DOE/R4/10483--T1

DE84 000390

FINAL REPORT

TITLE: Feasibility of Using Hydrothermal Resources in Malaysian Prawn Aquaculture.

GRANTOR: U.S. Department of Energy, Appropriate Technology Small Grants Program, Contract No. DE-FG4481R410483

GRANTEE: S. C. Wildlife & Marine Resources Department
P. O. Box 12559
Charleston, South Carolina 29412

DATE: August, 1982

PREPARED BY: Theodore I. J. Smith, Raymond J. Rhodes, and Allen W. Wannamaker

DISCLAIMER

TABLE OF CONTENTS

SUMMARY

This project examined the potential application of geothermal resources in South Carolina for freshwater prawn aquaculture. Such geothermal resources are currently successfully used to commercially culture a variety of fishes. In coastal S.C. 23 existing geothermal well sites were identified which encompassed an area which ranged from Georgetown to Beaufort. These wells were owned by city, state or federal governments or by private developers. Depth averaged ~615 m while temperature averaged ~ 37°C. Artesian flow rates varied from 190-2,650 l/min. Detailed water quality analyses were conducted at 12 sites. In general, major differences from surface waters were in chorides, fluorides, dissolved solids, ph, alkalinity, and ammonia levels.

A detailed replicated laboratory study was conducted to examine the effect of geothermal water on growth and survival of prawns. After 42 days very poor survival was recorded from the various 100% geothermal water treatments. However, 50:50 mixture of shallow well water and geothermal water resulted in a survival rate of 83%, which was similar to the control treatments. Growth was also similar to that observed among the control animals.

Next, a large scale on-site study was initiated at a Mt. Pleasant site which had both shallow well water (control) and geothermal water readily available. Treatments consisted of various dilution rates for the geothermal water. After 44 days poorest growth and survival (69%) were observed in the 100% geothermal water treatment. However, treatments consisting of 75% and 50% geothermal water provided results similar to those obtained in the shallow well water treatment (control). Survival in these two treatments averaged 95%. Thus, at least on a short-term basis, a dilution rate of only 25% appears satisfactory in an outdoor system.

In South Carolina there appears to be no major legal impediment to using geothermal resources. Such resources are classified as groundwater, and usage

is governed by applicable groundwater laws. Use of geothermal water to heat indoor nursery systems for prawns would probably be the best application for prawn aquaculture in temperate regions. However, the current cost of post-larval prawns is now already sufficiently high so as to greatly restrict the commercialization of prawn farming in temperate areas. Any additional cost to produce larger nursed juveniles would probably be economically prohibitive. If there were major reductions in postlarvae cost and/or market value of prawns increased substantially then geothermal water may be well suited for use in prawn aquaculture.

INTRODUCTION

In the past, there has been little development and utilization of geothermal energy resources in the United States. Today however, the scope and intensity of development efforts as well as the variety of applications under investigation suggests that geothermal energy can become a substanital energy source in certain areas of the United States. Historically, geothermal energy was used around the turn of the century to heat health spas and baths and some of the associated resort facilities. Later, usage was expanded to include residential and commercial space heating requirements and some agricultural applications. However, during the period 1930 to 1970 few additional development activities were initiated as oil and natural gas became readily available and served as inexpensive fuels. This remained the situation until the mid 1970's when petroleum and gas fuels became scarce and expensive. As a consequence, research and development efforts were encouraged to explore and develop alternate energy sources, including geothermal resources.

Today, innovation exploration and development of geothermal resources is underway in the United States. Projects involving utilization of geothermal energy are quite diversified and include: district heating (Allen, 1980;

Glazner, 1981; Vorum and Petterson, 1981), ethanol production (Hewlett et al., 1981; Uhrmacher, 1981), agricultural uses (Zeller et al., 1980; Robinson et al., 1981), use by metal industries (Davis et al., 1980; Erickson, 1980), waste water treatment (Racine and Larson, 1981), and a variety of other uses (Childs et al., 1980; Larson and Willard, 1980; Walker and Entingh, 1981).

Classification of Geothermal Energy

Geothermal energy is thermal energy which is contained in the earth's crust. The heat sources for this thermal energy have been classified by the United States Geological Survey (USGS) into three broad systems as follows (White and Williams, 1975):

1. Hydrothermal convection systems - the energy is transmitted by the convective circulation of water or steam in an aquifer rather than just by conduction through solid rocks.

2. Hot-igneous systems - the thermal energy is associated with recent or active volcanism.

3. Conduction-dominated systems - in the absence of previously described systems, the temperature of the earth's crust increases approximately linearly with depth due to the conduction of energy deep within the earth.

In general, the anomalous heat of the hydrothermal convection and hot igneous systems has been described as "hot spots" superimposed on regional conduction dominated environments (White and Williams, 1975). In comparison, the quantity of heat stored in the conduction-dominated environments is enormous and estimated to provide 98% of the heat content of the U.S. geothermal resource base.

In addition to the USGS geothermal resource classification, Costain et al. (1980) identified heat generated by normal radioactivity of rocks, mainly in the upper crust, as a local heat source for hydrothermal resources in the eastern United States. This geothermal resource, which is derived from radiogenic activity, may exist at a relatively shallow depth in the Appalachian Mountain System and the Atlantic Coastal Plain.

According to Costain (1979), the optimal location for the development of hydrothermal resources in the eastern United States will probably be associated with flat-lying, relatively unconsolidated sediments that underlie the Atlantic Coastal Plain. These sediments are relatively poor heat conductors (i.e., good insulators). Further, many potential aquifers may exist within the deeper, sandy parts of the sedimentary section which probably contain large quantities of hot water. If such sediments cover a radiogenic heat producing granite, then abnormally warm groundwater could be encountered at relatively shallow depths.

Geothermal Resources in Coastal South Carolina

Much of South Carolina's Coastal Plain has been classified as an area of inferred subsurface geothermal waters (Samuel, 1979). This inference by the USGS includes observations of above normal conductive thermal gradients (29°-37°/km) in coastal wells. Using Costain's classification, the source of South Carolina's geothermal water is the water-saturated sediments of low thermal conductivity overlying radioactive heat-producing granites.

Background and Objectives of Project

Malaysian prawns, *Macrobrachium rosenbergii*, have a number of desirable characteristics for aquaculture: they grow rapidly and are tolerant of a wide variety of environmental conditions; they are omnivorous; and their life cycle can be controlled in the laboratory and young produced on demand. However, this species is tropical and therefore very sensitive to environmental temperatures. Maximum growth occurs at $\geq$ 26°C while little or no growth is observed at ≤ 21°C. Prawn mortality results at temperatures ≤16°C.

Due to the temperature requirements of this species, commercial prawn aquaculture has developed in tropical areas where year-round growing conditions permit the continuous production of large prawns (∿22/kg) from earthen grow-out ponds (Goodwin and Hanson, 1975; Ling and Costello, 1976; Hanson and Goodwin, 1977). However, substantial interest also exists in more temperate areas where prawns can be produced on a seasonal basis (Sandifer and Smith, 1976; Cohen, 1976; Smith et al., 1976, 1978, 1982; Willis and Berrigan, 1977). Here, grow-out period varies from 5-7 months and all animals are "batch harvested" before the onset of lethal winter temperatures.

The S.C. Wildlife and Marine Resources Department's Marine Resources Research Institute has been involved in a development program which has demonstrated the technical feasibility of producing these freshwater prawns, M. rosenbergii, by stocking juveniles and/or postlarval prawns in outdoor ponds and growing them for 5-6 months. Preliminary economic analyses have indicated that the current technology may be commercially attractive under certain conditions (Sandifer et al., 1980; Bauer et al., 1982). However, the cost of maintaining suitable temperatures in indoor nursery systems using conventional energy sources is a significant impediment to the profitability of temperate zone prawn aquaculture.

Heat conservation and production techniques (e.g., pond covers, solar water heaters) have been attempted by aquaculturists, but so far these passive methods have shown only limited success for temperature sensitive species such as prawns. The report of the "Low Level Waste Utilization Project, Savannah River Plant" by the S.C. Energy Research Institute indicated that there was potential for development of successful commercial culture of Macrobrachium in South Carolina utilizing low level waste heat. However, the Savannah

River Plant heated effluent was not considered acceptable due to the legal constraints associated with food and drug regulations governing the direct use of cooling water effluent from nuclear production reactors and the apparent inefficiencies of heat exchangers for maintaining pond water temperatures.

