An analysis of greenhouse, aquacultural, biomass and other applications in the utilization of waste heat from steam electric power plants

by

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INTRODUCTION

This investigation was undertaken to address the problems associated with utilization of waste heat from steam electric power plants. Waste heat is manifested primarily as the cooling water discharged from the condenser and may represent 60% of the energy input to the power plant. Most power plants in operation today have efficiencies of under 40% due to thermodynamic constraints imposed on the turbine which limit the conversion of heat to electricity. This results in the production of a large quantity of low grade "waste heat" as cooling water in the temperature range of 80° to 100°F (26° to 37°C). Because of the limited conversion efficiency, most of the energy is lost as a waste product. This study identifies some appropriate immediate and potential users of waste heat and examines various aspects of waste heat utilization by computer simulation. The report also addresses the potential for utilization at selected power plant sites in Iowa and briefly discusses some short and long term problems and solutions for power plants and waste heat.

PROBLEM STATEMENT AND RESOLUTION TECHNIQUE

From the environmental standpoint, the limiting factor for almost all forms of energy production is the problem of how to dispose of the waste heat. The "waste heat" considered in this study is the by-product of electric power production from steam electric power plants, specifically, the heat discharged to the environment due to the steam condensing operation.

Disposal of waste heat centers around two main problem areas: first, the enormous quantities of heat to be discharged and, second, the relatively low discharge temperature. The objective of this investigation is, therefore, to identify specific immediate applications for waste heat, to search for additional applications, and to examine short and long range problems associated with waste heat.

The approach taken in the investigation involved the selection of three immediate applications (based on results of the literature review) and their computer modeling. Results of the simulation were then used to evaluate parameters and assess the potential for utilization of each respective application at selected power plant sites in Iowa.

Computer simulation was chosen so as to allow for variation of power plant parameters such as discharge temperature to examine options for greater utilization of the waste heat. The model constructed could then be refined in later studies to concentrate on overall system optimization.

CONCLUSIONS AND RECOMMENDATIONS

The results of this investigation have shown that utilization of waste heat from power plants with recirculating condenser cooling systems is economically feasible for greenhouse space heating and marginally economic for water heating in recirculating fish raising units. A major obstacle limiting the potential for waste heat utilization was that of seasonal demand. The discharge could be used for heating during the winter but there were few summer applications.

The waste heat utilization scheme studied in this investigation is presented in Figure 1. Note, however, that the computer model presented in this report covers only the power plant, greenhouse heating, and fish heating units.

As a result of the investigation, the problem of limited use was overcome by the introduction of the concept of the biomass production evaporative cooling marsh. In the marsh concept, the warm water discharge from the power plant is received into a natural or man-made marsh. The marsh then acts as a waste heat reservoir and gradually dissipates the heat to the surrounding biosphere. The heat transfer is aided by the marsh's aquatic emergent plant canopy which shades the water from solar heat gain and produces a turbulent flow at the water surface.

At the end of the growing season the emergent plant canopy can be harvested as a biomass material. The biomass can then be used directly as a fuel or as a source of animal feed. In addition, the marsh concept could be expanded to include separate units for waste water treatment,

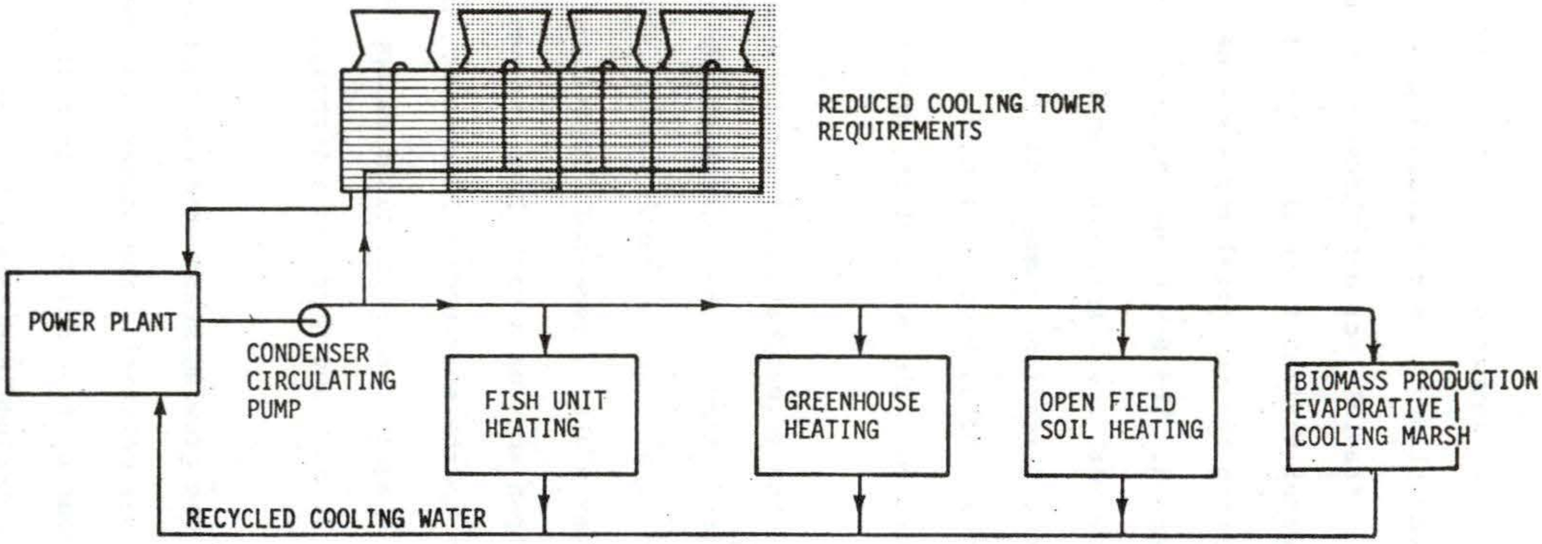

Figure 1. Assumed power plant waste heat utilization scheme

where the aquatic plants clean the water by nutrient and heavy metal removal, and the warm water environment could also be used for year round production of single cell protein (SCP) and fish polyculture.

Results from the empirical model showed that the waste heat from the Ames power plant during typical winter operating conditions (1.1 inch Hg) at a discharge temperature of 72°F (22°C) could be economically utilized for greenhouse heating. This temperature represents a cost of $530 per 1700 hr heating season for a 60°F (15°C) greenhouse air temperature or a maximum of 9 acres at $58/ac heating year. Similarly, the recirculating catfish production system could utilize the waste heat at a minimum discharge temperature of 85°F (29°C) at a cost of $13,000 per 8760 hr heating yr for 50,600 lb (live weight) of catfish per year.

One phase of this investigation has taken a somewhat nontraditional approach to the problem of power plant waste heat utilization in that it considered raising the temperature of the discharge water to make it "more marketable". A detailed treatment is presented in the results on the effect of raising the discharge temperature and the costs associated with it. The only potential limiting factor for utilization at temperatures above that normally discharged is that the user must purchase the entire coolant flow whenever the temperature is raised above the natural equilibrium condition. In other words, it will not be economic or efficient to raise the temperature of the entire coolant flow if the user only needs a small fraction of the total flow available, for example, if 16,000 GPM is available but only 500 GPM will be utilized.

Therefore, whenever a small temperature elevation is required a large scale utilization will also be necessary. That means heating of some number of acres of greenhouse or a large scale fish production complex. Temperature elevation for the biomass production concept would not be necessary because the marsh can utilize the waste heat in the "as discharged" condition.

With respect to Iowa power plants in the short run, it appears that the greatest potential for immediate large scale utilization of waste heat from power plants will be the biomass production evaporative cooling marsh concept. There are numerous locations throughout the state where the marsh concept could utilize waste heat and also provide cities with low cost efficient sewage treatment.

The potential for greenhouse heating and fish production using power plant waste heat in Iowa (as elsewhere) is very good; however, this does not mean that every power plant in the state would have either a greenhouse or a fish unit attached. Market considerations, power plant discharge temperature, and land availability will limit prospects for utilization throughout the state to only a few large scale sites. There is also a limited potential for space heating of animal enclosures, warehouses, and so on, which could be located close to existing or future power plants. The literature search revealed one potential year round application for waste heat which involved storage of the warm water in underground aquifers. The storage concept involves withdrawal, once through cooling, and reinjection of water into the underground aquifers. Then at some specified time the flow is reversed and the warm water is withdrawn for winter heating and reinjection after transferring its heat. The cycle then continues with the ground water aquifer being utilized as a large volume low cost heat storage well. This concept is relatively new and untested; however, it may very well hold good potential for utilization as more research is completed.

In the long run, because of growing concern over potential adverse climatic changes due to continued energy consumption, it is recommended that energy planners reassess the views of traditional energy production and distribution. The fact that over 40% of the energy used in this country is used as a direct heating application should be a sufficient signal to the planners that future power plants should be designed as total energy centers or dual purpose plants, supplying local heating, cooling, and electrical needs. Dual purpose power plants can achieve efficiencies of over 80% and heat transmission losses can be minimized by employing modern insulation technology. Thus, the decentralized total energy concept may not only be the environmentally required direction but also the economically prudent choice.

RESULTS AND DISCUSSION

Biomass Production

One of the major obstacles to large scale utilization of power plant waste heat was to identify a summer application. It is during the summer that waste heat is most available and its discharge temperature is highest. This is the result of increased condenser cooling required due to high temperature summer ambient conditions.

The investigation identified one important option for summer use of power plant condenser discharge, that is, biomass production. Biomass production from waste heat is a new idea and has not been addressed in this context in any of the literature. The biomass production concept was expanded to take advantage of several potential benefits. The idea was first addressed to using the waste heat to maintain or improve biomass production in a natural or artificial aquatic ecosystem. The biomass production evaporative cooling marsh concept was then introduced as a means of obtaining biomass material and to achieve cooling of the power plant's condenser discharge water. Not only can cooling be accomplished in an ecologically beneficial manner, but biomass resource material can be produced as a by-product.

Although empirical modeling of the biomass production evaporative cooling marsh was not conducted in the investigation, a further general refinement of the marsh concept revealed additional benefits. First, a low cost method of achieving cooling of the condenser discharge water for power plants with recirculating coolant systems. Second, as a source of plant biomass material that could serve as feedstock material for conversion to proteins, methane, or other chemicals. Third, the aquatic plants provide an efficient means of nutrient recovery (N, P, K) from the water and from nitrogen fixing plants. Fourth, the plants can also provide for waste water cleaning, that is, removal of undesirable toxic chemicals and heavy metals. Fifth, the marsh and aquatic plants, after cleaning the water, can act as a source for groundwater aquifer recharge. And, sixth, the warm water marsh can provide a natural ecosystem where fish and aquatic plants can thrive in the warm water of the power plant discharge. The warm water marsh ecosystem has so many advantages environmentally and economically that it would be wasteful and inefficient to dump the power plant's waste heat down a river or into a cooling tower.

The only possible barriers to the marsh concept would be the availability of land surrounding the power plant and its cost. Generally, power plants own and lease out a considerable amount of land surrounding the plant itself. A second constraint to implementation of the marsh concept would be availability of water. This should not be a problem in that condensing power plants (not employing dry cooling towers) must locate near a source of water and most power plants in Iowa (as elsewhere in the midwest) are already located along rivers.

The cooling of the condenser discharge water in the marsh would be accomplished by evaporation and radiation loss. A proper emergent plant canopy would aid the heat transfer by promoting a turbulent flow between the water surface and the free air stream. Thus, the marsh would act similar to a conventional cooling pond, except that the area required would be reduced, possibly by as much as one-half, due mainly to the effect of shading by the plant canopy which can intercept 70% of the incoming solar radiation and so prevent solar heat gain. Use of the cooling marsh would also reduce or eliminate entirely the need for expensive and energy intensive cooling towers. Cooling tower costs for a typical 500 MW power plant can range between five and ten million dollars, depending on the type of cooling tower and plant characteristics.

A marsh environment is ideally suited for biomass production. In fact, a fresh water marsh will yield more dry biomass material per unit area than any other land source. A variety of emergent aquatic plants would be well-suited to Iowa's climate and provide adequate solar shading. Phragmites (common reed) is one aquatic plant common to Iowa marshes and has the advantage of repropagating after each cutting without replanting. Another advantage of the marsh is that it is self-fertilizing. Blue green algae are nitrogen fixing and would be introduced into the marsh as a source of nitrogen fertilizer for the plant community.

Phragmites biomass dry yields of 28 tons/acre have been reported.[1] A variety of alternative uses exist for the biomass once it is harvested. These include direct combustion as a clean fuel source or conversion to an animal feed, protein supplement, methane, or other chemicals similar to those derived from traditional wood products.

The marsh could also be set up to recover nutrients and undesirable

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[1] Dr. Arnold VanDervalk, Department of Botany, Iowa State University, Ames, Iowa, personal communication, 1976.

heavy metals and chemicals from sewage waste water. In this application, water hyacinth would be employed to eliminate the undesirable chemicals which in turn could potentially be recovered from the plants. The system could be set up to clean waste water to a reusable state and thus act as a source for recharge of underground aquifers.

In an optimum use configuration, the warm water marsh could be used in sequence for biomass production, fertilizer production (through recovery of nitrogen fixing blue green algae), cleaning of sewage effluent, clean water recharge source, and as a fish polyculture system. Such a system would not be capital or technology intensive and is deserving of further study. (A discussion of additional variables relating to biomass production in Iowa is presented in Appendix E.)

Power Plant

Figures 2 and 3 present the cost of waste heat at various temperatures above the 1.0 and 1.5 inch Hg for typical power plants (Ames unit number 7 and ISU unit number 5). The significance of Figures 2 and 3 to a potential waste heat user or to power plant management lies in the fact that they provide a cost schedule of availability of waste heat at a specific temperature and flow rate. This is important to a potential user in that for a given Btu/hr requirement, a comparison can be made between the cost of waste heat discharged at various temperatures and the cost of heat produced by conventional sources. The figures are also important to power plant management in that a graphic correlation is available to describe the added fuel cost

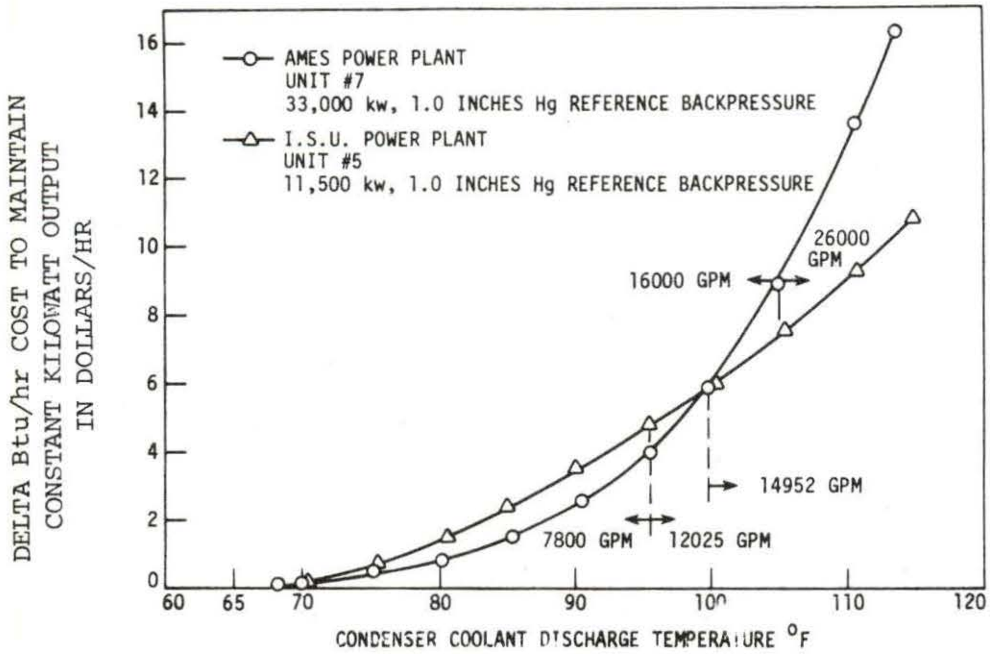

Figure 2. Delta Btu/hr cost vs coolant temperature for 1.0 inches Hg

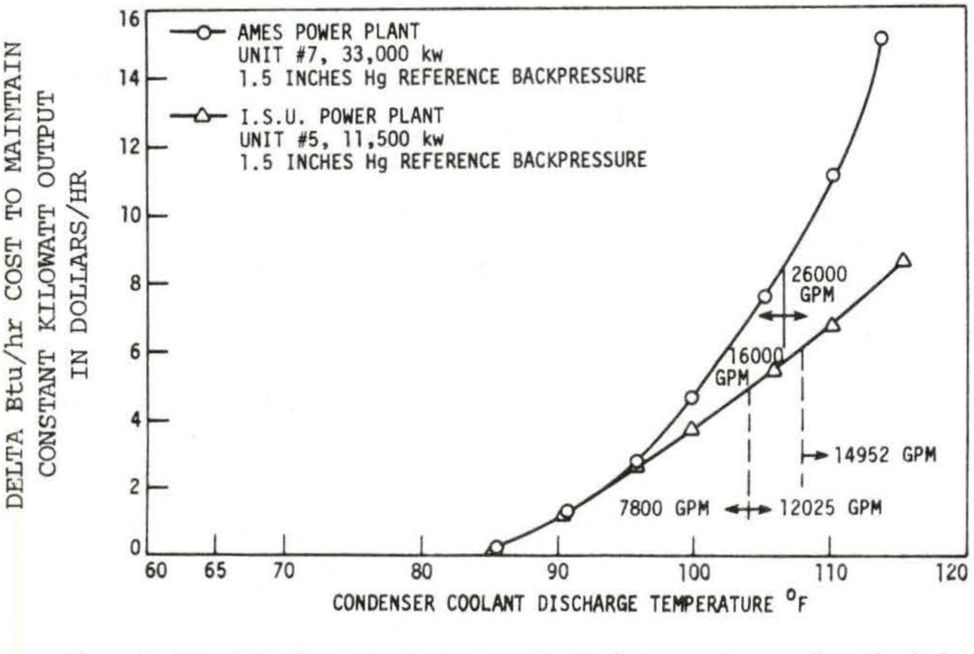

Figure 3. Delta Btu/hr cost vs coolant temperature for 1.5 inches Hg

associated with summer operation at high condenser discharge temperatures and backpressures. With respect to backpressure and Btu/hr cost, the figures indicate when an additional coolant circulating pump should be brought on the line or taken out of service. For the power plants surveyed in this investigation, no specific schedule was available to the plant operator from which determination could be made as to when extra pumping capacity would be economically justified.

