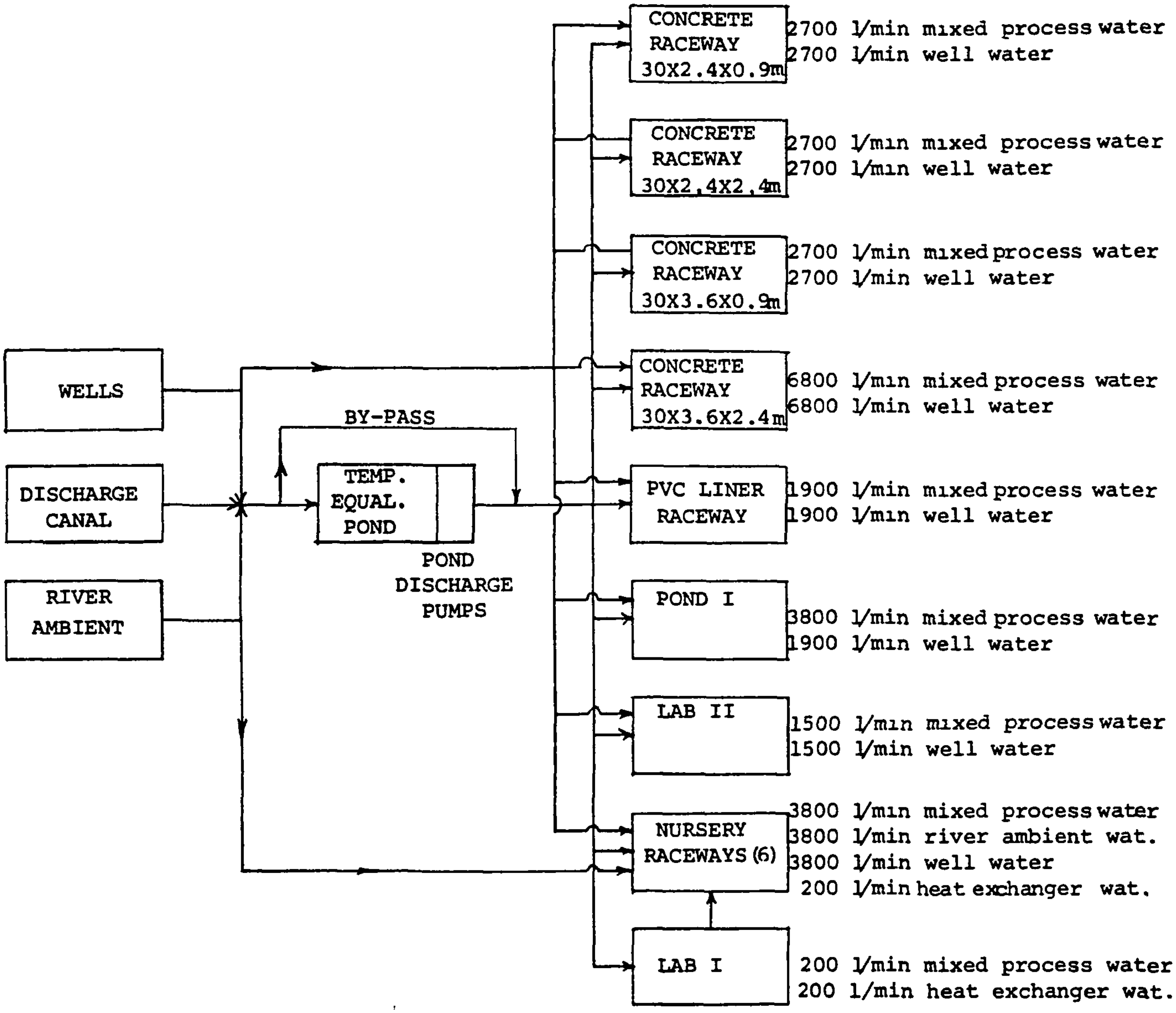
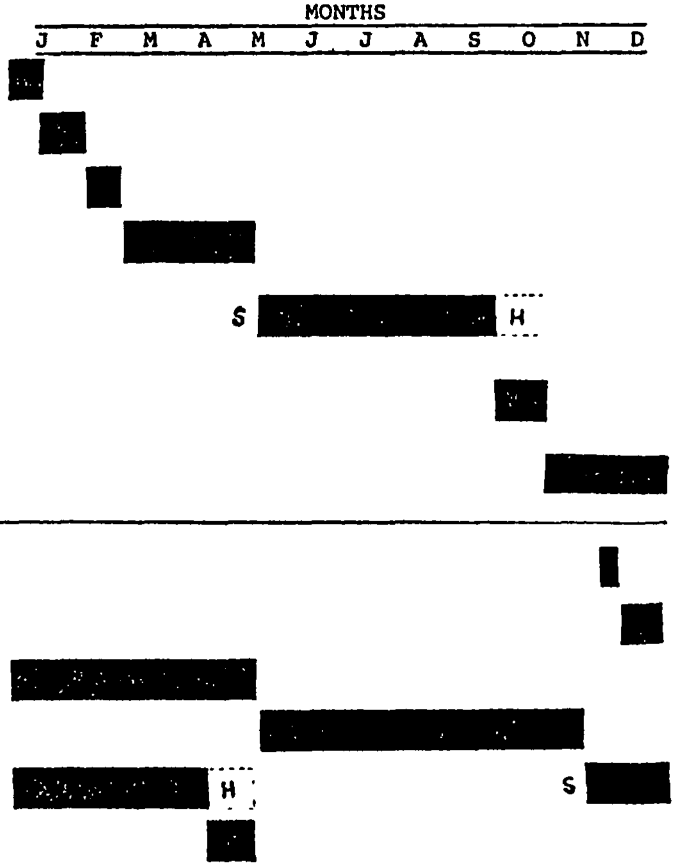