An idea development project was submitted to the U.S. Department of Energy, Appropriate Technology Small Grants Program, to test the potential application of geothermal resources for prawn aquaculture in South Carolina. This project was accepted and had a number of objectives including: 1) identification and characterization of coastal geothermal waters; 2) experimentation to provide preliminary assessment of biological feasibility; 3) an analysis of legal and economic considerations associated with development of geothermal resources in South Carolina; and 4) an evaluation of the preliminary commercial feasibility of prawn farming if acceptable waters are identified. This report summarizes the findings of these various objectives.

Geothermal Aquaculture in the U.S.

There is reasonable potential for incorporation of geothermal resources in aquaculture in the United States. Use of this hydrothermal resource in aquaculture operations can produce a number of advantages including: reduced fuel and pumping costs; maintenance of optimal rearing temperatures; expansion of suitable farming sites for both indigenous and non-indigenous species; and development of local specialty markets.

In the United States a number of species are being farmed either experimentally or commercially using geothermal resources. Below is a brief summary of various species being rearing in geothermal water and some associated U.S. aquaculture ventures.

Channel Catfish - Two catfish aquaculture firms in the United States, Fish Breeders of Idaho, Inc., and CalAqua, Inc., of California, directly use geothermal water. Fish Breeders is located in the Snake River Canyon near Buhl, Idaho. Their concrete raceway facilities use five artesian geothermal wells that supply 7,000 gal/min of 90°F (32°C) water which is mixed with cold water to produce a satisfactory water temperature (Ray, 1981). Fish Breeders maximum recommended commercial stocking density is about 10,000 to 15,000 lbs. per second-foot of water (Ray, 1981).

CalAqua near Paso Robles, California, employs geothermal water mixed with cool water to produce a stable 84°F (29°C) rearing temperature. Channel catfish are raised in a series of circular tanks arranged in a parallel system which receives the mixed 84°F water. The oxygen system used by CalAqua is comprised of a side-spare liquid oxygen unit capable of injecting more than 25 liters of oxygen per minute at 1.2 kilowatt of energy output (Conte, 1981). During two years of commercial production, CalAqua has been able to grow 2" fingerling channel catfish to market-size fish (1½-lb) in nine months (Conte, 1981). Normally, a two-year growing season is required in conventional catfish farming operations.

Freshwater Prawns - In contrast to the farming of catfish, culture systems for raising the tropical freshwater prawn, *Macrobrachium rosenbergii*, in geothermal water are still being developed. The largest commercial development venture is AquaFarms International, Inc. This prawn culture facility is located on approximately 250 acres of land in the Dos Palmas area, Coachella Valley, California. Geothermal artesian pressure wells (82°F-107°F) are being used to develop about 50 acres of ponds (U.S. Department of Energy, n.d.).

Trout - The successful Idaho trout aquaculture industry has been sustained by an ample supply of low-grade geothermal water from artesian wells. Natural spring waters, 50°-59°F, are used to provide conditions for raising rainbow trout (McNeil, 1978).

Other Species - Fish Breeders of Idaho also commercially grows Tilapia species for U.S. markets. Other warm-water market species, including ornamental fishes like goldfish, have been considered for culture in geothermal water systems. Additionally, several sites in Alaska which have geothermal resources have been identified as possible locations for the establishment of salmon hatcheries (Ogle, 1977).

Identification and Characterization of Geothermal Resources in S.C.

The first step in evaluating the potential use of geothermal water for prawn aquaculture in South Carolina involved identifying the various well sites in the Coastal Plains Region. A partial listing of 23 deep wells and test holes was obtained from the South Carolina Water Resources Commission (Table 1, Fig. 1). In general, such wells were owned by city government, the federal government, or by private developers. Depth averaged ∿ 615 m (range, 457-1,052 m) while temperature averaged ∿ 37°C (range 32-43°C). Artesian yield of these wells was quite variable and ranged from 190-2,650 l/minute. Based on well head temperatures, these hydrothermal resources were considered low grade; however, such temperatures are above optimal prawn rearing temperatures (28-30°C).

The next step was to conduct in-depth water quality analyses at a variety of these well sites. Various contacts were established through which we were permitted access to the various wells (Table 2). Water quality analyses were conducted on-site using test equipment listed in Table 3. Data from these analyses were summarized and are shown in Table 4. Of particular biological interest were the pH, alkalinity, and ammonia levels. In the deep water wells these parameters were typically high with additional increases in pH levels (on the order of 0.5 to 1.0 pH units) observed within 1-2 days after the well water was placed in culture tanks. Additional detailed analyses were obtained from a private water quality testing lab (Parker Laboratory, Inc., Charleston, S.C.) and were compared with typical in-state lake waters, Lake Moultrie (Table 5). As can be seen, major differences were in chlorides, fluorides, alkalinity parameters, and total dissolved solids.

Biological Testing of Geothermal Water

After completion of the characterization phase a site was selected for on-site testing based on evaluation of water quality recorded from the various coastal wells. Walterboro was selected due to the relatively low alkalinity and ammonia levels and acceptable water temperature (Table 4). Permission was granted to set up a 100 l tank and run water to it. This tank was stocked on eight occasions over a 40-day period with small and large juvenile prawns. Throughout the study a number of logistical problems occurred which were associated with maintenance of water flow, temperature, oxygen, and feeding the prawns. In general, low survival rates prevailed and these were in part believed to be associated with the logistical problems involved in trying to maintain an on-site bioassay in Walterboro. Because of this experience and the lack of definitive data obtained we decided to conduct an in-depth replicated bioassay at our laboratory facilities in Charleston.

In this laboratory bioassay the water quality parameters pH, ammonia, and alkalinity were of primary interest. Geothermal water from Charleston wells was used as it was characteristic of most coastal geothermal water and was readily available. Treatments consisted of: (1) nonfiltered (static) geothermal water; (2) prefiltered geothermal water; (3) continuously filtered geothermal water; (4) nonfiltered tap water; (5) continuously filtered tap water; and (6) a continuously filtered 1:1 mixture of well water and geothermal water.

Filtration in all cases consisted of pumping the treatment water through a bed of clinoptilolite (particle size 3.7 mm, range 2-6 mm, volume 375 cm^2) contained in an aquaria filter. The clinoptilolite was used to reduce the ammonia concentration in the water (Bower and Turner, 1982). Each treatment was replicated in three 74 x 30 x 30 cm deep glass aquaria (75.7 l). All tanks in which water was filtered contained a tank mounted power filter (Living World Dyna-Flo Power Filter 150). In non-filtered treatment airlines were installed in each tank to aerate the water. Additionally, each tank contained 4,440 cm^2 of 2 cm^2 plastic mesh which was rolled and served as prawn habitat. Ten juvenile prawns (mean size 28.7 mm, 0.45 g) were stocked in each tank and fed Purina Marine Ration 25 once daily. Certain water quality parameters (temperature, pH, ammonia, nitrite) were measured daily while other parameters were less frequently monitored. Water quality test equipment used in this study is listed in Table 6.

Water quality was considerably different among the various treatments. In all the geothermal treatments pH and alkalinity levels were high (Table 7). PH was lowest in the tap water treatments (controls) but still relatively high. PH and alkalinity were at intermediate levels in the mixed well and geothermal water treatment. Total ammonia levels were high in all treatments. However, it is the un-ionized which is toxic and the percent un-ionized ammonia is highly dependent on pH and temperature levels (Table 8). It can be seen that as pH and temperature increase so does the percentage of un-ionized ammonia in solution. The amount of un-ionized ammonia was quite different initially with the controls containing only about 20% of the levels recorded in the geothermal treatments (Table 7).