From Figure 2, the reference discharge temperature for Ames (winter conditions) is 68°F (20°C) and 70°F (21°C) for ISU. This point defines the zero intercept for the waste heat cost and therefore means that at this temperature the heat associated with the entire condenser coolant flow rate is free to the user. If, however, the user required a higher discharge temperature than is available at existing ambient conditions, then the unit would need to be operated at a higher backpressure to give the desired discharge temperature. Thus, an increased Btu/hr input would be required for the unit to maintain its reference kilowatt output at the higher condenser pressure. This delta Btu/hr cost would then be the cost incurred by the user to obtain waste heat from the unit at a condition above the reference level corresponding to maximum efficiency at ambient steady state conditions.

For the user (greenhouse or aquaculture), Figure 3 represents a more realistic backpressure condition for typical winter operation. The units are designed for continuous operation at 1.5 inches Hg but can be economically operated below design pressure to 1 inch and above to 3.5 inches Hg. Thus, from Figure 3 it is seen that the waste heat is free at 85°F (29°C) for Ames and ISU, and above this temperature

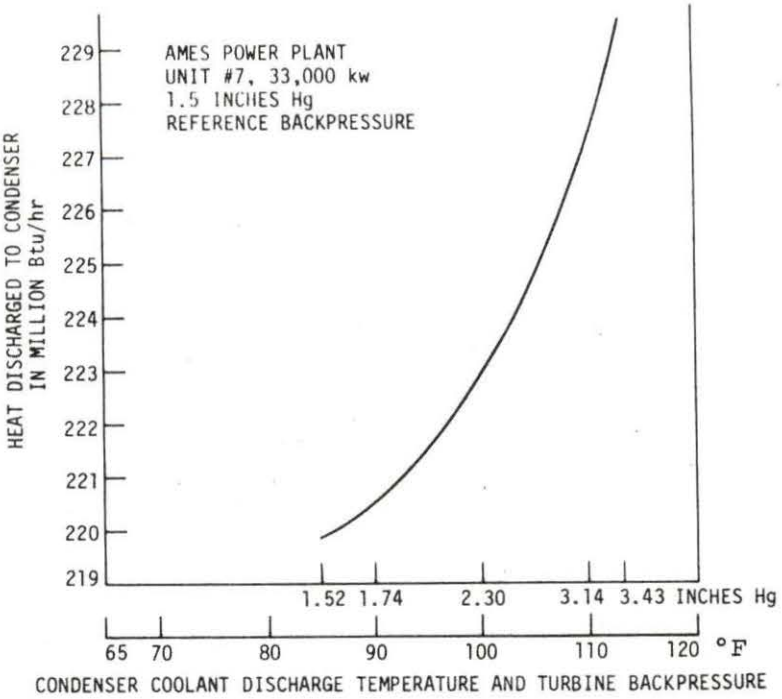

Figure 4. Heat discharged vs coolant temperature and turbine backpressure, Ames power plant unit number 7

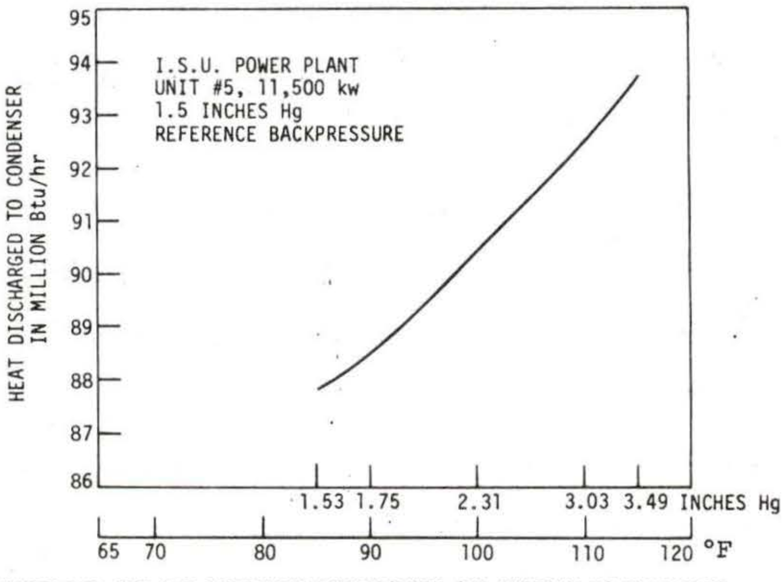

Figure 5. Heat discharged vs coolant temperature and turbine backpressure, ISU power plant unit number 5

the cost can be obtained from the curve and from the vertical scale.

The quantity of waste heat available from the unit is also an important parameter to a potential user. Figures 4 and 5 present the waste heat discharged to the condenser in million Btu/hr for the Ames and ISU units, respectively. For example, a greenhouse operator could determine that 119.8 million Btu/hr is available from Ames unit number 7 with 85°F (29°C) discharge water (based on a 27°F condenser delta T). Similar data can be obtained for ISU from Figure 5 and from Tables J.1 and J.2 in Appendix J.

Whenever a condensing turbine is operated at backpressures higher than the design value, the unit's efficiency is penalized because it is no longer condensing into a (low pressure) vacuum condition. The operation of a unit at a high backpressure is normally encountered during summer months, due to a higher ambient inlet temperatures, and can result in condenser pressures in excess of 3 inches Hg absolute. This same backpressure penalty will be encountered in waste heat utilization if the user, for example a catfish raising facility, required a minimum discharge temperature of 80°F (26°C) to maintain production during winter conditions. Then the user would have to compensate the power plant operator for the reduced efficiency resulting from the higher discharge temperature.

Figure 6 presents for ISU unit number 5 the delta kilowatt loss and revenue losses for operation at discharge temperatures above the reference condition. This figure presents the potential loss if a constant kilowatt output is not maintained. Note in Figures 2 and 3,

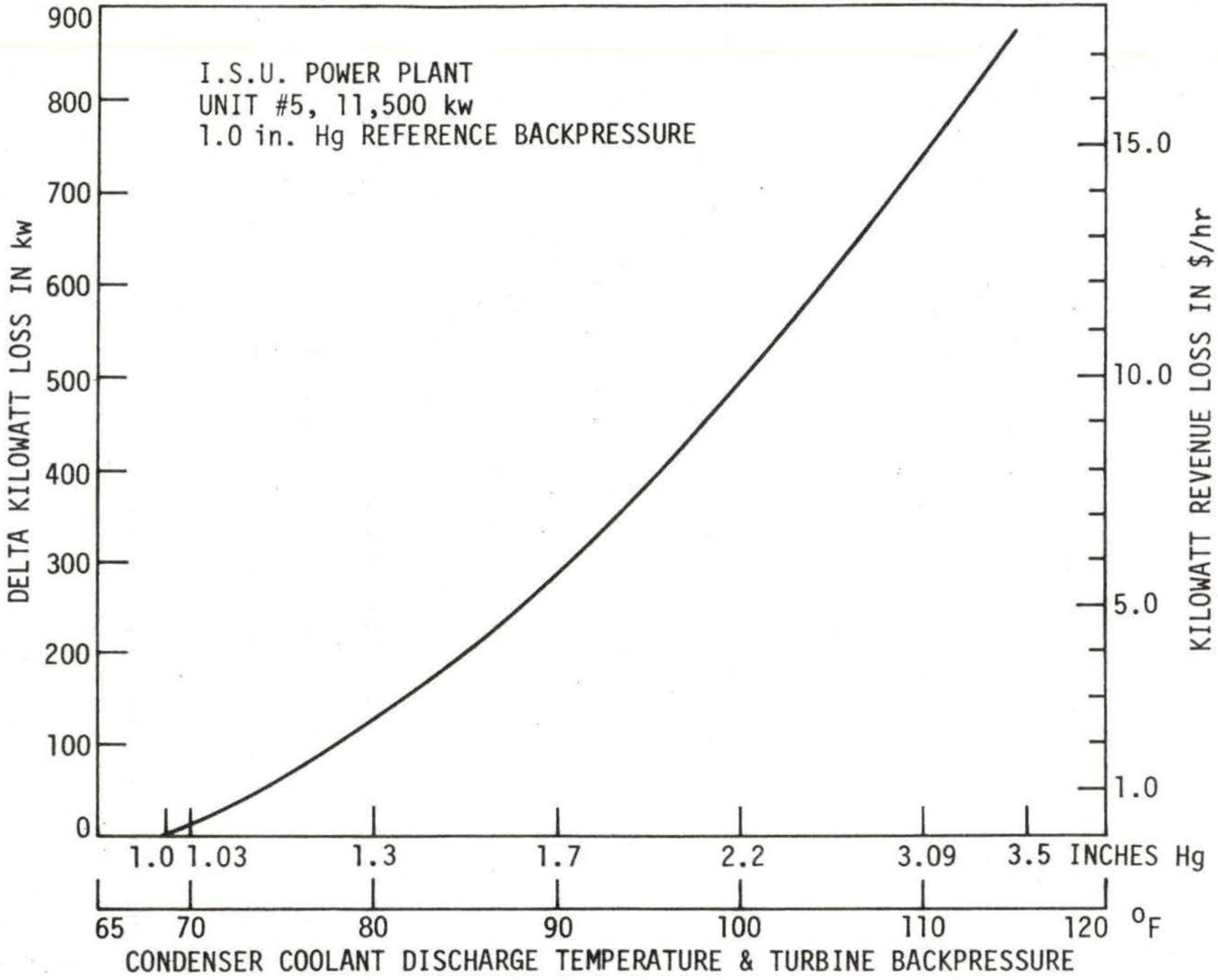

Figure 6. Delta kilowatt loss and revenue loss vs condenser coolant discharge temperature and turbine backpressure

however, that a constant kilowatt output was assumed. A constant kilowatt output was chosen because it best describes the actual performance of the power plant. The change in efficiency with condenser backpressure and coolant discharge temperature for ISU unit number 5 is given in Figure 7. Note from Figure 7 that for the normal winter to summer operating range, the efficiency drops from 33.5% to 31.3%, respectively. A loss in efficiency of 1 to 2% is typical for most power plants during summer operation. The 2% penalty could be accepted during the winter when the lost efficiency goes into heating applications. The waste heat would be available at a higher and more desirable temperature and could be justified economically if the added heat rate required was paid for by the consumer of the waste heat.

Figures 8 and 9 present a comparison of waste heat cost from ISU unit number 5 for the steam extraction and the condenser backpressure methods for obtaining waste heat. For the steam extraction case, two coolant flow rates of 100 and 500 GPM were selected. The coolant was assumed to be drawn off the condenser coolant discharge and further heated by means of a heat exchanger (similar to a feedwater heater) which receives the 90 PSIG extraction steam. See also Figure E.2. This concept was selected to permit a comparison of the added cost of raising the temperature of a small fraction of the condenser coolant flow to the cost of raising the temperature of the entire condenser coolant flow.

Using Figure 9 and Tables J.5 and J.12, it is seen that a 5000 sq ft greenhouse, subject to the Ames climate, has a maximum heating

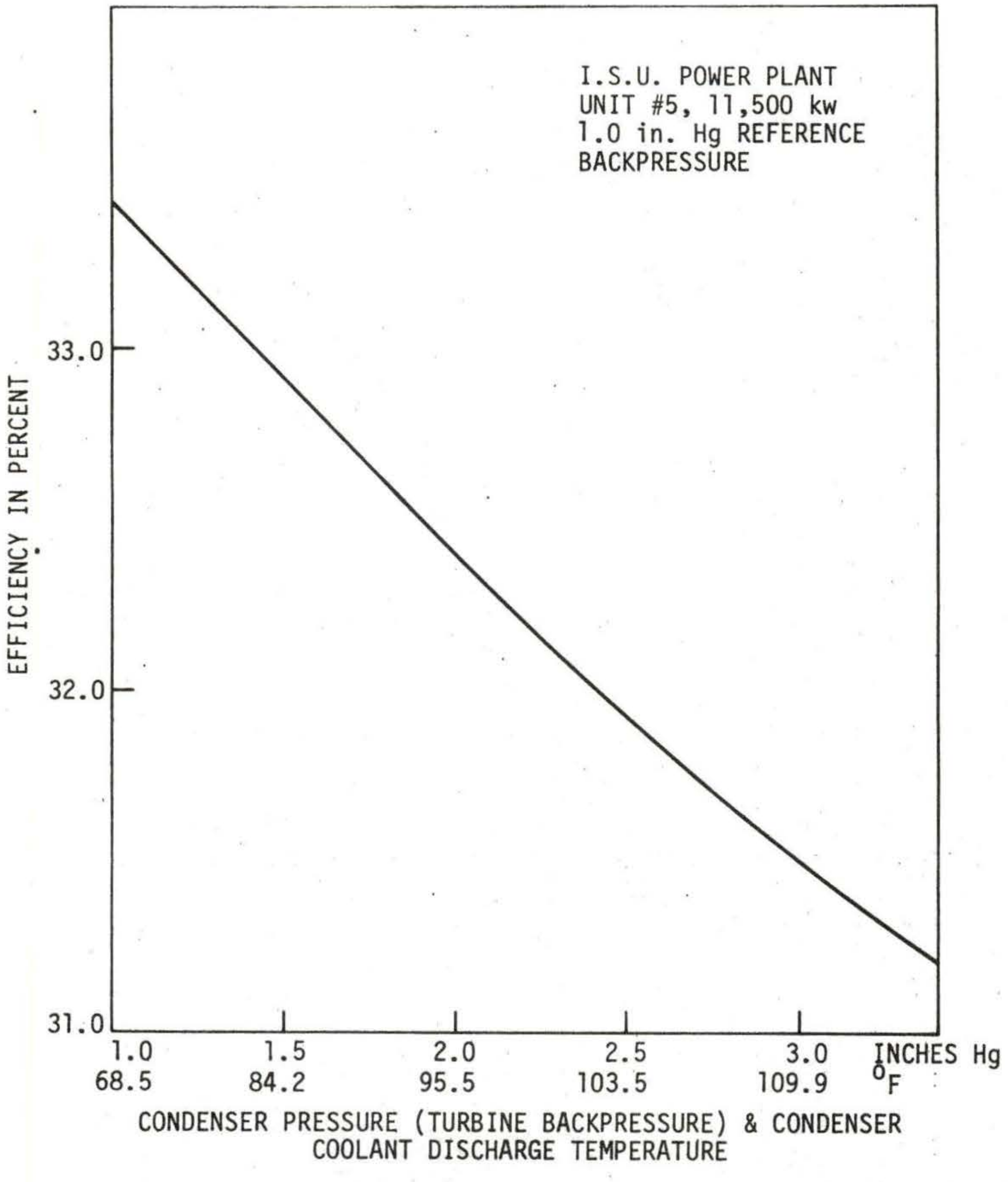

Figure 7. ISU unit number 5 efficiency vs turbine backpressure and condenser coolant temperature

