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Beneficial Uses for Thermal Discharges

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by

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PREFACE

This report reviews the problem of thermal discharges from power plants and examines possible solutions to their beneficial uses. A summary of the major findings appears before the text and an annotated bibliography is presented at the end.

The major impetus to prepare this report came from Mr. J. P. Bruce, Director, Canada Centre for Inland Waters, Burlington, and Dr. Robert W. Durie, and for this we are grateful. We would also like to acknowledge the assistance of Miss Bianca Roberts (bibliography compilation), Don Williams and Bob Fortin (drafting), Mrs. L. Delorme (typing), Don Elfner (proof reading) and Alan Penn of McGill University (review).

CONTENTS

SUMMARY OF REPORT

This section is intended to be a summary of conclusions reached in this report.

The total peak thermal input to Canadian fresh and tidal waters is estimated to increase from 6.025×10^{13} BTU/hr in 1970 to 136.7×10^{13} BTU/hr in 2000 A.D. Approximately 80% of heat rejection to the environment in Canada is contributed by electrical power production. The effects of future large-scale heat release remain unknown.

To date, nuclear power plants, operating at about 33% overall thermal efficiency, pose a greater threat in terms of thermal pollution than fossil-fuel plants, which can attain about 40% efficiency. Future fast reactors may have greater thermal efficiencies, though their development is at present unpredictable. Large nuclear plants require some 50% more cooling water for a given temperature rise than fossil-fuel plants of comparable size, though this may be reduced to 25% by 1980 through further technological innovations. Typically, overall thermodynamic efficiency in power plants falls off with increased temperature of turbine exhausts. Power plants currently discharge low grade heat at 80° to 100°F range, for which there are few economic uses because of heavy transportation costs. The paradox of the "thermal pollution" situation is that if the temperature at the turbine exhaust is raised to a temperature which is useful for a variety of purposes, then thermodynamic efficiency is reduced and more low-grade waste heat is produced than can be used. Future power plants should be designed in conjunction with large integrated systems of urban, industrial, or agricultural energy usage to maximize thermal efficiency of the total system and minimize energy waste.

Alternative methods of power production with fewer heat rejection problems are limited in number and practicality. Heat exchangers, converting waste heat to electrical power are currently uneconomic, and technology does not exist to commercially harness solar power. Canada's potential for hydro-power development is limited in terms of site availability and money and, in any case, the total demand for electrical energy in the long-term will far exceed our economic hydro potential. In addition, the ecological and social impacts of large-scale flooding associated with hydro schemes may well prove to be far worse than pollution problems associated with other forms of energy generation. Canadian geothermal potential is very small and seems rather impractical to develop. Fusion reactors and magneto-hydrodynamic generators are still experimental, though they hold exciting possibilities for future large-scale "clean" power production.

In controlling thermal pollution from fossil and nuclear-fuel power plants, cooling ponds and reservoirs, evaporative cooling towers and dry cooling towers are the main alternatives to the once-through cooling process. However, considering the variables of relative ground area required, average condenser water requirement and consumption use, and capital investment, operating and maintenance costs, the once-through cooling process is the most economic as well as efficient way of dissipating residual heat. It may, however, be the most environmentally destructive technique, and hence it is necessary that the total (including environmental) costs and benefits of alternative cooling systems be evaluated objectively.[1]

Whether the predicted scale of waste heat rejection is potentially harmful (above a socially acceptable level) in either the long or short term, remains to be evaluated. Some researchers claim effects are harmful; others suggest that effects may be harmless, or perhaps even beneficial to fisheries. Any further evaluation should consider the effects of waste heat discharge in conjunction with other forms of waste loading for total drainage basins. The nature of the effects will depend heavily on the unique features of each situation, which poses the problem of evaluating and monitoring the condition of each particular ecosystem. Mathematical models have largely followed the basic DO-BOD relationship with very little attempt at modelling other quality parameters. Development of comprehensive models necessitates

1 All material previous to this footnote is drawn from chapter 1, page 13 to 18.

large amounts of data which are usually unavailable and often have to be interpolated. Models may, however, permit the planner to gain a broader perspective on a complex problem. It is evident that considering the costs and time involved, total investigation is seldom practical. Therefore, investigation should perhaps be directed towards identifying and selectively studying the more meaningful parameters such as key species (presence/absence), and species diversity. In extending this, however, to developing generalized indices of environmental quality, there is a danger that these can be easily misused or misinterpreted.

This report deals with one of five basic alternatives in managing thermal discharges, namely, finding other ways to dissipate heat, or developing beneficial uses for them. The alternatives are listed in chapter 2 (p. 22). In planning a beneficial use, a number of general criteria have been listed (chapter 2, page 22-23)[2].

One suggested use of waste heat to extend navigation seasons on the Great Lakes - St. Lawrence Seaway is theoretically possible. Feasibility studies have, however, presented no detailed cost-benefit analyses, though a general review indicates that problems and concomitant costs would outweigh benefits. In view of the annually increasing net losses incurred in the Seaway operation, any further large scale, high cost alteration would increase these losses in the short term. Thus, stronger and tangible evidences are necessary to prove that final returns would be worthwhile in the long term. A major problem is that although navigation season extension would use large amounts of waste heat in winter, there is no adequate alternative for a summertime use.[3]

Many different forms of aquaculture have been cited in the literature as holding good possibilities for beneficial use of thermal discharges. Aquaculture may be adaptable to a variety of power plant siting and technological constraints. However, more research is required into biological restraints and limitations, and into the optimum conditions required for year-round production of some of the more likely commercial species. The use of heated effluent to increase production in natural and uncontrolled populations is very limited, but the potential for such use in closed or restricted controlled systems deserves further investigation, particularly in marine aquaculture where experiments with plaice, sole, oyster, lobster and shrimp have shown more promise of being commercially successful than freshwater aquaculture.

Though most forms of aquaculture are possible on a small scale, aquacultural products have to be competitive with agricultural and conventional fisheries products on an open market. Most systems described are high cost ventures which should therefore direct production on a large scale towards high priced luxury commodities such as lobster and salmon, choosing where possible fast growing species.

Multipurposes schemes such as deep-ocean water utilization, algae/fungi-sewage treatment — agro-industrial centres, and closed system recycling plans (e.g., in estuarine environments) should be considered cautiously and regarded as nothing more than preliminary concepts. Although they may promise efficient and beneficial use of thermal and municipal wastes and may solve problems of conventional aquaculture (e.g., fish feed supply problem solved using high protein algae), they may themselves create environmental problems such as organic wastes from fish farms, or the side effects of interference with energy budgets, nutrient and water circulation systems on a large scale. Many forms of aquaculture may still not meet "safe" temperature standards for outfall waters.

Before any aquacultural system is developed commercially, waste treatment procedure has to be defined, marketing systems developed for the products, and benefit-cost analyses conducted to demonstrate their economic viability. Recent Canadian East Coast experience has highlighted the need to preplan for an aquaculture facility in power plant design before operating costs can be reduced sufficiently to make the venture profitable. It is highly unlikely that aquacultural facilities would use all available thermal effluent in summer, which is the critical period for thermal management in Canada due to high ambient water temperatures.[4]

It is possible that waste heat may be used in certain waste and water treatment processes. Low grade heat, around 100°F, is probably well suited to stimulating secondary biochemical reduction

[2] All material back to the previous footnote is taken from chapter 2, page 19 to 24.

[3] All material back to the previous footnote is drawn from chapter 3, page 25 to 28.

[4] All material back to the previous footnote is taken from chapter 4, page 29 to 46.

of activated sewage sludge, raising flocculation and filtration efficiency and perhaps improving sludge settling efficiency. Savings may be possible over conventional chemical treatment methods if power plant effluents can be delivered at the treatment site with minimum transportation costs. Such low grade heat is, however, too low for pasteurization, drying and oxidation processes which, at current levels of technology, require temperatures in the range of 150 - 300°C.

Raw or secondary treated sewage may be successfully filtered through coal, with 95% BOD removal at a coal to sludge ratio of 4 to 1. In a high temperature boiler, the sludge can then be burnt odorlessly and with less detrimental waste combustion products than pure coal. The system is prone to mechanical problems in pumping a slurry of coal and sludge.

Plans have been presented for the treatment and recycling of municipal waste waters using power plant heat and various systems of distillation. Technical problems include tube fouling and distillate quality. Cost estimates have to date been very crude, ranging from an increase of 50% over present water supply and treatment costs, to one of $0.20 to $0.22/1000 ga. A major benefit, however, is that this could be a year-round use for thermal effluents. By-product residues may have use in the fertilizer and chemical industries. Such systems have the added advantage of not being continuous, depending on heat availability and water need. The U.S. experience has found more advantages and fewer problems to industries and municipalities in using treated waste water as a coolant rather than well water or another pristine supply.

Snow melting schemes could provide a valuable seasonal use for waste heat. They can, however, only be used in winter, when thermal pollution, at least in Canada, is a minor problem. Alternative summertime uses for waste heat would still be required.

Waste heat can be used in distilling brackish — or salt-water to produce potable and irrigation water. This has been successfully done in agricultural expiremental stations in desert areas, and in Puerto Rico, where a by-product, salt, provides the basis for a chemical industry. Cost-benefit studies indicate, however, that power plant-desalination units are economically impractical unless there is a demand for extremely large quantities of water, i.e., 150 mgd., close to the production site. Because current demands for freshwater at any one site are usually less than 10-20 mgd., it will be some time before dual purpose plants are, in general, feasible. Recent British research suggests that freeze-desalination will offer economies compared with distillation processes because of the use of direct contact heat transfer, and low energy consumption due to the relatively low latent heat of fusion of water and the high thermodynamic efficiency of the heat pump cycle. Possible environmental hazards, i.e., in brine effluents, and pollution control potential, i.e., in using thermal discharge, should be considered in any cost-benefit analysis of such systems.

Icelandic research has been successful in economically producing soda ash, magnesium and other chemicals from seawater using cheap geothermal steam. The application of such processes to a power plant complex, however, would require 100°-180°C temperature, which could only be supplied by using "live" steam.

Oxygenation and aerobic processes may be improved in polluted lakes by pumping in air and heated water, though the impacts of heat increases on the aquatic ecology still require quantitative documentation. The use of spray modules to cool thermal plant discharge water will also have the benefit of aerating receiving waters.

Although sewage and water treatment systems could make beneficial use of waste heat, these and other industrial/urban processes usually also require higher grade heat than is usual in thermal effluents. If high quality steam is therefore taken from the steam cycle to supplement the heat obtained from cooling waters, then some potential for electricity generation is lost to the waste heat use. A question of trade-off then arises between more power and heat use. Given a guaranteed market for higher grade waste heat all year round, the sacrifice of some electricity generation for better quality steam may be worthwhile, especially when total environmental degradation costs are considered. Alternatively, costs of high quality steam usage should be compared with costs of fuel and hardware necessary to raise the temperatures of only partially heated power plant effluent to required levels independently from the power plant.

Another option is to utilize surplus off-peak electricity production to increase the temperature of thermal effluent, with the advantages that energy is more easily stored in water than as electricity, and that a power waste would be used. A disadvantage to the user would be an intermittent high temperature water supply, which may be more suited to an interruptable process such as desalination rather than to a continuous use such as controlled green house heating, or urban space heating.[5]

Industrial uses of low grade waste heat particularly in chemical and processing industries such as heavywater production and freeze-drying, require further investigation, and in this respect, Icelandic experience in use of geothermal steam could prove a useful guide. Future planning should be toward total energy — power plant — industrial and/or agricultural/aquacultural complexes for several reasons outlined in Chapter 6.[6]

Thermal discharges can also be used for defogging and deicing airport runways. Such systems, already proposed in the U.S., are technically possible using low grade waste heat (115°F), but they require high capital costs, and would be used for limited time periods. Deicing systems may be of greater value in the Canadian North.

Waste heat may be used to keep recreation lakes and beaches at more comfortable temperatures for longer periods in colder climates. A year-round beneficial use for waste heat may be to create, using off-shore barrages, clean warm water lagoons along the water fronts of major Canadian lakeshore or riverine located cities. These would serve both as cooling ponds, and as city recreational and water supply facilities. High initial capital costs and a number of potential ecological hazards, such as summer algal blooms, could present serious problems.

District heating and air conditioning systems are probably the most frequently proposed urban uses for waste heat. Useful insights to the practicality of such systems may be drawn from examples of geothermal district heating in Iceland, and power plant/thermal discharge district heating in Lund, Sweden. Such examples, however, usually require much higher grade heat (live steam) than that normally discharged from power plants, and, as in the case of Lund, because of this need the cost of a concomitant loss of electrical power production has had to be accepted. It also remains uncertain whether the use of live steam reduces the waste heat rejection problem of the power plants to acceptable limits.

Studies in the U.S. indicate that district heating and air conditioning by thermal discharge is technically feasible and ecologically desirable, for a distance up to ten miles from the distribution centre. The ecological desirability remains to be proved with empirical evidence. Problems could arise in spring and fall, when demands for heating and cooling are small. Waste heat would still have to be either disposed of by conventional atmospheric heat exchanger techniques, or would have to be used by increasing such 'base load' customers as waste-water and sewage treatment, and industry.

In the special case of Inuvik, N.W.T., with a remote location and an extremely cold climate, a combined central district heating and power system with above-ground "utilidor" ducts carrying power, heating, sewer, and water supply lines has proved economic and successful in combating perma-frost and freezing conditions.

In the literature on the functions of heat in cities, it is not clear whether the main intention is to use waste heat from power plants, or to develop centrally located boilers which serve no function of electricity generation, but provide cheaper high grade heat supply than conventional heating methods. Some authors suggest some combination of these two extremes. Generally, heat distribution costs are the biggest obstacle to district heating/cooling systems. Probably waste heat will only become generally acceptable and practical for these purposes when the questions of safety, public opinion, and other non-thermal pollutant emissions have been sufficiently resolved to allow the central location of power plants in an urban area. These applications should not, however, be overlooked in long term planning, especially as they help solve problems of non-thermal atmospheric pollution.[7]

One category of beneficial uses which holds exciting possibilities is that of thermal agriculture. The low-grade heat can be used to maintain controlled temperature environments for plants and animals. The choice of thermal agriculture technique and system to be used is partly dictated

[5] All material back to the previous footnote is taken from chapter 5, page 47 to 52.

[6] All material back to the previous footnote is taken from chapter 6, page 53 to 56.

[7] All material back to the previous footnote is taken from chapter 7, page 57 to 62.

by the prevailing climatic regime and local geographical situation, and partly by the types of produce for which there is enough demand to justify the large initial capital outlay.

"Open-Field" thermal agriculture in temperature latitudes can improve yields, crop quality and growing season lengths for certain crops, by providing spring and autumn frost protection, summertime plant cooling, and warm water irrigation. One problem is that these uses will not be required constantly, and, therefore, they do not totally solve the waste heat problem. High capital costs as well as heat losses with increasing distance piped restrict such agriculture to small area, high profit truck farming and fruit growing ventures.

Controlled-environment thermal agriculture incorporated into total power-food-desalination systems have been proved far more successful than conventional agriculture or "open-field" thermal agriculture in hot, arid, coastal-fringe lands. At present, high capital costs limit such systems to small operations in countries which can afford them, and to producing high value, perishable vegetable and horticultural crops. Whether they can be adapted to the situation of the Canadian north, where the problems are extremes of cold and frozen ground as opposed to hot, dry conditions and salty sands, remains to be tested.

Successful truck-farming methods in geothermally heated greenhouses in Iceland could be adapted to a power plant heat source and used to provide needed supplies of cheap fresh vegetables and poultry year-round, particularly to towns around mining complexes in northern Canada and to cities where the immediate hinterland is required for housing. However, experience in Alberta, Canada, has shown the lack of solar energy in winter months to be a critical limiting factor. Controlled-environment culture may also be well suited for farming high-profit fur animals. If algae growing facilities and waste-water/sewage treatment plants were incorporated with thermal agriculture in a totally integrated complex (using energy in a step down method as it passes from high to low grade energy), usefulness to a city would be increased, and food production, especially beef, could be made more economically sound. High initial capital costs, lack of knowledge of all inputs needed for a proper systems analysis, environmental problems associated with the complexity of plant-soil-water relationships, and heat balance problems involved in matching greenhouse heat needs with power plant heat output *throughout* the year in temperature latitudes, have so far limited temperate controlled-environment agriculture to concepts, and to some limited university-utility research. Although it is likely that agriculture can use only a limited amount of total thermal discharges available, increasing demands for food and water supplies, power, sewage treatment, etc., may ultimately force the issue. In a relative sense, controlled-environment agriculture is probably the most practical (technologically and economically) of all beneficial uses for low grade waste heat. However, it remains necessary to evaluate the advantages gained from using waste hot water in agriculture rather than using more conventional methods.

In examples of thermal agriculture systems cited in this report, their economic feasibility and much of their design is dictated by local circumstances such as weather conditions, market proximity, and the range of choice of alternative systems. Future planning will require most cost-conscious optimization of entire systems. Potential users of waste heat will need to know costs and specific design criteria for their local heat or water distribution systems, and potential suppliers of warm water will require an evaluation of the overall economics of a proposed system.[8]

The development of multipurpose systems for total energy usage, though somewhat utopian given the present economic, political, and social situation, may be eventually forced by increasing pressure on power and other resources, and increasing demands for all forms of pollution control. The application of beneficial uses of waste heat to alleviate thermal pollution of aquatic environments is only a stop-gap pollution control measure. Unfortunately, the objective is still to maximize electricity production, minimize production costs and deal somehow with the resulting environmental pollution, rather than aim at maximum efficiency in total energy usage which would tend to minimize total pollution, but which also would usually involve very high initial capital costs. Canada, being comparatively young in urban and industrial development, is in a better position than most countries to develop total energy use complexes. Some planners have devised a multipurpose canal-lake water use system for parts of the U.S. which could use existing canal resources

[8] All material back to the previous footnote is taken from chapter 8, page 63 to 72.

to their full potential. Although this system has many drawbacks, and although it may be only applicable to a specific American situation, its principle of reviewing and evaluating the potential of existing resources in the light of long range environmental planning is worth considering.[9]

In conclusion, the choice of beneficial use for thermal discharge is inevitably dictated by the particular situation. Many uses, such as ice control and snow-melting, are seasonal in nature and require that alternatives be found for off-seasons. Other uses, particularly industrial uses and district heating systems, require higher grade heat than that normally available in thermal discharge, and transportation of low grade heat to the user is generally a difficult and expensive proposition. In special cases, as in Inuvik, N.W.T., district heating may find a worthwhile application in Canada. Possibilities of developing cooling ponds as recreational facilities are worth pursuing in view of the increasing pollution of Canadian lakes and rivers, particularly around urban areas in southern Canada. Certain forms of thermal aquaculture and thermal agriculture hold good possibilities for Canadian application as they can extend the length of the producing seasons in some cases to a year-round venture. Furthermore, they can use land around power plants which is, under present safety regulations, barred to residential/urban development. Multipurpose energy use concepts should be seriously considered as part of the long term solution to the total pollution problem. Finding beneficial uses for waste heat is really only a short term stop-gap method of tackling part of this problem. In addition, it does not seem possible that the beneficial uses can utilize all the vast quantity of thermal discharges from power stations. This is especially true for summer, when the need for thermal pollution alleviation is at a maximum, but the possibilities for beneficial uses of waste heat are minimal.

[9] All material back to the previous footnote is taken from chapter 9, page 73 to 75.

RÉSUMÉ DU RAPPORT

La présente section est un résumé des conclusions du rapport.

L'apport de pointe total de chaleur aux eaux douces et aux eaux de marée canadiennes devrait passer de 6.025 x 10^{10} BTU/h en 1970 à 136.7 x 10^{10} BTU/h en 2000. La production d'électricité contribue pour près de 80% de ce rejet thermique dans l'environnement. On ignore encore les effets du rejet de chaleur futur à grande échelle.

Jusqu'à maintenant, les centrales d'énergie nucléaire qui fonctionnent à 33% environ de leur efficacité thermique totale constituent une menace plus grave du point de vue de la pollution thermique que les centrales à combustible fossile, qui atteignent parfois 40% de leur efficacité. Les futurs réacteurs rapides seront peut-être d'une efficacité thermique beaucoup plus grande, même si l'on ne peut encore prévoir leur importance. Les grandes centrales nucléaires nécessitent environ 50% plus d'eau de refroidissement pour une hausse de température donnée que les usines à combustible fossile de taille comparable, bien que ce pourcentage pourrait être réduit à 25% en 1980 grâce à la technologie. Habituellement, l'efficacité thermodynamique totale d'une centrale d'énergie diminue avec l'augmentation de la température d'échappement des turbines. Les centrales d'énergie rejettent habituellement une chaleur de faible qualité, de l'ordre de 80 à 100°F, pour laquelle il y a peu d'usages économiques à cause du coût élevé du transport. Le paradoxe de la «pollution thermique» est que si l'on élève la température d'échappement d'une turbine, jusqu'au degré où elle pourra servir à diverses fins, son efficacité thermodynamique est réduite et la quantité de chaleur de basse qualité dégagée est plus grande qu'on ne peut en utiliser. Les futures centrales devraient être conçues parallèlement à de vastes systèmes intégrés d'utilisation urbaine, industrielle et agricole de l'énergie, afin d'augmenter l'efficacité thermique de tout le système et de minimiser la perte d'énergie.

Les autres méthodes de production d'énergie qui causent moins de problèmes de rejet de chaleur sont limitées, tant en nombre qu'en possibilités. Les échangeurs de chaleur qui convertissent la chaleur rejetée en puissance électrique sont actuellement peu économiques et il n'existe pas encore de techniques assez avancées pour convertir de manière commerciale l'énergie du soleil. Le potentiel d'exploitation hydro-électrique du Canada est limité par la disponibilité des emplacements et les coûts et, de toute façon, la demande totale d'électricité à long terme dépassera de loin notre potentiel économique hydro-électrique. De plus, les effets socio-écologiques des inondations à grande échelle qu'entraînent les aménagements hydro-électriques pourraient bien être pires que les problèmes causés par d'autres formes de production d'énergie. Le potentiel géothermique canadien est très réduit et il semble pratiquement impossible de le développer. Les réacteurs à fusion et les générateurs magnétohydrodynamiques en sont encore au stade expérimental, bien qu'ils présentent d'importantes promesses de production d'énergie «propre» à grande échelle.

Pour enrayer la pollution thermique causée par les centrales d'énergie à combustible fossile et nucléaire, il existe plusieurs solutions de rechange au procédé de refroidissement sans recyclage comme les réservoirs et les bassins de refroidissement, les tours de refroidissement à évaporation et à sec. Toutefois, si l'on étudie les éléments comme la surface nécessaire, l'eau nécessaire pour un condensateur moyen et sa consommation, ainsi que les frais de premier établissement, les coûts d'exploitation et d'entretien, le procédé de refroidissement sans recyclage est le moyen le plus efficace et le plus économique de dissiper la chaleur résiduelle. C'est peut-être, cependant, la technique la plus destructrice du point de vue de l'environnement et il est donc nécessaire d'évaluer objectivement tous les coûts et les avantages (du point de vue environnemental également) des autres systèmes de refroidissement.[1]

Il reste encore à déterminer si l'échelle prévue des rejets de chaleur est dangereuse (au-dessus d'un certain niveau socialement accepta-

[1] Tout ce qui précède est tiré du chapitre 1, pages 13 à 18.

ble). Certains chercheurs en sont convaincus; d'autres affirment que les effets seront sans danger, peut-être même profiteront-ils aux pêches. Toute nouvelle évaluation devrait envisager les effets des rejets de chaleur en même temps que d'autres formes de déchets rejetés dans les bassins. La nature des effets dépendra des caractéristiques propres à chaque situation, ce qui pose le problème d'évaluer et de contrôler les conditions de chaque écosystème. Des modèles mathématiques ont remplacé en grande partie les relations OD-DBO et on a rarement tenté d'établir des modèles des autres paramètres de qualité. L'établissement de modèles complets nécessite un grand nombre de données qui ne sont habituellement pas disponibles et qu'il faut déterminer par extrapolation. Cependant, les modèles permettent au planificateur d'avoir une meilleure perspective d'un problème complexe. Il est évident que si l'on tient compte du coût et du temps qu'il en coûte, les recherches sont rarement pratiques. Toutefois, il serait possible de les orienter vers l'identification et l'étude précise de paramètres plus importants, comme les espèces clés (présence/absence) et la diversité des espèces. Si l'on cherche de là, cependant, à en déduire les indices généraux de la qualité de l'environnement, il y a danger de les mal employer ou de les mal interpréter.

Le présent rapport traite de l'une des cinq solutions de gestion de rejets thermiques, c'est-à-dire, d'autres moyens de dissiper la chaleur ou de l'utiliser au profit de l'homme. Les solutions sont indiquées au chapitre 2 (p. 22). On a mentionné un certain nombre de critères généraux dont il faut tenir compte lors de la planification d'un usage avantageux (chapitre 2, p. 22-23).[2]

L'un des usages proposés est théoriquement possible, c'est-à-dire d'allonger les saisons de navigation sur les Grands lacs et la voie maritime du Saint-Laurent. Les études faites sur les possibilités de réalisation ne présentent cependant aucune analyse des coûts et des profits bien qu'une revision générale indique que les problèmes et les coûts qu'ils entraînent dépasseraient les profits. Toute modification dont le coût serait élevé ne ferait qu'augmenter à court terme les pertes annuelles déjà élevées subies au cours de l'exploitation de la voie maritime. Il faut donc d'autres preuves plus solides et plus tangibles que le fait que les profits seront avantageux à long terme. Le principal problème est que même si la navigation utilisait une grande partie de la chaleur résiduelle en hiver, on n'a aucune solution pour l'été.[3]

Les publications citent de nombreuses formes d'aquaculture avec lesquelles il serait peut-être avantageux d'utiliser les rejets thermiques. L'aquaculture peut s'adapter à divers emplacements de centrales d'énergie et contraintes technologiques. Toutefois, il faut faire d'autres recherches pour connaître les limites biologiques et les conditions optimales de la production de certaines espèces commerciales, douze mois par année. L'emploi de l'effluent chauffé en vue d'augmenter la production de populations en milieu naturel ou sans contrôle est limité, mais il faut encore étudier les possibilités d'un tel emploi en circuit fermé ou restreint, surtout dans le cas de l'aquaculture marine où les expériences avec la plie du Canada, la sole, les huîtres, le homard et les crevettes ont semblé plus prometteuses commercialement que l'aquaculture en eau douce.

Bien que la plupart des formes d'aquaculture soient possibles sur une petite échelle, leurs produits doivent concurrencer ceux de l'agriculture et des pêches traditionnelles dans le marché. Une grande partie des systèmes décrits sont des entreprises coûteuses qui entraîneraient la production, à grande échelle, de produits de luxe, comme le homard et le saumon, choisissant quand c'est possible des espèces qui se reproduisent rapidement.

Divers projets, comme l'utilisation des eaux marines profondes, le traitement des égouts au moyen d'algues et de champignons dans des centres agro-idustriels et les plans de recyclage en circuit fermé (par exemple dans les estuaires) doivent être examinés attentivement et considérés uniquement comme des idées à développer. Même s'ils promettent un usage efficace et avantageux des déchets thermiques et municipaux et peuvent régler des problèmes d'aquaculture classique (par exemple, usage des algues à haute teneur en protéines pour résoudre le problème d'alimentation du poisson), ils peuvent eux-mêmes créer des problèmes environnementaux comme les déchets organiques provenant de la culture du poisson, ou les effets secondaires de l'interférence avec le bilan énergétique, les substances nutritives et les systèmes de circulation de l'eau, à grande échelle. De nombreuses formes d'aqua-

[2] Tout ce qui suit la note précédente est tiré du chapitre 2, pages 19 à 24.

[3] Tout ce qui suit la note précédente est tiré du chapitre 3, pages 25 à 28.

culture risquent de ne pas satisfaire les normes de sécurité concernant la température des eaux rejetées.

Avant de développer un système d'aquaculture à échelle commerciale, il faut définir les procédés de traitement, établir des systèmes de commercialisation pour le produit et faire des études de rentabilité visant à démontrer leur viabilité économique. Il est peu probable que les installations d'aquaculture utiliseront tout l'effluent thermique disponible, en été, qui est la période la plus difficile pour la gestion thermique au Canada, à cause de la température élevée de l'eau.[4]

Il serait possible d'utiliser les rejets de chaleur dans le cas de certains procédés de traitement de l'eau. La chaleur de pauvre qualité, aux alentours de 100°, serait probablement très appropriée pour stimuler la réduction biochimique secondaire des boues activées, augmentant l'efficacité de la floculation et de la filtration et améliorant peut-être l'efficacité de la décantation. On pourrait réaliser des économies par rapport aux méthodes de traitement chimique classiques si l'on peut transporter l'effluent de la centrale nucléaire au lieu de traitement avec le minimum de frais de transport. Cette chaleur est toutefois trop faible pour servir dans le cas des procédés d'oxydation, de séchage et de pasteurisation qui, avec les connaissances actuelles de la technologie, nécessitent des températures de l'ordre de 150 à 300°.

On peut filtrer les égouts non traités ou qui ont subi un traitement secondaire au travers du charbon, ce qui permet de retirer 95% de DBO, le rapport charbon/boues étant de 4 pour 1. Dans une chaudière à très haute température, on peut brûler les boues sans odeur et avec moins de résidus de combustion que le charbon. Le système est sujet aux problèmes mécaniques que pose le pompage d'un mélange de boue et de charbon. La technique sera de moins en moins efficace à mesure que le charbon sera remplacé comme combustible primaire.

Des plans ont été présentés pour le traitement et le recyclage des eaux usées municipales à l'aide de la chaleur résiduelle des centrales d'énergie et divers systèmes de distillation. Parmi les problèmes techniques, on peut citer l'encrassement des conduits et la mauvaise qualité du distillat. Les évaluations des coûts jusqu'à présent ont été très imprécises: une augmentation de 50% par rapport à l'approvisionnement en eau et au coût de traitement actuel, jusqu'à une hausse de $0.20 à $0.22 les 1000 gallons. Le principal avantage, toutefois, est que l'utilisation de l'effluent thermique serait alors continuelle. Les sous-produits résiduels trouveraient peut-être un usage dans l'industrie des produits chimiques et des fertilisants. Ces systèmes ont de plus l'avantage de ne pas être continus, car ils dépendent de la disponibilité de la chaleur et du besoin d'eau. L'expérience des Etats-Unis montre qu'il y a plus d'avantages et moins de problèmes pour les industries et les municipalités qui utilisent les eaux usées traitées comme refroidisseur plutôt que de l'eau de puits ou autre produit naturel.

La fonte des neiges serait une solution saisonnière pour l'utilisation de la chaleur résiduelle, mais en hiver seulement, au moment où la pollution thermique, du moins au Canada, est un problème mineur. Il faudrait encore trouver des solutions pour l'été.

La chaleur résiduelle peut servir à la distillation de l'eau saumâtre — ou de l'eau salée, pour produire l'eau potable et l'eau d'irrigation. On l'a réalisé avec succès dans des stations agricoles expérimentales des régions désertiques et à Porto Rico, où le sous-produit, le sel, est à la base de l'industrie chimique. Les études de rentabilité montrent, toutefois, que les installations de dessalement en centrale d'énergie ne sont pas rentables économiquement, à moins qu'il n'y ait une demande pour de très grandes quantités d'eau, par exemple, 150 millions de gal./j, à proximité. Comme les demandes actuelles d'eau douce ne dépassent pas 10 à 20 millions de gal./j, il faudra encore un certain temps avant qu'il soit rentable de construire des centrales à double emploi. Des recherches récentes faites en Angleterre auraient démontré que le dessalement par congélation serait plus économique que le procédé de distillation parce qu'il y a échange de chaleur par contact direct et qu'il consomme moins d'énergie étant donné que le degré latent de fusion de l'eau est relativement bas et que l'efficacité thermodynamique du cycle de caloportage est assez élevé. Toute analyse de la rentabilité de tels systèmes devrait considérer les dangers environnementaux éventuels, comme l'effluent de saumure et les possibilités de lutter contre la pollution, par exemple, avec l'utilisation de rejets thermiques.

[4] Tout ce qui suit la note précédente est tiré du chapitre 4, pages 29 à 46.

La recherche en Islande a abouti à la production de carbonate de soude, de magnésium et d'autres produits chimiques à partir de l'eau de mer grâce à la vapeur géothermique, peu coûteuse. L'application de ces procédés à une centrale d'énergie complexe exigerait, toutefois, des températures de l'ordre de 100 à 180° qui ne pourraient être obtenues qu'à l'aide de véritable vapeur.

Les processus aérobies et d'oxygénation peuvent être améliorés, dans les lacs pollués par le pompape d'air et d'eau chaude, bien que les effets des augmentations de chaleur sur l'écologie aquatique nécessitent encore beaucoup de recherche, du point de vue de la quantité. L'usage de vaporisateurs pour refroidir les rejets des centrales aura aussi l'avantage d'aérer les eaux réceptrices.

Même s'il y a des avantages à utiliser la chaleur résiduelle dans les systèmes de traitement des eaux d'égout et des eaux naturelles, ces derniers, ainsi que d'autres procédés urbains ou industriels nécessitent souvent une meilleure chaleur que celle des effluents thermiques. Si l'on prend de la vapeur du cycle de vapeur pour améliorer la chaleur obtenue de l'eau de refroidissement, on perd alors un certain potentiel de production d'énergie. Il faut alors choisir entre l'énergie et l'utilisation de la chaleur. S'il existait un marché pour la chaleur résiduelle efficace tout au long de l'année, il vaudrait la peine de sacrifier un peu de la production d'électricité pour se servir de la vapeur surtout si l'on considère les coûts totaux de la détérioration environnementale. Il faut aussi comparer le coût de la vapeur à celui des combustibles et du matériel nécessaire pour élever les températures des effluents de centrales partiellement chauffées, aux niveaux désirés, indépendamment de la centrale.

L'autre solution est d'utiliser le surplus d'électricité produit en dehors des heures de pointe pour élever la température de l'effluent thermique; l'avantage est qu'il est plus facile d'emmagasiner l'énergie dans l'eau que sous forme d'électricité et ainsi, l'énergie perdue serait utilisée. Le désavantage pour l'usager serait que l'approvisionnement d'eau chaude est intermittent, ce qui serait plus approprié pour un procédé de dessalement, qui peut être interrompu, que pour le chauffage continu d'une serre ou d'un espace urbain.[5]

[5] Tout ce qui suit la note précédente est tiré du chapitre 5, pages 47 à 52.

Les usages industriels de la chaleur résiduelle tout particulièrement dans les industries de traitement et les industries chimiques, comme la production de l'eau lourde et le séchage à froid, doivent faire l'objet d'un examen et, à ce sujet, on pourrait se guider sur l'expérience islandaise de l'usage de la vapeur géothermique. La planification dans l'avenir devrait porter sur des complexes d'énergie totale industriels, agricoles ou aquacoles reliés à une centrale d'énergie, comme l'indique le chapitre 6.[6]

Les rejets thermiques peuvent aussi servir à dénébuler et à déglacer les pistes d'aéroport. Ces systèmes, qui ont déjà été proposés aux Etats-Unis, sont techniquement réalisables à l'aide de chaleur peu élevée (115°F), mais ils nécessitent de grands frais de premier établissement et ne servent que pendant certaines périodes. Les systèmes de déglaçage seraient très utiles dans le Nord canadien.

La chaleur résiduelle peut aussi servir à garder les lacs et les plages à une température plus confortable pendant de plus longues périodes dans les climats froids. On pourrait créer un usage pour toute l'année en dressant des barrages au large et en aménageant des bassins d'eau propre et chaude le long des rives des principaux lacs et rivières. Ils serviraient de bassins de refroidissement, de source d'approvisionnement d'eau pour les villes et de lieu de récréation. Les frais de premier établissement élevés et un certain nombre de dangers écologiques possibles, comme le foisonnement d'algues en été, pourraient soulever de graves problèmes.

Les systèmes de climatisation et de chauffage sont probablement les moyens d'utilisation de la chaleur résiduelle que l'on propose le plus fréquemment dans les villes. Pour savoir si ces systèmes sont praticables, on peut étudier les exemples de chauffage géothermique en Islande et de chauffage par rejet thermique de centrales d'énergie à Lund (Suède). Ces systèmes, cependant, exigent une chaleur beaucoup plus efficace (vapeur) que celle qui est habituellement rejetée des centrales d'énergie et, dans le cas de Lund, il a fallu, pour satisfaire à ce besoin, accepter le coût de la perte d'une certaine production d'électricité. De plus, il n'est pas sûr que l'emploi de la vapeur réduise à un niveau acceptable les rejets thermiques.

[6] Tout ce qui suit la note précédente est tiré du chapitre 6, pages 53 à 56.

Les études faites aux Etats-Unis montrent que le chauffage et la climatisation à l'aide des rejets thermiques sont techniquement praticables et écologiquement souhaitables, dans un rayon de 10 milles du centre de distribution. Il reste à en prouver empiriquement les avantages. Certains problèmes pourraient se poser au printemps et en été, lorsque les demandes de chauffage ou de climatisation sont réduites. Il faudrait donc s'en débarasser en se servant des techniques classiques à l'aide d'échangeurs de chaleur atmosphérique ou en augmentant le nombre des usagers de base, comme l'industrie et le traitement des égouts et des eaux usées.

Inuvik (T. du N.-O.) est un cas spécial. Son éloignement et son climat froid ont fait qu'un système central combiné de chauffage et d'énergie et des conduits «utilidors» au-dessus du sol pour transporter l'énergie, le chauffage, les égouts et l'eau, s'est révélé économique et efficace pour combattre le pergélisol et le gel.

La documentation sur les utilisations de la chaleur dans les villes ne spécifie pas s'il vaut mieux utiliser la chaleur résiduelle des centrales d'énergie, ou installer des chaudières centrales qui ne produisent aucune électricité, mais une meilleure chaleur à meilleur marché que par les méthodes classiques. Certains auteurs proposent un moyen terme. Habituellement, les coûts de distribution de la chaleur sont le plus grand obstacle des systèmes de chauffage et de climatisation. La chaleur résiduelle servira probablement à ces fins quand les questions de sécurité, d'opinion publique et d'émissions polluantes non thermiques auront été résolues et permettront l'aménagement de centrales dans les régions urbaines. Il ne faut pas oublier ces applications lors de la planification à long terme, surtout si elles aident à résoudre des problèmes de pollution atmosphérique non thermique.[7]

L'agriculture thermique offre de grandes possibilités. La chaleur de peu d'efficacité peut servir à maintenir la température environnementale des plantes et des animaux. Le choix du système et des techniques est en partie dicté par le climat et la situation géographique, et en partie par les sortes de produits dont la demande est suffisante pour justifier des frais élevés de premier établissement.

L'agriculture thermique «à découvert» dans les climats tempérés peut améliorer le rendement, la qualité des récoltes et la longueur de la saison de croissance de certaines récoltes en les protégeant contre la gelée à l'automne et au printemps, en les rafraîchissant pendant l'été et en fournissant une irrigation à l'eau chaude. Mais ces usages ne sont pas constamment nécessaires et, par conséquent, n'apportent qu'une solution partielle au problème de la chaleur résiduelle. Les coûts de premier établissement et les pertes de chaleur qui augmentent avec la longueur des tuyaux limitent ces techniques à des secteurs restreints, à la culture maraîchère et à la culture des fruits.

L'agriculture thermique à environnement contrôlé associé aux systèmes combinés énergie-agriculture-dessalement s'est révélée beaucoup plus efficace que l'agriculture thermique «à découvert» ou que l'agriculture classique dans les régions côtières chaudes et arides. A l'heure actuelle, les coûts de premier établissement élevés limitent cette technique en importance, à des pays qui en ont les moyens, et à l'horticulture et la culture de légumes de valeur. Il reste encore à faire des essais qui montreront si ces techniques peuvent être appliquées dans le Nord canadien où existent les problèmes du froid et du gel du sol, et non la chaleur, la sécheresse et les sables salés.

Les méthodes efficaces de culture maraîchère dans les serres chauffées géothermiquement en Islande, pourraient s'adapter à une source de chaleur comme les centrales thermiques et pourraient servir à satisfaire les besoins de légumes frais et de volaille à bon marché, tout au long de l'année, particulièrement autour des centres miniers du Nord canadien et dans les villes dont les environs immédiats servent aux habitations. La culture à environnement contrôlé peut aussi très bien servir à l'élevage des animaux à fourrure à profit élevé. Si les installations de culture des algues, de traitement des égouts et des eaux usées étaient combinées à l'agriculture, on augmenterait l'utilité du système dans le cas des villes et la production alimentaire, surtout du boeuf, pourrait être beaucoup moins coûteuse. Les coûts de premier établissement élevés, le manque de connaissances pour réaliser une analyse complète du système, les problèmes environnementaux reliés à la complexité des relations plantes-eau-sol et les problèmes du bilan de chaleur que soulève le chauffage des serres à l'aide de la chaleur résiduelle des centrales d'énergie, pendant toute l'année, dans des climats tempérés,

[7] Tout ce qui suit la note précédente est tiré du chapitre 7, pages 57 à 62.

ont, jusqu'ici, limité l'agriculture à environnement contrôlé à des concepts et à la recherche sur les applications limitées aux universités. Même s'il est probable que l'agriculture ne pourrait utiliser qu'une quantité limitée de rejets thermiques, la demande de plus en plus grande de nourriture, d'eau, d'énergie, de traitement des égouts, etc. pourrait fort bien faire pencher la balance. L'agriculture à environnement contrôlé est probablement le moyen le plus pratique (technologiquement et économiquement) d'utiliser avantageusement la chaleur résiduelle de faible efficacité. Toutefois, il est nécessaire d'évaluer les avantages obtenus par l'utilisation d'eau chaude résiduelle en agriculture plutôt que des méthodes classiques.

Ce sont les conditions météorologiques, la proximité des marchés et l'éventail de choix des autres systèmes qui déterminent les possibilités de réalisation et, en grande partie, le design des systèmes d'agriculture thermique cités dans le présent rapport. La planification future exigera une plus grande prise de conscience des coûts de tous les systèmes. Les usagers éventuels de chaleur résiduelle devront connaître les coûts et les critères spécifiques de conception de leurs systèmes locaux de distribution de l'eau ou de la chaleur et les fournisseurs éventuels d'eau chaude voudront une évaluation économique des systèmes proposés.[8]

Le développement de systèmes d'utilisation de l'énergie à fins multiples, bien qu'il soit assez utopique, compte tenu de la situation économique, politique et sociale actuelle, deviendra probablement obligatoire à cause des sollicitations de plus en plus fortes imposées à l'énergie et aux autres ressources et de la demande de plus en plus grande de dépollution, sous toutes ses formes. L'application d'usages avantageux de la chaleur résiduelle pour empêcher la pollution thermique de l'environnement aquatique n'est qu'une mesure de plus contre la pollution. Malheureusement, l'objectif visé est encore de pousser au maximum la production d'énergie, de réduire les coûts de production et d'enrayer comme on peut la pollution qui en résulte, plutôt que d'utiliser efficacement toute l'énergie, ce qui réduirait la pollution, mais comporterait des coûts très élevés de premier établissement. Le Canada, étant un pays relativement jeune dans le domaine du développement urbain et industriel, se trouve en meilleure position que la plupart des pays pour établir des systèmes complexes d'utilisation de l'énergie. Certains planificateurs ont conçu un système d'utilisations multiples des eaux des canaux et lacs pour les parties des Etats-Unis qui pourraient utiliser les ressources des canaux à leur pleine capacité. Même si ce système a plusieurs inconvénients et qu'il ne s'applique qu'à une situation américaine bien précise, il vaut quand même la peine d'étudier le principe selon lequel les ressources existantes sont évaluées à la lumière de la planification environnementale à long terme.[9]

En conclusion, le choix de l'utilisation avantageuse des rejets thermiques dépend de la situation qui prévaut. De nombreux usages, comme la fonte des neiges et des glaces, sont de nature saisonnière et exigent des solutions pour les autres saisons. D'autres usages, surtout les usages industriels et les systèmes de chauffage collectif, nécessitent une chaleur de meilleure qualité que celle qui est habituellement disponible et le transport de la chaleur résiduelle à partir du producteur jusqu'à l'usager est généralement difficile et coûteux. Dans les cas spéciaux, comme celui d'Inuvik (T. du N.-O.), le chauffage collectif pourrait être une solution applicable. Les possibilités de développement de bassins de refroidissement servant d'installations récréatives valent la peine d'être étudiées si l'on considère la pollution de plus en plus grande des lacs et cours d'eau du Canada, surtout autour des centres urbains du sud du Canada. Certaines formes d'aquaculture et d'agriculture thermique présentent de bonnes possibilités d'application puisqu'elles peuvent allonger les saisons de production, dans certains cas, jusqu'à douze mois sur douze. De plus, elles pourraient utiliser les terrains qui entourent les centrales d'énergie, qui, en vertu des règlements de sécurité actuels, ne peuvent servir à des développements résidentiels ou urbains. Les concepts d'utilisation de l'énergie à fins multiples devraient être étudiés attentivement comme partie de la solution à long terme du problème de la pollution. Les utilisations avantageuses de la chaleur résiduelle ne sont qu'un moyen à court terme de régler une partie du problème. En outre, il ne semble pas possible que ces solutions utilisent tous les rejets thermiques des centrales d'énergie, surtout l'été, quand le besoin d'élimination de la pollution thermique est le plus grand, mais que les possibilités d'utilisation sont les moins nombreuses.

[8] Tout ce qui suit la note précédente est tiré du chapitre 8, pages 63 à 72.

[9] Tout ce qui suit la note précédente est tiré du chapitre 9, pages 73 à 75.

CHAPTER 1

INTRODUCTION

In view of the rapid growth in demand and use of energy in North America, and, in particular, the increase in thermal power generation of all types (Figure 1), it may be anticipated that the effects of thermal discharges from power stations may present serious ecological problems in Canada in the future. The projected rapid increase in the Canadian demand for electricity can easily be seen from Table 1 and Figures 2 and 3. Such an increase could have very significant environmental repercussions, since nearly 80% of heat rejection to the environment results from electrical power production (M.E.C. 1971).

The amounts and pattern of thermal inputs to Canadian waters from the present to 2000 A.D. have been assessed in two recent reports (Acres, 1970; M.E.C., 1971, Table 2). Present thermal input to fresh and tidal cooling water sources in Canada (with the exception of the Great Lakes Basin area) is estimated at 2.86 x 10^{10} BTU/hr., and is predicted to increase to 76.7 x 10^{10} BTU/hr. by the year 2000 (M.E.C., 1971). Corresponding figures for the Canadian portion of the Great Lakes Basin are 2.39 x 10^{10} BTU/hr. for 1968, and 60 x 10^{10} BTU/hr. for 2000 (Acres, 1970). Thus, for the interval 1968-1970, the total peak input to Canadian fresh water is estimated to increase from 4.815 x 10^{10} BTU/hr. in 1970 to 98.6 x 10^{10} BTU/hr. in the year 2000 (M.E.C., 1971). The total peak thermal input to Canadian fresh and tidal waters is estimated to increase from 6.025 x 10^{10} BTU/hr. in 1970 to 136.7 x 10^{10} BTU/hr. in 2000 (M.E.C., 1971).

Thermal Inputs other than from Power Generation

In the United States, an estimated 70% of process water withdrawn by industry is for cooling purposes. Although the most significant contribution to thermal pollution is from the power industry, at least 20-30% of the total heat rejected is in cooling water from wet-process industries. These contributions are usually in the form of less concentrated heat loads which do not cause the same problems as those resulting from single, large point sources which are typical of power plants. Even sewage contributes a rise in temperature to the receiving water, although its effect on the receiving water is negligible (Krenkel and Parker, 1969). The heat absorbed by cooling water in some typical industrial processes is shown in Table 3.

Thermal Efficiency, Present and Future

In industrially developed countries, the major sources of thermal discharges are fossil-fueled and nuclear power stations. The rapid growth in population, the even more rapid growth in demand for electric power, and the trend toward power grids rather than many small, self-contained electric systems, are all leading in the direction of ever larger generating plants (Cairns, 1968). Fossil-fueled plants are now built to produce four or five times the electricity of those built 20 years ago. Nuclear power is predicted to dominate U.S. electricity generation by 2020 A.D. (Figure 4). Nuclear power plants are not economic in small sizes, and have much lower thermal efficiencies than fossil-fuel plants. Quantities of heat discharged into cooling water by electric power plants depend on the thermal efficiencies of these plants. Oil- or coal-fired plants with a high overall efficiency will discharge heat equivalent to approximately 1.3 times the electrical energy, whereas water-cooled nuclear power plants discharge heat equivalent to about twice the electrical energy produced (Vinck, et al., 1970). Although both types of plant use the same basic steam cycle to drive the turbines needed for electricity generation, nuclear plants remain less efficient because they operate at lower steam temperatures (500-600°F) and pressures (800-1000 psi) than conventional fossil-fuel plants. The most efficient fossil-fuel power plants using high temperatures (1000-1100°F) and high pressure steam (1800-3500 psi) can operate at about 40% overall efficiency at present, while the corresponding figure for the most efficient nuclear power plant is about 33%. Today, large nuclear plants require 50% more cooling water for a given temperature rise than fossil-fuel plants of comparable size. Improved technology is expected to reduce this added requirement to 25% by 1980 (Krenkel and Parker, 1969).

Nuclear plants using breeder (or fusion) reactors (Molten-Salt Breeder Reactor, Liquid-Metal Cooled Breeder) and advanced converters such as high temperature gas reactors may, in the future, have heat rates which would approach those of the most efficient fossil-fuel plants (Krishnamoorthy, 1970). These developments, however, are not expected until the 1980's (U.S. Water Resources Council, 1968), and doubts still exist as to the practicality of fusion plants (Cairns, 1968).

Figure 5 illustrates the relationship between process heat and electricity production, and also shows how overall thermodynamic efficiency declines with an increase in the temperature of turbine exhausts during typical thermodynamic cycles.

The paradox of the 'thermal pollution' situation is such that if the temperature at the turbine exhaust is raised to a level which is useful for a variety of purposes, then the thermodynamic efficiency would be reduced and more waste heat may be produced than there are uses. Thus, a balance should be aimed for in planning of future power plants between plant efficiency and heat rejection temperatures suitable for beneficial uses. Every BTU of waste heat beneficially used increases the efficiency of the overall cycle as effectively as improving the efficiency of the steam-to-electric conversion process. (Beall, 1970b). Future power plants should be designed, in conjunction with large integrated systems of urban, industrial, or agricultural energy usage to maximize thermal efficiency of the total system, and minimize energy waste — a large part of the total pollution problem.

At present, power plants discard heat in the 80°-100°F (or 15°F average above ambient) range. This is low grade heat which, if a once-through cooling system is employed, will vary seasonally, depending on ambient temperature. There are few economic uses for such low-grade heat, and it is uneconomical to transport a large volume of low temperature water (Beall, 1970b). Heat at temperatures over 200°F is applicable to some needs, but 300°F plus (almost 200°F higher than typical power plant waste heat temperatures) is needed to make long distribution systems profitable (Beall, 1970b). Despite the argument by some utilities that direct discharge of low-grade heat to the aquatic environment may not have harmful effects (see page 20), the amount of heat involved is so great that such an inefficient use of energy and nuclear or fossil-fuel resources can no longer be ignored.

Current predictions for the United States indicate that the most probable efficiency of the entire electricity production system may not exceed 55% before 1990 (Figure 6). Since all electrical energy is eventually degraded to heat energy, and because there are many other sources of energy release associated with industry, transportation, and urban living, the long term problem will not merely be concerned with the control of electrical plant heat dissipation specifics, but rather how to regulate the total amount of energy released to the environment from all sources. For example, from present consumption methods, the projected heat release in some major American cities, for the year 2000, will be approximately 500 BTU/ft^2/day (based on a release of 36 x 10^{12} kilowatt hours in an area of 20,000 square miles). This is about 50% of the average total solar radiation (1000 BTU/ft^2/day) reaching the earth's surface in the U.S. latitude. How it may affect weather patterns remains unknown (Jaske, 1969; Chapman, 1970).

Power Industry Planning

At present, the North American power industry is partly to blame for the projected thermal pollution problem. The utility planners expected nuclear power to be more economic than conventional sources and would create less of an air pollution problem. Aided and stimulated by government policies, the industry committed itself too heavily on nuclear power for the required future expansion. Investment and cost curves have now changed their initial shapes in the face of higher safety and quality control measures, increased wages for skilled labour, and higher prices for basic materials. Nuclear reactors are aggravating the thermal pollution problem because, at the present level of development, they have lower thermal efficiencies and greater cooling water requirements than conventional plants.

The European nuclear power industry has not developed as fast as expected. Advanced gas cooled reactors, though reliable, have turned out to be less economic than anticipated. Due to the current high cost of investment, nuclear power stations with their comparatively large capital cost per megawatt installed are at a disadvantage in relation to conventional generating stations. In the late 1970's or 1980's, better and fast reactors (High Temperature "Dragon" type; American Water-Cooled type; and the Atomic Energy "heavy water" reactor) may be available, which leaves the power industry in the dilemma of either investing now in equipment which could be obsolete soon in terms of efficiency, capacity and economics, or deciding to wait for better developments such as the liquid-metal cooled fast reactor in the 1980's (*Nature*, 232, 1971). The latter may have greater thermal efficiencies and lower water requirements than present reactors, thus reducing the thermal pollution problem, but its development at present is rather unpredictable.

Alternative Methods of Power Generation

A long-term aim should be to achieve a more efficient production of power with as little adverse environmental impact as possible. One possibility is to utilize waste heat to generate power. Thermoelectric generators have been developed using thermoelectric units built into cross-flow type heat exchangers with plate-fin surface geometry. While conducting the latent heat from the condensing steam to the cooling water, the units convert a portion of this heat to electricity. Similar systems can also be designed for hot stack gas releases, and for hot exhaust gases from gas turbine electric power systems. Currently, it is not economical to use thermoelectric devices to generate electricity from waste heat, largely due to high capital costs per kW of production (Shirazi, 1970).

The use of solar energy to generate electricity would both bypass the production of steam and would not require cooling water. At its present stage of development, however, solar energy is not applicable to the tremendous generating capacities required from single plants. It would be applicable only to decentralized systems, in which smaller capacities for each unit would be acceptable (Cairns, 1968).

Any nation has a limited potential for hydroelectric developments. Canada has not yet reached the limit of this potential, though much of this is in the more northerly and remote locations, making it costly to transport the energy to the major markets in the south. Small lakes and river systems on the Canadian Shield, close to markets such as the Great Lakes and the St. Lawrence urban and industrial areas, could be developed as a series of small closely-linked hydro-schemes, but collectively, they will probably have higher capital costs than individual large schemes. Tidal schemes, i.e., the Bay of Fundy, and projects like the James Bay hydro scheme, hold possibilities for the future, but again there is a limit, both in terms of money and site availability, to the nation's potential for such developments. Furthermore, in the long term, the total demand for electrical energy will exceed all economic hydro potential. It should also be noted that the ecological and social impacts of large scale flooding of hydro schemes may create far worse environmental problems than those associated with other forms of power generation.

The possible development of geothermal energy in Canada is very limited, and does not have the same potential as Iceland (Matthiasson, 1970). The majority of Canada's known geothermal resources are in the Western Cordilleran Region, where there are 60 groups of thermal springs (Souther and Halstead, 1969). Of these, 35 can be classified as hot (over 90°F), and 25 as warm (higher than local mean air temperature but lower than 90°F) (White, 1957a, 1957b); 18 have large flows (over 100 Igpm[1]), 19 have small flows (below 100 Igpm), and data are unavailable for the remaining 23. At least 10 springs have temperatures over 100°F and flows over 100 Igpm.

Geothermal energy could be artificially tapped by means of a deep shaft and chamber, into which water would be pumped, and the resulting steam could be used to spin a turbine before cooling and returning to the 'natural' boiler in a completely closed cycle, with very little waste heat and no atmospheric pollution (*Business Week*, Oct. 3, 1970). Such a system could be located anywhere on earth. At present, however, it is technologically and economically impractical.

On a smaller scale, the American electricity and gas utilities and the Pratt and Whitney division of the United Aircraft Corporation are developing the pollution free hydrogen-oxygen fuel cell, for commercial service by 1975 (Benedict, 1971). Although it might slightly reduce the load on power plants, particularly of urban/domestic demand for electricity, it is unlikely to make a significant contribution to the nation's total power output.

1 Igpm: Imperial gallons per minute.

Controlled atomic fusion provides one possibility for future energy production, although the problem of devising a container to hold the fusion reaction at a temperature in the order of 100 million °C remains to be solved. At present, the only possible container would be a magnetic field which can be either open-ended, confining atomic nuclei by a "pinch" effect within magnetic field coils, or toriodal (doughnut-shaped), confining nuclei in a ring of magnetic field coils. The most successful Russian (Tokamak) and American (Stellarator) experimental reactors use the latter system. To date, both systems can only achieve fusion temperatures for about 15 milliseconds before the "magnetic container" becomes unstable and "leaks."

Fusion will only become useful when the reaction is confined long enough for the energy output to be significantly greater than the energy input needed to force nuclei together (i.e., breaking the force of the Coulomb repulsion barrier). The recovery of energy from a fusion reaction and its conversion to usable power also present difficult technical problems which have yet to be overcome. Whether the fusion reactor will be an efficient means of energy production with less environmental impacts remains to be seen.

Thermoelectric, magnetohydrodynamic, and thermionic systems, all of which require no steam or cooling water-cycle for power generation, are at present in experimental stages of development (Stevens and Mathur, 1970; Brown, 1970). The MHD generator (Figure 7) has the advantages of the absence of hot, highly stressed moving parts, and the capacity for production of very large amounts of power. For example, a compact MHD power plant producing as much as 10^{10} watts (the equivalent of 10 large utility plants) seems feasible, using a rocket engine (plus fuel supply and control system) connected to the duct of the MHD generator. Significantly higher thermodynamic efficiency could be achieved in a fossil-fuel power plant with MHD topping of the steam cycle. By applying this system to a natural gas-fired power plant, the Russians claim to have gained 15% more thermodynamic efficiency than in a conventional coal-fired station, though present shortcomings in the Russian experiment are low combustion pressures and field strength (Brogan, 1970).

Efforts to adapt MHD to a nuclear heat source have yet to achieve concrete results, the basic problem being that MHD works best at temperatures greater than 2000°K, whereas today, few reactors produce a temperature in excess of 1000°K (Rosa, 1968).

Present Technical Problems

At present, the energy available in fuels is transformed into heat by combustion or nuclear reactions. The generated heat transforms water into high pressure steam which turns the turbine rotors. The turbine rotor is connected with a generator where mechanical energy is transformed into electrical energy. Typically, cooling water is necessary to remove the waste heat of vaporisation of spent steam leaving the turbine exhaust. The steam then condenses into water and is pumped back under high pressure to the boiler for repeat of the steam cycle. The spent steam leaving the turbine has low energy content, but since enormous quantities of steam are involved, it necessitates large amounts of water for cooling purposes. Thus, the purpose of the cooling water is to transport the waste heat from the steam condenser tubes into the atmosphere (Figure 8).

The cooling water for the condenser is generally obtained by pumping from a river, lake or ocean into an intake pipe. In 'once-through' cooling systems, cooling water is passed through the condenser and is returned to the source through an outlet pipe. The outfall water temperature ranges roughly from 10 to 20°F. (Roddis, 1970) above the ambient temperature of intake water, depending on the amount of water available for cooling, the season of the year, and a variety of other factors. The average maximum temperature rise across the condenser is about 10°C for a nuclear power plant, and 8.3°C for a fossil-fuel plant, with nuclear plants requiring between 20 to 60% more cooling water than fossil-fuel plants (Nakatani et al, 1970).

There are alternatives to once-through cooling systems. In 'closed cycle' water systems, the condenser cooling water flows from the condenser to some form of atmospheric heat exchanger (either a cooling tower, artificial lake or pond), where heat is dissipated and then the water is returned to the condenser. Thus, there is no physical discharge of heated water to the natural aquatic environment. 'Variable cycle' cooling water systems are intermediate of the closed and open systems. Some heat is removed from condenser cooling water in a cooling tower or through-flow cooling pond before it is discharged to a natural water body (Nakatani, et al, 1970). Recently, it has been suggested that a nuclear power station — reactor, heat exchangers, and turbines — could all be contained within one large cooling tower, dissipating waste heat to the atmosphere. Its advantages are its low cost and minimal thermal pollution of surface waters (Lawes and Kenward, 1970).

Details of advantages and disadvantages of atmospheric heat exchangers involved in closed or variable cooling systems are already available (Krenkel and Parker, 1969; Parker and Krenkel, 1969, 1970; Symposium, *Industrial Water Engineering*, May, 1970). Broadly, they can be divided into three main groups:

1. *Cooling Ponds and Reservoirs*

Water is circulated through the condenser and is returned to a cooling pond for heat rejection. It is then recirculated. Cooling ponds and reservoirs use more ground area than other exchangers, an important consideration in plant siting and costs (Table 4). They are also rather inefficient because of low heat-transfer rates. Spraying of the cooling water improves heat-transfer rates and therefore considerably reduces the surface area of cooling pond required (Table 4).

2. *Evaporative Cooling Towers*

Currently, natural draft hyperbolic cooling towers are being increasingly used to dissipate residual heat to the atmosphere by evaporation of a small percentage of the condenser cooling water. Mechanical draft cooling towers have been used by the power industry for a considerable time. Generally, they are subject to high initial costs, but have moderate running and maintenance costs and are reasonably efficient.

3. *Dry Cooling Towers*

Dry cooling towers can be either natural draft or mechanical draft types, and they operate on the principle of direct transfer of sensible heat from a tubed radiator-type cooling tower to the atmosphere. The capital costs of these towers are high, and there is also the problem of turbine derating due to higher back pressures. Despite these drawbacks, dry towers, or air-cooled heat exchangers have recently been proposed as the best alternative in areas where water is becoming more precious and where thermal pollution is already close to legal temperature limits (Elliott, 1971).

Considering the variables of relative ground area required (Table 4), average condenser water requirement and consumption use (Table 5), and different evaluations of investment/capital, operating and maintenance costs (Tables 6 to 9), the once-through cooling process is the most economic as well as efficient way of dissipating residual heat. This, however, has created the problem that what is most economic and efficient for cooling the condenser is not necessarily conducive to preserving environmental quality. Thus, it is necessary to evaluate objectively the total costs and benefits of alternative methods of cooling, including the possible beneficial uses of waste heat. Discussion of the economics of thermal pollution control, focussing mainly on cooling system costings, are given by Lof and Ward (1969; 1970a; 1970b) and Kneese, Ayres & d'Arge (1970).

The possibility of improving power plant thermodynamic and total system efficiencies has been briefly reviewed in this report (page 13) and should be further investigated. Stress should also be placed on research into the prediction of drainage basin and marine-estuarine environment heat load capacities, and advanced planning of thermal discharges (Jaske, 1969).

This report is primarily on the critical evaluation of the current research efforts to beneficially use thermal discharges from power stations so that adverse ecological and environmental effects can be alleviated substantially.

CHAPTER 2

WASTE HEAT MANAGEMENT AND THE AQUATIC ENVIRONMENT

This report is primarily intended as a critical review of possible beneficial uses of thermal discharge and, therefore, it is not intended to discuss in detail such aspects as the role of temperature in aquatic environments, or types of changes in flora and fauna that may accompany natural or artificially induced temperature changes, except where this has direct bearing on a particular beneficial use, i.e., increased growth rates of fish in controlled fish farming. There is, however, little point in discussing beneficial uses if waste heat could be safely and cheaply dissipated to the environment, with acceptably few or no adverse effects.

The potential large-scale nature of waste heat rejection has already been described in the previous chapter. Total thermal additions to Canadian freshwaters are predicted to be as large as 98.6×10^{11} BTU/hr. by 2000 A.D. (M.E.C., 1971). The main question which needs answering is to what extent will such large-scale thermal additions alter existing aquatic ecosystems. If this information is available, proper decisions can be made in waste heat management, giving due weight to the trade-offs between possible environmental degradation and burgeoning energy needs. How much heat can a particular waterbody absorb before the environmental effects become socially unacceptable, and an alternative and more expensive method of disposal, such as a beneficial use, becomes socially, economically and politically acceptable?

This latter question raises the many thorny problems involved in defining and measuring social acceptability. Tangible benefits and costs can usually be measured in dollar terms, unlike intangibles, such as aesthetics, which are harder to quantify. Adverse effects on the environment may be long-term phenomena which, in the short-term, may lack immediate popular impact, or are not easily recognized and, hence, not acted upon before a threshold of no return has been reached.

A review of current research results indicates that scientists are divided in their opinions as to whether thermal additions to natural waterbodies have deleterious effects on flora, fauna, and water quality. Many biologists claim that effects are adverse, ranging from "the direct lethal effects of high temperatures on individual organisms to subtle changes in behavioral, metabolic, and performance responses, long-term genetic selection, and alterations in community-productivity and food chain relationships." (Coutant, 1968). Comprehensive bibliographies and reviews of such biological adverse effects are given by Kennedy and Mihursky (1967), and Coutant (1968; 1969a; 1970a; 1971).

Although the studies referred to in the above sources frequently draw their conclusions from laboratory experiments in which many of the interrelated variables found in a natural aquatic ecosystem are held constant, most of them do deal with the temperature ranges (80-100°F) to be expected at power plant outfalls. In a real situation, such temperatures may or may not extend to considerable distances from the outfall, depending on outfall design criteria and on factors such as rates of mixing with water at ambient temperature, thermal stratification, rate and volume of flow, and ambient temperature of intake water, all of which vary seasonally. The areal extent of adverse thermal effects will be dictated partly by these factors, and partly by the biological mechanisms of the ecosystems involved. For example, fish migration patterns may be interrupted by a thermal plume which extends completely across the cross-section of a river.

If the areal extent of harmful effects is small, the question then arises as to whether or not they are acceptable. Currently, increasing public awareness of environmental problems is in opposition to the economic reasonings of the power utilities. Guidelines for thermal water quality standards have been set forth in the U.S. National

Technical Advisory Committee (NTAC) Report, "Water Quality Criteria." The temperature criteria advocated for legislation in most states largely reflect these recommendations (U.S. Dept. of Interior, 1968, Nakatani, et al, 1970):

- 5°F artificial increase above 'natural' ambient (at the expected minimum daily flow for that month) for streams classified for either warm or cold water fish.
- 3°F artificial increase limit (in the epilimnion) in lakes and reservoirs, based on the monthly average of the maximum daily temperature. Withdrawal or discharge to the hypolimnion is not recommended.
- 1.5°F artificial increase limit in estuarine and marine waters in summer months.
- 4°F artificial increase limit in estuarine and marine waters for the rest of the year, based on monthly means of maximum daily temperatures.

Problems have been raised as to the definition of, for example, the "mixing zone" for outfall and receiving waters, which in some cases is exempt from temperature standards. Uniform standards, even at the state or provincial level, may not be ideal for individual rivers and local environmental conditions.

Fish-kills could occur when a rare event such as a long period of very low flow coupled with high ambient water temperatures occurs in a river. It is hard to legislate against this without applying thermal and abstraction standards which, during periods of normal or peak flow, are not well below the safe thermal capacity of the river.

It is known that the rate of oxygen use by bacteria rapidly increases with temperature, whereas stream reaeration, indicating oxygen absorption, changes only gradually. The solubility of oxygen decreases with increases in temperature. Thus, an increment in stream temperature is tantamount to either reducing the stream's waste assimilation capacity, or increasing the load of oxygen-demanding organic materials. As many Canadian and American rivers already receive high waste loads, they are more prone to develop an oxygen sag below the life support level if subjected to the further stress of heated discharges (Wright, et al, 1970).

Hence, it is essential to gain accurate estimates of the seasonal capacities of rivers, river systems, and other water bodies to withstand water abstraction and thermal additions. In order to determine how a specific temperature increase will affect fish or other aquatic organisms, one should know not only the usual biological requirements of these species, but also an estimate of the extent to which these species are already being affected by other forms of waste discharges (agriculture, industrial, municipal, etc.). Each drainage basin should be regarded as a single operation unit (Cairns, 1969a), and the synergistic effect of all potentially harmful agencies upon the aquatic organisms should be considered, as well as the effect of individual and potentially harmful factors. Present laws and assessment techniques are designed primarily to cope with wastes individually, rather than collectively. Further work on applying systems analysis techniques to entire drainage basins, such as COLHEAT (Jaske, 1971; Peterson & Jaske, 1970a, 1970b) and THEDY (Bogh, & Zünd, 1970); mass-exchange models and mass energy balances (Ashbury, 1970) and maps of stream heat loads (Eckholdt et al, 1969), is recommended (Cairns & Humphrey, 1969). Environmental quality control and effective regional management will only be possible if we treat drainage basins as single systems, and design waste loadings on that basis rather than one fragment at a time.

In contrast to the pessimism of many biologists, conclusions from much of the research performed, usually for the American electric utility companies, indicate that waste heat discharges have little or no adverse effect on aquatic ecosystems, and in some cases may even have beneficial effects such as, for example, improving salmon feeding conditions (Becker, 1969).[1] Usually, however, the utilities observe certain maximum temperature limits. Biological studies on all operative TVA steam plants, since 1955, have

[1] Examples of research with such conclusions include: Roddis 1970; Gartrell et al, 1970; Gould and Moore, 1970; Alabaster, 1969; Beauchamp et al, 1970; Merriman, 1970a, 1970b; Churchill & Wajtalik, 1969; Philbin & Philipp, 1970; Proffist, 1970; Goubet, 1965; Brezina, et al, 1970; Roback et al, 1969; Cairns & Koesler, 1969; Coutant et al, 1969; Coutant 1969b; Becker, 1969; Harvey, 1970; Raymond & Carrie, 1964; Scharfenberg, 1970; Braun & Jones, 1970; Gammon, 1969; Cairns & Paterson, 1970; Cairns, 1969b; Heinle, 1969; Brandt, 1969; Templeton & Coutant, 1970.

produced no result which indicated detrimental effects on aquatic life attributable to maximum allowable heated discharges of 93°F (Churchill & Wajtalik, 1969; Gartrell et al, 1970). Some have suggested that at certain times of the year, discharge temperatures of 105°F, 10°F higher than usual state maxima, have no adverse effect on aquatic life (Kolflat, 1968). However, freshwater ecosystems apparently can tolerate greater temperature differentials than oceanic and estuarine ecosystems (Roddis, 1970; Stearns, 1970). Apart from the example of TVA operations, most of the findings quoted in this report are from short-term research studies. Long-term effects are still unknown.