Results of this laboratory study are summarized in Table 9. By the end of day 12 survival was poor in the 100% geothermal treatments but extremely good (100%) in all other treatments. On day 24 the prawns reared in 100% geothermal water had all died except in the treatment where the water was continuously filtered. In this treatment survival was only 23%. In the other treatments survival averaged almost 97%. At conclusion of the study (day 42) survival was still excellent in the treatment containing a 50:50 mixture of geothermal and well water. In the geothermal treatment with filtered water survival was only 17%. All surviving prawns had grown during the study. Mean size of prawns in the various treatments on day 42 were: geothermal filtered - 33.3 mm, 0.82 g; tap, no filter - 35.4 mm, 0.95 g; tap, filtered - 35.3 mm, 0.98 g; and geothermal/well mixture filtered - 34.9 mm, 0.88 g.

Examination of the water quality data suggests that there may be some interaction effects which caused the poor prawn survival. Although the unionized ammonia levels were high in the 100% geothermal treatments, some similarly high levels were also encountered in the mixed geothermal and well water treatment but the pH was slightly lower as was the alkalinity in this mixed water treatment. The results suggest that it was some combination of the high pH, alkalinity, and ammonia levels in the geothermal water that caused the high mortality. In summary, it should be noted that some prawns did survive in the 100% geothermal water but more importantly mixing the water with shallow well water markedly improved survival. Thus, it may be possible to use geothermal water for prawn farming if it is diluted with surface or shallow well water.

Mt. Pleasant Field Test

The results obtained from the laboratory study encouraged us to conduct a large scale field trial testing different dilution rates for the geothermal water. Permission was obtained to set up 5 500 gallon fiberglass tanks at a Mt. Pleasant pumping station which had both geothermal and shallow well water available. Five treatments were tested but because of the logistical problems no replications were possible. Treatments consisted of: 1) 100% geothermal water; 2) 75% geothermal water : 25% shallow well water; 3) 50% geothermal water : 50% shallow well water; and 4) 100% shallow well water (control). All tanks contained soil enough to cover the bottom of the tank so as to simulate pond conditions. One additional treatment at the 50:50 mixture level was included which contained no soil and which might provide information on the effect of soil to modify water quality conditions.

Each tank was stocked with 100 juvenile prawns (mean size 1.8 g, 43.1 mm) and valved so that the various geothermal water dilution rates could be obtained. Daily flow rates equalled about 3/4 tank exchanges/day. Besides the soil substrate in 4 tanks each tank was fitted with several artificial habitat units and aquatic macrophytes placed in each tank for supplemental feeding. Prawns were fed Purina Marine Ration 25 daily. Each treatment was sampled on day 22 and day 44. On these days all animals were removed and counted and about 25% of each population measured. Detailed water quality analyses were performed daily during the early part of the study and then weekly thereafter.

Water quality data for the various treatments at the beginning of the study and the average levels for the entire study are shown in Tables 10 and 11. The water from the shallow well was more typical of deep water as the pH, alkalinity, and ammonia levels were high when compared to surface waters or other shallow well waters in state. In spite of this problem we proceeded with the study as no other local geothermal well sites were as suited (location, space, water availability, electrical outlets, etc.) for our research needs. In general, water quality parameters throughout the study reflected the various dilution rates (Table 11). Total ammonia levels were high in all treatments, but the amount of un-ionized ammonia was relatively low in the shallow well treatment when compared with the other treatments. Increases in weight were recorded in all treatments; however, poorest growth was recorded from the 100% geothermal water treatment (Table 12). Growth in the 75% and 50% geothermal water treatments was similar to that recorded in the control treatment (shallow well water).

Survival rates were quite satisfactory on day 22 and ranged from 91.0 to 98.0% for all treatments. However, by day 44 a substantial decrease in survival was observed among prawns reared in the 100% geothermal water treatment. Nevertheless, survival rate was 69% in this treatment and this is considerably better than that observed in the previous indoor study using 100% geothermal water. Survival rates among the other treatments were excellent and ranged from 94.0 to 97.0%. There was no apparent effect of lack of bottom soil on survival or growth rate.

Results of this study are very encouraging and suggest that prawns can be cultured in geothermal water which is diluted with surface water or with shallow well water. Further, it can be assumed that when prawns are reared under more natural conditions some of the deleterious effects of certain characteristics of geothermal water will be ameliorated.

Additional research will be needed to more closely define dilution rates and specific and interative water quality parameters of particular biological significance in geothermal water. Further, longer term studies will need to be conducted to verify the finding of the short term studies.

Legal Aspects of Utilizing Geothermal Water

Greater volumes and higher quality (warmer water) hydrothermal resources generally exist in the western states. Further, development and utilization of such resources has been more widespread than in the eastern states. Thus, most of the western states have enacted laws which address the utilization of geothermal resources for the production of electricity. In contrast, the geothermal resources in the eastern states are usually inadequate for the generation of electricity and so legislation in the east is generally quite different.

In 1976, there were no laws in the eastern states specifically regulating utilization of geothermal resources, nor were the legal issues associated with this energy source even under consideration. Beginning in 1978, with support of the Department of Energy, the National Conference of State Legislatures (NCSL) began to offer assistance to selected state legislatures interested in developing geothermal legislation. In part as a result of this effort the following legislation was enacted in certain states:

Maryland - The State of Maryland passed the Geothermal Resources Act in 1978 and in 1981 passed several amendments to this Act, together with amendments to other acts to clarify and aid in the development of geothermal energy. The original act was passed prior to any effort by NCSL.

Virginia - The State of Virginia passed a Geothermal Resources Act in the 1980-1981 Legislative Session.

Delaware - The State of Delaware's legislature passed a Geothermal Resources Act in 1980, but it was vetoed by the Governor. A revised bill was not reported out of committee in 1981. However, the issue was to be considered in the next legislative session.

Geothermal resources are normally classified either as a groundwater or as a mineral resource. This distinction in classification is particularly important as the laws regulating its usage vary considerably depending on the resource classification. In general, geothermal resources suitable for residential, commercial and agricultural uses are considered groundwater resources while deep, hot systems suitable for electrical generation or industrial process heat are usually defined legally as mineral or unique resources.

Definition of a hydrothermal resource as a water or mineral resource may affect ownership status. Mineral ownership originates from an estate in land, which may be "severed" from property rights to overlying surface area. In contrast, groundwater is generally held to be an aspect of surface ownership in the eastern states. Finally, mineral resources are often leased and subject to royalties and/or severance taxes while groundwater usage is generally free if it is located on your property.

Pertinent S.C. Groundwater Laws

In South Carolina there are no specific laws regulating the use of geothermal resources. Thus, geothermal waters would be classified as groundwater and the laws and regulations governing use of groundwater resources would apply. In the east, statutory systems generally require water pumping permits which are issued by various administrative agencies. In South Carolina the pertinent statute is the Groundwater Use Act of 1969 (Means, 1975). This Act empowers the South Carolina Water Resources Commission to designate from time to time certain areas of the state as capacity use areas, when the Commission determines that such designation is necessary to protect ". . . the interests and rights of residents or property owners of such areas or of the public interest." The Act requires that those persons using groundwater in a capacity use area submit reports stating the quantity of the water pumped, the source from which it came and the purposes for which it is to be used. The Act further requires that any person withdrawing $\geq$ 100,000 gallons of water per day to obtain a permit from the Commission authorizing such usage. The Act is inapplicable to wells intended for domestic use of single family dwellings.

In addition to the Groundwater Use Act, Governor Richard W. Riley signed into law on February 24, 1982, the Water Use Reporting and Coordination Act (S-242). The purpose of the law is to gather and make available information on the uses being made of South Carolina surface and groundwater resources by major water users (Anonymous, 1982). All users, including industry, agriculture, municipalities and utilities, where 100,000 gallons per day or more are used, will be required to report their use to the State. Reporting will be on a quarterly basis for all uses except agriculture, which shall report annually. Agricultural reporting during droughts may be on a quarterly basis if drought conditions become severe. As a provision in the law, well drillers and contractors will be required to provide to the State copies of well logs for all wells four inches in diameter or greater, except for wells intended for single family domestic use which are excluded from this requirement.

The 1982 Water Use Reporting and Coordination Act will not be implemented until the 1983 General Assembly approves regulations and rules for reporting on water use (Brooks, 1982). This Act will be administered by the South Carolina Water Resources Commission and will result in reduced report requirements to various state agencies.