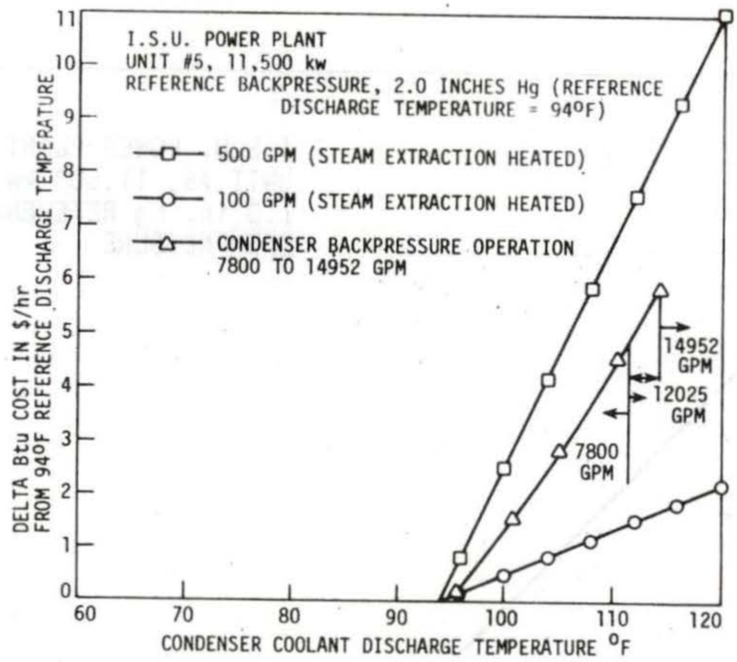

Figure 8. Cost of heat discharged vs temperature for steam extraction and condenser backpressure methods, 2.0 inches Hg reference

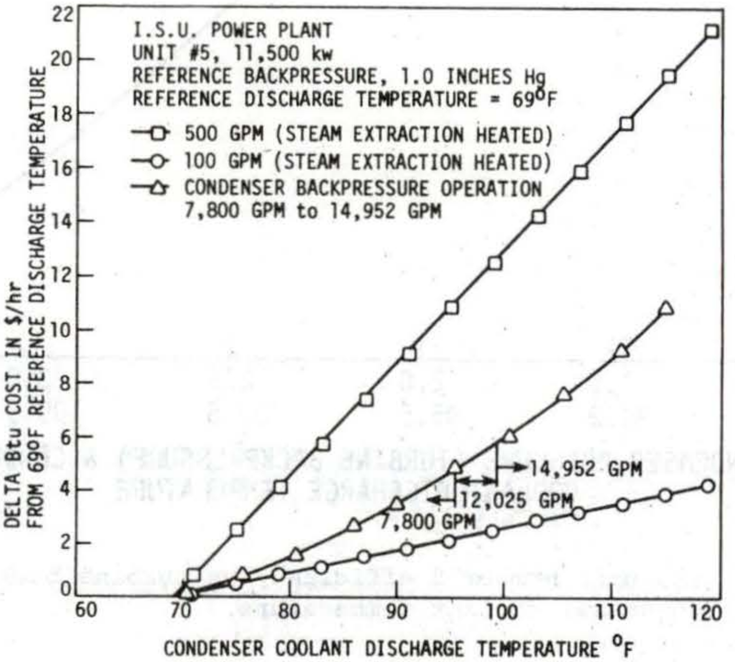

Figure 9. Cost of heat discharged vs temperature for steam extraction and condenser backpressure methods, 1.0 inches Hg reference

requirement of 370,000 Btu/hr, and if condenser coolant water at 80°F (26°C) is used to maintain the desired 65°F (18°C) air temperature, the cost for using the extraction heat source for a 100 GPM would be $.90/hr delivering 500,000 Btu/hr. (Since the heat delivered at 100 GPM is greater than that required, a smaller flow rate would be employed.) For direct use of the condenser coolant using a worst case condition of 1.0 inch Hg, then from Figure 9 and Tables J.1 and J.5, the cost using the backpressure curve would be $1.46/hr with 87 x 10^6 Btu/hr available. However, a more realistic comparison for direct use of the condenser coolant would be to assume 1.5 inches Hg, which is closer to the normal winter operating conditions. From Figure 9 and Table J.2, the reference outlet temperature is 84°F (28°C); thus, the waste heat would be "free" at this condition.

When the Btu/hr requirement is small, the extraction technique will be more economical than the backpressure method. This is due to the fact that if the backpressure method is used, the waste heat consumer would have to pay for raising the temperature of the entire condenser coolant flow to the desired temperature level. This technique is not economic if only a small portion of the flow is to be utilized.

Now consider a large heating requirement, for example a 50,000 sq ft greenhouse for the Ames climate with a 2.8 x 10^6 Btu/hr heating requirement and again using 80°F (26°C) water to maintain the desired 65°F (18°C) air temperature. Referring to Figure 9 and Table J.5, the 100 GPM rate could supply a maximum of 500,000 Btu/hr at 80°F (26°C) at a cost of $.90/hr, or using 119°F (49°C) water can supply 2.5 x 10^6 Btu/hr at a cost of $4.25/hr. Consider also the 500 GPM rate; at 81°F

(27°C) it will supply the required 2.8×10^6 Btu/hr at a cost of $4.93/hr. Comparison of extraction costs to direct use of coolant at the desired 80°F (26°C) from Figure 9 gives a $1.46/hr cost for the entire 7800 GPM at 87×10^6 Btu/hr (using a 22°F condenser temperature rise).

It appears that the backpressure method would be cheaper; however, closer inspection is required to explain why raising the temperature of only 500 GPM costs more than raising to the same temperature a flow rate of 7800 GPM. The explanation lies in the fact that the cost assigned to extraction steam included only the fuel, makeup water, distribution, and maintenance charges, whereas the extra heat rate required to achieve the higher backpressures for the condenser technique included only the cost of the additional Btu/hr (fuel) required.

A refined secondary analysis in this area would most likely confirm that some form of extraction technique to achieve a specific heating need would be less expensive and more energy efficient than raising the temperature of the entire coolant flow, when only a small fraction of the flow would be utilized.

Greenhouse

The results of the computer simulation for waste heat use in greenhouse space heating are presented in Figures 10 through 14. Figures 10 and 11 present the heater cost and total cost as a function of coolant temperature and condenser (turbine) backpressure. In Figure 10 the upper curve presents the variation of "waste heat" heater cost with temperature and backpressure. As would be expected, the heater cost goes up as the temperature of the condenser coolant approaches

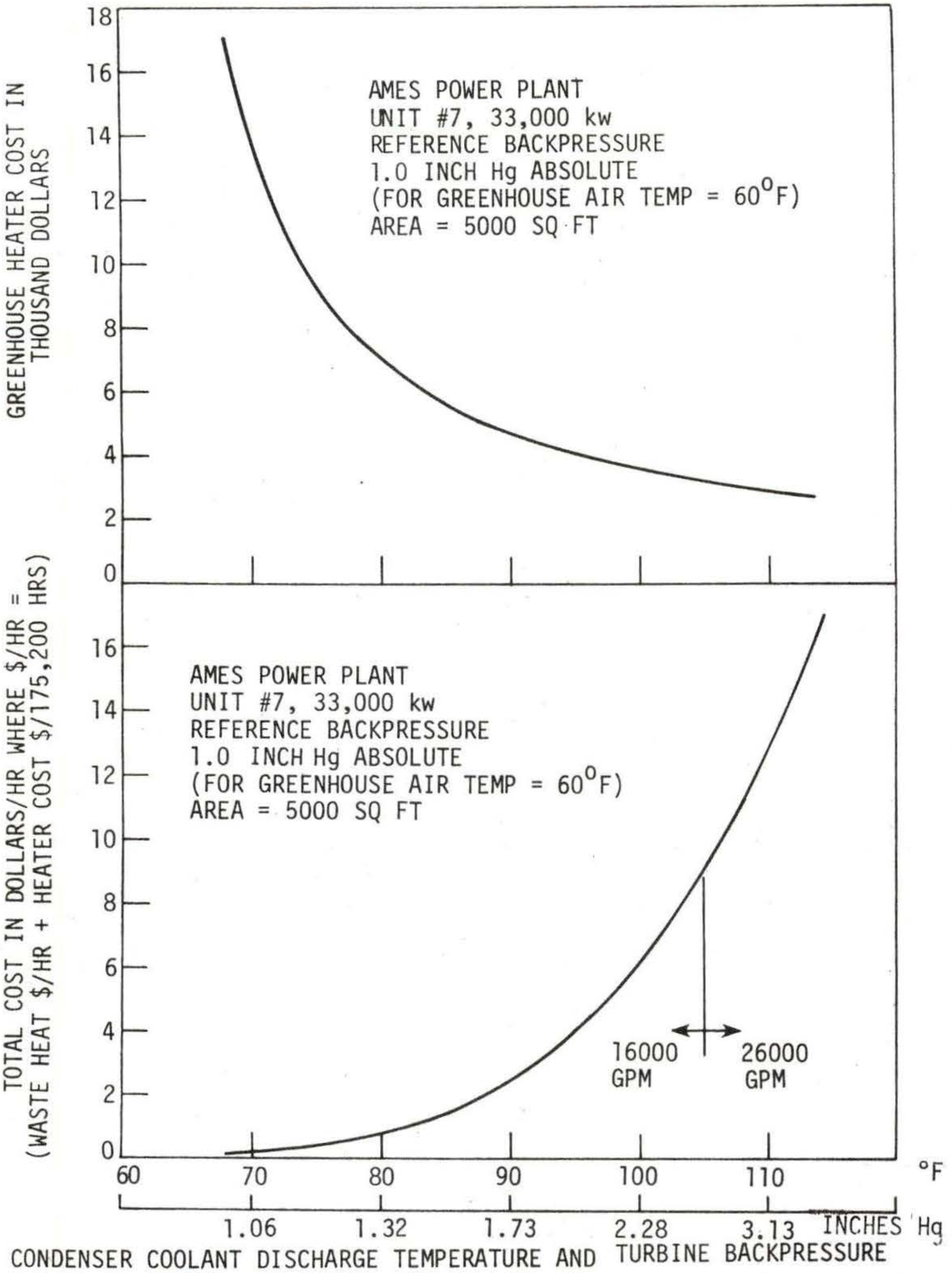

Figure 10. Total cost and greenhouse heater cost vs condenser coolant discharge temperature and turbine backpressure, for air temperature = 60°F

the desired air temperature. This is because the temperature difference between the air temperature and the waste heat has dropped. Therefore, to transfer the required Btu's, the surface area of the heat exchanger must increase.

The computer model for greenhouse space heating was programed with only one size of a commercial hot water to air type heat exchanger. The model determines how many heat exchanger units are required to meet a specific heating need. A more refined model could select a heater surface requirement based on several commercial model sizes. However, for the purpose of this investigation, the model gives a realistic estimate of the heater cost for a potential commercial greenhouse operation using waste heat. More discussion on the greenhouse heating system is provided in Appendix A.

The lower curve in Figure 10 presents the total cost as a function of waste heat temperature and turbine backpressure. Total cost is defined as the sum of the waste heat cost per hour from Figure 2 plus the heater cost (upper curve) spread over a twenty year life. Note that a minimum cost is not apparent on the curve. This is due to the fact that for the 60°F (16°C) air temperature selected and the worst case condition of 1.0 inch Hg, the discharge temperature of the condenser coolant does not approach close enough to the 60°F (16°C) point to give a minimum for the summation. From Figure 10 it can be seen that the discharge begins at 68°F (20°C). Therefore, the minimum cost occurs between 60°F (16°C) and 68°F (20°C). To demonstrate the minimum cost, consider Figure 11 where an air temperature of 70°F (21°C) has been

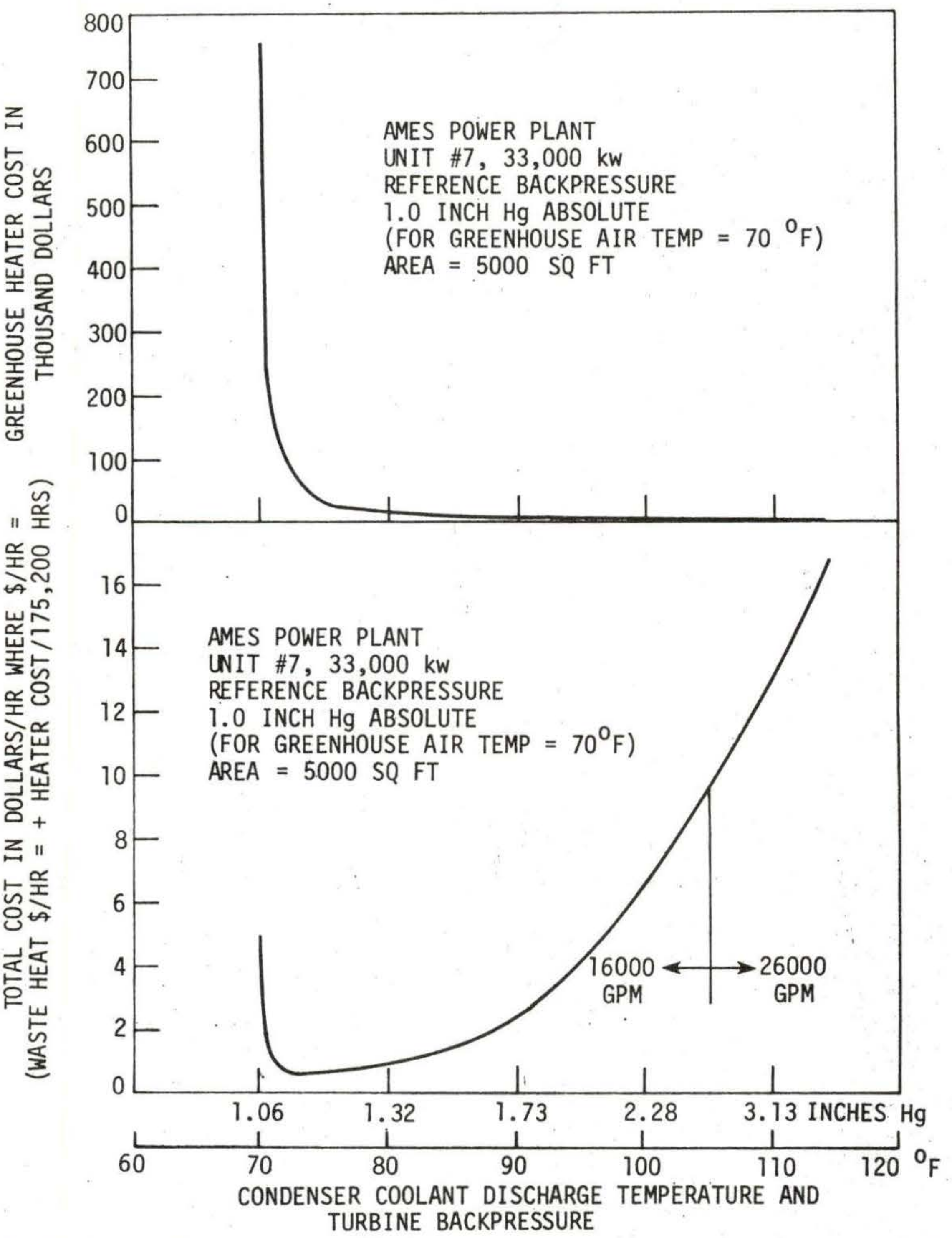

Figure 11. Total cost and greenhouse heater cost vs condenser coolant discharge temperature and turbine backpressure, for air temperature = 70°F

selected. Note that the minimum cost for the reference greenhouse appears at 72°F (22°C).