There are two main reasons for such differences of opinion. Firstly, not enough is known about the detailed biochemical and limnological processes operating in aquatic environments and, secondly, the nature of these effects probably depends a great deal on the unique features of each situation. In an already badly polluted river, effects may be bad whereas in a relatively unpolluted river, with a large flow throughout the year, effects may be minimal. This conclusion poses the problem of evaluating and monitoring the condition of a particular ecosystem.

Aquatic Ecosystem Evaluation

There are two major approaches toward evaluating and monitoring the condition of an aquatic ecosystem with the aim of better management of both the water resource and the disposal of wastes. The first approach includes mathematical modelling and total systems analysis, and the second attempts to identify those criteria which, when monitored, will show trends symptomatic of the condition of certain aspects of the ecosystem. Using a medical analogy, the first approach may try to replicate and monitor the whole body, and the second may look for a pulse. These approaches do overlap, and in some circumstances complement one another. A mathematical simulation might well indicate worthwhile 'pulse' criteria. However, a mathematical model is only as good as its input data, and frequently a major limitation is the use of improvised constants or coefficients in lieu of adequate biological information.

At the present time most mathematical modelling techniques in water quality modelling follow the classical Streeter-Phelps DO-BOD relationship, (Biswas et al, 1972). DO-BOD models, however, represent just a small segment of water quality. Other submodels of water quality would have to be developed, including chemical, eutrophication, sediment, and toxicological submodels, so that planners may be able to use them with more confidence than otherwise possible (Kramer, 1972). Many of the mathematical models proposed so far have enormous data requirements which usually far exceed data available. Many parameters necessary for such modelling as waste sedimentation rates, and oxygen reduction and addition due to plant respiration and photosynthesis, are simply not known in actual situations (Pentland et al, 1972).

Although in practise a total systems approach, including accurate mathematical models are, except in rare cases, hard to achieve, they are valuable tools to answer such complex questions as:

1. What is the temperature threshold up to which the ecosystem is adequately buffered to receive thermal inputs without marked alteration of state?
2. What length of time is needed for an ecosystem of readjust to a new stable state upon application of thermal stress?
3. What will be the nature of this new stable state, i.e., how much change will occur in the species and concentration of species of the aquatic community?
4. What will be the nature of the ecosystem during the process of readjustment? What events and changes are likely to occur?
5. To what extent will thermal discharge interact synergistically with impurities in the water to cause major environmental stress (e.g., BOD levels, see p. 20)?

In addition, during the process of model development, resource managers are forced to consider aspects of the total complex problem which they may otherwise have overlooked.

An interesting offshoot of the systems approach, which attempts to rapidly predict and trace water quality problems, is the development of the logic diagram. This technique if often used by engineers in fault analyses. A simplified diagram developed for analyzing actual or potential fish-kill situations is shown in Figure 9. From such a fault analysis diagram, it may be possible to identify:

1. critical factors that have high probabilities of influencing mortality;
2. factors that cannot be controlled by man in ecosystem management;
3. critical areas that are sensitive to thermal stresses; and
4. critical areas associated with pollutants that are not generated by the power plant.

However, for this technique to work, one still requires much information about each factor in the fault tree.

Ideally, a systematic investigation into the effects of thermal discharges on the environment should follow four phases:

1. Obtain baseline data on the particular ecosystem and, as a preliminary step, compare it with other known ecosystems for which a classification has been developed.
2. Evaluate these data, projecting (with aid of models) the possible environmental stresses that may develop, and provide recommendations for corrective action where required.
3. Monitor, during plant operation, the real changes taking place in the aquatic ecosystem, and take appropriate action when required.
4. Compare real changes measured with those predicted in order to assess and improve the method of prediction for future problems.

Considering the costs and time involved, however, such a total investigation is not really practical. Therefore, investigation should perhaps be directed towards a selective study of the most meaningful criteria — the 'pulse' criteria referred to at the beginning of this section. Such criteria might include an analysis of the life support systems for key floral and faunal species whose presence or absence may provide a test for certain minimum water quality standards. Species diversity is another index of change which has been well developed in the fields of plant and animal biogeography, but has so far been rarely used in practical management of water quality. Further research and interdisciplinary discussions on possible applications of these types of criteria may well prove worthwhile to the resource managers.

Alternatives in Management of Heated Wastewater

Given the present levels of knowledge, there are five basic alternative solutions to the heated wastewater disposal problem which may be used individually or in various combinations (Bregman, 1968; Black, 1968; Cairns, 1969):

1. Placing all heated wastewater in streams, lakes, and oceans without regard to the effect, and considering the environmental damage as a consequence of our increased demand for power.
2. Improving present power plant thermodynamic efficiency and developing new methods of power generation which are efficient and result in less heating of water or pollution of the environment.
3. Using, but not abusing, present ecosystems. This means regulating the heated discharge according to the receiving capacity of the environment and, consequently, requires a knowledge of the ecosystem and its tolerances.
4. Modifying ecosystems to fit the new temperature conditions, which requires a detailed knowledge of each particular ecosystem, and a technique for evaluation of the functioning of ecosystems.
5. Finding alternative ways to dissipate heat, or developing beneficial uses for heated waters.

For meaningful beneficial uses, the following criteria are worth considering (Boersma, 1970).

1. Operation of the power station must not depend upon the use of waste heat or be affected by variations in that use. *The warm water should be taken at the outlet.*
2. Schemes for using waste heat must not be catastrophically affected by the loss of the warm water supply. *The system should be able to operate without warm water for short periods of time, or a back-up heating system should be available when necessary.*
3. The cooling water may have to be treated with chemicals continuously or intermittently to prevent fouling of the cooling system. In the beneficial use, the water may also be-

come contaminated, for example, with sewage from aquaculture. Therefore, *the cooling water, if polluted, should be recycled in a closed system with a built-in purification unit.*

4. The temperature level of the cooling water is low when use for industrial processing is considered, but it is suitable for many biological activities. Therefore, *the heat should be primarily used to stimulate life cycle processes.*
5. Although the grade of heat is low, the quantity of heat is large. Therefore, *several uses of low grade heat are required.*
6. *If several uses are to be deployed in one cooling system, they should be mutually beneficial or, at least compatible.* For example, waste heat may stimulate large algae production during sewage treatment. Algae may then be converted to feed for cattle housed in stalls heated with warm water. Different uses require different grades of heat, therefore, within one cooling system, the sequence of uses for the same warm water should be in an appropriate descending order of temperature requirements. Certain uses may be incompatible when incorporated in the same system. For example, untreated runoff from heated irrigation in greenhouses could be chemically unsuitable for use in a fish-farm.
7. Water is a finite resource. Therefore, *systems which recycle the water should be considered.*
8. Pollution problems, such as disposal of agricultural and domestic sewage, air pollution, heat effects in rivers, and the use of persistent chemicals must be solved in concert, not individually. Therefore, *integrated systems, the components of which reinforce each other, must be considered.*
9. As steam-electric power generation usually continues throughout the year, *the use for warm water should either be a year-round proposition, or else the system should be so designed that one use can be replaced by another during the season when the first use is inappropriate.* In Canada, much warm water could be used for ice control in winter, but feasible alternatives are necessary for the summer season.
10. The objective is to solve a problem of thermal discharge into an aquatic environment, be it for purposes of saving waste of heat or for alleviating possible harmful effects to the ecosystem. Therefore, *if a closed system of water recycling is not employed, the water ultimately discharged to the aquatic environment after serving cooling and beneficial functions should be pollutant free and of a similar temperature to the ambient temperature of the waterbody into which it is discharged.* Ideally, such a temperature should be controlled to correspond to "natural" seasonal fluctuations in ambient temperatures. In practice, before any heated discharge is made, other sources of heat additions to the ocean, or to the entire river, lacustrine or estuarine network, should be considered in the light of the heat assimilation capacity, without detrimental effect to the ecosystem.
11. *The beneficial uses and cooling functions should together not require an abstraction of water from the natural water body in excess of that waterbody's capacity for abstraction, bearing in mind seasonal fluctuations in flow and other points of abstraction for human usage throughout the whole river or estuarine network.* Beneficial uses and more conventional cooling systems, such as cooling towers and sprays, can result in considerable loss of water by evaporation. Account should be taken of these types of losses when assessing amounts of abstraction, as this water is not directly returned to its source.

CHAPTER 3

NAVIGATION

It has been suggested that waste heat from power plants may be sufficient to keep major portions of navigable rivers free from ice and that the proper positioning of thermonuclear reactors might significantly elongate the shipping season.

Theoretical Considerations

The length of an ice-free reach that develops during the winter below a thermal pollution site on a river can be calculated using a differential equation for the steady-state heat balance of a volume element of a river (Dingman et al, 1967, 1968; Dingman and Assur, 1969a, 1969b):—

$$X = C \int_{T_o}^{T_x} dT/Q$$

Where:
- X = Distance downstream from the pollution site to the river cross section where water temperature equals T_x.
- C = A constant that includes flow velocity and depth.
- T_x = Water temperature of a cross-section of river downstream from the pollution site.
- T_o = Water temperature at X equals zero.
- Q = Rate of heat loss from the water surface.
- T = Water temperature.

The value of x at T_x equals 0°C is taken as the length of the ice-free reach. Q is the sum of heat losses due to evaporation, convection, long- and short-wave radiation and other processes; each of which is evaluated by an empirical or theoretical expression such as Bowen ratio, Kohler equation, and the Russian Winter equation (Dingman et al, 1968, p. 352-357). The two principal limitations in accurately calculating downstream temperature changes are related to difficulties in evaluating the degree of lateral mixing in natural rivers and the convective and evaporative heat losses under unstable atmospheric conditions. Observations of lengths of ice-free reaches on the Mississippi River are in good agreement with calculated values (Table 10).

The same prediction technique was applied to a section of the St. Lawrence Seaway, the 32 km of the South Shore Canal including the St. Lambert and Côte St. Catherine locks.[1] It was calculated that, for a present conventional nuclear reactor with a thermal pollution output of 2.9 x 10^8 cal sec^{-1} ($\approx$ 1.2 x 10^9 watts), 17 km (Russian Winter equation) to 25 km (Kohler's equation) of this reach could be kept ice-free. For the size of nuclear reactors currently being designed (thermal rejection 8.4 x 10^8 cal sec^{-1}; $\approx$ 3.5 x 10^9 watts), the ice-free length predicted was 50 km (Russian Winter Equation) to 75 km (Kohler's equation). When an average winter temperature of −11°C was assumed along with the Russian Winter Equation, values of 27 km and 75 km were obtained for the conventional and recently designed reactors respectively (Figure 10).

Power Plant Siting Considerations

Calculations such as those described above indicate that thermal discharges from power plants may be adequate to keep a significant length of a canal ice-free during winter, which suggests the possibility of siting future reactors along the St. Lawrence Seaway at critical points, such as lock areas and ship canals. If these were kept ice-free, it would be possible to move shipping into the Great Lakes, if not for the whole winter, for at least part of it. One of the biggest problems would be the stretch of the St. Law-

[1] These predictions, from Dingman et al, 1968, assume:
- i. Severe winter temperatures of −17°C
  (mean monthly minimum, January, Ottawa −16.7°C
  February, −15.6°C;
  31 years record)
  (mean monthly minimum, January, Quebec −16.1°C
  February, −15.6°C;
  32 years record).
- ii. Wind speed of 5 m sec^{-1} (January and February, Cornwall, Ontario) — probable high.
- iii. Average canal depth 9m; width 150m; water flow velocity 0.5m sec^{-1}.
- iv. Complete cloud cover, c = 10.

rence River from Montreal to Quebec City, and the St. Lawrence Gulf. This reach can be kept open by ice breakers for part of the winter, and for the remainder of the season, even though it may be closed, traffic will still be able to operate within the Great Lakes System.

Currently, a major criterion for the positioning of power plants is the availability of an adequate supply of cooling water. A reactor can be linked to the general power grid system that is being used in the U.S. and Canada. Advantage may be taken of the possibility of nuclear plant siting to position plants in optimum positions for the beneficial use of the heated discharge. Positioning power plants close to the Seaway may be ideal for use of waste heat in winter; that the question of a summertime use remains unanswered. Perhaps, a summer use, such as in a sewage treatment plant[2], may benefit from a different power plant location. The relative trade-offs between these two seasonal uses and locations must be assessed. In the Canadian context, summertime uses for waste heat are harder to find than wintertime uses.

If waste heat is to be used for extending the navigation season on the Great Lakes — St. Lawrence Seaway System, it is essential that the U.S. and Canadian power authorities and other Seaway users work in close collaboration at both national and international levels, in optimal power plant siting or ice-jam control. It may, however, be rather utopian to look for this degree of cooperation amongst the various vested interests.

Feasibility Studies

Biggs (1968) has proposed two cases for the use of power-plant waste heat. One is to extend the navigation season of the St. Lawrence Seaway to the end of December, the other to the end of January. Ice on the Great Lakes — St. Lawrence Seaway System in February and March is a more difficult navigation problem which requires other solutions.

In the first case, nuclear generating stations are sited at the head of existing canals and locks (Figure 11). Locks would require modification to permit continuous flow, and river and lake pack-ice from flow-ice build-up would need controlling. Under this system, however, navigation would be delayed by extremely cold spells, and would be largely impossible after the 31st December. The first case could be operative by 1987, based on forecasts of installed nuclear capacity (Quebec >9000 MW; Ontario and New York could install sufficient capacity for this plan by 1985 (Merlin, 1967). Since siting has a lead time of about twelve years for large stations, there is not much time for the implementation of this plan.

Although the second case extend the navigation season to the end of January, is requires more waste heat, and the addition of barrage works to the Seaway. As recommended in a previous report (Boyd, 1959), the barrage works would form canals and limit open water areas, thus minimizing the quantity of waste heat required to maintain an ice-free navigation channel. They would be constructed along the channels of Lakes St. Peter, St. Francis, and St. Clair, and between islands and the mainland to restrict the Upper St. Lawrence and St. Mary's Rivers to a narrow channel (Figure 12). The barrage works would be designed to optimise a minimum channel width and a minimum volume of rock movement (E.M.R. 1967). The total nuclear capacity required for extending the navigation season to the end of January is estimated to be 13,000 MW for Quebec, 600 MW for Ontario, 3,000 MW for New York, and 2,000 MW for Michigan. Using forecasts of installed nuclear capacity, this could be achieved by 2000 A.D. (Quebec 4,000 MW by 1987-1990, Ontario 5,000 MW by 1985-2000, Michigan 2,000 MW after 1980 (Merlin, 1967)). Omission of barrages on Lakes St. Francis and St. Clair, though halving barrage costs, requires 40,000 MW additional installed capacity, which is not feasible until the early 21st century.

An advantage of the second plan is that the elimination of ice at Beauharnois Hydro Generating Station would permit full flow at maximum head during peak periods and effectively increase dependable capacity by about 300 MW. A similar technique could perhaps improve the Niagara Generating Station energy output (Rosenberg, 1967). Pack ice control by ice-breakers would be reduced to controlling the Great Lake outlets.

A study by Pruden et al (1954) on methods of ice control and navigation season extension in the St. Lawrence River, has considered the use of power-station waste heat as well as regimented channels (Kerry, 1951), oil films, and coal-fired channel heaters. The study[3] concludes that waste

[2] See chapter 5, page 47.

[3] Pruden et al, 1954, p. 43-46.

heat from electrical generating stations is not a practical form of heat supply for an unconfined channel. If the water speed in a contained, 35-ft deep channel is increased to 3 m.p.h., the heat required to maintain an ice-free condition is much reduced. It is conceivable that waste heat from power generation can supply this heat. Under these circumstances a total system cost for 200 miles of channel from Lake Ontario to Trois Rivières, Quebec, maintained ice-free all year-round, might be about $10 million per annum, plus a few million dollars for ice-breakers to maintain ice-free entry ducts in the Gulf of St. Lawrence and in Lake Ontario. The accuracy with which such a contained system can be designed is appreciably higher than for the uncontained form of channel. Pruden et al (1954) also conclude that extension of the navigation season for a few days of weeks may be a more economic proposition than attempting navigation for the whole year.

Research by the U.S. Army Corps of Engineers (Graves, 1971) does not view navigation season extension as an all-or-nothing proposition, but rather as a progressive development, both geographically and in time. For the purpose of analyzing economic benefits, three time horizons were considered: a firm closing date on December 15th, navigation through January 31st and navigation year-round. Three geographic phases considered were the upper four lakes — Superior, Michigan, Huron and Erie; the upper four lakes plus the Welland Canal and Lake Ontario; and the addition of the St. Lawrence Seaway from Lake Ontario to Montreal. Thus, nine alternatives were evaluated for economic benefits and costs. Initial estimates of benefits range from $2.5 million/annum from December 15th closing date on the upper four lakes to $35.8 million/annum from a year-round navigation on the entire system. These estimates for 1980, could grow to $100 million annually by 2030. Vague estimates of costs are given ranging from $5-27 million/annum for the various geographic-time alternatives, although these estimates do not place emphasis on use of heated discharges. Obviously, costs depend as heavily on the geographic extent and duration of season extension, as do benefits.

Cost-Benefit Considerations

Besides power plant siting and alternative summertime uses for waste heat, there are other major problems involved in implementing such schemes as proposed by Biggs (1968); Pruden et al (1954) and the U.S. Corps of Engineers (Graves, 1971). Overcoming many of these problems will involve other costs apart from initial costs of channel modification, which should be evaluated in any cost-benefit analysis. Problems which should be considered are:

i. Navigation may be hindered by steam and fog over open water in winter, but such conditions are no different to those encountered on the lower St. Lawrence.
ii. Most ports would have to expand ice control systems, though Quebec, Detroit and Montreal are already successful in handling the problem.
iii. Ice-flow control at canal heads would be a problem; ice booms however, are already effective at the head of the Niagara river, as are ice-breakers in the Lower St. Lawrence.
iv. Bad weather would normally prevent navigation, irrespective of the state of the channel. Though radar assists navigation, the loading and unloading of cargo might still be impracticable.
v. Certain cargoes may freeze, though heaters could be used in some cases.
vi. Due to blown spray and sleet, ships can acquire a thick coating of ice which must be removed before it becomes a menace to stability. All deck and cargo-handling equipment, will have to be fitted with deicing protection.
vii. Icing of navigational equipment and lock gates must be countered.
viii. Operations under winter conditions will be unpleasant and it may be difficult to obtain labour of the essentially mobile sort without paying very high wages.
ix. Ice in the Gulf of St. Lawrence constitutes a shipping hazard, but this may be countered by increased air reconnaissance and by use of radar and sonar. Ice surveillance and a network for information dissemination would be essential.
x. Ship insurance in ice conditions would increase operating costs by approximately 20% (Biggs, 1968). This may act as a restraint on season extension since rates are based on experience.
xi. A lack of operating experience may tend to discourage shippers to use the system.
xii. The potential for shut-down of a nuclear generating station creates the risk of navigation disruption. Restoration of navigation would be difficult after several days of ice formation. Extremely cold spells may, des-

pite the warm power plant discharge, cause a freeze and curtail Seaway traffic.

xiii. Extra costs may be incurred in having to transmit electricity over greater distances as a consequence of siting power plants in positions strategic for seaway ice control.

xiv. Increased usage of the seaway, due to navigation season extension, would increase already existing problems of bankside erosion resulting from heavy ship washes. It may create silting problems in locks and harbour slack water areas. Erosion would be greatest on banks which are not protected with a stone or concrete facing. Proposed artificial canalling of sections of the seaway could overcome some bank erosion control problems. However, costs of canalling will greatly exceed any savings resulting from better erosion control.

xv. Hydro-power authorities fear that any season extension which may require the use of ice booms would eventually cause jams which, especially in spring, could result in upstream flooding, major blockages to navigation, and reduced flows downstream with a concomitant reduction in hydro output (LesStrang, 1971).

xvi. Economic and political repercussions are likely to arise out of a decline in the present winter trade of east coast ports such as Halifax and New York.

xvii. Adverse environmental effects may result from discharging heated water into the already badly polluted Great Lakes. One report concludes that for ecological reasons, there should be no significant discharge of waste heat (no more than 1°F temperature rise above ambient) into Lake Michigan (U.S. Department of the Interior, Fish and Wildlife Service, 1970; Nakatani et al, (1970).

Several authors have emphasized possible economic benefits to be gained from an extension of the navigation season (Graves, 1971; LesStrang, 1971; Beukema, 1971; Biggs, 1968). These are:

i. increased trade on the Great Lakes — St. Lawrence System;

ii. more efficient use of ships and crews on an annual basis. This has been demonstrated by the U.S. Steel Corporation in shipping taconite from Minnesota to lower lake ports for a period until mid-January of the 1970-71 winter (Beukema, 1971);

iii. reduction in storage costs associated with stockpiling;

iv. reduction in the cost of carrying large inventories;

v. more efficient operation of terminal-production facilities;

vi. possible expansion of income and employment for the whole region served by the Great Lakes ports; and

vii. more efficient use of this transportation network which reduces the need to develop others.

Despite the optimism of some authors, however, any plan for extending the navigation season cannot be regarded as viable until a thorough benefit-cost analysis has shown that its implementation and operation is economically justifiable. To date, this has not been properly done. Reviewing the financial statistics of St. Lawrence Seaway operations (Tables 11 & 12), it is evident that despite a yearly increase in traffic and income, there remains a marked increase in total debt which can only be accounted for by increases in interest owed on loans. With this in mind, the Seaway is operating at a net loss of $17 million (1971), a loss which increased by $1.5 million over the 1970 figure of $15.5 million. Any large scale alteration of the seaway, at costs such as the $10 million p.a. cited by Pruden et al (1954), would have the effect of increasing this debt at least in the short-term, and would require stringent analytical evidence that the financial returns from such an alteration would be worthwhile in the long-run. It seems doubtful that at this time the Seaway Authorities would wish to get further in debt to the Governments concerned.

Even if the Seaway Authorities were willing to invest in schemes for ice control and navigation-season extension using waste heat from power plants, the problem of finding viable alternative summertime uses for this heat would still remain.

CHAPTER 4

AQUACULTURE

1. General Criteria and Types

In recent years, heated wastewater has been increasingly used on an experimental basis for aquaculture. The type of aquaculture applicable to a particular power plant generally depends on the following factors:

i. Type of water (freshwater, brackish, or salt) used by the power plant in its cooling system.
ii. Technique of cooling (once-through method of recirculation schemes using cooling ponds, reservoirs, or towers).
iii. The function of water after cooling and aquacultural usage (recirculation or rejection to the environment).
iv. The design of the discharge outlet (if a once-through cooling system is used).
v. The seasonal ambient temperatures of the cooling water; the temperatures of the heated discharge; and the thermal requirements and limitations of local fish and aquatic life most likely to be of value in aquaculture.
vi. The time of peak demand for electricity. If peak demands occur in summer, additional thermal exposure resulting from the requirements of extra generating capacity could be lethal, particularly to restricted or immobile species living near their limit of tolerance to temperature or oxygen. Coastal power plants will have greater amounts of water available, as coolant and as a heat-sink, than most plants with a freshwater location (Nash, 1970).
vii. The minimum volume of heated water likely to be produced in winter when, in cool temperature latitudes, there is a priority for temperature maintenance on the fish farm. This volume will dictate the capacity and design of the fish farm, and will have to be used efficiently. Production may be limited to raising yearlings, with little demand on space, water and feed, for stocking ambient seawater facilities (in a similar fashion to fingerling trout or day-old chick industries) (Nash, 1970).

Depending on these factors, one or a combination of several of the following general forms of aquaculture may be used:

i. Freshwater or marine (mariculture) aquaculture.
ii. Development of fisheries in natural rivers, lacustrine or oceanic environments by a largely natural process of readjustment of the ecological balance altered by thermal additions.
iii. Allowing the natural development of fishery resources in an artificial cooling pond or reservoir, or in the neighbourhood of an outfall channel; monitoring growth; and hoping that useful local fish species will flourish.
iv. Stocking artificial cooling ponds, reservoirs, or outfall channels with suitable commercially valuable fish, and controlling feeding and harvesting so that a minimum restocking is necessary.
v. Stocking natural water bodies with suitable, commercially valuable fish; monitoring growth; and controlling harvesting. Additional feed would not be provided.
vi. Developing fish farms in artificial enclosures in which all phases of the fish life cycle from hatchery to harvest are controlled.
vii. Using heated discharges for hatcheries from which the fry are then released in natural environments, which are fished by usual commercial or sports methods.

2. Biological Limitations on Thermal Aquaculture

Before any of these systems of aquaculture can be operated, it is necessary to understand the effects of temperature increases on the particular fish species involved, at all stages of life history. Heated water, possibly carrying wastes from a previous use, may cause biochemical changes harmful to the fish species or to aquatic organisms in its food-chain. It is therefore essential that careful surveys are made and a reasonably detailed knowledge of the environment and particular fish species are available *prior* to site selection.

Details and bibliographies of known temperature effects on marine and freshwater fishes are given by deSylva (1969), Raney and Menzel (1967, 1969), Kennedy and Mihursky (1967), and Coutant (1968, 1969a, 1970a, 1971).

A principal assumption in aquaculture is that increased temperatures of thermal effluents can be utilized to increase the growth rates of desired species and, thus, shorten the time required to produce a marketable product of uniform size suitable for packaging. This assumption must be qualified by a number of factors before planning a culture system at a power plant. These factors include (Coutant, 1970):

i. *The complex relationships among temperature, food utilization, and growth.*

For certain species of fish, particular combinations of temperature and feeding rate are necessary for optimum growth and conversion efficiency (Figure 13). The water temperature required for maximum conversion efficiency (11.5°C in Figure 13) is different to that required for maximum growth (14.5°C in Figure 13). Since conversion efficiency[1], in terms of dry weight, depends mainly upon the quality of feed, the optimum temperature for maximum conversion efficiency could vary as better feeds, with higher caloric content or better amino acid balance, are developed. A simple index, providing a useful measure of growth and combining both maximum conversion efficiency and the criteria for the most economical use of feed is given by:

$$E = \frac{G}{I} \times 100\% \text{ (Brett et al, 1969)}$$

where E = gross food conversion efficiency G = growth, and I = intake, both in terms of dry weight.

ii. *Temperature and carrying capacity.*

Carrying capacity describes the influences of water exchange rates, nutrient levels, oxygen content, waste removal, nuisance growths of algae or fungus, metabolism, activity and population size of other organisms, on the survival, growth, food utilization efficiency, and population size of the particular fish species important to the aquaculturalist. Changes in temperature may alter the carrying capacity by altering factors such as oxygen content or rates of waste breakdown and removal.

iii. *Thermal requirements of aquatic organisms, particularly marine invertebrates.*

A number of examples serve to illustrate problems arising from the lack of knowledge of the different thermal requirements of various life-stages of aquatic organisms, and the alterations likely to occur in life-cycles due to thermal additions. Experimental colonies of *Venus mercenaria* (clams) in water effluent under otherwise 'natural' conditions at Poole Harbour (U.K.), had extended growth periods and an increase in the growth rate, compared to those reared in cooler natural waters. Rearing the clams in warm water, however, produced a population comparable to that naturally occurring in the southern part of the U.S., for it spawned in spring as well as in late summer. Spring hydrographic conditions in England are unfavourable to larvae survival, thus, increased spawning activity is not advantageous unless adult clams and larvae are maintained in artificially-warmed enclosures. Reproduction may also be limited by blooms of zooplankton which predate on clam larvae. Clearly, it is not enough to release warm water into an open area populated by a desirable species, in order to stimulate reproduction and attempt to increase yields. Aside from the loss of larvae to predation and the unfavourable temperatures outside the influence of the effluent, there is a possibility that spawning in an unfavourable period might impair its success at a more favourable time. This is an important consideration for an animal which has only one or two natural spawning periods per year (Ansell et al, 1964a, 1964b; Ansell and Lander, 1967; Hedgpeth and Gonor, 1969).

In planning aquacultural projects, the theory that a constant temperature is a desirable feature of the system should be considered with caution. There are well-defined breeding and growth cycles in animals of both the uniformly cold and less variable tropical regions of the seas. The abundance of tropical penaeid prawn larvae during most of the year in Singapore Straits probably represents successive recruitments from different breeding populations of the same species (Figure

[1] The advantage of fish over conventional farm animals in terms of food conversion efficiency is worth noting:

Table 13:	Trout	1.5	Poultry	2.1
	Carp	2.0	Pig	2.4
	Channel catfish	1.3	Beef cattle	8.0

Animal Food Conversion Rates are given in lbs of feed/lb of edible flesh gained. When all waste portions of the animal are considered, beef becomes nearly 12 lbs/lb while there is little waste in catfish. Land animals use large amounts of energy in body support and in growing heavy support frames, which are not needed by water animals.

14). This periodicity may be associated with different monsoon conditions which, in turn, may reflect differences in surface runoff and nutrient supply for near-shore species, since the temperature range appears to be very narrow. It is suggested that if a culture of organisms from a narrowly variable temperature regime is to be attempted, the stock would have to be selected from several breeding populations to take advantage of an artificially stable thermal environment (Hedgpeth and Gonor, 1969).

Experiments with the amphipod, *Gammarus duebeni*, show that maintenance of a stable temperature for organisms from temperate regions would not produce the best results. The amphipod could not be cultured at a constant temperature as it requires temperature fluctuations similar to those of its natural environment. It has been suggested that a constant temperature of 20°C, and temperatures fluctuating between 15°C and 25°C, with a 20°C average, do not necessarily have similar biological effects (Kinne, 1963).

At present, we lack essential knowledge of gonadel cycles and the relations of larval stocks, inducted out of phase with the environment, to predators or ambient temperature conditions (Hedgpeth and Gonor, 1969).

iv. *Effect of temperature on diseases.*

Clearly, it is not desirable to raise temperatures to levels that favour the growth of warm water disease organisms. However, temperature elevation may retard cold water diseases, and thus may stimulate growth of the cultured fish species. Temperature change must be viewed with regard to endemic diseases at a particular site.

v. *Thermal Constraints Imposed by Power Plant Design.*

Designed temperature elevation at the condensers may not produce optimum temperatures for the growth and reproduction of organisms being formed. The responses of organisms to rapid temperature changes of cooling water, particularly from power plants which are not base-load facilities, should be investigated.

vi. *Tolerances of organisms to biocides (e.g. chlorine) used to control fouling or corrosion in a steam plant.*

vii. *Market considerations.*

Estimates must be made of the size of the commercial market for the proposed farm products, and the extent to which demand may be reduced by public fear of radioactive contamination. Health standards must be met for traces of radionuclides that may be concentrated in nuclear power station effluents by the organisms.

viii. *Relative tolerances of the ultimate receiving water, for heated water alone (without aquaculture) and for heated water enriched with aquacultural wastes.*

ix. *In a system of recycled water, the limits imposed by the power plant on the purity of cooling water after use in the aquaculture facility.*

Certain other difficulties inherent in any aquaculture development are:

i. *Choice of species.*

It will depend on the temperatures involved, rates of growth, ease of production, economic demand for the type of fish, and comparative costs with the usual methods of fish supply.

Studies at the Marine Laboratories of Duke University (U.S.A.), show that species adapt more easily and grow more rapidly at temperatures near the mean annual temperature of their natural environment. Both tropical and northern species are acclimatised to a rather narrow temperature range. Mid-latitude varieties tolerate a wide annual range, but are largely dormant during cold periods. It is these species that can benefit from year-round controlled temperatures. The productivity potential, ease of culture and temperature requirements of some tropical species should be investigated to determine if they are better substitutes for northern-temperate fish in thermal aquaculture.

ii. *Genetic Selection.*

If fish are totally bred within an artificially controlled environment, there are dangers of breeding out certain advantages in genetic characteristics, such as suitable mature sizes, and breeding in disadvantages that could include a low tolerance to disease. Evaluation of the most desirable, useful genetic characteristics is necessary when selecting fish from natural populations for breeding purposes.

iii. *Production and Supply of Fry.*

Aquaculture requires either a simple reproduction process, or a consistent and adequate supply of fry. These requirements apply if there are no facilities for the spawning and hatching of fish; if fish production is confined to tropical species, or if fish are difficult to breed in artificial conditions.

iv. *Feed Characteristics.*

An essential need in aquaculture is the ready availability of cheap, nutritious, easily stored and prepared feeds which the cultured fish can efficiently convert to usable products. This raises the question of whether the feeds could be more cheaply and efficiently converted to high-demand products by a process other than fish farming.

v. *Predator Exclusion.*

Should predators be excluded from artificial or semi-natural fish-farm populations? If so, how can this exclusion be implemented? Should harvesting provide a sufficient population control during stages of fish life in the absence of predators? A reduction in gross food conversion efficiency and an increase in disease could accompany the overcrowding of fish, as a result of poor population control.

vi. *Cannibalism.*

In crowded populations, cannibalism amongst fish could be a problem which would require control.

vii. *Water Supply.*

Will thermal effluent be sufficiently cooled and non-toxic to be harmless to a natural aquatic ecosystem (in a once-through cooling system)? If a closed or semi-closed cooling water system is employed, will the water be sufficiently cool to be recycled for cooling purposes? There might be a threshold temperature for cooling water above which losses in power plant electricity production, resulting from the reduced efficiency of the water as a coolant, might not be offset by the gains derived from the aquacultural facility. One solution to this problem could be to develop a fish farm with different levels of temperature step-down for different species. Economic advantages might accrue from diversity of production and savings in power efficiency, but the number of species grown might also result in a multiplication of many of the aforementioned biological problems.

3. Case Studies

A brief review of major experiments in marine, estuarine and freshwater aquaculture is presented herein.

a) Marine Aquaculture

i. *British Experience*[2]

In 1963, an experimental hatchery was established to develop a costed technology for hatching plaice (*Pleuronectes platessa*) in quantity and rearing marine fish to marketable size in enclosures in the sheltered waters of Ardtoe on the west coast of Scotland. Similar research has been carried out in the warm water (6-10°C above ambient temperatures) discharges of power stations, notably in Carmarthen Bay, Wales, and Hunterston, Scotland. It has been found that the optimum temperature ranges for the growth of plaice and sole (*Solea vulgaris*) are 15-16°C and 18-20°C respectively.

At Carmarthen, fish reached minimum marketable size (23-24 cm.) within 2 years, about a year earlier than normal. At the Hunterston hatchery, intensive larval feeding advanced growth so as to complete metamorphosis by the fourth week. From a population of several thousand plaice (selected and culled at intervals), more than 17% reached marketable size in 14 months after hatching. Survival rates in fattening tanks were high. The practice of grading fish by size at eight and twelve months may well have reduced the effects of interaction (notably aggression) in crowded tanks (Bowers, 1970). The high growth rate may be attributed to winter growth in warm water and to a plentiful food supply of chopped mussels.

In Carmarthen and Hunterston, cooling water contained chlorine and ferrous sulphide to prevent corrosion as well as mussel and slime growth in the condenser and the intake at concentrations ranging between 0.002 ppm and 0.1 ppm., which have little effect on fish. Other power plants which use a system of intermittent high doses of chlorine, as opposed to a continuous low concentration injection, may require elaborate by-pass arrangements to prevent toxic pollution of the cooling water. At very low concentrations, chlorine combines with seawater, producing low residual levels of compounds and derivatives of other halogens which are sufficiently dilute to be harmless (Markowski, 1958, 1960; Hirayama and Hirano, 1970). Other British investigators have pointed out that chlorine may be an effective prophylactic for marine fishes, and problems are more likely to arise from the ability of fish and shellfish body tissues

[2] The following section is a summary of Richardson, 1970 *"White fish Authority of the United Kingdom"* and Nash, 1970 *"Marine Fish Farming."*

to concentrate metals (e.g., copper, Roosenburg, 1969) and radioactive material (McNeil, 1970; Rabanal, 1970) released in very small amounts from power plants.

There have been successes in farming grey mullet (*Mugil cephalus*), turbot (*Rhombus maximus*), and lemon sole (*Microstomus kitt.*), but neither hatchery techniques nor feeds for fry have yet been fully developed. Commercial fish farms will require selectively bred hybrids for faster growth, higher food conversion, disease resistance and lower hatchery failure rates. In crustacean farming, the British prawn (*Palaemon serratus*) has proved difficult to cultivate, but other initial experiments show promise, particularly with both indigenous and non-indigenous shellfish, such as the Japanese prawn (*Penaeus japonicus*), brown shrimp (*Crangon vulgaris*), Pacific oyster (*Crassostrea gigas*), and hard clam (*Venus mercenaria*). Several suggestions have been made for mixed farming using grey mullet as herbivores, and ormers (*Haliotis tuberculata-abalone*) as algae eaters in tanks used by bottom-living carnivorous flat-fish. If this is exploited commercially, it could lead to savings in capital cost and space. Food chains could be shortened by creating algal blooms (Gross, 1950), feeding algae to mulluscs, and feeding these directly to humans or to farmed fish and crustacea.

Tank systems and dammed sea-lock enclosures are being discussed at the moment. Using a high density cage (20 ft x 10 ft x 3 ft) predicted plaice production rates are 1 ton/2 years/cage for an unheated sea-lock enclosure area and 1 ton/18 months/cage for a heated power plant tank area. With either system, it will be necessary to determine the tolerance of fish to changes in the physical environment, and the effect of changes on growth and survival for the improved design systems of engineering. Limited experience in the U.K. shows that production costs for the more highly prized species should be equal to or less than present production costs by traditional fishing methods, if losses from disease can be kept low. The cost of suitable and nutritious food is likely to be the most significant single cost in the program. Further research is necessary to determine fish tolerance limits in a water discharge system in which it would be hard to optimise the parameter like dissolved oxygen, without detriment to another. Compromise systems will have to be defined. Fish mortality and bacterial and protozan infections under crowded conditions should be investigated, and suitable balanced low cost food requires development. A technology for marine aquaculture, together with a cost-benefit analysis, could be available from the White Fish Authority by 1975-1980.

Other British experiments in thermal aquaculture include studies in flounder growth rates at Newton Abbot Generating Station (Iles, 1963a), and successful shrimp farming giving yields three times normal production rates at Bridgewater. Approximately 25,000 shrimps reached maturity in 18 months, rather than the normal 3 to 5 years, by being kept in water made 7°C warmer than the ambient temperature of the adjacent Bristol Channel by the Hinkley Point Power Station (Bregman, 1971).

Bowers (1970)[3] summarizes the problems to be overcome before the Ardtoe ambient temperature sea "ranch" and the "intensive" fish culture in heated tanks at Hunterston Nuclear Power Plant are able to supplement trawler catches on the market.

Early difficulties of Ardtoe can be attributed to the enclosure of the sea arm which provided inadequate control of the environment, and hence the fish. Predators were hard to control, rainfall altered the salinity of the water, and growth and mortality were hard to assess. Water quality control has since been improved by engineering work, and stocks are now controlled and monitored by retaining and protecting seed-fish in net cages. More robust cages, allowing a high stock density, are being developed by the Highlands and Islands Development Board (HIDB) for use in open bays. Though capital outlay will be fairly high, a reasonable return for the crofter or coastal farmer can be expected if a suitable feeding programme can be established.

Research at Hunterston showed that although fish fatten well on chopped mollusc, it is too expensive for commercial fish farming. Minced trash white fish, plus prawn offal with a binder and fish oil and vitamin additives, gave an efficiency ratio of 7-8 kg food/kg of fish. However, it is still expensive as a commercial proposition. Herring, though cheap and readily available, induced disappointing growth rates and caused high mortality in plaice and sole. Most fish are carnivorous, and research is required to determine their adaptabili-

[3] The following section is a summary of Bowers, 1970, *"What ever happened to fish farming?"*

ty to an inexpensive diet of low grade protein and cereal.

Bacteria and ciliate protozoa have affected young fish life-forms, though no epidemics have occurred in crowded conditions. Growth has been adversely affected by *Vibrio* (bacteria), skin flukes (*Gyrodactylus species*), and gill parasites (*Lernaeocera species*). Parasites with complex life histories can modify their habitats in tank conditions and attack fish which are not their normal adult hosts.

Algal blooms on tank walls are troublesome, though these could be controlled by edible herbivore fish and molluscs (page 33).

The techniques of plaice and sole farming are now well developed, but a cost-benefit analysis has yet to be carried out for a commercial proposition.

Turbot and lemon soles are fast-growing commercially valuable fish which may be suitable for fish farming. Wild turbot thrive on herring feed in tanks, and are efficient food converters. Early spawning problems have now been solved, but very young turbot have mouths too small for a conventional feed or brine shrimp larvae. A rotifer substitute is insufficient for successful turbot maturation.

Experiments in producing better domestic fish from interspecific hybridization have so far produced non-viable hybrids, though plaice-flounder hybrids bear promise. Little work has yet been done in interspecific crosses between geographical races of fish. Research at Lowestoft indicates that the value of selecting fast growing strains of fish by inbreeding may be doubtful due to the development of a "pecking order" effect in grouped fish which depresses the growth rate of all but the largest fish. Extrapolation of these results to large tanks with graded fish may, however, be misleading. Long term plaice breeding (Fort Erin Biological Station) and pure strain development (using irradiated fish sperm at Lowestoft) seem promising for producing fast growing fish. Other experiments concern the control of maturity and spawning time. If maturation can be delayed in fish being reared for the market, there would be no diversion of energy away from meat production to unwanted gonad development. If fish can be induced to spawn at any season of the year, stock management would be easier.

Future large-scale mixed fish farms, using heated water from power plants, will also require adequate supplies of clean, cool seawater and sufficient land area. Therefore, early planning is necessary since such sites are in demand for alternative developments.

ii. *Japanese Experience*[4]

The Japanese depend heavily on fish as a high source of protein, and hence it is not surprising that Japan leads the world in marine aquaculture. In 1967, Japan's total fish catch of 7.8 million tons (worth approximately $2 billion) included a mariculture production of 470,000 tons (worth $300 million), six per cent of the total catch and 15% of the total value. Two important species do well under aquaculture methods: the Kuruma shrimp (*Panaeus japonicus*) and the pelagic yellow-tail or amberjack (*Seriola quinqueradiata*).

Usual techniques for yellow-tail culture are to gather wild fry in April and May, plant them in either sea cages, shallow net-fenced lagoons, or a diked tidal bay, and feed them raw anchovies, small horse mackerel, sand lances (*Ammodytes*) and some pelletized feed. Growth rates are higher in the second year, but the lowest winter temperatures tolerated by yellow-tails are 12 to 13°C. Therefore, most fish are sold in the December of the first year. Recent experiments have shown that the growth of the yellow-tail in heated effluent was nearly 1.5 times the usual rate, and the average feeding efficiency was nearly double (Tanaka and Suzuki, 1966). It was possible with heated water to achieve rapid growth during usually non-productive winter months, with no loss of commercially desirable characteristics. Successful mass culture of yellow-tail from artificially fertilized eggs has been made (Harada, 1967).

Normal Japanese shrimp culture methods are to use fenced off inshore water, diked ponds, or large cement walled ponds, and fatten wild stock shrimp on crushed clams (*Tapes*). Using heated water in controlled seawater tanks, it was possible to continue shrimp culture into the winter, and still maintain the growth rate at the summer level (Mori, 1969). Year-round culture made

[4] The following section is a summary of Yang (1970) "*Marine Aquaculture in Japan using Heated Effluent Water*", and Yee (1971 a) "*Thermal Aquaculture Design.*"

it unnecessary to seek early seed shrimps in competition with the ordinary culturalist of shrimp in unheated water. Products could be marketed during the off-season at a much higher price.

It is suggested that eurythermal organisms may even be cultured in summer months by mixing thermal effluent with normal seawater. One of the biggest problems facing the aquaculturalist is the lack of a high yield, low cost, easily and constantly available food for culture organisms. Aquaculture using heated effluent water, and practised on a high density basis, however, can operate at full capacity all year, and reduce production costs.

Large-scale utilization of waste heat for aquaculture will depend on its commercial viability, and this requires extensive engineering design and evaluation work. Yee (1971a) has presented a conceptual design for intensive aquaculture in a flowing stream of warm water. Shrimp is cultured in this case, but the concept is applicable to any other culturable species.

The usual hatchery techniques and design used in the Japanese shrimp culture (*Penaeus japonicus*) are employed in this conceptual design (Ryther and Bardach, 1968; Hudinaga and Kittaka, 1966, 1967; Sutton et al, 1969). To this hatchery is added a shrimp culture channel, divided into pens, each successively larger in bottom surface area than the previous (Figure 15). Each pen area is proportional to the area of a segment of a typical S-shaped shrimp growth curve. Thermal effluent is blended with ambient temperature water to maintain a constant inlet temperature of 80°F. Water flows in a stream of constant depth through the channel at a constant linear flow rate. Shrimp being cultured are allowed to remain in one pen until they have attained a density which is constant for all pens. They are moved successively to larger and larger pens until they reach a specified marketable size. Once steady-state is reached, it should be hypothetically possible to harvest the shrimp on a year-round basis.

A number of biological justifications for this design are given:

1. Shrimp growth in the Gulf of Mexico is limited to the April to November period when water temperatures range from 70° to 85°F (Linder and Anderson, 1956). Two crops rather than one might be produced annually, if water in this temperature range is available on a year-round basis. Research also shows that an increase in water temperature from 70° to 80°F increases the growth rate of juvenile shrimp (*Penaeus aztecus*) by more than 80%, implying that better control of water temperature might even produce three crops annually (Zein-Eldin and Griffith, 1965; Zein-Eldin and Aldrich, 1966).
2. In principle, a controlled flow provides a better medium for intensive fish culture than other systems like ponds or cages, because dissolved oxygen is more uniformly distributed and fish wastes and excess food are flushed away so that BOD in the culture system is minimized. Shrimp yields per acre have been shown to be over 5 times greater in flowing-water culture than in stationary water bodies (Wheeler, 1961). The system is also much more responsive to temperature control.

Some of the economic considerations of such a system are as follows. The retail price in Japan for cultured shrimp is $8.00/lb (*Ocean Industry, 1969*), compared to less than $3.00/lb for premium quality shrimp in the U.S. (DiMarco, 1969). Thus, culture operations in Japan can tolerate a higher unit operating cost and still be a profitable venture. By modifying Japanese technology (Figure 15), the annual unit yield of live weight shrimp in the U.S. could be increased four-fold to 10 tons/acre af water surface. The availability of constant temperature seawater should give at least two crops per year, and the higher temperature water should allow growth rates twice the rates currently obtained by the Japanese. According to the growth curve, each shrimp should be of premium grade and weigh 42 grams, i.e., 10 whole shrimp/lb worth over $1.00/lb (ex-vessel price). Each week, approximately 2.1 million shrimp (200,000 lbs) are harvested and processed to a frozen, headless state, and on an annual basis this is equivalent to 10 million lbs of live weight. It is assumed that cheap artificial food pellets with a fish meal base ($0.10/lb; Subrahmanyam and Oppenheimer, 1969) are available in preference to the more expensive trash fish feed used by the Japanese. At a food conversion ratio of 3 lb of dry food feed/lb wet fish produced, the cost of pelletized feed is $0.30/lb of fish produced, while trash fish feed costs $1.00/lb of fish produced. The latter assumes $0.10/lb fresh fish (live weight) and a 70% moisture content.

Further detailed information on year-round aquaculture and some of the problems of implementing a demonstration programme can be seen in Yee (1970, 1971b, 1971c).

iii. *American Experience*[5]

At the Northport Power Station in New York, the growth characteristics of oysters in a discharge canal (Figure 16) have been studied.

Data are available for a year. The experiment was conducted by governmental and commercial groups (e.g., Vanderborgh & Sons, oyster culture specialists) in co-operation with the utility. Results have been sufficiently encouraging to Long Island Oyster Farms, Inc., to warrant hatchery construction, and to budget yearly research and development expenditures of U.S., $300,000 to $400,000.

The techniques and problems of oyster culture are briefly discussed herein. Spawning is temperature dependent and takes place in the hatchery. The free floating eggs grow by cell division and when the larvae are fully developed, they seek attachment to a clean, smooth surface. Old shells are provided so that juvenile oysters may fasten to them and grow. The shells bearing the oysters are then placed in mesh bags and suspended from floats in the discharge basin. Since baby oysters will feed and grow at temperatures above 40°F, they are allowed to remain in the discharge basin during the cold months, thus permitting the hatchery to operate throughout the year. During the summer, the oysters grow from the size of pepper grains to that of a thumbnail in about a month, which is half the growth time of naturally developed oysters. They are then planted in beds in the Long Island Sound. The exceptional conditions in the discharge basin during the time of early growth substantially increase the probability of the baby oysters surviving to mature size after reaching the natural body of water. Factors which still may endanger oyster beds in open water include silting, the oyster drill snail (which can be chemically controlled), and the starfish (which can only be mechanically controlled).[6]

To minimize the losses from natural enemies, the feasibility of rearing oysters to marketable size in the discharge basin is being tested. This could have the additional benefit of making the oysters saleable in about three years instead of the four or more normally required. While the limited size of the Northport discharge basin would restrict oyster production at this location, large scale lagoon culture at a number of other power plant sites would be a distinct possibility.

The Northport work may be of great benefit to the Long Island oyster industry, which in recent years has declined from $50,000,000 to $1,000,000 annually (based on the April 22, 1969 constant dollar value). A rise in annual income of $5,000,000 within five years is predicted.

A number of experiments by the American utilities in crustacean farming in heated water indicate that industry is willing to consider aquaculture, and in some cases implement it as a commercial operation.

The Maine Power and Light Company is supporting an experiment which would attempt to accelerate lobster growth rates with warm water (Beall, 1970b). Experiments in heated seawater (9°C above ambient) by the San Diego Gas and Electric Company at Chula Vista, California, show that eastern lobster larval development speed is increased by 10 to 30 days, and normal maturation times can be cut from 4 to 7 years to 2 years (Schumann, 1970; Miller, 1970). The importance of lobster culture is indicated by the fact that the American lobster has the highest unit value of any major commercial species in the United States, and supports the fourth most valuable fishery in North America (Miller, 1970). It has been suggested that heated discharge could be used on the Maine coast to warm shoreline coves to increase lobster yields (Science News, Vol. 93, 1968; Dow, 1969). Other investigators have stressed, however, that the reasons for recent declines in the number of lobster fisheries are due to silting, deoxygenation, and the limiting of "planktonic" lobster larvae dissemination. A decrease in larvae dissemination can result from man's interrupting influence on ocean current circulation patterns in lobster breeding areas such as the Gulf of St. Lawrence (Lourmais, 1971).

Experiments are being conducted with shrimp culture in water similar to that discharged from the Turkey Point power station in Florida

[5] Parts of the following section dealing with oyster farming are summaries of Burns (1969); and Philbin and Philipp (1970).

[6] Oyster and mussel pests include *Urosalpinx* and *Thais*. (Hedgpeth and Gonor, 1969). *Urosalpinx cinerea* feeds most actively at 25°C (Hancock, 1959), and the European *Thais lapillus* feeds at 20°C (Largen, 1967). Once established in a closed-culture system, these pests might flourish better than the bivalves actually being cultured.

(Beall, 1970b; *Electrical World*, 30, 1968). At Panama City and at Key West, Florida, commercial shrimp farms are being established (Beall, 1970b), and the San Diego Gas and Electric Company, having successfully hatched and raised fish, lobster and shrimp, is now developing on a commercial scale of 50-acre heated salt pond with a carrying capacity for 600,000 shrimps (Schumann, 1970). It is expected that these shrimps will be harvested within a year from stocking (Bregman, 1971).

b) *Brackish and Estuarine Aquaculture*

Brackish waters and estuarine ecosystems, particularly on the eastern American Seaboard, such as the Gulf of St. Lawrence, Long Island Sound, and Delaware and Chesapeake Bays, are already subject to high concentrations of municipal and industrial effluents. A major research programme is at present investigating the effects of added nutrients on the estuarine ecosystem, with a view to developing aquacultural techniques to use organic wastes for seafood production (Kuenzler and Chestnut, 1971).[7] So far, experimental waste ponds have developed into productive, well integrated but slightly unstable systems, performing some of the functions of tertiary treatment, and holding promise for the production of harvestable seafood protein from blue crabs, for example (Beeston, 1971).[7] These experiments in estuarine environments have not yet made use of waste heat to aid the growth of algae, one of the main constituents of the aquatic food chain.

Mihursky (1967) has suggested a variety of possible constructive uses of thermal additions to estuaries, including a complete closed-system recycling of organic wastes (Figure 17). Waste heat could be used at the sewage treatment plant to enhance the growth of algae, zooplankton, shellfish and fish, and also in district-heating (Parker and Krenkel, 1970). These systems will have to be evaluated in the light of certain geographic considerations, such as:

i. domestic waste availability,
ii. proximity of generating stations to domestic and industrial needs,
iii. availability of adequate land and water,
iv. climatic regimes best suited for such installations, e.g., maximum sunlight for algal production.

[7] Structure and Functioning of Estuarine Ecosystems Exposed to Treated Sewage Wastes. Annual Report and Phase Reports. University of North Carolina, Institute of Marine Sciences, Chapel Hill. In: North Carolina University, Institute of Marine Sciences, Chapel Hill. Annual Report. 345 pages. Feb. 1971.

Some of the major biological and engineering requirements of the system proposed in figure 17 can be tabulated as follows:

i. *Raw sewage* requires, at least in primary and secondary lagoonal treatments, full aeration for complete conversion of organic wastes to inorganic components (Downing and Bayley, 1961). Temperature control during summer and especially winter conditions would use waste heat, assure total conversion, and help eliminate periodic digestion breakdowns due to inadequate temperature ranges.
ii. *Algal culture* requires careful control of nutrient, light, temperature and pH levels. Rapidly reproducing, non toxic, and suitably sized or shaped algae are required for efficient filtering by the next trophic level. Algae considered include the thermophilic (55°C) algae, *Cyanidium calderium* (Ascione et al, 1966), *Cyanidium cardium*, and high temperature blue-green algae. High algal species diversity in estuaries may allow natural selection to quickly provide suitable algal species that meet necessary system requirements.
iii. *Filter-feeder selection* requires high thermal tolerance as well as high reproductive and growth rates. Species diversity within higher trophic levels is poor in estuarine and brackish ecosystems (Segerstroale, 1950; Gunter, 1961; Cronin et al, 1962) and therefore there are fewer animals to select for necessary characteristics. Copepods are the most important and common crustacean members of the zooplankton (Herman et al, 1967), though their environmental and thermal needs are rather unknown. Filter feeders of the *Clupeidae* offer possibilities.
iv. *Invertebrates:* the use of oysters in Long Island Sound has already been described (page 36).
v. *Fish species* suggested as suited to estuarine environments include:[8]
Tilapia mossambica — a thermophilic estuarine herbivore (Allanson and Noble, 1964).
Catla catla — bottom debris and plankton feeder with a rapid growth rate potential.
Chanos chanos (milk fish) — high market value; rapid growth rate; tolerant of wide ranges in salinity and temperature; largely

[8] See Hickling (1961) for a list of subtropical and tropical fish suited to eat bacteria, detritus, plant, phytoplankton, and epiphytes in estuarine environments.

disease-free; vegetarian, eating blue-green algae in particular.

Mullets — largely vegetarian estuarine and marine species.

vi. *Other Invertebrates*, e.g., manatee stocking in Chesapeake Bay where they could winter in heated discharges, and seasonally control aquatic weed growth (Mihursky and Cory, 1965).

If exotic species are used in ecosystems with artificially increased temperature regimes, and if the existing food web becomes undesirable, a designed winter temperature reduction would cause death, and hence provide control on the system. Systems proposed by Mihursky (1967) seem more practical in northern latitudes, as tropical and subtropical species already live near their upper limit of thermal tolerance in their native habitat (Naylor, 1965). Creation of subtropical and tropical temperatures in northern latitudes with incorporation of southern latitude species seems the best first approach (Mihursky, 1967).

In altering, modelling, or constructing such ecosystems, a major problem is one of energy flow in relation to population diversity and structure. It is necessary to evaluate whether a simple or a complex population will maximise energy conversion efficiency at given trophic levels (Mihursky, 1967). Some ecologists argue that it makes no difference if species diversity is reduced due to environmental alteration, provided biomass remains the same. Not only must aesthetics be considered in the counter argument but the question of efficient energy conversion within simple populations must be resolved. Although significant contributions have been made in the field of species diversity and primary production (Margalef, 1965), little is known about higher trophic levels within the aquatic and, specifically, the estuarine environment. Population structures within the particular species must also be considered in the light of energy flows. Energy conversion efficiency will depend on age distribution of the organisms at a given trophic level, and conversion efficiency is of major interest in establishing criteria for harvesting (Slobodkin, 1960).

c) *Freshwater Aquaculture*

i. *Catfish Farming* (Pickering, 1970)

Catfish farming is a new industry in the U.S.[9] Previously, it was believed that catfish reproduced only in moving water. It is now recognized, however, that the critical factor is the availability of spawning sites in hollow logs or washout holes in banks. Hence, reproduction is possible in still water, given suitable hollowed and covered nesting sites. In commercial hatcheries, eggs gained from controlled spawning in aquariums, pens, or still ponds, are hatched in wire baskets under well oxygenated, flowing water conditions (replicating natural aeration by tail fanning). Small-fry rearing ponds can be stocked at between 20,000 and 100,000 fry/acre. Resulting 3 to 8 inch fingerlings are sold to the farmer who can stock 1 acre of still water with 2,000 fingerlings in March, and harvest 1.0 to 1.25 lb fish within seven to eight months, given optimum harvest conditions and good management (i.e., 1500-2000 lbs/acre).

Catfish can have feed conversion ratios as high as 1.3 lbs feed to 1 lb meat. Yields increase if fish are grown in ponds with a freshwater through-flow, or in raceways. Heavy feeding in still water ponds often result in rich algal blooms. In summer months, high water temperatures, initially low dissolved oxygen concentrations, and algal die-off can result in a severe oxygen depletion which can kill off an entire catfish crop. Throughflow ponds and raceways flush out ammonia, nitrogen, and other waste products; allow for oxygen replenishment, and permit heavy feeding without dangers of algal blooms or oxygen depletion.

Since catfish is a warm water fish, its feed conversion rate falls off rapidly after water temperatures drop below 60°F. Optimum conversion rates occur between 80°F and 85°F, and conversion rates decrease in water over 90°F. Making use of warm water discharged from power plants would enable the industry to extend the growing season from seven to eight months to the full year, thus overcoming the impediment of seasonality of the market (McNeil, 1970). It would be dangerous, however, without elaborate controlled mixing techniques, to use thermal effluents in the summer months, when ambient water temperatures are close to the optimum for catfish feed conversion rates. Thermal discharges also have the advantage of providing large volumes of

[9] Production of catfish in the U.S., in 1960 was 200,000 lbs. In 1970, 40,000 to 45,000 acres were used for catfish production. In 1969, income figures from catfish production were approximately $20,000,000, and the production is expected to double by 1975.

water, suitable for through-flow or raceway culture methods.

In Colorado City, Texas (Texas Electric Service Company), power plant discharge is carried through drainage canals into and through three smaller lakes before being discharged back into Lake Colorado City. Successful winter cage culture of catfish is being operated in this system on a commercial scale. In January 1970, a net increase in weight of over 400% was achieved in 62 days. In contrast, no increase was recorded at all for the fish in the unheated control pond. Control fish would only feed when several days of warm air temperatures increased pond water temperatures (Tilton and Kelley, 1970).

Other catfish projects include culture in Lake Hico (380 acres), which is heated by the Jackson plant of the Mississippi Power and Light Company and raceway experiments at the TVA's Galletin Plant, Tennessee. TVA researchers are developing ideas for year-round culture in stacked tanks and a series of small raceways using a mixture of heated ambient "intake" waters.

Condenser effluent has been used to raise the temperature of a 26-acre lake on the shore of Lake Michigan for fish rearing purposes throughout the winter. By diverting thermostatically controlled amounts of water from the condenser outlet and inlet, a temperature of 55 to 65°F is maintained all year.

This could be increased to 80 to 85°F for catfish farming. This system, however, requires more heat in winter than in summer, whereas the demand for power is currently higher in summer than in winter in the U.S. Therefore, the scheme is not really suitable for large scale waste heat consumption in the U.S. (Foell and Benedict, 1970). Additional problems would be created by power plant modulation. Fish are subject to injury by thermal shock, and large losses can result from sudden temperature changes. Peak load situations, or power failures, could cause loss of an entire fish crop.[10]

Problems in developing the catfish industry include foreign competition from the Mexican and South American imports, a lack of very cheap efficient feed, and marketing problems. Catfish ranks only fifth in number of servings per day on the menu of one 57-outlet restaurant chain investigated by Greenfield (*S.F.I. Bulletin*, 214, May 1970). Restaurant managers prefer 8 ounce fish chunks breaded up to 10 ounces with ½ ounce tolerance either way, but cannot obtain them on a reliable basis. There is no real nationwide large demand for catfish per se compared with a good demand for a wide array of aquacultural products. There is only localized pocket-type regional demand (*S.F.I. Bulletin*, 214, May 1970).

Catfish priced at 90¢ — $1.29 per pound can not compete with codfish blocks selling at 40¢ per pound. These points must be weighed against the somewhat over enthusiastic predictions by catfish farmers of large scale production in heated waste waters.

ii. *Canadian experience*

Recent feasibility studies have highlighted problems of thermal aquaculture in Canadian environments. A lack of pre-planning has meant that in order to develop an aquacultural facility using heated water from the Pickering, Ontario, nuclear power plant, drastic redesign of the cooling system and installation of a water cleaning plant is necessary to remove cooling-water contaminants, such as biocides used to control tube fouling and corrosion.

Engineering and feasibility studies by MacLaren Atlantic Ltd.* on a proposed aquacultural facility for the Lorneville, New Brunswick, power plant showed that rainbow trout and Atlantic salmon had the greatest potential for the N. American market, but that total costs including operating costs involved in labour, feeding, a supporting heating system, and a sewage treatment plant would result in break-even costs of $1/lb Atlantic salmon and 40¢/lb rainbow trout. At best these costs just make the venture economically viable, but not profitable. Again, as with Pickering, the lack of pre-planning for an aquacultural facility in power plant design has raised costs by necessitating the use of heat exchangers to extract heat (55°-68°F) from contaminated cooling waters. A useful computer model is available from this study which relates all design and operating variables to ultimate product costs.

[10] Catfish culture is also being researched at the fish farming experimental station, Stuttgard, Arkansas; Southern Illinois University in Carbondale, Illinois; and at Auburn University, Auburn, Alabama.

*See: Simms, J. J. G. & M. Wiggen, "*The engineering and economic aspects of aquaculture with particular reference to the proposed Lorneville aquaculture facility*" in Canadian Conference on Freshwater Fisheries Research, Ottawa, Jan. 7, 1974.

iii. *Other fish farming*

Certain hybrid tropical fish may usefully supplement local fish in cooling ponds and lakes. At Four Corners Generating Station (New Mexico), a tilapia hybrid introduced to the artificial Lake Morgan has been shown to have the environmental advantages of having a predominantly male progeny, leading to a self regulating population and, being unable to survive in colder waters outside Lake Morgan, it is unlikely to affect the surrounding ecology (Gould and Moore, 1970). It has been suggested that heated water in England may be used to raise ornamental fish, some of which sell for over $140/lb (Iles, 1963). In addition, Chinese Carp, Tilapia, Grass Carp, Silver Carp, and Rainbow and Brown Trout have been used in fish culture experiments by the Central Electricity Generating Board of England (Iles, 1968). Crayfish, a possible aquacultural product, have only 20% useful edible meat, so they lack substantial potential for cultural purposes (*S.F.I. Bulletin*, 214, May 1970).

Russian operations report very high production rates, as high as 900,000 lb/acre/year of carp, in warmed pond cultivation, and plans have been put forward to develop a fish hatchery near the Arctic Circle using heated discharge from a 220 MWe nuclear power plant (Keller and Sowards, 1970). Gribanov et al (1967) also working in Russia, cultured carp in tanks in a power plant cooling pond and, at a stocking rate of 250 fish/m^2, produced 100 kg/m^2 of 400 gm carp at the end of the rearing period. The Japanese have gained even higher growth rates for carp in flowing water with controlled temperature conditions (Keller and Sowards, 1970). Problems of optimizing fry production and supply and reducing manpower and feeding costs, need resolving before industrial production of carp in warm water becomes a practical proposition (Menzel, 1969), though theoretically there is a potential for exceedingly high protein yields (Coutant, 1970a). An expensive advertising campaign would also probably be required to convince the North American public to increase fish consumption and to overcome public resistance to fish from ponds heated by thermal discharges from nuclear power stations (Keller and Sowards, 1970).

4. Alternative Approaches to Thermal Aquaculture

A review of case studies in aquaculture in marine, brackish and freshwater environments has been presented (pages 32-40). In general, these studies assumed complete control of the fishery.

Some experiments indicate that under certain conditions, heated water may be used to improve already existing 'natural' fisheries, or fisheries not as strictly controlled as the fish farm facilities previously described, and to develop multipurpose aqua and agro-industrial facilities.

I. *Experiments using heated water to improve pre-existing fisheries*

Warm water from power plants is being used in Oregon and Washington to overcome the limitations imposed on maximum salmon growth by cold winter temperatures.[11] Wild stock fry are being raised in laboratory tanks to 1 lb table fish size in six months, by maintaining water temperatures near 60°F (blending heated salt water from power plant and cold ocean water) and by following a rigorous feeding schedule. Three salmon species so far cultured are pink, chum, and chinook, though hybrids of pink and chinook, and chum and chinook appear to be promising (McNeil, 1970). In Iceland, salmonoids are raised to release-size in eight months rather than the normal two years by using geothermal discharges to maintain the proper temperature range (10° to 12°C for Atlantic salmon, Stewart and Bjornsson, 1969; Gudjonsson, 1967; Matthiasson, 1970).

A study at Par Ponds in Aiken, S.C.,[12] indicates that the pumping of 1 billion gallons of hot water (up to 115°F) per day into the 2,700 acre Par Pond makes turtles *Pseudemys scripta* (Gibbons, 1970) and 24 species of native warm water fish grow faster and occur in greater abundance than under normal conditions. It has also become a refuge for a comparatively rare wild life species, the American alligator (Frye, 1970; Bregman, 1970). Gizzard shad and largemouth bass have been reported to concentrate in heated water during the winter. Heated water is known to accelerate spawning times in largemouth bass, although its effects on gonadal development and the long-term survival of the fishery are uncertain (Witt et al, 1970).[13] The beneficial effects that may be derived from controlled discharge of cooling water are:

[11] Seattle Laboratory of the Bureau of Commercial Fisheries and Oregon State University Sea Grant Program.
[12] Du Pont, operating the Savannah River, Plant, U.S.
[13] Missouri Water Resources Research Centre, Columbia.

i. migration of fish may result in a build-up of fish densities,

ii. increased fish density may provide an extended winter harvest,

iii. continued growth of game fish may occur in the winter period,

iv. increased production of commercially raised fish may be possible, and

v. the location of the power plant might be planned to provide optimal conditions for fish harvest and for use of heated water in hatchery and rearing pools adjacent to the main water body (Campbell et al, 1970).[14] A T.V.A. report shows that sport fishing has improved in that area, particularly in discharge channels and basins receiving heated waste water. The watershed supports some 36 fish species of which the principal ones caught include bluegill, channel catfish, carpsucker, shad, and carp (T.V.A., 1969). The Lake Kincaid, built as the cooling pond for the Kincaid Station in Illinois, has developed as an important sport fishery, and is now the focal point of the Sangchris State Park (Foell and Benedict, 1970). However, on the Potomac River, though fishing has improved in winter below power plant discharge points, it has also been noted that summer fishing in these places is poorer, especially for channel catfish (Elser, 1965). Most observers have noted that heated waters do not actually produce more fish, but merely concentrate fish during the cold winter months (Trembley, 1965). In winter, snappers, barracuda, needle-fish, sharks, and mullet congregate in warm effluent of power plants at Cutler and Turkey points on Biscayne Bay, Florida (de Sylva, 1963), where they are sought by anglers. However, grey snappers caught in these effluents sometimes have body lesions. Hoak (1963) has noted that "the discharge of heated water has an effect that pleases fishermen but not aquatic biologists" (de Sylva, 1969).

II. *Deep Ocean Water — A Coolant and Source of Nutrients*

In oceans, just below the photic zone, there is a vast resource of plant nutrients (nitrates, phosphates, and silicates) and organic growth factors (vitamins). These nutrients increase in concentration at depths of 600 to 1500 ft, peaking at approximately 2200 ft (Biefang, 1971).

Cooling water piped perhaps 5 miles offshore to the ocean bottom could produce a thermonutrient pump. Rising warm water would carry rich bottom water to the surface to increase phytoplankton production and, consequently, the production of fish in the vicinity of the upwelling. At the same time, cooling water would be cooled to the ambient temperature of the surface sea water. Best sites for developing artificial upwellings would be where deep water occurs close to shore, i.e., within 2 miles of the Hawaiian shoreline.

The underlying biological principle of this scheme assumes a relatively constant nutrient supply, and has the disadvantage of no control on fish movements (Martino and Marchello, 1968). A 5-mile pipe, even if insulated, might result in considerable effluent cooling, yielding lower heat-flow values than calculated. Such a method of stimulating production requires not only the presence of phytoplankton and fish but also that the intermediate links in the food chain linger in these nutrient-rich patches. Induction of significant upwelling would probably result in cooler surface water above the outlet than in the surrounding ocean (Hedgpeth and Gonor, 1969), and as many zooplankton species are susceptible to comparatively small temperature differences (LaFond and LaFond, 1967), steady growth and an increase in productivity is uncertain. The lack of control on the system makes it relatively unattractive to private capital investment (Scott, 1969-70).