Figure 5. Simplified Flow Schematic of the Mercer Aquaculture Facility

ACTIVITY	LOCATION
MACROBRACHIUM ROSENBERGII	
1. Brood Stock Spawned	Laboratory I
2. Eggs Hatched	Laboratory I
3. Larval Cycle Completed	Laboratory I
4. Post-Larvae Grow Out	Insulated Nursery Raceways
5. Juvenile Grow Out (2-5 cm at Stocking)	Outdoor Ponds and Raceways
6. Harvest	Outdoor Ponds and Raceways
7. Brood Stock Recruited and Maintained	Laboratory I
SALMO GAIRDNERI	
1. Eyed Eggs Received	Laboratory II
2. Eggs Incubated and Hatched	Laboratory II
3. Early Fry Reared	Laboratory II
4. Fry Grow Out (9 cm at Stocking)	Nursery Raceways
5. Fingerling Grow Out (20 cm at Stock.)	Outdoor Ponds and Raceways
6. Harvest 30 cm Trout	Outdoor Ponds and Raceways



S = START, H = HARVEST

Figure 6. Sequence of Shrimp and Trout Culture Operations at the Mercer Aquaculture Facility

TABLE I. PROCESS WATER FLOW ALTERNATIVES (LITERS/MIN.)

Process Unit	Mixed Process[1] Water (Max. Inflow)	Ambient River Water (Cap. 3800 l/m)	Well Water (Cap. 3800 l/m)	Heat Exchanger Water (Cap. 200 l/m)	Station Heated Effluent (Cap. 17,400 l/m)
Laboratory I	200	-	-	200	-
Laboratory II	1,500	-	1,500	-	-
Existing Raceway (50m X 2.4m X 0.9m)	1,900	-	1,900	-	-
Pond I	3,800	-	1,900	-	-
Temperature Equalization Pond (Pond II)	25,000[2]	3,800	3,800	-	17,400
Concrete Raceway (30m X 2.4m X 0.9m)	2,700	-	2,700	-	-
Concrete Raceway (30m X 2.4m X 2.4m)	6,800	-	3,800	-	-
Concrete Raceway (30m X 3.6m X 0.9m)	2,700	-	2,700	-	-
Concrete Raceway (30m X 3.6m X 2.4m)	6,800	-	3,800	-	-
6-Nursery Raceways (12.2m X 1.8m X 0.9m)	3,800	3,800	3,800	(200)[3]	-

1. Obtained by blending of plant discharge water, ambient river water and well water as needed.

2. Equalization pond throughput capacity is presently only 15,000 l/m.

3. This heated water is derived from the Laboratory I discharge.

TABLE II. SUMMARY OF FACILITIES FOR TROUT AND PRAWN PRODUCTION

					Trout		Shrimp	
Grow-Out Facilities	No.	Dimensions (m)	Area (m^2)	Volume (m^3)	No. Stocked	Harvest (kg)	No. Stocked	Harvest (kg)
Main Raceway	1	30m X 2.4m X 0.9m	73	66	13,200[1]	4,545[7]	8,800[6]	191[8]
Main Raceway	1	30m X 3.6m X 0.9m	110	99	13,200[1]	4,545[7]	13,400[6]	282[8]
Main Raceway	1	30m X 2.4m X 2.4m	73	176	26,200[1]	9,090[7]	22,600[6]	475[8]
Main Raceway	1	30m X 3.6m X 2.4m	110	264	26,200[1]	9,090[7]	35,400[6]	745[8]
Pond I	1	27m X 7.6m X 0.9m	209	188	13,200[1]	4,545[7]	27,000[6]	567[8]
PVC Liner Raceway	1	50m X 2.4m X 0.9m	120	108	13,200[1]	4,545[7]	-	-
				TOTALS	92,400	36,360	107,200	2,260
Nursery Facilities								
Hatchery Building (Lab I)	1	6.7m X 14.6m	98	-	-	-	300,000[4]	-
Hatchery Building (Lab II)	1	6.7m X 14.6m	98	-	125,000[2]	-	-	-
Nursery Raceways	6	12.2m X 1.8m X 0.9m	131	118	100,000[3]	-	175,000[5]	-

Notes

1 - 20cm fingerlings (10.7 animals/kg)
2 - eyed-larvae to yolk-sac fry
3 - 9cm fingerlings
4 - fertilized eggs to newly metamorphosed post larvae
5 - 1cm PL shrimp stocked at 214 animals/m^2; draped netting added to increase total surface area
6 - 5cm to 6cm shrimp juveniles at 22 animals/m^2; draped netting (approximately 0.3m apart) added to increase total surface area
7 - 30cm trout - 380 g average individual weight @ 1.3kg trout/liter/min. to 2.4kg/liter/min.
8 - 14cm shrimp - 30 g average individual weight @ 16 animals/m^2 of total surface area