The significance of Figure 10 lies in the fact that the commercial greenhouse operator can see that for the worst case condition using the Ames power plant (backpressure of 1.0 inch Hg absolute), the waste heat could be used economically at its minimum discharge temperature. Thus, no temperature elevation would be necessary and no power plant efficiency loss would be encountered when using the condenser discharge directly. Another benefit to the greenhouse operator for using waste heat at the "as discharged" condition is that it is "free". Note, however, that although the waste heat is free, some pumping cost might be incurred by the operator depending on how and where the condenser coolant discharge is obtained. If the coolant is taken just after passing through the condenser with sufficient pump head remaining, then it could be run through the greenhouse and returned to the cooling tower catch basin. The coolant could be returned to the basin if the temperature had dropped sufficiently after passing through the greenhouse. Otherwise the coolant would need to be returned to the top of the cooling tower to achieve the required (temperature drop) delta T.

Table J.7 presents more information on the greenhouse operation. Figures 10 and 11 and Table J.7 do not represent the optimum configuration for waste heat use in greenhouse space heating. A more detailed treatment would include evaluation of such variables as size of heat exchangers, flow rates, both air and condenser coolant, and inlet and exit air temperatures.

To extend the dimensions of the greenhouse space heating model into the commercial utilization sector, several greenhouse floor areas were analyzed for cost comparison between power plant waste heat and conventional hot water propane-fueled boiler heat. Figure 12 presents the waste heat heater cost as a function of coolant temperature and turbine backpressure. Conventional heater costs are superposed. Thus, a family of curves is generated for greenhouse floor areas from 5,000 to 50,000 sq ft.

Note that the Ames power plant was selected and that 1.5 inches Hg absolute was chosen as the reference backpressure. To make the results more meaningful to a commercial greenhouse operator, a commercial power plant which has land available for a waste heat utilization complex was selected. (Refer to data collection and site selection for large scale installations in Appendix B.) The 1.5 inch Hg reference turbine backpressure condition was chosen because it closely resembles the actual normal winter operation range for unit number 7. For a greenhouse operator interested in using waste heat, Figure 12 presents a capital cost comparison of the waste heat system and the conventional hot water system.

Consider Figure 12 and the curve for the 5,000 sq ft floor area. Note that the cost of the waste heat heat-exchanger using the lowest discharge temperature of 84°F (29°C) is about \$5,500 and the intersection of the two lines where the cost of the two are equal (\$4,000) occurs at a temperature of 96°F (36°C). (The horizontal lines represent the cost of the conventional hot water heat exchangers.) This gives a heat exchanger cost increase of roughly \$1,500, if the waste

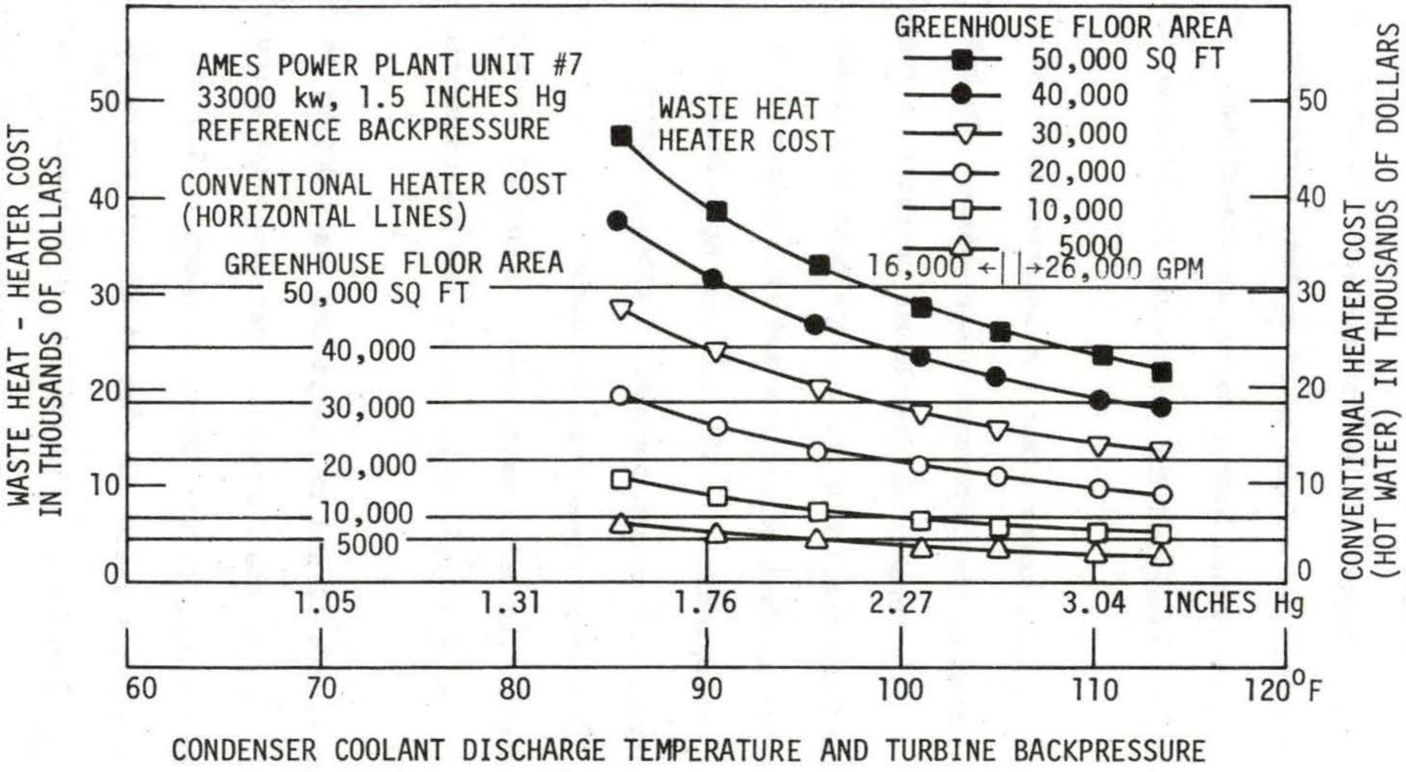

Figure 12. Greenhouse heater cost, waste heat, and conventional vs condenser coolant discharge temperature and turbine backpressure, for air temperature = 60°F

heat is used. Note, however, that the model did not include a cost analysis of the piping system, pumps, and controls. Because the comparison is to a conventional hot water heating system which would require the same pipes, pumps, and controls, the difference is assumed to be small.

Now consider the case of a large scale greenhouse (Figure 12). For example, the 50,000 sq ft floor area requires a heater cost increase of about $15,000 for the waste heat system at the reference temperature of 84°F (29°C). The intersection of the curve with the horizontal line corresponding to 50,000 sq ft occurs at 97°F (36°C) where the conventional heater cost is $31,000. Therefore, at the high temperature end the use of waste heat provides a $9,000 saving over the conventional system.

The most important parameter to be considered by the greenhouse operator is the annual heating cost or specifically how much the annual heating costs could be reduced if waste heat were utilized. Figure 13 presents a comparison of the waste heat cost at various temperatures with the superposed conventional propane fuel costs. Again, consider the 5,000 sq ft floor area case and note that the indicated horizontal line represents an annual propane heating cost of $2,500. Using the minimum waste heat temperature available, 84°F (29°C) and the curve in Figure 13, the waste heat cost is found to be zero (the curve intercepts the zero cost line). Therefore, when utilizing the condenser coolant at the reference discharge condition at 1.5 inches Hg, no turbine backpressure penalty is encountered and thus no added Btu/hr cost is charged. The intercept of the 5,000 sq ft

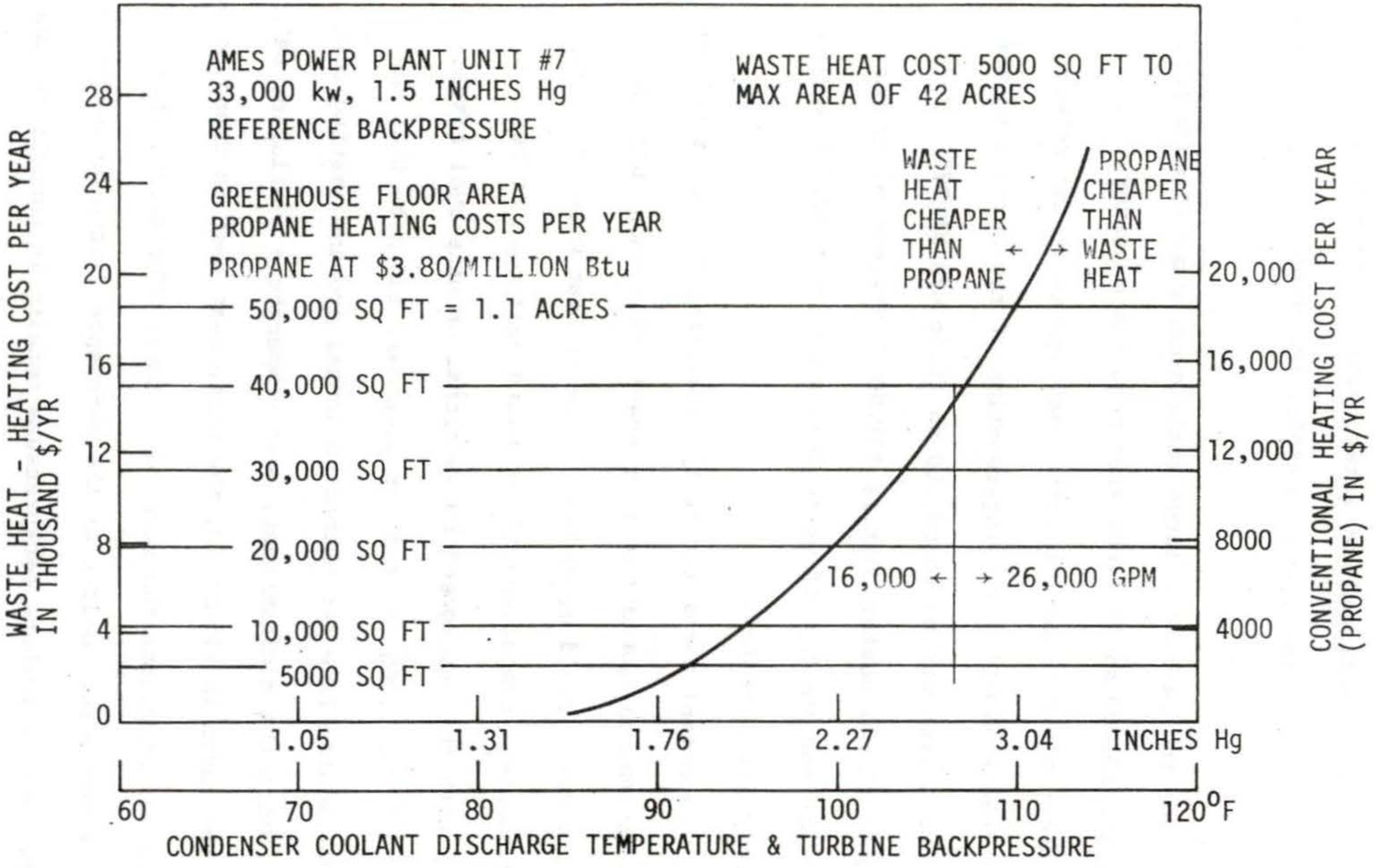

Figure 13. Greenhouse heating cost, waste heat, and conventional vs condenser coolant discharge temperature and turbine backpressure for air temperature = 60°F

line with the waste heat cost curve at 92°F (33°C) represents the break even cost. The intercept is the point where the cost of the waste heat (at temperature elevated above the reference condition) just equals the cost of propane for a conventional fossil fuel system. It should also be pointed out from Figure 13 that the maximum greenhouse area which could be heated from the waste heat available at the various temperatures is limited by the condenser coolant flow. From the curve (Figure 13), 16,000 GPM is available from the reference discharge temperature of 84°F (29°C) to 105°F (41°C). Beyond 105°F (41°C) the second circulating pump is brought on the line, making 26,000 GPM available from the steady state temperature of 95°F (29°C) to the upper limit of 113°F (45°C). These flow rates would heat 18 acres of greenhouse at 84°F (29°C) to 42 acres at 113°F (45°C). Refer to Table J.7 in Appendix J for detailed greenhouse results.

If the greenhouse operator considers only the waste heat temperature and cost compared to that of propane, then for the floor areas shown the waste heat at any temperature to the left of the curve on Figure 13 is more economic than propane heat and to the right of the curve propane heat is more economic than waste heat. However, one other very important aspect must be pointed out. Even though it is shown that the waste heat at an elevated temperature is competitive with propane, care must be exercised to insure that all available waste heat at the elevated temperature is utilized. If the temperature of the condenser coolant is raised from the reference, to for example the 100°F (38°C) level, and used at the economic breakeven point for a 20,000 sq ft green house area, this results in only 210 GPM or 1.3% of the flow being utilized. The net result of small utilization at other than the reference condition is that more waste heat is produced than is effectively utilized. In any utilization scheme, this condition must be avoided; otherwise it will defeat the purpose of using waste heat.

Figure 14 presents the savings (over propane) made possible by using waste heat at various temperatures and for several greenhouse floor areas. The intercept of the curves with the zero axis clearly shows the breakeven point for the areas listed. The percent utilization concept should also be considered in the evaluation. For example, the savings resulting from using waste heat at 84°F (29°C) for the 5,000 sq ft greenhouse is shown to be $2,000/yr but for the same temperature for 50,000 sq ft an $18,000/yr savings is realized. If 100°F (38°C) coolant discharge temperature is picked for the 50,000 sq ft area, a $10,000/yr savings is realized over the use of propane fuel. However, note that if the 100°F (38°C) condenser coolant temperature is used for the 50,000 sq ft heating requirement, only 3% of the 16,000 GPM available is utilized, whereas for the same floor area an additional $8,000/yr more is saved if the reference discharge temperature of 84°F (29°C) is used. Thus, there is no charge for the waste heat at the "as discharged" condition. Figure 14 shows the savings available for the various areas and temperatures, but the percent of utilization at a given elevated temperature must also be considered.