As an alternative to producing an uncontrolled ocean upwelling, deep ocean water, after serving as a coolant, could be channelled into confined pond systems where the desired crops would be cultivated under controlled conditions (Bienfang, 1971). This idea was originally derived from Gerard and Worzel (1967), who proposed a method for obtaining drinking water by condensing moisture from the atmosphere in suitable sea-shore or island areas. In their scheme (Figure 18), cold seawater from the deep ocean was used to condense moisture in the highly humid trade winds of the Caribbean. In the present scheme, this earlier emphasis has been changed from the supplying of drinking water to an increase in biological activity. Later stages of development, however, should consider the possibility of the production of fresh-water, electrical power generation, airconditioning, and mineral production, employing the same deep water used to create the marine "fields" (Lawes and Kenward, 1970). The shoreline close-pond sys-

[14] Missouri University, Columbia, Department of Zoology, Montrose-Thomas Lake project.

tem as opposed to a general oceanic upwelling system is being developed experimentally by the Columbia University scientists at St. Croix, Virgin Islands, and by the Hawaiian Institute of Marine Biology.[15] The first group uses molluscs as the secondary trophic level. They grow very fast when fed on dense cultures of phytoplankton. Hawaiian research has focussed on the growth and production of phytoplankton populations when suspended in deep ocean water at surface level light and temperature conditions. Bienfang (1971) has summarized the biological and economic considerations of the Hawaiian system. Significant results to date are that production by deep water phytoplankton populations may exceed that of surface water populations by as much as 60 times, and that carbon fixation values in excess of 200 $mgC/m^3/hr.$ were commonly achieved. Applying these results to a design for a 100 megawatt plant, with a pond volume of 10^5 m^3, and a residence time of water in the pond of one day, it is estimated that production could be 175 metric tons of organic matter, dry weight/pond/year, giving approximately 70 metric tons of fish/pond/year. Nutrients such as nitrate were found in the water in sufficient amounts to permit such protein production. Rough estimates of benefits from such a system based on a 150 acre pond, one metre deep, with a daily turn-over rate are

i. a yearly fish production of 1,200,000 lb,
ii. fuel savings (due to lack of waste heat) of $400,000/year, and
iii. air pollution reduction of 10% (related to fuel savings).

After installation, these benefits would cost roughly $90 per day or $30,000 per year, due to the cost of pumping up deep water.

The "shoreline pond" systems of using deep seawater as a coolant and as a nutrient source for aquaculture, are more controllable than free-ocean upwelling systems, and are therefore more attractive to private capital investment. It is necessary, however, to consider the impact on global energy balances, ocean current systems, large-scale nutrient cycling systems, and global wind circulation patterns before such projects can ever operate on a large commercially viable scale.

III. *Algae production, Sewage Treatment, and Multipurpose Facilities*

Large-scale aquaculture, such as that proposed by Gaucher (1969-70) involving an annual yield of 4500 x 10^6 lbs/year of protein rich fish and invertebrates,[16] will have to face the problem of finding enough nutrients to support production. Pilot studies by Ansell et al (1964a, 1964b) and Ansell and Lander (1967) used flue gas from the steam generating plant as a source of carbon dioxide, and the water was fortified with domestic sewage, providing nutrients to culture algae for food for the clams to be cultivated in the warm effluent waters. This system would not be suitable for reactors sited remotely from major sewage sources (Hedgpeth and Gonor, 1969).

Use of algae has been developed experimentally since the idea was first seriously proposed in the 1950's. (Burlew, 1953; Raymont, 1957). In 1962, experiments were performed to feed algae to clams and thereby solve problems of harvesting algae and preparing a final product (Ansell, 1962).

Algae may be grown at a low cost in domestic, industrial, and agricultural wastes (Oswald and Golueke, 1967). Increasing treatment temperatures, particularly in the mesophylic range of 27 to 35°C, can improve the performance and capacity of sewage treatment plants, generate high algal yields, and make good use of waste heat whilst at the same time reducing sewage treatment costs and removing nutrients efficiently (Klock, 1968; Shih and Stack, 1969; Oswald and Golueke, 1967).[17] Studies of separation, concentration, and drying of algae indicate that the combined costs of these steps will be two to four cents/lb of dry algae (Oswald and Houghton, 1968). The largest cost factor, electricity needed to drive continuous flow centrifuges for separation, may be reduced if harvesting is done in off-peak hours.

An intensified form of a high rate algae pond system, growing algae concurrently with water undergoing activated sludge treatment, has recently been developed[18] (Anonymous, 1970c). The process can remove 90% BOD and COD, 80% total nitrogen, and 50% dissolved phosphorous, leaving, after a final activated carbon treatment, water pure enough for human consumption. Production rates of 20 to 60 T/acre per annum of algae containing 50% protein is possible. Given 5 million acres of algae culture (20,000 installa-

15 Funded by the Hawaiian Electric Company.

16 This assumes a production of 50 lbs/gallon/minute of flow (Hedgpeth and Gonor, 1969).

17 For further discussion on uses of heated water in waste and water treatment, see chapter

18 Research at Jerusalem University, Israel, into Advanced Photosynthetic Systems, under a contract from the Ecology Development Corporation, Wash., D.C.

tions of 250 acres each) it would provide enough protein for all meat animals currently in the U.S. Cooling basin systems would provide steady optimum temperature conditions and possibly could reduce costs of elaborate temperature control systems (Fisher, 1955; Tamiya et al, 1955). Algae ponds would require a loading rate of 200 to 400 lbs of BOD/acre/day, a rate which would be provided by 2000 to 4000 people or processing 4 acres of beans or 2 acres of potatoes (Table 14).

Algae are the most efficient converters of solar energy into foods — 20 to 40 times more efficient than conventional crops (Boersma, 1970). Uses for algae include:

i. Protein supplement for beef and dairy cattle, sheep, swine, and chickens (Hintz et al, 1966; Hintz, 1967) — algae containing 50% protein can be supplemented with a small amount of vitamin B_{12} and can be fed to swine at a 10% level, pelletized with barley. Resulting swine growth and meat production equals that of swine fed on fish meal in barley. Micro-algae meal is worth eight cents/lb dry weight as swine protein supplement.

ii. An economically feasible feed for shrimp larvae, fish and oyster spat, using vitamins and amino-acids extracted from dehydrated algae.

iii. Food for human consumption such as algae dumplings, algae noodles, mashed algae potatoes and algae ice-cream (Anonymous, 1970 a, b, c).[19]

Boersma (1970) has shown that waste treatment, fish farming, and algae culture can be incorporated around an evaporative cooling unit as an agro-industrial complex appended to a power station (Figure 19).[20] The evaporative cooling system could be either a large open basin, with or without cooling coils, for cooling purposes and waste treatment only (*"extensive"* cooling system), or an intensive cooling system (Figure 20), in which cooling water is contained in cooling tubes or coils, and *"intensive"* use is made of waste heat in basins devoted to sewage reduction, fisheries, and algae culture. Perhaps one of the biggest advantages of such an intensive system is that it overcomes the major problem of environmental pollution likely from agro-industrial processes utilizing waste heat. For example, 114 salmonoid hatcheries in the Pacific Northwest are releasing approximately 23 tons[21] of BOD/day as well as large amounts of nutrients into receiving waters (Bodien, 1970; Garton and Christianson, 1970). Table 14 illustrates BOD production likely from agricultural processes which may be developed in the type of system envisioned by Boersma (1970).

Assuming that 250 acres is available for use in an intensive evaporative cooling system, and the extensive system is designed only for cooling and waste treatment, annual costs can be estimated at $5,188.00/acre of intensive system, and $2,594.00/acre of extensive system (+ cooling coils, Boersma, 1970). Values and uses of each of these systems within the complex described in Figure 19 are judged as follows (Boersma, 1970):

i. *Extensive system*
   a) *Only used for cooling:-* No additional benefit accrues, and the system must be financially supported by the operations of the rest of the complex.
   b) *Simple fish farming:-* Assuming fish production at a profit of $0.10/lb, an annual production rate of 25,940/lb acre would be required, which is not obtainable from free-swimming fish species. Using a cheaper, simple flow-through system without cooling coils, the total annual cost would then be $432,400, which adds $86.00/acre to the operation of the rest of the complex.
   c) *Use for waste treatment only:-* Not analyzed.

ii. *Intensive system*
   a) *Pool used for fish culture:-* Operated in its simplest form, using free-swimming channel catfish which feed on insects and crustaceans produced by the fertilized water, a production rate of 1000 lbs/acre may be obtained, yielding an annual return per acre of $100.00, at a profit margin of $0.10/lb. This system could not be self sustaining.

   Production rates could be increased to 2,000 lb/acre per year by using a heavy plankton feeder such as Indian carp (*Catla*

[19] Research is being carried out in Bonn, Germany, by the U.S.D.A. Economic Research Service; and by the Ecology Development Corporation, Washington, D.C.

[20] For details concerning agricultural aspects of the scheme, see Chapter 8.

[21] Equivalent to a city of approx. 270,000 in total population, or an average of about 2,400 people per hatchery.

catlae).[22] Much higher production rates could be obtained with the high density cage culture techniques. For analysis of this operation, a production rate of 48,880 lbs/acre/year has been estimated (Boersma, 1970). It also takes advantage of growing season extension. Since no operating or market experience is available for this system, the return analysis is considered in reverse. Production costs would be \$5,188.00/48,880 = 10.6 cents/lb. Labour and feed costs might easily raise this to \$0.30/lb. As channel catfish sell for \$0.90/lb, the operation might be feasible, although it is questionable whether or not the size of demand and the most financially efficient size of operating systems are compatible.

b) *Pool used for algae production:*- Assuming 300 acres are available for algae production, the annual cost per acre is \$4,300.00 or \$2,200.00, depending on whether concrete- or earth-lined canals are used.

Rates of return for different production rates and prices are shown in Table 15. Assuming a value of \$0.08/lb dry weight and a cost of \$1,000.00/acre/year for harvesting, the annual cost per acre is \$5,300.00 or \$3,200.00, depending on canal lining. These figures suggest that profitable operation is possible, using earth-lined basins and obtaining yields of 20-25 T/acre. A higher return rate can be achieved, for example, by consuming algae within the same complex in some animal or fish-raising facility.

[22] The importance of organic fertilizers in maintaining high fish production rates can be judged from the following survey comparing production (lbs/acre/annum) in "wild water" and in managed fish ponds (Hickling, 1962).
Fish Production: Pounds per Acre Per Annum.

Wild Water			
Swiss & German Alpine Lakes	12.9	Germany	200-400
Freshwaters of England & Wales	20.6	Yugoslavia	366
Lake Mendota, Wisconsin	22	Israel	2000
Lake Nakivali, Uganda	168	China	2800-6000
Lake Kitangiri, Tanganyika	282		(Hickling, 1962
Lake Waubesa, Wisconsin	400		Mihursky, 1967)

Other work on fish culture using activated sludge from sewage treatment as fertilizer can be seen in Gopalakrishnan and Srinath (1963, India), Reichenbach-Klinke (1963, German Carp), and MacKenzie and Cambell (1963).

IV. *Fungal Synthesis, Waste Heat, and Sewage Treatment*

Treating food-plant wastes with fungi to reduce BOD to low levels permits shorter holding times and the recovery of marketable products (Church, 1970). BOD levels of 4000 and 8000 mg/litre from corn and soy processing wastes were reduced to levels of 80 to 200 mg/litre by selected fungi, and the mycelium was removed from digested waste by simple coarse filtration. Optimal process temperatures were around 30°C, with half maximum rates at 20°C and 40°C. Thermal effluent could be used to provide such low grade heat. Fungal protein synthesis offers the advantages of utilizing inexpensive, widely available raw waste materials, giving a rapid rate of protein synthesis, and being high in the relatively scarce crystalline basic amino acids, lysine and tryptophan.

5. General Conclusions on Aquaculture as a Beneficial Use of Waste Heat

A number of general conclusions can be summarized from the previous discussion on aquaculture as a potential beneficial use of waste heat:

i. There are many different forms of aquaculture. It is adaptable to a variety of power plant siting conditions and technological constraints.
ii. Within each environment, and for each species or group of species cultivated, a large number of biological restraints and limitations must be recognized. More research is required into optimum conditions for some of the more likely commercial species.
iii. Thermal aquaculture may not necessarily make use of all heated effluent all year round, especially in summer, when the water is already warm.
iv. Although heated aquaculture may provide year-round production, the manner in which continuous growth affects the physiology and the reproductive and biological cycles of the particular culture species must be investigated.
v. The use of heated effluent to increase production in natural and uncontrolled populations is very limited, but the potential for this use in closed or restricted controlled systems deserves further investigation.
vi. To date, experiments in controlled marine aquaculture, particularly of plaice, sole, oyster, lobster and shrimp, hold more promise of being commercially successful than fresh-

water aquaculture. Though most forms of aquacûlture are theoretically reasonable and experimentally practical on a small scale, aquacultural products must be competitive with agricultural and conventional fisheries products on an open market. Most of the systems described are high cost systems, requiring large investment in equipment and facilities, and much highly skilled labour to maintain healthy fish stocks and harvest and process animals. Aquacultural production should therefore be directed, on a large scale, towards high priced luxury commodities such as lobster and salmon, choosing where possible fast growing species.

vii. If a governmental, political, and financial structure is available and willing to accept long-term planning, then multipurpose schemes, including deep-ocean water utilization; algae/fungi — sewage treatment — agro-industrial centres; and closed system recycling plans (e.g., in estuarine environments), should be considered with caution. Although some of these schemes may promise an efficient and beneficial use of thermal waste in cooling waters and municipal waste, and might solve many problems of conventional aquaculture (e.g., fish feed supply problem solved by using high protein algae), they themselves might also create environmental problems such as organic wastes from fish farms, or the side effects of interference with energy budgets, nutrients, and water circulation systems on a large scale. Many forms of aquaculture may still not meet "safe" temperature standards for outfall waters. For these reasons, such schemes will require extensive pre-planning, modelling, and research, as well as detailed cost-benefit analyses before they can be considered anything more than preliminary concepts.

viii. Before any aquacultural system is developed on a commercial scale, waste treatment procedure has to be defined, marketing systems should be developed for the products, and rigorous economic analyses must be conducted to integrate all costs and potential profits to determine if enough profit can be made from the thermal discharge to warrant the trouble and expense of utilizing it. Experience has shown that such ventures may only be profitable if there is sufficient preplanning for aquacultural facilities in powerplant design.

ix. It is highly unlikely that aquacultural facilities would utilize all available thermal effluents in summer, when ambient water temperatures are already high, and when the critical period for thermal management occurs in Canada.

CHAPTER 5

WASTE AND WATER TREATMENT

1. Heat Treatment of Sewage

In sewage treatment, heat is required to stimulate algal and bacterial growths[1] and the processes of drying, oxidation and incineration, and pasteurization. Dallaire (1970) reports that a 10°C rise in temperature nearly doubles the biochemical reaction rate in the activated-sludge process. This concept could result in increases in potential capacities of existing sewage treatment plants. It has also been found that passage of sewage through the condenser in a power plant is an effective device for speeding up the rate of decomposition of putrescible matter. Treatment rates can, at least theoretically, be doubled if the circulating sewage temperature is raised from 70°F to 100°F. The problem of transferring the requisite heat to the sewage could be solved if prefiltered sewage could be routed through part of the power plant condensers in which the water header has been modified to keep the flows separated (Figure 21). Increased activity, however, is limited by the amount of oxygen available in the system for the degradation of organic matter in the sewage, and the deposition of grease and micro-organisms inside the cooling tubes poses potential problems, which should be solved before a feasible treatment method can be developed.[2]

Flocculation and filtration process for treating water are more efficient at higher temperatures (Camp et al, 1940; Fair and Geyer, 1954; Renn, 1957; Parker and Krenkel, 1970), and savings in the cost of water treatment chemicals, for each 10°F rise in temperature, could be $0.30 to $0.50 per million gallons (Arnold, 1962).[3] At present average total chemical costs of about $14.00 per million gallons (with a range of $3-$30/million gallons, Parker and Krenkel, 1970), considerable savings could accrue if power plant effluents could be delivered at the treatment site. A cost-benefit analysis is needed for this use, taking into account warm water, or steam, delivery costs (e.g., piping costs), as well as the benefits arising from the elimination of thermal pollution.

Although the low grade heat (around 100°F) rejected by power plant cooling systems is probably well suited to stimulating secondary biochemical reduction of activated sewage sludge, raising flocculation and filtration efficiency, and improving sludge settling efficiency (Crotty et al, 1968), it is too low for pasteurization, drying, and oxidation processes which, at current levels of technology, require temperatures in the range of 150° to 300°C (Bjorkman, 1969a, 1969b; Fisher and Swanwick, 1971).

2. Power Plant Fuel and Filter Treatment

Heat as well as the fuel of a power plant might be utilized for sewage treatment. Raw or secondary treated sewage can be successfully filtered through coal, resulting in a 95% BOD removal rate, at a coal to sludge ratio of 4 to 1. In a high temperature boiler, the sewage sludge can be burnt odourlessly and with less detrimental waste combustion products than coal (Nutant, 1970).

A joint Consolidated Edison and Westinghouse Electric Corporation task force (Bell et al, 1970) approached the systems of coal filtration of sewage in two ways. The first, shown in Figure 22, provides primary and secondary treatment, while the second (Figure 23) adds thermophilic stabilization. As seen in Figure 22, raw sewage is filtered through a filter bed consisting of coal crushed to 20-mesh size. Approximately 10 tons of coal is required per million gallons of sewage. During filtration, the top portion of the coal and sewage sludge is scraped off and returned through a centrifugal or hot air dryer to be mixed with the crusher feed coal, where it is crushed to 200-mesh size, and burned in the boiler. The coal fil-

[1] Use of thermal effluent to increase rates of sewage treatment has already been described with respect to algae and fungi farming (page 42).

[2] Research currently underway at Mississippi State University (Dallaire, 1970).

[3] Report on the State of Pennsylvania's 1962 Committee on the "Effects of Heated Discharges".

tration process accounts for approximately a 70% reduction in BOD. Further reduction to 90% would be accomplished in the aerated biological process. Figure 23 shows the thermophilic stabilization addition to the treatment process. This system utilizes a heated aeration tank, followed by phosphate removal and final polishing of the secondary effluent. This type of system has been used as a pilot plant in Cleveland (and is supported by the Office of Coal Research). This system, however, suffers from mechanical problems and difficulties in pumping a slurry of the coal and sludge into the boiler for combustion. While the system has considerable potential, it has not been considered further by Consolidated Edison, as coal will not be used as a primary fuel after 1971.

3. Urban Waste and Water Treatment Systems

Dissolved solids in waste water discharges should not exceed a maximum of 500 ppm (Beall, 1970a; 1970b). This limit should be considered in the light of solids already in the water supply. As many city-discharges already exceed safe limits, it will be necessary to remove total dissolved solids (TDS) by some process, evaporation, reverse osmosis, or other treatments.

Spiewak (1969) has investigated how sewage and waste water from a city might be treated for reuse with nuclear power plant exhaust steam. In his scheme, municipal waste waters are demineralized by distillation. Cost estimates are given for a number of possible systems using distillation to treat effluent from a city of 1 million in population. The analysis indicates that although advanced waste treatments may increase the cost of sewage processing by factors of up to four times, the overall cost of water supply and treatment need not be increased over 50%. Distillation appears to be a promising method of waste treatment, although methods of controlling tube fouling and distillate quality remain to be developed.

Beall (1970a; 1970b) has proposed an urban water supply and reclamation system, using a vertical tube evaporator, and powered by the waste heat from a 6.0 MW power plant (heat output: 1200 x 10^6 BTU/hr.) The assumptions are shown in Table 16, and in the flowsheet in Figure 24. By evaporating 34.5 million gpd, which requires 400 MW heat, and blending the distillate with 65.6 mgd filtered and carbon-treated secondary effluent and 50 mgd from the treated natural water supply, the full 150-mgd supply for the city of a million in population can be provided at a cost of 20 to 22¢/1000 gal. No credit is taken for *not* polluting a stream with the sewage effluent. The concentrated nutrient stream from the evaporator has uses in aquaculture, and in the fertilizer and chemical industries, which might result in further benefits. The system also makes beneficial use of waste heat and provides electric power at installed capacity.

If reuse of waste water is not required, stream pollution can still be avoided by using waste water as the cooling tower medium. Beall (1970a; 1970b) reports that at least 2 steam plants (one in Los Alamos) in water-short areas use such a system. The tower blowdown, containing most of the dissolved solids can be evaporated to dryness to avoid any stream pollution. The system has the advantages of eliminating serious thermal water pollution (though not thermal air pollution) and conserving pristine water for other uses, as well as reducing the required capacity of sewage treatment plants. Any waste water evaporation capacity, which can be varied depending on the availability of heat and the need for water, is an "interruptible" load which tends to increase the power plant's heat load factor. Thus, it is a valuable type of load (Beall, 1970a; 1970b). Such a system would, however, have to include the costs of modifying cooling tower design, introducing condenser cleaning systems, and removing possible pollutant aerosols from cooling tower spray rejection to the atmosphere. The last three considerations may not pose too much of a problem, if waste-water has already been partly treated.

In a survey of *Potentials for Reuse of Wastewater in North Central Texas*, McKee (1971) stresses that American experience in the direct use of well-treated municipal wastewater in condenser cooling circuits has found fewer problems, (i.e. fouling) and encountered lower costs, than when well water or another pristine supply was used. McKee (1971) lists the advantages that accrue to the power industry and to municipalities which use treated wastewater as a coolant:

i. Advantages to the power plant industry:
   a. consistent availability of cooling water for power plants in sufficiently great quantities,
   b. location of cooling water source near power demand centres, and
   c. allowance for future power plant expansion because of ample supply of cooling water.

ii. Advantages to municipalities:
   a. ready market for treated wastewater with significant revenue from its sale,
   b. availability of electric power in large quantities, and
   c. elevated temperature of blowdown water that may benefit biological processes.

4. Snow Melting Systems

Snow removal and disposal pose major financial and environmental problems in many Canadian cities. One aspect of this problem concerns the danger of ground water contamination by road salt, heavy metals, and street debris (Smithers, 1971). Power plant heat could be used to melt snow, purify water for reuse by evaporation, and perhaps recycle some of the chemicals left in residue. Snowmelting could, especially in winter, use very large amounts of heat.

To the best of our knowledge, there is no snow melt feasibility study on these lines to date. As a guideline to an economic evaluation of such a system, however, a cost-benefit analysis of a modern "jet-engine" style snow-melter unit[4] can be considered. Such an analysis indicates that the savings to the community will depend on the average winter snowfall, the method being currently used, and the availability of environmentally "safe" and aesthetically suitable snow-dumping sites with good holding capacities and strategic locations in terms of transport costs. Use of a "jet-engine" snow-melter system, with operating costs from $20/hour for the smallest single unit to $300/hour for the largest permanent installation, can create savings of $0.05 to $0.50 per ton of snow melted (McDougall, 1971). A power plant snow-melter scheme could bring about savings by using waste heat: it might well be operated at lower costs than standard snow melter units; and it would not have to be limited by the site constraints of standard snow clearance schemes, although the restrictions imposed on power plant siting would still apply.[5] The advantages of snow melter schemes are limited from a thermal pollution alleviation point of view, as they can be used only in winter when thermal pollution in Canada is not a real problem. Alternative uses for waste heat would still be required during the summer months.

[4] Trecan Limited Cooksville, Ontario and Thermal Research & Engineering Corp. of Conshohocken, Penn.

[5] See page 62, for comment on power plant siting, public opinion, and environmental hazards.

5. Freshwater Production by Distillation of Seawater or Brackish Water

Waste heat could be used for brackish-or-salt-water distillation to produce potable and irrigation water. At an experimental agro-industrial power plant complex at Puerto Penasco, Mexico,[6] a humidification cycle desalting plant has been developed (Figure 25). This system has the advantages of reusing energy four times (multiple effect operation); being simple and operating at moderate temperatures and pressures, thus reducing the gradient for energy losses; and having the potential to evolve into lightweight portable systems (Groh, 1970; Hodges et al, 1965). A similar system is used in another agro-industrial project at Abu Dhabi.[6]

An urban electricity-freshwater supply system was projected by the southern California Metropolitan Water District at Bolsa Island (Beall, 1970a; 1970b). The cost of water from that dual purpose desalting plant was too high (estimated at 35¢ to 40¢/1000 gal. Wilson and Homer (1967) quote estimates of 21.9¢ and 27¢/1000 galls.) when compared to the cost of other water sources. This proposition, however, is likely to become more attractive to other times and locations, particularly in water short areas, when one gives it credit for eliminating thermal pollution.

In Puerto Rico, a desalination unit entirely operated by waste heat is being developed to produce 20,000,000 gallons of freshwater daily, with the salt, recovered from by-product brine, forming the raw material for an adjacent chemical industry which will use waste heat to produce chemicals from salt (Swidler, 1970).[7]

Beall (1970a) has proposed that by back-pressuring the turbine exhaust slightly (100°-120°F), the resultant exhaust steam from a 1000 MWe station could produce 25-30 mgd of desalted water. Cost-benefit studies, however, indicate that power plant-desalination units are economically impractical unless there is a demand for extremely large quantities of water (i.e., 150 mgd) close to the production site. Because current demands for fresh water at any one site are usually less than 10-20 mgd, it will be some time before dual purpose plants are generally feasible (Foell and Benedict, 1970).

[6] Research by the Environmental Research Laboratory, Institute of Atmospheric Physics, the University of Arizona, Tucson. For details on agro-industrial complexes see chapter 8.

[7] For further industrial use of waste heat see chapter 6.

Tidball (1969) has summarized the overall heat balance, material balances, and economics for the combined power-desalination plant at St. Thomas, Virgin Islands. Total cost per annum is $641,000 for the production of 825,000,000 gallons of freshwater at a cost of $0.78 per 1000 gallons. A similar unit is operating at Eilat, Israel (Tidball et al, 1968). The technique used is to design for higher condenser back pressures, which would allow water to be desalted by flashing the condenser outlet water through one or more stages of flash distillation (Tidball and Graydos, 1969; 1970).[8] Research is needed to assess limiting conditions of sea water temperature, power demand and water needs, amortization rates, and operating characteristics.

Hodge (1970) feels that power-plant desalination units will become particularly valuable in developing arid coastal regions both in hot desert areas (there are about 22,000 miles of uninhabitable desert backed coastline throughout the world) and, perhaps, in cold Arctic or Antarctic regions. Such widespread application could aggravate already serious world population problems, particularly if generators fail for extended periods, or fuel supplies are cut (by intent or accident) or become increasingly scarce in the future, possibly accelerated by such applications (*S.F.I.*, 1970).

British research workers are currently investigating the practicalities of water supply from a freeze-desalination process.[9] Cost data supplied by UKAEA showed the freezing process to be significantly cheaper than conventional distillation under conditions appropriate to that country. Predictions for the test plant near Ipswich show that costs of water from a freezing process, at a scale of 5 mgd, in comparison based on discounted present values, were slightly lower for all probable ranges of demand growth, discount rate, and power costs, than those of the proposed new local reservoir (Alton Water). Other work by the UKAEA has identified potential overseas markets for the process. Some problems in developing the process remain to be solved. These will require investigations into the ecological effects of discharging concentrated by-product brine back into the ocean or estuarine source, and the effects of variation in temperature, salinity, suspended solids, and bacteriological contamination of the feed on the plant operation and on the product water.

Freeze-desalination offers economies when compared with distillation processes because of the use of direct contact heat transfer and low energy consumption due to the relatively low latent heat of fusion of water and the high thermodynamic efficiency of the heat pump cycle.

Cost-benefit analysis for any future plans for desalination by distillation, using waste heat or surplus steam energy, must be compared with cost-benefit analyses for alternative methods such as freeze-desalination, which may well prove to be more economic. The factors of environmental hazard, i.e., in brine effluents and pollution control potential, i.e., in using waste power-plant heat should be considered in all these cost-benefit analyses.

Combinations of nuclear generating units and giant desalination systems have been planned and discussed for a considerable time, but no construction has been undertaken since the costs of desalted water have been substantially underestimated. So far, estimates have been primarily based on the need for desalted water only. A better economic approach is to consider a situation where power will be generated anyhow. The logical question then is how to integrate desalting units with power generation, so that advantage is taken of the excess available energy. Present discussions are still aimed at small scale desalting units, of the order of 5 to 8 mgd. For nuclear power generation desalting capacities will be roughly between 50 and 100 mgd. By the time this process is properly devised and executed perhaps in the late 1970's, the cost of desalted water

[8] Further details on power-plant-desalination units and agro-industrial complexes may be seen in Anderson and Thompson (1970).

[9] Reference to the new desalination process, designed by Simon Engineering Ltd., can be seen in: *Ecolert*, vol. 1, no. 9, July 15, 1971; *London Times*, July 7, 1971, p. 2, col. 13; *Civil Engineering and Public Works Review*, July, 1971, p. 757; *The Ecologist*, (PUFFET, A. J.) vol. 1, no. 13, July, 1971.
The principle of freeze-desalination is as follows: "The freeze desalination process depends on the fact that ice crystals grown in seawater do not themselves contain salt. A liquid direct contact refrigerant, butane, is pumped into a crystalliser containing seawater and a slurry of ice crystals and concentrated brine is formed as the butane evaporates. The slurry is passed to the base of a wash column, where the ice crystals are moved upwards forming a cake, and brine drains away. In addition, recirculated product water is used to wash the ice cake such that when the ice reaches the top of the wash column it is free of salt. The ice is removed to a melter, where it is contacted with compressed gaseous butane from the crystalliser, causing the ice to melt and the gaseous butane to condense for re-use in the crystalliser. The melted product water is passed through a final debutanising process." (*Civil Engineering and Public Works Review*, July 1971, p. 757).

will probably be down to about $0.35 to $0.40/1,000 gal., as compared to the current $0.85 to $1.00/1,000 gal. (Bregman, 1971).

6. Production of Industrial Salts

Icelandic research workers (Lindal, 1970b; Matthiesson, 1970) are currently investigating the possibilities of a sea chemicals complex using, as raw materials, salt derived from seawater and processed along the lines shown in Figure 26. The salt is treated with large amounts of electrical power to produce more valuable products such as magnesium,[10,11] soda, and other electrolytic dissociation products of salt. Finally, chlorinated hydro-carbons may be produced in connection with an oil refinery. The initial salt plant and the magnesium plant would require large amounts of geothermal heat, and the latter would also require much electricity. These processes, however, are currently not applicable to a power-plant complex because the grade of heat required (approx. 100° to 180°C) could only be supplied by using "live" steam which, though it would reduce heat losses to a condenser cooling system, would be at a cost proportional to losses in electricity generating potential. The Icelandic magnesium project is believed to be profitable only because the use of cheap geothermal steam reduces production costs/ton of soda ash from $20-$30/ton (for a fuel-based steam production) to $2-$3/ton (at a selling price for soda ash of $35/ton).

7. Lake and River Purification Systems

A different approach to using thermal energy in waste treatment has been demonstrated by Hinde (1970). His 'Air-Aqua' system is designed to clean up polluted lakes by bubbling air and heated water through them. The principle is to supply oxygen to anaerobic lake bottoms. After oxygenation, aerobic processes could be made to proceed more rapidly by using warm effluents. This could eliminate a hypolimnion and bring warm water to the organic sediments. The Florida Game and Freshwater Fish Commission has used the oxygenation part of the system to recover the Lake Francis recreational fishery, although warm water was not used in this case to hasten aerobic processes (Fletcher, 1971). The total 'Air-Aqua' system has been successfully used in some small Illinois and Wisconsin lakes, and power and cost estimates have been worked out for the western portion of Lake Erie (Hinde, 1970). The overall effects on lake heat balance and lake ecology, however, seem to lack quantitative documentation.

Nutant (1970) advocates a similar aeration system that would use condenser discharge and that would increase DO levels to improve river water quality. It may be easier to treat water in the river rather than add tertiary sewage treatment facilities. One suggested system (Figure 27) is to divert a small percentage (2%) of condenser discharge into separate loops, where it will be pressurized and injected with pure oxygen. The water would then return to the main flow of condenser discharge before final rejection to the river. The system could only operate during the summer months of low flow when dissolved oxygen levels are low. System efficiencies are estimated at over 50%, and the cost/lb of oxygen added to the river ranges from $0.01 to $0.04 (Nutant, 1970).

It is worth noting at this point that, by the same principle of oxygenation, the use of spray modules necessary to cool thermal plant discharge water will have the additional benefit of aerating receiving waters (Frohwerk, 1971).

8. Waste Heat and Higher Grade Steam — Economic and Usage Considerations

Although sewage and water treatment systems could, with careful planning, be excellent beneficial uses for power plant waste heat, a word of warning is necessary. If these and other industrial and urban processes require higher grade heat than that provided by thermal effluents, and if high quality steam is consequently being taken from the steam cycle to supplement the heat obtained from cooling waters, then some potential for electricity generation is being lost to the waste heat use. Therefore, the question is one of a trade-off between more power and waste heat use. Higher grade steam must be paid for, and the price is high if steam is taken from a power plant designed strictly for electricity pro-

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[10] In order to avoid the need of chlorine feedback normally associated with magnesium production from seawater, brine from the salt plant provides the chloride through ion exchange, and lime is gained from seashells for precipitating the magnesium from seawater and supply CO_2 for converting the magnesium hydroxide precipitate to magnesium bicarbonate prior to the ion exchange. Magnesium chloride solution formed by the ion exchange process is concentrated by using geothermal steam, and reduced to magnesium and free chlorine by using electrical power (Lindal, 1970b).

[11] Bradley (1970) has emphasized the value of magnesium oxide as a substitute for the more common sulphite process in paper manufacture. This substitution may reduce paper mill pollution.

duction. Taking as an example a nuclear plant operating at 100% capacity, the steam at the end of the cycle after passage through the turbines will be at 92°F and 1.5" Hg pressure. This plant will have a heat rate of about 10390 BTU/kWh of electricity produced. Using the same system, but taking the steam at 161°F, increases the back-pressure to 9.0". Hg and increases the heat rate to 12000 BTU/kWh. In terms of dollars, fuel costs increase and additional expenditure/annum can reach $2,240,000, assuming a plant generating capacity of 7 x 10^9 kWh/year of electricity and typical fuel cost of $0.20/$10^6$BTU (Garton & Christianson, 1970). Therefore, if industry or urban use takes all the 161°F steam available from such a plant, it will have to pay all the distribution and hardware costs plus $2,240,000 to the power company to make the operation economical. Of course, the cost of steam will decrease proportionally with a decrease in the amount used.

It should be pointed out that if there is a guaranteed market for high quality waste heat all year round, then it may be worthwhile to sacrifice some electricity generation of better quality steam, especially when the costs of damage to the environment due to waste heat discharge are considered in the benefit-cost analysis.

As an alternative approach, the prospective user of power plant heat should compare costs of high quality steam usage with the costs of the fuel and hardware needed to raise the temperature of only partially heated power plant effluent to required levels independent of the power plant. Another alternative may be to utilize surplus off-peak electricity production to increase the temperature of thermal effluent. This would have the advantage that energy is more easily stored in water than electricity, and it would be using a power waste. A disadvantage, however, is that the user would have to tolerate an intermittent high temperature water supply. This might be more suitable for an "interruptable" process, such as desalination, rather than for a continuous use, such as controlled greenhouse heating or urban space heating.

CHAPTER 6

INDUSTRIAL USES AND CONSIDERATIONS

1. Types of Industry

Most industries that require heat at some stage in the production process usually need large amounts of high grade heat. The usual heat contained in thermal discharge is only suitable for a limited range of industrial uses, unless the effluent is taken out at a higher point of the steam cycle or a slave heating system is installed.[1] Certain industries, i.e., desalination, and by-product chemical industries based on waste and waste-water treatments, have already been discussed.[2] At the present levels of technology, other industrial uses for waste heat include:

i. *the chemical industry (chloralkali and heavy water production, and total energy use systems)*

ii. *the processing industries associated with agriculture and aquaculture.*

Although most of the following discussion will be directed at industrial processes, it is important that, for long term planning, these processes be viewed as part of a larger, efficient integrated system of total energy use, which may incorporate power production, agriculture and/or aquaculture, sewage, waste and water treatment, and possibly urban space heating and cooling needs.[3]

i. *The Chemical Industy[4], and Total Energy Use Concepts*

The Dow Canada Chemical company has a big demand for process steam in chemical processing. This large demand has justified investment in two gas turbines to generate 102,800 kW of electricity for on-site use, chiefly in three chloralkali plants, and concurrently, to recover large quantities of steam at two pressures. A project at Sarnia, Ontario, has developed from previous experiments in 'total energy usage' by Dow at Pittsburg, California, where three 16,000 kW gas turbines feed 10 process units with 48,000 kW of electricity and 450,000 lb/hr of process steam. Increasing costs of electricity (8-10% increase/annum in Ontario Hydro costs) and recent technological improvements in efficiency and reliability of gas turbines, heat recovery equipment, and centrifugal and adsorption air conditioning equipment, were deciding factors in developing the total energy facility at Sarnia. Gas turbine thermal efficiencies have risen from 16% to 26%, with a fall in heat rates from 21,000 BTU/kW to 13,800 BTU/kW. At the higher exhaust temperatures of large gas turbines, the use of waste heat boilers makes economic sense, and with recovery of this waste heat, system thermal efficiency rises to 88% (Figure 28). When the Sarnia total-energy facility goes into operation, Dow will continue to maintain existing steam-plant boilers for low-cost standby uses. The major steam supply will come from the new waste-heat boilers.

In Canada, other plans for total power-plant energy use are being made to utilize steam from the Douglas Point and Bruce nuclear plants to power an 800 ton/annum heavy-water extraction plant by 1981.[5] In this respect, the operating experience from Icelandic experiments using geothermal steam in heavy-water production might prove useful (Valfells, 1970; Matthiasson ,1970).

Another variant of the total energy system is the concept of the *nuplex* (nuclear power industrial complex), which is currently being developed by the Consumers Power of Midland, Michigan,[6,7] and by B.A.S.F., in West Germany. Consumers Power plans a twin reactor station with an electrical output of 1,300,000 kWh, and a large side production of low-grade exportable process

[1] Costs of higher grade steam and waste heat are discussed in chapter 5, page 51.
[2] See chapter 5, page 47.
[3] For multipurpose systems, see chapter 9, page 73.
[4] Abstracted largely from *Canadian Chemical Processing*, August 1971, Vol. 55/8 — Special Report on Plant Energy Systems 1, and from J. C. Swidler (1970).

[5] *Canadian Chemical Processing*. Special Report on Plant Energy Systems 1; August, 1971, vol. 55/8.
[6] Other U.S. state agency nuplexes are proposed for Texas, Kentucky, and Puerto Rico.
[7] On a smaller scale, waste heat is used at DuPont's Chambers Works, New Jersey; and by Union Carbide in South Charleston, S.C. (Bregman, 1971).

steam.[8] Industry can only economically use nuclear-derived energy if the industrial operation is on a large scale, and if it is remotely located from low-cost fuel sources. This is the case with Dow Chemical (Midland), whose steam energy requirements will be met by bleeding live steam (40%) and using waste steam (60%). The present (1971) estimated 1975-cost of coal to the Dow Midland[9] has risen by 46% over its first estimation in 1968, and the conversion to oil is likely to increase fuel costs by approximately 60% over coal. Fossil-fuel power plants (coal, natural gas and oil) also present the ecological and technological problems of fly ash and sulphur dioxide production. Therefore, for certain uses, nuclear power is an ecologically and economically sound proposition. There still remains, however, strong public opposition to centrally locating nuclear facilities, such as B.S.A.F.'s two 600,000 kW reactors, to a complex employing as many as 5,000 people and in close proximity to urban conurbations like the twin city of Ludwigshafen-Mannheim, having to total population of 500,000. This is a major problem, as centrality, one of the major premises of the nuplex concept, is required to minimize energy transport costs and make on-site total energy usage practical.

Although the subject of this report is the utilization of waste heat from power plants, it is essential to remember that many other industries produce heated fluid effluents, often at higher temperatures than power plant cooling waters.

Much of this heat energy in industrial processes could be re-cycled, within a total energy system complex by means of polybloc heat exchangers (Hilliard, 1964), other forms of high temperature heat exchangers,[10] and in acid recovery by evaporation (Culotta, 1967).

ii. *Processing Industries Associated with Agriculture and Aquaculture*

In Iceland, geothermal steam is used for freeze-drying. It is estimated that 200 tons of fish per hour could be freeze-dried with the heat rejected by a 1,000 MW steam electric plant (Stewart and Bjornsson, 1969). The freeze-drying process may also be applied to vegetable products, facilitating the production of perishables for export.

Since freeze-dried meat weighs 10 to 30% of its original weight, storage and transportation costs are reduced, and it may also be stored for several years without degradation. This weight reduction is due to the distillation of water from the products, and since items such as fish and meat contain up to 80% water, distilled water could be a useful by-product of this process.

The German and British experiences indicate that approximately 45% of the costs of processing comprise energy costs. High energy demand has tended to limit freeze-drying of foodstuffs to delicate and relatively high priced commodities such as coffee, fruit juices, mushrooms, shrimps, etc. Freezing 1 kg of fish takes 10.5 kWh or 36,000 BTU of heat energy. Standard freeze-dry processing therefore needs a lot of steam at 140°C. Thus, the large quantities of heat required necessitates that the process be located close to the steam source in order to minimize heat losses and costs associated with steam transportation. Also, the grade of waste heat in cooling water is insufficient and additional high grade steam should be bled from the turbine. This procedure would reduce overall reactor efficiency, but might be preferable in the overall cost-benefit analysis of a multipurpose scheme, i.e., the power-agricultural or power-aquacultural complex, which includes a reduction in thermal pollution as a final goal.

Waste heat may also be used in developing refrigeration systems, such as ammonia or lithium bromide absorption (Dallaire, 1970),[11] although additional high-grade steam or a slave heating system would be necessary. According to Nutant (1970), the ammonia water system usable with an air-cooled condenser and absorber requires a 250°F heat supply, and the more efficient (50% efficiency increase) lithium bromide system requires a heat supply of about 200 to 220°F.

Other Icelandic industrial projects using steam from geothermal resources, which may be adapted to a waste-heat and high-grade turbine steam supply in a "nuplex" total-energy use system, include:

a) drying diatomites (Lake Myvatn, at Na-

[8] In a nuclear power plant 2MW (t) are produced for each MW (e) generated (A. J. Miller, ORNL, *S.F.I.* 1970).

[9] Harold Bosscher, general manager, Dow Midland Division. Presently, at Dow Midland, fossil fuels have to be transported from the Gulf Coast regions of Texas and Louisiana, which doubles fuel costs.

[10] See *Canadian Chemical Processing*, August 1971, vol. 55/8, Special Report on Plant Energy Systems — 2 and 3 (J. Pahapill).

[11] See also urban space-cooling, chapter 7, page 58.

mafjall, N. Iceland; Lindal, 1970a; Matthiasson, 1970) uses 260 to 280°C steam at 6.3 atmospheres pressure; and

b) seaweed drying (Reykholar, West coast, Iceland; Hallsson, 1969; Matthiasson, 1970) uses 80 litres per sec of 100°C water to dry 3600 tons/annum of seaweed.

2. Total Industrial Water Reuse Concepts

Paralleling the concept of total energy use is that of total industrial water reuse, which is also applicable to a nuplex form of industrial development. Water reuse is essential to conserve, as an adequate base for future industrial expansion, an increasingly scarce, high demand resource which serves three major industrial functions: process use, cooling purposes, and steam production; and to act as a tool for pollution control and abatement. To these ends, the Water Quality Office of the U.S. Environmental Protection Agency (EPA) is sponsoring a research and development programme which has been briefly described by Rey et al (1971). Their recommendations for closed-loop industrial waste water and water systems are summarized in Figure 29. Some of the treatment costs involved, and to be compared with standard pollution control costs, are summarized in Table 17. As a general rule industrial water quality requirements for reuse are less demanding than for municipal supplies. Accordingly, industrial water reuse should be technically and economically achievable earlier than comparable municipal water reuse systems.

3. Conclusions: Industrial Use of Waste Heat

Industrial use of low grade waste heat (usually in the form of warm water) requires further investigation, and in this respect, Icelandic experience in use of geothermal steam could prove a useful guide. Possible uses in chemical and processing industries usually require, and must bear the additional costs of higher grade steam or some form of heating system, to raise thermal effluent temperatures to usable levels. Higher grade steam and low grade waste heat could be made available for these industries (and for desalination and sewage/waste treatment plants) by siting them in a "nuplex" development around a power plant. Future planning should be towards total energy power-plant-industrial and/or agricultural/aquacultural complexes because:

i. energy usage is maximized and fuel consumption and costs are minimized;
ii. energy transportation costs are minimized;
iii. production cost savings are possible in large scale vertically-integrated industries;
iv. increasing pressure on water resources requires the development of concepts of total industrial water reuse, which may involve several industrial processes working in harmony; and
v. it provides greater opportunity for careful pollution control once any problems of radionuclide leakage from nuclear plants sited close to dense populations have been completely eliminated.

CHAPTER 7

URBAN, RESIDENTIAL AND RECREATIONAL USE FOR WASTE HEAT

1. Urban Heat Demand

Table 18 shows the trends in total heat and electrical power consumption for urban uses in the U.S., and it indicates high heat to electricity ratios of 9 to 1 in 1965, and 6.5 to 1 in 1980.

As cities use so much heat, they should at least investigate the possibilities of utilizing some low-grade waste heat.

2. Urban Uses for Waste Heat

Many ideas for urban usage of waste heat have already been discussed. These include:

i. Sewage and waste water treatment and recycling systems.[1]
ii. Potable water supply by desalination of estuarine or seawater.[2]
iii. Snow melting systems replacing municipal snow dumps.[3]
iv. Developing total energy use industrial complexes which will act as employment centres for sectors of urban populations.[4]

Low grade heat (115°F) may also be used for defogging and deicing airport runways (Nutant *in S.F.I.*, 1970). Approximately 700 MW of heat would be needed to defog one runway and its approach path (Figure 30). Using heat available from larger power plants, and using a bank of fan-driven heat exchangers, heated air would be blown across the runway and rise to heat fog droplets causing them to evaporate. This system has, however, limited use (e.g., 53 hours of fog at LaGuardia Airport, New York, per year, and installation costs of $3 million to use waste heat from Consolidated Edison's Astoria Generating Station, Nutant, 1970; Bell et al, 1970).

Thermal discharge from a 1,000 MW nuclear plant would deice over two square miles of runways, using an underground piping system (Figure 31), and assuming a requirement of 1 inch of ice melt per hour (Nutant, 1970; Bell et al, 1970). Again, high capital costs for equipment would be necessary for only limited use, although such a system may be of greater value in the Canadian North. A similar system may be used to keep sidewalks ice-free.

Another aspect of beneficial uses of waste heat which is often ignored is the control of undesirable conditions of local climate which can result from the operation of cooling towers and ponds. A typical 1,000 MW nuclear power plant uses 10^6 gallons/minute of cooling water from which almost 1% evaporates (Stewart and Bjornsson, 1969). Evaporation of such a high magnitude concentrated at one location often changes the micro-climate and can cause fogging, icing, and clouds under appropriate weather conditions. If a beneficial use of waste heat reduces evaporation of cooling water, this should be included as an advantage in any cost-benefit analysis of the use.

Beall (1970b) suggests that waste heat may be used to keep recreation lakes and beaches at more comfortable temperatures for longer periods in cold climates. Using the same principle as elaborated for maintaining ice-free navigation on the St. Lawrence-Great Lakes system,[5] it may be possible, by using barrages, to create lagoons along the waterfronts of the major Canadian lakeshore cities. These lagoons could be pumped dry and cleaned, or perhaps flushed and cleaned by an air-aqua system,[6] and then refilled with warm and clean power plant cooling water. This system would have the benefits of:

i. creating large cooling ponds for power plant effluent in an area of high urban population density where the demand for greater electrical generating capacity is likely to continue to increase, but where water is going

[1] See chapter 5; page 47.
[2] See chapter 5; page 49.
[3] See chapter 5; page 49.
[4] See chapter 6; page 53.
[5] See chapter 3; page 25.
[6] See chapter 5; page 51.

to become increasingly scarce due to rising urban, industrial and domestic demands;

ii. creating (with additional treatment units) in an area of high water demand, a clean water supply for power plant reuse and urban industrial usage;

iii. improving the recreational value of the lakeshore in high density residential areas where the demand for such facilities is high. While it would not solve the problem of total lake pollution, it would improve those parts of the lakes that are used most often. Swimming and possibly fishing facilities could be improved and the length of the recreation season possibly extended by the use of warm water; and by creating a zone of calm warm water near shore, which would protect shorelines from wave and ice erosion and flotsam, dead fish, oil and sewage accumulations.

Some of the costs which might be included in a cost-benefit analysis for this scheme include:

i. costs (including compensation costs) of altering existing lakeshore facilities (sewage outfalls; jetties; harbour entrance facilities; etc.), particularly in urban areas where such costs are going to be high;

ii. installation and maintenance costs of barrage construction; water treatment system, and cooling water supply systems; and

iii. costs of the initial lagoon pumping and cleaning operation.

This scheme has several environmental problems which must be considered:

i. What will be the nature of the "natural" ecosystem likely to develop in such heated lagoons? Are high algal blooms with concomitant deoxygenation likely in summer?[7] How can the development of this ecosystem be controlled to give maximum amenity benefits and minimum problems? Would the mosquito population increase?

ii. How would the lagoon ecosystem respond to a possible failure in warm water supply from a power plant stoppage?

iii. How would a zone of warm water affect the micro-climate of the city waterfront? Possible problems are:
   (a) fogging, particularly in colder weather and at night;
   (b) increased humidity;
   (c) greater cloud formation and concomitant losses in sunshine; and
   (d) a tendency to keep atmospheric pollution close to the ground surface. In some cases, smog could develop (a parallel can be drawn on a larger scale with the smog development over Los Angeles, associated with the California warm current). This aggravation of pollution in urban areas may increase health hazards more than the cleaning of lakeshore waters will reduce them. Pollution problems would be lessened if the idea was applied to creating recreational amenities in more rural residential lakeshore regions where atmospheric pollutant emissions are lower.

Another urban use of waste heat could be the utilization of steam storage tanks to drive buses and switch engines (Beall, 1970b). A city bus with a full 40 cu. ft. tank of 380°F water could carry 40 passengers a distance of 20 miles, with "fuel" operating costs of 0.2-0.8¢/mile compared with a diesel oil cost of 1-2¢/mile (before tax). Steam engine maintenance costs may also be lower. At a temperature of 380°F, this necessitates a higher-grade heat than available from power plant effluent.

Probably the most debated urban uses of thermal discharges are in district heating, usually as piped hot water and steam, and in air conditioning systems. Heat-driven absorption type air conditioners can, with simple circuitry modifications, supply *heating* during the cold season using hot water distributed at 150-170°F (Nutant, 1970).[8] This temperature range is lower than that of 200-250°F required by ammonia or lithium bromide absorption *cooling* systems (Nutant, 1970). In evaluating and proposing schemes for urban energy centres and distribution networks, most authors are generally concerned with district heating and air conditioning.[9]

3. Existing Experience in Urban Heat Supply Systems

There are already several operating urban heat supply systems orientated toward district heating.

Of the 8.8×10^{12} BTU of geothermal energy

[7] See chapter 2; page 21.

[8] For discussion of absorption systems, see chapter 6; page 54.

[9] Review of such systems are presented in chapter 7; page 58 to 62.

used in Iceland, in 1970, a large portion was used to supply district heating for 40% of the country's total population (Matthiasson, 1970). For 25 years, hot water has been transported at a rate of 40 litres/second, from a geothermal source 10 miles away to heat residences in Reykjavik (population: 80,000), with a drop in temperature of 3°C from the original 86°C, and at 60% of the cost of heating with fuel oil (Nutant, 1970; Stewart and Bjornsson, 1969; Dallaire, 1970; Matthiasson, 1970).[10] This flow is augmented from wells in the city (raising temperatures to 90°C) and distributed by sub-street piping (Figure 32) for space heating, processing, industry, swimming pools, and other sporting facilities. During the space heating cycle, water temperatures fall from 90°C to 40°C. Normally, 2 kW/inhabitant or 23.2 watts/m^3 of the house is considered as the maximum load factor. Total costs to the user are approximately $1.02/$10^6$ BTU (compared with U.S. costs of $1.45/$10^6$ BTU). Besides lower heating costs, the service replaces fossil fuel burners which cause air pollution, saves installation cost and space in houses, and reduces the city fire hazard. Projected plans include a 19 mile long, 16-in. diameter pipe line to transport 180°C water under pressure, at a temperature drop of 5°C. 50% of the volume (at 130°C) will be used by industry at $0.50/$10^6$ BTU; and 50% (at 90°C) will be used by the domestic market at $1.00/$10^6$ BTU (Stewart and Bjornsson, 1969).

Technical details of the Reykjavik scheme have been discussed by Matthiasson (1970). The following principles, derived from an economic evaluation of the urban use of geothermal energy (Matthiasson, 1970), can be applied to the use of waste heat:

i. Economic feasibility of using waste heat will depend on its ability to compete with other available energy sources.
ii. This comparison should be based on the total cost to the ultimate user per unit of net energy utilized. This involves comparing costs of entire systems, taking into account the desired return on invested capital of all plants used, direct operating costs, annual load factors, efficiency of energy utilization, etc.
iii. Factors affecting the economic feasibility of power plant district heating systems include:
    (a) production costs per unit of energy production. These costs will include additional costs involved in using "live" steam electricity generating potential.[11] In the light of Icelandic experience (Table 19), it will be essential to use a substantial quantity of high-grade steam to boost low-grade waste heat energy. In this respect, urban space heating is not really a beneficial use of waste heat;
    (b) temperature of steam or hot water at its source and the distance, heat loss, transportation, and pumping costs involved in supplying it to market;
    (c) annual load density of the market;
    (d) annual load factor of the system; and
    (e) power of the system (G. cal./h.).
iv. Capital investment involves the costs shown in Table 20.
v. Energy price to the customer (average utilization basis) can be broken down to the costs shown in Table 21.

In Lund, Sweden (population: 55,000), the Municipal Board of Health recommended that in view of the high atmospheric pollution levels (dust particles and SO_2), centralized district or electrical heating be installed (Josefsson and Thunell, 1970). By 1963, an underground steam distribution network was operating, using heat produced in central plants *without* producing electricity. Maximum heat demand in 1969 was about 175 MW, and the estimates for 1980 and 2000 are 300 MW and 600 MW respectively. By 1968, there was a marked reduction in atmospheric pollution levels. To meet increasing demand for heat, two alternatives were investigated: an oil-fired, combined heat and power plant in Lund, with a back pressure unit and an electrical the 600 MW(e) nuclear power plant at Barsebeck, 10 miles from Lund. Steam at 150°C would be extracted from the turbine into a main heat exchanger and hot water would be pumped at 2 m/sec to Lund at 100°-130°C, returning at 60°C. A second heat exchanger in Lund would transfer the heat into the local hot water network which would have a design temperature of 90°-100°C. Loss of heat in the pipelines would be 5 MW, and electric power required for pumping would be 1.5 MW for a water velocity of 2.2 m/sec. Slave boilers would be located in Lund for standby purposes.

The two alternatives were found to be equal from an economic viewpoint, using a 9% interest

[10] The Reykjavik scheme is a project of the National Energy Authority of Iceland.

[11] See chapter 5: page 51.

rate and an oil price of U.S. \$13.50/m^3 at the power plant. Ecologically, the pipeline system would minimize urban air pollution, but some thermal pollution would occur at the electricity generation site and the pipes could cause some landscaping problems. Costs of putting pipes entirely below ground would be prohibitive (Josefsson and Thunell, 1970).

The Inuvik Generation Station of the Northern Canada Power Commission is an example of a functioning combined central power and district heating system (M.E.C. 1971). By combining the heat loads of many buildings into a central power plant it has been possible to burn residual oil instead of the more expensive high grade fuel oils needed by small heating plants in each building. There has also been a marked reduction in the fire hazard present with numerous fuel storage tanks. The above-ground 'utilidor' ducts prevent melting of permafrost by hot pipelines, and by including these heating lines in the utilidor, the dual functions of preventing freezing of the water supply and sewer lines in the utilidor and the provision of a piped heating system was met. In reviewing the efficacy of centralized district heating, Inuvik should be regarded as a special case. Its extreme northern climate created a high year-round demand for space heating and necessitated that some means be found to protect sewer and water pipes from freezing. Its small town size, and very recent urban expansion make for easier development of the utilidor system than would be the case in large, older, Southern Canadian cities. Although the combined system has been found to be economical of Inuvik, it is highly improbable that such a system would be used in Southern Canada (M.E.C. 1971).

In view of Inuvik's remote, isolated location and its climate, a high degree of reliability is required in the power supply and heating system, hence almost 100% standby capacity has been installed in the electric supply system. The design is such that the heating system is not entirely dependent on power generation, nor is the power generation system limited in meeting peak demands by the central heating system. This could not be the case if the heating system was entirely dependent on power plant thermal discharge.

Low grade waste heat has been used in England, and in Finland for district heating (Santala, 1966). Furthermore, the Puerto Rican government is currently planning an urban-nuclear complex (Bregman, 1971). Experience in this field is limited in North America. Much of central Manhattan receives energy for heating and air conditioning from the steam system of the Consolidated Edison Company, and the Rochester Gas and Electric Company makes large commercial steam sales to upstate New York (Swidler, 1970). It has been suggested that on the Hudson River, near Indian Point, N.Y., eleven power plants planned or operating could heat 800,000 housing units, and at the same time supply 5,500 MW of electricity (Bregman, 1971).

In Owhyhee County, Idaho, geothermal water at 85°-100°F is used for domestic heating. Several public swimming facilities in the U.S. use geothermal water with temperatures of less than 140°F (Ralston, 1970). Such experience with low grade heat in southern locations lends more support to similar uses for waste heat than does northern experience in Iceland, Canada, Sweden or Finland, where a much higher grade heat (live steam) is required with (as in the case of Lund) concomitant loss of electrical power production.

4. Feasibility of Urban-Power Systems in North America

Within the last five years there have been several feasibility studies directed at the use of waste heat in urban-power systems, in southern locations usually for domestic heating and air conditioning. A critical review of these systems is briefly presented herein.

The Consolidated Edison and Westinghouse task force (Bell et al, 1970) accepted, as one of the most feasible uses for power plant heat, the system shown in Figure 33, which utilizes live steam from a generating station to supply a distribution substation, from which homes could draw heated or cooled water for home heating and air conditioning. Advantages of the system are that it removes heating and air conditioning systems from the individual home, which reduces air pollution from low level house stacks, removes a potential fire hazard, and frees home space. It also utilizes *all* steam from a plant once it reaches a threshold temperature and pressure. Thus, no waste heat is discharged to a water body, and inevitably ultimate heat rejection to the atmosphere is from widely scattered points. It does *not*, however, solve problems of dealing with waste heat rejected in coolant from electric generation stations. This system differs from Consolidated Edison's Manhattan system in that the condensate is not returned at the plant for reuse. Some economic benefits may accrue if distribution substations are located no more than 3 miles from the generating station, and homes are located with ¼ mile of each substation. Increasing these distances increases transmission and annual costs, and pumping and heat losses, to impractical limits. To be economically feasible, the system must probably be built to a new city and not to a refitted existing community. Alternate energy sources are still needed as standby measures.

Two major conclusions were drawn in an on-going study on urban heat consumption for the U.S. Department of Housing and Urban Development[12] (Beall, 1970b). In most American cities, more heat can be used for air-cooling during the crucial (from a thermal pollution standpoint) summer period compared to commercial and residential heating in winter, and 300°-380°F steam from a 500 MW power plant can be competitive with other heat sources, even if the power plant is 10 miles from the heat distribution focus.

Some critical comment can be made on the above two conclusions. With respect to seasonal heat requirements, problems will occur on days, particularly in spring and fall, when demand for heating and cooling is small. Waste heat would still have to be either disposed of by conventional atmospheric heat exchanger techniques or would have to be used by increasing such "base-load" customers as waste-water and sewage treatment plants or industrial users. In more northerly Canadian situations, it may be that more heat is required in winter than in summer.

With respect to use of hot water from a power plant, costs of utilizing electrical production potential (live steam) must be borne by the user.[13] It is also not clear whether the use of live steam reduces the waste heat rejection problem of the power plant to an acceptable limit.

In the literature on the functions of heat in urban environments, it is not clear whether the main intention is to use *waste heat from power plants*, or to develop *centrally located boilers. These boilers would serve no function of electricity generation*, but would provide cheaper high-grade heat than conventional heating methods.

Beall (1970b) has proposed a system which lies between these two extremes. A city of 1 million people could be served by an energy centre of two 500 MW reactors, producing 3000 MW of heat (steam) at 300°F. Oil-fired standby boiler units capable of 1500 MW (thermal) would insure a 99% reliability of supply. Costs of heat from the dual purpose centre would be approximately 30¢/10^6 BTU, if electricity were sold at 4.3 mills/kWh. Heat delivery costs for a reactor located 10 miles from downtown would be 20¢/10^6 BTU. The profit and cost of distribution from downtown would increase consumer price to $1.00 (or more)/$10^6$ BTU. This price could be $1.50 and yet still be competitive with fossil-fuel heat in most cities.

Nutant (1970) suggests that a population of 450,000 could be provided with electricity, heating, and air conditioning by extracting steam at 220°F from a 1000 MW design nuclear plant. In this scheme,[14] thermal energy in one of several possible forms would be transmitted underground to substations throughout the town. Each substation would contain absorption refrigeration equipment and would provide a distribution service into living space and working space for one or more large buildings, a cluster of single residences or townhouses to control air temperature. Within a residence, there would be simple systems for controlling the flow of chilled water in

[12] This research is elaborated in Miller (1968; 1969; 1970): "Space Heating in Urban Environments". Only an abstract of Miller's work was available, and is as follows:
The article reports the preliminary findings of a systems analysis of the usefulness of nuclear energy centers in or near large cities and the application of energy centers to the development patterns and problems of American cities. It is concluded that in 1980 the heat from a nuclear energy center should be used to heat and air-condition a large portion of a large city at a cost per unit of heat equivalent to that now incurred by district heating in downtown commercial and high-rise apartment areas. The areas served could be much larger and they could consume much less heat per unit of area than those now served in this country by district-heating systems. Heat from back-pressure steam and turbine bleed would be used rather than heat from prime steam; therefore the waste of heat from the plant generating electricity would be significantly reduced. Such a system would reduce both chemical pollution of the air and thermal pollution of streams. Calculations indicate that distribution piping systems could be extended to serve larger areas economically, and that the use of medium or high temperature water would be more economical than high-pressure steam. Investigations of system reliability, time variation in load, economics, geographical influences, and accuracy of calculations are recommended. (Selected Water Resources Abstracts: 1970: W70-09192).

[13] See chapter 5: page 51.

[14] This scheme is very similar to that proposed by the Consolidated Edison/Westinghouse task force, chapter 7: page 60.

summer and hot water in winter. There would be no pollution, no fire hazard, no chimney, and no space set aside for the conventional heating and cooling apparatus. Heat exchangers on the roofs of the substations or large buildings would discharge unused energy to the air throughout the town where it is much less of a problem than it would be in the receiving waters. The overall effect should be superior to even the dry cooling tower approach, since the rate of discharge per unit areas is markedly reduced (Nutant 1970).

Nutant's argument for "scattering" the problem of waste heat disposal can be disputed. Surely, the *grade* of heat used to replace many individual boilers or electrically driven systems would determine the reduction of the total heat discharge to the biosphere. Admittedly, air pollution from fossil-fuels would undoubtedly be reduced. Nutant's argument may hold true if only low-grade waste heat is used, but it may not be the case if either very high temperature steam or supplementary slave heating systems are employed. There is a lack of empirical evidence, and, hence, energy balance models for centralized and decentralized urban heat generation systems must be compared as a prerequisite for future city planning.

Questions of safety, public opinion, and other non-thermal pollutant emissions (SO_2, NO_2, flyash) must be resolved before nuclear, gas-fired, or other fossil-fuel power stations can be sited close to urban-residential complexes to reduce the costs and heat losses associated with steam/hot water[15] transportation to economically acceptable levels. Future development of nuclear fusion reactors, and controlled thermonuclear reactors (CTR) will greatly reduce the large radioactive inventory of a light-water reactor. Hence, the reactor will need less stringent safety requirements. A CTR location closer to the load centre should therefore be possible, and would make space heating a more viable proposition (Foell and Benedict, 1970). Present U.S. AEC rulings require that plants be located some distance from population centres. Consequently, heat distribution for urban use is at present inefficient, expensive, and impractical (Foell and Benedict, 1970). Other writers agree with this analysis of the present situation (M. E. Lackey, ORNL Reactor Division, in *S.F.I.*, 1970; Nutant, 1970). Nutant (1970), reviewing the policies of Consolidated Edison and Westinghouse,[16] feels that whilst at present there is very little possible *economic* benefit likely from urban-power plant combinations, *social* benefits are high and should be regarded as the most significant choice factor. In the future, use of live steam and condenser heat for the space heating and air conditioning of residential structures should be viewed as part of a larger long-term plan. This plan would use a centrally located nuclear power plant as a multipurpose energy source (both of electricity and heated water) for urban area use, especially as it helps solve problems of non-thermal atmospheric pollution.

[15] So that delivery may be economic and that service meets customer needs, the heat must be at least 300°F (Beall, 1970a).

[16] Consolidated Edison (New York) and Westinghouse are currently backing research on all conceivable combinations of urban systems and power plant resources. The general procedure of this programme is to make a cursory analysis of all systems, one (or two) for detailed full-scale analyses (for the real world situation); plan a demonstration project; and finally build such a project to:
(i) validate the real world systems analysis, and
(ii) determine the empirical parameters required for full scale operation (Nutant, 1970).
The first phase of this project is to rank concepts according to technical feasibility. The basis of selection of various combinations will be the economic *and/or* social benefits derived from this combination.

CHAPTER 8

THERMAL AGRICULTURE

1. Introduction

Thermal agriculture may be defined as any form of agriculture that uses hot water to assist the growing process. Current experiments and proposed systems in this area can be classified according to the functions served:

i. "open- field" thermal agriculture (sprays, direct warm water irrigation); and
ii. controlled environment agriculture
   (a) greenhouse crop production; soil heating systems using piped hot water;
   (b) animal raising facilities; and
   (c) combinations of (a) and (b) and systems of total energy usage in power-water-food production.

The classification can also be according to the suitability of various forms of thermal agriculture to different climatic regimes:

i. hot, arid land agriculture (usually coastal fringe deserts);
ii. temperate agriculture; and
iii. extreme northern agriculture.

Since both the classifications are closely inter-related, an attempt will be made to combine them, and critically review technologies and feasibilities under the following headings:

i. "open-field" thermal agriculture in temperate latitudes;
ii. controlled-environment thermal agriculture in the northern latitudes, i.e., Iceland;
iii. controlled-environment thermal agriculture (power-water-food systems) as an alternative to "open-field" thermal agriculture in hot, arid lands (usually coastal fringes);
iv. review of proposed total-energy/thermal agriculture/industrial systems mainly for temperate latitudes;
v. general environmental problems of thermal agriculture; and
vi. general conclusions.

2. "Open-Field" Thermal Agriculture in Temperate Latitudes[1]

The uses of warm water in 'open-field' agriculture are being investigated on the Mackenzie River flood plain in Oregon[2] (Miller, 1970a; 1970b). The significant aspects of the project are briefly discussed herein.

I. *Frost Protection*

Frost protection, by sprinkler application of warm water, relies on the release of heat by water as it freezes. Following a warning of an early spring frost, 50 acres of orchard trees (pears, peaches, sour cherries and filberts) are sprayed with warm water (95°F) from a staggered series of overhead sprinklers. Warm water cooling and freezing on the twigs and buds releases heat to the plant cells, thereby protecting them from frost damage. A critical factor in this technique is the proper management of water application to preclude limb breakage by over-weighting with ice. A heated "canopy" effect over crops is also being investigated as a means of frost control (Miller, 1970a).

II. *Plant Cooling*

During warm summer months, warm water may be applied by sprinkler to cool plants by evaporative cooling. This procedure reduces sun-scald, eliminates cold water "shocks," increases yieds, and improves crop quality.

III. *Irrigation*

It has been estimated that a 1000 MW nuclear plant could provide enough water to *irrigate* approximately 100,000 to 150,000 acres. At Springfield, Oregon, water at 90 to 130°F is piped 2 miles from the condensing system of the Weyerhaeuser Pulp and Paper Plant to a series of bleed valves and buried pipelines at the project

[1] Temperate latitudes are defined here as regions of the world usually located in middle latitudes with climates which are markedly seasonal in nature and which lack extremes of temperatures and rainfall incidence.

[2] Thermal water demonstration project by the Federal Water Quality Control Administration, Eugene Water and Electric Board, seven Springfield farmers, and the Vitro Corporation, reported by Miller (1970a; 1970b).

site, with a heat loss of 4 to 10°F. Irrigation and spray water eventually seeps through 60 ft of soil before re-entering the Mackenzie River at or below river ambient temperatures and with no significant increases in nutrient levels. Irrigated crops, which at the same time receive frost protection (95°F water will give frost protection even at temperatures of 27°F, Dallaire, 1970), include walnuts, Blue Lake pole beans, sweet corn, tomatoes, bush beans, potatoes, and a variety of garden crops and nursery plants. A recent suggestion has been to use hot water from nuclear power plants to irrigate plantations of fast growing cottonwood and sycamore trees. This scheme would produce substantial savings on cooling towers ($10 million for a 1000 MW(e) station) and provide valuable hardwood (Cone, 1970).

In an experiment conducted at the Oregon State University (Boersma, 1970),[3] initial results have shown that heating soil by buried electrical cables (which simulate heating by underground water pipes) substantially increases the growth rate and may triple the yield of several crops. The problem of keeping "available (to plants) soil moisture" in the soil, though, has yet to be resolved (Dallaire, 1970). Thermal irrigation may be used in Canada to extend growing seasons.