Permitting S.C. Aquaculture Operations

Depending on specific site location, water use requirements, and discharge considerations various permits may be required. Most likely freshwater aquaculture activities would not occur within "critical areas" as defined by the

S.C. Coastal Council. Such areas include tidelands, beaches, and primary ocean front sand dunes (Bara et al., 1977). If development activities are intended within such "critical areas" of the coastal zone, then a permit would be required from the S.C. Coastal Council. Additionally, certain coastal counties including Horry, Georgetown, Collecton, Jasper, and Beaufort have been designated as "capacity use areas". As such, the S.C. Water Resources Commission presently has authority over wells with rated capacities of 100,000 gallons/day or more within capacity use areas (Chesley, 1982). Thus, aquaculture operations planning to locate within a "capacity use area" would need to obtain a permit to withdraw $\geq$ 100,000 gallons/day from their well.

In cases where construction of facilities or other activities occur involving: land below the mean high water line in tidally influenced areas; submerged lands in tidally influenced areas; or land below the ordinary high water line on any navigable waterway in non-tidal areas, there would be a requirement of a permit from the State Budget and Control Board (Bara et al., 1977). This permitting function is administered by the S.C. Water Resources Commission.

A permit from the U.S. Army Corps of Engineers (USACOE) is required for any type of construction or other alterations in navigable waters of the United States, including all coastal waters and contiguous or adjacent wetland as well as inland rivers, lakes and streams that are naviable waters and their contiguous or adjacent wetlands. This includes all navigable waters and all tributary streams having a flow of five cubic feet per second or greater and their contiguous or adjacent wetlands and all eligible lakes (Bara et al., 1977). The USACOE permit requires a SCDHEC 401 Water Quality Certification. Because the aquaculture technology under consideration would probably not involve navigable waters, none of the USACOE permits would be required.

At present, there are no laws or regulations which would require a permit for construction or use of a well if the well water is not intended for a public water supply system. However, in 1983 standards for well construction developed by the S.C. Department of Health and Environmental Control are expected to be promulgated under the S.C. Safe Drinking Water Act (D. A. Duncan, SCDHEC, personal communication). Consequently, any new well construction for non-domestic use will have to conform to the SCDHEC construction standards to insure protection of the groundwater source.

Depending on discharge characteristics, the aquaculture operator may be required to obtain a discharge permit. A discharge permit is issued by SCDHEC in conformance with the National Pollutant Discharge Elimination System (NPDES) for point source discharges to waters of the State. The permit contains effluent limitation setting the amount of pollutants that may be discharged and also contains monitoring requirements. The effluent limitations are based on applicable effluent guidelines promulgated by the U.S. Environmental Protection Agency and on State Water Quality Standards.

Under the NPDES regulations (40CFR 45, No. 98, May 19, 1980) concentrated aquatic animals production facilities used in culturing warm water species would be required to obtain a discharge permit if they discharged more than 29 days per year and produced more than about 100,000 pounds of aquatic animals per year. However, at present it is assumed that in the near future production facilities would not have the above characteristics consequently, no NPDES discharge permit would be required.

Economic Feasibility Analysis

A direct-user of geothermal water does not sell energy to others. Instead, the geothermal direct-user reduces conventional fuel costs. The real benefit from geothermal water use is the value of fuel costs avoided less the operating costs (e.g., pumping costs, maintenance, etc.) incurred in using the geothermal water.

If there is an incremental savings to the aquaculture venture through conversion to geothermal well water, the savings should be evaluated like the revenue from any ordinary investment. Consequently, to realistically evaluate the net worth of the stream of incremental savings expected to result from a geothermal investment, a discounted cash (savings) flow (DCF) method should be used. DCF methods like net present value and internal rate of return take into account the time value of money (Solomon and Pringe, 1980). Even with sophisticated DCF methods which include risk premiums, the desirability of such a system is ultimately judgemental. As in all investment opportunities, an aquaculture investment decision will be a subjective one based upon the investors' personal preferences in addition to comparative risks and returns of alternative investments (Walker and Gates, 1981).

Significant growth in the freshwater prawn industry has occurred in Hawaii, Taiwan and Thailand in recent years (Sandifer, 1981). Hawaiian production has risen from about five metric tons in 1974 to nearly 14 metric tons in 1980. In 1981 there was a slight decline in production to 12 metric tons (Morison et al., 1981). Favorable climate, strong local market demand, and a state supported hatchery has contributed substantially to the growth of the Hawaiian prawn industry.

As previously discussed, the seasonal nature of the prawn growing period constitutes serious biological and economic constraints to the successful commercialization of prawn aquaculture in temperate climates (Smith et al., 1981). Despite the climatic constraints, past investigations have suggested that <u>Macrobrahchium</u> prawn farming has potential as an alternative agricultural option in coastal South Carolina (Roberts and Bauer, 1978; Sandifer et al., 1980). The highest profit potential was predicted for stocking large, nursery-reared juveniles in South Carolina farm ponds (Sandifer et al., 1980). This potential was based upon using a "seed" cost of $30/1,000 or less and developing a specialty market for large whole prawns. Unfortunately, just the cost of postlarvae necessary to produce large juveniles recently increased to ≥ $30/1,000. Additionally, information on the nursery costs to produce larger juveniles is lacking but a cost equal to that of the postlarvae cost is probably reasonable. Thus, irrespective of the nursery costs, the current cost of postlarvae is such that profitable farming may be tenuous at best. We believe that the use of geothermal water may reduce nursery costs compared to conventional energy costs. Consequently, if postlarvae cost declines in the future and/or prawn market value increases substantially then geothermal water may play an important role in prawn aquaculture in temperate climates. At present, commercialization of prawn aquaculture in South Carolina appears questionable. Also, additional biological testing will be required to fully identify the best methods for incorporating South Carolina geothermal water into prawn aquaculture.

Additional economic analysis is planned for examining cost-effective technology employing geothermal water for prawn aquaculture. However, this analysis is outside the present contract but should be completed next spring. In essence, it involves a project utilizing a class of graduate level engineers at Clemson University. Based on suggested parameters they will design an enclosed nursery system and estimate the nursery costs. Their work will include determining the best way to use the goethermal water (direct or indirect), most efficient tank or pond designs, best method of construction for the enclosure, energy transfer coefficients for the enclosure and nursery systems, etc. Both economists and biologists from the current D.O.E. project will be working with them on this project.

SUMMARY AND CONCLUSIONS

1. Numerous geothermal well sites were located and water quality data obtained and summarized.

2. Water quality parameters of particular biological consideration were pH, temperature, and alkalinity. All were elevated in geothermal waters.

3. Direct use of local supplies of geothermal water for rearing prawns appears biologically feasible if the geothermal water is diluted with surface or shallow well water.

4. Currently, there are no legal impediments to the utilization of geothermal waters and such resources are classified as groundwater resources in S.C.

5. The recent increase in cost of postlarval prawns limits the profit potential of farming this species even if geothermal resources are utilized in the nursery phase.

6. Geothermal water may have application for prawn farming in the nusery phase if postlarval prawn costs are reduced and/or crop value increases substantially. However, additional research is needed to determine the most cost effective technology for using geothermal water in a commercial production system.

7. A conference on the application of geothermal water resources to prawn aquaculture was convened in Charleston on May 27, 1982. The workshop facilitated exchange of information between project staff and potential user groups. Topics discussed included availability and quality of geothermal resources, biological testing, legal issues, environmental impacts, and economic considerations.

8. Additional dissemination of results by presentation at pertinent conferences and through publication in scientific journals is scheduled during the following year.

ACKNOWLEDGEMENTS

We greatly appreciate the assistance provided by a number of individuals who helped in various ways throughout the project. They are: Wally Jenkins, Frank Taylor - S.C. Wildlife and Marine Resources Department, Marine Resources Research Institute; Margaret Davidosn - S.C. Sea Grant Consortium; John Bettis - Commission of Public Works, Charleston, S.C.; Russell Campbell, Charles Bridges, Furman Renyolds - Sea Brook Island Company; Lee Baldwin, Don Moore - Mt. Pleasant Water Works and Sewer Commission; Wayne Fanning - Department of Health and Environmental Control; Ellison S. Kelly, Jr. - Medical University of South Carolina; David Ruth, Betty Phillip - Ft. Sumter National Monument; Drennan Park - S.C. Water Resources Commission; Mayor Wetsin Brooks - Edisto Island, S.C.; D. C. Haden - City of Walterboro, S.C.; and special thanks are due Buck Chapman - Governor's Divison of Energy who provided encouragement and assistance during this project.