The trade-off between fuel cost savings, cost of waste heat, and heat exchanger cost can be seen in Figure 10. The greenhouse operator can see that by using waste heat at 100°F (38°C), a higher total cost

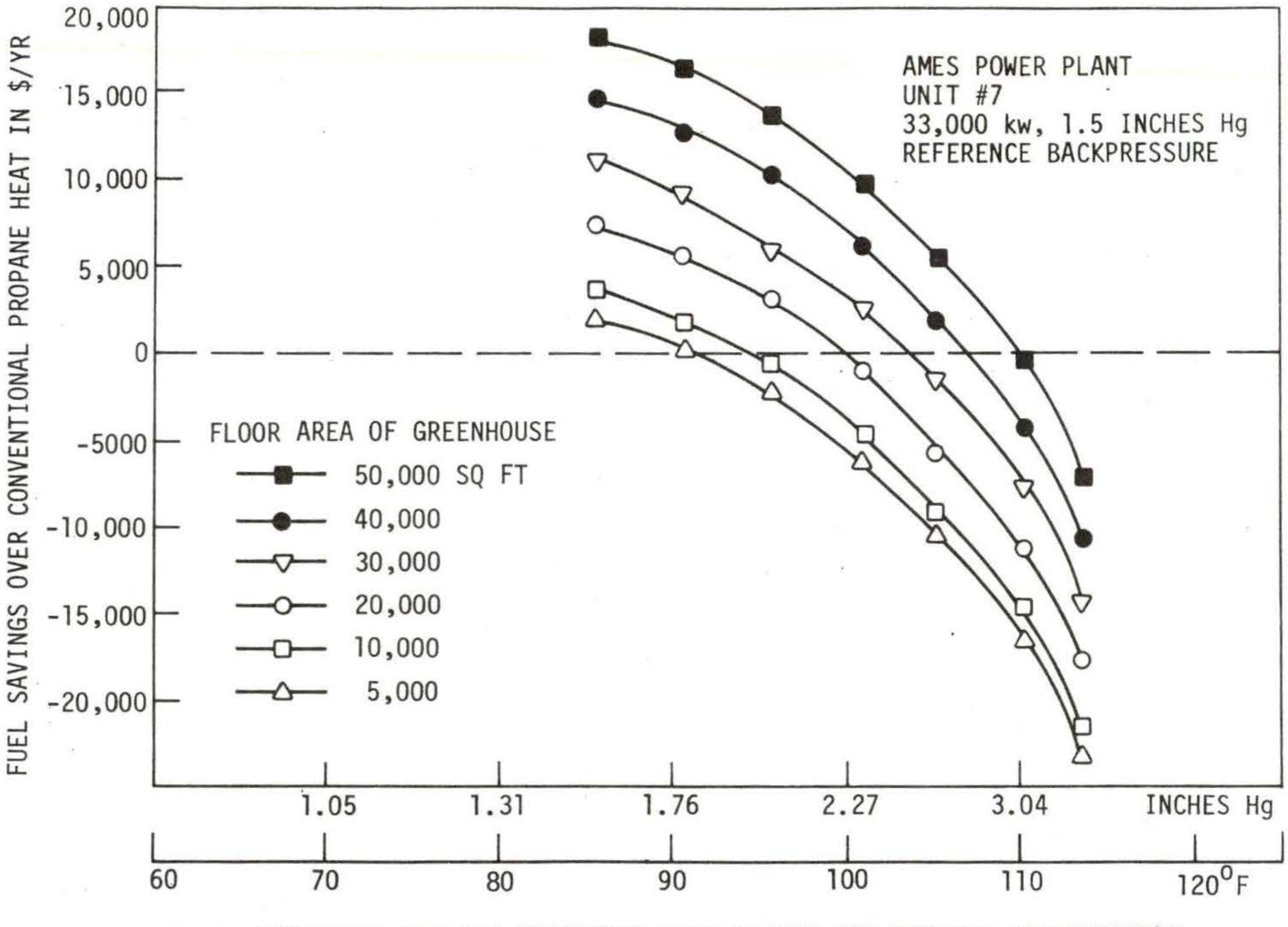

Figure 14. Greenhouse fuel savings vs condenser coolant discharge temperature and turbine backpressure for air temperature = 60°F

results than if water at 84°F (29°C) discharge temperature is utilized, and thus the savings over propane would be less. This can also be seen from Figures 12 and 14. For example, from the 50,000 sq ft line at 100°F (38°C) in Figure 12 the heat exchanger cost is $28,000 and $45,000 for the heat exchanger at 84°F (29°C), an increase of $17,000 in heater costs to use the lower temperature. From Figure 14 the differences in heating cost savings for 100°F (38°C) and 84°F (29°C) are $10,000/yr and $18,000/yr, respectively, which gives an $8,000/yr increase in savings over propane for an additional $17,000 investment in heat exchangers. Also, note that at the reference temperature the waste heat is free and at 100°F (38°C) it costs $8,000/yr for the entire 16,000 GPM flow whether all is utilized or not.

In summary, for the greenhouse it has been shown that economic waste heat utilization is possible even when the worst case condition of 1.0 inch Hg is assumed and the results are even more feasible at a more realistic discharge condition of 1.5 inches Hg. For the 1.5 inch Hg case, the Ames power plant unit number 7 could potentially heat 18 acres under normal winter operating conditions of one circulating pump delivering 16,000 GPM. Also, the cost of the waste heat to the greenhouse operator would be free at the reference discharge condition. A similar analysis and discussion with similar conclusions could be presented for the ISU power plant unit number 5 by reference to Tables J.1, 2, and 8. The data provided in Tables J.11, 12, 13, and 14 in Appendix J permit the determination of the heating requirements for several different climatic conditions and greenhouse inside air temperatures.

Aquaculture

Data from the 7,500 lb/yr catfish production model were extrapolated to a 75,000 lb/yr commercial production size by assuming a linear multiple of the reference model unit. Although this scenario leads to a higher estimated cost, it is considered for the purpose of this investigation to adequately approximate the expected overall performance of the fish production system.

The results presented in Figures 15 and 16 and in Table J.9 in Appendix J show that the assumed fish production system can operate economically using waste heat (from a recirculating condenser coolant system) at a minimum discharge temperature of 85°F (29°C). However, it should be noted that the high capital cost required for heat exchangers is a limiting factor in the utilization of waste heat for fish production from a power plant with a recirculating condenser coolant system. (The heat exchangers provide for separation of the condenser coolant water from the fish rearing water.) Alternative methods for use of power plant waste heat in fish production are presented later.

Figure 15 presents a comparison of water heating cost using conventional and waste heat sources. The conventional system consisted of a 1,000,000 Btu/hr 180°F (82°C) propane fueled boiler and a U tube heat exchanger. Propane fuel was assumed to cost \$3.80 per million Btu and the cost of the boiler and heat exchanger was placed at \$10,000 for the assumed 7,500 lb/yr unit. The 85°F (29°C) discharge temperature was arbitrarily selected as the minimum temperature, because the optimum temperature for catfish production lies near 83°F (28°C). A more

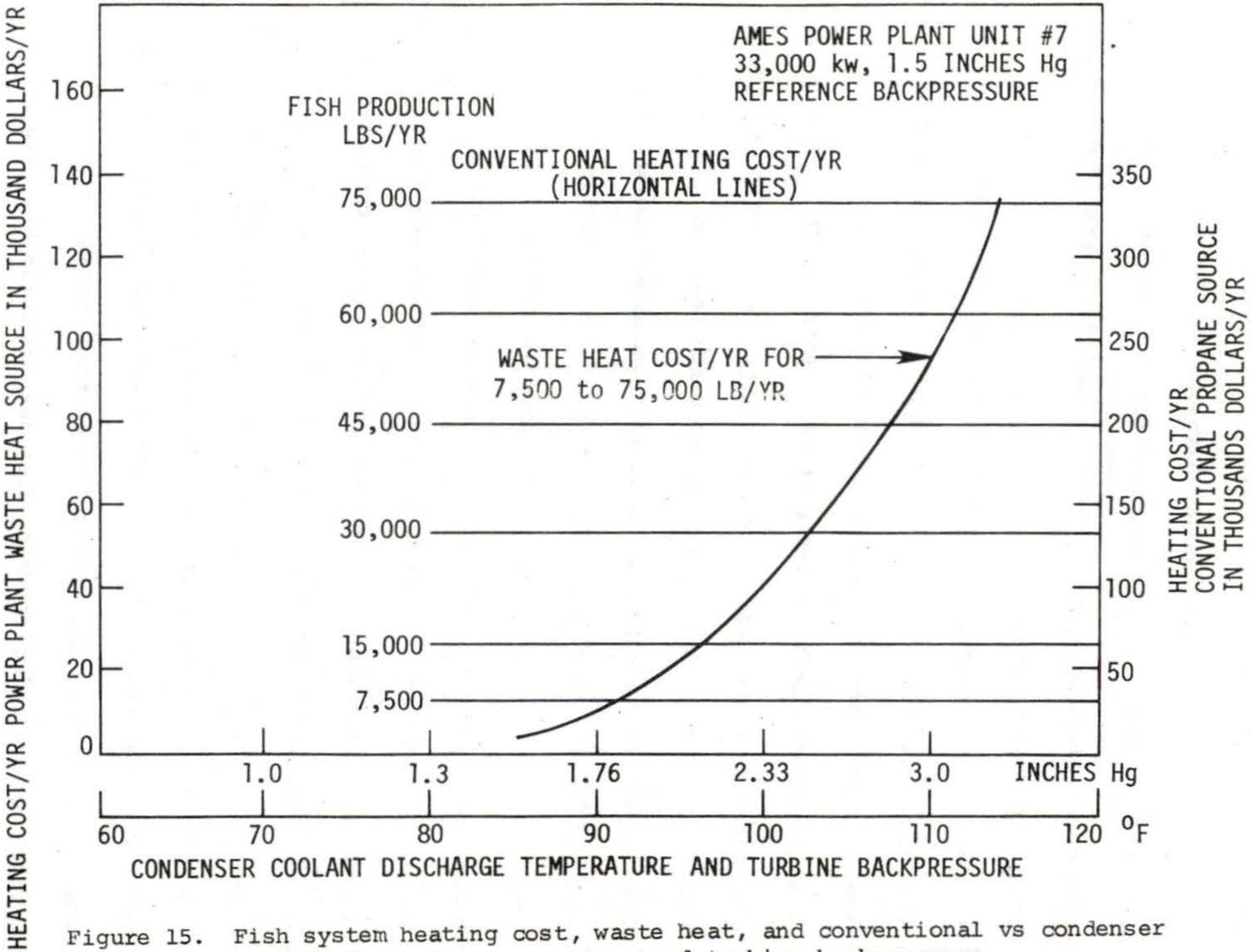

Figure 15. Fish system heating cost, waste heat, and conventional vs condenser coolant discharge temperature and turbine backpressure

detailed treatment of the variables affecting intensive fish production is provided in the final report to the Iowa Energy Policy Council (Roberts and Bahr, 1978). The heat exchanger selection for use with power plant waste heat was accomplished in the model by determining the required heat exchange surface area for various temperatures and selecting the next larger commercial size. (Data for the heat exchangers were supplied by Bell and Gossett.)

The waste heat cost from the curve in Figure 15 based on a temperature of 85°F (29°C) gives a cost of $1,300/yr for the 16,000 GPM condenser flow rate. The $1,300 pays for the entire flow rate whether only the required 2,280 GPM is used for the 7,500 lb/yr production or if the entire flow is used for a 52,500 lb/yr production. (The 16,000 GPM flow represents the capacity of a single pump operating under winter conditions.) Note also that this is the low flow condition for the year. An increased coolant flow would be available during the spring, summer, and fall.

If propane fuel had been used to meet the heating requirements for the 7,500 lb/yr production facility, the cost would have been approximately $30,000/yr and about $230,000/yr for the 52,500 lb/yr plant. Thus, based on Figure 16, data show that the use of waste heat at 85°F (29°C) would result in a heating cost savings of $28,700/yr and $228,700/yr for production yields of 7,500 lb/yr and 52,500 lb/yr, respectively.

Propane fuel was selected arbitrarily as a basis for comparison. It needs to be clarified, however, that at the present market price of $2.00/lb (supermarket price) the catfish producer could not

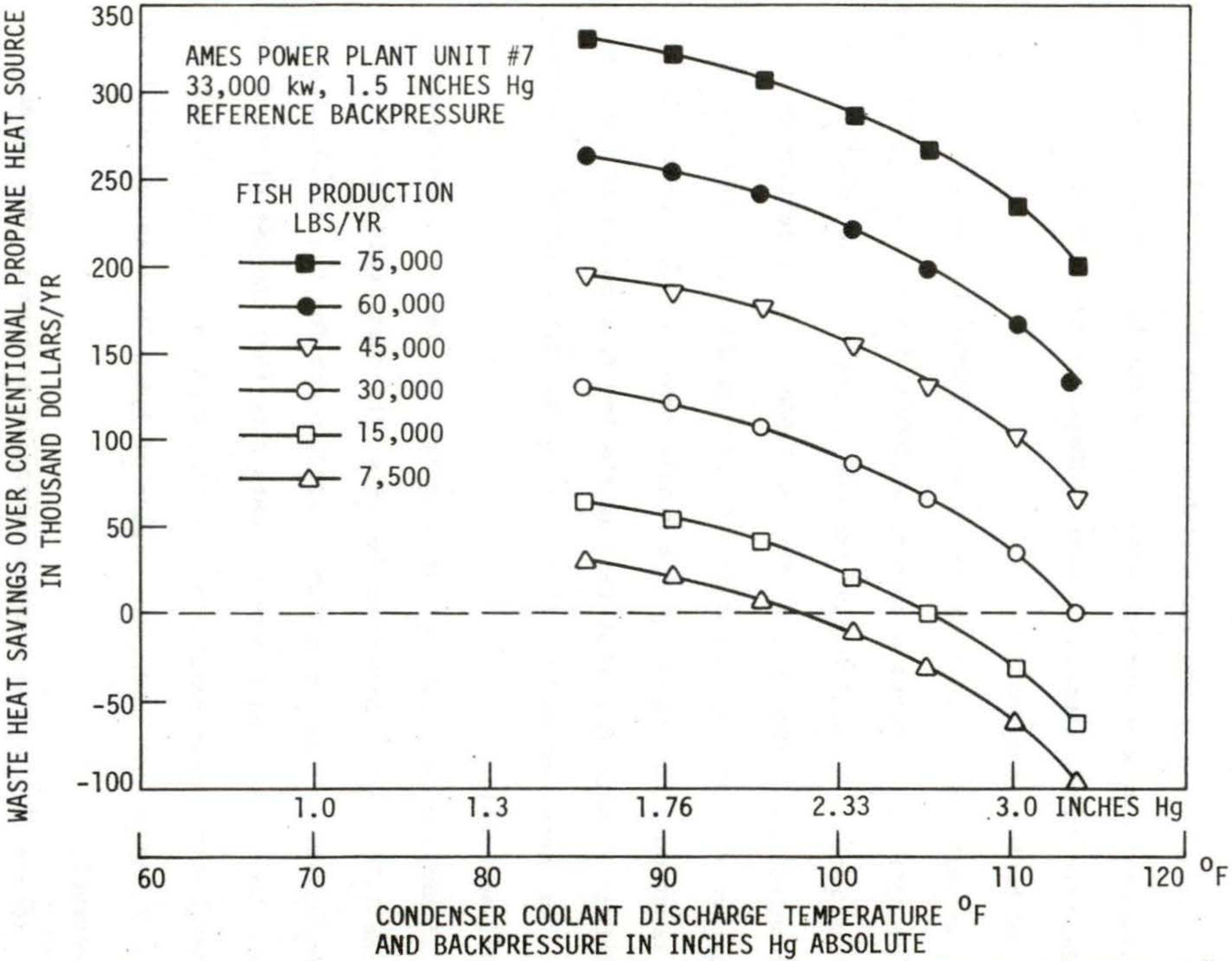

Figure 16. Fish system fuel savings vs condenser coolant discharge temperature and turbine backpressure

economically justify production using a propane heat source. Assuming that the producer receives $1.00/lb live weight, the heating cost of $1,300/yr represents 17% of the total $7,500 return. This leaves only $6,200 per year for salaries and other expenses. Therefore, it appears that even using the waste heat at the lowest discharge temperature of 85°F (29°C), the 7,500 lb/yr fish raising system would be only marginally economic, if at all. If the size of the unit is doubled to produce 15,000 lb/yr, however, then for the same 85°F (29°C) water the waste heat cost is still $1,300/yr and for this case represents only 9% of the $15,000/yr return.

Although this investigation did not conduct a detailed economic analysis of all the costs of the fish production system, it appears that the minimum size for breakeven operation is about 15,000 lb/yr. An important factor enters here that is not evident in either Figure 15 or Figure 16, that is, the percent of waste heat used by the fish production unit. When the user pays for the entire flow rate, the utilization of only a small quantity of waste heat becomes very expensive. To further illustrate this point, consider in Figures 15 and 16 a production level of 52,500 lb/yr. Using 85°F (29°C) water, this rate would require 16,000 GPM for the shell side of the heat exchanger, yet the waste heat cost is still only $1,300/yr. In addition, from Table J.9 in Appendix J, the apparent advantage in using higher temperature waste heat to obtain smaller heat transfer area and lower cost heat exchangers seems to be canceled by the rising cost of the waste heat. Note for Table J.9, EX COST = the cost of the heat exchanger, WH COST = the cost of the waste heat, and SUMCOST = the sum of the heat exchanger cost over 20 years plus the waste heat cost. (The complete symbol dictionary is available in Appendix I.)