IV. *Economic Benefits*

Given a co-operative agricultural venture, plentiful supply of cheap or free warm water at a close proximity, and the production of high profit crops in small acreages, "open-field" thermal agriculture can be an economic venture in temperate latitudes, as demonstrated by the Springfield experiment. High initial outlay costs (for pumping, piping, sprays, etc.) are a handicap. High capital and maintenance costs, as well as heat losses increasing with distance piped, would limit such "open-field" thermal agriculture to small-area, high-profit ventures. Environmental limitations to be considered are discussed later.[4]

3. Controlled-Environment Thermal Agriculture in Northern Latitudes: Example of Iceland

In Iceland, greenhouse heating by geothermal water has grown steadily over the years to a present land coverage of 115,000 m². Seventy per cent of this land is devoted largely to tomatoes, cucumbers, and lettuce, and 30% to flowers and potted plants. The annual value of greenhouse production equals U.S. $910,000 (1969). As the Icelandic situation is comparable to that of northern Canada (e.g., Yellowknife, 62°N; Reykjavik, 64°N), it seems appropriate to briefly describe some of the parameters of Icelandic greenhouse heating.[5]

Global radiation averages 74,100 cal/cm²/year, and climatic conditions in Iceland require 300 to 350 Kcal/m² of greenhouse area at maximum load. The annual load factor is 35 to 40%, and total use of geothermal energy for this purpose is 120 Tcal/year at energy price $0.43/Gcal. Approximate greenhouse construction costs are $15/m² for timber framed houses, and $20/m² for aluminum frame houses (Matthiasson, 1970). Year-round growth at northern latitudes is restricted by available radiation. Stewart and Bjornsson (1969) report, however, that a recent U.S. Patent (No. 3.352.058) describes a method of converting most of the incoming solar radiation into the spectral range plants can absorb. This would increase the percentage of radiation absorbed, which, in turn, would increase productivity.

4. Controlled-Environment Thermal Agriculture as an Alternative to "Open-Field" Thermal Agriculture in Hot, Arid Lands

Preliminary research by the University of Arizona, at its Environmental Research Laboratory (Tucson Airport),[6] showed the feasibility of controlled environment agriculture in hot, arid lands by developing an experimental total energy-agricultural complex and by investigating the physiologies of crops grown in greenhouses, high humidity chambers, and phytocells (which allow crop growth in full sunlight with complete control over all other environmental variables). At Tucson, all electrical power requirements are generated on-site from natural gas engines for four reasons:

i. The design, construction, and continuing operation of the total-energy package pre-

[3] See chapter 2, page 22; and chapter 8, page 68.

[4] See chapter 8; page 70.

[5] Heat units used by Mathiasson (1970), are:

Kcal	= kilogramme-calorie	= 3.968 BTU
Gcal	= giga-calorie	= 10⁶ Kcal
Tcal	= Tera-calorie	= 10⁹ Kcal

[6] Research by the Environmental Research Laboratory, University of Arizona, supported by funds from the Rockefeller Foundation; and the ruler of Abu Dhabi, Shaikh Zaid Bin Sultan Al-Nahya. The summary of this research presented in the following pages is synthesized from: Hodges & Hodges (1971); Jensen & Teran (1971); Anon (1969); Hodges et al (1970); Elder (1970); Anon (1970d); Staff of E.R.L. (1970; 1970-71); Dallaire (1970); Bazell (1971).

pared an engineering staff for the ultimate design and operation of similar systems in the more remote desert areas — Puerto Penasco, Mexico and Abu Dhabi, Arabian Gulf.

ii. Waste heat (⅔ of input fuel energy) from the gas engines is used in a waste heat recovery to make steam for an absorption refrigeration unit and to generate hot water. Thus, with a given amount of a limited natural resource, i.e., natural gas, not only is electrical power supplied, but also chilled water for cooling and hot water for heating. This enables temperature control in environmental growth chambers within a range of 45° to 170°F.

iii. Exhaust gases from the combustion of hydrocarbons in the engines, instead of being released as an atmospheric pollutant, are scrubbed and used to raise carbon dioxide levels to 1200 ppm in plant growth chambers, for the acceleration of the photosynthetic process. Examples of increase in yield gained by this method are shown in Table 22.

iv. By combining the power, thermal energy, and carbon dioxide system as one unit, significant economic savings can accrue.

Following the guidelines of the Tucson experiment, two commercial total-energy power/water/food complexes have been developed at Puerto Penasco and Abu Dhabi. Both complexes (Figure 34) also incorporate humidity cycle desalination units producing distilled water (for domestic and agricultural use) and salts from seawater using waste powerplant heat. Desalination helps prevent salt evaporation problems usually present in the arid-land, open-field, irrigated agriculture. Open-field irrigation in hot and dry climates requires large amounts of water because of high evapotranspiration rates. To produce such large amounts of desalted water would be too costly. The alternatives to open-field agriculture used at Puerto Penasco and Abu Dhabi are closed-environment greenhouses made of plastic and inflated by pumped air (Figure 35). These greenhouses may be regarded as horizontal cooling towers in other powerplant/agricultural complexes. Stuart (*S.F.I.* 1970) estimates a loss in long wave radiation from plastic covered greenhouses of 48 x 10^5 BTU/minute/acre.[7] Within the Abu Dhabi and Puerto Penasco greenhouses, the required amounts of irrigation water are supplied to plants by one of four standard types of irrigation systems. One emits a fine spray over the growing area from above-ground sprinklers and is used for closely spaced crops such as radishes. Another waters each plant individually below ground, by a spaghetti-like network of tiny plastic tubes. The two other systems release water in small droplets at soil surface level. The type of irrigation system depends largely on the plant spacing. Water is applied as needed, and some crops receive as much as four waterings each day. In each application only enough water is added to moisten the sand beds to the depth of root penetration (Jensen and Teran, 1971).

Humidity is maintained inside these greenhouses at near 100% by recirculating air through a seawater spray. This lowers transpiration and, hence, water requirement rates. For example, red kidney beans grown in 100% humidity used only ⅕ of the water needed by those grown at 35% to 70% humidity. It also allows for a control that raises or lowers greenhouse temperatures in order to maintain constant temperatures suitable for optimum growth.

The greenhouses also provide protection from other external environmental dangers such as sandstorms, pests, and disease.[8] Within these structures, crops are planted directly in desert sand, which is leached free of excess salts. Plants are given controlled nutrient supplies mixed into irrigation waters.

Some of the problems being faced in the greenhouse cultivation include:

i. failures of inflated structures due to high winds;

ii. screening of redundant solar radiations which require expensive environmental controls;

[7] Stuart (S.F.I. Bulletin #214, May 1970) approaches the problem of waste heat on the basis of abating thermal pollution and improving overall economic efficiency of power plant operation. He states that 11,00 acres of soil are required to dissipate the waste heat produced by a 1000 MW plant. Use of spray ponds or reservoirs reduces surface area needs to 1/20th of cooling pond requirement, under 100 acres of water surface per 1000 MW generating capacity. A recent study by Stone & Webster indicates that dry cooling towers are economically feasible, about 16 acres being required for dry closed circuits. Stuart estimates that about 500 acres of plastic greenhouses would dissipate half the heat produced by a 1000 MW plant. He noted that the shading of discharge canals, by cutting off direct insulation, will reduce thermal discharge water temperatures by several degrees, and that induced turbulence in the canal serves to increase the rate of heat dissipation.

[8] See chapter 8; page 70.

iii. absence of shade can create some undesirable heat transfer problems in the plant;
iv. complex temperature and productivity relationships require long investigations of alternative physical conditions within the greenhouse; and
v. continuous dripping of condensate from the plastic cover of the greenhouse onto rice plants prevents proper pollination.

Solutions are now available for some of these problems.

Large quantities of a number of different vegetables such as beans, beets, broccoli, cabbage, cantaloupe, watermelon, etc., have been grown and have matured more rapidly and with greater yield than they would have done in open fields. For example, cucumber and lettuce production have been at least six times more than would be expected from open fields. 71 tons of tomatoes/acre were harvested at Abu Dhabi compared with good open-field yields of 30 tons/acre in the U.S. This is expected to be improved to 196 tons/year. Rapid maturation has been demonstrated; normal 90 to 100 day periods for tomatoes have been reduced to 80 days. Further examples of yield and harvest date improvements are given in Tables 23 to 26.

Cost estimates for a typical Puerto Penasco greenhouse, and for the entire operation of an Abu Dhabi greenhouse, are shown in Tables 27 and 28. It is expected that the Abu Dhabi facility will produce 2 x 10^6 lbs/year of fresh vegetables from 5 acres of such greenhouses. Due to high capital equipment and maintenance costs (initial costs equal $300,000/year), the costs of this type of agriculture still exceed the costs of conventional arid-land farming techniques, and make the technique impractical for most nations, particularly those which are very poor. The limited size of the operation restricts production to perishable vegetable and horticultural crops. After capital investment, it is, however, hoped to keep production costs at 20¢/lb which compares favourably with imported vegetable prices of $1.50/lb in Abu Dhabi. Cheap labour is necessary to attain low production costs. According to the investigators, a 22% investment return is expected, even in Tucson, Arizona.

These studies indicate that, given money and foreign aid, there is the potential for some of the 20,000 miles of desert coastline existing around the world to be converted into likely locations for integrated power-water-food packages. Plants, poultry, or swine could be grown inside 200 acres of greenhouses next to a 300-MW(e) gas-cooled nuclear reactor (Bregman, 1971). Whether these systems could be converted to the situation of the Canadian north, where the problems are extremes of cold and frozen ground as opposed to hot, dry conditions and salty sands, remains to be tested. There is undoubtedly a high demand in the Canadian north, particularly in towns around mining complexes, for cheap, fresh vegetables, and meat production.

5. Total-Energy/Thermal Agriculture/ Industrial Systems for Temperate Latitudes

a) *General Principles of Controlled-Environment Agriculture*

Waste power plant heat is usually within a temperature range ideally suited to maintaining controlled temperature environments for plants and animals, in which energy loss to the environment by processes of heat-transfer, respiration, evaporation, etc., ("comfort" processes) is minimized and energy expenditure on metabolism and growth processes is maximized for maximum productivity efficiency. The advantages of using waste heat in controlled-environment agriculture include:

i. Optimum production and growth in farm animals (Figure 36) and crops (Figure 37) usually occurs within a temperature range of 50°-90°F (10°-25°C).
ii. Animal feed conversion efficiency is usually high within a 50°-90°F temperature range (Table 29). If environmental temperature is not controlled, animals will have to convert feed to heat. Using feed as fuel in this manner is expensive, about $5/$10^6$ BTU compared to 50¢ to $1/$10^6$ BTU for gas.
iii. Labour costs, an increasing problem in food production, may be reduced by controlled environment or enclosed operations which offer more possibilities for mechanization than "open-field" culture.

Beall (1970a) gives the following optimistic estimates of possible yields in controlled environments:

i. increase of 100,000 lbs/acre for broilers, and
ii. increase to 500,000 lbs/acre for tomatoes grown as three crops in greenhouses where complete environmental control (water, fer-

tiliser, CO_2, temperature, turbulence) is maintained, (high "open-field" yields = 60,000 lb/acre/year in California).

Estimates of values for some yield increases range from $20,000/acre (pork) to $100,000/acre (tomatoes). A possible mix of crops for a 500 acre range-controlled environment greenhouse complex, with yield and value estimates, is given in Table 30. Beall (1970b) suggests that average annual income could reach $27,230/acre.

Although, as shown in Table 30, profits could be high, economic analysis should also consider:

i. initial profit of an alternative open-field operation;
ii. increased value from controlled environment operation based on increased productivity;
iii. space savings;
iv. costs of structures and environmental control;
v. the market size and situation for the project. For example, is the market likely to be flooded as a result of increased productivity, and are prices likely to fall to a level which will exclude the small farmer, and only make very large commercial farming enterprises competitive; and
vi. the elasticity of demand for each particular commodity in planning controlled environment agriculture with intentions to increase yields. The choice of commodity must be made with a view to its elasticity of demand and to the planned size of the agricultural operation in terms of investment/capital equipment; economies of scale, and market competition and competitive ability.

b) *Controlled Environment Agriculture in the Mid Western U.S.A.*

One proposal is to utilize the 120°F waste heat from the Colorado Public Service Company high-temperature gas cooled reactor[9] at Fort St. Vrain, Denver, to heat greenhouses and other controlled environment structures in winter and cool them in summer by means of an evaporative cooler (Figure 38, Beall, 1970a, 1970b; Samuels and Holcomb, 1969). Such a system is suited to areas like the Western or Mid-Western United States, where the wet-bulb temperature depression is 10°F or more. In Denver, at a wet-bulb temperature of 65°F, a summertime greenhouse temperature below 75°F can be gained by evaporating enough warm water to cool the water and air, and in winter temperatures can be kept over 65°F, as dictated by crop requirements. In summer, air is blown through the house to the outside (as in a wet cooling tower), and in winter, when it is necessary to maintain warmth, the heat in the air is conserved by recirculating. A plastic sheet forming an attic (Figure 39) allows recirculation of air through warm water from the reactor station. To counter high humidities, a finned tube heated downstream from the evaporative cooler pads can provide dry heat, keeping humidities in the 70-80% range. An integrated agricultural complex around the powerplant is envisioned (Figure 40).

The Fort St. Vrain studies suggest that the use of greenhouses as cooling towers can result in the following:

i. cooler water returning to the power plant cooling system than would normally be expected from ordinary cooling towers in summertime. This would improve the electricity conversion efficiency of the power plant;
ii. savings to the utility in capital and operating costs for usual cooling tower facilities. The utility can benefit in several ways:
   a) land otherwise unused, can be leased;
   b) no (or less) capital investment for cooling towers;
   c) tower chemicals and operating costs are reduced or eliminated; and
   d) the public image of the utility is enhanced due to alleviation of thermal pollution.

Profit to the utility, assuming waste heat is given away and credit is taken only for cooling tower capital and operating-cost savings, can approach $250,000/year (Beall, 1970a).

iii. air is cleaned by washing as it is inducted through the evaporative pad system;
iv. savings in food costs to local city markets. Conventional poultry batteries and swine sheds could easily be adapted to accommodate the evaporative cooling system. The Denver area could support a 200 acre spread of broiler and laying houses (Beall, 1970b). Many large U.S. and Canadian cities depend heavily on truck and rail shipments for fresh vegetable, poultry, and food supplies. Local production would save on these transport costs;
v. savings in capital and operating costs (e.g.,

[9] Operating at 330 MW(e) and 40% efficiency.

fuel bills) to greenhouse farmers. If the present commercial cultivation of vegetables in greenhouses is profitable (it *certainly* is for tomatoes) with heat from gas- or oil-fired heaters at $1.00 to $1.50/10⁶ BTU, reactor heat at 20¢/10⁶ BTU would produce an additional profit of $4,000 to $6,000 per acre. A 20¢/10⁶ BTU charge would just about return the investment in piping, pumps, and equipment not normally needed by the greenhouse. Depending on the location, profits to growers on heat costs savings may be as high as $5,000/acre/year (Beall, 1970a).

c) *Controlled Environment Agriculture in Canada*

Recently, Alberta has been carrying out some successful experiments at Wabamun Lake in a 3,000 sq. ft. greenhouse facility heated by air which is passed through a specialized cooling tower-heat exchanger in which power plant thermal discharge flows. Major problems encountered are high air humidities, freezing and condensate in winter, and, most important of all, limited solar energy particularly in December, January and February which limits crop choice (mainly to reafforestation products) and the number of cropping seasons. A future greenhouse area planned for about 10 acres at $1.25/sq. ft. gross is expected to break even. This use, however, would require only a small fraction of the thermal discharge from the Wabamun plant. It is estimated that some 400 acres of greenhouses would be required to utilize the total discharge. However, environmental regulations concerning discharges may encourage this sort of development.

d) *Greenhouse Facility for New York State*

Bell et al (1970) describe a system for heating greenhouses with waste heat in New York State (Figure 41). The lower limit on the size of the greenhouse facility, that can be supplied by waste heat from a given power plant, can be estimated by comparing the maximum greenhouse heat input required under the most adverse weather conditions expected with the minimum effluent heat from the power plant at minimum electrical load. This estimate is fairly realistic if waste heat is supplied directly to the greenhouse through conventional heating equipment having no intermediate storage facilities. Although this may be the cheapest method of using waste heat in this case, it leads to problems in correlating greenhouse heat load to power plant electrical load. The daytime solar heat input greatly reduces the artificial heat requirements for the greenhouse at the time the diurnal peak occurs in the electrical load. A comparison of standard heating costs versus waste heat methods indicates that greenhouse heating would be an economical way to use waste heat, if space was available. A 1,000 megawatt nuclear plant could heat 4.4 square miles of greenhouse. This plan was rejected by the Consolidated Edison and Westinghouse Task Force because of its large space requirement and the problems involved in matching greenhouse needs with power plant output.

e) *A Power-Food-Processing System*

Controlled-environment agriculture was incorporated in a power-food facility already described in this report[10] (Boersma, 1970). Such an integrated system includes a power generating facility, a cooling cycle which incorporates an aquaculture/waste treatment/algae growing unit within an evaporative cooling basin and a soil warming loop for raising vegetables, and animal feeding and food processing units which use products from the aquacultural and agricultural units (e.g., algal animal feeds) and which are powered in part by waste heat and by electricity from the power generating facility (e.g., for freeze-drying and refrigeration processing). These units fit together effectively because soil warming (shown by experiments at the Oregon State University) can stimulate a high rate of crop production for the efficient operation of the processing plant, or for animal meat production. The warm water arriving in the evaporative cooling basin also accelerates the decomposition of the organic wastes from the processing plant, or from animal rearing facility, and stimulates the growth of organisms feeding on these wastes. Further refinements which could be considered are the warming of greenhouses in winter to ensure a year round supply of products for the processing plant, and space heating and cooling for the animal enclosures. The separate elements of the system are described and discussed in detail by Boersma (1970), in terms of energy dissipation and benefits derived from the heat in the cooling water. The system proposed satisfies the general criteria for good beneficial use of waste heat,[11] listed previously in this report.

Boersma (1970) recognizes several *social values*, enumerated below, in the total system

[10] See chapter 4: page 43.
[11] See chapter 2: page 22.

which might be included as benefits in a cost-benefit analysis:

i. some pollution problems are solved in concert and not as isolated events. The system permits re-cycling of heat, cooling water, and nutrients such as nitrates and phosphates. When a closed cooling system is used, the need to construct a power plant near a large water supply is not critical;

ii. Potentials for waste water and sewage treatment may be advantageous to urban communities;

iii. the system maximizes agricultural production and minimizes the space used at the same time as it utilizes space which is normally left free near a nuclear plant for safety purposes. In these ways, the system helps to solve the problem that arises when productive agriculture is practised on expensive land that is desirable for urban development. If this idea is extended, one danger is the loss of conventional farmland which acts as a "green-belt" and recreational zone that contains urban sprawl;

iv. as an industrialized concern with a capital intensive operation, this agricultural system can, in the future, aim at maximum efficiency (much higher yields per unit surface area) at minimum prices to the consumer.

In formulating a cost-benefit analysis of the total system, social benefits are not usually included as they require future evaluation. The input required for a systems analysis of the problem is not available and can only be obtained through additional research. The ultimate system and land area required for heat disposal purposes will have to be decided on the basis of a heat budget analysis. With these reservations in mind, a cost-benefit analysis can be presented[12] for a subsoil heating system of 5,000 acres and an evaporative cooling system of 500 acres. Criteria considered important in selection of the site include: uniform block single ownership, flat-land, good soil, good drainage, and proximity to market. Total system costs are shown in Table 31, and annual system costs in Table 32 (for assumptions see Boersma, 1970, page 39).

In calculating annual returns of the soil warming system, Boersma calculates that at a total annual cost of $21,185,900.00 and with 5,000 acres involved, the annual cost is $437.18/acre/year. He estimates that bean cropping would pay for the total system and its operation at a yield of 7.9 tons/acre for a single crop and 9.9 tons/acre for a double crop. This estimate includes all charges, and it is suggested that the operation would actually allow the utility to realize a profit. The profit would, however, be attained at the cost of the farmer who would no longer be able to contract with the processor who obtained these beans.

Farming silage and hay, the system loses money or is marginal at best. Very high production rates need to be achieved, followed by high winter annual yields of dry matter of 5 to 7 tons/acre in order to make a profit. Whether this is possible in certain geographical regions remains to be known.

Beef production could benefit from improved feed conversion efficiency in controlled environments and cheap feeds from other parts of the facility (e.g., algal feeds from sewage conversion). At a price of $0.25/lb live weight, an annual production value could be $7,500,000.00 (Boersma, 1970). This is a profit of $1,766,900.00 considering the following costs:

Soil warming system	$2,185,900.00
Evaporative basins	1,297,200.00
Farming the land	1,250,000.00
Harvesting algae	500,000.00
Handling cattle	500,000.00
	$5,733,100.00

In summary, the power-agricultural facility requires high capital investment and running costs and, hence, is only efficient economically in the production of high yield and high profit commodities such as beef which can benefit from several aspects of the system and which require little space. The system is at present too expensive to be practical, but the social values and increased efficiencies derived from its integrated nature make it worthy of consideration in future planning of land use, particularly with the increasing demands from urban populations for building space, power, cheap food, water, sewage disposal, and pollution control in agriculture and food processing industries.

f) *An Energy-"Step Down" System for an Integrated Power-Food Complex*

Stewart and Bjornsson (1969) describe a power-food system, the main elements of which are shown in Figure 42. The condenser cooling

[12] Annual returns of the evaporative system have already been discussed in chapter 4; page 43.

loop (incorporating greenhouses, fish ponds, farmland irrigation and water storage) could also accommodate chicken houses. Evaporative losses are compensated by water taken from a river. A freeze-drying plant using steam extracted from the turbine would greatly increase the value and storage life of the products from the complex, and decrease storage and transportation costs. The freeze-dried products could be used for balancing out variations in production and market demands. Additional factors could be waste water treatment, adding water to the cooling system and food to the fish ponds, space heating of a nearby city during winter, and central space cooling and air conditioning during summer, using the same distribution system in the city and the central cooling facilities in the complex.

This complex is designed to provide a step-down method of using the available energy as it passes from high-grade, readily available energy to low-grade, partially unavailable energy. The result is an economically feasible complex which reduces thermal pollution after maximum use of the available energy. It may be used in most climates by choosing those options which are suitable for the area (Stuart and Bjornsson, 1969).

6. Some Environmental Problems of Thermal Agriculture

Despite the optimism shown by many researchers in this area, many environmental problems have yet to be considered in applying heated water to agriculture. These include:

i. changes in temperature or chemical characteristics of ground water;
ii. flushing of pesticides into ground water, rivers, lakes, etc.;
iii. concentrated farmyard manure, fertilizer, and processing wastes rejected by the power-food facility;
iv. stream warming through short-circuiting of return water;
v. plant or animal disease and pest prevalence under high temperatures, or under constant temperatures which may alter the possible seasonal nature of their incidence;
vi. adverse effects of high temperatures on plants and animals, e.g., excessive transpiration; excessive respiration (careful assessment of optimum humidities and temperature tolerance ranges for specific crops and crop combinations is required in order that such adverse effects may be recognized and controlled);
vii. alterations of soil micro-organism populations, its influence on organic breakdown, nutrient availability, etc.;
viii. effects on soil chemistry systems, and on heat transfer and moisture relationships in different soils;
ix. effects of possible excessive soil drying around heated pipes (will this aid soil erosion? How will this influence nutrient uptake by plants?); and
x. possible changes in local micro-climate resulting from soil heating.

Many of these problems apply both to "open-field" and to "greenhouse/controlled environment" thermal agriculture. An advantage of the latter is that more control is possible in suppressing an unexpected disease outbreak or cleaning effluents of fertilizers and farm wastes before returning the effluents to the water source or recycling through a condenser cooling system.

7. General Conclusions

A number of general conclusions can be drawn from the previous discussion of thermal agriculture:

i. the choice of thermal agricultural technique and system to be used is in part dictated by the prevailing climatic regime and local geographical situation, and in part by the types of produce for which there is adequate demand to justify the large capital outlay needed by most systems.
ii. "Open-Field" Thermal Agriculture in temperature latitudes holds good possibilities for improving yields, crop quality, and growing season lengths for certain crops[13] by providing spring and autumn frost protection, summertime plant cooling, and warm water irrigation. One problem is that these uses will not be required constantly and, therefore, they do not provide a total solution to the waste heat problem. High capital costs, as well as heat losses with increasing distance piped, restrict such agriculture to

[13] An exception to this would be cotton growing in Texas, reported by Valliant and Longnecker (1969): "Cotton crops were irrigated over 3 years with heated water of 65-85 degrees F. temperatures ranges in an effort to determine the effects on crop yield. Irrigation treatment included: (1) preplant irrigation only, (2) preplant plus 2 irrigations, and (3) preplant plus 2 irrigations with heated water. Heated and unheated water both reduced soil temperature 1-6 degrees F. below air temperature. Heated water had no consistent effect on earlier flowering, the number of bolls or earlier cotton production."

small area, high profit truck farming, and fruit growing ventures (usual co-operative). "Open-field" thermal agriculture is liable to more environmental problems which are harder to control than those of "greenhouse/controlled environment" agriculture.

iii. Successful truck farming methods in geothermally heated greenhouses in Iceland[14] could be adapted to a powerplant heat source and used to provide needed supplies of cheap fresh vegetables and poultry, particularly in towns around mining complexes in northern Canada. However, in much of Canada the availability of solar energy in winter months is a critical limiting factor. Controlled-environment culture may also be well suited to farming high-profit fur-bearing animals.

iv. Controlled-environment thermal agriculture incorporated into total power-food-desalination systems have been proved far more successful than conventional agriculture or "open-field" thermal agriculture in hot, arid, coastal-fringe lands. Waste heat, carbon dioxide exhaust and seawater sprays have been utilized to maintain greenhouse environments in which productivity is increased, and in which transpiration rates and, hence, plant water requirements, are drastically reduced.

At present, high capital costs limit such systems to small operations in countries which can afford them and to producing high value, perishable vegetable and horticultural crops. Potential exists, given capital and foreign aid, to develop such systems on much of the world's 20,000 miles of desert coastline. Whether such techniques can be adapted to the situation of the Canadian north, where the problems are extremes of cold and frozen ground as opposed to hot, dry conditions and salty sands, remains to be tested.

v. Waste powerplant heat is usually within a temperature range ideally suited to maintaining controlled temperature environments for plants and animals, in which energy loss to the environment by processes of heat transfer, respiration, evaporation, etc. ("comfort" processes) is minimized and energy expenditure on metabolism and growth processes is maximized with an aim to gaining maximum productivity and feed conversion efficiencies.

[14] Similar uses for geothermal heat are reported in the USSR (Dvorov, 1969).

A proposed "evaporative cooler" technique seems technically sound for maintaining controlled-environmental greenhouses in areas like the Western or Mid-Western States where the wet-bulb temperature depression is 10°F or more. Savings are likely to accrue to both the utility and the grower by using greenhouses as "horizontal" cooling towers. A technique similar to this has been successfully applied to growing reafforestation crops in Alberta. A power-food complex incorporating a reactor, these greenhouses, swine and poultry units, and a food processing plant could well supply a city such as Denver, Colorado, with its power and poultry/vegetable supplies. If aquaculture-algae growing facilities and waste-water/sewage treatment plants are also incorporated in a totally integrated complex (using energy in a step-down method as it passes from high to low grade energy), usefulness to a city will be increased, and food production (particularly beef) could be made more economically sound. High initial capital costs, lack of knowledge of all inputs needed for a proper systems analysis, environmental problems associated with the complexity of plant-soil-water relationships, and heat balance problems involved in matching greenhouse heat needs with powerplant heat output throughout the year in temperate latitudes, have so far limited temperate controlled-environment agriculture to proposals on paper, and to some limited university-utility research. Jaske and Touhill (1970) reject the efficacy of this use of waste heat on two counts: the total amount of heat that agriculture can consume is relatively much smaller than the heat potentially available, and agricultural use of waste heat is a matter of public policy. Hence, its use would be handicapped in dealing effectively with the immediate problems. An increase in demands by urban populations in temperature latitudes for building space, better control on fertilizer and pesticide application and waste heat rejection, food and water supplies, power and sewage treatment, may ultimately force this issue. In a relative sense, controlled-environment agriculture is probably the most practical (technologically and economically) of all beneficial uses for powerplant low grade waste heat. Integrated power-food-sewage/water treatment-industrial systems are ultimately the most efficient means of maximizing energy use and minimizing pollution and waste.

Garton and Christianson (1970) stress the need to evaluate the benefits gained from using waste hot water in agriculture. For example, where warm water irrigation is involved, the value of the contribution due to warm water use over the value of irrigation with water of ambient air temperature requires quantifying in terms of crop value (in dollars). From this position, one can judge how much one can afford to invest in distribution and control systems.

Distribution, irrigation and heating systems must be designed to minimize cost while achieving the desired operational characteristics. Experimentation is needed to find the best methods of supplying water and heat for optimum results. In examples of thermal agriculture systems cited in this report, their economic feasibility and much of their design is dictated by local circumstances such as weather conditions (e.g., wet-bulb temperatures), market proximity, and the range of choice of alternative systems (e.g., Iceland lacks good solid-fuel supplies, and has a poor climate for "open-field" agriculture). Future planning will require more cost-conscious optimization of entire systems. Potential users of waste heat will need to know costs and specific design criteria for their local heat or water distribution systems, and potential suppliers of warm water will require an evaluation of the overall economics of a proposed system (Garton and Christianson, 1970).

CHAPTER 9

MULTIPURPOSE SYSTEMS AND ENVIRONMENTAL PLANNING

A recurrent theme throughout previous chapters has been the development around a power plant of multipurpose systems for total energy usage,[1] which could encompass ranges of heat applications shown in Table 33. These systems maximize efficiency in energy usage and could therefore be included in the logical objectives of long term planning. Burgeoning demands for energy and other resources, and increasing pressure on pollution control may ultimately force this issue. Such systems, however, are somewhat utopian under present social, economic and political situations, which force the implementation of only parts of these systems as stop-gap pollution control measures, e.g., beneficial uses of waste heat to alleviate thermal pollution.[2] The objective is still to maximize electricity production, minimize the cost of each kW (e), and deal somehow with resulting pollution problems, rather than aim at maximum efficiency in total energy usage which would tend to minimize pollution problems, but which also would involve very high initial capital costs in most cases. The emphasis may switch to the latter when pollution control costs become prohibitively high.

Canada could start developing total energy use complexes since new housing and industrial schemes are still being developed in the bush or "old-field" country surrounding urban and mining centres. Advantage should be taken of this situation, as it is cheaper and technologically easier to implement total energy systems in new developments than to modify existing structures. It would, however, be necessary to educate the public so as to accept changes that may include establishment of nuclear power plants near residential areas, or the loss of some conventional forms of space heating and domestic appliances.

When a decision has to be made between two extremes (i.e., cheap electric power as against total energy usage and the conservation of resources), there is generally an accepted compromise. Jaske and Touhill (1970), Jaske (1970) and Jaske et al (1970) have presented one such approach — a canal-lake system, that would simultaneously solve at least three of the major long-range problems in the U.S.A.[3] These are:

i. redirection of megalopolis growth, aiming at a more even geographic distribution of the industrial and population bases whilst retaining the operational flexibility of urban clusters along arterial transport networks, and zones for recreational needs (e.g., greenbelts);
ii. dissipation of heat from energy sources; and
iii. more optimum use of continental water resources.

A brief review of the available avenues by which organized development can take place shows that existing waterways in the U.S. are already highly developed or scheduled for redevelopment to an extent that the availability of land and land zoning requires intensive study. Accordingly, one solution to the dilemmas of rising nuclear station costs, increasing thermal pollution, and increasing opposition to single purpose hydrodevelopment near metropolitan areas, would be the creation of a national system of canals of relatively large size (flows up to 15,000 cfs) which would serve as elongated cooling ponds for the dissipation of condenser heat of large nuplex stations.

Use of the heated water discharged from power plants must be planned at the scale of discharge water flows, which in a 1000 MW thermal station equal 800 to 1200 cfs (360,000 to 580,000 gpm). In a recent study of the dual

1 Examples of total energy systems are described by Miller (1968; 1969; 1970); Boersma (1970); Beall (1970a; 1970b); Nutant (1970); Stewart and Bjornsson (1969); Hodges and Hodge (1971); Staff of E.R.L. (1970); Swidler (1970).

2 Recent Canadian examples would be the Inuvik space-heating scheme and the Point Tupper power-heavy water plant, Nova Scotia, described in M.E.C. (1971).

3 The following is largely taken from Jaske and Touhill (1970).

purpose use of canal cooling for a 100 MW electrical station operated in conjunction with the irrigation of staple crops in Phelps County, Nebraska,[4] the station was found to be too small to materially affect the temperature of the canal system all the way to its extremities. Figure 43 shows the operations of the existing station at 100 MW (e), with the hypothetical addition of two larger stations of 300 and 500 MW (e), in order to explore the additional cooling capacity of the canal. This system, which currently has flows under 100 cfs during the irrigation season, appears to be able to dissipate the heat associated with a considerably larger size power plant in a 30 to 40 mile stretch of the main canal, without producing large changes in soil temperature. The study further suggests that in the United States, the irrigation network systems, the navigation canal systems, and other presently unused waterways may provide untapped cooling potential. The headwater canal of the existing Columbia River irrigation system could support a significant number of 1,000 MW plants, provided that the uncertainties of crop diseases and transmission instances can be resolved.

Figure 44 is a schematic illustration of the basic concept of a canal-lake cooling system, developed on the basis of these supporting studies and the experience of a study of thermal plant siting in the Northwestern U.S. (Battelle-Northwest, 1967). It consists of a series of either natural or artificial waterways covering an extensive distance and providing a central power spine system for redirecting the growth of population centers. The canal system could also supply water for the new cities and industries along the route, and for local transportation and navigation, if desirable. Parks and green belt areas would be an intrinsic part of the development plan. Its principal objective, however, would be to provide an extended heat sink of major proportions that would be away from the currently regulated public water courses. The canal system would be capable of supporting nuplex-sized thermal stations all along its route with the added advantage of reusing the water several times. It is assumed that the opportunities for pumped storage plants along the canal route would be limited only by the electrical requirements. The experience of large systems suggests that 2 kW of peaking capability could be used for every kW of firm in-place thermal capability, assuming that the system would complement existing firm sources of significant size.

Using the COLHEAT simulation model (Jaske and Spurgeon, 1968) for predicting heat sink capacities, Jaske and Touhill (1970) have shown how the canal-lake system could be applied in theory to the Pacific Northwest (Pirkey, 1963). The results are as follows:[5]

i. A total of 30 GW (e), a substantial fraction of the Western firm power requirements through the year 2000, could be sited on the canal system.
ii. The annual evaporation chargeable to the thermal plant system using the canal-lake complex was 30% lower than the annual equivalent in direct cooling tower capacity (452,000 acre-ft vs. 650,000 acre-ft).
iii. The total evaporation of the canal-lake system was substantial (approx. 350,000 acre-ft/month in July), an order of magnitude higher than that required for thermal plants themselves.
iv. There is a threshold size for canal throughput. A substantially larger canal throughput would not increase the base evaporation levels, and smaller systems optimized for thermal cooling canals would suffer relatively large disadvantages from evaporation unless considered as multipurpose for irrigation and land development in arid regions.
v. The development of an extended canal-lake system for cooling thermal effluents is technically feasible, and is also suited to the large flows from thermal plants. Because of the size of these flows, any project using this warmed water is immediately in a large project category. This would provide added justification for planners who think in terms of large water redistribution projects.
vi. The multipurpose use of canal-lake systems as cooling conduits, in conjunction with other uses, appears to offer a considerable advantage in the redirection of metropolitan growth rates along planned lines.

The advantages of the proposed canal-lake system are:[6]

i. Nuclear stations can be located as far from centers of population as desirable.
ii. The large transmission system could parallel and reinforce local grids.
iii. Where impoundments can be made to de-

[4] A study by the Central Nebraska Power and Irrigation Cooperative and Battelle-Northwest.

[5] Jaske and Touhill (1970, p. 125; 129).
[6] Jaske and Touhill (1970, p. 129-130).

crease canal construction costs, the possibility of large nuclear pumped storage peaking stations in conjunction with base load plants could be exploited.

iv. The canal-lake system provides very large heat dissipative capacity without disturbing the surrounding environment of existing population centers.

v. The canal-lake system could be used to supplement irrigation requirements by using and reusing condenser water in transit down the system or to supplement groundwater supplies. It could, however, pollute streams with farm and fertilizer wastes.

vi. The system has possibilities for the use of existing resources (canal, irrigation, and lakes systems), with possible savings in capital costs.

vii. Developing the irrigation potential along the line of the system offers a means of diversifying the economic base and creating new directions of economic expansion away from present population centers. It thereby permits a more rational distribution of resources throughout the country without the concentration of energy releases in metropolitan areas beyond the capacity of the physical environment to absorb the impact.

viii. Impounded portions of the route could offer recreational opportunities.

ix. The water quality of portions of the system can be systematically planned and optimized for industrial, municipal, or recreational purposes without upsetting existing fisheries or related water uses.

x. The opportunity to plan and develop the transmission system from the beginning reduces right-of-way acquisition costs and permits close control of and opportunity for on-site power contracts as a means of relocating industry along the line of the canal.

xi. Instead of assigning the entire cost to agriculture, water redistribution costs can be allocated more broadly and efficiently with apparent immediate benefits to the large group of people participating in various economic and industrial activities along the line of the canal system.

xii. In conjunction with navigation projects, the canal-lake system suggests major extensions of navigation on an all-season basis to areas currently limited by weather or physical access.

There are a number of disadvantages with regards to the canal-lake system which are not covered by Jaske and Touhill (1970). These include:

i. The system is only appropriate, and probably only economic, in particular areas where some form of canal system already exists as an under-used resource, and where there are demands for canals to be used not just as heat-sinks, but also for recreation, irrigation, transportation, etc. This situation may be true in parts of the U.S., but it is doubtful whether it would exist in Canada.

ii. The system requires a certain degree of industrial relocation. There is no evidence, on a cost-benefit basis, that the advantages of the canal-lake system will outweigh the disadvantages that result from relocation.

iii. The use of COLHEAT and similar predictive models is a step in the right direction towards careful water resource management. To implement the findings of such research, as described by Jaske and Touhill (1970), however, would require a drastic alteration of present U.S. land and water uses, and waste disposal laws and policies, which vary between states. Cooperative inter-state planning would be required and new laws, coping with collective, rather than individual waste treatments, would have to be enacted. It is questionable whether the present U.S. politics and the legal constraints would allow this. Perhaps planners should be more realistic and attempt to find alternatives which are viable within the existing political, institutional and socio-economic frameworks.

Despite the drawbacks to the multipurpose canal-lake system, and although the specifics of this particular system may not necessarily be appropriate to the Canadian situation, its principle of reviewing and evaluating the potential of existing resources (i.e., canals) in the light of long range environmental planning is worth considering.

TABLES

% PER ANNUM

	NATIONAL ENERGY BOARD		STATISTICS CANADA		M.E.C. STUDY FORECASTS	
	1966-1975	1975-1990	1966-1969*	1966-1974**	1966-1975	1975-2000
CANADA	6.22	5.65	7.28	7.17	7.17	6.51
ATLANTIC PROVINCES	8.00	6.09	9.15	10.06	10.06	7.02
QUEBEC	5.16	5.00	5.92	5.76	5.76	5.76
PRAIRIE PROVINCES	8.18	6.96	10.72	9.54	9.54	8.02
BRITISH COLUMBIA	6.73	5.70	8.45	6.72	6.72	6.72
YUKON & N.W.T.'S	6.39	6.30	16.10	12.03	12.03	7.26

* Actual
**Firm Intentions

TABLE 1. FORECAST GROWTH RATES OF ELECTRICITY DEMAND

(M.E.C. 1971)

YEAR	HEAT REJECTION	GREAT LAKES	REMAINDER OF CANADA			CANADA		
		Fresh Water	Fresh Water	Tidal Waters [a]	Total	Fresh	Tidal	Total
1970	BTU/Hr. x 10^{10}	3.165 [b]	1.65	1.21	2.86	4.815	1.21	6.025
	Water Loss By Evaporation USgpd x 10^6	69	36	28	64	105	28	133
2000	BTU/Hr. x 10^{10}	60	38.6	38.1	76.7	98.6	38.1	136.7
	Water Loss by Evaporation USgpd x 10^6	1308	846	838	1684	2154	838	2992

(a) 100% of future thermal plants assumed to be Salt Water Cooled in Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick, British Columbia and 50% in Quebec.

(b) 1968 total x 1.3225, assuming 15% annual growth rate for region.

(c) Using ratio $\frac{\text{BTU/Hr}}{\text{USgpd}}$ = 21.8 derived from figures for Remainder of Canada.

TABLE 2. HEAT REJECTION TO COOLING WATER - CANADA

(M.E.C. 1971)

Industrial Process	Heat load absorbed by cooling water	BTUs per
Alcohol	20,000	Gal
Aluminum	31,000	lb
Beer	91,000	bbl
Butadiene	31,000	lb
Cement	150,000	ton
Refined Oil	150,000	bbl
Soap	97,000	ton
Sugar	200,000	ton
Sulphuric Acid	650,000	ton
Cooling Power Equipment:-		
Air Compressors:		
Single stage	380	BHP-h
Single stage with aftercooler	2540	BHP-h
Two-stage with intercooler	1530	BHP-h
Two-stage with intercooler and aftercooler	2550	BHP-h
Diesel engine jacket water and lube oil (incl. dual fuel):		
Four-cycle supercharged	2600	BHP-h
Four-cycle non-supercharged	3000	BHP-h
Two-cycle, crank-case compr.	2000	BHP-h
Two-cycle, pump scaveng (large)	2300	BHP-h
Two-cycle, pump scaveng (high speed)	2100	BHP-h
Natural-gas engines:		
Four-cycle (250 psi compr.)	4500	BHP-h
Two-cycle (250 psi compr.)	3000	BHP-h
Refrigeration		
Compression	250	min-ton
Adsorption	500	min-ton
Steam jet refrig. condenser (100 psi dry steam supply, 2" Hg cond.)	1100	lb of steam
Steam-turbine condenser	1000	lb of steam

TABLE 3. HEAT ABSORBED BY COOLING FOR VARIOUS INDUSTRIAL PROCESSES

(McKELVEY AND BROOKE, 1959)

COOLING DEVICE	GROUND AREA REQUIRED*
1 PONDS	
a) Cooling	1000
b) Spray	50
2 ATMOSPHERIC (Natural Draft)	
a) Spray-filled	15
b) Wood-filled	4
3 CHIMNEY TOWERS (Natural Draft)	
4 CHIMNEY TOWERS (Mechanical Draft)	
a) Forced draught	
b) Induced draught	
i) counter-flow	1.5
ii) cross-flow	1 - 2
5 DRY COOLING	

*Ground area figures all assume the same heat load and are relative to an assumed area of 1000 units required by a cooling pond.

TABLE 4. DEVICES FOR COOLING WATER

(McKELVEY AND BROOKE, 1959)

CONDENSER REQUIREMENTS	CONSUMPTIVE USE		
	ONCE-THROUGH	COOLING PONDS	COOLING TOWERS
1965 40	0.3	0.4	0.5
1980 35	0.2	0.3	0.4
2000 30	0.15	0.25	0.35
2020 25	0.1	0.2	0.3

TABLE 5. ESTIMATED CONDENSER WATER REQUIREMENT AND CONSUMPTIVE USE FOR FOSSIL FUELED STEAM-ELECTRIC POWER-PLANTS IN U.S.A., 1965-2020. (Galls/Kwh)*

(KRENKEL AND PARKER, 1969)
(U.S. WATER RESOURCES COUNCIL, 1968)

(*figures assume a temperature rise of 15°F;
the predicted decrease in unit water requirements
is based on improved technology)

TYPE OF SYSTEM	INVESTMENT COST, $/Kw	
	FOSSIL FUELED PLANT[1]	NUCLEAR FUELED PLANT[1]
Once-through[2]	2-3	3-5
Cooling ponds[3]	4-6	6-9
Wet cooling towers:		
Mechanical draught	5-8	8-11
Natural draught	6-9	9-13
Dry cooling towers	17-21	25-32

[1]Based on unit sizes of 600 MWe or greater

[2]Circulation from lake, steam or sea, involving no investment in pond or reservoir

[3]Based on pond able to handle 1200-2000 MWe of generating capacity

TABLE 6. COMPARATIVE INVESTMENT COSTS OF COOLING WATER SYSTEMS FOR STEAM-ELECTRIC PLANTS

(INDUSTRIAL WATER ENGINEERING, MAY, 1970)
(FOELL AND BENEDICT, 1970)

TYPE OF TOWER	APPROXIMATE CAPITAL COST Millions $
Wet, mechanical draught	5-8
Wet, natural draught	6-11
Dry, mechanical draught	25-28
Dry, natural draught	25-30

TABLE 7. CAPITAL COST OF COOLING TOWERS

(BREGMAN, 1971)

COOLING SYSTEM	CAPITAL COST ($/KW of plant capacity)
Run-of-river cooling system	5
Bay-lake cooling system	6
Natural-draught cooling tower; run-of-river make-up	7.5
Cooling-pond system	10
Natural-draught cooling towers; reservoir make-up	11
Dry-cooling towers	22

TABLE 8. COMPARATIVE COST ESTIMATES FOR SIX TYPES OF COOLING SYSTEMS

(SHADE AND SMITH, 1969)
(LOF AND WARD, 1970b)

	ONCE THROUGH COOLING	RECIRCULATED COOLING	% INCREASE
65% capacity factor:			
Capital costs	2.295	2.421	5.5
Operation and maintenance	0.295	0.311	5.5
Fuel at 25¢ per mBtu	2.104	2.127	1.1
TOTAL	4.694	4.859	3.5
80% capacity factor:			
Capital costs	1.865	1.968	5.5
Operation and maintenance	0.261	0.275	5.4
Fuel at 25¢ per mBtu	2.104	2.127	1.1
TOTAL	4.230	4.370	3.3

Size of generation unit: 1,000 megawatts

Cooling water requirements - once-through: 400,000 gallons per min.

New water (make-up) for recirculated cooling: 10,000 gallons per min.

TABLE 9. ENERGY COSTS FROM NEW COAL-FUELED POWER PLANTS (Mills/Kwh)

(Jackson and Moreland, 1966; Kreese, Ayres and d'Arge, 1970)

Date	RIVERSIDE REACH				HIGHBRIDGE REACH			
	Observed Area KM^2	LENGTH (KM)			Observed Area KM^2	LENGTH (KM)		
		Observed*	Russian Winter Equation	Kohler Equation		Observed	Russian Winter Equation	Kohler Equation
Jan. 20'65	2.169	12.0	17.9	26.6	4.597	40.0	42.6	62.5
29'65	0.777	4.3	4.3	7.0	0.882	7.8	11.8	18.6
Feb. 4'65	0.890	4.9	5.8	10.0	1.036	9.0	15.1	25.6
Jan. 11'66	----	----	----	----	2.428	21.2	15.7	21.8
14'66	2.023	11.3	16.0	28.9	4.233	36.8	41.3	73.2
24'66	1.311	7.3	3.2	5.8	1.546	13.4	12.1	21.2
28'66	1.287	7.2	3.5	5.3	1.076	9.4	10.4	13.8
Feb. 23'66	2.161	12.0	17.1	60.8	5.063	44.0	39.5	124.6

* Because the open water-ice boundary, observed from aerial photographs, is usually quite irregular, the area of open water was converted to an effective length by dividing it by a representative width of the river.

TABLE 10. OBSERVED AND CALCULATED VALUES FOR ICE-FREE REACHES BELOW THERMAL POLLUTION SITES ALONG THE MISSISSIPPI RIVER, MINNEAPOLIS - ST.PAUL, MINNESOTA. (DINGMAN ET AL, 1968)

MONTREAL-LAKE ONTARIO	1959	1960	1961	(1)1962	1963	1964
(5)Traffic (figures in thousands)	20,600.0	20,300.0	23,400.0			
Total cargo tonnage				25,593.6	30,942.9	39,309.0
Total vessel transits				6.3	6.3	6.8
Average gross tonnage, per transit				4.9	5.6	6.0
Average cargo tonnage per vessel transit				4.0	4.9	5.8
Finance (in millions of $)						
Toll revenue				$ 8.9	$10.7	$13.5
Other revenue				.3	.6	.6
Total revenue				9.2	11.3	14.1
Expenses				3.7	4.1	4.1
Net operating profit				5.5	7.2	10.0
Interest				13.9	14.8	15.5
Loss for the year				8.4	7.6	5.5
Accumulated losses				25.2	32.8	38.3
Total debt at end of year				(2)337.5	357.1	363.3

WELLAND	1959	1960	1961	1962	1963	1964
(5)Traffic (figures in thousands)	27,500.0	29,200.0	31,500.0			
Total cargo tonnage				35,406.3	41,303.5	51,388.5
Total vessel transits				7.6	7.6	8.3
Average gross tonnage, per transit				5.7	6.3	6.6
Average cargo tonnage, per vessel transit				4.6	5.4	6.2
Finance (in millions of $)						
Toll or lockage charge revenue				(3) $ .6	$ --	$ --
Other revenue				.8	.8	.9
Total revenue				1.4	.8	.9
Expenses				4.4	4.9	6.3
Net operating loss				3.0	4.1	5.4
Interest				1.8	2.1	2.6
Loss for the year				(4) 4.8	6.2	8.0
Capital debt at year end				33.0	40.0	43.6

(1) Annual figures incorporate all subsequent retroactive adjustments.
(2) Debt equals borrowings plus deferred interest.
(3) Welland Canal tolls were suspended on July 18th, 1962.
A lockage charge was introduced in 1967.
(4) Covered by Parliamentary appropriations.
(5) Cargo traffic (in thousands of short tons).

TABLE 11. ST.LAWRENCE SEAWAY STATISTICAL SUMMARY

(ST.LAWRENCE SEAWAY AUTHORITY, ANNUAL REPORT,1971)

(Continued next page....)

(cont'd)

1965	1966	1967	1968	1969	1970	1971
43,382.9	49,249.3	44,028.6	47,953.8	41,014.0	51,170.9	52,987.4
7.3	7.3	6.9	6.6	6.4	6.3	6.1
6.1	6.8	6.7	7.3	6.7	7.2	8.2
5.9	6.7	6.4	7.3	6.4	8.1	8.7
$15.5	$17.3	$16.4	$18.1	$15.6	$18.6	$20.0
.6	1.0	.9	1.2	1.2	1.3	2.2
16.1	18.3	17.3	19.3	16.8	19.9	22.2
4.4	5.2	6.0	6.7	7.6	8.5	10.5
11.7	13.1	11.3	12.6	9.2	11.4	11.7
15.8	16.4	16.7	17.2	17.8	18.8	19.8
4.1	3.3	5.4	4.6	8.6	7.4	8.1
42.4	45.7	51.1	55.7	64.3	71.7	79.7
371.3	375.8	384.2	390.6	399.0	409.3	419.0

1965	1966	1967	1968	1969	1970	1971
53,420.2	59,271.7	52,809.4	58,074.7	53,532.2	62,962.8	63,058.2
8.4	8.7	7.4	7.2	6.9	7.1	6.9
6.8	7.3	7.4	8.2	8.4	8.8	9.4
6.4	6.8	7.1	8.1	7.8	8.8	9.2
$ --	$ --	$ .9	$ 1.8	$ 2.5	$ 3.5	$ 4.3
.8	1.1	1.2	.9	1.1	1.2	1.3
.8	1.1	2.1	2.7	3.6	4.7	5.6
8.9	11.2	10.3	11.0	10.7	11.9	12.5
8.1	10.1	8.2	8.3	7.1	7.2	6.9
.1	--	--	.7	.8	1.0	2.0
8.2	10.1	8.2	9.0	7.9	8.2	8.9
53.6	80.2	98.1	121.2	147.3	185.0	237.2

TABLE 11. ST.LAWRENCE SEAWAY STATISTICAL SUMMARY

(ST.LAWRENCE SEAWAY AUTHORITY, ANNUAL REPORT, 1971)

MONTREAL-LAKE ONTARIO SECTION	1971	1970	VARIATION
Income	$ 22,188,382	$ 19,956,995	+$ 2,231,387
Operating expenses and replacement provision	10,509,440	8,523,094	+ 1,986,346
Net operating income	11,678,942	11,433,901	+ 245,041
Deduct interest on loans	19,769,491	18,803,280	+ 966,211
Net loss for the year	$(8,090,549)	$(7,369,379)	+$(721,170)
WELLAND SECTION			
Income	$ 5,603,153	$ 4,743,038	+$ 860,115
Operating expenses	12,543,369	11,883,828	+ 659,541
Net operating loss	(6,940,216)	(7,140,790)	- (200,574)
Add interest on loans	2,011,137	1,024,326	+ 986,811
Net loss for the year	$(8,951,353)	$(8,165,116)	+$(786,237)
COMBINED RESULTS			
Income	$ 27,791,535	$ 24,700,033	+$ 3,091,502
Operating expenses and replacement provision	23,052,809	20,406,922	+ 2,645,887
Net operating income	4,738,726	4,293,111	+ 445,615
Deduct interest on loans	21,780,628	19,827,606	+ 1,953,022
Net loss for the year	$(17,041,902)	$(15,534,495)	+$(1,507,407)

TABLE 12 FINANCIAL REVIEW OF ST.LAWRENCE SEAWAY OPERATIONS

(source: ST.LAWRENCE SEAWAY AUTHORITY, ANNUAL REPORT, 1971)

Trout	1.5	Poultry	2.1
Carp	2.0	Pig	2.4
Channel catfish	1.3	Beef cattle	8.0

TABLE 13. ANIMAL FOOD CONVERSION RATES

(given in lbs of feed/lb of edible flesh gained)

Source	Pounds of BOD
1 Ton of beans processed	20-90
1 Ton of potatoes processed	125
1 Ton of corn processed	25-60
1 person	0.20/day

TABLE 14. RATES OF WASTE PRODUCTION BY SEVERAL SOURCES IN POUNDS OF BOD (BOERSMA, 1970)

PRICE PER POUND $		ANNUAL RETURNS PER ACRE ($) AT GIVEN PRODUCTION RATES (Tons/Acre)			
		15	20	25	30
0.05		1,500.0	2,000.0	2,500.0	3,000.0
0.06		1,800.0	2,400.0	3,000.0	3,600.0
0.07		2,100.0	2,800.0	3,500.0	4,200.0
0.08		2,400.0	3,200.0	4,000.0	4,800.0

TABLE 15. POSSIBLE ANNUAL RETURNS PER ACRE OF ALGAE PRODUCTION

(BOERSMA, 1970)

Population of city	1 million
Water supply	150 million gallons/day (mgd)
Waste supply	100 mgd
Natural water cost	10¢/1000 gal.
Natural water salinity	0-500 ppm TDS (tot. dissolved solids)
Desired salinity, supply	≤ 500 ppm
Increase in salinity of waste over supply	250 ppm
Cost of primary treatment	2¢/1000 gal.
Cost of disposal of primary sludge	1¢/1000 gal.
Cost of primary plus secondary treatment	4¢/1000 gal.
Cost of disposal of primary-secondary sludge	2¢/1000 gal.
Cost of pumping and storage of reclaimed waste water	4¢/1000 gal.

TABLE 16. TECHNICAL AND ECONOMIC ASSUMPTIONS FOR WATER SYSTEMS STUDY

(BEALL, 1970a, 1970b)

Undesirable component	Assumed method of removal	Range of cost ¢/lb removed
Suspended Solids[a]	Sedimentation	2.0
Organic matter[b] (as BOD)	Biological oxidation	2.0
Total dissolved salts[c] (including hardness)	Multieffect evaporation and solar evaporation	3.5
Alkalinity (as $CaCO_3$)[d]	Acid addition	2.0

NOTES:
(a) Primary treatment at 2.5¢/1000 gal with 200 ppm removal and sludge disposal at 0.5¢/lb.
(b) Secondary treatment at 5¢/1000 gal with 400 ppm removal and sludge disposal at 1¢/lb.
(c) Feed at 3500 ppm, hardness 250 ppm. One MG plant with total costs at $1.00/1000 gal and no credit for product water produced.
(d) Total cost at two times chemical cost. Sulfuric acid at 1¢/lb.

TABLE 17. WATER TREATMENT COSTS

(REY ET AL, 1971)

USE	1965		1980	
	ALL HEAT	ELECTRICITY	ALL HEAT	ELECTRICITY
Residential	9,014		13,587	
Commercial	2,992		7,396	
Industrial	17,803*		31,591*	
TOTAL	29,809	3,238	52,574	7,991
Ratio of heat to electricity	9 : 1		6.5 : 1	

TABLE 18. COMPARISON OF TOTAL ELECTRICAL AND HEAT REQUIREMENTS IN U.S.A. (Trillion BTU)

(BEALL, 1970b)

* The low-temperature users (food, textile, lumber, chemicals, rubber, machinery) consume 20% of this total; the high-temperature users (primary metals, storeware) also consume 20%. Paper, petroleum, consume 15% but mostly supply their own; remaining 45% is various small users.

YEAR STARTED	LOCATION	INHABITANTS	WATER TEMPERATURE °C
1943	Reykjavík	72,000	80-128
1948	Selfoss	2,200	80
1953	Hveragerdi	820	180
1955	Saudarkrokur	2,000	70
1964	Ólafsfjordur	1,000	56
1969	Dalvík	1,000	60
1970	Húsavík	2,000	90

TABLE 19. ICELANDIC GEOTHERMAL HEATING SYSTEMS SERVING MORE THAN 200 INHABITANTS

(MATTHIASSON, 1970)

FACTOR		% OF TOTAL CAPITAL INVESTMENT COST (REYKJAVÍK)
Heat Production or Collection System		33
Energy Distribution System (+ land purchase costs)		67
Maintenance		not included

TABLE 20. CAPITAL INVESTMENT COSTS

(ZOEGA ET AL,1970; MATTHIASSON,1970; COOK,1971)

FACTOR		% OF FINAL COST
Energy Production at Source		21
Main Pipeline		12
Storage		4
Distribution		63
Final Cost to Consumer		100

TABLE 21. COMPUTATION OF ENERGY PRICE TO CONSUMER[a] IN REYKJAVIK

(PALMASON ET AL,1970;MATTHIASSON,1970;COOK,1971)

[a] This does not include any high profit margin considerations

No Additional CO_2

Variety	No. 1 # Fruits	No. 1 Yield (kg.)	No. 2 # Fruits	No. 2 Yield (kg.)	Cull # Fruits	Cull Yield (kg.)
Cherokee 7	162,552	51,164	31,200	6,258	17,784	3,083
Best seller	160,368	85,530	54,912	22,040	30,576	5,169

CO_2 Enrichment

Variety	No. 1 # Fruits	No. 1 Yield (kg.)	No. 2 # Fruits	No. 2 Yield (kg.)	Cull # Fruits	Cull Yield (kg.)
Cherokee 7	180,024	49,431	39,000	7,437	24,960	3,718
Best seller	221,832	116,730	70,200	30,293	26,316	8,072

TABLE 22. COMPARATIVE YIELDS FROM TWO VARIETIES OF CUCUMBER WITH OR WITHOUT CARBON DIOXIDE ENRICHMENT AT PUERTO PEÑASCO, MEXICO, WINTER 1969-70*

(HODGES ET AL, 1970)

* Plant grown at a spacing of 25,000 plants per hectare.
Last harvest: 12 March 1970.

Puerto Peñasco Greenhouses		Comparative Data for U. S. (Acres)		
Kind of Vegetable	Marketable Yield/Ac	Approx. Av. Yield from Greenhouses	Approx. Av. Yield Outdoors	Good Yield Outdoors
Carrots	800 bu @50 lb	--	390 bu*	600* bu
Cucumber (European type)				
Winter crop	3,000 bu @48 lb	--	155 bu*	500* bu
Eggplant				
Winter crop	760 bu	--	300 bu*	500* bu
Spring crop	2,500 bu*** @33 lb		300 bu*	500* bu
Lettuce				
Bibb & Leaf				
Winter crop	3,500 ctn @2 doz	3,500 ctn	360 ctn*	600 ctn*
Okra				
Winter crop	40 ton	--	--	5 ton*
Peppers				
Chili	640 bu @25 lb	--	--	--
Bell				
Winter crop	1,200 bu @25 lb	--	245 bu*	500 bu*
Radish				
Winter crop	40,000 bnch @12/bnch	40,000 bnch	--	20,000 bnch*
Squash				
Zucchini				
Winter crop	555 bu	--	--	400 bu*
Spring crop	2,000 bu*** @45 lb	--	--	400 bu*
Tomato				
Winter crop	46 ton	40 ton**	10 ton	30 ton
Spring crop	65 ton	60 ton**	10 ton	30 ton
Watermelon	5.5 ton	--	3.5 ton	6.5 ton

*From: Knot, James E., 1957. Handbook for Vegetable Growers, John Wiley & Sons, Inc., New York.

**Based on a harvest period of 90 days.

***Increased yields due to a change in variety and plant spacing.

TABLE 23. VEGETABLE CROPS GROWN IN GREENHOUSES AT PUERTO PEÑASCO, SONORA, MEXICO. (1968-1969)

(JENSEN & HODGES, 1969; JENSEN & TERAN, 1971)

	Puerto Peñasco Greenhouses	U.S. Field Crops
Cucumber (European type)		
Fall Crop	355,680	9,992[1]
Spring Crop	392,864*	
Eggplant		
Fall Crop	148,200*	16,055[1]
Spring Crop	148,200*	
Okra		
Winter Crop	89,611	11,201[2]
Pepper (Bell)		
Winter Crop	33,681	10,441[1]
Tomato		
Fall Crop	168,021*	15,269[1]
Spring Crop	145,618	

*Based on a harvest period of 90 days.

[1]United States Department of Agriculture, *Agricultural Statistics 1969* - (data for fresh market).

[2]Knott, James E., 1962, *Handbook for Vegetable Growers*, John Wiley and Sons, Inc., New York.

TABLE 24. SOME YIELDS FROM CONTROLLED ENVIRONMENTS IN PUERTO PEÑASCO (1969-1970), COMPARED WITH AVERAGE YIELDS FROM FIELD CROPS IN THE U.S., IN KILOGRAMS/HECTARE

(HODGES ET AL, 1970)

Puerto Peñasco Greenhouses			Comparative Data for U.S.			
			Field Crops		Greenhouses	
Kind of Vegetable	Growing Period	Harvest Period	Growing Period	Harvest Period	Growing Period	Harvest Period
Carrots	70	--	70	--	--	--
Cucumber	100	60*	90	30	--	--
Eggplant	130	50	130	40	--	--
Lettuce (Bibb and Leaf types)	40	--	70	10	--	--
Okra	100	60	118	60	--	--
Peppers Bell	146	41	155	55	--	--
Chili	146	41	--	--	--	--
Radish	30	--	30	--	--	--
Squash (Zucchini)	105	60	80	30	--	--
Tomato	140	60	140	50	190	90
Watermelon	125	45	120	30	--	--

NOTE: Growing periods and harvest periods depend greatly on local conditions. Above field yields are based on summer data. Harvest period - growing period = no. of days to first harvest.

*European type

TABLE 25. GROWING AND HARVEST PERIODS IN DAYS

WINTER CROPS GROWN IN GREENHOUSES AT PUERTO PEÑASCO, SONORA, MEXICO. (1968-1969)

(JENSEN & HODGES, 1969; JENSEN & TERAN, 1971)

	Puerto Peñasco Greenhouses		U.S. Field Crops	
	Growing Period	Harvest Period	Growing Period	Harvest Period
Cucumber (European type)	130	90	90	30
Eggplant	170	90	130	40
Lettuce (Bibb and Leaf types)	40	--	45	--
Okra	100	60	118	60
Pepper (Bell)	146	41	155	55
Radish	30	--	30	--
Squash (Zucchini)	135	90	80	30
Tomato	170	90	140	50

NOTE: Harvest period - growing period = number of days to first harvest. Growing periods and harvest periods depend greatly on local conditions.

TABLE 26. GROWING AND HARVEST PERIODS FOR SOME WINTER CROPS GROWN IN CONTROLLED ENVIRONMENTS AT PUERTO PEÑASCO (1969-1970), COMPARED WITH AVERAGE FOR SUMMER FIELD CROPS IN U.S., IN DAYS

(HODGES ET AL, 1970)

Item	Total cost	Cost per ft^2
Total Area = 4,600 ft^2		
Concrete		
Entry		
10.7 yd @ \$25.00/yd^3	\$ 267.50	\$0.0581
Packed Column & fans		
6.9 yd @ \$25.00/yd^3	172.50	0.0375
Curbs		
16.5 yd @ \$25.00/yd^3	412.50	0.0896
Concrete sub total	\$ 852.50	\$0.185 [a]
Curbing (wood)		
500 ft @ \$0.33/ft	165.00	0.0358
Anchor bolts		
125 @ \$0.20 each	25.00	0.0054
Airlock Doors & hardware		
\$12.20 each	48.00	0.0104
Asbesdek		
Transfer area		
100 ft^3 @ \$2.75/ft^3	275.00	0.0597
Fans		
Two 3/4 hp circulation fans		
@ \$155.00 each	310.00	0.0673
Inflation Blowers		
2 @ 1/3 and 1.0 hp	250.00	0.0543
Electrical Hook up		
Estimate	300.00	0.0652
Plumbing		
Estimate	200.00	0.0434
Miscellaneous		
Wood Wedge, Nails, Paint	50.00	0.0108
Other	200.00	0.0434
	\$2,675.50	\$0.5800[b]

[a]This assumes an installed cost of \$25.00/yd^3. Material costs for Puerto Penasco (per yd^3) are \$11.50 (sand = 0; aggregate = \$1.50; cement = \$10.00).

[b]This figure does not include the water supply for the environmental control or the horticultural equipment; nor does it include the plastic covers, which are an operational expense.

TABLE 27. COST ESTIMATE, PUERTO PENASCO GREENHOUSE No2.

(HODGES & HODGE, 1971)

Item	Production cost for 10 acre unit - Production equals 2,000,000 lb.)	
	Per year	Per pound
Salaries and Wages		
Manager	$ 15,000	$0.0075
Horticulturist	12,000	0.0060
Foreman	8,000	0.0040
Sec. & Bookkeeper	4,000	0.0020
Greenhouse Labor 4 men per acre = 40 men @ $5.00 per day	73,000	0.0360
Packing & Marketing 3 men per acre = 30 men @ $5.00 per day	54,750	0.0270
Ins., Ret., Etc. @ 6%	12,344	0.0060
	$179,094	$0.0895
Operation		
Power Assume 25 KW/acre requirement 250 KW/10 acres 2 x 10^6 kwh/year @ $0.02/kwh	40,000	0.0200
Water Assume 1,000 gal/acre/day avg 10,000 gal per day @ $3.00/1,000 gal	10,950	0.0055
Maintenance @ 2,000 acre/year	10,000	0.0050
Seed & fertilizer	7,000	0.0035
Miscellaneous @ 10%	6,795	0.0034
Plastic film @ $0.04/ft^2	17,424	0.0087
	92,169	0.0460
Depreciation Assume $1.20/ft^2 capital investment for greenhouses[b] or $522,720. @ 15% amortization per year	78,408	0.038
Grand Total	$349,671	$0.198

[a]Assumes, (1) Conservative production, (2) intensive labor requirements, and (3) high labor cost (twice present).

[b]Amortization of capital investment in power and desalting plants accounted for in power and water operation.