LITERATURE CITED

Allen, E. M. 1980. Klamath Falls municipal district heating and reservoir management ordinance: A preliminary Oregon model ordinance. Geothermal: Energy for the Eighties, Geothermal Resources Council. 4: 759-762.

Anonymous. 1982. Water use reporting act becomes law. Palmetto Waters. 6(3): 3. S. C. Water Res. Commission, Columbia, S. C.

Bara, M. O., Tiner, R. W., and Newkirk, D. C. 1977. Guidelines for evaluating proposed wetland alterations in South Carolina. S. C. Wildl. & Mar. Res. Dept., Columbia, S. C. July, 1977. 36 p.

Bauer, L. L., Sandifer, P. A., and Smith, T. I. J. 1982. Economic feasibility of Macrobrachium production in South Carolina. S. C. Wildlife and Marine Resources Dept. (in review).

Bower, C. E. and Turner, D. T. 1982. Ammonia removal by clinoptilolite in the transport of ornamental freshwater fishes. Prog. Fish Culturist 44(1): 19-23.

Brooks, C. 1982. From the top. Palmetto Waters 6(7): 1. S. C. Water Res. Commission, Columbia, S. C.

Chesley, S. C. 1982. Coastal Summaries: A SCWRC Source Book. S. C. Water Res. Commission Rept. No. 135, Columbia, S. C. Jan. 1982. 194 p.

Childs, F. W., Jones, K. W., Nelson, L. B., Strawn, J. A., and Tucker, M. K. 1980. Progress in direct heat application projects. Geothermal: Energy for the Eighties, Geothermal Resources Council. 4: 549-552.

Cohen, D. 1976. The introduction of M. rosenbergii into Israel's fish ponds: The use of geothermal springs in heating the larviculture and nursery. Hebrew University, Jerusalem, Israel. 6 pp. (unpublished).

Conte, F. S. 1981. Intensive culture with limited resources. Calif. Aquaculture Newsletter: 81-3, U. of Calif., Davis. May, 1981: 2-4.

Costain, J. K. 1979. Geothermal exploration methods and results: Atlantic Coastal Plain. in A Symposium of geothermal energy and its direct uses in the eastern United States. Special Rept. No. 5, Geothermal Resources Council.

Costain, J. K., Glover, III, K. L., and Sinha, A. K. 1980. Low-temperature geothermal resources in the Eastern United States. EOS Transactions: Amer. Geophy. Union, 61(1).

Davis, A. E., Enderlin, W. I., Blahnik, D. E., Jacobson, J. J., and Weakley, S. A. 1980. Assessment of geothermal energy as a power source for U. S. aluminum reduction plants. Geothermal: Energy for the Eighties, Geothermal Resources Council. 4: 495-498.

Emerson, K., Russo, R. C., Lund, R. E., and Thurston, R. V. 1975. Aqueoues ammonia equilibrium calculations: Effect of pH and temperature. J. Fish. Res. Board Can. 32(12): 2379-2383.

Erickson, M. V. 1980. The utilization of geothermal energy in the mining and processing of tungsten ore. Geothermal: Energy for the Eighties, Geothermal Resources Council. 4:557-560.

Glazner, R. 1981. Modeling geothermal district heating systems. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 639-640.

Goodwin, H. L. and Hanson, J. A. 1975. The aquaculture of fresh water prawns (Macrobrachium species). Augmented summary of Proc. Workshop on Culture of Freshwater Prawns, St. Petersburg, Florida, The Oceanic Institute, Hawaii. 95 pp.

Hanson, J. A. and Goodwin, H. L. 1977. Shrimp and Prawn Farming in the Western Hemisphere. Dowden, Hutchinson & Ross, Inc. Stroudsburg, Pennsylvania. 439 pp.

Hewlett, E. M., Erickson, M. V., and Walter, K. M. 1981. The utilization of geothermal energy in production of fuel grade ethanol in the San Luis Valley, California. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 515-518.

Larson, T. and Willard, S. 1980. Market survey for industrial and commercial uses of geothermal energy in California. Geothermal: Energy for the Eighties, Geothermal Resources Council. 4: 731-734.

Ling, S. W. and Costello, T. J. 1976. Review of culture of freshwater prawns. FAO Tech. Conf. Aquaculture, Kyoto, Japan, 1976. Reference Paper 29. 12 pp.

McNeil, W. J. 1978. Overview in Geothermal Resources for Aquaculture. Oregon State U. Sea Grant College Prog., ORESU-W-78-0001: 29-31.

Means, D. H. 1975. Administrative law: Problems and potentials in water resources planning for South Carolina--Part A. Water Resources Research Inst., Clemson U., Clemson, S. C. Rept. No. 53.

Morrison, I. G., Kefford, N. P., and Haradd, W. T. 1981. Prawn aquaculture industry analysis. U. of Hawaii, Coll. of Trop. Agri. and Human Resources: Report submitted to the State of Hawaii Agr. Coord. Comm., Dec. 16, 1981. (photocopy). 27 p.

Ogle, W. E. 1977. Summary of geothermal energy application to aquaculture. Proc. of the 2nd Alaska Aquaculture Conference. Alaska Sea Grant Program, Sea Grant Rept. 77-7. July, 1977: 45-49.

Racine, W. C. and Larson, T. 1981. Feasibility of utilizing geothermal energy for waste water treatment in San Bernardino, California. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 557-560.

Ray, L. 1981. Channel catfish production in geothermal water. Bio-Engineering Symposium for Fish Culture (FCS Publ. 1): 192-195.

Roberts, K. J. and Bauer, L. L. 1978. Costs and returns for Macrobrachium grow-out in South Carolina, U.S.A. Aquaculture 15(1978): 383-390.

Robinson, F. E., Thomas, T. R., and Singh, K. 1981. Geothermal fluids to irrigate energy crops on Imperial East Mesa Desert, California. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 561-562.

Sammel, E. A. 1979. Occurrence of low-temperature geothermal waters in the United States, in Assessment of geothermal resources of the United States. L. J. P. Muffler, ed: U. S. Geol. Survey Circ. 790.

Sandifer, P. A. 1981. Recent advances in the culture of crustaceans. EMS/WMS Conf. on Aquaculture, Venice, Italy, Sept. 21-25. (in press).

Sandifer, P. A. and Smith, T. I. J. 1976. Experimental aquaculture of the Malaysian prawn, Macrobrachium rosenbergii (De Man) in South Carolina, U.S.A. FAO Tech. Conf. Aquaculture, Kyoto, Japan, 1976, Expressions Paper 3. 9 pp.

Sandifer, P. A. and Smith, T. I. J. 1978. Aquaculture of Malaysian prawns in controlled environments. Food Technol. 32(7): 36-38, 40-42, 44-45, 83.

Sandifer, P. A., Smith, T. I. J., and Bauer, L. L. 1980. Economic comparisons of stocking and marketing strategies for aquaculture of prawns, Macrobrachium rosenbergii (De Man), in South Carolina, U.S.A. Proc. Symposium on Coastal Aquaculture; Cochin, India. (in press).

Smith, T. I. J., Sandifer, P. A., and Trimble, W. C. 1976. Pond culture of the Malaysian prawn, Macrobrachium rosenbergii (De Man), in South Carolina, 1974-1975. Proc. World Mariculture Society. 7: 625-645.

Smith, T. I. J., Sandifer, P. A., and Smith, M. H. 1978. Population structure of Malaysian prawns, Macrobrachium rosenbergii (De Man), reared in earthen ponds in South Carolina, 1974-1976. Proc. World Mariculture Soc. 9: 21-38.