From Table J.9, it can be seen that the heat exchanger represents a major cost in the recirculating tank culture system (other components are discussed in the fish unit specifications in Appendix A). For example, using the 85°F (29°C) water, the heat exchanger for a 52,500 lb/yr production rate would cost approximately $95,000 (based on a combination of seven of the 7,500 lb/yr pilot units). Assuming a supermarket price of $2.00/lb, the optimistic case of $1.00/lb live weight to the producer therefore gives a return of $52,500/yr minus the $1,300/yr waste heat cost, leaving $51,200/yr to cover all other expenses. Even with the $51,200 return after waste heat cost, it could take up to 15 years to recover the original investment. Although the concept may seem economically feasible, the limiting factor for the waste heat user will most likely be the excessive initial capital investment required for the heat exchangers.

It can also be seen from Table J.9 that the condenser coolant temperature drop across the heat exchanger is very small, approximately a one degree drop. From the point of view of power plant efficiency, a larger delta T would be desirable so as to return the coolant at the equilibrium inlet temperature. To obtain a larger temperature drop, however, a larger heat exchanger would be required. Thus, a larger temperature drop would mean more heat transferred and higher equipment costs but, because there is a large volume of waste heat available, the user would prefer to take advantage of the large flow rate to minimize the size of the heat exchangers.

The heat exchange equipment considered in this investigation consisted of existing "off-the-shelf" units. It was felt that off-the-shelf equipment would be less costly than special order units. The selection and performance of the heat exchange equipment is deserving of continued study. A more detailed analysis of the heat exchanger requirements needs to be conducted to determine the optimum combination for waste heat cost, temperature drop, and equipment cost in assessment of the overall potential benefits and trade-offs available.

An alternative technique which could utilize the waste heat but not require the capital intensive heat exchangers is suggested. The alternative recommended could only be utilized with power plants not employing closed cooling systems, such as where cooling towers are used. The technique is best suited to power plants using "once through" river water (or cooling ponds) for cooling. For the case of once through river water, the fish production unit would be the same as the one described in Appendix A except that the warm condenser discharge water would be fed into the rearing tanks. Thus, the heat exchangers would be eliminated. Other fish culture techniques could be used to further reduce costs, such as raceway vs tank culture. In the case of the raceway system, waste removal must be assured before the water is returned to the river source. In addition, high level management would need to be employed (as in the case for the recirculating tank culture) to assure that the quality of the condenser coolant water (rearing water) is not compromised by periodic addition of chlorine or other chemicals used to clean the tubes in the condenser. Note that chlorination is regularly conducted to prevent buildup of microorganisms in the condenser. When chemical cleaning is scheduled an alternate condenser discharge would need to be used and, in order to insure a constant heat source, the fish raising complex would need to locate at a power plant with more than one continuously operating unit.

The concept of direct use of waste heat from once through cooling systems has good potential for large scale utilization and is deserving of further research.

APPLICATIONS FOR WASTE HEAT UTILIZATION

Many potential applications for waste heat use in Iowa have been identified and are discussed in detail in the Appendix. A brief summary of the applications is presented in the following paragraphs.

Figure 17 presents a flow chart of potential applications for power plant waste heat. Both the low temperature range and the high temperature range are considered in the utilization scheme. The low temperature is characterized by summer and winter condenser discharge temperatures, 90°F and 70°F (32°C and 21°C), respectively. The high temperature utilization scheme would apply to steam extraction turbines, high backpressure turbines (dry cooling tower system), or noncondensing turbines, 150°F to 350°F (66°C to 177°C). The low temperature applications include sewage treatment, biomass culture (biomass production evaporative cooling marsh), greenhouse heating, animal confinement building heating, subsoil heating, grain drying, and warm water storage in underground aquifers. The high temperature applications are directed toward the planned "total energy" or dual purpose power plants. Included are district heating and cooling, storage of high temperature water in confined underground aquifers, and refuse drying for power plant fuel. The high temperature applications such as district heating are discussed in more detail in a later section. The low temperature applications which seem to hold the greatest potential for immediate development on a large scale basis in Iowa are greenhouse heating, heat for aquaculture (fish raising in recirculating confined high density systems), and the biomass production evaporative cooling marsh.

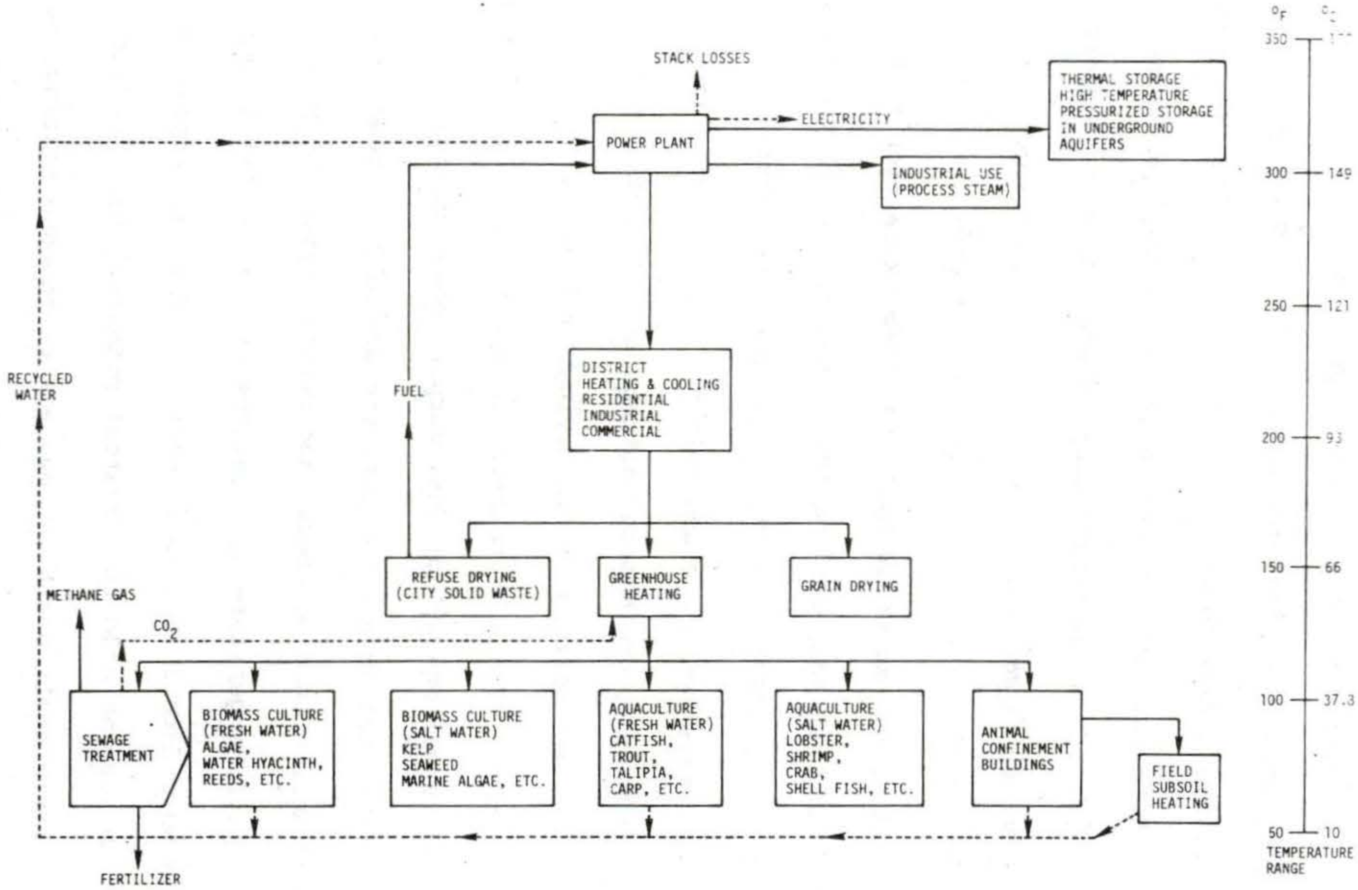

Figure 17. Combined high and low temperature heating applications for total energy power plant

ENVIRONMENTAL IMPACT

A detailed study of the potential impact of waste heat utilization on the environment has not been carried out in this study; however, two areas of concern are the effect of thermal and CO_2 emissions on climatic changes and water resources. Thermal pollution of rivers and lakes has been considered by others and is reported in a variety of publications. Therefore, it is not covered in this report.

The literature search revealed that reduced direct thermal and CO_2 emissions may be required within 50-100 years in order to avoid undesirable climatic alteration (Wolf, 1974). Although this seems to be a few years away[1] the planning and implementation of more efficient use of energy today could result in a reduction of energy wasted (lost in the thermal to electric conversion process) and thus reduce the total direct thermal emissions from power plants. This could be accomplished by long range energy planning, featuring total energy power plants and CO_2 and other stack gases recovery. Potentially, the CO_2 could be used directly to enhance the greenhouse environment, the NO_x could be recovered for conversion to nitrogen fertilizers, and SO_2 recovered for conversion to elemental sulfur, sulfuric acid, ammonium sulfate for fertilizer, and sodium sulfite for paper and gypsum. Further research in potential NO_x recovery is needed.

The water resource problem can be presented in two parts, conservation with respect to consumptive use in conventional wet evaporative

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[1] Paul Sidles, Ames Lab, U.S. Department of Energy, personal communication, 1977).

cooling towers and local effects of contamination by cooling water drift. The water resources of Iowa are limited and with the growing demand for electric power and construction of larger generating stations, the demand and consumptive use of water for cooling is increasing. As the demand for water by agriculture, industry, and utilities increases the consumptive use for cooling may be restricted. A possible solution may be a recirculating biomass production evaporative cooling marsh. Such a system has a number of obvious attractive features although the evaporative and evapotranspiration water loss from this type of cooling ecosystem has not been investigated.

The effect of cooling tower drift on vegetation involves the possibility of uptake of toxic elements. The practice of adding biocides and corrosion inhibiting chemicals (zinc and chromium) to make up water for cooling towers is the source of these chemicals, and drift from these towers provides a pathway for the transfer of toxic elements to the surrounding local environment (chromate use is now being restricted). This is significant in Iowa because often the cultivated vegetation that may surround the cooling towers is consumed by animals where secondary concentration occurs and thus a pathway is established for potential transfer of toxic trace elements into the food chain of man. Edmonds et al. (1974) and Taylor et al. (1974) indicate elemental uptake in plants from the soil is much less significant than is the uptake from leaf surface contamination. Additional research needs to be conducted to determine the relative toxicity of chemicals and biocides added to make up water and resulting drift from cooling towers to establish reference data applicable to the Iowa environment.

ENERGY CONSUMPTION PATTERNS

In order to become aware of the possibilities for more efficient utilization of the energy resources available from existing and future steam electric power plants, one must first look at the overall pattern of energy consumption. Specifically, to determine ways in which waste heat might be employed, the end use of energy consumed must be examined. Energy consumption by sector and end use is presented in detail in Tables 1 and 2 (Office of Science and Technology, 1972).

Table 1. Percent of total U.S. energy consumption for various heating applications

Heating application	Percent
Space heating (residential, commercial)	17.9
Process steam (industrial)	16.7
Water heating (residential, commercial)	4.0
Air conditioning (residential, commercial)	2.5
Refrigeration (residential, commercial)	2.2
Total	43.3

Referring to Table 2, it can be seen that energy consumption is divided into four major sectors: residential, commercial, industrial, and transportation. Each sector is then divided into various end use activities. The 1968 heating applications are listed in Table 2 (Stanford Research Institute, 1972) along with their respective percent of the national total energy consumption. The heating applications are listed in order of relative importance.

Table 2. Energy consumption in the United States by end use, 1960-1968 (trillions of Btu and percent per year)

Sector and end use	Consumption 1960	Consumption 1968	Percent annual rate of growth	Percent of national total 1960	Percent of national total 1968
Residential					
Space heating	4,848	6,675	4.1	11.3	11.0
Water heating	1,159	1,736	5.2	2.7	2.9
Cooking	556	637	1.7	1.3	1.1
Clothes drying	93	208	10.6	0.2	0.3
Refrigeration	369	692	8.2	0.9	1.1
Air conditioning	134	427	15.6	0.3	0.7
Other	809	1,241	5.5	1.9	2.1
Total	7,968	11,616	4.8	18.6	19.2
Commercial					
Space heating	3,111	4,182	3.8	7.2	6.9
Water heating	544	653	2.3	1.3	1.1
Cooking	98	139	4.5	0.2	0.2
Refrigeration	534	670	2.9	1.2	1.1
Air conditioning	576	1,113	8.6	1.3	1.8
Feed stock	734	984	3.7	1.7	1.6
Other	145	1,025	28.0	0.3	1.7
Total	5,742	8,766	5.4	13.2	14.4
Industrial					
Process steam	7,646	10,132	3.6	17.8	16.7
Electric drive	3,170	4,794	5.3	7.4	7.9
Electrolytic processes	486	705	4.8	1.1	1.2
Direct heat	5,550	6,929	2.8	12.9	11.5
Feed stock	1,370	2,202	6.1	3.2	3.6
Other	118	198	6.7	0.3	0.3
Total	18,340	24,960	3.9	42.7	41.2
Transportation					
Fuel	10,873	15,038	4.1	25.2	24.9
Raw materials	141	146	0.4	0.3	0.3
Total	11,014	15,184	4.1	25.5	25.2
National total	43,064	60,526	4.3	100.0	100.0

Table 2 shows that space heating for residential and commercial use is the largest single end use of energy (excluding transportation which consumes 25%). The total space heating consumption is close to 20%, which includes industrial space heating which was not separately identified. The growth rate for space heating consumption is approximately 4% per year which is close to the national total energy growth rate of 4.3% per year.

By examining the end use of energy it can be observed that over 40% of the total energy consumed in the United States is a direct heating application. Some fraction of these heating needs could be satisfied by dual purpose central power plants providing heating, cooling, and electricity to the surrounding area as is done in a number of northern European communities. Consideration of district heating and cooling deserves attention in relation to the utilization of power plant waste heat but will not be dealt with in detail in this investigation.

CONSIDERATION FOR STEAM ELECTRIC POWER PLANTS

To make the most effective use of the energy input to a power plant one must first understand the energy balance of the power plant itself. Figure 18 presents energy balances for three cases: a conventional (electric) plant, a dual purpose (heat and electric) plant, and a scaled up heat and electric plant. Referring to Figure 18a, the heat distribution and electrical conversion are shown for a conventional fossil fuel power plant. A unit heat input of 9,300 Btu is assumed. This input is roughly the Btu heating value for one pound of coal. This input will give a plant heat rate of 9,300 Btu/HWhr for a conversion efficiency of 37%. (The heat rate and conversion efficiency values listed are typical of most modern fossil fuel power plants.) Using the 37% efficiency, it is seen that 3,413 Btu can be converted into electricity, that is, one kilowatt-hour is generated. The remaining 63% of the input energy is discharged as waste heat. Approximately 12% of the energy input or 1,120 Btu is lost as stack gas discharge at a temperature ranging from 300 to 400°F (149 to 204°C). The other 51% or 4,767 Btu is dumped to the local biosphere by either cooling towers, a cooling pond, or once through river cooling. The temperature of the cooling water discharge from the condenser of the power plant will range from 70 to 110°F (21 to 43°C). This variation is caused by different ambient conditions and plant loads.