TABLE 28. ABU DHABI PROGRAM:
PRELIMINARY ECONOMIC PROJECTIONS FOR GREENHOUSE[a]
(HODGES & HODGE, 1971)

Animal	Temperature °C	°F	Lbs. Feed/lb Weight Grain	Feed Efficiency (%)
Chickens	24	75	2.7	39
(from: Howes, Grub (1962)	30	86	2.1	48
Barott and Pringle (1949))	34	92	1.9	52
Hogs				
(from Sorensen (1962))				
Individual Hog	3	37	5.9	17
Group	3	37	4.3	23
Group	8	46	3.8	27
Group	15-23	59-73	3.4	29
Milk Cows (Jersey)	-13	9	2.0	48
(from H.D. Johnson (1965))	10	50	0.65	128
	38	100	0.55	180

TABLE 29. EFFECT OF TEMPERATURE ON FEED CONVERSION FOR SOME TYPICAL FARM ANIMALS

(BEALL, 1970a)

Crop	Days/ Crop	Yield[a] Crop-Acre	Crops/ Year	Yield/Acre-Year	Wholesale Value[b]/ Acre/Year	Acres Assigned	Total Income
Cucumber	100	144,000 lb.	3.6	518,000 lb.	$41,440 at 8¢/lb.	50	$ 2,072,000
Eggplant	130	24,000 lb.	2.7	67,500 lb.	$10,100 at 15¢/lb.	50	505,000
Lettuce (leaf)	40	84,000 heads	9	756,000 heads	$37,800 at 5¢/head	100	3,780,000
Bell Peppers	146	30,000 lb.	2.5	75,000 lb.	$18,750 at 25¢/lb.	50	937,500
Radishes	30	480,000 bunches	12	5,760,000 bunches	$288,000 at 5¢/bunch	5	1,440,000
Squash	105	22,200	3.6	80,000 lb.	$12,000 at 15¢/lb.	50	600,000
Tomatoes	140	92,200	2.5	230,000	$23,000 at 10¢/lb.	100	2,300,000
Flowers	180	40,000 plants	2	80,000	$20,000 at 25¢/plant	50	1,000,000
Strawberries	180	40,000 lb.	2	80,000	$20,000 at 25¢/lb.	50	1,000,000
						505	13,634,000
					Projected Average Income:		$27,230/acre

[a]Winter Season, Puerto Penasco Experimental Station, Sonora, Mexico.
[b]1966 Wholesale prices, mostly from U.S.D.A. Yearbook for 1967

TABLE 30. POSSIBLE MIX OF CROPS FOR CONTROLLED ENVIRONMENT GREENHOUSE COMPLEX (500 acre range)

(BEALL, 1970b)

Soil warming system	
Soil warming loop	$13,000,000.00
Open canal	1,000,000.00
Land ($1,500.00/ha)	3,000,000.00
Irrigation system	1,000,000.00
Total	$18,000,000.00
Evaporative cooling system	
a. Intensive system	
Cooling basins	$10,000,000.00
Cooling coils	2,000,000.00
Total	$12,000,000.00
b. Extensive system	
Cooling basins	$ 4,000,000.00
Cooling coils	2,000,000.00
Total	$ 6,000,000.00

TABLE 31. TOTAL COSTS OF BOERSMA'S AGRICULTURAL FACILITY

(BOERSMA, 1970)

Soil Warming system	
Soil warming loop	$1,145,400.00
Open canal	88,100.00
Land	264,300.00
Irrigation system	88,100.00
Sub Total	$1,585,900.00
Property Tax (2%)	360,000.00
Operation of the system	240,000.00
Total	$2,185,900.00
Evaporative cooling system	
a. Intensive system	
Cooling basins	881,000.00
Cooling coils	176,200.00
Sub Total	$1,057,200.00
Property Tax (2%)	240,000.00
Operation (included above)	--------
Total	$1,297,200.00
b. Extensive system	
Cooling basins	352,400.00
Cooling coils	176,200.00
Sub Total	$ 528,000.00
Property Tax (25)	120,000.00
Total	$ 648,600.00

TABLE 32. ANNUAL COSTS OF BOERSMA'S AGRICULTURAL FACILITY

(BOERSMA, 1970)

The annual cost is calculated on the basis of a 30-year mortgage period and an 8 per cent interest rate (annuity $88.10/$1,000.00)

Application	Particular Use	Approximate Quantity of Product with Heat
Central heating	Steam and hot water for residential, commercial, and industrial heating	For a city of 500,000-1,000,000 people
Central cooling	Evaporative cooling for residential and commercial needs	For a city of 500,000-1,000,000 people
Manufacturing	Electricity and heat for (typical mix)	
	Evap. salt	2775 tons/day
	Petrochemicals	60,000 barrels/day
	Arc process acetylene	220 tons/day
	Polyvinyl chloride	500 tons/day
	Sodium hydroxide	1695 tons/day
	Kraft paper	500 tons/day
Desalination for Municipal Water	Waste water recycling	To 600 x 10^6 gal/day
	Brackish water distillation	To 600 x 10^6 gal/day
	Seawater distillation	To 600 x 10^6 gal/day
Agriculture	Arid land irrigation with distilled water	To 600 x 10^6 gal/day (320,000 acres)
	Arid land irrigation with condenser-discharge water	To 1000 x 10^6 gal/day (200,000 acres)
	Greenhouse heating and cooling	To 1000 acres
	Poultry house heating and cooling	To 1000 acres
Transportation	Stored steam for buses and trucks	120 lb water per bus mile
	Ice-free shipping lanes	10 to 20 miles ice-free water
Aquaculture	Warm water and sewage for culture:	
	Shellfish	Unknown
	Crustaceans	2,000,000 lb/yr (1000 acres)
	Fish	9,500,000 lb/yr (1900 acres)
	Algae	45 x 10^6 lb/yr
Miscellaneous	Outdoor heating	To 40 x 10^6 ft^2
	Snowmelting	To 40 x 10^6 ft^2

TABLE 33. ENERGY CENTER HEAT APPLICATIONS (2000 to 4000 Mw 'thermal') (BEALL, 1970a; 1970b)

FIGURES

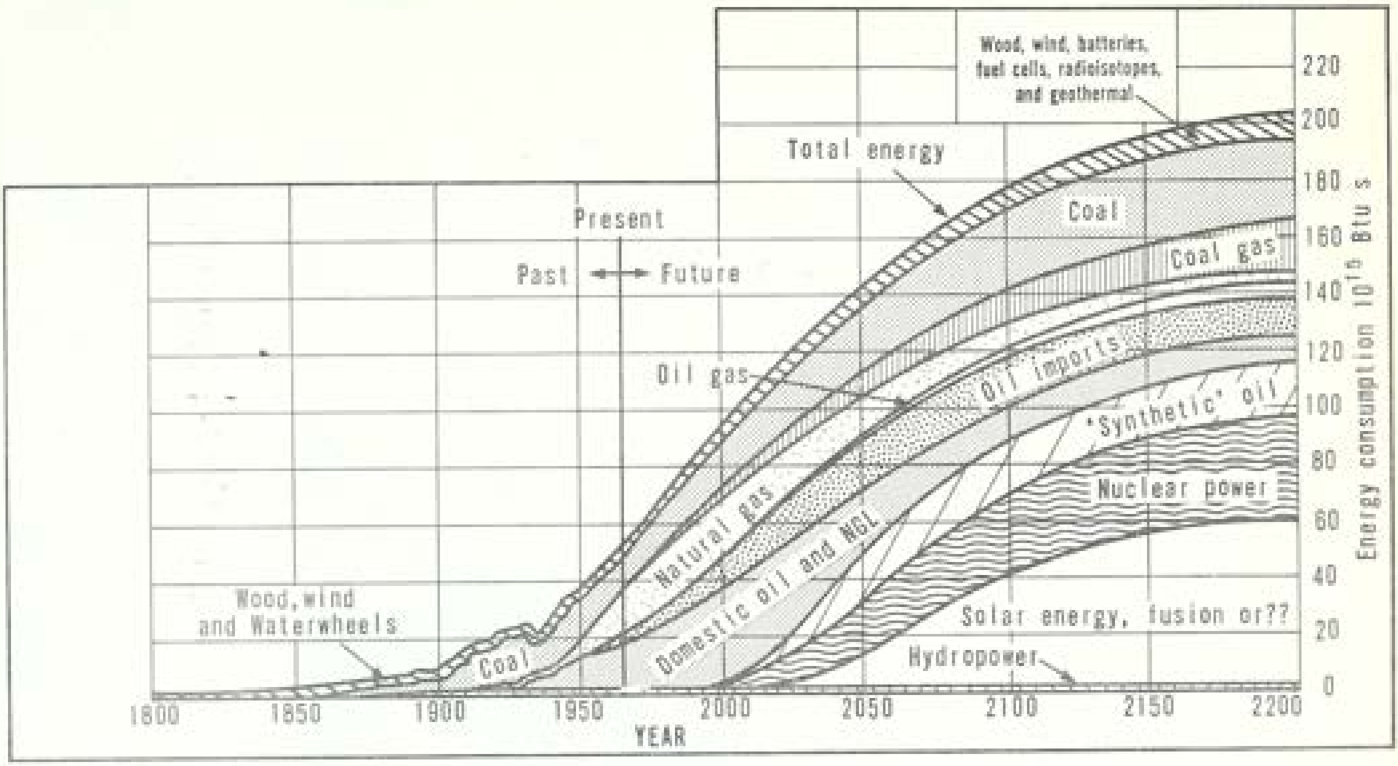


FIGURE 1. ENERGY CONSUMPTION TRENDS IN THE UNITED STATES IN DETAIL

(Gaucher, 1971)

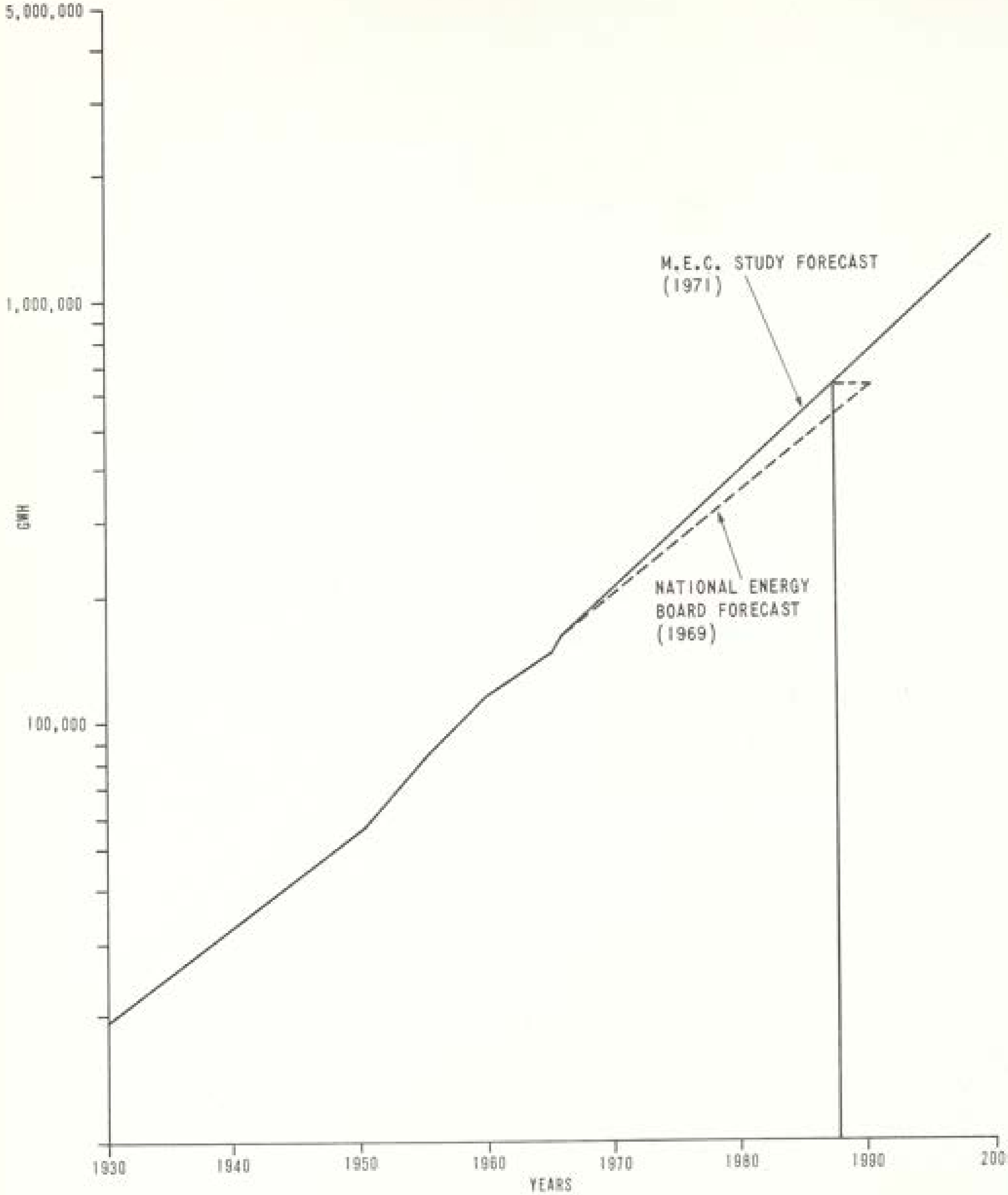


FIGURE 2. REQUIRED ELECTRICITY GENERATION - CANADA

(M.E.C.1971)

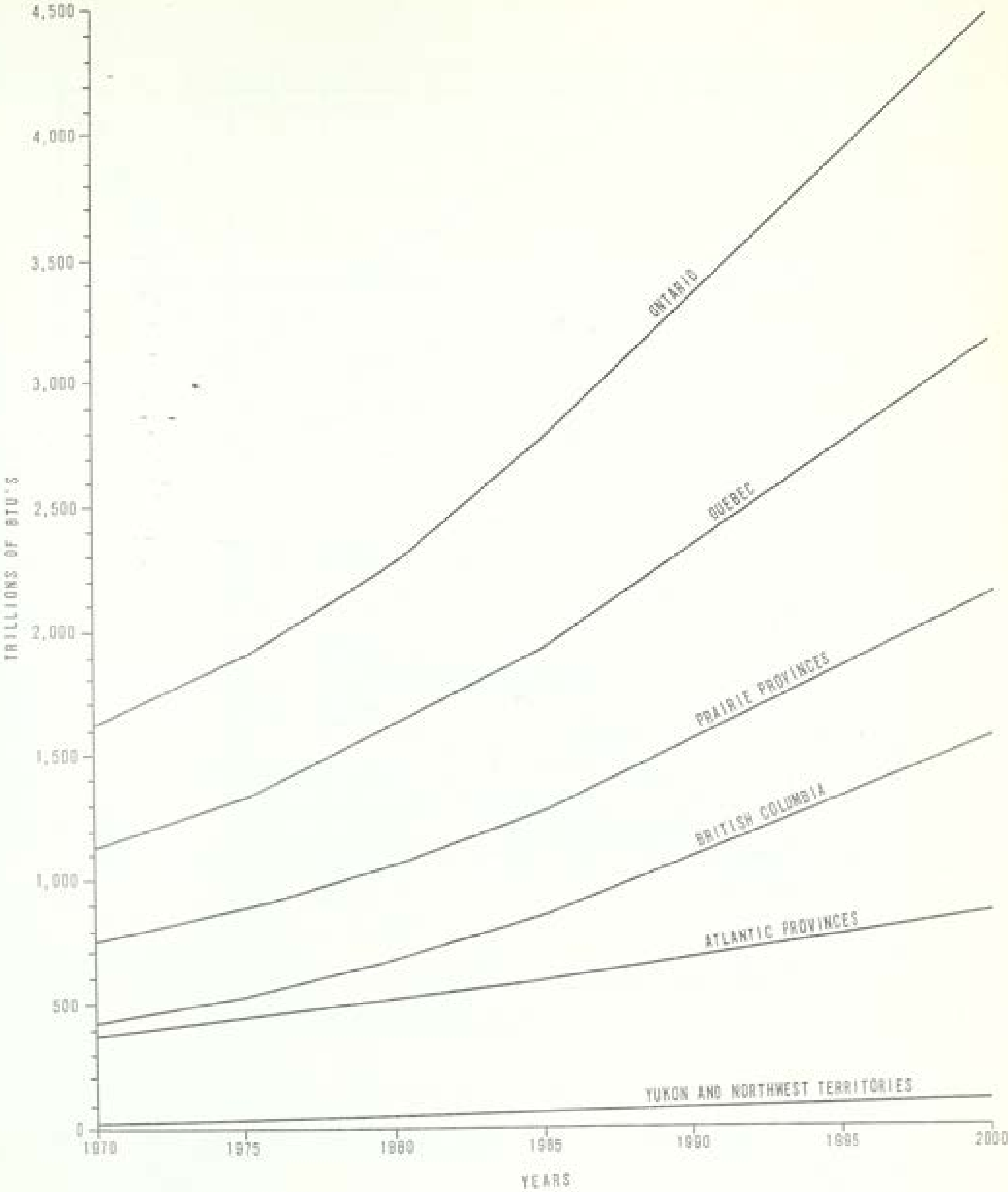


FIGURE 3. TOTAL ENERGY DEMAND BY REGION, 1970 to2000

TRILLIONS OF BTU'S (M.E.C.1971)

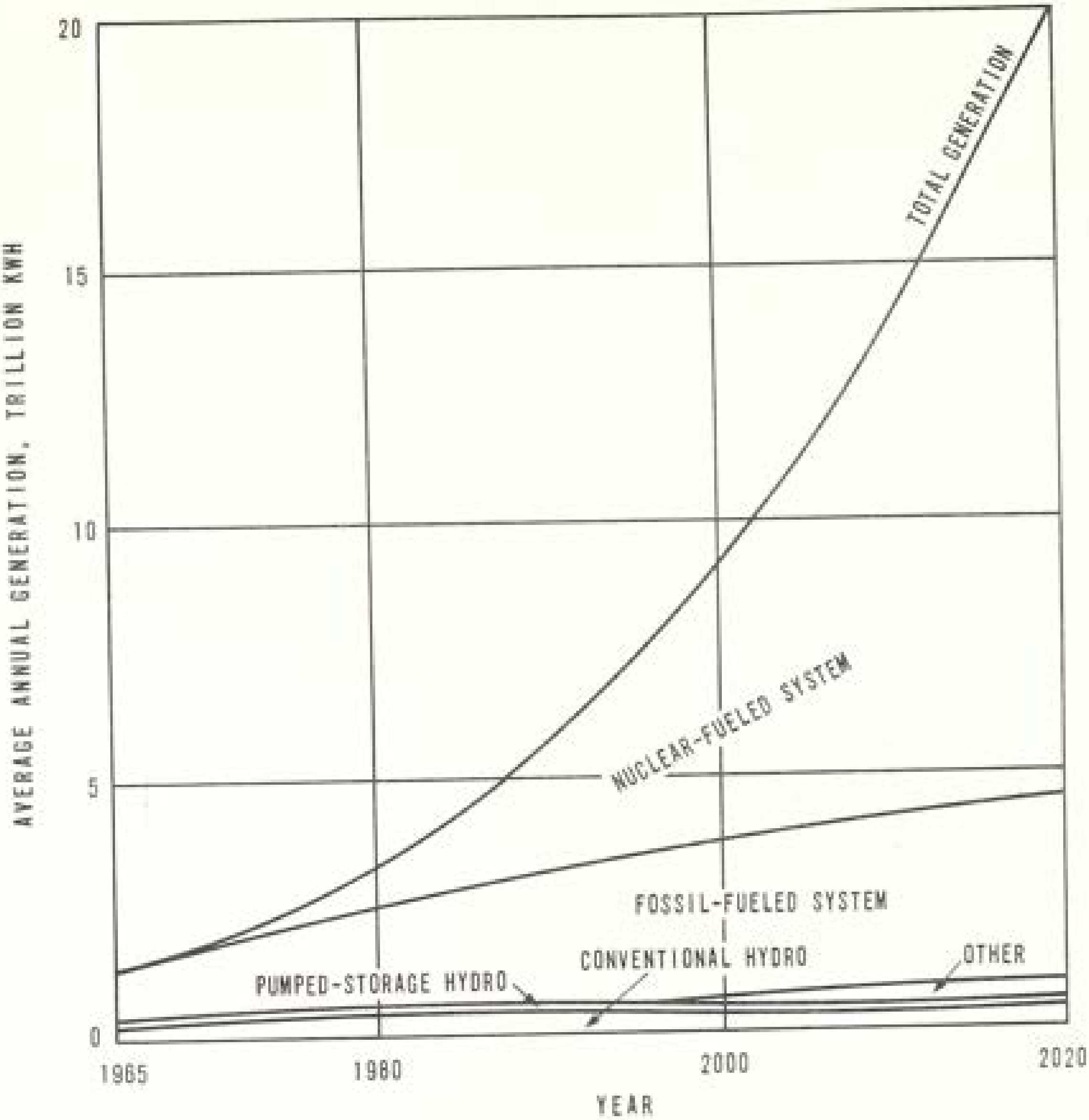


FIGURE 4. PROJECTED ELECTRIC GENERATION BY TYPES OF PRIME MOVER IN THE U.S.A.

(PARKER & KRENKEL, 1970)

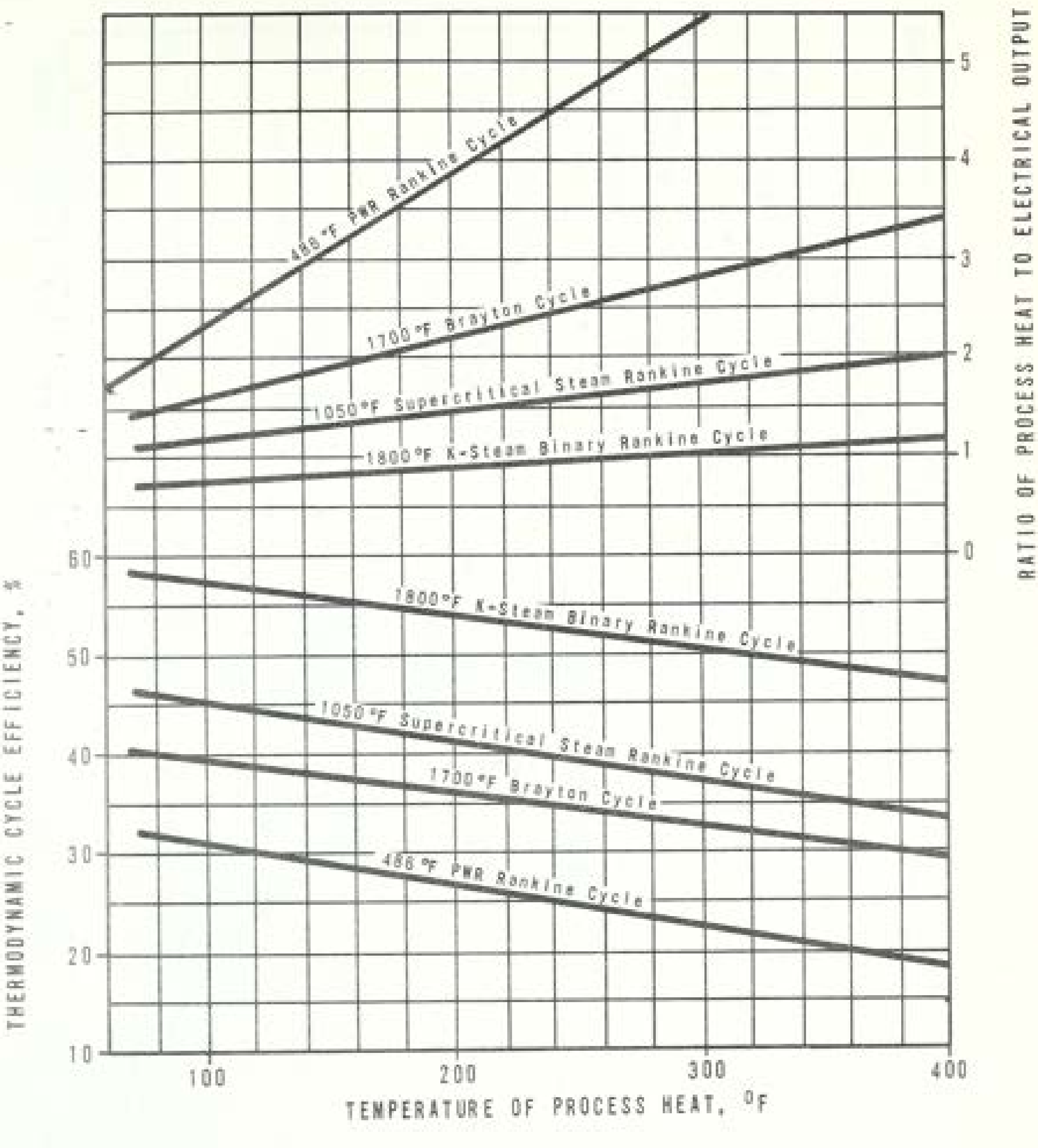


FIGURE 5. PROCESS HEAT-POWER PLANT EFFICIENCY RELATIONSHIPS FOR SOME TYPICAL THERMODYNAMIC CYCLES

(BEALL, 1970b)

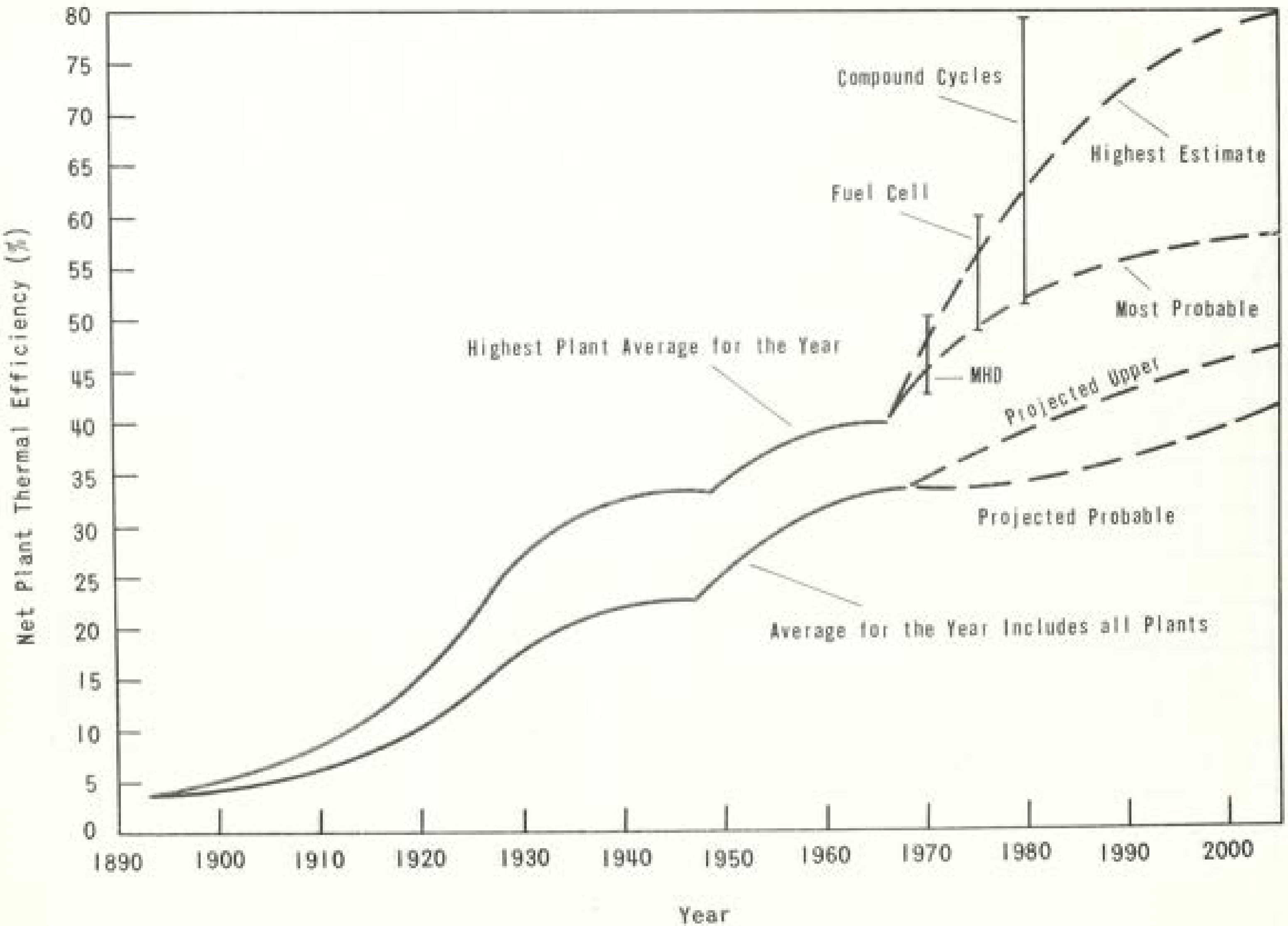


FIGURE 6. TRENDS IN POWER PLANT THERMAL EFFICIENCY (JASKE, 1969)

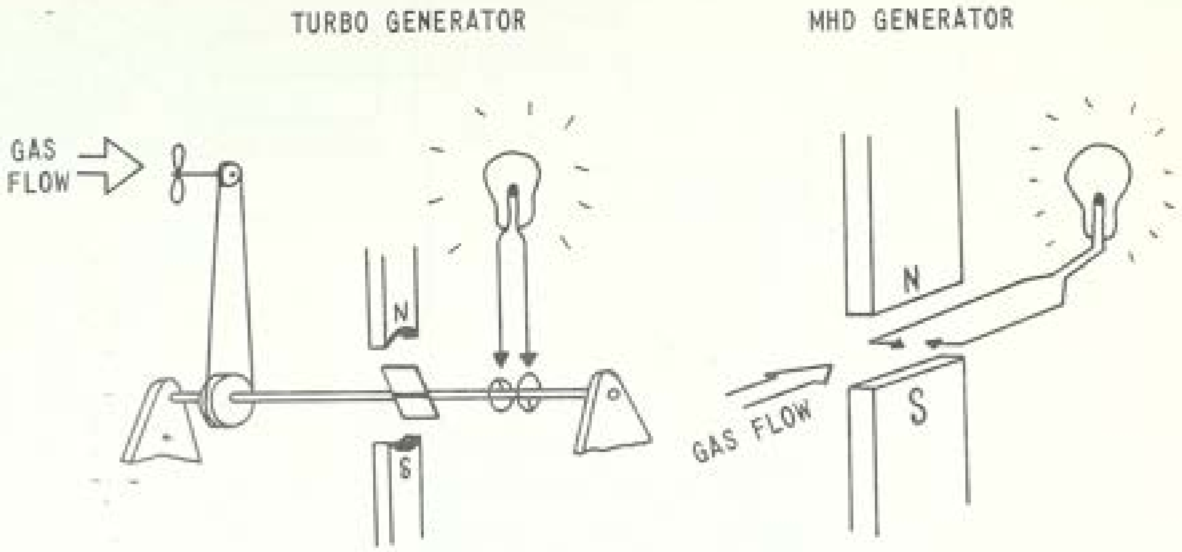


FIGURE 7. COMPARAISON BETWEEN THE TURBOGENERATOR AND THE MAGNETOHYDRODYNAMIC (MHD) GENERATOR (ROSA,1968)

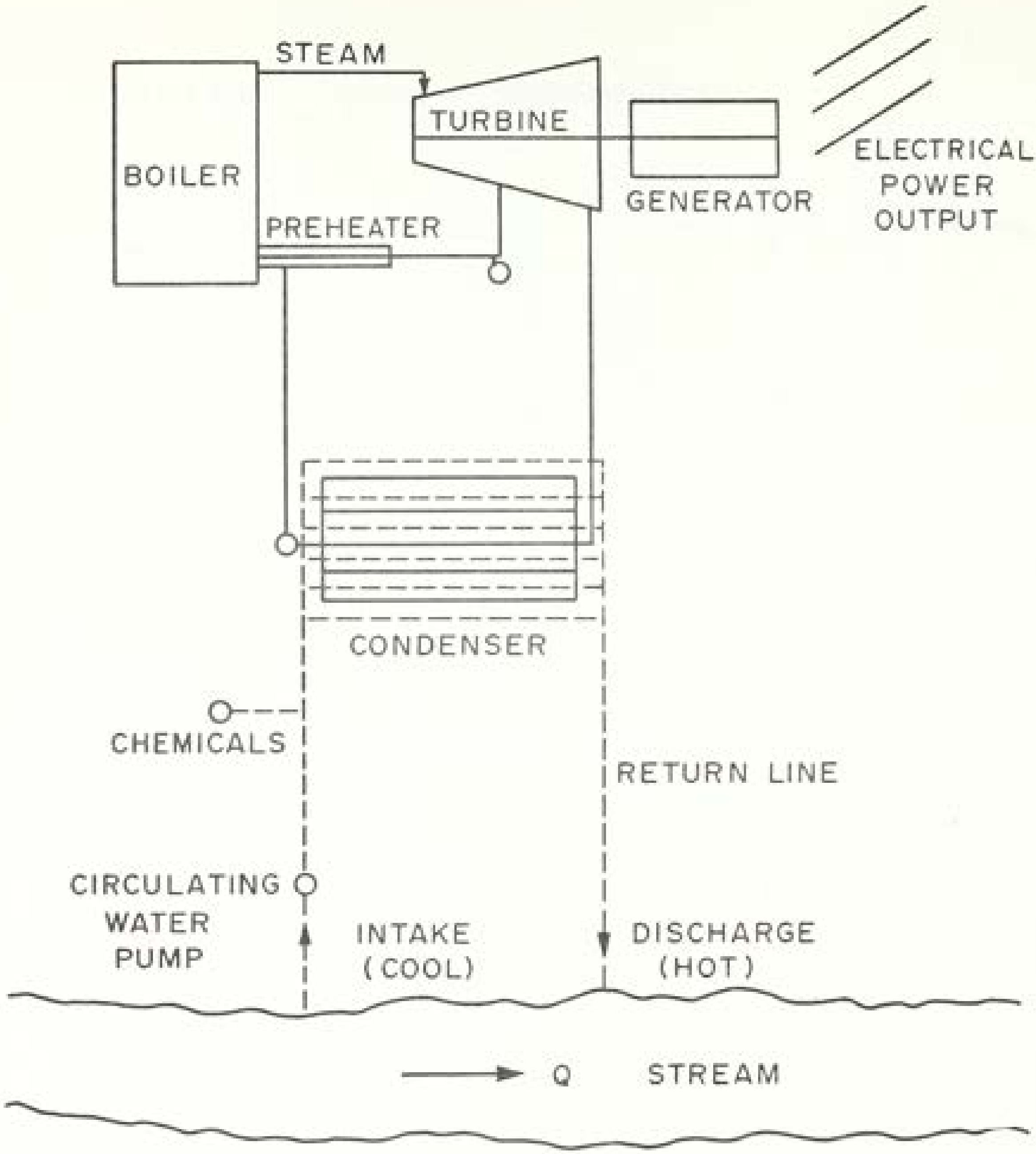


FIGURE 8. SCHEMATIC DIAGRAM OF STEAM ELECTRICAL GENERATION AND COOLING SYSTEM

(PARKER & KRENKEL, 1970)

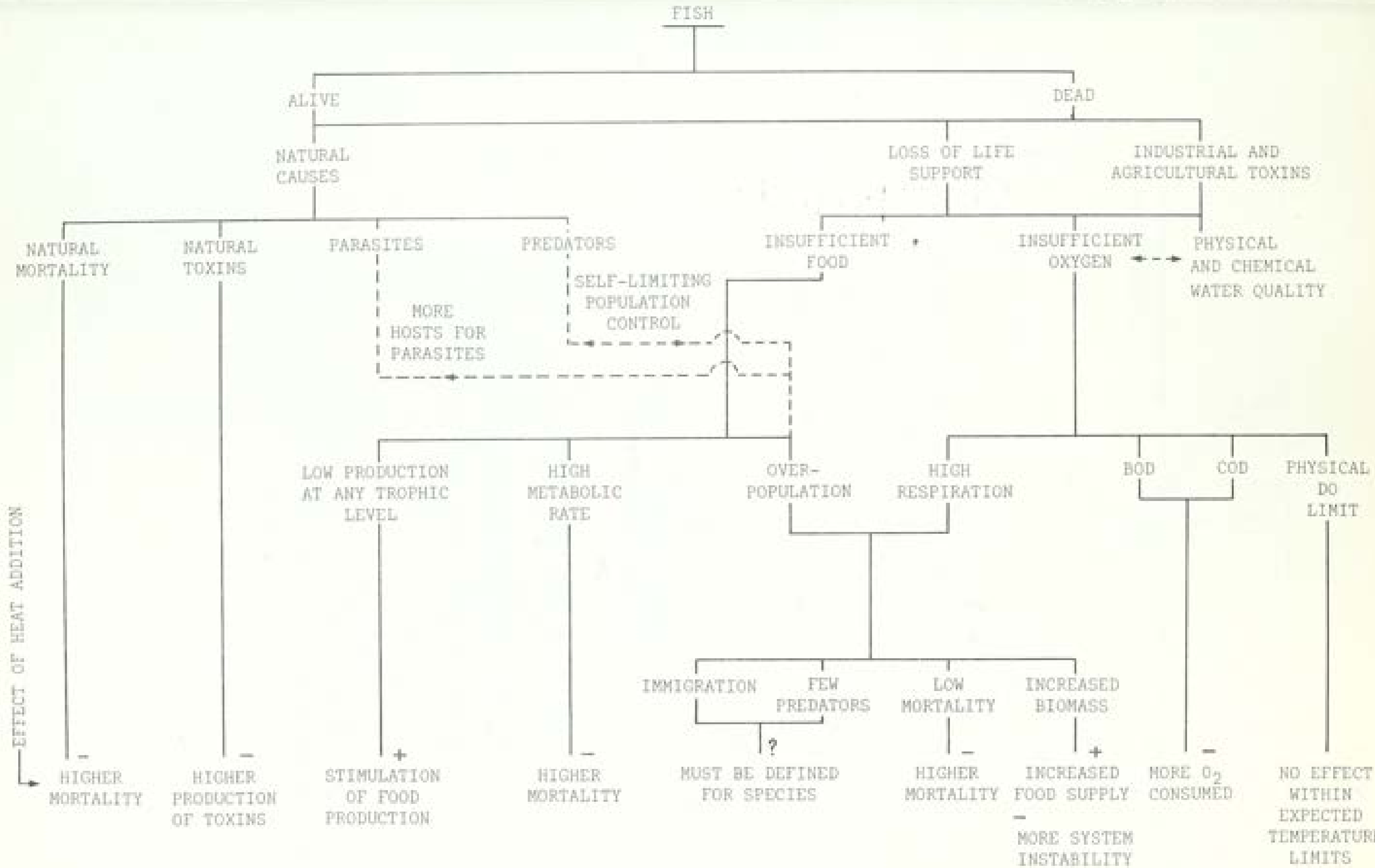


FIGURE 9. FAULT ANALYSIS FOR FISH MORTALITY (WRIGHT ET AL, 1970)

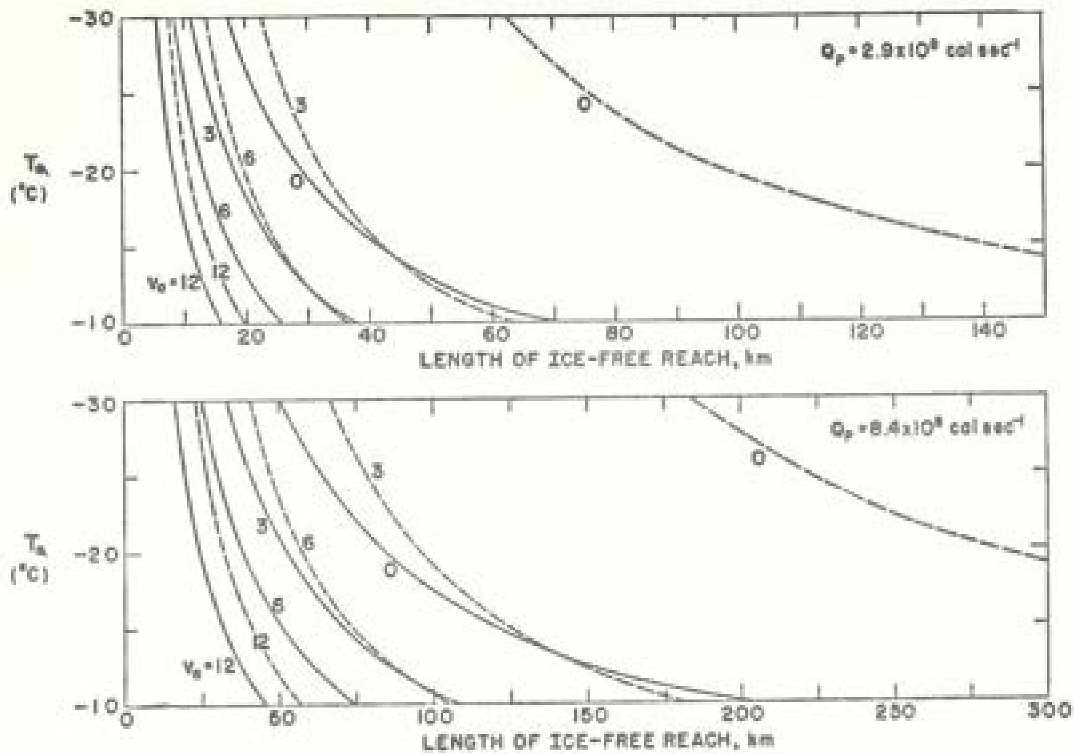


FIGURE 10. LENGTH OF ICE-FREE REACH AS A FUNCTION OF AIR TEMPERATURE (Ta) AND WIND SPEED (Va) (m.sec^{-1}): SOUTH SHORE CANAL, St.LAWRENCE SEAWAY

(DINGMAN ET AL,1968)

N.B. Solid curves are based on the Russianwinter equation and the dashed curves on the Kohler equation method.

Q_p = power plant thermal discharge.

FIGURE 11. CASE I, NUCLEAR GENERATING STATION SITES

(BIGGS, 1968)

FIGURE 12. CASE II, NUCLEAR GENERATING STATION SITES AND BARRAGE WORKS
(BIGGS, 1968)

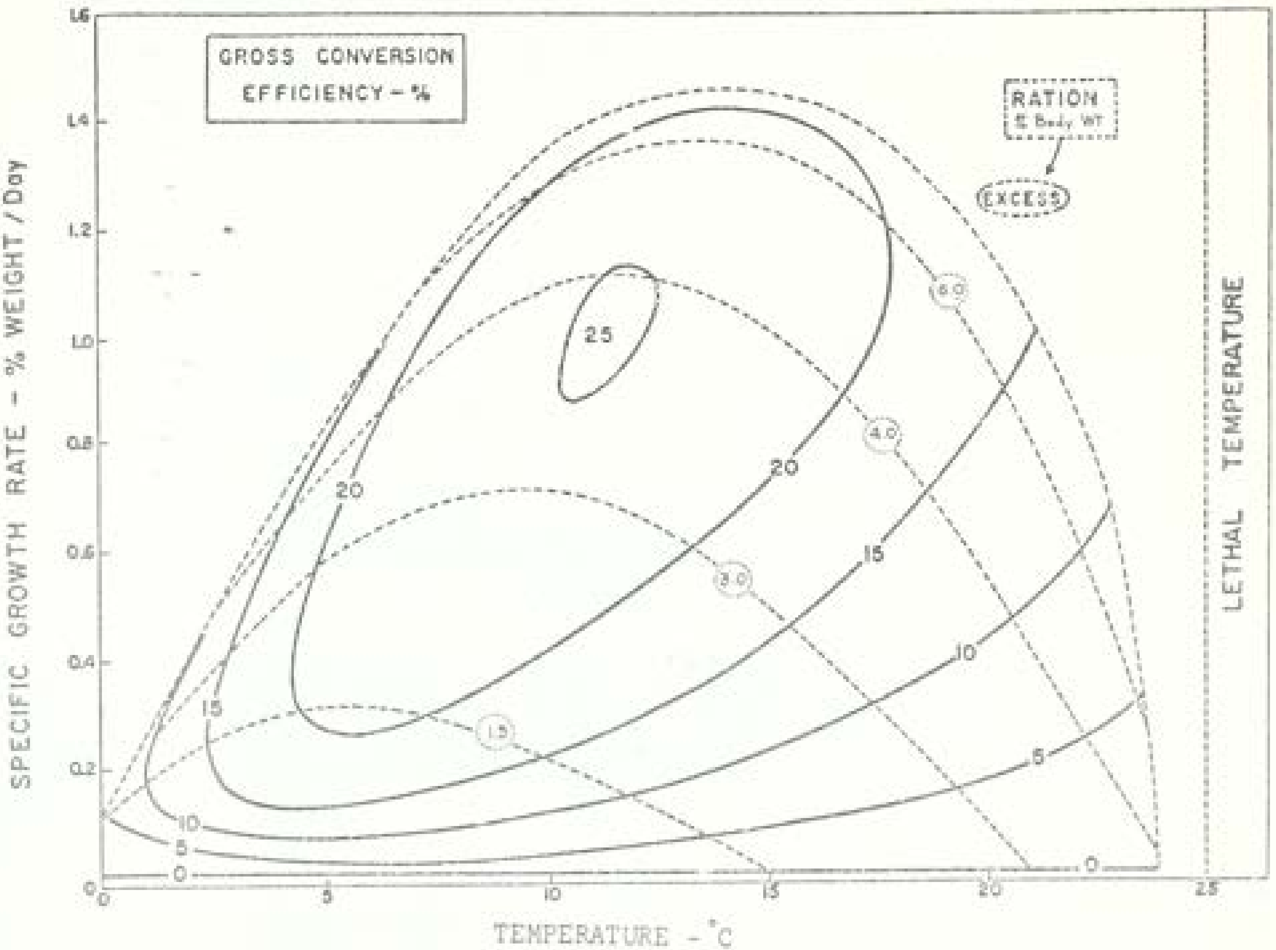


FIGURE 13. GROSS EFFICIENCY OF FOOD CONVERSION IN RELATION TO TEMPERATURE AND RATION, DRAWN AS ISOPLETHS OVERLYING THE GROWTH CURVES (BROKEN LINES)

(COUTANT, 1970b)

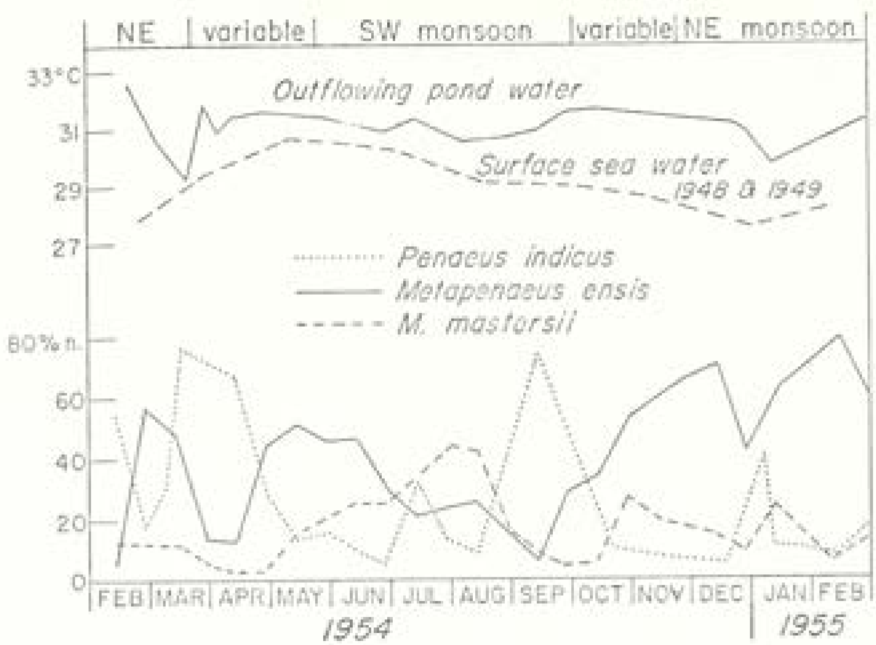


FIGURE 14. THE EQUATORIAL ALTERNATION OF POPULATION OF PENAEID PRAWNS IN A SINGAPORE POND

(HALL, 1962, fig37, 39)

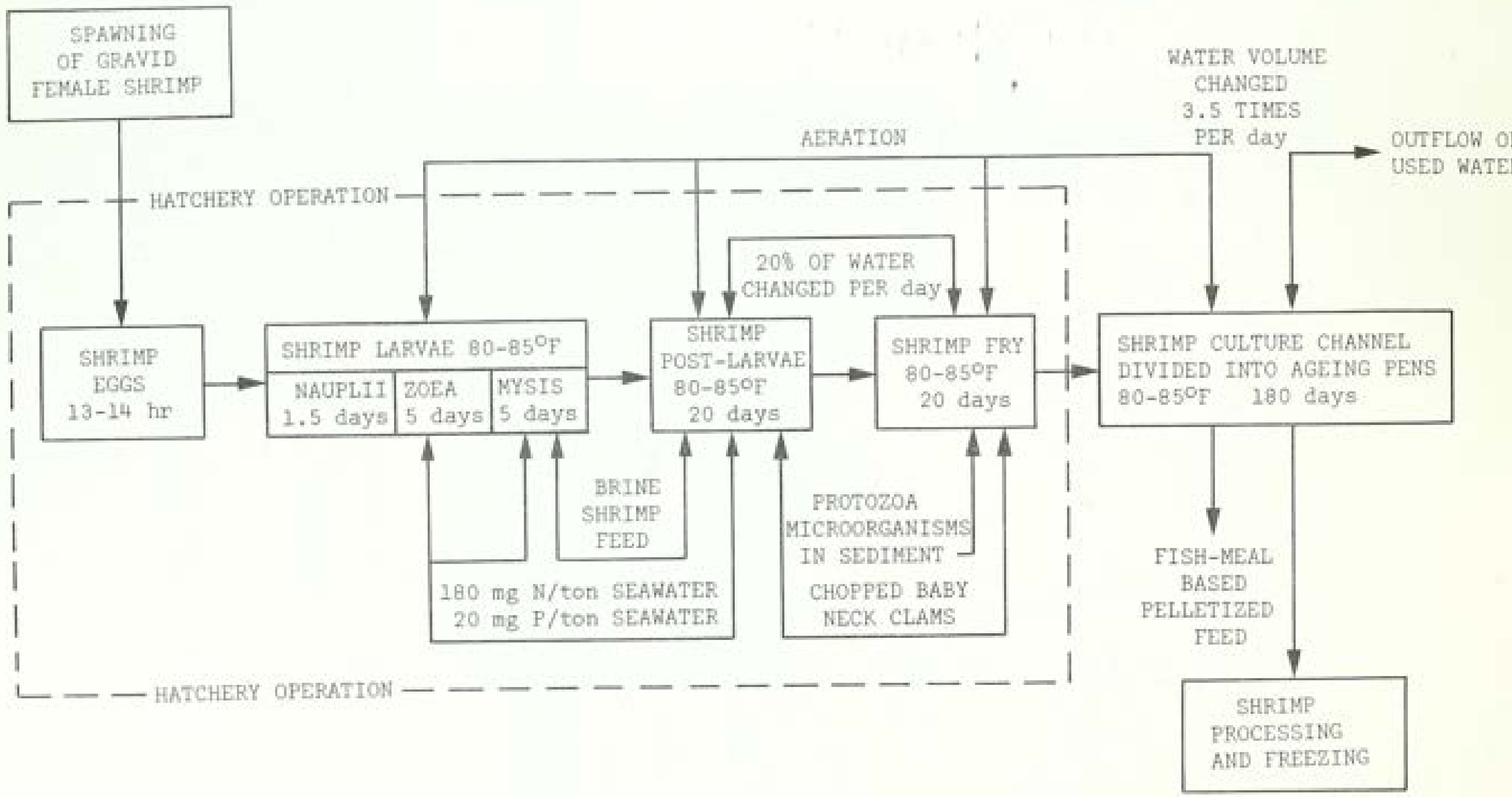


FIGURE 15. SCHEMATIC FLOWSHEET FOR INTENSIVE SHRIMP CULTURE FACILITY (YEE, 1971; modified by COOK, 1971)

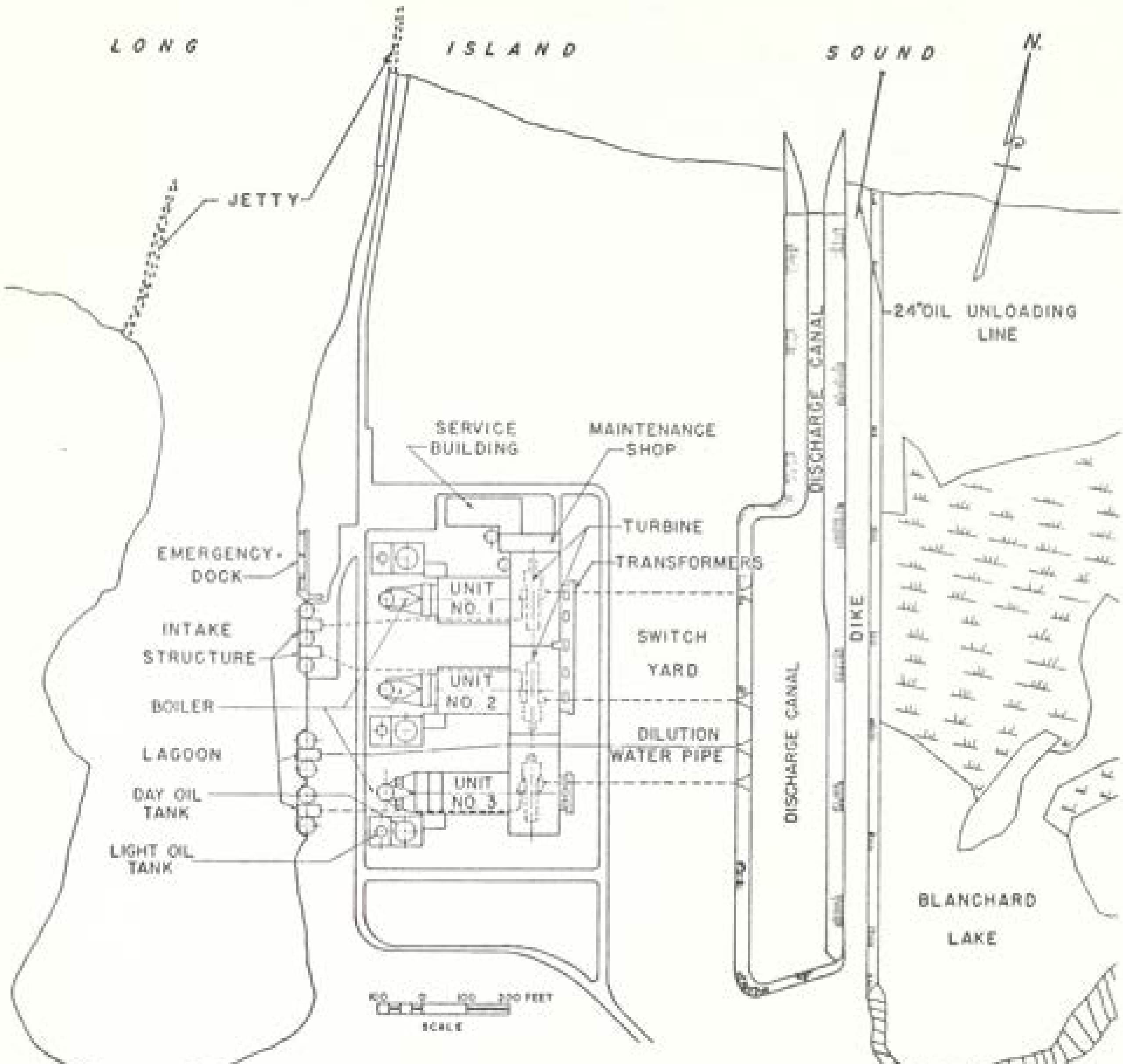


FIGURE 16. PROJECT LAYOUT, NORTHPORT POWER PLANT

(BURNS, 1969)

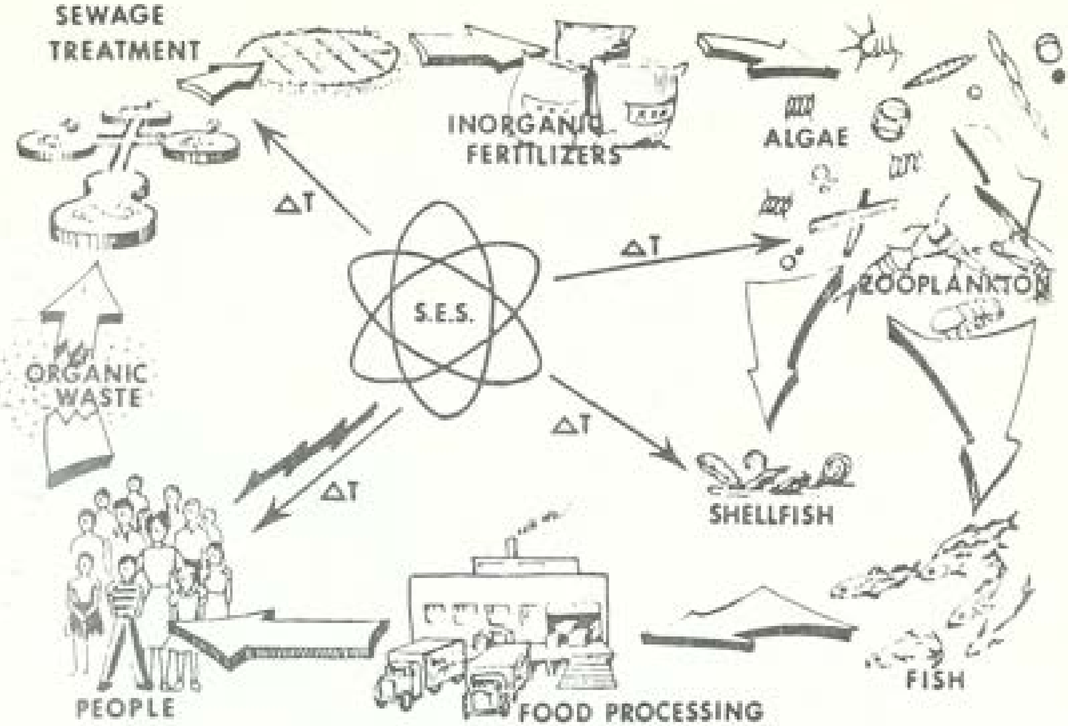
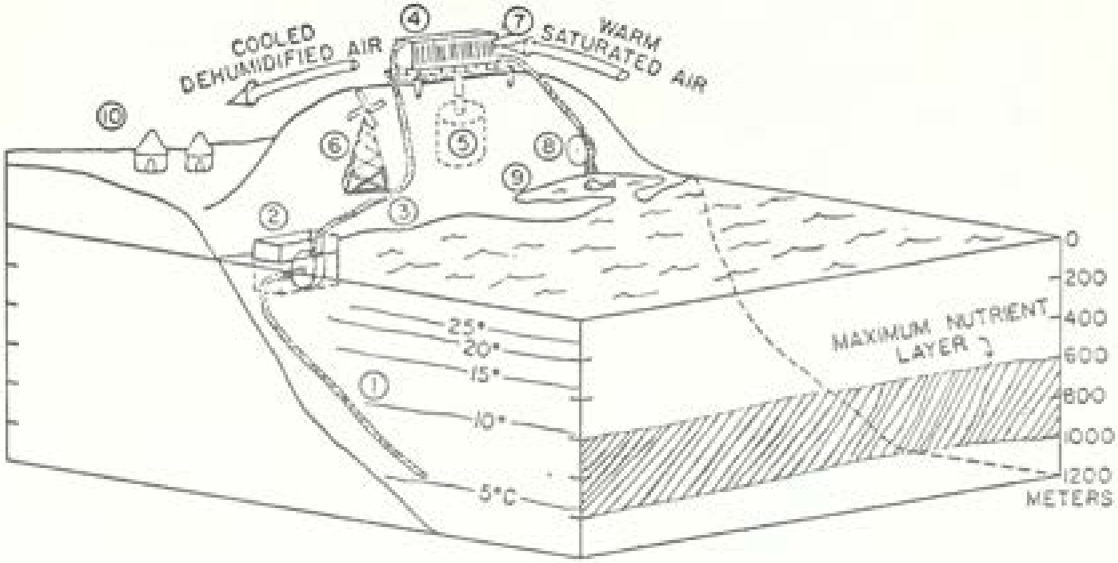


FIGURE 17. SCHEMATIC DIAGRAM OF A POSSIBLE RECYCLING APPROACH TO CONVERTING WASTE MATERIALS INTO USEFUL FOOD STUFFS

(MIHURSKY, 1967)



(1) Large-diameter pipe to deep water; (2) pump; (3) connecting pipe; (4) condenser; (5) freshwater reservoir; (6) windmill electric generator; (7) baffles to direct wind; (8) small turbine to recover water power; (9) lagoon receiving nutrient-rich water for agriculture; (10) community enjoying cooled dehumidified air

FIGURE 18. PROPOSED WATER RECOVERY PLANT

(GERARD & WORZEL, 1967)

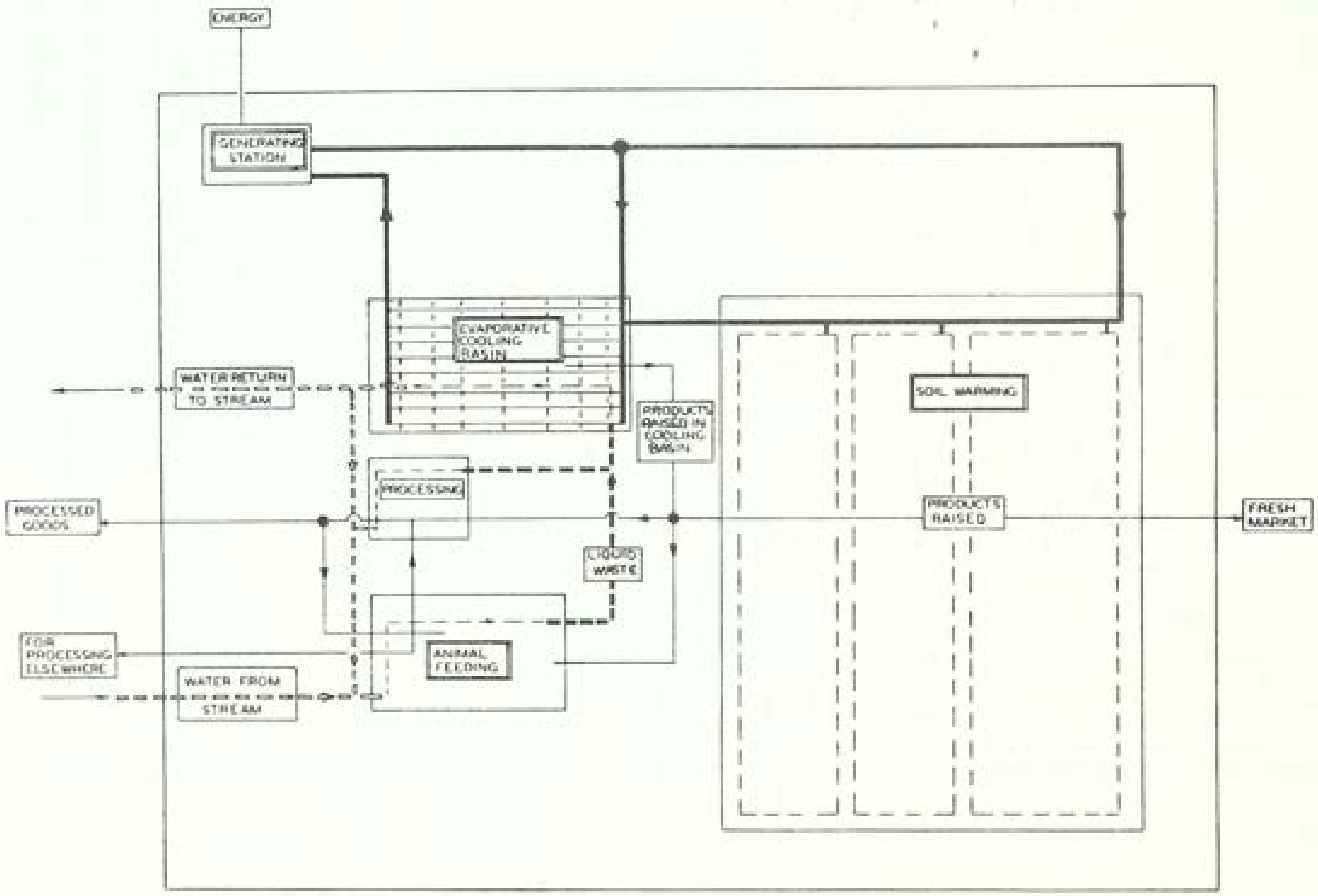


FIGURE 19. FLOW DIAGRAM OF A CONCEPTUAL AGRO-INDUSTRIAL COMPLEX USING WASTE HEAT FROM AN ADJACENT POWER PLANT

(BOERSMA, 1970)

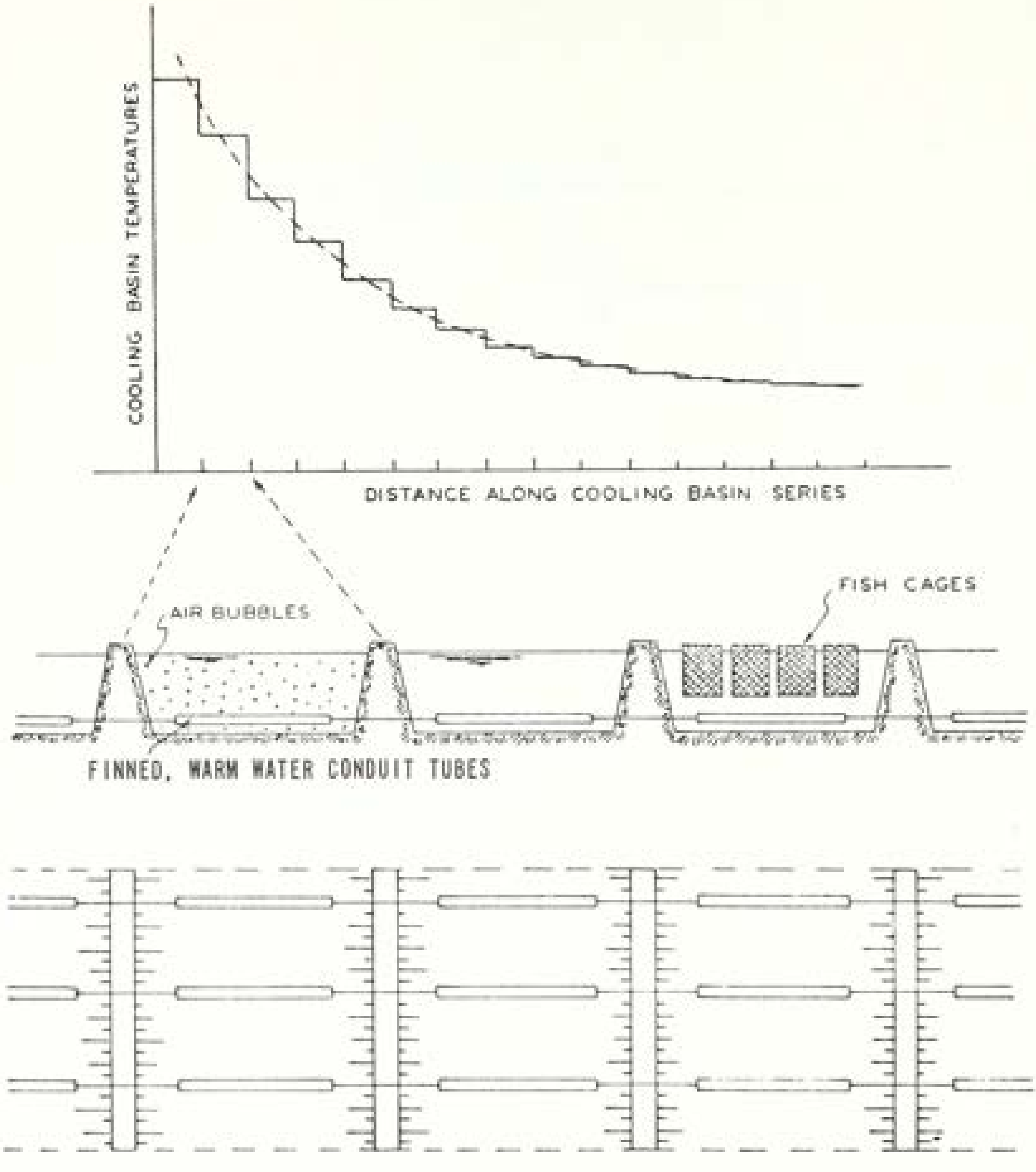
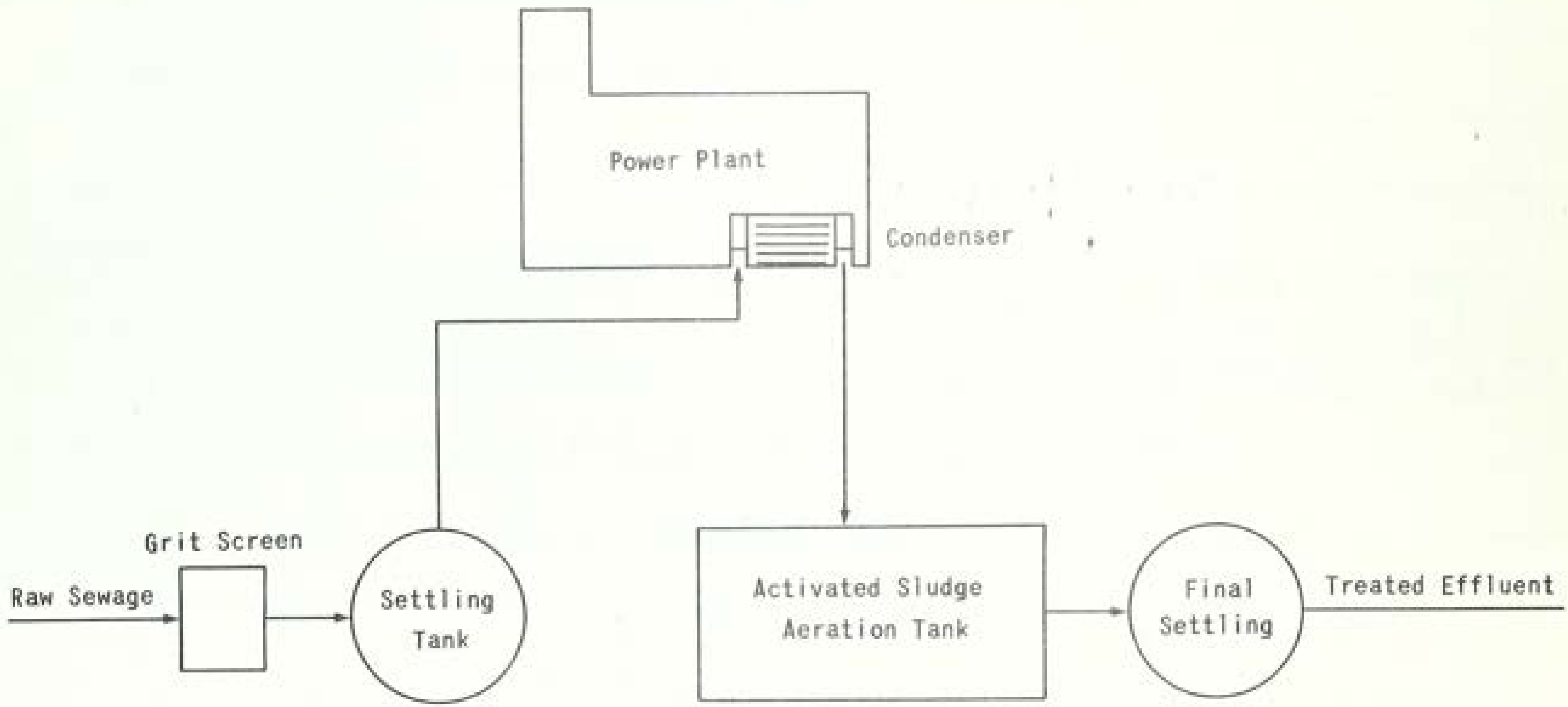


FIGURE 20. SCHEMATIC DIAGRAM OF AN EVAPORATIVE COOLING SYSTEM DESIGNED TO ALLOW COMMERCIAL USE OF THE WASTE HEAT

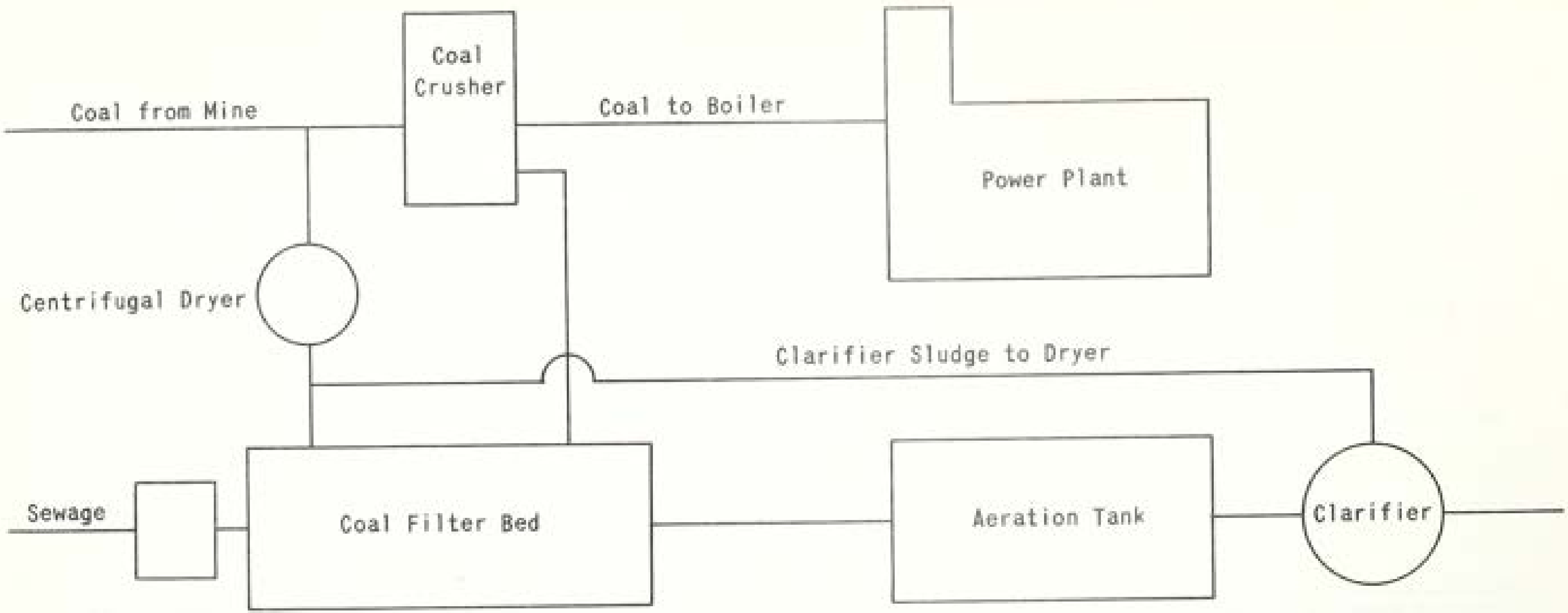
THE PROJECTED TEMPERATURE DECREASE IS SUPERIMPOSED ON THE LONGITUDINAL CROSS SECTION.