Smith, T. I. J., Sandifer, P. A., Jenkins, W. E., and Stokes, A. D. 1981. Effect of population structure and density at stocking on production and commercial feasibility of prawn (Macrobrachium rosenbergii) farming in temperate climates. Proc. World Mariculture Soc. 12(1): (in press).

Smith, T. I. J., Sandifer, P. A., Jenkins, W. E., Stokes, A. D., and Murray, G. 1982. Prawn rearing trials with private growers in South Carolina. Proc. World Mariculture Soc. 13: (in press).

Solmon, E. and Pringle, J. J. 1980. An Introduction to Financial Management. Goodyear Publ. Co., Inc., Santa Monica, CA. (2nd edition). 756 p.

Uhrmacher, J. C. 1981. Technical feasibility of use of eastern geothermal energy in vaccuum distillation of ethanol fuel. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 571-574.

Vorum, M. and Patterson, C. N. 1981. A feasibility analysis of geothermal district heating for LaReview, Oregon. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 575-582.

Walker, B. A. and Entingh, D. J. 1981. Status of U. S. direct utilization of geothermal energy. Geothermal Energy: The International Success Story, Geothermal Resources Council. 5: 577-582.

Walker, N. P. and Gates, J. M. 1981. Financial feasibility of high density oyster culture in saltmarsh ponds with artifically prolonged tidal flows. Aquaculture 22(1981): 11-20.

White, D. E. and Williams, D. L., eds. 1975. Assessment of geothermal resources of the United States--1975: U. S. Geol. Survey Circ. 726, 155 p.

Willis, S. A. and Berrigan, M. E. 1977. Effects of stocking size and density on growth and survival of Macrobrachium rosenbergii (De Man) in ponds. Proc. World Mariculture Soc. 8: 251-264.

Zeller, T. J., Grams, W. H., and Howard, S. M. 1980. Direct utilization of a moderate temperature geothermal resource in agribusiness. Geothermal: Energy for the Eighties, Geothermal Resources Couucil. 4: 633-636.

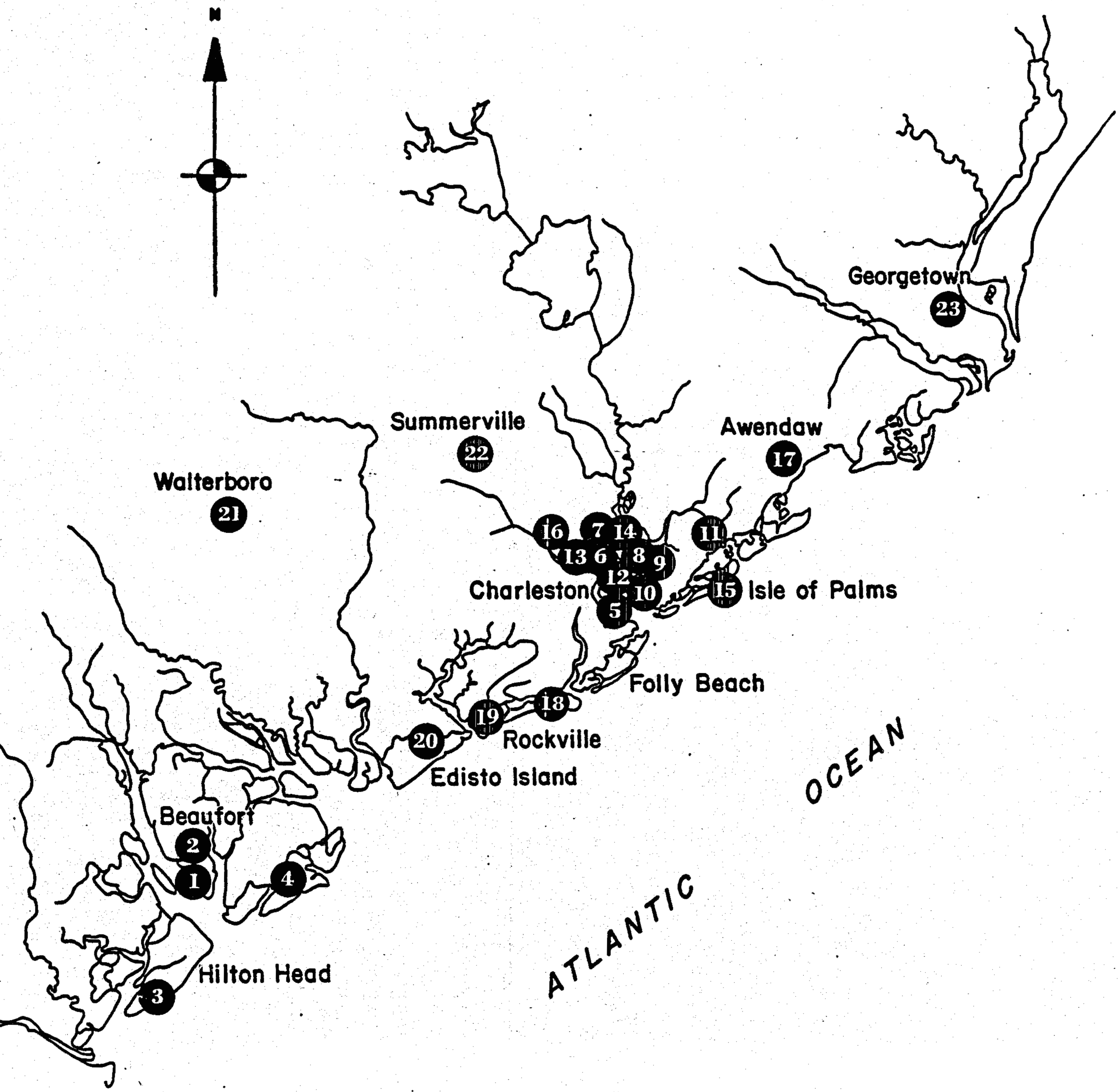

FIGURE 1. Map of coastal South Carolina showing location of geothermal wells.

Map No.	Location	Owner	Total depth (ft.)	Diam. (in.)	Depth to water (ft.)	Yield (gpm)	Temp (°F)	Aquifer
1	Parris Island	U. S. Government	3,450	12	+156	82		Tusc.
2	Parris Island	U. S. Government	2,700	18	+156	50	104	Tusc.
3	Hilton Head Is.	Sea Pines Corp.	3,114	8	Art.	50	108	Tusc.
4	Fripp Island	Fripp Devel. Corp.	3,147	24-12	Art.	50	104	Blk. Ck., Tusc.
5	Charleston	City	1,970		+46	465	97	Blk. Creek
6	Charleston	City	1,945	20	Art.	700		Blk. Creek
7	Fort Moultrie	U. S. Government	1,865		+82	350	95	Blk. Creek
8	Navy Yard	U. S. Government	2,136	20	Art.	500+	94	Blk. Creek
9	Mt. Pleasant	City	1,919	24-8	Art.		94	Blk. Creek
10	Mt. Pleasant	City	1,993	24-8	Art.			
11	Mt. Pleasant	City	2,286					
12	Charleston	City	1,970		92+	465	97	Blk. Creek
13	Charleston	City	2,000					Blk. Creek
14	Charleston	U. S. Government	2,067	12-6	Art.	365		Blk. Creek
15	Isle of Palms		1,919					
16	Charleston	Iron Gate Devel. Corp.	1,852	24-8	Art.	250		Blk. Creek
17	Awendaw	Bulls Bay Water District	1,984	16-8	Art.			Tusc.
18	Kiawah Island		2,282	Not Dev.				

Table 1. (Continued).

Map No.	Location	Owner	Total depth (ft.)	Diam. (in.)	Depth to water (ft.)	Yield (gpm)	Temp (°F)	Aquifer
19	Seabrook Island	Seabrook Devel. Corp.	2,697	16-8	Art.	50	90	Blk. Ck., Tusc.
20	Edisto Island							
21	Walterboro	City	1500-2500	8	28	135		Tusc. or Blk. Ck.
22	Summerville	U. S. Geol. Survey	2,500				96	
23	Georgetown	S. C. Water Resour. Com.	1,835					

Table 2. Contacts and Map Reference numbers for geothermal wells which were surveyed.