Figure 18b shows the change in efficiency for a combined or dual purpose plant (electric and heat production). When the unit input of 9,300 Btu is held constant while the temperature of the turbine exhaust

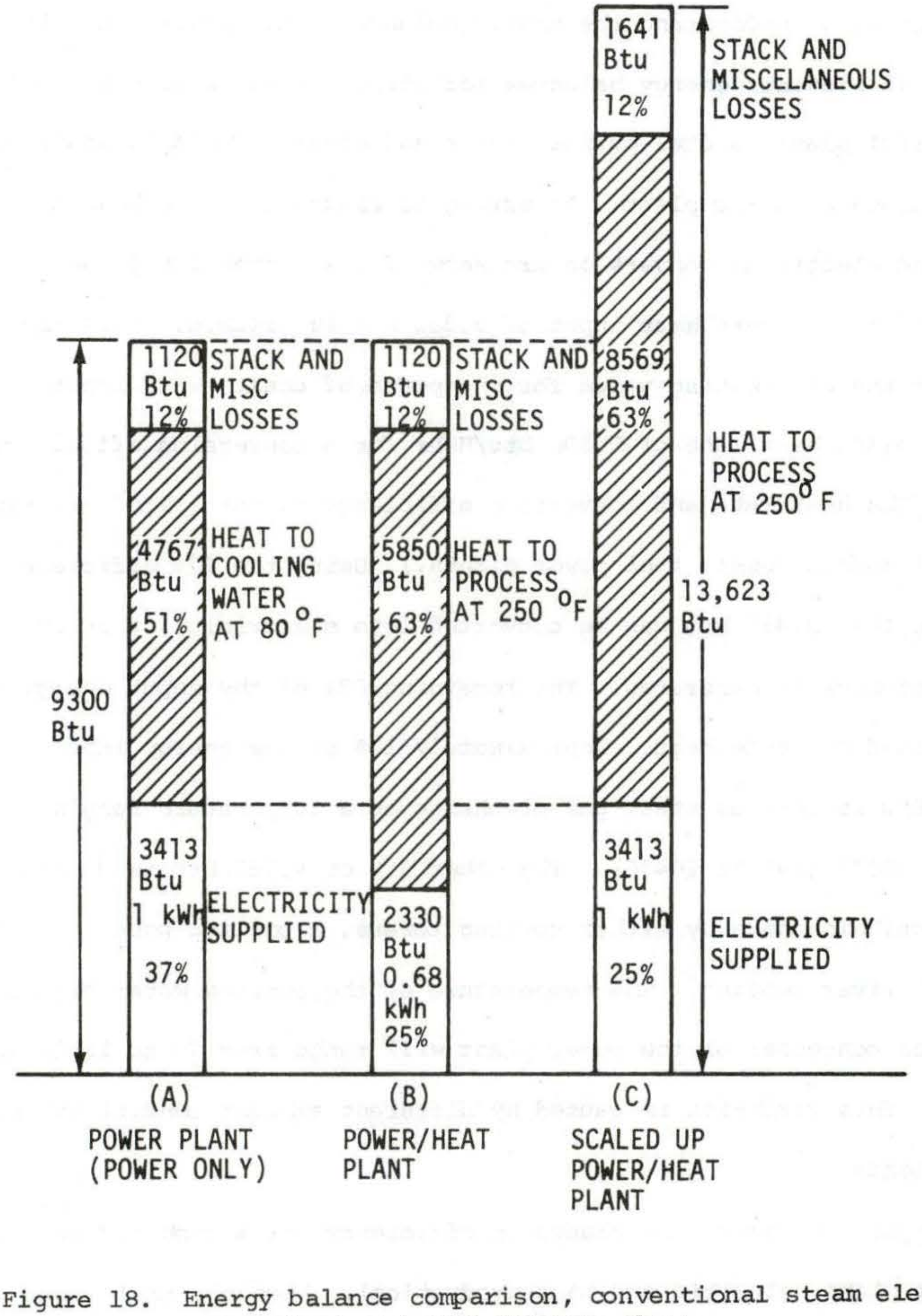

Figure 18. Energy balance comparison, conventional steam electric power plant and dual purpose plant

waste heat is increased to 250°F (121°C), only 2,330 Btu are converted to electricity and the conversion efficiency drops to 25%. Therefore, the quantity of heat required to raise the temperature of the waste heat exhausted by the turbine is 1,083 Btu. The turbine exhaust waste heat now becomes 63% of the input energy or 5,850 Btu available at a temperature of 250°F (121°C). Thus, as would be expected for a fixed input energy to the plant, a kilowatt production loss directly results from increasing the temperature of the turbine exhaust waste heat.

Figure 18c simply shows the quantity of heat required to maintain one kilowatt-hour output while supplying waste heat from the turbine exhaust at an elevated temperature. Note that for each case the stack losses are assumed to be a constant fraction of the input energy.

Although for the case represented by Figure 18c the input energy was increased by 46% (4,340 Btu), this increase resulted in an overall efficiency of 88% for the dual purpose power plant vs 37% for the single purpose plant. This is a 51% increase in overall efficiency.

In Figure 19, a series of schematic diagrams are provided to show how the division of energy for heat and electric generation can be accomplished. The conventional turbine-generator configuration at the top of Figure 19 corresponds to Figure 18a and its associated discussion. The steam extraction turbine arrangement (center) provides both electricity and heat at a higher temperature and thus corresponds to Figure 18b, a dual purpose plant. The difference is that for the dual purpose plant of Figure 18b a higher turbine exhaust temperature is used as from a noncondensing turbine and in this case (center diagram) steam is being extracted from the turbine at some higher pressure

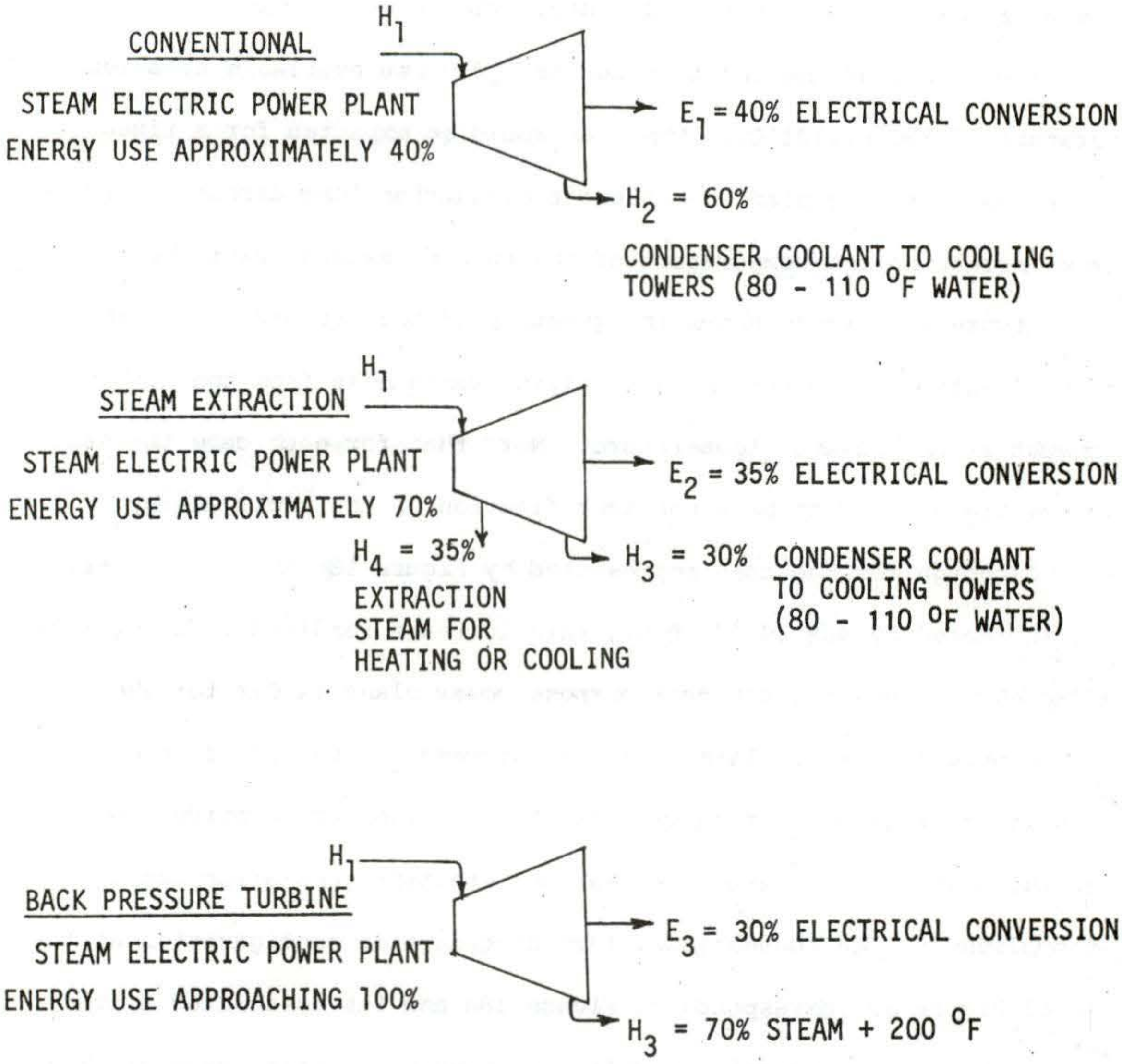

Figure 19. Energy utilization comparison for conventional steam extraction and backpressure turbines

rather than at normal exhaust conditions. (For the condensing turbine this would be at a low vacuum.) The backpressure turbine shown at the bottom of Figure 19 is a noncondensing steam turbine. This arrangement provides essentially the same conditions described by the heat balance in Figures 18b and 18c.

It was shown in the preceding sections that a market already exists for various heating applications. The following brief example is provided to demonstrate the potential use of existing power plants in a total energy scheme and thus reduce or eliminate altogether the waste heat dumped in a conventional condensing steam electric power plant.

Figure 20 presents an energy use map for the city of Ames, Iowa. High density energy users have been identified (industrial, commercial, and high density housing) and their location relative to the existing power plant is indicated on the map. Once the high density energy users have been located, it is possible to suggest and evaluate potential high temperature heating and cooling distribution lines from a central station. This is not a new concept as district heating is very common in Europe and has been common in most large cities in the eastern United States. Over the past several years the district heat systems in the U.S. could not compete with other relatively cheap and abundant energy sources and, therefore, many district heating systems were abandoned for economic reasons. However, today's rising energy costs and reduced availability of resources have renewed interest in the total energy scheme. Figure 20 presents a suggested distribution route from the power plant to the downtown business district, the hospital, North Grand Mall area, some high density housing areas, and some industrial

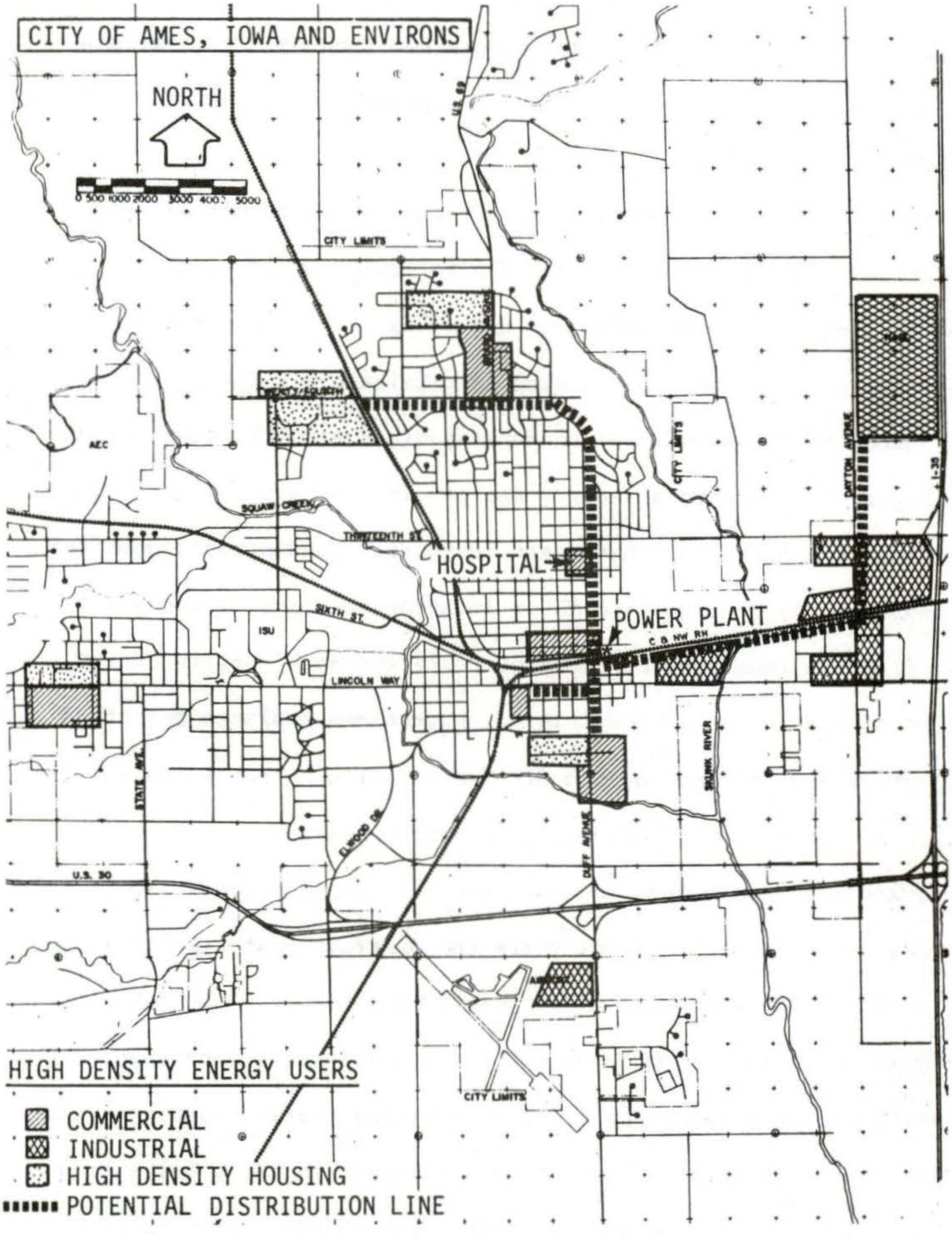

Figure 20. High density energy use map, City of Ames, Iowa

areas east of the plant. Obviously, a more detailed study would be required before any action could be taken.

Such a district heating and cooling scheme is not an unreasonable concept. It is a generally accepted fact that a single large heating system is more efficient than many small individual systems. In fact, the city of Ames in evaluating plans for its power plant expansion had a brief study conducted for district heating; however, only one user, the hospital, was considered. In general, the greater the utilization the less expensive the cost of supplying the heating or cooling requirement. Numerous recent studies have been conducted and have shown the energy savings and economic advantage of district or total energy schemes (Diamant, 1970; Diamant and McGarry, 1968; Geiringer, 1963). Similar studies could be undertaken to evaluate power plants throughout the state (and nation) as potential locations for district space heating and cooling, "total energy" schemes. Another total energy application that a power plant could supply is that of industrial process steam. However, the process heating applications will not be dealt with in this investigation.

CONTINUING RESEARCH

For waste heat to have some impact toward better utilization of energy resources available from existing and future power plants, it is essential that some pilot studies be conducted to test empirical results from this and other studies. More information must be made available to energy policy agencies as to the "field verified" data on technical and economic questions.

Small scale pilot projects at existing power plants would be used to verify the parameters and predictions obtained from model studies. The pilot project is in effect a proving ground for the large scale utilization complex. Thus, in the pilot system the design can be tested, refined, and fine-tuned to the characteristics of one or more power plants and hopefully prevent expensive design modifications of future large scale waste heat utilization systems.

An example of a pilot waste heat utilization complex is presented in Figure 21 for the Iowa State University power plant. Figure 22 presents an idealized user flow chart for a summer-winter utilization scheme. Additional potential pilot sites are described in brief detail in Appendix B.