(BOERSMA, 1970)



1. Pre-screened and settled sewage is routed through a section of the power plant condenser which has been blanked off from the rest by separators on the water boxes at each end.
2. The sewage is heated from approximately 70°F. (the average temperature of most sewage) to 100°F. in the condenser and then returned to the activated sludge aeration tank.
3. Potential problems of microorganism growth and grease buildup on the inside of the condenser tube would have to be studied and overcome.

FIGURE 21. HEATED SEWAGE TREATMENT SYSTEM
(BELL ET AL,1970)



1. The power plant coal crusher would be modified to produce a small amount of 20 mesh coal for the sewage filter beds.

2. Raw sewage filtration requires 10 tons of coal per million gallons of sewage.

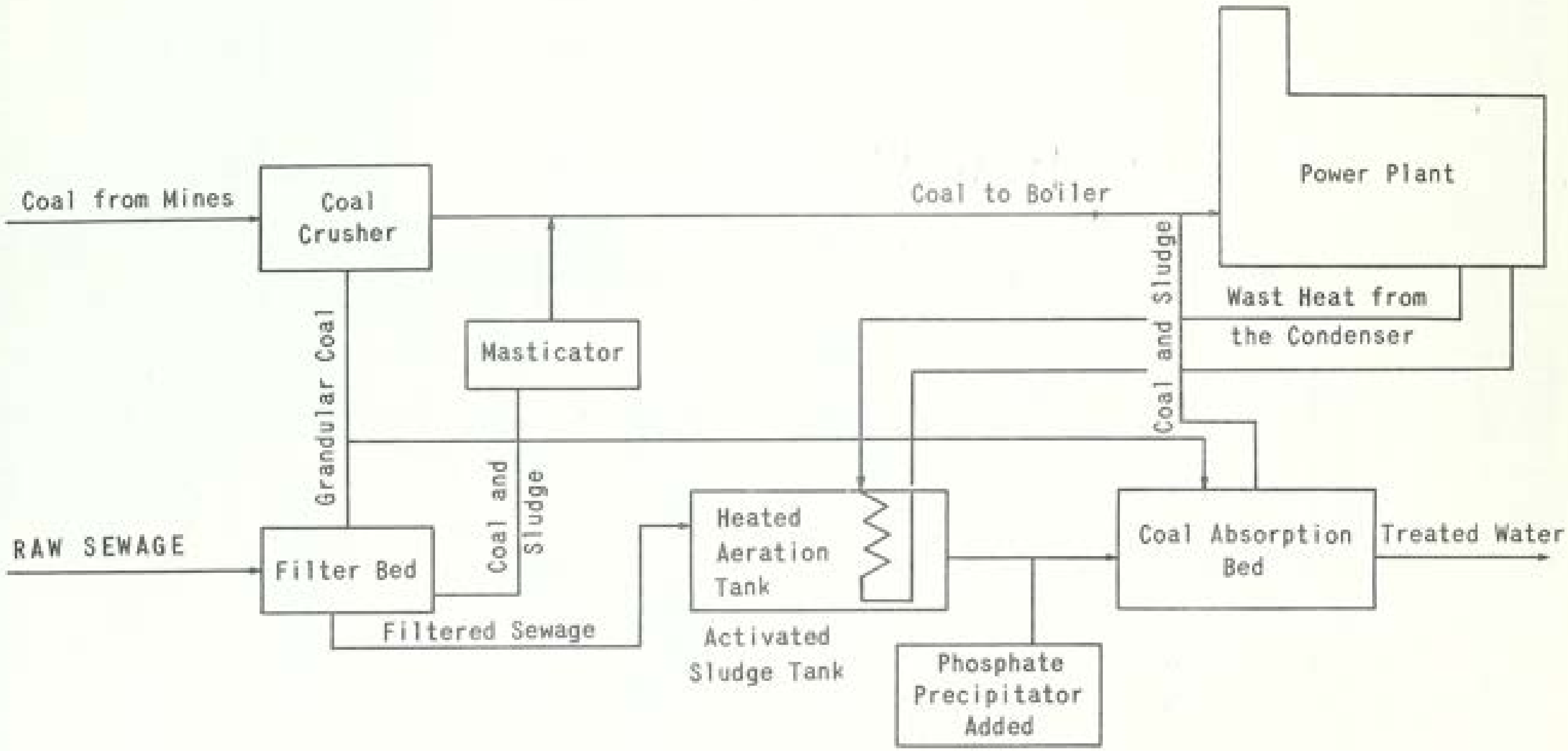
3. During filtration the top portion of the coal and sewage sludge is scraped off and returned through a dryer (centrifugal or hot air) to the crusher feed coal. The mixture would then be crushed to 200 mesh size and burned in the boiler.

4. Coal filtration would remove approximately 70% of the B.O.D. Further B.O.D. removal to 90% would be accomplished in aerated biological process.

5. Due to the relative sizes of most power and sewage treatment plants, the amount of coal used for sewage filtration would usually be less than 20% total coal fed to the boiler.

FIGURE 22. RAW SEWAGE COAL FILTRATION

(BELL ET AL, 1970)



1. The first filter bed requires approximately ten tons of granular coal per million gallons of raw sewage. 70 to 75% BOD removal is accomplished. Coal and sludge are returned through a masticator to chop up larger solids and is mixed with the boiler feed coal.

2. The filtered sewage is next treated in an aeration tank where biodegradation is accelerated through waste heat addition.

3. After addition of a phosphate precipitator, the sewage is given a final polish in a coal adsorption bed where the precipitate is removed and the BOD removal brought to above 90%. Coal and sludge can be added directly to the boiler feed coal. One ton of coal per million gallon of sewage is required.

FIGURE 23. SEWAGE TREATMENT: COAL FILTRATION/THERMOPHILIC STABILIZATION

(BELL ET AL, 1970)

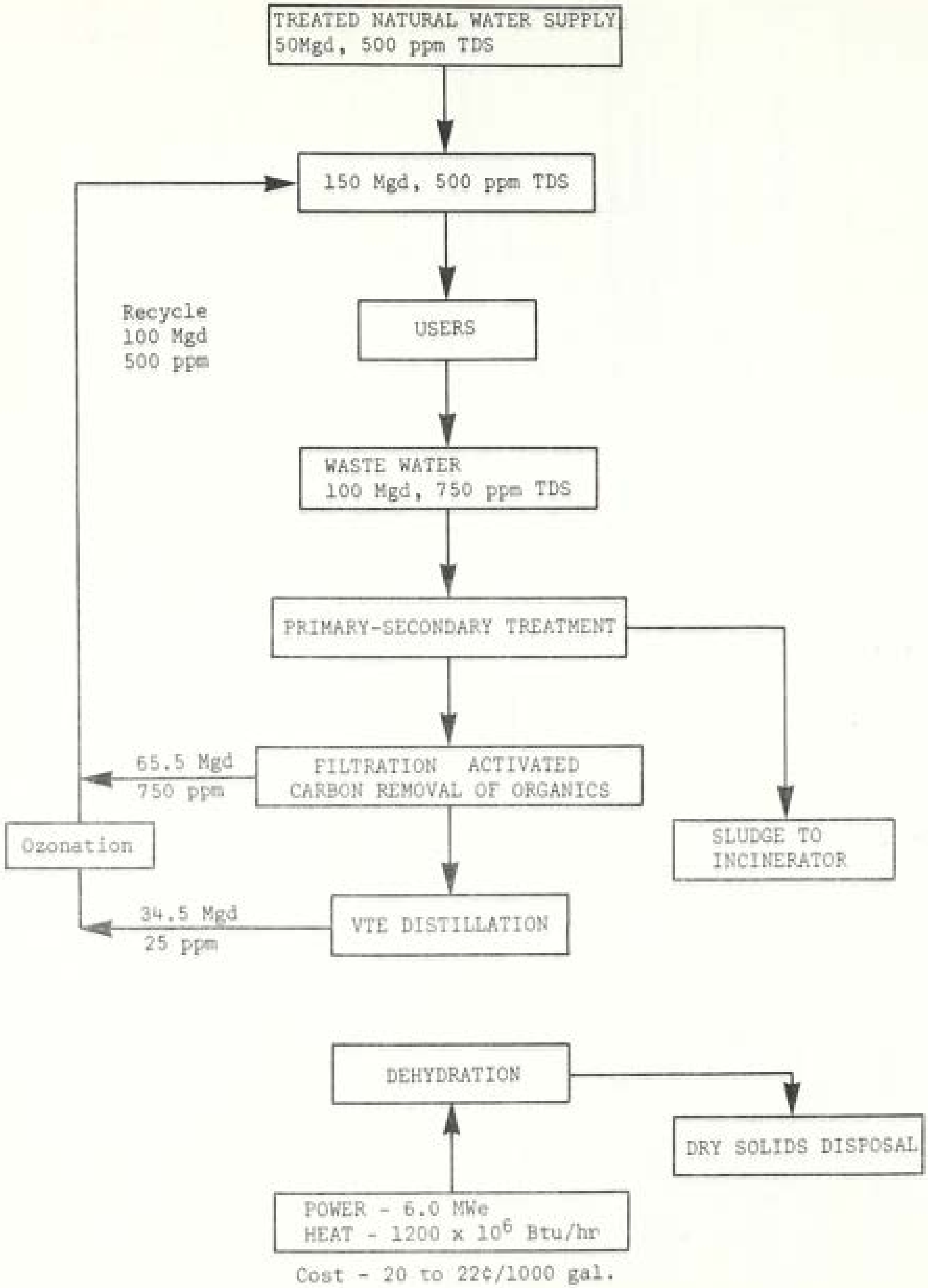


FIGURE 24. WATER SUPPLY INCLUDING WATER RECLAIMED WITH DISTILLATION, DISTILLATION TO DRYNESS (FOR CITY OF ONE MILLION)

(BEALL, 1970a; 1970b)

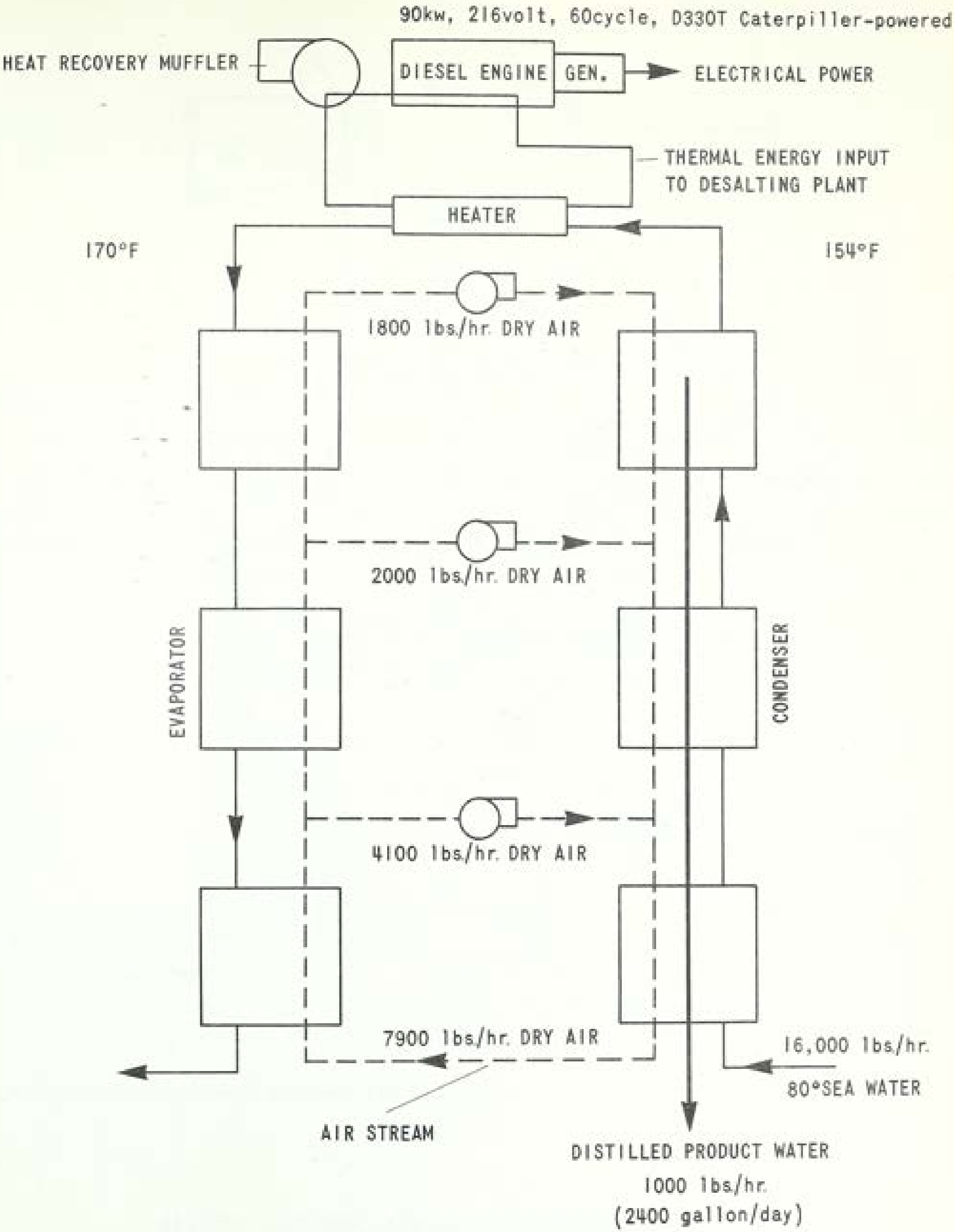


FIGURE 25. HUMIDITY TYPE DESALTING PLANT

(GROH, 1970)

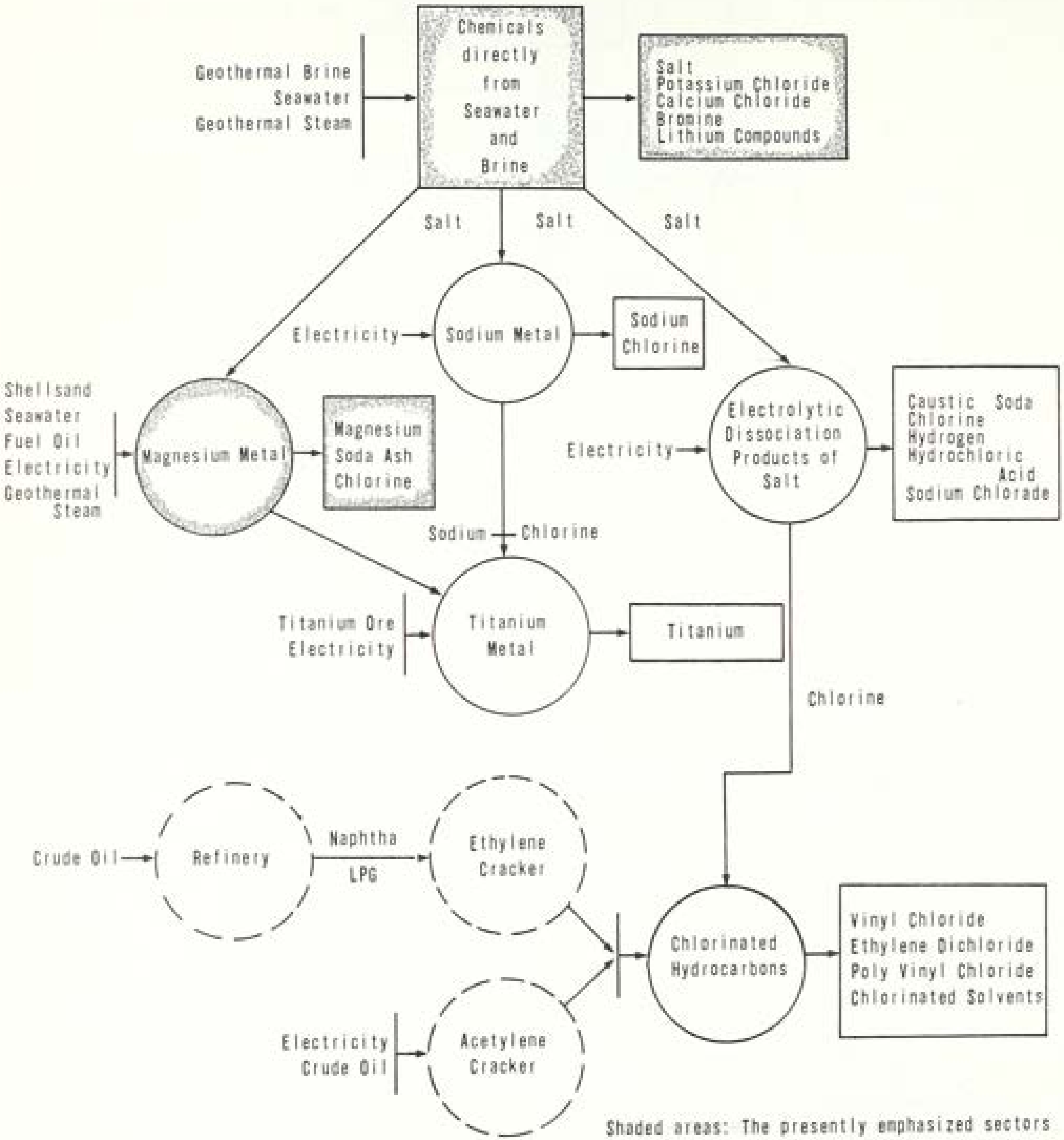
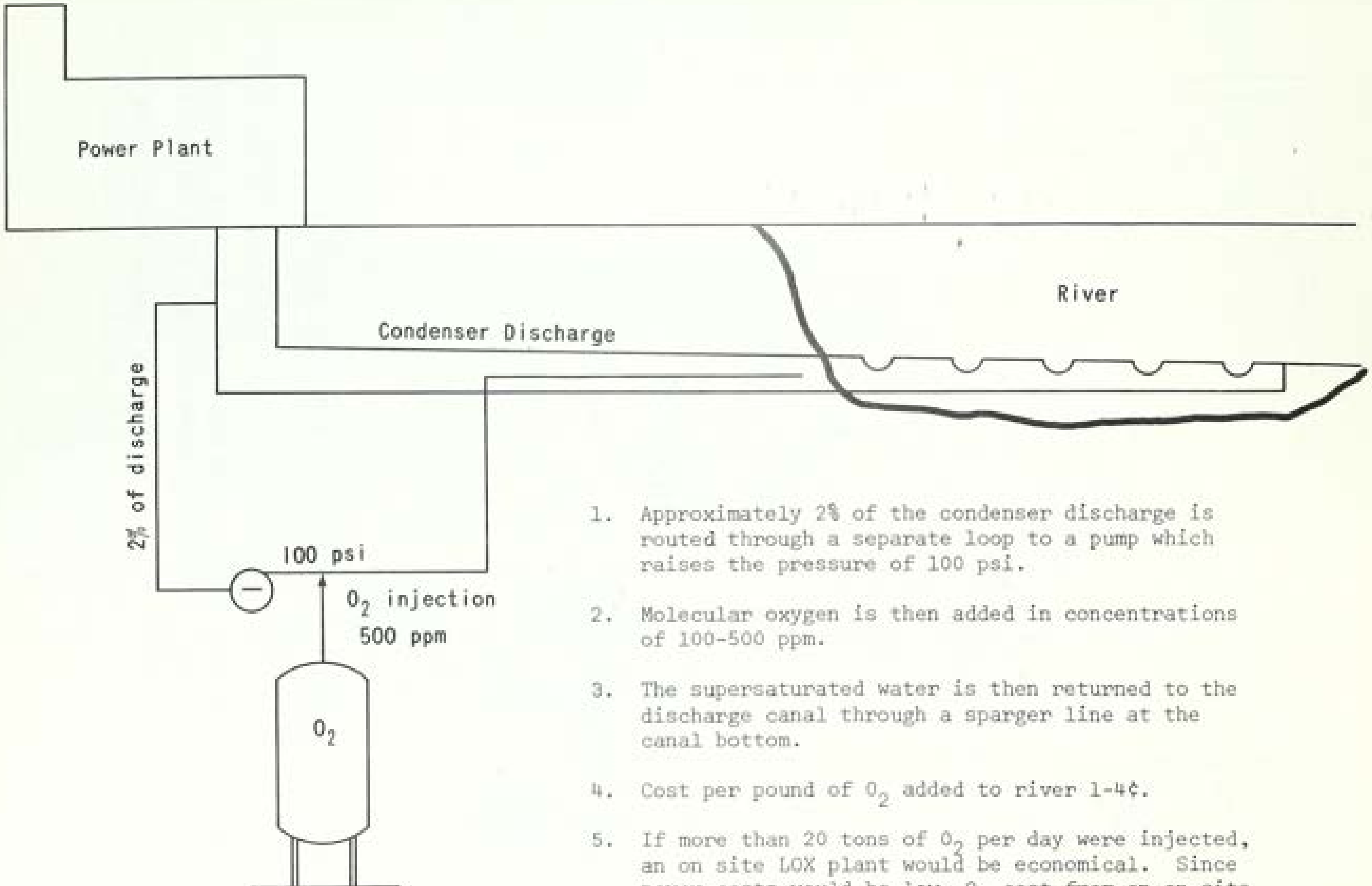


FIGURE 26. ORGANIZATION OF THE SEA CHEMICALS COMPLEX
(LINDAL, 1970b)



1. Approximately 2% of the condenser discharge is routed through a separate loop to a pump which raises the pressure of 100 psi.

2. Molecular oxygen is then added in concentrations of 100-500 ppm.

3. The supersaturated water is then returned to the discharge canal through a sparger line at the canal bottom.

4. Cost per pound of O_2 added to river 1-4¢.

5. If more than 20 tons of O_2 per day were injected, an on site LOX plant would be economical. Since power costs would be low, O_2 cost from an on site plant could be expected to be half or less than O_2 hauled to the site.

FIGURE 27. CONDENSER DISCHARGE AERATION SYSTEM

(BELL ET AL, 1970)

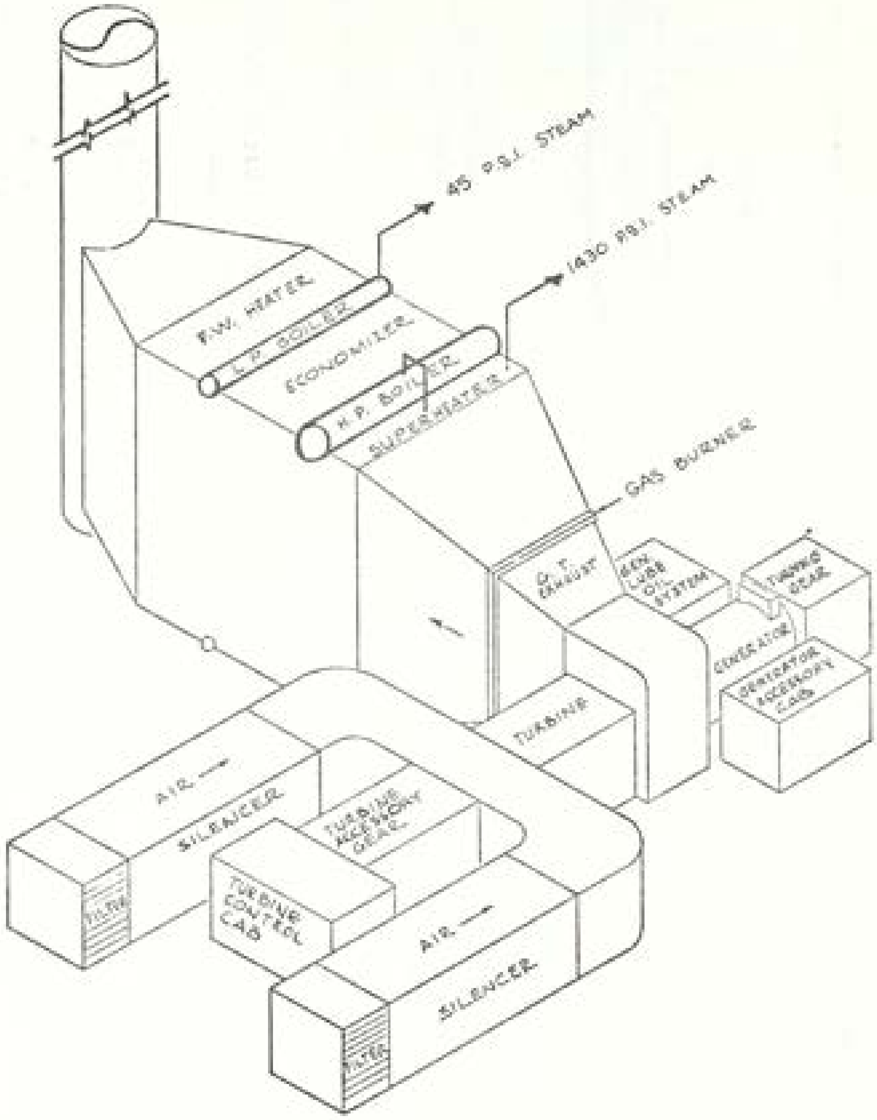


FIGURE 28. SCHEMATIC DIAGRAM OF GAS-TURBINE AND WASTE-HEAT BOILER (PLUS AUXILLARY BURNERS) UNIT

(DEVELOPED BY DOW CANADA AND GENERAL ELECTRIC TO ALLOW RECOVERY OF 88% HEAT ENERGY RELEASED WHEN NATURAL GAS IS BURNED)

(CANADIAN CHEMICAL PROCESSING, AUG, 1971)

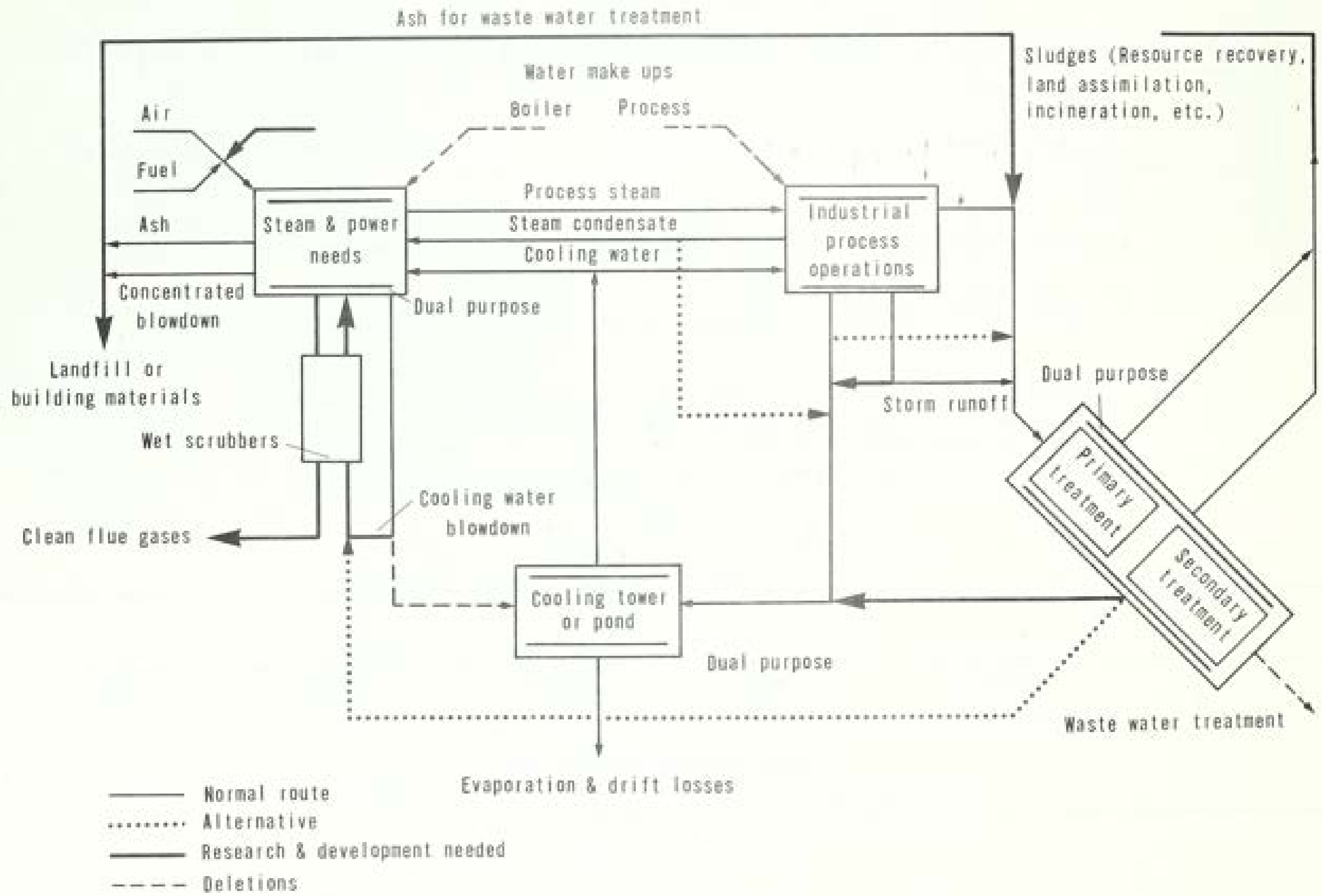
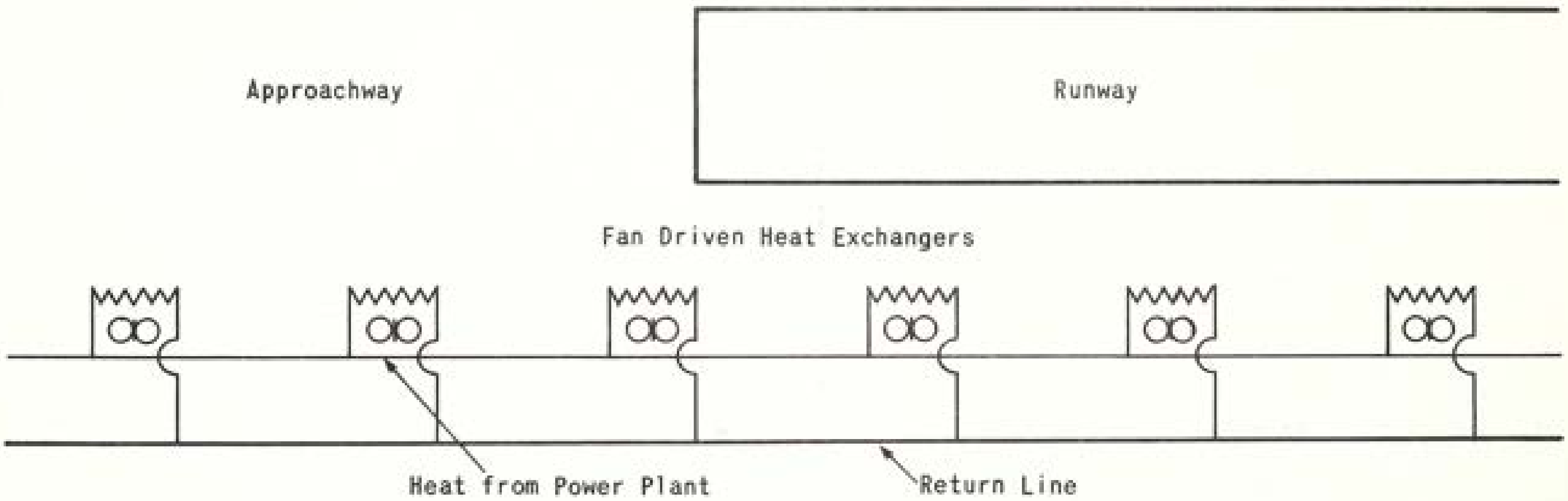


FIGURE 29. INDUSTRIAL WASTE WATER REUSE SCHEME

(REY ET AL,1971)



1. Waste heat in the form of hot water or steam would be diverted from the power plant to a bank of fan driven heat exchangers at the side of the runway and approach-way. Heated air blowing across the approach and runways would rise, heat the fog croplets and cause them to evaporate.

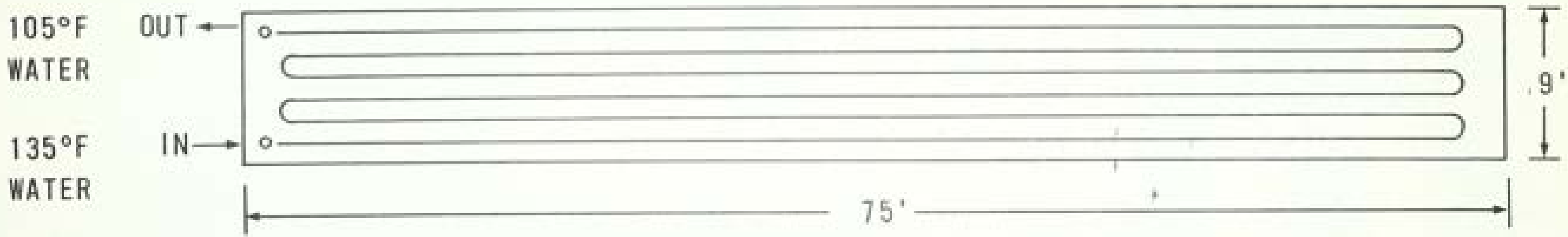
2. Heat required for one approach and runway would be approximately 700 M.W.

3. Estimated cost for an installation at LaGuardia using heat from the Astoria plant is $3,000,000.

4. With only 53 hours of fog (from FAA reports) per year, the use factor for the high capital cost equipment would be prohibitively low.

FIGURE 30. AIRPORT FOG DISPERSAL SCHEME

(BELL ET AL,1970)



ONE GRID CONTAINS 500' OF 1¼"PIPE

1. Provides 100 BTU/HR/FT^2.
2. Can melt 1" of snow per hour.
3. Water flow through pipe = 4.5 gpm.

FIGURE 31. RUNWAY ICE-MELTING GRID SYSTEM (BELL ET AL, 1970)

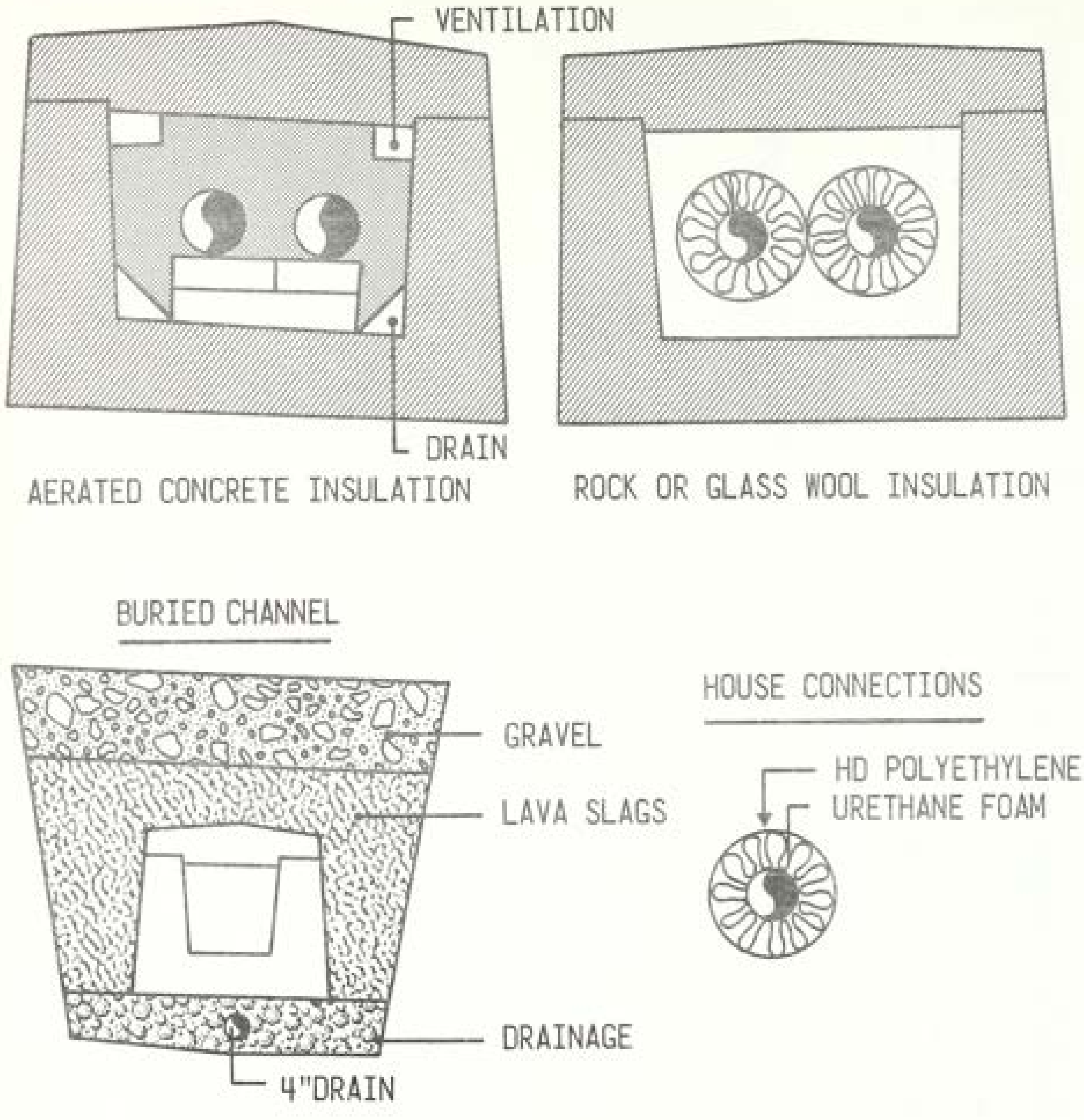


FIGURE 32. STREET MAIN CHANNELS

(MATTHIASSON, 1970)

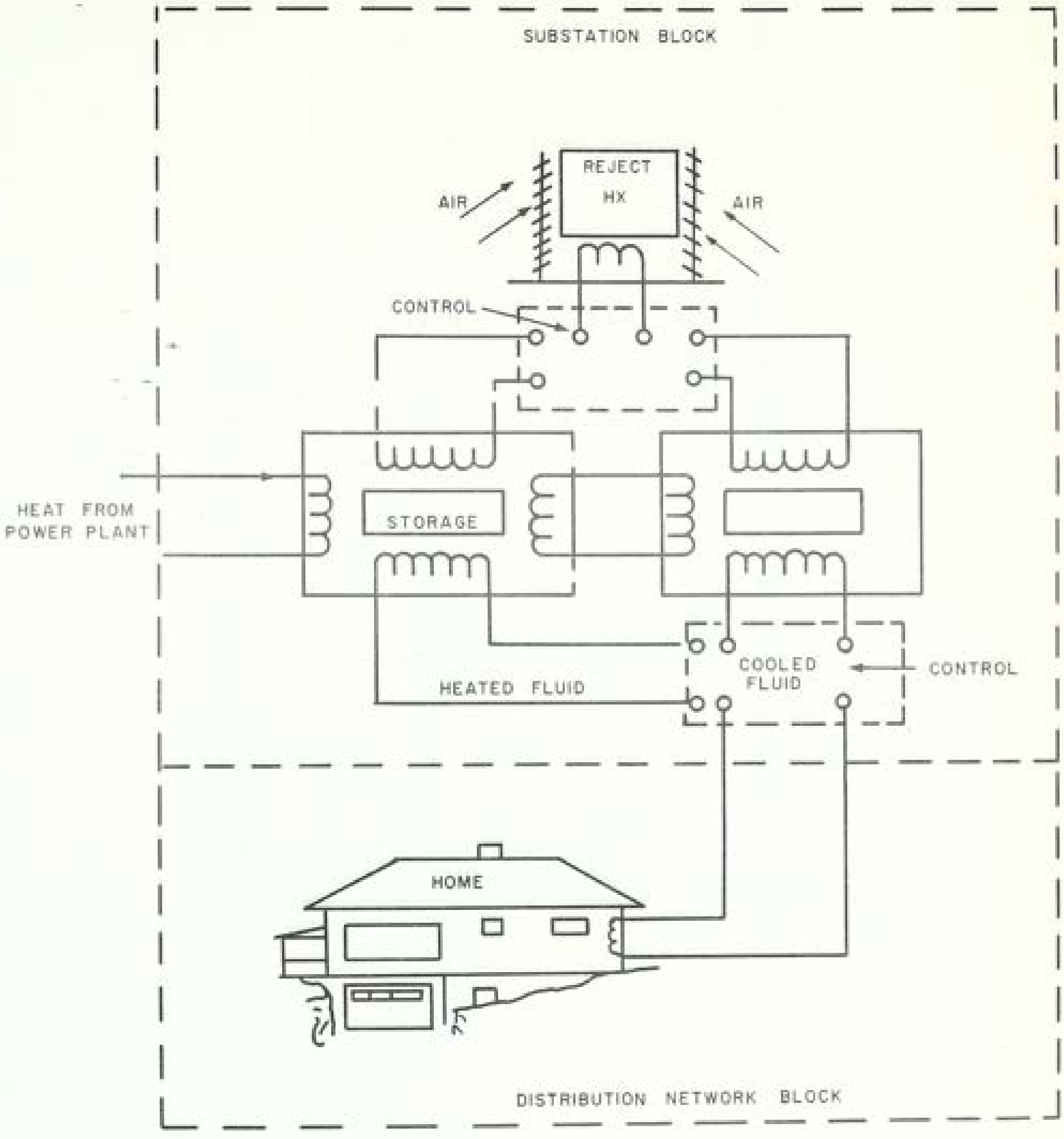


FIGURE 33 DIAGRAMMATIC REPRESENTATION FOR YEAR ROUND HOME CONDITIONING VIA SUBSTATIONS (BELL ET AL, 1970)

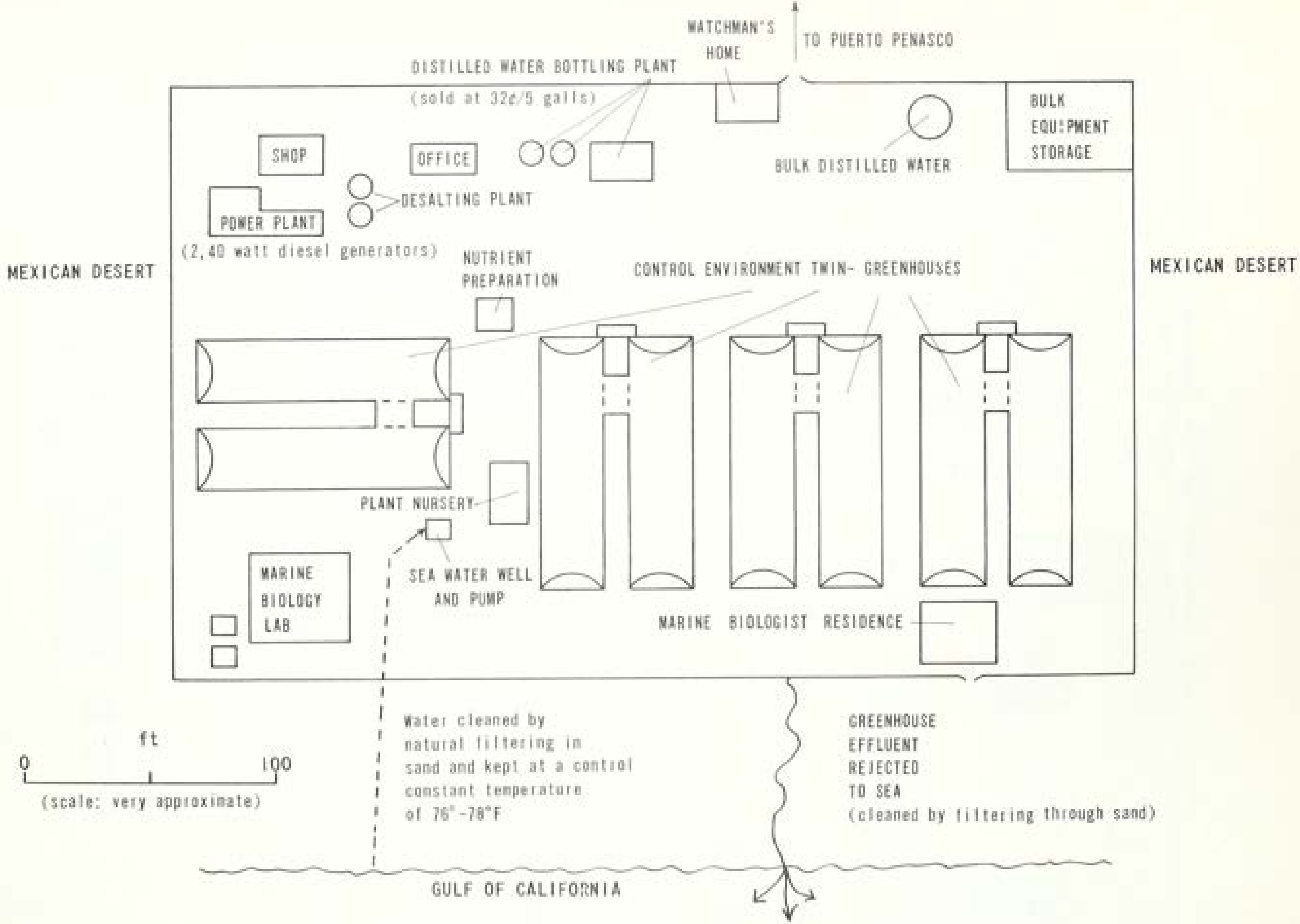
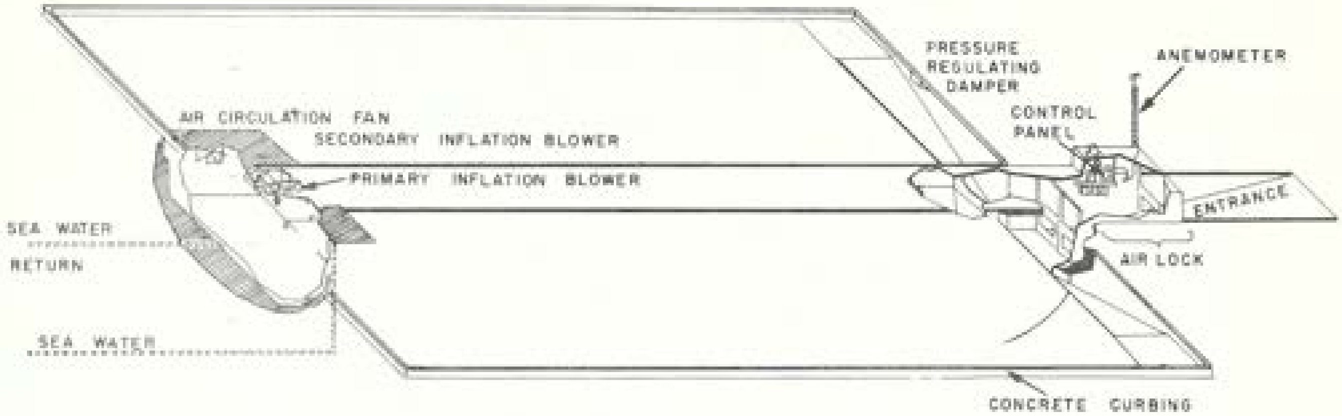


FIGURE 34. SKETCH OF PUERTO PEÑASCO - AN INTEGRATED POWER/WATER/FOOD FACILITY



NOTE: THE FLOOR PLAN IS COVERED BY AN INFLATED PLASTIC DOME WHICH IS NOT SHOWN IN DIAGRAM

FIGURE 35. GROUND PLAN OF CONTROLLED ENVIRONMENT GREENHOUSE

(HODGES AND HODGE, 1969)

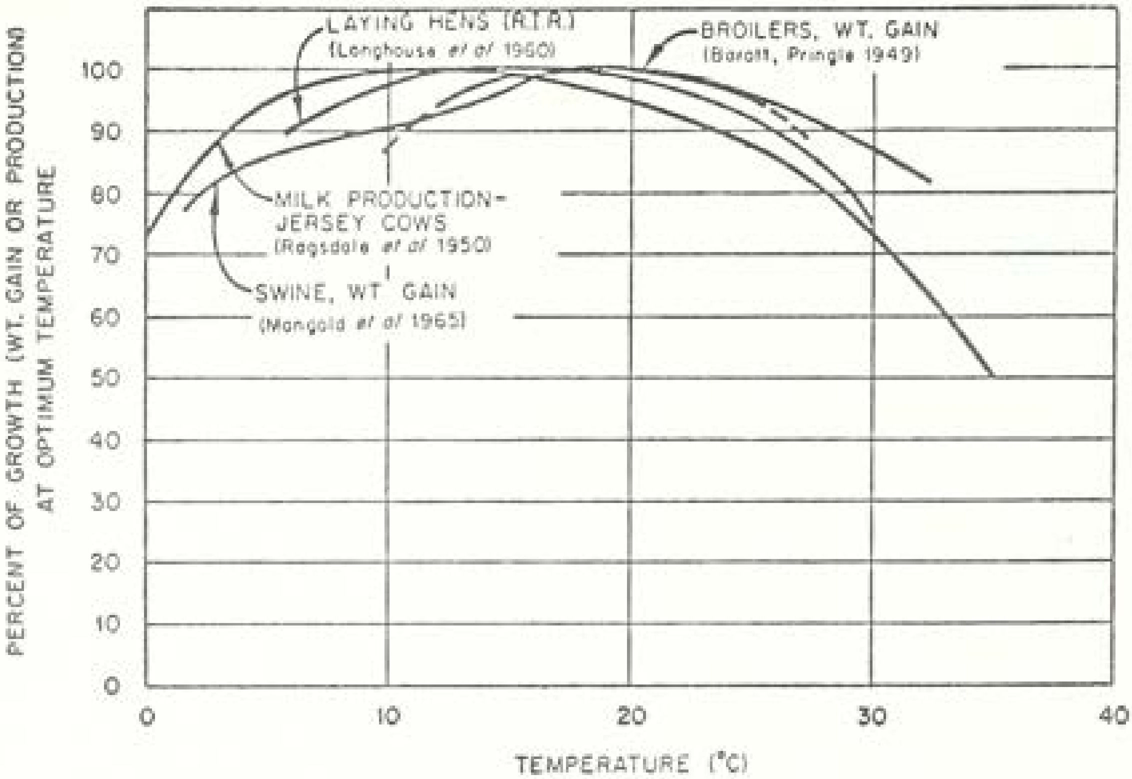


FIGURE 36. EFFECT OF TEMPERATURE ON GROWTH OR PRODUCTION OF FOOD ANIMALS

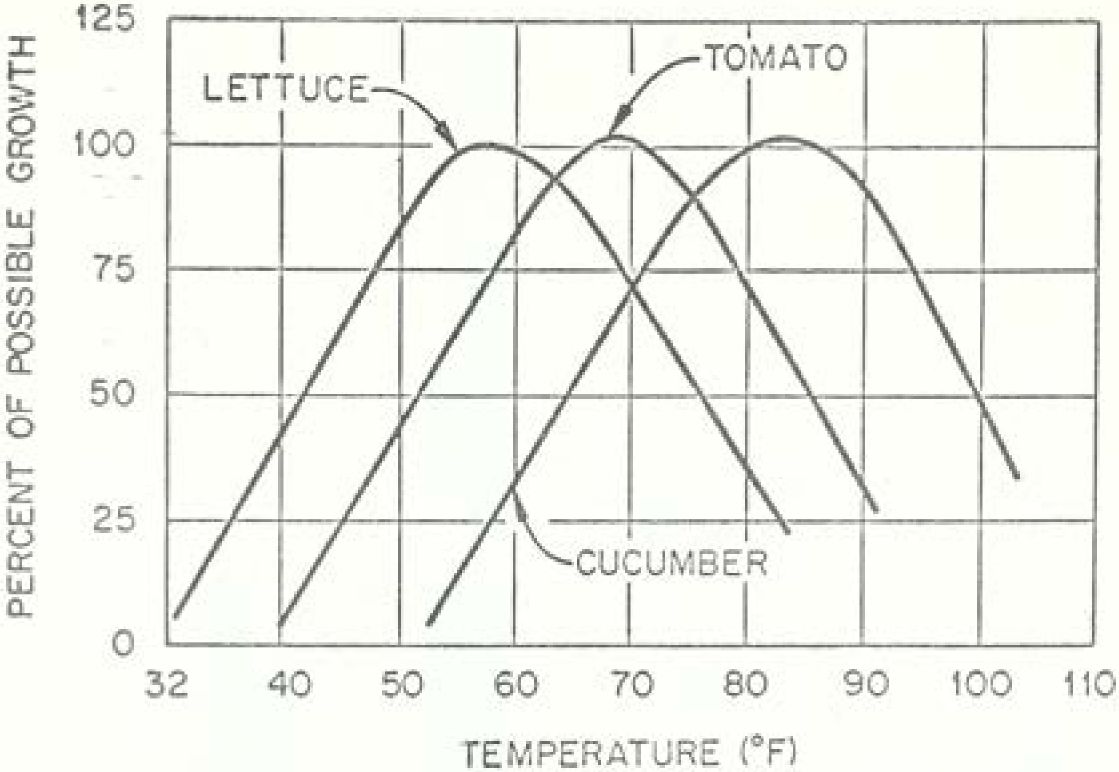


FIGURE 37. IDEALIZED GROWTH CURVES FOR SEVERAL CROPS (ONTARIO DEPARTMENT OF AGRICULTURE AND FOOD - PUBLICATION 526)

(BEALL, 1970a ORNL DWG. 70-10635)

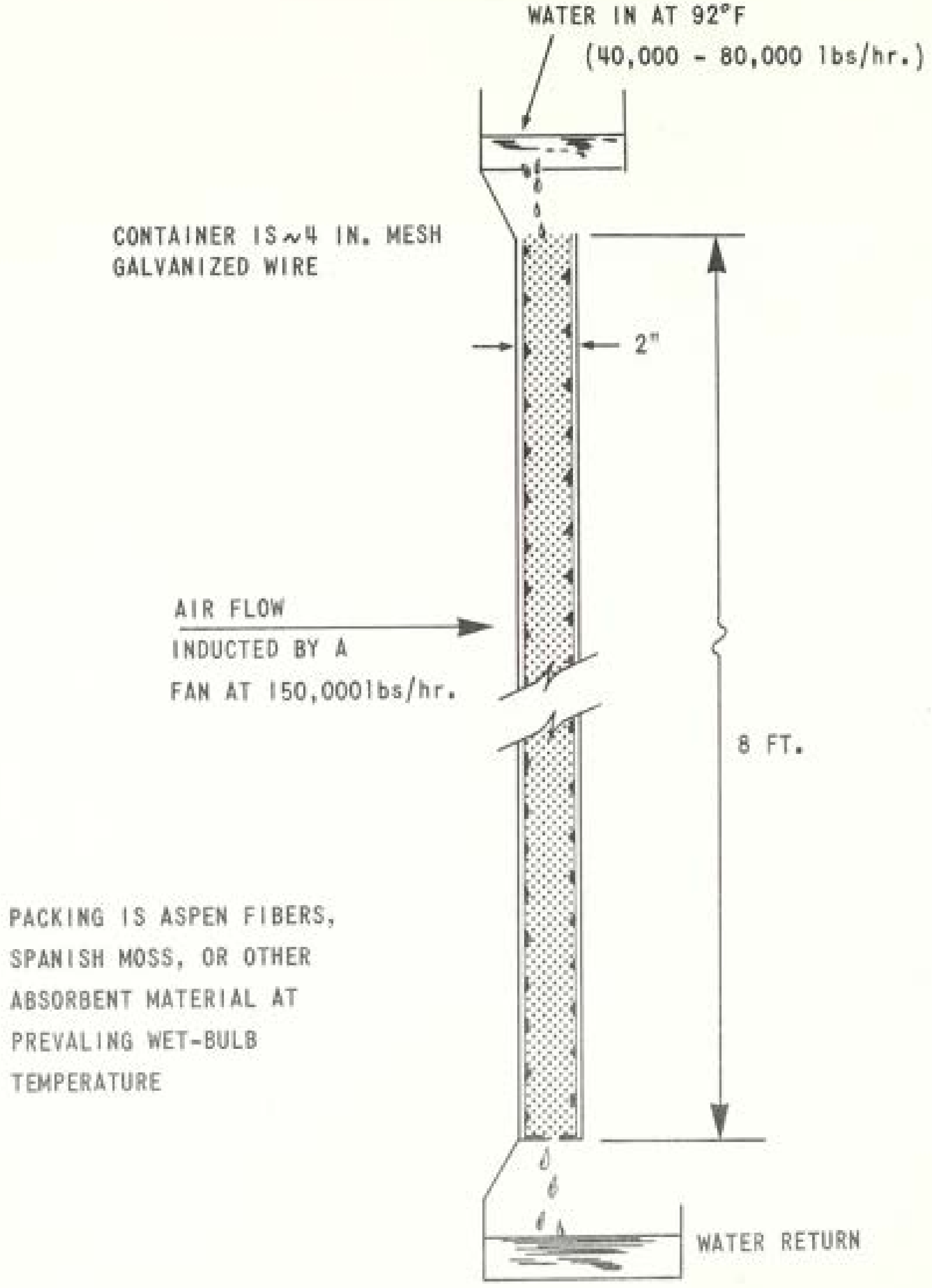


FIGURE 38. EVAPORATIVE-COOLER PAD ASSEMBLY

(BEALL, 1970a ORNL DWG.69-13962; COOK, 1971)

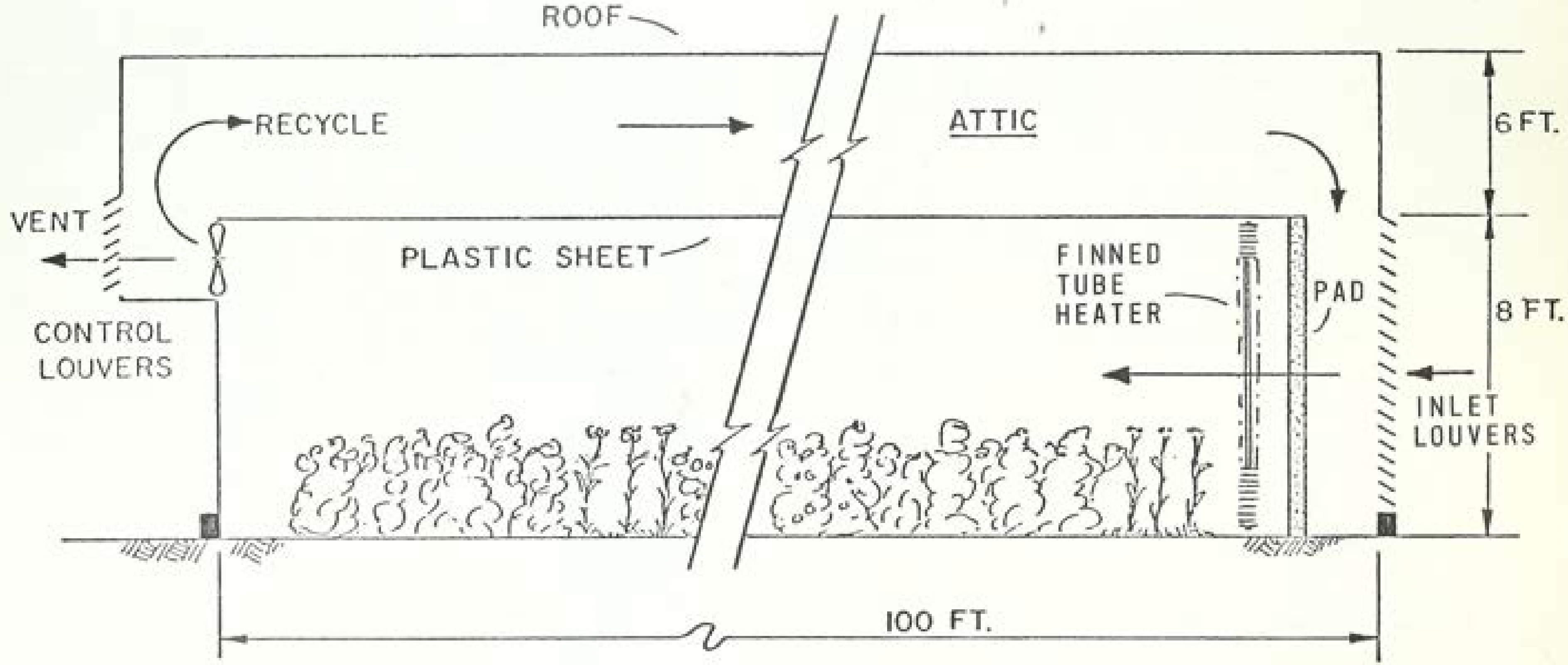


FIGURE 39. GREENHOUSE AND AIR FLOW SYSTEM

(BEALL, 1970a)

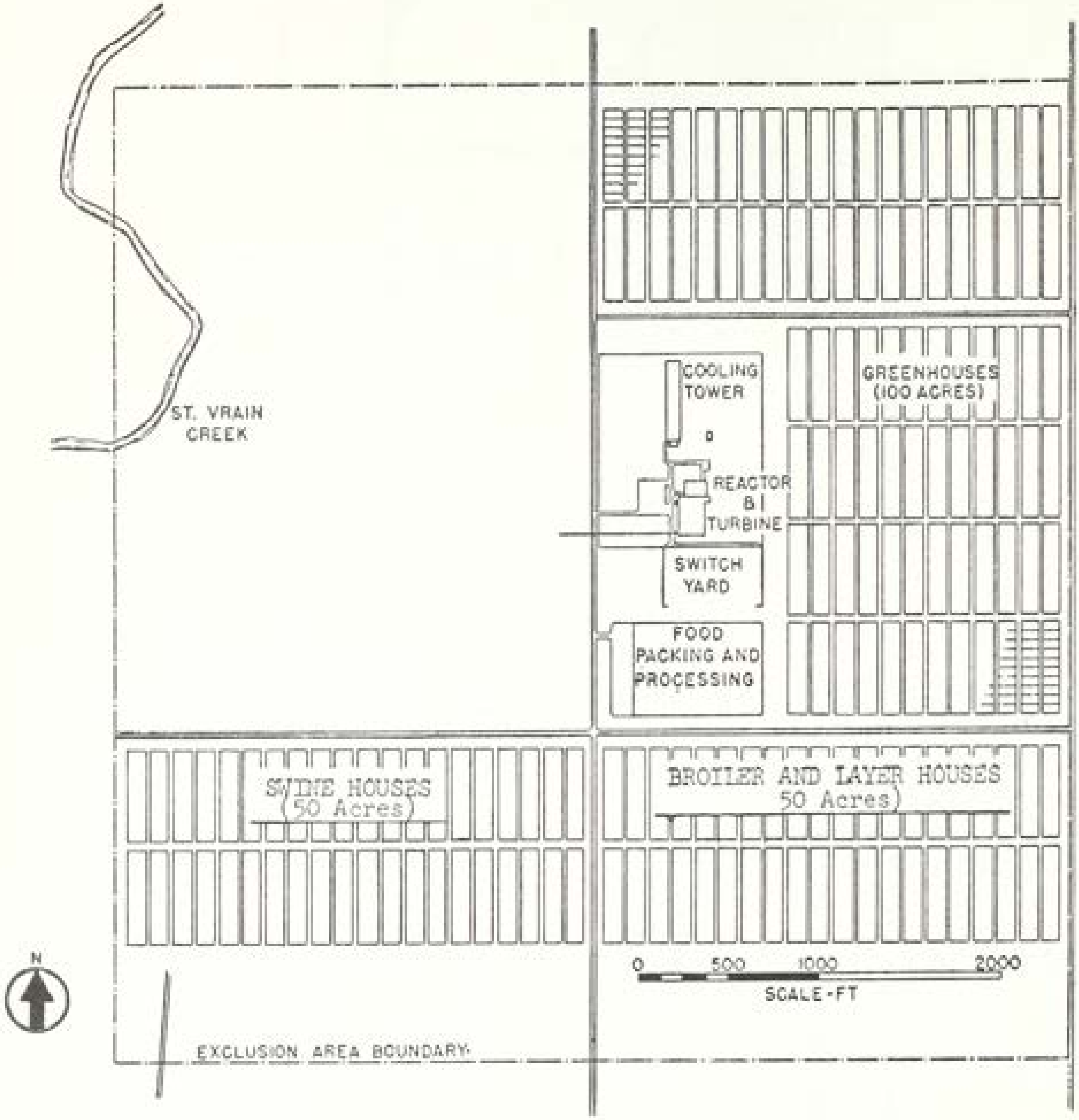
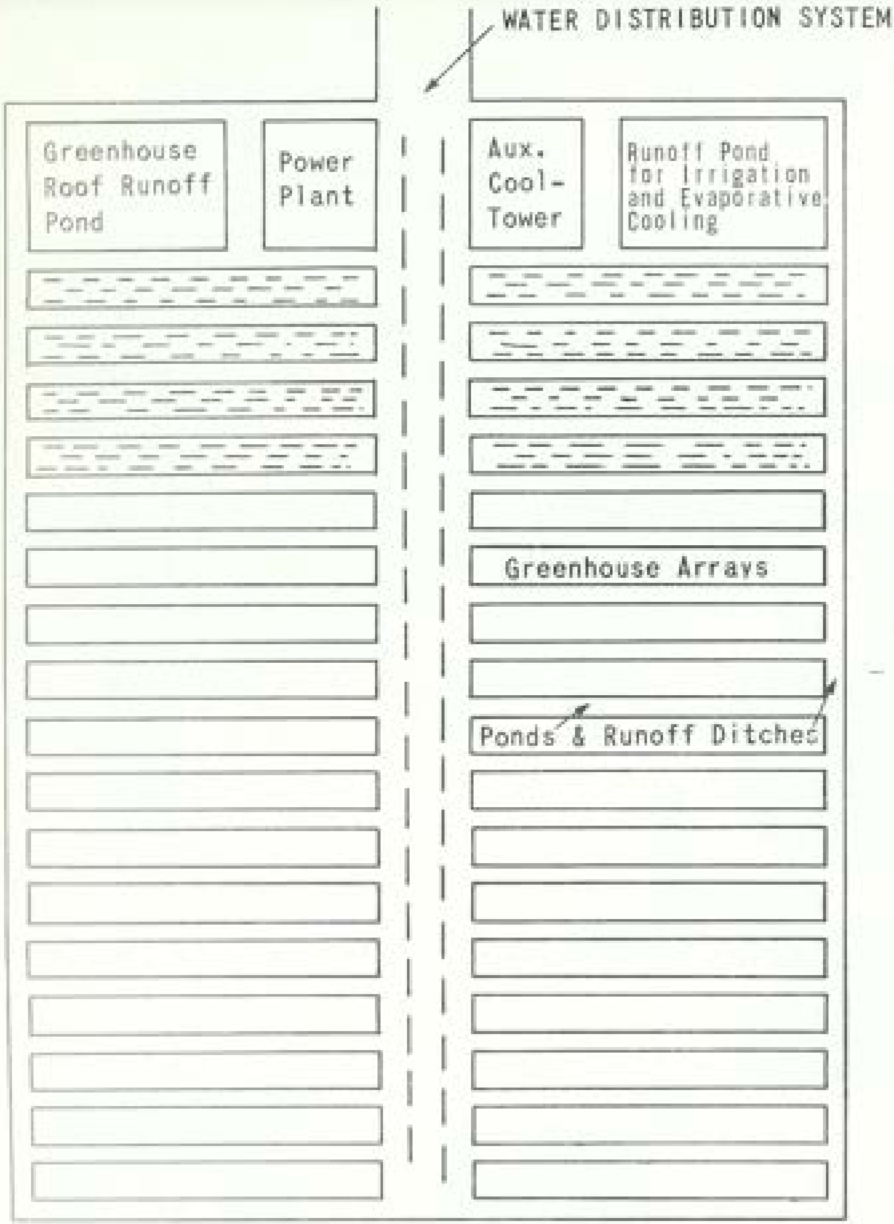


FIGURE 40. POSSIBLE LAYOUT OF FOOD PRODUCTION COMPLEX AT FORT St.VRAIN SITE

(BEALL, 1970a, ORNL DWG.69-11975R)



1. If the steam condensing temperature is raised to 200°F., a nuclear power plant could heat 123 ft^2 and a fossil plant 91.8 ft^2 of greenhouse per KW of plant capacity. The array above is for a 1000 MW plant.