Well Sites	Map Reference No.	Contact
<u>Charleston</u>		
1) Calhoun St. at Rutledge Ave.	6	Mr. John Bettis
2) Meeting St. at Wentworth St.	5	Commissioner of Public Works 14 George Street Charleston, S. C. 29401 Phone: 803-723-9411
3) Medical University of South Carolina at Charleston	13	Ellison S. Kelly, Jr. Director of Physical Plant 171 Ashley Avenue Charleston, S. C. 29425 Phone: 803-792-2721
<u>Edisto</u>		
1) Lion's Club	20	Mayor Wetsin Brooks City Hall P. O. Box 402 Edisto Island, S. C.29438 Phone: 803-869-2667
<u>Fort Moultrie</u>		
1) Battery Jasper	14	Mr. Brian Varnado Fort Sumter National Monument 1214 Middle St. Sullivans Island, S. C. 29482 Phone: 803-883-3123
<u>Mt. Pleasant</u>		
1) Deep well plant #1 Simmons Street	10	Ron Bycroft City of Mt. Pleasant Water Works
2) Deep well plant #2 Mathis Ferry Road	9	605 Center Street Mt. Pleasant, S. C. 29464
3) Deep well plant #3 Snee Farm	--	Phone: 803-884-9626
4) Morgan's Point Mt. Pleasant well #39	11	South Carolina National Bank Charleston, S. C.
<u>Seabrook Island</u>		
1) Seabrook Corporation Deep Well	19	Furman Reynolds Utilities Superintendent P. O. Box 32099 Charleston, S. C. 29407 Phone: 803-768-1000
<u>Walterboro</u>		
1) Stephens Road	--	Mr. D. C. Haden
2) Main Water Works Plant	21	City Hall P.O. Box 717 Walterboro, S. C.29488 Phone: 803-549-2545

Table 3. Water quality test equipment used for analyzing geothermal water in Charleston and vicinity during December, 1981 to March, 1982.

Water Quality Parameter	Equipment
Temperature	stemmed thermometer
pH	LaMotte Chemical Co. Test Kits Model AG-36, code 2079, and Model 5100, code 2120.
Carbon dioxide	Lamotte Chemical Co. Test Kit Model PCO-S, code 7297-S
Alkalinity	LaMotte Chemical Co. Combination Test Kit Model AR-10, code 7315
Hardness	LaMotte Chemical Co. Combination Test Kit Model AR-10, code 7315
Chloride	LaMotte Chemical Co. Combination Test Kit Model AR-10, code 7315
Sulfite	LaMotte Chemical Co. Combination Test Kit Model AR-10, code 7315
Ammonia	Bausch and Lomb Spectronic Mini 20 TM ammonia kit No. 33-09-05
Nitrate-nitrogen	Bausch and Lomb Spectronic Mini 20 TM nitrate kit No. 33-09-06
Nitrite-nitrogen	Bausch and Lomb Spectronic Mini 20 TM nitrate kit No. 33-09-07
Phosphate (ortho)	Bausch and Lomb Spectronic Mini 20 TM orthophosphate kit No. 33-09-09

Table 4. Water quality data from geothermal well survey (Charleston, S. C., and vicinity) conducted December 1981 thru March 1982.

Well Site	Temp. (°C)	pH	Alkalinity ($CaCO_3$) (ppm)	Hardness ($CaCO_3$) (ppm)	Carbon Dioxide (ppm)	Chloride (ppm)	Ammonia (ppm)	Nitrate (ppm)	Nitrite (ppm)	Phos-phorus (ppm)	Sulfite (ppm)
Charleston (Calhoun St. at Rutledge Ave.)	18.9	8.3	625	≤10	0.0	150	2.4	0	0	3.9	≤ 5
Charleston (Meeting St. at Wentworth St.)	19.2	8.1	700	≤10	0.0	165	1.8	0	0	0.0	≤ 5
Edisto* (Lions Club)	26.0	8.1	425	90	0.0	750	1.6	0	0	4.5	≤ 5
Fort Moultrie (Battery Jasper)	30.2	7.9	950	40	20.5	840	3.4	0	0	8.1	≤ 5
Medical University of South Carolina	35.2	9.0	750	≤10	0.0	75	1.1	0	0	0.0	≤ 5
Morgan's Point	34.8	8.5	890	≤10	0.0	135	1.5	0	0	0.0	≤ 5
Mount Pleasant (Deep well plant #1)	37.0	8.5	650	≤10	0.0	120	1.0	0	0	0.0	≤ 5
Mount Pleasant (Deep well plant #2)	38.0	8.5	650	≤10	0.0	105	1.0	0	0	0.0	≤ 5
Mount Pleasant (Deep well plant #3)	36.0	8.5	700	≤10	0.0	135	1.2	0	0	0.0	≤ 5
Seabrook Corp. (Deepwell)	38.7	8.5	1075	≤10	0.0	105	1.7	0	0	0.0	≤ 5
Walterboro (Stephen)	33.0	8.5	150	≤10	0.0	≤15	0.3	0	0	2.3	≤ 5
Walterboro (Main Water Works Plant)	33.2	9.0	150	≤10	0.0	≤15	0.3	0	0	2.3	≤ 5

*Edisto well depth approximately 700 ft.

Table 5. Water quality data for a geothermal well in Charleston and typical surface water of Lake Moultrie.

PARAMETER (mg/l)	HYDROTHERMAL (CALHOUN & RUTLEDGE)	SURFACE (LAKE MOULTRIE)
Turbidity (NTU)	1.4	5.0
Color	10	20
Chloride (CI)	170	7
Floride (F)	4.0	0.0
Sodium & Potassium (Na)	8.5	10.0
Total Alkalinity ($CaCO_3$)	860	21
Carbonate Alkalinity ($CaCO_3$)	60	0
Bicarbonate Alkalinity ($CaCO_3$)	800	21
Hardness ($CaCO_3$)	7	16
Silica (S_1O_2)	22	9
Calcium (Ca)	2.0	4.8
Magnesium (Mg)	0.5	1.0
Carbonate (CO_3)	36	0
Bicarbonate (HCO_3)	976	26
Sulfate (SO_4)	1	7
Iron (Fe)	.02	.03
Manganese (Mn)	.00	.00
Copper (Cu)	.00	.00
Aluminum (Al)	.00	.00
Total Dissolved Solids	1,698	56
Specific Conductance @ 25°C	2,240	83

TABLE 6. Water quality test equipment used in the laboratory study investigating culture of prawns in geothermal water.

Water Quality Parameter	Equipment
Temperature	Yellow Springs Instrument Company Oxygen Meter (temperature scale) Model 57.
pH	Horizon Ecology Company Digi Sense pH Meter, Model 607
CO_2	Bausch and Lomb Carbon Dioxide Kit No. 33-09-02
Alkalinity	LaMotte Chemical Company Combination Test Kit, Model Ar-10, Code 7315.
Hardness	LaMotte Chemical Company Combination Test Kit, Model Ar-10, Code 7315
Ammonia	Bausch and Lomb Spectronic Mini 20 TM, Ammonia Kit No. 33-09-06
Nitrate-Nitrogen	LaMotte Chemical Company Test Kit Model ENA, Code 7485
Nitrite-Nitrogen	LaMotte Chemical Co. Test Kit Model PLN, Code 7421
Dissolved Oxygen	Yellow Springs Instrument Company Oxygen Meter, Model 57
Chloride	LaMotte Chemical Company Combination Test Kit, Model Ar-10, Code 7315
Sulfite	LaMotte Chemical Company Combination Test Kit, Model Ar-10, Code 7315
Phosphate	Bausch and Lomb Spectronic Mini 20 TM, Orthophosphate Kit No. 33-09-09.

TABLE 7. Initial water quality data for laboratory study examining culture of prawns in geothermal water.