2. The capital cost per ft^2 of standard glass greenhouse is approximately \$3.00 and the cost of heat equipment approximately \$.50/ft^2. These costs could probably be halved if air supported plastic structures were used in conjunction with dry cooling towers as a hot air source.

3. Yearly heating costs using a standard boiler would be 18¢/ft^2. Using power plant waste and extracting heat: 10¢/ft^2.

4. Typical Production Estimates:

   Expected sale value
   Dollars per square foot per year \$1.62

   Operating costs
   Dollars per square foot per year \$0.91

   Profit
   Dollars per square foot per year \$0.71

   (The acreage which could be heated by a 1000 MW plant would yield 30 lb. of tomatoes for every person in New York City).

5. If space is available greenhouse heating could be an economical way to use waste heat.

FIGURE 41. POWER PLANT AND GREENHOUSE SYSTEM (BELL ET AL, 1970)

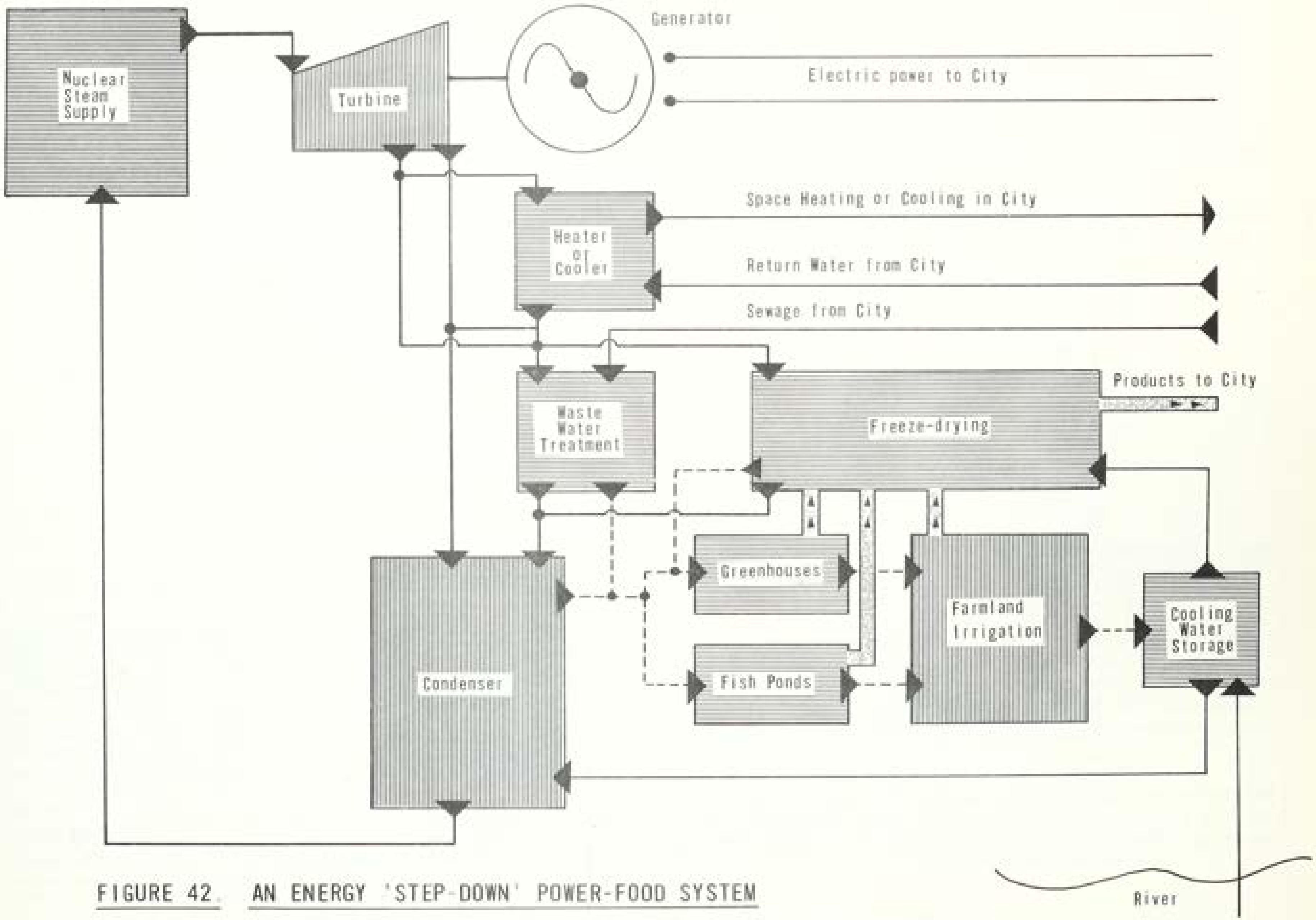


FIGURE 42. AN ENERGY 'STEP-DOWN' POWER-FOOD SYSTEM

(STEWART AND BJORNSSON, 1969)

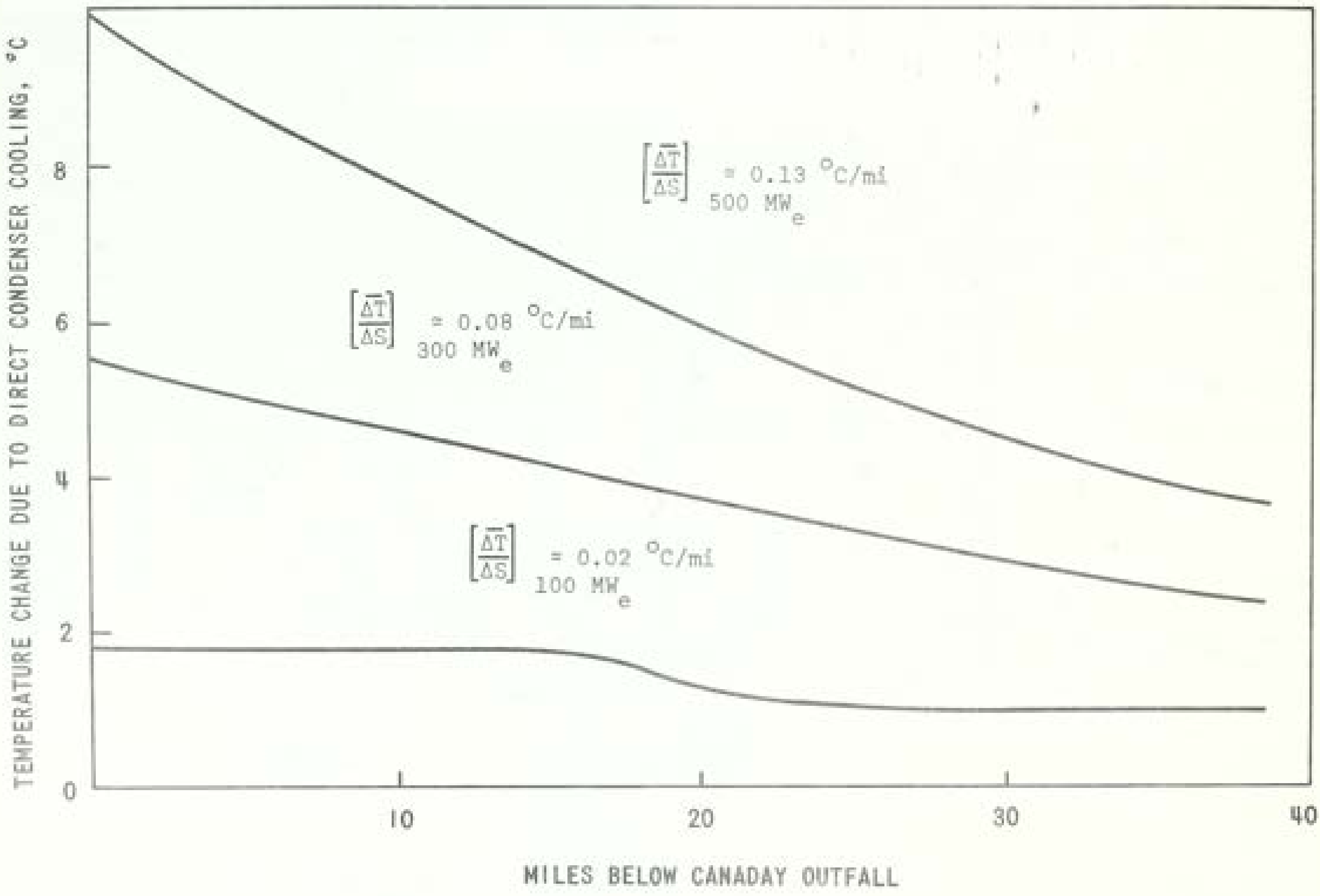


FIGURE 43 THERMAL CAPACITY OF PHELPS COUNTY CANAL SYSTEM (PETERSON & JASKE, 1970) (JASKE & TOUHILL, 1970)

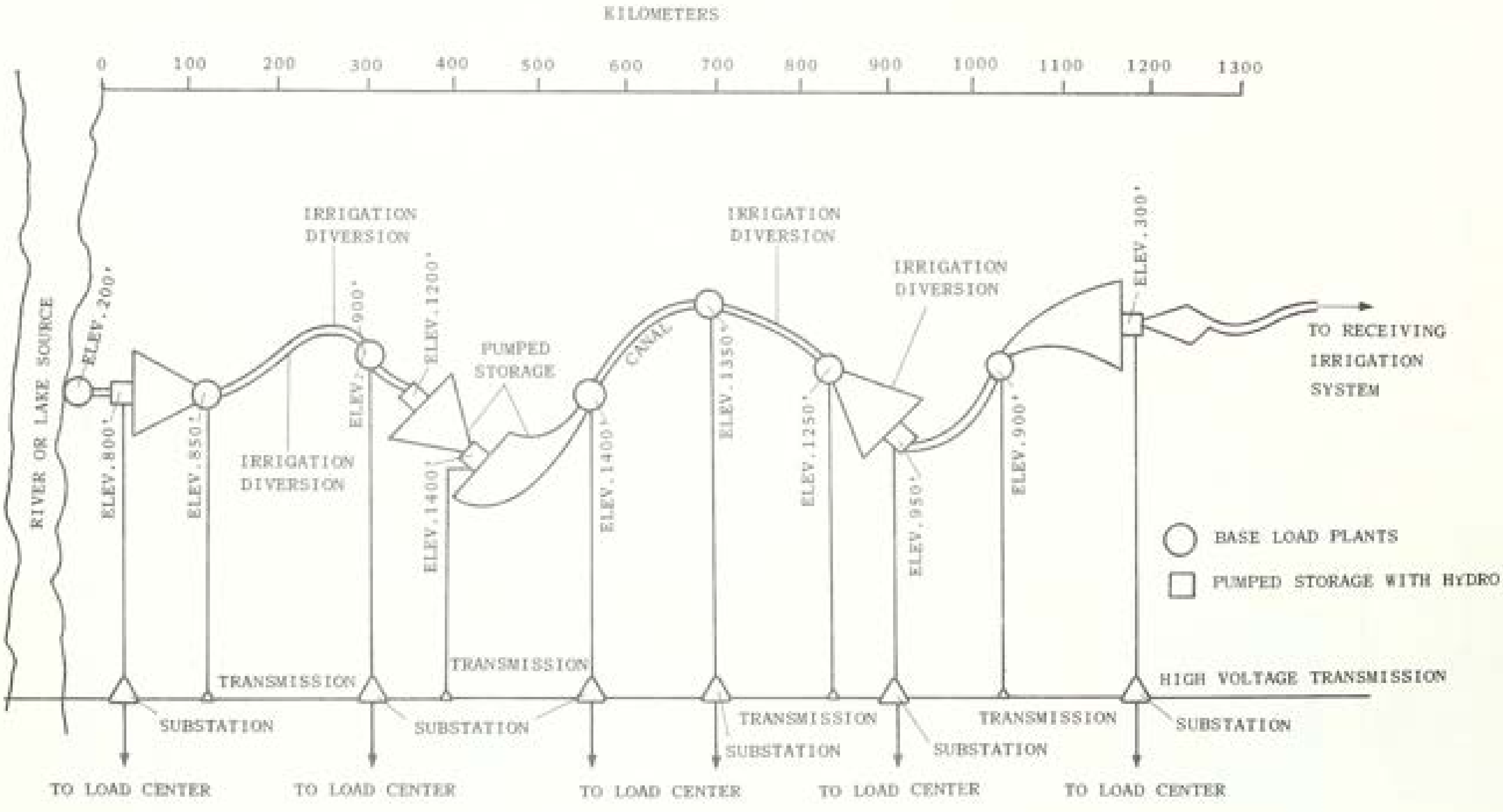


FIGURE 44. SCHEMATIC OF NUCLEAR-PUMPED STORAGE - CANAL LAKE SYSTEM

(JASKE AND TOUHILL, 1970)

ANNOTATED BIBLIOGRAPHY

ANNOTATED BIBLIOGRAPHY

Acres, H. G. Ltd. 1970: February *Thermal Inputs to the Great Lakes 1968-2000. Consultant Report for the Inland Waters Branch, Department of Energy, Mines and Resources, Niagara Falls, Ontario.*

Alabaster, John S. 1969: *"Effects of Heated Discharges on Fresh Water Fish in Britain" Proceedings: Biological Aspects of Thermal Pollution, National Symposium, 1968: 354-370, Nashville, Tennessee.*

The increase in temperature of the water used by electricity-generating stations for cooling purposes is often potentially lethal during the summer to trout and to the more sensitive species of coarse fish, such as roach, perch, and gudgeon, though not to tench and carp. Coarse fish are present in most rivers receiving these heated discharges but are rarely killed even close to the effluent outfall, probably because they avoid lethal conditions which are often confined to the surface layers, and also because those fish exposed to heated water in the neighbourhood of outfalls have become partially acclimated to temperatures above normal and thus become more resistant. When fish are killed, effluent temperatures are higher than normal, either because of exceptional operating conditions or intentionally for experimental purposes, but many fish apparently escape successfully. Most danger occurs near the outfalls, particularly when effluent recirculates both in the river and through cooling towers. Effluent temperatures are not always potentially level, even in summer, and may attract roach, gudgeon, carp, tench and bream. Indirect effects of heated effluents on fish in polluted rivers are likely to be important.

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Information is presented under the following headings: desalting plant system coupling studies; dual-purpose plant control studies; tradeoffs between electric power generation and transmission for large nuclear desalting plants; unclad-metal-fueled breeder reactor for desalting or power; metal-fueled pressurized-water reactors; general studies on agro-industrial complexes and of agricultural and industrial processes; applications of agro-industrial complexes; and Nuclear Desalination Information Center.

Anonymous. 1969: *Power/Water/Food Experiments at Puerto Penasco. Handbook of Universidad de Sonora Hermisillo, Sonora: and Environmental Research Laboratory, University of Arizona, Tuscon, Arizona.*

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The impact of man-made thermal discharges on the mass-energy balance of Lake Michigan is analyzed. The analytical method used is a generalized version of the heat-exchange model developed by Edinger and Geyer for small lakes and cooling ponds. The generalized model should be applicable to large bodies of water. Land-based meteorological data input to the model are corrected for systematic lake-land variation. The calculated annual average increase in Lake Michigan water-surface temperature is $1.4 \pm 0.4 \times 10^{3}$°F per gigawatt of advective input. The associated increase in evaporation water loss is 9 ± 2 cfs per gigawatt input. The model has also been applied to Lakes Superior, Huron, Erie, and Ontario. For each of these lakes, the respective increases in surface temperature and in evaporation water loss due to thermal discharges are presented.

Ascione, R. W., Southwick, W., Fresco, J. R. 1966: *"Laboratory Culture of a Thermophilic Alga at High Temperatures" Science, 153 (3737): p. 735-755.*

Battelle-Northwest, 1967: *"Power Reactor Sitting in the Pacific Northwest" Consultant Report to Bonneville Power Administration, July 1967.*

Bazell, R. J. 1971 (March): *"Arid Land Agriculture: Shaikh up in Arizona Research" Science: 171 (3975): p. 989-990.*

Beall, S. E. 1970: *"Agricultural and Urban Uses of Low Temperature Heat" Proceedings: Conference on Beneficial Uses of Thermal Discharges, New York State Department of Environmental Conservation, p. 185-201, Albany, New York.*

Beall, S. E. 1970 (December): *"Uses of Waste Heat" Paper presented at the Winter Annual Meeting, American Society of Mechanical Engineers, New York.*

A brief but comprehensive review on several continuing researches on potential applications of waste heat has been presented. Alternative mixes or packages of energy uses in diverse regions of the United States is suggested so that a large percentage, if not all, of the heat normally wasted can be utilized with benefits. Even if waste heat is used on a non-profit basis, it would still have the advantage of mitigating the adverse effects of thermal pollution. Numerous promising beneficial uses of waste heat have been summarized, and their engineering-economic implications have been discussed.

Beauchamp, R. Sa., Ross, F. F., Whitehouse, J. W. 1970: *"The Thermal Enrichment of Aquatic Habitats" Paper presented at the Fifth International Water Pollution Research Conference, July-August, 1970, San Francisco.*

This paper is concerned with power station cooling water discharges into rivers, lakes, estuaries and marine waters, and their effects on the ecology of such waters. Eighteen years' work by the biologists of the C.E.G.B. and its predecessors in title are summarized. The use of river water usually improves its quality and capacity to support a variety of aquatic life. In freshwater there would appear to be few problems, provided the temperature does not exceed the appropriate limit for the fish concerned, with no limitation on temperature-rise. It has to be established whether it is justifiable to install expensive engineering works to restrict maximum temperatures to less than 30°C in marine waters. It will be economically advantageous to discharge a small quantity of cooling water per kWh at a higher temperature than has been the practice hitherto. If this discharged warm water is spread out over the surface of the estuary it will cool rapidly, no harm to fish will result, and the benthos will not be affected.

Becker, D. C. 1969, December: *"The Food and Feeding of Juvenile Chinook Salmon in the Columbia River at Hanford" Biological Effects of Thermal Discharges: Annual Progress Report for 1968. Battelle-Northwest, Richland, Washington.*

Stomach contents of 445 young chinook salmon taken near Hanford were examined. They fed primarily upon aquatic insects, mainly chironomids, and secondarily on terrestrial insects. No evidence was found to suggest that heated effluents discharged in midwater plumes and which rapidly mix with the colder river water adversely affects either insect production or feeding activity of fish. Food intake was restricted in a few shoreline areas receiving warm water via intragravel seepage. The author feels that thermal discharge to the river, when waters are below preferred levels during spring runoff, may actually benefit the fish.

Bell, R. A., Cahill, W. J., Chiefetz, A. S., Cowherd, G. T., John, A., Nutant J. A., Wright, H. 1970: *"Combination Urban-Power Systems Utilizing Waste Heat" Proceedings: Conference on the Beneficial Uses of Thermal Discharges. New York State Department of Environmental Conservation, Albany, New York. September 17-18, 1970. p. 202-213.*

Benedict, R. W. 1971 May: *"Fuel Cell, long seen as electricity source, moves ahead in tests" Wall Street Journal 1, 29, May 19, 1971.*

The fuel cell is undergoing a renaissance that could have broad economic and ecological significance. It's a small, essentially pollution-free device with no moving parts that produces electricity through a chemical reaction of hydrogen and oxygen. The hydrogen can come from many common fuels — such as natural gas — and the oxygen, from the air. The first field test of a new lower-cost version of the fuel cell is underway in a display home in Farmington, Connecticut; 59 other units will be tested over the next year and a half in such diverse locations as a Los Angeles drugstore, a Chicago hamburger stand and a Brooklyn apartment. By the end of next year, its backers, Pratt & Whitney division of United Aircraft Corp., and 32 gas and electrical utilities, will decide whether they will proceed to commercial fuel-cell service by 1975.

Beukema, C. 1971: *"The Demonstration: U.S. Steel Shipping, Winter 1970-71 Seaway Review 2(2) 10-15, Summer, 1971.*

Beeston, M. D. 1971: *"Decapod crustacean and fish populations in experimental marine ponds receiving treated sewage wastes" Structure and Functioning of Estuarine Ecosystems exposed to treated Sewage Wastes: Annual Report 182-204, University of North Carolina, Institute of Marine Sciences, Chapel Hill, North Carolina.*

The effect of sewage plant effluents on estuarine ecosystems is investigated with emphasis on the decapod crustacean and fish populations. Experiments were conducted in six marine ponds (3 sewage-enriched and 3 control ponds). This paper deals chiefly with the population structure, biomass, and growth rates of some of the decapod crustaceans in the ponds. Populations and biomass determinations were accomplished for the fishes also. The control ponds contained twice as many species as the waste ponds. Blue crabs offer a possibility for harvestable food from estuarine ponds receiving treated sewage wastes.

Bienfang, P. 1971: *"Taking the Pollution out of Waste Heat" New Scientist and Science Journal 51(766): 456-457, August 26, 1971.*

The continuing rise in man's demand for energy brings with it the corresponding dangers of thermal pollution of inland waters. A solution is discussed in which cold, deep ocean water is used to neutralize its effect and to provide a bonus in the form of greater marine productivity and aquaculture.

Biggs, J. G. 1968: *"Waste Heat to Extend the St. Lawrence Seaway Season" Atomic Energy Commission of Canada, Report AECL-3061.*

Biswas, A. K. (Editor) 1972: *Proceedings: International Symposium on Modelling Techniques in Water Resources Systems. 3 vol. 775 p.*

Bjorkman, A. 1969: *"Thermal Treament of Sewage Sludge" Proceedings: Fourth International Congress of the International Research Group on Refuse Disposal. 670-681, Basel, June 2-5, 1969.*

Thermal treatment plays a growing role in the disposal of sewage sludge. It is used to pasteurize sewage for agricultural use. Hygienists recommend a temperature of 70 deg C for 20-25 minutes for pasteurization. Heat and pressure coagulate the solid materials contained in sludge, destroy the cell walls and release the strong binding of sludge water to solid materials. Treatment at 200 deg C and under 15 atmospheres pressure allows mechanical dehydration processes to obtain residual water content of 40-44%. Heat treatment is also applied in several drying processes such as multiple hearth dryers, drying drums, flash drying systems or a belt dryer. If the sewage cannot be used it can be incinerated and the smallest possible residues then disposed of. Fluidized bed incineration and wet incineration are described. Liquid or dehydrated sludge can also be incinerated in appropriate devices jointly with good results.

Bjorkman, A. 1969: *"Thermal Treatment of Sewage Sludge" Proceedings: Fouth International Congress of the International Research Group on Refuse Disposal. 682-686, June 2-5, 1969. Basel.*

Working Group Six of the 4th International Congress of the IRGR discussed four main issues of sludge treatment: hygienization, dehydration, drying, and incineration of sewage. The necessity for hygienization destroying the pathogenic germs in order that the sludge can be used in agriculture without any danger of infection was discussed. Problems concerned with use of sewage for irrigation were also discussed, for example groundwater pollution and heavy metal accumulation in soil. Thermal treatment for the purpose of dehydrating was evaluated emphasizing the exclusion of soil pollution, using drying beds, digestors or chemical admixtures as advantages. The discussion dealt mainly with the problem of what treatment should be applied to the highly polluted effluent of dehydration. Multi-use plants for both drying and incineration were described.

Black, D. S. 1968: *Keynote Address. Biological Aspects of Thermal Pollution. Proceedings: National Symposium on Thermal Pollution, sponsored by the Fed-*

eral Water Pollution Control Administration. 3-9. Vanderbilt University Press.

Bodien, D. G. 1970: *"An Evaluation of Salmonid Hatchery Wastes" U.S. Department of the Interior, Federal Water Quality Administration, Northwest Region. Portland, Oregon.*

Boersma, L. 1970: *"Warm Water Utilization" presented before the Conference on Beneficial Uses of Thermal Discharges, New York State Department of Environmental Conservation, Albany, New York. September 17-18, 1970.*

An integrated system for the management of thermal discharges from a steam electric generating station was suggested. The major elements of the system were: soil warming facilities, cooling units, processing plant, and animal rearing. A cost analysis indicated the economic advantages and limitations of the proposed system. Five basic criteria were proposed for properly selecting the elements of a suitable system for the beneficial uses of waste heat.

Bogh, P., Zünd, H. 1970: *"The Control of River Heating by Accurate Digital Simulation" in Environmental Aspects of Nuclear Power Stations. Proceedings of a Symposium on the Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency in cooperation with United States Atomic Energy Commission in New York, 10-14 August, 1970. 615-624. I.A.E.A., Vienna, 1971.*

The thermodynamic behaviour of rivers and river systems is carefully investigated in Switzerland which, as a country without access to the sea, more than most other nations depends on river cooling for economic nuclear power generation. The answer to the question of how to use the limited cooling capability to a maximum without harming the rivers and surroundings is an urgent problem. The optimum siting of the plants must be determined, considering the cooling capability of the river, the available plant sizes in addition to a number of economic factors. The possibility of combining cooling towers with river cooling requires determination of optimum tower capacity. In order to be able to approach the problem with the accuracy required by these important economic considerations, it was decided to prepare a digital simulation program to reproduce the thermodynamic behaviour of the rivers. The program was based on a formalism specially developed for this application. The basic requirement that all basic parameters were to be allowed to vary, so that the comparison between measured and computed river temperatures would permit the heat transfer coefficients to be improved. The resulting program was developed to have considerable flexibility, allowing for tributaries with variable temperatures, several different time-varying meteorological conditions along a river, heat sources with time-variable intensity, variable river geometry, simulation of the dispersion (longitudinal mixing) by having two (easily changeable to more) channels with different water velocities, etc. The time interval in the simulation can be made rather short (down to half an hour) allowing one to follow closely the important daily temperature variations. All the above characteristics of the program are necessary to simulate the fast-flowing rivers of Switzerland satisfactorily. The program is described and computations commented on. Sample results are compared with the measured natural temperatures and it is shown how the daily temperature variations (due to day-time heating and night-time cooling) can be used to adjust the heat transfer coefficients, up to now primarily measured in lakes, for the simulation of rivers.

Bowers, A. 1970: *"Whatever Happened to Fish Farming?" New Scientist, 48(728) 380-381, London, December 3, 1970.*

Several complex problems have to be solved before a suitable farming technique for mari-culture can be developed in Great Britain. Though the great potentials of artificial fish farming have been well publicized, its problems and difficulties have seldom been adequately discussed. Most of these problems need immediate attention from the researchers so that a commercially feasible fish farming technology can be developed. Britain, in order to maintain its leadership in this field, will have to undertake an expensive research program.

Boyd, W. 1959: *A Study of Possibility of All Year Navigation on the St. Lawrence Waterway. A. D. Little of Canada, Ltd.*

Bradley, L. *"There's Gold in Them Thar BTU's" in Transactions of the Thermal Effluent Information Meeting. July 9, 1970. Boise, Idaho. p. 47-57.*

Brandt, D. H. 1969: *"Michigan Utilities Thermal Effects Surveys." Citation No. 71-2TB-C302 p. 48-57. Consumers Power Company.*

Water control studies undertaken by Consumers Power Company to determine the behaviour of the thermal discharge from their generating stations showed that the B.E. Morrow Plant on the Kalamazoo River and the B.C. Cobb Plant on Cedar Creek met State Water Temperature Standards. A combined biological and temperature survey was conducted at the J. H. Campbell Plant to evaluate the input of heated water discharge on the biota of southeastern Lake Michigan, with results showing no apparent gross thermal damage to the benthic fauna of the main plume area. A five-year biological and temperature survey, presently in its second year in connection with the Palisades Plant on Lake Michigan, is described.

Braun, R. E., Jones, J. A. 1970: *"Thermal Loading in Dunkirk Harbour" Lake Erie Environmental Studies, Technical Data Report, No. 5, 16 p. New York State University College, Fredonia.*

Thermal loading due to warmed effluents from a power plant located on Dunkirk harbour, southest Lake Erie, has been studied over a 14-month period. To date no serious detrimental effects have been demonstrated.

Bregman, J. I. 1968: *"Putting Waste Heat in its Place" Keynote address in Parker and Krenkel: ch. 1, 3-14, 1969.*

Bregman, J. I. 1968: *"Thermal Pollution Control — Need for Action" Thermal Pollution Symposium of the Cooling Tower Institute Meeting. New Orleans, La., January 30, 1968. p. 1-8.*

By 1980, one-fifth of the total fresh water runoff of the U.S. will be used for cooling. The 95% of thermally-generated electricity that is presently produced by fossil fuel will decline to 65%, and the nuclear plants require 40% more condensed water for a given temperature rise than fossil fuel. The result will be larger, more concentrated loads of waste heat, which threaten the survival of the aquatic life in the streams on which power plants are located. The 1965 Water Quality Act has resulted in the setting of interstate water quality standards in all states, with different types of waters (warm, cold, marine) and different uses assigned different limits. Those standards will be enforced by the states, aided by the federal government if necessary. Many states have set standards for intrastate streams which include temperature changes. The federal government is working to set an example by controlling thermal wastes from nuclear reactors owned by the Atomic Energy Commission. Proposed controls include issuing licenses for construction of plants only when thermal pollution is prevented and providing department review of pending power applications.

Bregman, J. I. 1971: *"Useful Energy from Unwanted Heat" Chemical Engineering. 78(2): 83-87. New York. January 25, 1971.*

Once through cooling is certainly the most economical way of accomplishing heat dissipation. The results of a study conducted by Federal Power Commission show that about 71 stations in the 1,000 to 4,000 MW range are capable of being supported by reservoirs, 24 in the 4,000 to 12,000

MW range, and 8 at 12,000 MW or greater. Efficiency of a cooling pond may be increased markedly by introducing a spray into the system. Common problems connected with large cooling waters include wood deterioration, biological fouling, the formation of deposits, corrosion and scaling. Another major problem is drift and fogging. A typical tower with a flow of 250,000 gal. per minute operating on sea-water with a salinity of 35,000 ppm, and a drift loss of 0.1 per cent will emit about 4,400 lb. per hour of sodium chloride. Costs for dry tower runs from $25 to $30 per kW, compared to $8 to $13 per kW for wet towers. Cooling water from a nuclear power plant may be particularly suited to aquaculture. Possibility of placing a chemical plant next to a nuclear plant appears attractive. It is concluded that potential does exist for turning waste heat into a useful commodity.

Brett, J. R., Shelbourn, J. E., Shoop, C. T. 1969: *"Growth Rate and Body Composition of Fingerling Sockeye Salmon, Oncorhyncus nerka, in relation to temperature and ration size" Journal of the Fisheries Resource Board of Canada: 26, 2363-2394.*

Brezina, E. R., Campbell, R. S., Whitley, J. R. 1970: *"Thermal Discharge and Water Quality in a 1,500 Acre Reservoir" Journal of the Water Pollution Control Federation, 42(1): 24-32, January 1970. Washington, D.C.*

This study reports on the effects of thermal discharges from a 525,000-kW fossil-fueled steam-electric plant into a 1.57 x 107-cu m (4.5- x 10⁸-gal) reservoir with a mean depth of 2.5 m (8.2 ft): The location is central Missouri. The most significant effect observed during the 21-month study was temperature elevation which averaged 5 degrees to 8 degrees C with a maximum difference in mean temperature of 10 degrees C. Differences in DO were always less than 1 mg/l. The area heated by the thermal discharge is influenced by the direction of the prevailing wind. The relatively shallow depth of the reservoir with the wind effects minimizes with thermal stratification and maintains suspension of fine particles. Runoff water maintains the high level of turbidity in the reservoir. There was no significant difference in living matter present in the heated and unheated areas of the reservoir.

Brogan, T. P. 1970: *"Russians Push Magnetohydrodynamic Power" Power: 70-71, May 1970.*

The Russians are developing a magnetohydrodynamic power generating plant which will operate on natural gas and develop 75 MW, 25 MW of which will be produced by the generator and the remainder by a bottoming steam plant. In the generator plant, known as U-25, power is removed via 48 electrode pairs along the channel, and there are 48 investers which can be interconnected in a multitude of ways to provide operating flexibility. The main advantage of this method of power generation is its efficiency, some 15% above that of the conventional coal-fired stations. The apparent shortcomings of the Russian plant are its low combustion pressure and field strength.

Brown, D. 1970: *"Trends of Power Generation and Expected Heat Discharges" paper presented at the Conference on Beneficial Uses of Thermal Discharges, Albany, New York, September 17-18, 1970.*

It examines the present and future trends in the output of thermal exhausts of fossil-fuel and nuclear steam-electric power plants. Stringent environmental quality criteria may require about half the total installed capacity in the United States to use cooling ponds, towers and long ocean outfalls. Thus, a planned development of the power industry could only overcome the anticipated environmental crisis.

Burlew, J. S. (ed.) 1953: *Algal Culture from Laboratory to Pilot Plant, Carnegie Institute, Washington, D.C.*

Burns, W. J. 1969: *"Beneficial Effects of Warm Water Discharges from Power Plants" Paper presented by Long Island Lighting Company at South Eastern Electric Exchange Production Section Meeting, Clearwater, Florida, 13 p. April 22, 1969.*

Business Week, 1970: *"Utilities put Faith in Old Faithful" Business Week, (2144): 50, 52, October 3, 1970.*

With utilities throughout the United States trying to balance a power crisis against an environmental one, there is increased interest in geothermal energy. Scientists hope it will eventually be possible to tap geothermal energy anywhere on earth. To put this underground heat to work, a shaft would be dug and an underground cavity blasted in the rock with a nuclear device. Water would then be piped into the hot cavity, turning it into an underground boiler. The resulting steam would rise through a shaft to spin a turbine generator, and then would be cooled and returned underground in a completely closed cycle. That would minimize the radiation hazard; also there would be no smoke and little waste heat. Geothermal power has been called "absolutely pollution-free."

Cairns, J. Jr., 1968: *"We're in hot water." Scientist and Citizen, 10(8): 187-198, October 1968.*

A biologist explains the ecological imbalance which results from thermal discharges into streams, lakes and tidal waters and makes recommendations: The aquatic ecology of waters to be used as a source of cooling water should be studied extensively before approval of any new sites for generating stations, and a continually operating monitoring program should start when the plant begins operations. "A simpler, though more drastic approach, would be for a state to require all new steam electric generating plants to include closed system cooling towers in their design." (All electric generating plants in England are required to have cooling towers). Another approach would be federal support for research and development of alternative power sources. The author asserts, "We cannot continue to expand our production of electric power with present generating methods without causing a major ecological crisis."

Cairns, J., 1969a: *"Heat Effects Upon the Aquatic Environment" Paper presented at the Governor's Conference on Thermal Pollution, July 18, 1969, Traverse City, Michigan. p. 21-30.*

Discharge of heated wastewater may effect the entire aquatic ecosystem and, if the temperature change is large, may destroy the capacity of the ecosystem to serve a variety of beneficial purposes. However, it is possible to discharge heated wastewater in carefully controlled amounts without seriously degrading the aquatic ecosystems. Four alternatives of the heated wastewater problem are: placing all heated water in streams, lakes and oceans without regard to the effects; using, but not abusing, existing ecosystems; finding alternative ways to dissipate or benefically use waste heat; and modifying ecosystems to fit the new temperature conditions. Today the non-expandable ecological portion of our life-support system is endangered by the expanding industrial portion. A variety of descriptions and views must cooperate and work together. Since wastes in amounts that are acceptable taken one at a time may be lethal collectively, environmental management should be on a regional basis.

Cairns, J. Jr. 1969b: *"The response of fresh-water protozoan communities to heated wastewaters." Chesapeake Science, 10 (3-4): 177-185, September-December, 1969.*

The response of fresh-water protozoan communities exposed to both severe acute temperature shocks as well as small gradual long-term increases are discussed. The former experiments were carried out in plastic troughs with a constant flow of unfiltered lake water. Severe acute shocks (some to nearly 50°C) resulted in a marked reduction in number of species present. However, recovery was quite rapid (a matter of a few days) once the temperature stress ceased. Observations of the effects of small gradual long-term increases were made on the protozoan communities of the Savannah and Potomac rivers each of which received heated waste water discharges. Each of these studies covered a period in excess of nine years and observations are still being made. At the time the paper was prepared there was no evidence that indicated the protozoan communities of these rivers had been degraded by the small

gradual temperature increases resulting from the discharge of heated wastewaters. However, there is evidence that competitive exclusion of algal species by other more tolerent algal species may cause qualitative shifts in the community structure which may be undesirable. It is probable that similar shifts occur in protozoan communities — a factor which should be considered in future studies.

Cairns, J. Jr., 1970: *"Ecological Management problems caused by heated waste water discharge into the aquatic environment." Water Resources Bulletin, 6(6): 868-878. December 1970. Paper presented at the Governor's Conference on Thermal Pollution, Traverse City, Michigan, July 18, 1969.*

Discharge of heated waste water may affect the entire aquatic ecosystem — the interrelated biological, chemical, physical, system — and, if the temperature change is large, may destroy the capacity of the ecosystem to serve a variety of beneficial purposes. However, it is possible to discharge heated waste water in carefully controlled amounts without seriously degrading the aquatic ecosystem. Four basic alternatives to solve the heated wastewater problems are presented.

Cairns, J., Humphrey, P. S. 1969: *"A Resources Ecology Capability for the Waterways Experiment Station and the U.S. Army Corps of Engineers." U.S. Army Corps of Engineers Contract Report 0-69-1, 26 p.*

Cairns, J. Jr., Kaesler, R. L. 1969: *"Cluster Analysis of Potomac River Survey Stations Based on Protozoan Absence Data." Hydrobiologia, 34(3-4): 414-432. December 1969.*

Four high-water and six low-water limnological surveys of a portion of the Potomac River were made from 1956 to 1965; samples were collected at three stations on each survey to determine the effects of operation of the PEPCO Dickerson Power Station on the aquatic biota. Cluster analyses were made of various combinations of Jaccard coefficients relating 46 aggregations of 647 protozoan species. Similarities of aggregations of species within a survey were nearly always greater than similarities among aggregations from different surveys, indicating linear or along-stream environmental influences. Within-survey similarities for the early and late surveys were usually higher than similarities within middle-year surveys, a possible indication of environmental change at all stations, including the control, and subsequent biotic readjustment. Clustering of the 1956 aggregations, taken under high-water conditions before plant operations began, with aggregations from other surveys for any one station indicate that 1956 may have been different from other surveys years. One explanation is that increased urbanization upstream from the power station after 1956 caused some environmental change. No changes in aquatic biota could be attributed to thermal pollution as a direct result of operation of the electric power generating station. The clustering method used provides a convenient means of quantitative analysis of limnological survey data.

Cairns, J. Jr., Paterson, R. A., 1970: *"The effects of heated waste waters upon microbial communities." Virginia Polytechnic Institute, Water Resources Research Centre Bulletin No. 40: 131-142 December 1970.*

Research was initiated towards the study of the effects of thermal stress on diatom populations. The major approach involved the development of effective staining techniques to demonstrate physiological alterations induced by exposure to such stress. Protozoan studies consisted of three categories: tests conducted to determine the effects of a sudden heat shock on natural protozoan communities collected from bodies of water around Blacksburg, Virginia; time until death curves constructed with various individual species of protozoans recording both maximum survival temperature and median survival temperature after the heat application; and a simulation of the passage of water containing protozoans through the condensing coils of a steam electric generating power plant. Results of this work indicate that there was no significant reduction in diversity between control and experimental communities, and that there may be subtle differences in colonization rate and ultimate maximum population density between control and experimental communities.

Camp, T. R., Root, D. A., Shoota, B. U. 1940: *Journal of the American Water Works Association, 32, 1913.*

Campell, R. S., Witt, A. Jr., Whitely, J. R. 1970: *"Possibilities for Beneficial Uses of Heat Water Discharges into Cooling Reservoirs." Paper presented at the Fifth Annual Water Resources Research Conference, February 3-4, 1970. U.S. Department of the Interior, Washington, D.C. June 1970. p. 57-64.*

Montrose Lake and Thomas Lake in Missouri were studied. Both were artificial cooling reservoirs. Studies included water quality, primary production of algae, plankton and bottom fauna and fish. Impact of heated water upon the ecology of a reservoir will be lessened as the volume of the reservoir is increased. Employment of a long cooling canal results in loss of heat to the atmosphere prior to discharge into the reservoir. Under the conditions existing in Thomas Hill Reservoir, no lethal effects from heated water inflow were observed. Beneficial effects which may be derived from controlled discharge of heated water are: (a) Migration of fishes may result in a buildup of fish densities. (b) The increased density of fishes may provide an extended harvest into the winter period. (c) Continued growth of game fishes may occur during the winter period. (d) An increased production of commercially raised fish may be possible. (e) The location of the power plant might be planned to provide optimal conditions for fish harvest and for use of heated water effluent in hatchery and rearing pools.

Canadian Chemical Processing, 1971: *"Special Report on Plant Energy Systems — 1." Canadian Chemical Processing, 55(8): 31-33. August, 1971.*

Chapman, P. F. 1970: *"Energy production — A world limit?" New Scientist, 47(720): 634-636. London, September 24, 1970.*

Changes in the power input to the earth will cause a change in the surface temperature as derived from Stefan-Boltzmann's law. Thus the percent change in the surface temperature is four times the percent change in the power input. Using the value of 280° K for the surface temperature, it follows that a one percent rise in the power input corresponds to a temperature rise of 0.7° K. It is this effect which imposes a limit on the production of energy on earth. This limit on energy production only restricts the production of energy which is not normally included in the earth's thermal equilibrium. At the present time only 90 percent of the world's energy production is derived from non-equilibrium sources. Virtually all this energy ends up as heat. The global equilibrium will not be affected by extracting energy from the tidal, solar, and geothermal sources. To prevent thermal pollution of the earth's atmosphere, there is an urgent need for a research and development program into the utilization of solar power.

Church, B. D., 1970: *"Fungal Synthesis offers advantages." Food engineering: reported in BOESMA, 1970. "Warm Water Utilization" Paper presented at the Conference on Beneficial Uses of Thermal Discharge, New York Department of Environmental Conservation, Albany, New York, September 17-18, 1970.*

Churchill, M. A., Wojtalik, T. A., 1969: *"Effects of heated discharges: T.V.A. experience." Nuclear News, 12(9) 80-86, September, 1969.*

Since 1955, TVA has been observing the distribution in streams and reservoirs of heated waters discharged from TVA's thermal-electric power plants. Detailed biological surveys have been made at all of TVA's steam plants except the Shawnee located on the Ohio River. No significant effects on aquatic life have been found except at the Paradise plant on the small Green River in Kentucky. Here, observed effects on fish-food organisms indicated more control of maximum stream temperatures to be [illegible]. Cooling towers have been built here. At the two nuclear power plants now under construction, multiport diffusers on the bottom of the old river channel in the receiving reservoirs will provide diffusion and rapid mixing. Stream temperatures will not be allowed to increase more than 10°F, nor to exceed 93°F, at any time.

Civil Engineering and Public Works Review, 1971. July: *"Ipswich Freeze Desalination — Plant: Shown by the Water Resources Board," p. 757.*

Cone, B. W., 1970: *The Economic Feasibility of Establishing an Irrigated Forestry Enterprise on the Hanford Reservation, Washington. Battelle Memorial Institute Research Report, YR9341, 43 p. Pacific-Northwest Laboratories, Richland, Washington.*

Water discharged from reactors and processing plants, temperature climate, and controlled access may provide the residues to sustain a forest on the Handford Reservation, Washington. The reservation is in a desert, where the relative humidity falls to 6%, and the temperature rises to 115 degrees. Some tree species survive in a few isolated areas as the remains of an older irrigated agriculture. To determine the economic feasibility of irrigating trees, available land, water and atmospheric factors are initially assessed. Estimates are made on the quantity of wood fiber which could be produced with a given water quantity. Finally, net returns on the most promising irrigated species (Ponderosa pine, Douglas fir, Poplar and Sycamore) are evaluated. Irrigated ornamentals also show considerable growth. The analysis concludes that it is economically feasible to establish an irrigated cottonwood or sycamore forest, providing the trees are mechanically harvested every 5 years, and the chips are used in an adjacent pulp mill. Net annual return from cottonwood and sycamore are estimated at $23.52 and $45.54 per acre. Forest establishment under these circumstances is a calculated risk, where there is an 88% probability that present value of the cottonwood enterprise would be greater than .0, and an 85% probability that it would exceed 0 from a sycamore enterprise.

Coutant, C. C., 1968: *Literature Review, 1967. (Thermal Pollution-Biological Effects). Journal of the Water Pollution Control Federation, 40 (6) 1047-1052.*

This article reviews the literature of 1967 on the biological effects of thermal pollution. The main topics are the biological problems associated with nuclear power plants, water criteria to protect aquatic life, DO in streams in correlation with thermal pollution, influence of temperature on aquatic life, resistance of cells to high temperature, relationship of water temperature to growth of some fish, preference temperatures of some fish, constructive uses of waste heat from thermal power plants.

Coutant, C. C., 1969: *"Thermal Pollution — Biological Effects". Journal of the Water Pollution Control Federation, 41 (6): 1036-1053.*

This review summarizes the results of the most recent research concerning the biological effects of thermal pollution. Subjects covered specifically include heated- discharges, reviews of temperature effects, thermal resistance, temperature selection, primary production, and waste stabilization. Also covered are the effects of temperature on reproduction, performance, growth, learning (conditioned response), and physiological activities, as well as synergistic effects of temperature and other pollutants.

Coutant, C. C., 1969: *"Behavior of Sonic-Tagged Chinook Salmon and Steelhead Trout Migrating Past Handford Thermal Discharges". Biological Effects of Thermal Discharges: Annual Progress Report for 1968. Battelle-Northwest Laboratories, Richland, Washington, p. 21-26.*

Eighty-nine chinook salmon and 279 steelhead were marked with sonic tags to determine their pathways of spawning migrations as they move through the warm waters surrounding the Hanford facilities. The fish were found to migrate mainly along the shoreline, principally utilizing the left bank opposite the reactors during peak river temperatures. No statistical difference was found between migration rates of the two species or between rates along shorelines inside and outside the reactors' thermal influence. Average migration rates were studied and found to be distinctly nonuniform. The authors feel there is data available to identify the causes of anomalies in distribution and migration rate.

Coutant, C. C., 1970: *Thermal Pollution — Biological Effects, A Review of the Literature of 1969. Journal of the Water Pollution Control Federation, 42 (6): 1025-1057, June 1970.*

This article reviews the literature of 1969 on the biological effects of thermal pollution. It sites a number of other reviews published during 1969 dealing with temperature effects in aquatic ecosystems, industrial thermal discharges, and subtle responses of organisms to temperature changes. The main topics covered are the biological problems associated with biogeography, synergism, resistance, reproduction, polymorphism, feeding, growth, temperature selection, physiology, disease, primary production, waste assimilation, and beneficial uses. Another topic covered briefly is on-site field studies of biological effects resulting from thermal discharges.

Coutant, C. C., 1970 B: *"Biological Limitations on the Use of Waste Heat in Aquaculture". Proceedings of the Conference on Beneficial Uses of Thermal Discharges, New York State Department of Environmental Conservation, Albany, New York, September 17-18, 1970, p. 51-61.*

Coutant, C. C., 1971: *1970 Literature Review, Water Pollution, Thermal Pollution — Biological Effects. Journal of the Water Pollution Control Federation, 43 (6): 1292-1334.*

Article reviews the literature of 1970 on Biological Effects of Thermal Pollution in Aquatic Environments.

Coutant, C. C., Becker, C. D., and Prentice, E. F., 1969: *Passage of Downstream Migrants, Biological Effects of Thermal Pollution, Annual Progress Report for 1968. Battelle-Northwest Laboratories, p. 9-12.*

Juvenile chinook salmon were confined to live boxes which were drifted through reactor discharge plumes below Hanford on the Columbia River. No direct or 24 hour latent mortalities were induced during spring and summer. Shoreline areas affected by intragravel seepage of heated water reached lethal levels for chinook. In these area losses of test fish during mid-summer occurred. Most temperature rises did not exceed the ultimate incipient lethal level for the species. Emigrating juvenile chinook trapped in May following passage through the warmest part of the thermal discharge plume showed no mortality, equilibrium loss or 'gas bubble' disease. The authors feel that most emigrating juvenile salmon are successful in passing areas of maximum thermal change at Hanford.

Cronin, L. E., Daiber, J. C., Hubert, E. M., 1962: *"Quantative seasonal aspects of zooplankton in the Delaware River estuary." Chesapeake Science, 3 (2): 63-93.*

Crotty, P. A., Feng, T., Skrinde, R. T., Ruzminski, L. N., 1968: *First Northeastern Regional AntiPollution Conference. University of Rhode Island.*

Culotta, J. M., 1968: *"Evaporation System Recovers Chemicals from Planting Wastes." Water and Wastes Engineering, p. 62-64.*

Significant advances have been made in handling cyanide and chromic acid plating waste operations by new sophisticated systems that recover the bulk of the wastes by evaporation, and neutralize or chemically destroy only the small fraction which is not economically recoverable. Described are: the close-loop system, in which a single-effect evaporator concentrates flow from the rinse water holding tank, and the open-loop system. The circulation loop

through the evaporator is opened by creating another loop for the cyanides. The dragout solution can be retreated before sewering. An economic table-analysis of this system is given. In the third system, called optimized system, 80-90% of the chromic acid normally lost by dragout is recovered from waste, through evaporation, by utilizing waste heat. This helps prevent thermal pollution also.

Dallaire, E. E., 1970: *"Thermal Pollution Threat Draws Near". Civil Engineering, 40 (10): 67-71. October 1970.*

The thermal pollution threat will be met by, disposing of excess heat through cooling towers, cooling ponds, or spray ponds, by upgrading power generating efficiency, by managing the receiving waters to reduce the harmful impact of heat on water bodies and by making use of waste heat. Increase in temperature of the water body causes increase in metabolism, decrease in reproductive ability of fish and other organisms. They become more susceptible to disease and poisoning and their ability to catch food decreases. Recent biological studies at several power plant sites around the U.S. found that thermal discharges had no significant short-term impact on aquatic life. The use of evaporative cooling tower rather than once-through systems increases the cost of generating power by about 5%. Some of the more frequently heard proposals for putting this heat to good use include space heating, industrial processes, agriculture, aquaculture, water and waste treatment, desalinization, de-icing harbors, and recreation. Temperature recommendations proposed by the National Technical Advisory Committee on water quality standards are discussed.

de Sylva, D. P., 1963: *Systematics and life history of the great barracuda, Sphyræna barracuda. (Walbaum) Studies in Tropical Oceanography, 1: 1-179. Miami, Florida.*

de Sylva, D. P., 1969: *Theoretical considerations of the effects of heated effluents on marine fishes. Proceedings: National Symposium on Biological Aspects of Thermal Pollution. Vanderhailt, University Press. 229-293.*

The complex long-term effects of heated effluents on marine fishes at all stages of their lives have been described. The study concludes that a thorough investigation is necessary for each geographic location for the beneficial utilization of heated water, from the standpoint of fishermen as well as aquatic biologists.

Dimarco, P., 1969: *Personal Communication. Fishery Market News Editor, Bureau of Commercial Fisheries, Chicago, Illinois.*

Dingman, S. L., Weeks, W. F., Yen, Y. C., 1967, December. *The Effects of Thermal Pollution on River Ice Conditions. 1. A general method of Calculation. Cold Regions Research and Engineering Laboratory Research Report 206, 35 p. Army Terrestial Sciences Center, Hannover, New Hampshire.*

An attempt is made to calculate the length of the ice-free reach which develops during the winter below a thermal pollution site on a river. A differential equation for the steady state heat balance of a volume element of a river is developed, which leads to the expression: X = (C sub x) the integral from (T sub wo) to (T sub wx) of (d(T SUB W)/Q (*)) where x is distance downstream from the pollution site to the cross section where the water temperature equals (T sub wx), (T sub wo) is water temperature at x equals zero, Q (*) is rate of heat loss from the water surface, and C sub x is a constant which includes flow velocity and depth. The value of x at T sub wx equals 0 deg C is taken as the length of the ice-free reach. Q (*) is the sum of the heat losses due to evaporation, convection, long and short wave radiation, and other processes, each of which is evaluated by an empirical or theoretical expression. The two principal limitations in accurately calculating downstream temperature changes are related to difficulties in evaluating the degree of lateral mixing in natural rivers and the convective and evaporative heat losses under unstable atmospheric conditions. Observations of lengths of ice-free reaches on the Mississippi River are in good agreement with the calculated values. Significant portions of the St. Lawrence Seaway can be kept ice-free by the installation of nuclear reactors at appropriate locations.

Dingman, S. L., Weeks, W. F., Yen, Y. C., 1968: *"Ice-free Shipping Lanes." Water Resources Research 4, 960. 1968.*

A recent study by Dingman et al. showed that it should be possible to keep significant portions of the Saint Lawrence Seaway open the year round by the judicious location of central station electric power complexes. This would save transportation costs of several million dollars per year. It is estimated that a 60 MW reactor could keep a stretch of the river between 11 and 16 miles ice-free. No study was made of the ecological effect of such an undertaking, however.

Dingman, S. L., Assur, A., 1969, August: *The Effects of Thermal Pollution on River Ice Conditions: 2. A Simplified Method of Calculation. Cold Regions Research and Engineering Laboratories Research Report No. 206.*

Equations are presented and explained for use in calculating heat loss, rates, temperature profiles, and lengths of ice-free reaches caused in rivers by thermal pollution sources. The use of computers is not necessary to solve the equations, which are linear functions of the difference between water temperature and air temperature. Another simple procedure for calculating heat losses is based on air temperature, wind speed, solar radiation, and general atmospheric conditions.

Dingman, S. L., Assur, A., 1969 b. August: *Thermal Pollution Effects on River Ice Conditions: Part 3. A Simplified Method of Calculation. U.S. Army Cold Regions Research and Engineering Laboratories Research Report No. 206, 14 p. Hannover, New Hampshire.*

This paper describes a simplified approach to a method for calculating the temperature profile of a cooling river below a source of thermal pollution and the length of ice-free reach which could be maintained by such a source. Heat loss calculated as a linear function of the difference between water temperature and air temperature, so that the integration can be performed analytically. A simplified but fairly general procedure for calculating water-air heat-loss rates on the basis of air temperature, windspeed, solar radiation, and general atmospheric conditions is also presented.

Dow, R. L., 1969: *"Cyclic and Geographical Trends in Seawater Temperature and Abundance of American Lobster". Science 164: p. 1060.*

The correlation between cyclic sea temperatures and commercial catches of American lobster in the N.E. Atlantic Coast was investigated. Higher temperatures in the Boothbay Harbour indicated better yields along the northern ranges whereas lower temperatures had reverse effects.

Downing, A. L., Bayley, R. W., 1961: *"Aeration Processes for the Biological Oxidization of Waster Waters". The Chemical Engineer, No. 157, pp. A53-A60.*

Dvorou, I. M., 1969: *The Prospects of Utilization of Thermal Waters. (The Makhachkala Conference) Vestnik Adademu Nauk SSSR., No. 9, 127-129.*

A brief outline of the results of the geothermal conference on the Thermal Waters of the USSR and the Prospects of Their Utilization is given. Large resources of thermal waters are present in Kamchatka, the Magadan region, the Transbaika Lake area, and other areas of the USSR. Thermal waters of 40 to 70 deg C can be utilized for agricultural purposes.

Eckoldt, M., Knopp, H., Liebscher, H. J., 1969: *Effects of Introduction of Heated Water on Streams. Bundesaustalt für Gewasserkunde 67 p. Studie, bearbeited in Auftrage des Bundesministers fur Gesundheitswesen. April 1969. Koblenz.*

This report summarized possible negative effects of heated waters discharged from electric-steam power stations on streams. The report deals with the physical problems of the introduction of cooling of water into streams, with its influence on the oxygen content, self-purification, biological properties, effects on water supply and shipping. The different types of cooling systems are discussed and their influence on cooling water demand is stated. The main conclusions of the report are: (1) introduction of heated waters prevents ice formation. (2) One must take into account higher evaporation rates both in cooling towers and streams. (3) The decay coefficient for BOD has two optimum values, one at 30-32 deg C and the other at about 40 deg (C). (4) Model investigations showed an increase of microbiological activity measured as BOD (2). (5) The introduction of cooling water at temperatures up to 30 deg C or heating of water up to 28 deg C could be tolerable if oxygen is supplemented. Artificial aeration has to be used in most cases. (6) Photo-synthesis is influenced to a very low degree by the temperature increase. (7) A proposal for preparing maps of streams showing heat loads for future planning of steam-power stations is presented.

Ecolert, 1971: *"UK Experiment to Freeze Fresh Water from Sea" Ecolert, 1 (9): 85. July 15, 1971.*

A proposal by the UK Atomic Authority and Water Resources Board to build a plant for extracting 1 million gallons of fresh water a day from the sea has been approved by the UK Dept. of the Environment. The objectives of the experiment are to prove the economic practicability of the secondary freezing desalination process.

Elder, F. C., 1970: *Report on "Conference on Beneficial Uses of Waste Heat". Oak Ridge National Laboratories, Oak Ridge, Tennessee.*

Electrical World, 1968, Vol. 30.

Elliott, T. C., 1971, August: *"Air-cooled Heat Exchanges —New Growth? Power, p. 88-90.*

Elser, H. J. 1965: *"Effects of a warmed-water discharge on angling in the Potomac River, Maryland, 1961-1962". Progressive Fisheries Cultivation, 27(2): 79-86.*

Department of Energy, Mines and Resources, 1967: *Canadian Hydrographic Service Charts, Nos 1400, 1410 to 1421, 2100, 2220.*

Fair, G. M., Geyer, J. C., 1954: *Water Supply and Waste Disposal. J. Wiley and Sons, New York, p. 658.*

Fisher, A. W., jr., 1955: *"Engineering for Algae Culture". Proceedings: World Symposium on Applied Solar Energy, Stanford Research Institute Menlo Park, California, p. 243-253.*

Fisher, W. J., Swanick, J. D., 1971: *"High Temperature Treatment of Sewage Sludges". Water Pollution Control.*

Fletcher, D. H., 1971: *"Aeration Saves a Lake", Parks and Recreation 6 (11): 23-24; 54, November, 1971.*

Foell, W. K., Benedict, B. J., 1970: *"Electrical Power Use and Thermal Pollution". Heating, Piping and Air Conditioning, 42 (11) 113-120, November 1970.*

Thermal pollution, a serious long range problem in water resource management, receives a penetrating look. Focusing on the electric power generation industry, the authors define the magnitude of the thermal pollution problem, outline the available methods of waste heat disposal, discuss the effects of thermal discharges on water and the life it supports, and point to several current and future solutions.

Frohwerk, P. A., 1971: *"Spray modules cools plant discharge water" Power, September 1971, Environmental Management Section, p. 52-54.*

Frye, J., 1970, October: *"Thermal Effluent Gives Scientists a Break". National Fisherman, 51 (6): 20B. Camden, Maine.*

Nine thousand turtles, two dozen species of fish and some alligators seem to be thriving in 2,700-acre Par Pond, a lake built as a cooling and recirculating basin for heated water discharged from the nuclear reactors of the Atomic Energy Commission's Savannah River plant south of Aiken, S.C. The pond, one of a series through which plant cooling water flows before finding its way to the Savannah River, was formed about 10 years ago by the construction of a dam. Since the pond has never been stocked, the 24 species catalogued there are native, warm water fishes. Temperature of the effluent ranges up to 115°F.

Gammon, K. M. 1969: *"Planning Cooling Water for Power Stations". Advances in Water Pollution Research, Proceedings: Fourth International Conference on Water Pollution Research, (Prague, Czechoslovakia, April 21-25, 1969) Pergamon Press, New York, p. 927-936.*

Water is required to make up evaporation and purge. The amount of purge is related to the nature of the source and to the treatment given. Analysis on inland wet tower cooled stations abstracting fresh water and discharging to rivers, and direct cooled stations on tidal waters taking and returning much greater volumes of brackish or salt water are presented in this paper. Chemical changes in water used for cooling are complex. Investigations show purge discharges to be well aerated with more concentrated salts in solutions and some heat added. With cooling towers heat is lost to the atmosphere by evaporating about 1% of the water circulated in the cooling water system. Salts in solution are progressively concentrated by this evaporation and will eventually lead to deposition of scale. Scaling on the river surface of condenser tubes reduces heat transfer rates, and its control is an important aspect in operation. It is stated that purge discharges can be integrated with benefit into river management schemes. Heat is the main addition to cooling water discharges. This can have both immediate and long-term effects. Care is taken to avoid rapid successive reheating of water for operational and environmental reasons.

Garton, R. R., Christianson, A. G., 1970: *Beneficial Use of Waste Heat an Evaluation. Paper presented at Conference on Beneficial Uses of Thermal Discharge, New York State Department of Environmental Conservation. September 18, 1970.*

There are a number of proposed beneficial uses of waste heat contained in power plant cooling water. Included are those for which the technical feasibility has been demonstrated in pilot programs and those which are, at best, imaginative ideas. Primary concern is with solving the environmental pollution problem. Seen from this standpoint, a beneficial use must help offset the cost of cooling devices. The use must not result in additional pollution such as that resulting from untreated organic wastes. Some uses, such as the culture of certain fishes, are now at the pilot program, or even commercial, stage. Other uses, such as for industrial processes, require additional research. Integrated systems planned to produce steam as well as electrical power have been successful in special situations. In nearly all cases additional information is not on the overall economics of proposed methods. This is especially true where high quality heat is taken directly from the power plant steam cycle for another use. Only with a complete economic analysis, including cost of distribution and waste treatment, can the final decision be made to whether a 'beneficial use' is truly beneficial in the long run.

Gartrell, F. E., Stone, G. F., Wojtalik, T. A., 1970: *"Environmental Quality Protection: Large Steam-Electric Power Stations". Environmental Aspects of Nuclear Power Stations Proceedings of a Symposium on*

Environmental Aspect of Nuclear Power Stations, International Atomic Energy Agency in Cooperation with United States Atomic Energy Commission in New York, 10-14th August 1970. I.A.E.A., Vienna p. 453-473.

Environmental Quality Protection: Large Steam-Electric Power Stations. The concept of protecting environmental quality has always been an integral part of Tennessee Valley Authority's total operations. Its activities are directed not only at conserving the region's water, air and land but also at improving their quality for future use. Since the early fifties, as a part of its coal-fired steam plant operations, TVA has carried out comprehensive air and water quality programs to appraise environmental aspects; thus, in planning and designing its nuclear plants, TVA has been able to draw from extensive experience in air and water quality management and in handling thermal discharges from coal-fired plants. To appraise the effects of a large multi-unit nuclear plant on the whole environment, TVA is planning comprehensive and integrated environmental monitoring programs. Already under way at the Browns Ferry Nuclear Plant being built in North Alabama are studies to document levels of natural and man-made radioactivity in air, soil, vegetation, water and aquatic life to establish baseline data some two years before plant start-up. Similar studies are being conducted in Wheeler Reservoir to document pre-start-up stream temperatures and to obtain data on fish populations and other related aquatic organisms. To obtain much needed quantitative and qualitative information on the potential effects of heated water discharges on aquatic life, TVA and the Federal Water Quality Administration are planning a special research station adjacent to the Browns Ferry Plant. The basic elements of this station involve eight simulated naturalistic stream channels, each 14 feet wide and 390 feet long, with provisions for maintaining desired controlled temperature in the waters flowing through them. The planned operation of these channels for detailed studies of heat effects on the spawning, egg fertilization, egg and larvae development, and growth of warm water fish is described; and the integrated approach being taken by TVA to protect total environmental quality at all of its large thermal plants is presented.

Gaucher, L. P., 1971: *"Energy in Perspective". Chemical Technology, p. 153-158. March 1971.*

Gerard, R., Worzel, J. L., 1967: *"Condensation of Atmospheric Moisture from Tropical Maritime Air Masses as a Freshwater Resource. Science, vol 157: 1300-1302.*

Gibbons, J. W., 1970: *Reproductive dynamics of a turtle (Pseudemys scripta) population in a reservoir receiving heated effluent from a nuclear reactor. Canadian Journal of Zoology, 48 (4): 881-885. July 1970.*

Individual yellow-bellied turtles (Pseydemys scripta) in Par Pond, a thermally polluted reservoir on the Savannah River Plant, Aiken South Carolina, U.S.A., reach exceedingly large body sizes and maintain extraordinary juvenile growth rates when compared with turtles of this species from other populations in the vicinity. Increased water temperatures are not directly responsible for the observed size and growth differences. Diet differences resulting from increased productivity at lower trophic levels as a result of the hot-water effluent may be the cause of the observed growth and size phenomena. The increased growth rates and larger body sizes in the Par Pond turtles result in changes in reproductive rate which may have interesting consequences on the demography of the population.

Gopalakrisknan, U., Srinath, E.G., 1963: *"Some Experimental Observations on the Use of Activated Sludge on Fertilizer for Fish Culture." Proceedings of the Indian Academy of Science, B 57: 379.*

Goubet, A., 1965: *"Influence of Thermal Power Plants on Streams". Délégation générale au District de la Région de Paris, 1965, 115 p.*

This report deals with determination and analysis of the influence of four steam electric power stations on streams below the stations. The report is divided into 7 parts. First it contains the statistical temperature analysis of each of the four streams. The mixing of waters with different temperatures is discussed in the second part. The author's conclusion is that from the standpoint of influence on aquatic life, the average cross-sectional temperature should be the main parameter. The effect of cooling in the channel and streams is solved in the third part. The author used the formula Theta=Theta sub o exp (Lx/QD) where the thermal exchange coefficient D is the recommended value of D 75. In this equation Theta sub o is an initial temperature difference between the actual water temperature and the temperature which would occur if no heat pollution existed; Q is the discharge of water in the stream (m. cu.)/sec; x is the distance downstream in km; L is the width of the river in m, and D is a constant dependent on meteorological conditions. The following parts deal with the influence of power stations on chemical and biological properties. The change of oxygen content of water passing through the cooling cycle is negligible. The influence on other chemical substances and similarly on biological and bacteriological properties has not yet been proved.

Gould, W. R., Moore, J. B., 1970: *"Regional Environmental Considerations in the Evolution of and Operating Experience with the Southern California Edison Company Generating System", Environmental Aspects of Nuclear Power Stations, Proceedings of a Symposium on Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency in cooperation with United States Atomic Energy Commission, New York, August 10th-14th, I.A.E.A. Vienna, 1971, p. 413-424.*

Graves, E., 1971: *"Economics of Seaway Extension". Seaway Review 2 (2) 17-19. Summer, 1971.*

Gribanou, L. B., Korneev, A. N., Korneeva, L.A., Pronin, G. M., 1967: *Some Aspects of Carp Breeding and Nutrition in Tanks in Thermal Waters. Trudy Vsesoyuznogc Nauchno — Issledovatel'skogo Instituta Prudovogo Rybnogo Khozyaistva (URSS) 15, 3, 1967.*

Biological Abstracts, 50, 11842, 1969.

Groh, J. E., 1970: *"Desalting Plant Design" in Staff of Environmental Research Laboratories. May 1970, p. a59-a62.*

Gross, F., 1950: *"A fish cultivation experiment in an arm of a sea lock". Proceedings of the Royal Society, Edinburgh, 64 (b): 1-4, 64 (b): 109-135.*

Gudjonsson, P., 1967: *Salmon Culture in Iceland. Institute of Freshwater Fisheries, Reykjavik, Iceland. International Council for the Exploration of the Sea.*

Gunter, G., 1961: *"Some relations of estuarine organisms to salinity". Limnology and Oceanography 6 (2): 182-190.*

Hall, D. N. F., 1962: *"Observations on the Taxonomy and Biology of Some Indo-West Pacific (Penæidæ Custacea, Decapoda)" Colonial Office Fishery Publication, No. 17, U.K.*

Hallsson, S. U., 1969: *"Parapurrkstoo að Reykholum for N.A.L. and N.P.C., Iceland, Matthiasson, 1970.*

Hancock, D. A., 1959: *"The Biology and Control of the American Whelk Tingle, (Urosalpinx cinevea) (Say)." U.K. Fishery Investments, 22: 1-66.*

Harada, T., 1967: *"Hamachi and Kanbachi". Fish Culture, Kosheisha Publishing Company, Tokyo, 817 p.*

Harvey, R. S., 1970: *"Temperature Effects on the Sorption of Radionuclids by Freshwater Algae." Health Physics, vol. 19, August 1970, Pergamon Press, p. 293-297.*

The species studies were collected from the reactor effluent streams at Savannah River Plant. Unialgal cultures were developed in inorganic media. All tests were conducted using the continuous flow culture system described by Watts and Harvey. Water temperatures of 23, 26, 29 and 30°C had no significant effect on the sorption of 137Cs, 85Sr, 65Zn, 59Fe, 57Co and 54Mn by the filamentous green alga Stigeoclonium lubricum. Radionuclide concentrations in the unicellular diatom Navicula seminulum were 2-5 times higher at 32°C than those obtained at lower temperatures. Water temperatures of 25, 30, 35, 40°C had no significant effect on the sorption of 137Cs, 85Sr, 65Zn and 59Fe by the filamentous blue-green alga Plectonema boryanum. However, 57Co concentrations in P. boryanum decreased with temperature, and 54Mn concentrations increased from 25 to 35°C. Growth rates of N. seminulum and P. boryanum were inhibited at 32 and 25°C, respectively. Growth of S. lubricum was not influenced by the temperatures tested. These data show that nonlethal changes in water temperature had no major influence on the sorption of essential elements by the algae studied.

Hedgpeth, J. W., Gonor, J. J., 1969: *Aspects of the potential effect of thermal alteration on marine and estuarine benthos. Proceedings of the National Symposium on the Biological Aspects of Thermal Pollution. Federal Water Pollution Control Administration, Vanderbilt University, Portland, Oregon, June 3-5, 1969. Vanderbilt University Press, Nashville, Tennessee. 1969. p. 80-139.*

Laboratory experiments on thermal tolerances, death points, and the life, without reference to the natural conditions, including previous temperature experience and state of tide or season at which experimental material was gathered, have questionable utility in reference to what the organisms may actually do in nature. Intensive field studies with in situ measurements of the environment and the organisms, combined with continuous monitoring, especially of thermal gradients, are needed. Field evidence indicates that some intertidal herbivores are well adjusted to the temperature ranges from seawater to rather high air temperatures for varying periods of time, and that indeed such a temperature range may be an ecological requirement, rather than an environment to be endured. How extensive this may be, and to what degree it may apply also to subtidal organisms, remains to be determined. There is evidence indicating that some marine organisms do not flourish in a stable temperature regime but require the variation around the statistical mean. However, such temperature requirements are not yet established for many organisms, since most experiments involving laboratory culture are of comparatively short duration. In contrast to the observed ability of many marine organisms to withstand wide ranges of environmental temperatures at some stages of their life cycles, there is the growing body of evidence that comparatively small fluctuations in oceanic temperatures may influence the distribution and abundance of many species, especially those that occur in large populations.

Heinle, D. R., 1969: *"Temperature and Zooplankton". Chesapeake Science, 10 (3-4): 186-209, September-December 1969.*

All metabolic rates of zooplankton are dependent on temperature. Rates generally rise in a linear fashion, with inflection points when plotted on a semi-log scale, and fall at higher temperatures. The upper limits of thermal tolerance for two species of copepods from Chesapeake Bay were found to be near the normal temperature of the habitat during the summer. Acclimation temperature had little effect on the upper limits of thermal tolerance. Estuarine copepods were killed by passage through the condensers of a power plant, although temperatures encountered were generally below the upper limits of thermal tolerance. Chlorine gas was applied at relatively high rates at that particular power plant and is suspected to be the cause of mortalities. The operation of the power plant did not alter the seasonal patterns of distribution or production of estuarine copepods.

Herman, S. S., Mihursky, J. A., McErlean, A. J., 1967: *"Zooplankton and Environmental Characteristics of the Patuxent River Estuary". Chesapeake Science.*

Hickling, C. F., 1961: *Tropical Inland Fisheries, Longmans, Green and Company Ltd., London, 287 p.*

Hickling, C. F., 1962: *Fish Culture, Faber and Faber, London, 295 p.*

Hilliard, A.,: *"Recovery of Heat from Effluent" Rayonne et Fibres Synthétiques, 20 (12): 1127-1138.*

The polybloc heat exchanger units are shown to be suitable for effluent liquors. The units are built up from perforated cylindrical metal discs, with polytetrafluoroethylene or graphite seals. Heat recovery units which embody this Polybloc exchanger are described with diagrams; one installation, in which heat from hot washing liquor effluent is used to preheat the bleaching bath in a viscose spinning plant, is described in particular detail.

Hinde, J. N., 1970: *"Utilization of Thermal Energy and Air to Remove Organic Sludge from a Decaying Lake". Paper presented at the Conference on Beneficial Uses of Waste Heat. Oak Ridge National Laboratory, Tennessee. April 20-21, 1970.*

Feasibility of an air-aqua system was demonstrated to clean up polluted lakes by bubbling air and heated waste water. Benefit and cost analyses tend to favour the application of this technique, especially for small lakes, and may well prove to be equally beneficial for larger ones. However, no assessment was made of the overall relationship between heat balance and ecology of the lakes due to such measures.

Hintz, H. F., Heitman, H., Weir, W. C., Torrell, D. T., Meyer, J. H., 1966: *"Nutritional Value of Algae grown on Sewage". Journal of Animal Science 25: 657.*

Hintz, H. F., 1967: *"Sewage from algae as a protein supplement for swine." Animal Protein 9 (2): 135.*

Hirayama, K., Hirano, R., 1970: *"Influences of high temperature and residual chlorine on marine phytoplankton". Marine Biology, 7,205-213.*

Hoak, R. D., 1963: *Thermal Loading of Streams, American Society for Testing Materials Special Report No. 337, in Paper Industries and Water Industries Waste Waters, (1962): 20-31.*

Hodge, C. O., 1970, *"Coastal Desert Studies", in Staff of Environmental Research Laboratories, May 1970, p. a63-a75.*

Hodges, C. N., Groh, J. E., Thompson, T. L., 1965: *"Solar powered humidification cycle desalination: a report based on the Puerto Penasoco pilot desalination plant", International Symposium on Water Desalination; Proceedings 2: 429-459.*

Hodges, C. N., Jensen, M. H., Hodge, C. O., 1970: *"Waste Heat Use in Controlled-Environment-Greenhouse", Proceedings of the Conference on the Beneficial uses of Thermal Discharges, New York State Department of Environmental Conservation, Albany, New York, September 17-18, 1970, p. 108-116.*

Hodges, C. N., Hodge, C. O., 1971: *"An Integrated System for Providing Power, Water and Food for Desert Coasts," in Proceedings of the Symposium on Environmental Factors in Vegetable Production, Washington State University, Pullman, Washington, August 21, 1969. Published in Horticultural Science 6 (1): 10-16, February 1971.*

Hudinaga, M., Kittaka, Z., 1966: *"Studies on Food and Growth of Larval Stage of a Prawn Penæus japonicus, with Reference to the Application to Practical Mass Culture" Bulletin of the Plankton Society of Japan, 13: 83.*

Hudinaga, M., Kittaka, J., 1967: *"The Large-Scale Production of the Young Kuruma Prawn Penæus japonicus*

Bate". Bulletin of the Plankton Society of Japan, 14: 35.

Iles, R. B., 1963: *"Cultivating fish for food and sport in power. Station waters." New Scientist, 17: 227-229.*

Iles, R. B., 1968: *Journal of the Institute for Electrical Engineering, 9, p. 246.*

Industrial Water Engineering, 1970: *Special Report: Cooling Towers, Industrial Water Engineering, 7 (5): 22-53.*

A special report consisting of several contributions is presented. This report is divided into five sections: (1) tower section; (2) water-consumption; (3) chemical treatment; (4) automatic controls; and (5) field evaluation of the tower. The use of evaporative cooling towers rather than once-through systems could increase the cost of generating power by as much as 5%. Cooling tower selection is dependent on (1) amount of cooling water, (2) entering water temperature, (3) leaving water temperature, (4) temperature of the air entering the tower. The possibility of water reuse is discussed. The cooling operation can be automated and automatic control systems are described. Four types of pollution exist, thermal, steam, air, and land which have to be taken into account when towers are considered.

Jaske, R. T., 1969: *An Independent View of the Thermal Effects and Radioactive Releases from Nuclear Plants, paper presented to the university of Montana Seminar on Hydrologic Problems, January 15, 1969, 26 p.*

Jaske, R. T., 1970: *"Improved Methods for Evaluation of Thermal Discharge Practices and Alternative Actions". Paper presented at the 1970 Annual Technical Meeting of the Institute of Environmental Sciences, Boston, April 12-16, 1970, p. 261-266.*

Colheat, a deterministic stream temperature prediction system, describes the thermal regime of a river or estuary and permits advance estimates of thermal effects of impoundments, single thermal plants, or an extended series of thermal and hydro installations with overlapping effects on a single or regionally combined watershed. The basic operation is a two step process: multiple shell or zonal transport system with adjustable allocation of inter- and intra-shell transport. Assuming that most streams will be turbulent and relatively homogeneous in hydraulic characteristics, the distribution of velocity contours within the stream will be similar for width to depth ratios exceeding 24. Based on this concept, the model sets up a series of difference equations and, using applicable budget methods based on continuity, iteratively computes the downstream temperatures as a function of the input parameters. In its initial operation, the rudimentary system was used to evaluate the manipulation of the discharges of Grand Coulee Dam, Deerfield River simulation, and on the upper Mississippi River Basin system with great success. The economics and technology of thermally evaluated condenser discharges for agricultural usage bear critical examination. The study covering the operation of a 1000 MW thermal station discharging heated effluent into the distribution canal system of Phelps County, Nebraska, reveals that the present plant heat load is fully attenuated within the error measurement, plus or minus 0.5°C, in 25 miles of main canal. A 500 MW nuclear plant could be sited on the present system and the heat attenuated at the rate of 0.13 deg C per mile.

Jaske, R. T., 1971: *"Use of Simulation in the Development of Regional Plans for Plant Siting and Thermal Effluent Management". Presented at the American Society of Mechanical Engineers Winter Annual Meeting, Washington, D.C. November 28-December 2, 1971.*

Jaske, R. T., Karr, M. H., Toumill, C. J., 1970: *"Multiple Purpose Use of Thermal Condenser Discharges From Large Nuclear Systems to Supplement Interregional Water Supply". Chemical Engineering Progress, Symposium Series 67 (107): 26-39.*

The multipurpose use of canal-lake systems as cooling conduits, in conjunction with other uses appears to offer considerable advantage in the redirection of metropolitan growth rates along planned lines. A 1000 MW thermal station requires the passage of from 800 to 1200 cfs of water through the condenser system. The flow of two of these plants would supply the entire water use needs of the cities of Chicago, Los Angeles, or metropolitan New York. A total of 30 GWe, a substantial fraction of the western firm power requirements through the year 2000 could be sited on the canal system. The annual evaporation chargeable to the thermal plant system using the canal-lake complex was 30% lower than the equivalent in direct cooling tower capacity (452,000 AF vs. 650,000 AF) annually. But the total evaporation of the system was considerably larger. A substantially larger canal throughout would not increase the base evaporation levels, and smaller systems optimized for thermal cooling canals would suffer relatively large disadvantages from evaporation unless considered as multipurpose for irrigation, navigation and land development in arid regions.

Jaske, R. T., Spurgeon, J. L., 1968: *A Special Case, Thermal Digital Simulation of Waste Heat Discharges. Water Research, vol. 2, p. 777-802.*

The description and designs of mathematical models for the prediction of conservative and non-conservative materials in streams is presented. The major emphasis is on the prediction of temperature changes in streams due to energy plants using atomic energy. The hydraulic part of the model is based on similarity of turbulent flow which leads to the conclusion that there is a fixed relationship between the volume and the surface area of a section of a universal channel. The energy budget method was used for the evaluation of the mass or heat balance in a section of the model. The model considers the weather data as one of the major inputs. The input data are grouped into three parts: (1) weather parameters; (2) reservoir or river dimensional data; and (3) advected heat or material cards up to 9300 individual cards. The particular procedure was developed for density currents which occur with densimetric Froude numbers less than 0.26. The model permits the advection of heat into any of the input defined troughs. Two streams carrying heated discharges were used for testing of the model.

Jaske, R. T., Touhill, C. J.: *"An Independent View of the Use of Thermal Power Station Cooling Water to Supplement Inter-Regional Water Supply." Paper presented at the Conference on Beneficial Uses of Thermal Discharges. New York State Department of Environmental Conservation, Albany, New York, September 18, 1970. 21p.*

Jackson and Moreland, Inc., 1966: *Costs of Large Fossil Fuel Fired Power Plants, Boston, Massachusetts, April 30, 1966.*

Jensen, M. H., Hodges, C. N., 1969: *"Plastics and their Use in Vegetable Production in Desert Regions of the World." Paper presented at the 9th National Agricultural Plastics Conference, Fort Collins, Colorado. October 20-22, 1969. See Staff of Environmental Research Laboratories, May, 1970.*

Jensen, M. H., Teran, R. M. A., 1971: *"Use of Controlled Environment for Vegetable Production in Desert Regions of the World." Proceedings of the Symposium on Environmental Factors in Vegetable Production, Washington State University, Pullman, Washington, August 21, 1969. Published in Hort Science, 6 (1): 10-16.*

Josefsson, L., Thunell, J., 1970: *"Nuclear District Heating: A Study for the Town of Lund." in Environmental Aspects of Nuclear Power Stations. Proceedings of a Symposium on Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency. United States Atomic Energy Commission. New York, August 10-14, 1970. I.A.E.A., Vienna. p. 687-692.*

Keller, F. R., Sowards, N. K., 1970: *Constraints and Guidelines in Harnessing Nuclear Power Plant Waste Heat. Transactions of the Thermal Effluents Information Meeting. Boise, Idaho, July 9, 1970.*

Potentially useful applications of the low grade waste heat produced by nuclear power plants are discussed and evaluated. Constraints of geography, climatic conditions, and populations are considered as it is essential to take into account the relationship of each plant to its particular environment. Utilization of thermal effluents has been proposed for heating greenhouses, irrigating crops, fish farming, cooling public ponds for recreation and for heating homes and business buildings. Recommendations are drawn up for a working group to study the possible siting of a nuclear power plant in Idaho with the objective of utilizing waste heat.

Kennedy, V. S., Mihursky, J. A., 1967: *"Bibliography on the Effects of Temperature in the Aquatic Environment" University of Maryland, Natural Resources Institute, Contract No. 326. May 1967.*

Kerry, J. G. G., 1951: *"The St. Lawrence Waterway, an all-Canadian and very deep route." Engineering Journal, 34, 537. June 1951.*

Kinne, O. 1963: *"The Effects of Temperature and Salinity on Marine and Brackish Water Animals. I. Temperature." Oceanography and Marine Biology. Annual Review. 1:301-340.*

Klock, J. W., 1968: *"Thermal Energy Conservation and Sequential Biological Processing Applied to Sewage Lagoon Design." Engineering Research Center Report. October 1968. 28 p.*

This study incorporated the following principles into a reliable and simply operated lagoon system: (a) thermal energy conservation, (b) sequential phase processing, and (c) utilization of thin plastic films to form channel barriers and heat transfer interfaces. The lagoon was designed on an 8-day flow-through-time with approximately one-half of this period in each of the first and second phases. Phase I was intended to be principally a bacterial culture and phase II was an algal culture followed by limited growth of crustaceans and aquatic insects. The two phases are superimposed to improve heat utilization and prevent premature algal growth and nutrient fixation. Lagoon performance was notable by its treatment uniformity throughout the year, ranging from a low of 75.8 in the fall to a high of 78.9% BOD removal in the spring. The lagoon was clean with minimal surface solids and no odors at any time. The phase I effluent was a clear liquor and the phase II effluent had a pale green of a dilute algal culture. Seasonal performance was evaluated with studies of suspended solids reduction, deposited solids accumulation, Eh-time and pH-time patterns, BOD and COD reductions, presence of H_2S and molecular oxygen, and algal activity.

Kneese, A. V., Ayres, R. U., d'Arge, R. C., 1970: *Economics and the Environment: A Materials Balance Approach. The Johns Hopkins Press. Baltimore, Maryland. 129 p.*

A new program of research has been initiated at Resources for the Future, dealing with the management of residuals and of environmental quality. This report presents some of the broad concepts on which the program is based and presents some new empirical material as well. It represents an effort to break out of the traditional approach in pollution policy and research, which treats air, water, and solid wastes problems as separate categories. A framework is developed for identifying priority research, and some important research areas are described. The materials balance concept applies the approach that all resources entering the economy should be considered as a single flow with residuals recycled, reused, or added to inventory, with minimum waste designated for disposal.

Knott, J. E., 1957 (revised 1962): *Handbook for Vegetable Growers. John Wiley and Sons Inc., New York.*

Kolflat, T. D., 1968: *"Cooling-Water Debate Needs Clarification" Electrical World, 170 (8): 23-27. August 19, 1968.*

The quantity of heat added to the cooling towers is essentially equal to that exhausted from the turbine. This exhaust heat can be reduced by modifying the basic thermal cycle. Each 100-psi increase in pressure of steam entering the turbine will decrease waste heat 0.4%. If the steam generated in the boiler is passed through a superheater the heat rejection will be reduced by about 1.4% for each 50F added. Another method of reducing heat from the turbine exhaust is to extract a portion of the steam from various points in the turbine and use it to heat water entering the boiler. This can reduce heat rejection up to 37%. There seems to be sufficient evidence to seriously question 93°F as a water limit. Many plants have discharged water to rivers at 105°F in summer with no adverse effect on aquatic life; fish have been caught alive in 105°F water. Fish acclimatize to higher temperatures and migrate to and from areas not to their liking. Tolerance levels vary with different species and dissolved oxygen is above the minimum for fish at temperatures as high as 105 deg F.

Kramer, J. R., 1972: *"Discussion of 'State of the Art' Water Quality." A discussion arising from the International Symposium on Modeling Techniques in Water Resources Systems. Ottawa.*

Krenkel, P. A., Parker, F. L. 1969: *Biological Aspects of Thermal Pollution. Proceedings of the National Symposium on Thermal Pollution. Federal Water Pollution Control Administration, Vanderbilt University, Portland, Oregon. June 3-5, 1968. Vanderbilt University Press. 407 p.* The best, most comprehensive review of the subject.

Krishnamoorthy, P. N., 1970: *"Methods of Effluent Control in Nuclear Plants." Environmental Aspects of Nuclear Power Stations. Proceedings of a Symposium on Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency, United States Atomic Energy Commission. New York, 10-14 August 1970. I.A.E.A. Vienna. p. 317-324.*

Current methods of effluent control developed to meet standards set in respect of nuclear facilities are discussed. Problems related to the control of thermal pollution from some of these facilities are also considered. Methods of treatment of solid, liquid and gaseous radioactive effluents prior to disposal or dispersal to the environment are covered in this review.

Kuenzler, E. J., Chestnut, A. F. (editors) 1971: *"Structure and Functioning of Estuarine Ecosystems Exposed to Treated Sewage Wastes." University of North Carolina, Institute of Marine Sciences, Chapel Hill, Annual Report. February 1971. 345 p.*

Faculty and students from the University of North Carolina have studied various phases of community structure and metabolism of six experimental brackish-water ponds, three of which receive treated sewage wastes, and of a small tidal creek and its salt marshes. Chapters include productivity, carbon metabolism, the phosphorus budget, nitrogen, and bacterial heterotrophy; standing crops of phytoplankton, decapod crustaceans, fishes, meiofauna, foraminifera, insects, molluscs, and birds; calcium analysis; and growth and reproduction of algea. The waste ponds have developed into productive, well-integrated, but slightly unstable systems. They perform some of the functions of tertiary treatment and hold promise for production of harvestable seafood protein.

Lafond, E. C., Lafond, K. G., 1967: *"Temperature Structure in the Upper 240 meters of the Sea. 'The New thrust seaward'". See Hedgepath and Gonor, 1969.*

Largen, M. J., 1967: *"The Influence of Water Temperature upon the Life of the Dog-Whelk. (Thais lapillus) (Gastropoda: Prosobranchia)." Journal of Animal Ecology 36(1): 207-214.*

Lowes, G., Kenward, M., 1970: *"Stirring up the Oceans for Profit". New Scientist, 20, August 1970, p. 378.*

Lawes, G., Kenward, M., 1970: *"Sounding the all-in-one nuclear drum". New Scientist 46 (696) p. 69. April.*

A nuclear power station — reactor and shielding, heat exchangers and turbines — all contained within one large cooling tower, dissipating the waste heat into the air, is recommended for its low cost and negligible thermal pollution of surface waters.

Les Strang, J., 1971: *"What Price Power?" Seaway Review. 2/2): 5-7. Summer, 1971.*

Lindal, B., 1970 a: *"The Use of Natural Stream in Diatomite Plant". U.N. Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy.*

Lindal, B., 1970 b: *"The Production of Chemicals from Brine and Seawater Using Geothermal Energy". U.N. Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy.*

Lindner, M. J., Anderson, W. W., 1956: *"Growth, Migration, Spawning and Size Distribution of Shrimp, Paneaes Setiferus." Fishery Bulletin 106 from Fishery Bulletin of the Fish and Wildlife Service. 56:555.*

London Times, 1971: *"U.K. Experiment to Freeze Fresh Water from Sea". 7 July 1971, p. 2, col. 13: 9.*

A proposal by the U.K. Atomic Authority and Water Resources Board to build a plant for extracting 1 million gallons of fresh water a day from the sea has been approved by the U.K. Department of the Environment. The objectives of the experiment are to prove the economic practicability of the secondary freezing desalination process.

Lof, G. O., Ward, J. C., 1969: *"Economic Considerations in Thermal Discharge to Streams" in Engineering Aspects of Thermal Pollution, Chapter 10, p. 282-301.*

The economic consequences of thermal discharge from steam-electric power plants, the largest users of cooling water, are modest increases in operating costs by the downstream users. It is observed that the operating cost of recirculation cooling merely to reduce the temperature of an inlet cooling water supply is greater than the benefit. The annual expense C sub I in cents per thousand gallons of water circulated is given in terms of the cooling tower investment per unit capacity (dollar/gpm); r, the interest rate; t, cooling tower service life (years); P, annual property-taxation rate; and N, the load factor. Costs of operation are functions of R, the cooling range in F; C, the cycles of concentration; Y, alkalinity of make up water; W sub a, cost of make up water; K, the relative rating factor of cooling tower, p, the height to which water must be pumped for flow through the cooling tower (fee); and A, cost of electric power (cents/kwhr). Results of a downstream power plant using warmer condenser water than would naturally have been available are in decrease in total electrical generation and a decrease in thermal efficiency, hence, an increase in costs per kilowatt-hr generated.

Lof, G. O., Ward, J. C., 1970: *"Economics of Thermal Discharges", Industrial Water Engineering. 7 (1): 12-18. January 1970.*

Economic implications of thermal discharges were examined. The discharges from power plants and the potential effect that the discharges have on downstream water-users, that is, on downstream water used for cooling purposes, were described. It was pointed out in the literature that the temperature of water used for cooling purposes was often of more significance than the composition and chemical quality of water. The main objective was to indicate the approximate range of costs involved in completely preventing thermal discharge; i.e., by circulating water through cooling towers, and to show the approximate costs to a downstream power plant being forced to use cooling water containing thermal discharges from an upstream electric station. The cost of cooling water recirculation included capital costs, primarily of the cooling tower installation, and operating costs, which were the make-up water, chemicals, and power for operating fans and pumps. The capital costs were dependent upon water flow required, prevailing wet bulb temperature of the air, the water temperature change through the tower, and the temperature of water delivery from the cooling tower to the condenser.

Lof, G. O., Ward, J. C., 1970: *"Economics of Thermal Pollution Control". Journal of the Water Pollution Control Federation, 42 (12): 2102-2116. December 1970.*

The increasing use of water for industrial cooling is requiring the electric utility industry to pay more attention to the technical, economic, and environmental factors related to heat discharge from large power plants. The paper shows how once-through vs. recirculation costs are determined, and extends the method to the year 2000. The cost of thermal pollution to downstream cooling water users is also shown. A discussion is included of the use of nuclear power plants with tower thermal efficiencies, future growth of natural draft cooling towers, shifts toward larger plants, site requirement restrictions, and the use of higher condenser temperatures.

Lourmais, L., 1971: *"Mémoire sur la situation dans le Golfe du Saint-Laurent et l'aménagement du 'Causeway' de Canso". Personal Correspondence.*

MacKenzie, C. R., Campbell, D. R., 1963: *Hygienic evaluation of the food fishes, tilapia melanopleura and tilapia mossambica cultured in sewage effluent. South African Medical Journal 37:968 (1963).*

Margalef, R., 1965: *"Ecological Correlations and the Relationship between Primary Productivity and Community Structure". Primary Production in Aquatic Environments. Memorie dell' Istitituto Italiano di Idrobiologia dolt. Milan, p. 355-364.*

Markowski, S., 1958: *'The cooling water of power stations — a new factor in the environment of marine and freshwater invertebrates'. Journal of Animal Ecology, 28-243.*

Markowski, S., 1960: *'Observations on the response of some benthic organisms to power station cooling water.' Journal of Animal Ecology, 29: 349.*

Martino, P. A., Marchello, J. M., 1968: *"Using Waste Heat for Fish Farming" Ocean Industry. April: 36-39.*

Matthiason, M., 1970: *"Beneficial Use of Heat in Iceland". Paper presented at the Conference on Beneficial Uses of Thermal Discharges New York State Department of Environmental Conservation, September 18-19, 1970. Albany, New York.*

In Iceland, in 1970, geothermal energy was primarily used for district heating, greenhouse farming, industrial processing in the Diatomic Earth Plant, and electric power generation. The future development in the utilization of geothermal energy is expected to include production of chemicals from sea water and heavy water. Consumption of heat energy in this form has doubled in Iceland during the last decade, and similar trend is anticipated in the future. The potential of geothermal resources are estimated at 280 x 10 12 BTU/year, while the total current consumption is only 8.8 x 10 12 BTU/year.

M.E.C., 1971: *Thermal Inputs into Canadian Waters excluding the Great Lakes Basin, 1970-1000 A.D. Montreal Engineering Company, 88 p.*

Merlin, H. B., 1967: *"Review of 1965 Forecast of Installed Nuclear Capacity (1970-1985)" Atomic Energy of Canada, Ltd. AECL 2875, April 1967.*

Merriman, D., 1970 a: *"Does Industrial Calefaction Jeopardize the Eco-System of a Long Tidal River?"*

in Environmental Aspects of Nuclear Power Stations. Proceedings of a Symposium on the Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency, United States Atomic Energy Commission. August 10-14th, 1970. New York. I.A.E.A., Vienna, p. 507-533.

The Connecticut Yankee Atomic Power Company discharges its effluent into the Connecticut River at a temperature of 12.4 degree C above that at intake and at a rate of 1400 m cu/min. To determine the effects of the effluent, the preoperative phase while the plant was being built (1965-1967) was compared with the operative phase (1968-present). Included in this comparison were present and past studies of physical and chemical characteristics of the lower reaches of the river, of the benthic fauna, of the population dynamics of the resident fish fauna, and of the fish kills. Salmon restoration in the river would not be affected by electric generating plants. River water was being effectively used for the production of electricity with minimum harmful environmental disruption. The short term observation failed to take into account subtle, long-term effects which were not predictable at that time. By 1971-1972, much more information will be available to determine the success of shad emmigrating past the Connecticut Yankee effluent, but presently, the harm is outweighted by the benefits.

Merriman, D., 1970 b: *"The Calefaction of a River". Scientific American, 222 (5): 42-52. May 1970.*

Calefaction, according to the author, means a gradual warming process. The term seems to have been used for the first time for thermal pollution. It seems to be the better of the two terms because thermal pollution suggests that any addition of heat to a natural body of water is always harmful. The article discusses a recent study on calefaction carried out on the Connecticut River. It was found that no drastic harmful effects can be foreseen in the near future due to the condenser cooling water being discharged into the river from a nuclear power plant at Haddom Neck.

Mihursky, J. A., Cory, R. L., 1965: *"Thermal loading and the aquatic environment. An approach to understanding an estuarine ecosystem". Paper presented at the International Conference on Industrial Electronics/Control Instrumentation, September 8-10, 1965. Philadelphia, Pennsylvania.*

Mihursky, J. A., 1967: *"On Possible Constructive Uses of Thermal Additions to Estuaries". Bioscience, 17 (10): 698-702. October 1967.*

Elaborates the idea of developing integrated systems of water and nutrient recycling to convert wastes to useful food products.

Miller, A. J., Payne, H. R., Lackey, M. E., Samuels, G., Heath, M. T., Hagen, E. W., Savolainen, A. W., 1971, January: *"Uses of Steam Electric Power Plants to Provide Thermal Energy to Urban Areas". U.S. Department of Housing and Urban Development. Oak Ridge National Laboratory, Oak Ridge, Tennessee.*

This study has shown that with coordinated planning of energy centers and new cities, it would be feasible to provide thermal energy from steam electric power plants to urban areas. An analysis was made of 1980 reference city of 380,000 people with a climate similar to that of Philadelphia. Thermal energy extracted from the turbines of a generating plant that employed light water reactors would be used for providing space heat, hot water, and air conditioning for both commercial and domestic use. This use of heat would reduce the average heat rejected to the plants cooling water to 63% of that which would be rejected from a single purpose plant, with a reduction to 21% of that single purpose plant during the period of maximum heat consumption in the summer. A cost analysis for the distribution of this heat was based on current (1968-70) costs escalated 4% per year during a 5 year construction period; a 14% annual fixed-charge rate, and a charge to the consumer for electricity equal to that which would have been incurred from a single purpose plant. Further cost estimates were made for reference cities in other climatic regions. Costs were determined to be competitive. Apart from providing low-cost thermal energy, such a scheme would sharply reduce air and water pollution.

Miller, A. J., 1969: *"Space Heating in Urban Environments". Paper presented at the Conference on Abundant Nuclear Energy. Gallinburg, Tennessee. August 26-29, 1969.*

The findings of an on-going research on the pattern of urban heat consumption were summarized. The research, financed by the United States Department of Housing and Urban Development, concluded that high temperature (300° to 380°F) waste steam or hot water from the nuclear or fossil-fueled power plants could be quite competitive with the existing sources of heat, even if the power plant is situated some 10 miles from the center of the consumption area. Air cooling during summers, generally the most critical period for thermal pollution, would consume a substantial amount of heat. Further research is suggested for utilization of low temperature waste heat.

Miller, A. J., 1970: *"Waste Heat Utilization in an Urban Area". Paper presented at the Conference on the Beneficial Uses of Waste Heat. Oakridge National Laboratory. Oakridge, Tennessee. April 20-21, 1970.*

A comprehensive study of a total energy system with respect to the light-water-energy requirements of a large urban complex was undertaken. The purpose of such a system was to make maximum use of the available natural resources to optimize the total consumption of energy as well as to alleviate the worsening thermal pollution problem of the receiving streams. A cost analysis indicated that the proposed system was quite competitive with the existing alternative energy production systems that create pollution.

Miller, H. H., 1970 a: *"The Thermal Water Horticultural Demonstration Project at Springfield, Oregon". Paper Presented at the Conference on Beneficial Uses of Thermal Discharges. New York State Department of Environmental Conservation, September 17-18; Albany, New York, p. 62-69.*

Agricultural utilization of thermal effluents from industrial plants and power plants is being investigated. The Eugene Water & Electric Board is sponsoring a field demonstration project to study applications in frost protection, summer cooling, and irrigation of crops and orchards. The thermal effluent is supplied from a paper and pulp plant. Data is being compiled on rate and amount of water application, atmospheric temperature, humidity, soil moisture, soil temperature, and crop-yield comparisons. The project and methods are described. Vitro, a division of Automation Industries, is managing the project.

Miller, W. C., 1970: *"California lobster interests businessmen, poachers". National Fisherman, Camden, Maine. 51 (6): 11A, 22A. October 1970.*

Dr. George S. Schumann, fishery biologist, is raising eastern lobsters in the warm water discharged from the San Diego Gas and Electric Co. power plant at Chula Vista, Cal. The sea water which has cooled the plant's condensers is thereby heated about nine degrees, and it speeds larval development from ten to thirty days. The importance of lobster culture is indicated by the fact that the American lobster has the highest unit value of any major commercial species in the United States and supports the fourth most valuable fishery in North America.

Mori, E., 1969: *"Winter Culture of penaeid shrimp using power-plant heated effluent. Fish Culture, 6 (67): 113-115.*

McDougall, H., 1971: *"Meters Make Snow Flow Like Water". Civic Administration. September 1971, p. 34-41.*

A study of a new "jet-engine" snow melter installation.

McKee, J. E., 1971: *"Potentials for Reuse of Wastewater in North-Central Texas". Water Resources Bulletin, 7 (4): 740-749. August 1971.*

McKeluey, K. K., Brooke, M., 1959: *The Industrial Cooling Tower, Elsevier Press, New York.*

McNeil, W. J., 1970: *"Heated Water in Agriculture". Transactions of the Thermal Effluent Information Meeting. Idaho Nuclear Energy Commission. July 9, 1970. Boise, Idaho, p. 24-28.*

Utilization of thermal discharges from electric power plants for the development of fish farms and shellfish farms is discussed. Much of the current research is directed toward biological studies to determine what technological problems must be solved for the commercial production of foodfish and shellfish. Experiments show great potential for both freshwater and seawater fish farming. It will be necessary to control and monitor effluents containing chemicals, metals, and radioactive isotopes to protect the fish and results to date are encouraging.

Nakatani, R. E., Miller, D., Tokar, J. V., 1970: *"Thermal Effluents and Nuclear Power Stations in the U.S.A.", in Environmental Aspects of Nuclear Power Stations; proceedings of a Symposium on the Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency; United States Atomic Energy Commission, in New York. August 10-14th, 1970, I.A.E.A., Vienna, p. 561-573.*

Steam-electric stations discharging heated condenser cooling water into public waters will modify the aquatic environment. There is no question that some changes will occur, but the biological problem is to determine the degree of changes, both short-term and long-term, the extent of these changes, and to determine if they significantly affect water uses. Pressing biological problems are identified and needed research and development are recommended. Examples of problems considered are as follows: (1) Compliance with water temperature standards; (2) Lack of definition of mixing zones; (3) Lack of approved state water temperature standards; (4) Predicting temperature distributions in receiving water; (5) Assessment of biological changes; (6) Design of intake and outfall structures to minimize biological damage — fish protection facilities; (7) Nuisance growth of plants and algae; and (8) Sublethal effects of temperature on aquatic life.

Nash, C. E., 1970: *"Marine Fish Farming", Marine Pollution Bulletin, 1 (2): 28-30, February 1970.*

The British aquaculture programme is largely concerned with the use of condenser cooling water discharged from coastal electricity generating plants. This represents an enormous volume of seawater with fluctuating temperature differentials up to 10 deg. above ambient. The effects of temperature on growth are well known, and the aim is to use the warm water to maintain growth of potential farm species throughout the winter and so reduce the overall time from hatching to harvest.

Naylor, E., 1965: *"Effects of heated effluents upon marine and estuarine organisms", Advances in Marine Biology, 3: 63-103.*

Nutant, J.A., 1970: *"Utilizing Waste Heat for Urban Systems". Transactions of the Thermal Effluents Information Meeting. Idaho Nuclear Energy Commission, July 9, 1970, Boise, Idaho, p. 18-23.*

Consolidated Edison of New York and Westinghouse Electric Corp. are investigating waste heat utilization in various combinations of urban systems and power plants. Several concepts which show promise for further evaluation are described such as space heating and air conditioning for residential and business buildings; river aeration to improve water quality; sewage plant-power plant combination; de-icing and de-fogging airports and heating greenhouses. These concepts are specifically for the New York area. Detailed analysis will be made to select a demonstration project.

Ocean Industry, 1969: *"Japan and the Sea. Exchange Rate: 70 pounds of Shrimp for 1 pound of gold". Ocean Industry, 4 (12): 49.*

Oswald, W. J., Golueke, G. G., 1967: *"Large Scale Production of Algae". Paper presented at the International Conference on Single Cell Protein. Cambridge, Massachusetts. October 9-11, 1967.*

It was reported that a combination of warm temperatures and nutrient supply (sewage effluents) could generate high yields of algae. The algae served as a highly productive food for culture of fishes, fowls and animals. Thus, aquaculture with warm water can be profitable and could partly bear the burden of waste heat disposal costs.

Oswald, W. J., Houghton, C.D., 1968: *"Edible Algae from Potato Waste". See: Boersma, L., 1970.*

Pahapill, J., 1971: *"Special Report on Plant Energy Systems — 2 and 3." Canadian Chemical Processing, 55 (8): 34-39. August 1971.*

Palmason, G., Zoega, J., 1970: *"Geothermal Energy Development in Iceland 1960-1969", United Nations Symposium on the Development and Utilization of Geothermal Resources. Pisa, Italy. See: Matthiasson, 1970.*

Parker, F. L., Krenkel, P. A., (editors) 1969: *Engineering Aspects of Thermal Pollution. Proceedings of the National Symposium on Thermal Pollution. Federal Water Pollution Control Administration, Vanderbilt University, Nashville, Tennessee. August 14-16th, 1968. Vanderbilt University Press, 1969.*

The best, most comprehensive work on the subject.

Parker, F. L., Krenkel, P. A., 1969: *"Summary and Status of the Art", Engineering Aspects of Thermal Pollution. Vanderbilt University Press, Chapter 11, p. 313-328.*

Analysis of steam-electric cooling discharges for 1965 indicates an average 13F rise in water temperature after passing through the condensers. The amount of water withdrawn for this purpose is approximately 42 trillion gallons per year, which is roughly 10% of total flow of water in the U.S. The electric generating industry is doubling in magnitude every 10 years. We can expect that the thermal problems associated with cooling water discharges from steam-electric generating plants will even further exceed the problems from industrial sources, because it appears that industrial plants have, by and large, already reached the maximum economically efficient size. The best efficiencies for present day fossil-fueled plants are about 40% and for light-water reactors about 34%. The MHD systems with single cycles can achieve thermal efficiencies of 50 55%, which possibly could be boosted to 60 to 70% by using a binary cycle. If a binary cycle using a gas turbine is utilized, the thermal pollution problem is avoided entirely. Another possibility for central station generation of electricity is by controlled thermonuclear fusion. Of all the effects of the increased heat to our streams, possibly the most striking is the induction of stratified flow by the discharge of these warmed waters to surface streams, reducing the waste-assimilative capacity of the stream, changing the algal population, and causing chemical reactions to proceed at a faster rate.

Parker, F. L., Krenkel, P. A., 1970: *Physical and Engineering Aspects of Thermal Pollution. C.R.C. Press, Cleveland, Ohio. 100 p.*

Pentland, R. L., Reynolds, P. J., Biswas, A. K., 1972: *"Water Quality Modelling: State-of-the-Art." Paper presented at the International Symposium on Mathematical Modelling Techniques in Water Resources Systems, Ottawa, Canada 1972, 16 p.*

Peterson, D. E., Jaske, R. T., 1970 a: *"Potential Thermal effects on an expanding power industry: Ohio River*

Basin 1." Battelle Memorial Institute, Columbus, Ohio. Pacific Northwest Laboratories, Richland, Washington. Report no. BNWL-1299. 69 p. February 1970.

The average stream temperatures of the Ohio River System were simulated for 1969. It was estimated that the cooling water requirements will equal low monthly average direct cooling capacity of the Ohio Basin by 1990.

Peterson, D. E. Jaske, R. T., 1970 b: *"Potential thermal effects of an expanding power industry: Upper Mississippi River Basin", Battelle Memorial Institute, Columbus, Ohio. Pacific Northwest Laboratories Richland, Washington. Report no. 1405. June 1970. 104 p.*

Direct cooling capacities of the main stem Mississippi River and eight major tributaries between Royalton, Minnesota and Alton, Illinois for average and low flow conditions were simulated within a temperature constraint of 5° F above natural background. Total assimilative and dissipative capacity of the upper Mississippi Basin ranged from a high of 130 GWT to a low of 46 GWT. Analyses of projected power growth patterns indicate that the main stem has adequate cooling capacity to accommodate forecasted loads through the year 1990, except in the St. Paul-Minneapolis area. Partial recirculatory cooling facilities appear to be a possible solution to tributary basin cooling water requirements beyond the year 1980.

Peterson, D. E., Jaske, R. T., 1970: *"Simulation Modelling of Thermal Effluent in an Irrigation System". AEC Research and Development Report, BNWL-1277, UC-70. Pacific Northwest Laboratories, Richland, Washington, January 1970. 21 p.*

Simulations of hourly average water temperatures along a 40 mile reach of the Phelps county canal of south-central Nebraska were carried out by utilizing moving means of hourly regional weather data as input to the COLHEAT computer program. The COLHEAT simulation model applied a heat budget to a given section of a river or canal. The water temperature for a section Tw is determined. The simulation of the addition of a 500% increase in heat rejection to the canal system indicated a large potential sink capability for future expansion of the system without extensive modification of the simulated thermal history. The computed rates of heat transfer from the canal indicate overall coefficients as high as 700/BTU (day) (ft 2) (deg F) compared to 100-200 BTU/(day) (ft 2) (deg F) for lakes and ponds. Neither benefits nor liabilities to agriculture resulted from water temperature modification.

Philbin, T. W., Philipp, H. D., 1970: *"Thermal Effects Studies in New York State" in Environmental Aspects of Nuclear Power Stations. Proceedings of a Symposium on the Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency, United States Atomic Energy Commission, New York, 10-14, August 1970. I.A.E.A. Vienna, p. 575-589.*

The increasing size of modern base-load generating stations and increasing proportion of nuclear plants have made the effects of thermal discharges a major factor in US power station site selection, regulatory approval and community acceptance. Extensive pre- and post-operational studies of the lake, river, estuary or other cooling water source for the station have become an important and integral part of overall power project management. The pre-operational studies attempt to establish base-line characteristics of the water source and to provide data for the design of cooling water intake and outlet structures. The post-operational studies repeat similar pre-operational work to establish the actual effects of the thermal discharge. This paper describes the thermal effects studies being carried out in New York State by the member companies of ESADA. The studies themselves generally fall into two categories. One is the prediction of temperature profiles around cooling water discharges: this is accomplished by model studies, aerial surveys, calculational methods, and measurement of existing discharges that are similar to the one under consideration. The principal benefits of this type of study have been in providing data for design of the actual discharge in compliance with state criteria, and in estimating possible effects on aquatic life. The second category covers the ecology of the body of water to be used for cooling. This involves observations of fish populations by netting and use of a unique hyperfine fathometer device, sampling of various forms of other aquatic species, and chemical and hydrological measurements. The studies have been performed pre-operationally at specific sites and on some existing discharges. The data will be used principally as the base-line for comparisons with post-operational surveys which are usually repeats of the pre-operational ecological work.

Pickering, C. W., 1970: *"Catfish Farming — A Beneficial Use of Waste Heat", Proceedings of the Conference on the Beneficial Uses of Thermal Discharges. New York State Department of Environmental Conservation, September 17-18, 1970. Albany, New York. p. 46-50.*

Pirkey, F. Z., 1963: *"Water for All". Sacramento, California. November 1963, See: Jaske and Tonhill, 1970.*

Proffitt, M. A., 1970: *"A View of the problem of thermal pollution, with special reference to the White River in Indiana". The Environmental Challenge of the 70's. Institute of Environmental Sciences, Sixteenth Annual Technical Meeting. April 12-16, 1970, Boston, Massachusetts, p. 258-260.*

Based on a 5-year study of the ecosystem of the White River, it is concluded that effects of thermal effluents from power plant installations have been minimal. There is no evidence to support the fears of thermal pollution. Temperature standards can be developed which will permit economic cooling by industry and still protect the fishes and man's other uses of these water resources.

Pruden, F. W., Wardlaw, R. L., Baxter, D. C., Orr, J. L., *1954: A Study of Wintertime Heat Losses From a Water Surface and of Heat Conservation and Heat Addition to Combat Ice Formation in the St. Lawrence River. National Research Council of Canada, Report no. Md-42. Ottawa, 30 June, 1954.*

Puffet, A. J., 1971: *"Ecotechnics". The Ecologist, 1 (13): 31-32 July 1971.*

Rabanal, H. R., 1970: *"Aquacultural Development and Public Health", Factures Biologiques d'Auto-épuration. Colloque International d'Océanographie Médicale, Quatrième, Naples, October 2-5, 1969.*

There are certain public health problems associated with aquacultural development. Environmental changes brought about by impoundment of estuarine and coastal areas may result in increased hazards of water-borne diseases. Sewage effluents and animal manures as fertilizers for aquaculture, the uptake and accumulation of pesticide residues, industrial by-products, radioactive wastes and other pollutants and the danger of eating contaminated fish or shellfish grown in polluted water are all dangers to be considered.

Ralston, D. R., 1970: *"Utilization of hot ground water in Elmore and Owyhee counties, Idaho". Transactions of the Thermal Effluents Information Meeting, Idaho Nuclear Energy Commission, July 9, 1970, Boise, Idaho.*

The use of hot ground water from thermal springs and wells in Elmore and Owyhee Counties in southern Idaho is recounted. Residents use the heated water for greenhouses, domestic home heating, public swimming pools, and irrigation of crops. Agricultural usage is the most dominant. Well waters range in temperature from 90° to 150°F. The problems associated with the use of these hot waters for irrigation of crops and the solutions applied by Idaho farmers are presented. It is suggested that these areas offer opportunities for field studies into the utilization of thermal effluents.

Raney, E. C., Menzel, B. W., 1967: *A Bibliography: Heated Effluents and Effects on Aquatic Life with Emphasis on Fishes. Cornell University, Ithaca, New York: Fernon Hall.*

Raney, E. C., Menzel, B. W., 1969: *"Heated Effluents and Effects on Aquatic Life with Emphasis on Fishes — A Bibliography." Cornell University, Water Resources and Marine Sciences Center, Philadelphia Electric Company, and Ichthyor Associates, Bulletin no. 2.*

Raymont, J. E. G., 1957: *New Scientist, 1, 10, 2957.*

Raymont, J. E. G., Carrie, B. G. A., 1964: *"The Production of Zooplankton in Southampton Water." Int. Revue ges. Hydrobiological, Vol. 49, No. 2, p. 185 - 232.*

Riechen Bach-Klinke, H., 1963: *"Abwasser kleinerer Fischteiche zur biologischen Nachreinigung der Abwasser kleinerer und mittlerer Gmeinden." Münchener Beiträge zur Abwässer Fisherei und Fluss Biologie, 10: 190-197, Verlag R. Oldenbourg, München.*

Renn, E. J., 1957: *Journal of the American Water Works Association, 49, 1957, p. 410.*

Rey, G., Lacy, W. J., Cywin, A., 1971: *"Industrial Water Reuse: Future Pollution Solution", Environmental Science and Technology, 5 (9): 760-765, September 1971.*

Richardson, I. D., 1970: *"Development of Systems of Marine Cultivation in the United Kingdom by the White Fish Authority". Conference Paper, Albany, New York, September 17-18, 1970.*

In Great Britain, much progress has been made during the last five years in developing the techniques of hatching plaice in quantity, and to determine the feasibility of rearing fish to marketable size. It has been possible to establish the viability of the latter, while the former would require further investigations to solve several complex problems.

Roback, S. S., Cairns, J., Kaesler, R. L., 1969: *"Cluster Analysis of Occurrence and Distribution of Insect Species in a Portion of the Potomac River." Hydrobiologia, vol. 34, p. 484-502.*

Limnological surveys of a portion of the Potomac River were made from 1956 to 1965 to determine the effects of operation of the PEPCO Dickerson Power Station on the aquatic biota. Samples were collected at three stations on each of four high-water and six low-water surveys. Cluster analyses were made of various combination of Jaccard coefficients relating 50 aggregations of 370 insect species. Similarities of aggregations of species within a survey were in all cases greater than similarities among aggregations from different surveys, indicating relatively strong within-year or along-stream environmental influences. Clusters of aggregations from middle-year surveys show a greater similarity to each other than to the earlier or later surveys, possibly indicating environmental change at all stations, including the control. The marked dissimilarity of aggregations from the last survey to all others suggests biotic change in the river. One explanation is that increased urbanization upstream from the power station after 1956 caused some environmental change. No changes in aquatic biota can be attributed to thermal loading as a direct result of operation of the electric power generating station.

Roddis, L. H. jr., 1970: *"Metropolitan Siting of Nuclear Power Plants" in Environmental Aspects of Nuclear Power Plants. Proceedings of a Symposium on the Environmental Aspects of Nuclear Power Plants. International Atomic Energy Agency in cooperation with United States Atomic Energy Commission, New York, 10-14th August, 1970. I.A.E.A. Vienna, p. 723-729.*

This paper analyses the case for and against metropolitan siting of nuclear plants, using as a model the New York City area. The economic benefits of proximity to load centre are explored with respect to transmission costs and to opportunities for waste-heat utilization in urban areas. The relative environmental impact of nuclear and fossil-fuel plants are evaluated. It is these considerations which will be assessed in a given society. The paper notes that the benefits are discounted by residents of a metropolitan area because the obvious per capita benefits are small. By contrast, residents of smaller out-of-city locations perceive construction and operation of a plant as yielding large, and tangible economic gains (through utility tax payments, jobs, etc.). This has obvious ramification for relative public acceptance. The paper explores how a metropolitan site presents unique advantages and disadvantages with respect to geological, meteorological and hydrological criteria for siting nuclear plants. For example, large cities throughout history have tended to be located on navigable waters. This has ramifications for cooling water availability and for disposal of radioactive waste.

Roosenburgh, W. H., 1969: *Greening and Copper Accumulation in the American Oyster, Crasostrea virginica, in the Vicinity of a Steam Electric Generating Plant. Chesapeake Science, 10 (3 & 4): 131-138.*

Rosa, R. J., 1968: *Magneto-hydro-dynamic Energy Conversion, McGraw-Hill, 1968, 234 p. L.C.C. No. 68-18552.*

Rosenberg, H. B., 1967: *"Hydraulic Factors Affecting Thermal Power Plant Location in Great Lakes Region". Inland Waters Branch, Department of Energy, Mines and Resources, Canada.*

Ryther, J. H., Bardach, J. E., 1968: *"The Status and Potential of Aquaculture, Particularly Invertebrate and Algae Culture". Prepared for the National Council on Marine Resources and Engineering Development BP 177768. Clearinghouse of the Federal Scientific Technical Information Service, Springfield, Virginia.*

Samuels, G., Holcomb, R. S., 1969: *"Utilization of Low-Temperature Heat for Greenhouse Heating". Oakridge National Laboratory Internal Memo to S. E. Beall (CF69-11-26) November 20, 1969.*

The possibility of regulating environmental temperatures within greenhouses and poultry-houses by use of low temperature (below 100°F) waste heat at Denver, Colorado, was discussed. Cheap evaporative cooler-heaters could be used for heating during winter seasons, and cooling during summers to maximize the production of vegetables and poultry.

Santala, V., 1966: *Heating, Piping, Air-Conditioning, 38, 129.*

Scharfenberg, K., 1970: *"Scientist Disputes A-plant Objections". Washington Post: c2, December 3, 1970.*

A Johns Hopkins University oceanographer disputed the belief that discharges of warm water from the $387 million Calvert Cliffs nuclear power plant would have adverse effects on marine life. Dr. James H. Carpenter said he based his opinion on a study of the first year's operation of a plant in New Jersey where the discharged water reached 93 degrees, 3 degrees higher than would be permitted at the Calvert Cliffs plant being constructed by the Baltimore Gas & Electric Company.

Schumann, G. O., 1970: *"Hot Water Used in Hatchery". Air and Water News, vol. 4, no. 19, May 11, 1970.*

Warm water from a San Diego Gas & Electric cooling water outfall is being successfully used to hatch and raise fish, lobster and shrimp. Commercial applications will begin soon. Dr. George O. Schumann, a biologist at San Diego State College and president of Mariculture Research Corp., which has been conducting the experiments, plans to divert some of the utility's hot water effluent to a 50-acre salt pond stocked with 600,000 shrimp. The pond is situated near the power plant discharge canal. A supplementary feed will be

needed to raise the shrimp, which will be harvested in about a year. Dr. Schumann also believes that lobster can be rapidly matured in the warm water. Normal four-to-seven-year maturity, he says, may be cut to two.

Science News, 1968: *Science News 93, 169.*

Scott, A., 1969-70: *"Economic Impediments to Marine Development". Proceeding of the Conference on Marine Agriculture. Corvallis, Oregon. Oregon State University.*

Segerstroale, S. G. 1950: *"The amphipods on the coast of Finland — some facts and problems." Scientifica Fennica, Comment. Biol. 10(18): 1-28.*

S.F.I. Bulletin 1970: *"Waste Heat Conference". Sport Fishing Institute Bulletins, no. 214, May 1970, p. 1-5. (719 thirteenth St. N.W. Washington D.C. 20005).*

Shih, C. S., Stack, U. T. jr., 1969: *"Temperature Effects on Energy Oxygen Requirements in Biological Oxidation." Journal of the Water Pollution Control Administration. 41(11): 461.*

The treatment of wastes dependent on biological oxidation processes which, in turn, is affected by temperature. It was shown that temperature acclimated biological growth should be established so that temperature induced changes can be measured reliably.

Shirazi, M. A., 1970: *Thermoelectric generators powered by Thermal Waste From Electric Power Plants. Federal Water Quality Administration. Water Pollution Control Research series 16130. September 1970. Presented at the I.E.C.E.C. Energy '70 Conference, Las Vegas, Nevada. September 1970. p. 27.*

A crossflow type heat exchanger with the plate fin surface geometry is described. The plate separating the hot fluid from the cold fluid contains the thermoelectric unit. Equations for calculating convective heat transfer coefficients, the friction power extended per unit surface area and the maximum conversion efficiency are described. The alloys considered in this study were Bi2Te3 - Bi2Se3 (n type) and Bi2Te - Sb2Te 3 (p type). While conducting the latent heat from the condensing steam to the cooling water, the couples convert a portion of this heat to electricity. A second source of waste heat in a conventional fossil-fueled electric power-plant is the hot stack gases released into the atmosphere. Another source is hot exhaust gases from a gas turbine electric power system. Condenser performance data are presented in three separate tables. Power generated increases with turbine back pressure. A capital cost estimate for three plate module thickness of 0.01, 0.02 and 0.05 inch are estimated at $1250, $1560 and $3720 per kW, respectively. Ratio of the cost of thermoelectric to stream electric generation increased with plate thickness and is as high as 14 for a plate thickness of 0.05 inch. It is uneconomical, at the present time, to use thermoelectric devices to generate electricity from waste heat.

Slobodkin, L. B., 1960: *"Ecological Energy Relationships at the Population Level". American Naturalist 94: 213-236.*

Smithers, D., 1971: *"Summer snow job: City Plows harmful wastes into the Ottawa", The Ottawa Citizen, Wednesday, July 14, 1971, p. 3.*

Souther, J. G., Halstead, E. C., 1969: *"Mineral and Thermal Waters of Canada". International Geological Congress. Report of the 23rd Session. Czechoslovakia, 1968. Proceedings of Symposium II, Mineral and Thermal Waters of the World. B-Overseas Countries.*

A review of Canadian Thermal Water Resources.

Spiewak, I., 1969: *"Investigation of the Feasibility of Purifying Municipal Waste Water by Distillation". Oakridge National Laboratory Report ORNL-TM-2547. Oakridge, Tennessee. April 1969.*

The report focuses upon the technical and economic feasibility of applying the distillation process for demineralization of municipal waste waters. Principal applications of the method would be for improving the quality of effluents released from treatment plants to receiving streams, and to supplement water supply requirements in urban communities. This investigation is one of a series sponsored by HUD to determine the feasibility of nuclear power plants for the provision of low cost thermal energy to urban areas. Distillation has two potential roles in municipal waste treatment, one as a means of purifying waste water for reuse and second as a step in the ultimate disposal of solids. The technical problems of waste water distillation, described in the literature, are summarized. Cost estimates are given for a number of possible systems using distillation to treat effluent from a city of 1 million population. The analysis indicates that, although advanced waste treatments may increase the cost of sewage processing by factors of up to four times, the overall cost of water supply and treatment need not be increased over about 50%. Distillation appears to be a promising method of waste treatment, although methods of controlling tube fouling and distillate quality remain to be developed. Electrodialysis, reverse osmosis, freezing and ion-exchange are also discussed.

Staff of E.R.L., 1970: *The Development of a System for the Production of Power, Water and Food in Costal Desert Areas and the Development of a Large Scale Controlled-Environment Research Facility for Agriculture Production. Progress Report to the Rockefeller Foundation, Environmental Research Laboratories, Institute of Atmospheric Physics; University of Arizona, Tucson, Arizona. 109 p.*

Staff of E.R.L., 1970-71: *Annual Report; Environmental Research Laboratory. University of Arizona and the Arid Lands Research Centre, Abu Dhabi. 66 p.*

Stearns, B., 1970: *"Heat Waste", Sea Frontiers, 16 (3): 154-163. May-June 1970.*

Florida Power and Light Company is constructing a combination conventional (in operation) and nuclear (under construction) electric powerplant at Turkey Point on the southwestern shoreline of Biscayne Bay. This area is of special interest since it is the first nuclear power plant under construction in a tropical or near tropical area. It was observed that temperature at the effluent canal exists averaging 9 deg to 11 deg F above bay ambient and the thermal plume position is persistent. Significant damage of bottom vegetations was observed. Many cooling methods were discussed. Due to the huge size of plant, hurricane force winds and drift problem, no satisfactory cooling method can be achieved. The author suggested that whole population control or population density control should be done before we can solve the problem of increasing power demands.

Stevens, D. B., Satyendra, P., 1970: *"Thermal Pollution: Cause effects and solutions". New York State Department of Health Monograph 16 p.*

Thermal pollution can be reduced by improving thermal efficiencies of power plants, by evaporative or nonevaporative cooling, or by generating electricity by methods that do not use steam cycles, such as thermo-electric, thermionic or magneto-hydrodynamic generation. Improvement of thermal efficiencies, as a method of thermal pollution control, is limited by the condenser pressure and ambient temperature of cooling water. Evaporative cooling is the most common method of reducing thermal pollution at present. More progress should be made toward utilization of waste heat, which might be used for aquaculture, to heat houses (as houses in Iceland are heated by geothermic wells) or to heat greenhouses in order to extend the growing season.

Stewart, R., Bjornsson, S., 1969: *"Beneficial Uses of Thermal Discharge", from Adirondack Conference sponsored by Industrial Sciences and Technology. New York State Department of Commerce and the Atmospheric Sciences Research Center, State Uni-*

versity of New York, Albany, October 14-17, 1969, 12 p.

This article is the summary of the Adirondack conference and deals with present and future uses of hot water and low grade steam. In Iceland geothermal discharges are being used for space heating, processing, industry, swimming pools and other sporting facilities. The Icelandic fish culture designed to raise salmonoids to release-size in eight months instead of the normal growth period of two years, uses the geothermal discharge to maintain the proper temperature range (0-12°C). Of greater economic significance is the use of the steam for freeze-drying. A freeze-dried product weighs about 10-30% of its original weight and may be stored for years. To freeze 1kg/fish takes 10.5 kWh so discharge from 1000 MW plant contains sufficient heat to freeze-dry 200 tons of fish per hour. A 1000 MW reactor could heat a 500 acre greenhouse farm (effectively horizontal cooling towers) producing $12 million/year in crops.

Subrahmanyam, C. B., Oppenheimer, C. H., 1969: *"Food Preference and Growth of Grooved Penaeid Shrimp". Proceedings of the Symposium on Food and Drugs from the Sea. University of Rhode Island, Kingston, R.I., August 1969.*

Sutton, A. H., Main, G., Ronald, A., 1969: *"An instrument for Counting the Larvae of the Prawn, Palalmon Serratus, and the Brine Shrimp, Artemia Salina". Laboratory Practice 18 (4): 433.*

Swidler, J. C., 1970: *"Problems and Opportunities in Waste Heat Disposal" in Proceedings of the Conference on the Beneficial Uses of Thermal Discharge. New York State Department of Environmental Conservation. September 17-18, 1970. Albany, New York. p. 132-138.*

Tamiya, H., Sasa, T., Nihei, T., Jshibashi, S., 1955: *"Effect of variation of day length, day and night temperature, and intensity of daylight upon the growth of Chlorella". Transactions of a Conference on the Use of Solar Energy. The Scientific Basis. Vol. IV. Photochemical Processes. University of Arizona, Stanford Research Institute and Association for Applied Solar Energy. p. 38-47.*

Tanaka, J., Suzuki, S., 1966: *"High results of Serida culture by utilization of heated effluent water from fossil fuel power plants". Fisheries Culture 3 (8): 13-16.*

Templeton, W. L., Coutant, C. C., 1970: *Studies on the Biological Effects of Thermal Discharges from Nuclear Reactors to the Columbia River at Hanford" in Environmental Aspects of Nuclear Power Stations. Proceedings of a Symposium on the Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency, United States Atomic Energy Commission. New York, 10-14th August, 1970. I.A.E.A., Vienna, p. 591-613.*

In 1945, within a few months after the start-up of the original Hanford reactors, studies were begun to determine whether the cooling water discharged to the Columbia River might affect the important fisheries resources. The broad approach to the problem included pragmatical identification and investigation of the physical and biological facets of the river, complemented with rigorously controlled laboratory experiments. This integration of the field and laboratory work has yielded a much better understanding of the possible biological effects of heated effluents and the mechanisms involved than could have been derived by separate studies not carried out in situ. This paper reviews highlights of some of the research carried out over the past twenty-five years on the biological effects of elevated life stages of salmon, including the eggs, the fry, the juveniles, and the adults. New technology was developed to evaluate the risks to young salmon as they pass the reactor discharges en route to the sea. Field and laboratory data were combined to create a hybrid computer model that predicts the hazards to young fish in the mixing zones. The behaviour of adult salmon and trout on their spawning migration upstream past the reactor discharges was studied with the use of sonic tags. Some fish diseases are known to be aggravated by increases in temperature and studies were made on the incidence of the bacterial disease columnaris. The information derived from these studies is essential to the derivation of appropriate temperature criteria applicable to cold-water fish and to the specification of boundary conditions that must be met by the engineering design of outfall structures.

T.V.A. Report, 1968: *"Fish and Fishing around T.V.A. Steam Plants" Tennessee Valley Authority Report, Division of Forestry Development. 8 p.*

Some of the heaviest fishing in the Tennessee Valley takes place in the discharge channels and basins that receive warm water from the condensers of T.V.A. steam plants. Various species have been observed in steam plant discharge channels at temperatures up to 100 deg. F. John Sevier, with a discharge area of 6 acres, has the heaviest concentration of fish in the spring but throughout the year there were more fish in the discharge channel than in the river. Bluegill and channel catfish are the principal fishes and average catch of fishermen was 3.5 fish weighing 2.1 pounds per trip and success rate was 62%. Colbert, with fishing area of about 4 acres and discharge temperature of 9-13 degrees above lake temperature, has carpsucker, catfish, shad, carp as the principal fishes. February offered the best fishing followed by November and average catch was 2.5 fish and 1.1 pounds. Bull Run has a 3.5 acre basin and discharge temperature 10-13 degrees higher than lake temperature. The basin has 36 fish species. Both Kingston and Johnsonville discharge 10-14 degrees warmer water. The latter plant discharges to an 80 acre basin. The best months for fishing at Kingston are September, October, and May and average catch is 2.1 fish weighing 1.4 pounds per trip. At Johnsonville, the best months for fishing are October and January and average catch was 1.9 fish weighing 1.3 pounds per 3.8 hour trip.

Tibball, R. A., Gaydos, J. G., 1968: *"High Temperature Desalination Plants for Nuclear Power Stations" in Nuclear Desalination. Proceedings of International Atomic Energy Agency Symposium, Madrid, Spain. November 18, 1968, p. 495-506.*

The maximum temperature to which the brine can be heated in a MSF plant affects both the capital costs and energy costs charged to the product water. At the OSW East Coast Test Facility fresh sea water can be treated with sulphuric acid and heated in a 'once-through' plant to 300 deg F without scale formation in the condenser tubes. When this sea water is recirculated with or without concentration, scaling will occur at temperatures above 270 deg. F. A combination of a 'once-through' high temperature effect with either a single-effect multi-stage (SEMS) flash plant or a multi-effect multi-stage (MEMS) flash plant can be utilized to reduce both capital cost and energy charges. The purity of the product water from most MSF plants varies between 5 and 100 ppm TDS. Purer water can be made at an increase in capital cost. Make-up water for modern fossil-fuel boilers or for primary systems of nuclear reactors require water containing as little as 0.05 ppm. Generally a small part of the product water of a desalination plant is passed through a demineralizer to obtain the desired purity for make-up. However, a method is available to produce a few percent of the total product as very high-purity water. This process is presented and included in the design of the proposed plants.

Tidball, R. A., Gaydos, J. G., King, W. M., 1968: *"Operating Experiences of one MDG Desalination Plant on the Red Sea". Paper presented at the Symposium on Western Water and Power, Los Angeles, California. April 8-9, 1968. p. C43-C49.*

A one MGD desalting plant was erected in conjunction with a 6700 kilowatt steam generating station in Eilat, Israel. The design, manufacture and construction of the plant are discussed. The operating history and performance of the first 2½ year period are summarized. The effects of brine chemistry on corrosion, scaling and heat transfer are discussed with methods of selecting proper operating conditions. No calcium nor magnesium scale deposits have formed at any point in the system. The results of the corrosion tests, chemical analyses and visual inspection indicate that the plant should have an operating life in excess of thirty years. From December 21, 1965 to December 30, 1966 the plant produced 349 million gallons or 93% of the design capacity on a continuous basis. On a daily basis, the plant actually averaged 110% of design capacity. However, scheduled downtime for maintenance, along with periods when there was no demand for water reduced the total annual production. From January 1, 1967 to the present, the plant has averaged about 105% of design.

Tidball, R. A., 1969: *"St. Thomas 2.5 MDG Combined Desalination Power Plant". Paper presented at Puraqua, U.S. Exhibition and International Conference on Water Purification and Desalination. Rome, Italy. February 17-23, 1969. 5 p.*

The overall heat balance material balances, and economics for the combined power and desalination station at St. Thomas, Virgin Islands are summarized. The boiler is fired with 18,140 lbs. per hour of residual fuel oil. 233,093 lbs. per h. of the 600 psig 825 deg F. steam is piped to the turbine generator set which produced 15,500 kW of saleable power. Bleed steam is removed at 26 psig and piped to the brine heater of the desalting plant, which produces 2,500,000 gpd of potable water. The water plant was designed to produce water containing less than 10 ppm total dissolved solids, using not more than 110,000 lbs./h. of bleed steam from the turbine. Scaling of the heat transfer surfaces in the stage condensers and the brine heater was to be prevented by the use of sulfuric acid treatment to the make-up stream. The plant was designed for a 90% availability factor. The total cost is $641,000.00 per year. During the year, the plant could produce 825,000,000 gallons of water at a cost of 78 cents/thousand gallons.

Tidball, R. A., Gaydos, J. L., 1970: *"Desalination Using Waste Heat from Thermal Power Stations". Paper presented at the 3rd International Symposium on Fresh water from the Sea. Dubrovnik, Yugoslavia, September 13, 1970. 11 p.*

The use of very large steam turbines in the United States has been accompanied by a trend toward designing for higher back pressures. These higher back pressures in the condenser allow economic production of desalted water by flashing the condenser outlet water through one or more stages of flash distillation. Design of the systems and the economics of the water produced are discussed. This analysis is based on a narrow range of conditions. Additional work is required to determine limiting conditions of sea water temperature, power demand and water needs, amortization rates, and operating characteristics.

Tilton, J. E., Kelly, J. F., 1970: *"Experimental Cage Culture of Chanel Catfish Ictalurus Punctatus in the Heated Discharge Water of the Morgan Creek Steam Electric Generating Station, Lake Colorado City, Texas". Second Annual Workshop, World Mariculture Society, Baton Rouge, Louisiana. February 9, 1970. 14 p.*

Beneficial effects are summarized of heated discharges to the fish population of inland reservoirs in Texas. The sample fish were cultured in a discharge canal for three months. A net increase in weight over 400% in a cage of small test fish in 62 days was observed. In the control pond (with no temperature increase) the fish sample showed no increase in weight. The experiment was performed in January 1970. The control fish were fed but they would consume feed only when several days of warm air temperatures increased pond water temperatures.

Trembley, F. J., 1965: *"Effects of cooling water from steam-electric power plants on stream biota" in Tarzwell, C. M., ed., Biological Problems in Water Pollution. Public Health Service Publication Number 999-WP-25: 334-345.*

U.S.D.A. 1967: *U.S.D.A. Yearbook.*

U.S.D.I., 1968: *National Technical Advisory Committee Water Quality Criteria, FWPCA, U.S. Department of the Interior. U.S. Government Printing Office. Washington, D.C. April 1, 1968.*

U.S. Department of the Interior, Fish and Wildlife Service, 1970: *Physical and Ecological Effects of Waste Heat on Lake Michigan.*

Comprehensive review of the ecology and likely impact of thermal loading on Lake Michigan. A major conclusion is that *no* significant discharge of waste heat to Lake Michigan should be permitted.

United States Water Resources Council 1968: *The Nations Water Resources. U.S. Government Printing Office. Washington, D.C., 32 p.*

Valfells, A., 1970: *"Heavy Water Production with Geothermal Steam". United Nations Symposium on the Development and Utilization of Geothermal Resources, Pisa.*

Valliant, J. C., Longnecker, T. C., 1969: *Micro Climate Evaluation of Heating Irrigation Water on Cotton and the Resulting Effect on Cotton yield and Quality. Symposium on Thermal Agriculture, Sixth. Atlanta, Georgia. January 22-23, 1969. p. 40-41.*

Vinck, W. F., Maurer, H. A., Leonardini, L., 1970: *Engineering Safety Factors and their Influence on Siting Practices for Nuclear Power Plants in the European Communities. Proceedings of the Symposium on the Environmental Aspects of Nuclear Power Stations. International Atomic Energy Agency, United States Atomic Energy Commission. New York 10-14, August 1970. I.A.E.A. Vienna, p. 661-686.*

The paper refers primarily to the nuclear power plants installed or under construction in the European Community. Emphasis is given to the technological aspects of safety assessments and to the engineering used to prevent or mitigate the effects of abnormal occurrences, rather than to a discussion of the limits permitted by safety assessors. Mention is also made of the problem on cooling capabilities and its influence on site selection. In the discussion of abnormal and accidental situations, the loss-of-coolant accidents are treated as a significant example. Preventive and mitigating systems (engineered safeguards) installed in recent European nuclear power plants are considered. Emphasis is placed on the importance of high efficiency and reliability in such systems. The possibility of improving systems design by comparative reliability analysis is discussed. Emphasis is placed on specific problems of containment and reactor pressure vessel design, the safety factors considered in the design of these components and their influence on siting practices. Information is finally given on site conditions, distance zones, population centres and densities of some important nuclear power plants in Europe, most of which are installed or planned in populous areas.

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