	Parameters								
Treatment	Temp. (°C)	pH	Alkalinity (ppm)	Hardness (ppm)	Ammonia (ppm) Total	Ammonia (ppm) Un-ionized	Nitrite-Nitrogen (ppm)	Nitrate-Nitrogen (ppm)	Dissolved Oxygen (ppm)
Geothermal									
Not Filtered	25.0	8.97	783	17	1.87	0.65	0.00	4.3	8.3
Pre-Filtered	25.0	9.35	792	10	0.45	0.25	0.00	1.7	8.4
Filtered	25.0	9.25	775	20	0.40	0.20	0.00	4.3	8.3
Tap									
Not Filtered	24.8	8.20	83	10	0.57	0.05	0.00	2.7	8.5
Filtered	25.0	8.22	75	10	0.61	0.05	0.00	0.8	8.5
Mixture									
Filtered	25.4	8.87	483	30	0.81	0.24	0.01	1.0	8.0

TABLE 8. The percentage of un-ionized ammonia in aqueous solutions at various temperatures and pH levels (Emerson et al., 1975).

pH	Temperature (°C)			
	0	10	20	30
6.0	0.01	0.02	0.04	0.08
7.0	0.08	0.19	0.40	0.80
8.0	0.82	1.83	3.82	7.46
9.0	7.64	15.7	28.4	44.6
10.0	45.3	65.1	79.9	89.0

TABLE 9. Water quality and survival data for laboratory study examining culture of prawns in geothermal water (April-June, 1982).

Treatment	Temp. (°C)	pH	Alkalinity (ppm)	Hardness (ppm)	Ammonia (ppm) Total	Ammonia (ppm) Un-ionized	Nitrite-Nitrogen (ppm)	Nitrate-Nitrogen (ppm)	Survival (%)
Day 1-12									
Geothermal									
Not Filtered	27.2	9.21	788	13	1.49	0.77	0.27	0.0	7
Pre-Filtered	27.1	9.31	809	10	0.58	0.33	0.05	0.2	40
Filtered	27.1	9.24	805	15	0.45	0.24	0.00	0.7	57
Tap									
Not Filtered	27.0	7.75	82	17	1.12	0.04	0.00	0.1	100
Filtered	27.3	7.91	75	10	0.73	0.04	0.02	0.0	100
Mixture									
Filtered	27.6	8.95	486	15	0.41	0.15	0.15	0.0	100
Day 13-24									
Geothermal									
Not Filtered*	27.4	9.29	757	10	0.42	0.24	1.55	0.0	0
Pre-Filtered	27.0	9.32	738	15	0.73	0.42	0.25	0.8	0
Filtered	27.3	9.27	791	14	0.46	0.25	0.00	0.3	23
Tap									
Not Filtered	27.1	7.70	94	39	1.56	0.05	0.43	1.4	93
Filtered	27.5	7.85	94	10	0.67	0.03	0.01	0.0	97
Mixture									
Filtered	27.6	9.00	500	20	0.45	0.18	0.00	0.0	100
Day 34									
Geothermal									
Filtered	28.2	9.25	900	30	0.84	0.47	0.01	0.3	20
Tap									
Not Filtered	27.9	7.83	100	47	1.41	0.06	1.50	15.0	83
Filtered	28.1	7.95	108	10	0.96	0.06	0.00	0.1	83
Mixture									
Filtered	28.3	9.03	517	20	0.56	0.24	0.01	0.2	97
Day 42									
Geothermal									
Filtered	29.4	9.30	900	30	0.72	0.44	0.00	2.0	17
Tap									
Not Filtered	28.9	7.68	100	47	0.97	0.03	0.62	1.8	67
Filtered	29.2	8.02	100	10	0.68	0.05	0.00	1.3	80
Mixture									
Filtered	29.4	9.03	500	20	0.31	0.14	0.00	1.3	83

*Terminated on Day 16.

TABLE 10. Initial water quality data at stocking for study examining dilution rates for geothermal water at Mt. Pleasant.

	Treatments				
	Shallow Well 100%	Geothermal 100%	Geothermal Mixture 75%:25%	Geothermal Mixture 50%:50%	Geothermal Mixture 50%:50%*
Temperature °C	26.0	26.5	25.4	26.0	26.0
pH	8.40	8.70	8.60	8.50	8.50
Total Ammonia (ppm)	0.60	0.73	0.84	0.48	0.60
Un-ionized Ammonia (ppm)	0.08	0.18	0.16	0.08	0.10
Nitrite-N (ppm)	0.01	0.25	0.25	0.05	0.00
Nitrate-N (ppm)	<1.0	<1.0	<1.0	<1.0	<1.0
Alkalinity (ppm)	250	575	550	400	400
Hardness (ppm)	60	10	20	45	50
Dissolved Oxygen (ppm)	8.0	8.0	7.6	8.0	7.5
Carbon Dioxide (ppm)	0	0	0	0	0

*This treatment contained no soil substrate.

TABLE 11. Mean water quality data recorded during on-site study in Mt. Pleasant which examined the effects of various dilution rates for geothermal water for rearing prawns. Data are for days 1-44.

Water Quality Parameter	Treatments Shallow Well 100%	Geothermal 100%	Geothermal Mixture 75%:25%	Geothermal Mixture 50%:50%	Geothermal Mixture 50%:50%*
Temperature (°C)					
Mean	24.9	28.8	28.0	27.4	27.3
Range	23.0 - 29.0	26.0 - 32.0	25.5 - 30.0	25.0 - 30.0	25.0 - 30.0
pH					
Mean	8.10	8.72	8.56	8.44	8.45
Range	7.75- 8.30	8.60- 8.95	8.40- 8.75	8.20- 8.75	8.10- 8.75
Total Ammonia (ppm)					
Mean	0.66	0.83	0.95	0.78	0.83
Range	0.35- 1.09	0.42- 1.60	0.41- 1.60	0.42- 1.33	0.55- 1.33
Un-ionized Ammonia (ppm)					
Mean	0.04	0.23	0.19	0.12	0.13
Nitrite-Nitrogen (ppm)					
Mean	0.03	0.19	0.17	0.09	0.06
Range	0.01- 0.06	0.05- 0.40	0.02- 0.40	0.02- 0.20	0.02- 0.15
Nitrate-Nitrogen (ppm)					
Mean	0.96	1.38	1.55	1.21	0.69
Range	0.90- 1.02	1.00- 1.97	0.80- 1.97	1.00- 1.40	0.67- 0.72
Alkalinity (ppm)					
Mean	296	649	574	463	476
Range	250 -350	600 -790	500 -720	400 -580	375 -610
Hardness (ppm)					
Mean	78	9.5	16	37	35
Range	70 - 90	6.0 - 10.0	10 - 20	30 - 42	20 - 42
Dissolved Oxygen (ppm)					
Mean	6.5	6.4	5.6	6.4	5.7
Range	3.5 - 7.8	4.4 - 7.8	2.6 - 7.0	4.4 - 7.8	2.4 - 7.5
Carbon Dioxide					
Mean	10.5	0	0	0	0
Range	0 - 16	0 - 0	0 - 0	0 - 0	0 - 0

*This treatment contained no soil substrate.

TABLE 12. Growth and survival data for on-site study at Mt. Pleasant examining dilution rates for geothermal water. Prawns were stocked at 100/tank and initial mean size was 1.8 g (0.6-4.7 g), 43.1 mm (32-61 mm).

Treatment	Growth: Weight (g) (Range)	Growth: Length (mm) (Range)	Survival (%) (Mean)
	Day 22		
Shallow Well	2.9(1.2- 4.8)	49.2(37-58)	97.0
100% Geothermal	2.7(1.1- 8.3)	47.8(34-71)	91.0
75% Geothermal	2.7(1.0- 5.0)	48.1(33-58)	98.0
50% Geothermal	3.3(1.6- 9.8)	50.4(41-69)	99.0
50% Geothermal* (no soil)	2.5(1.1- 4.9)	47.6(42-60)	97.9
	Day 44		
Shallow Well	4.7(2.4-11.7)	56.5(47-75)	97.0
100% Geothermal	3.1(1.0- 5.6)	50.5(34-62)	69.0
75% Geothermal	4.2(1.5-10.6)	54.9(41-71)	95.0
50% Geothermal	4.7(2.0-19.0)	56.1(44-87)	94.0
50% Geothermal* (no soil)	4.2(2.4-10.3)	54.8(46-73)	96.8

*Survival rate adjusted for 7 prawns which jumped out of the tank during second week of study and died.