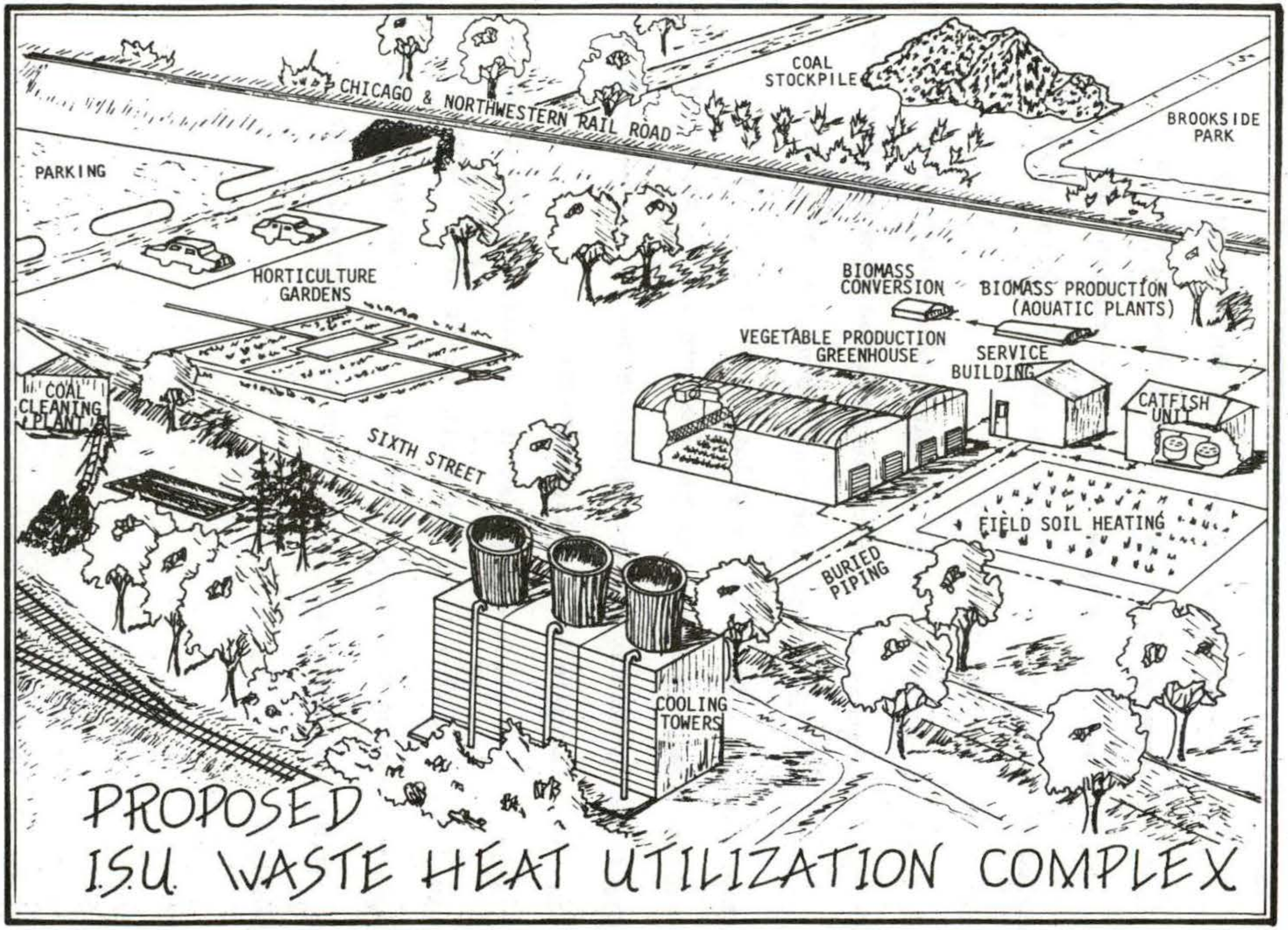

Figure 21. Artist's conception, proposed ISU waste heat utilization complex

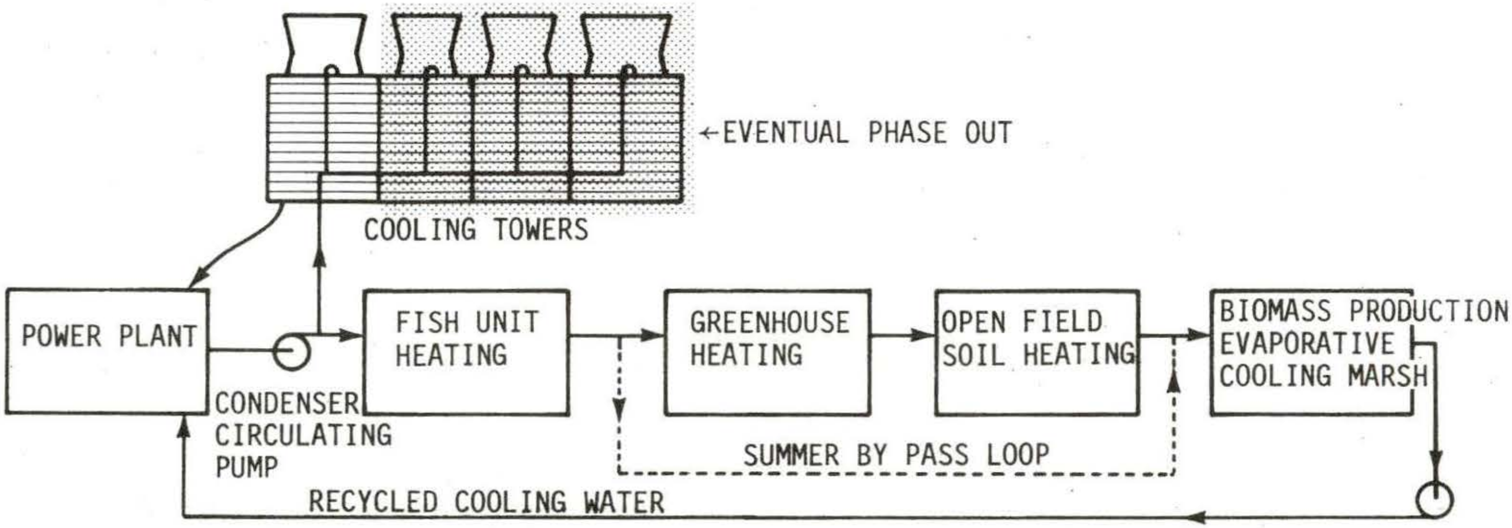

Figure 22. Idealized summer-winter power plant waste heat utilization scheme

REVIEW OF LITERATURE

To determine the present state of the art in applied waste heat utilization, an extensive literature search was conducted. Much has been published on proposed power plant waste heat utilization schemes, many of which follow the initial groundwork of Boersma (1970). A detailed listing is available in Utilization of Waste Heat from Electric Power Generating Stations, Vol. 2, Roberts and Bahr (1978), a report to the Iowa Energy Policy Council. Therefore, only a partial treatment will be provided here.

Early studies by Beall (1970), Beall and Samuels (1971), Miller et al. (1971), Boersma and Rykbost (1973), and Yarosh et al. (1972) cited such applications as greenhouse heating and cooling, thermal aquaculture (fish raising), heating of animal confinement buildings, subsoil heating, warm water irrigation, sewage treatment, and district space heating. These studies suggested that the most practical scheme for economically successful utilization would be some combination of greenhouse and aquaculture heating applications. This was confirmed in later studies by Iverson et al. (1976) and Olszewski et al., (1976).

The greenhouse heating studies conducted by Iverson et al. (1976) revealed that dry heat exchangers employing forced circulation over a finned tube heat exchanger had many advantages over the direct contact wet-pad exchanger used by Olszewski and Trezek (1976). The dry heat exchange system eliminated the extremely high humidity of the wet-pad system, which caused disease problems. The dry system provided uniform heat distribution, CO_2 dispersion, good humidity control, and accurate temperature control.

Waste heat use in greenhouse heating is being studied by the University of Minnesota, Northern States Power, and the Environmental Protection Agency (Ashley and Hietala, 1976). This study consists of a 1/2 acre demonstration greenhouse, space heated with finned tube heat exchangers, and subsoil heated with buried plastic pipe. Condenser discharge from Shero Unit #1 is then piped 1/2 mile to heat the greenhouse. First year results have shown that the warm water is able to meet all of the greenhouse heating requirements, even with outside temperatures of -40°F (-40°C). Greenhouse air temperature was maintained between 55-60°F (12-15°C) using only the 85°F (29°C) condenser discharge water. The economic analysis indicated that the greenhouse operator could realize a $10,000/yr savings by using waste heat rather than oil at $3.21/ million Btu. The only problems reported were fouling of heat exchangers which was corrected by chlorination and acid cleaning; also, some shading of the greenhouse from the cooling tower plume was observed.

Some of the early problems and potentials of power plant waste heat use in aquaculture were reported by Watts (1971) and Yee (1972). The first large scale effort in the experimental culture of fish at an actual power plant was undertaken in the Gallatin catfish project by the Tennessee Valley Authority (Goss, 1973). The objective of the Gallatin catfish project was to determine the feasibility of high density raceway culture of catfish using power plant condenser discharge water. The problems reported in the Gallatin project were also reported by other investigators using channel and cage culture techniques (Chesness et al., 1976, Heffernan, 1973; Kerr, 1976; Tilton and Kelley, 1970). These problems included disease prevention, requirements for dissolved oxygen, and waste treatment. Basic research on stocking density, water turnover rate, growth rate, and food conversion efficiency along with other physiological parameters for intensive culture of catfish were reported by Andrews et al. (1973), Stickney and Andrews (1973, and Colt et al. (1975).

No specific work involving waste heat use for biomass production was reported; however, some related studies were identified. Studies closely related to the biomass production evaporative cooling marsh concept include Devik (1974), Duncan (1976), Queijo (1977), and Seaquist (1977). These studies covered the use of aquatic plants such as water hyacinth and algae in waste water treatment. Bassham (1976), Benemann and Oswald (1976), Greeley (1976), Kirkbride (1976), and Szego (1976) discussed other aspects of biomass production and conversion.

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APPENDIX A. DESCRIPTION AND SPECIFICATIONS OF ASSUMED SYSTEM[1]

General

The overall system to be modeled consists of a steam electric fossil fueled power plant, a permanent rigid structure greenhouse, and a catfish production aquaculture unit. The biomass production evaporative cooling marsh and the field soil heating were not included in the model.

The interfacing of each element of the complex involves an energy balance analysis. In this analysis, the thermal energy needs of the complex are supplied by waste heat from the power plant (see Figure A.1). With this approach the waste heat is considered an output product of the power plant and when the system as a whole is analyzed, a greater use of existing thermal energy may be realized with the net result of reduced overall energy consumption and increased efficiency of total energy use.

In each element considered, the model was designed to simulate actual off-the-shelf equipment. This procedure was employed when performance data were available from the various manufacturers. For example, in the greenhouse space heating model, a commercial heater manufacturer was selected at random. Then the actual equipment performance curves were used to describe the heater operation. (Not an idealized mathematical model of an assumed heater performance.) The same analysis approach was used in the power plant model for the turbine and condenser and in the aquaculture model for the heat exchanger.

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[1] The Appendices presented are an abridged and slightly altered version of Part C in Roberts and Bahr (1978) report to the Iowa Energy Policy Council.

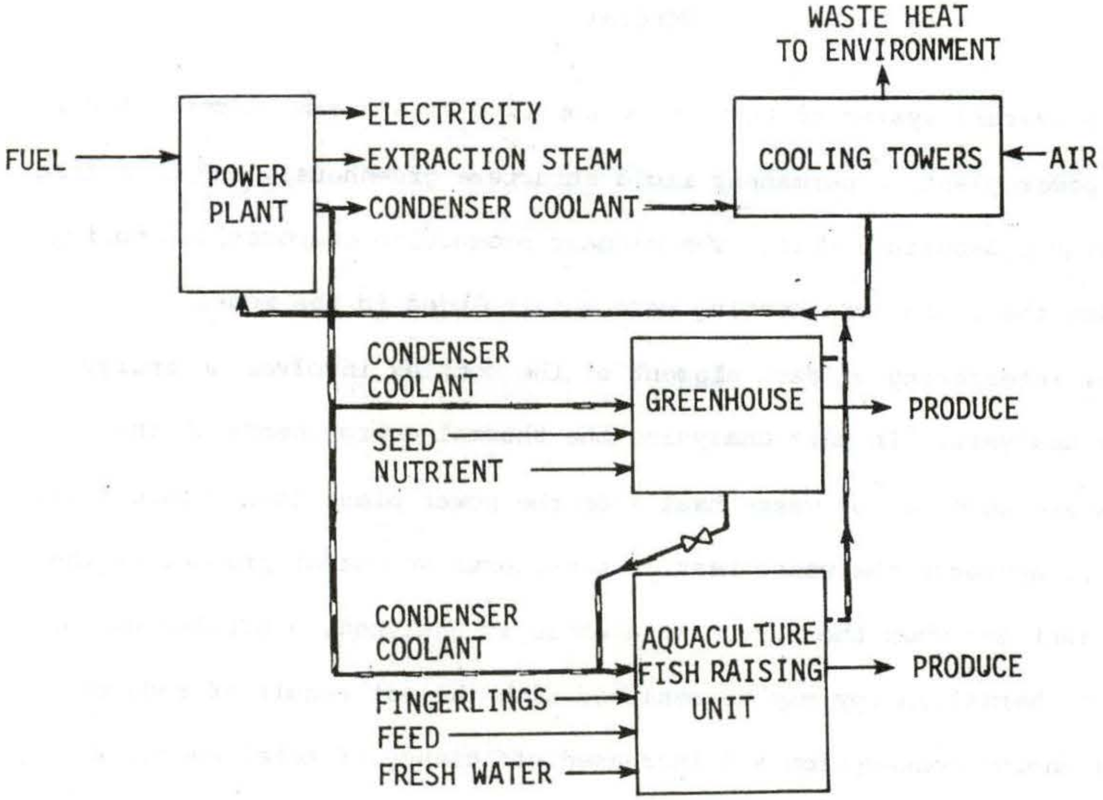


Figure A.1. Power plant waste heat user flow chart

Power Plant

The parameters listed in Table A.1 have been identified as required data for the purpose of computer simulation of a fossil fueled steam electric power plant.

Table A.1. Required parameters for power plant simulation

Primary input data common to all steam electric plants	Input data characteristic[a] of select individual steam electric plants
KW output	Turbine specifications operating limits, performance curves, etc.
Btu input	
KWhr generation cost	Condenser specifications, surface area, loading, flow rates, etc.
Steam flow rate into condenser	
Condenser coolant flow rate through condenser	Plant or unit heat-balance cycle diagrams
Condenser coolant inlet temperature to condenser	Auxiliary equipment performance curves, circulating pumps, etc.
Condenser backpressure	
Boiler efficiency	

[a] Characteristics of equipment supplied by manufacturer.

These parameters are specified so as to define the configuration of the power plant being modeled. After this study was initiated, visits were made to both the Iowa State University power plant and the City of Ames power plant. Information obtained from the visits revealed that a detailed model of the ISU power plant would be very difficult to accomplish. This is because the Iowa State power plant is an older plant with many units interconnected, i.e., common steam feed to turbines, common system for condenser coolant circulating water, and so on. In addition, the desired input data common to all power plants are not easily obtainable from the ISU plant. This is due to the fact that the plant has older equipment for which performance curves are unavailable and the equipment is not as completely instrumented as a modern power plant would be. The problem of availability of instrumentation and/or equipment performance curves is common to most power plants throughout the state, with the exception of relatively new plants. With proper instrumentation or equipment performance curves, such operating parameters as steam flow into the turbine, automatic extraction, condenser steam flow, Btu input, and KW output could be obtained for any given operating condition and for each unit considered.

The purpose of the power plant model is to provide a basic computer model describing the performance of a steam electric power plant. Since this research effort is concerned with the utilization of waste heat from the point of view of total system efficiency of end energy use, then only those components of the power plant involved with receiving or transferring waste heat, i.e., low temperature steam and condenser coolant discharge, were modeled. In this manner, the model can be made general enough to adequately describe the waste heat production and operational performance of any steam electric power plant using common inputs previously listed. Using this approach, only the input data and equipment performance equations would differ for each plant or unit considered and the computer model itself would remain the same. The power plant computer model is described in more detail in Appendix D.

The model describes a single unit power plant, i.e., the turbine-generator-condenser combination. Power plants are generally set up to operate in units, so that one unit may be taken off the line and shut down for maintenance or an emergency while other units remain in service (refer to Figure A.2). The units are generally independent; however, for convenience they are sometimes interconnected to allow for multiple operation, i.e., from one boiler.

Both the ISU plant and the City of Ames plant are modeled, but only the ISU plant is described in detail. Data and performance curves from the equipment considered were used to provide the physical and empirical inputs for the power plant computer model and simulation.

The ISU power plant is primarily a steam heating plant with an output of 105 MW(t) and 23.5 MW(e). The addition of a new 11.5 MW(e) condensing automatic extraction turbine generator will bring the total output to 35 MW(e) when completed in 1979. The plant is fossil fueled and is designed to operate on either coal or natural gas (when available). Condenser cooling is provided by two sets of induced draft wet evaporative cooling towers. Figure A.3 presents the plant layout with cooling tower location. The cooling towers located north of the plant are very old and are being phased out and replaced by additions to the new tower complex located east of the plant.

For the ISU power plant, only unit number 5 was considered in the study. This decision was based on the lack of availability of technical specifications for the older and smaller units 1, 2, and 4. (Note: Unit number 3 is a decommissioned unit.)

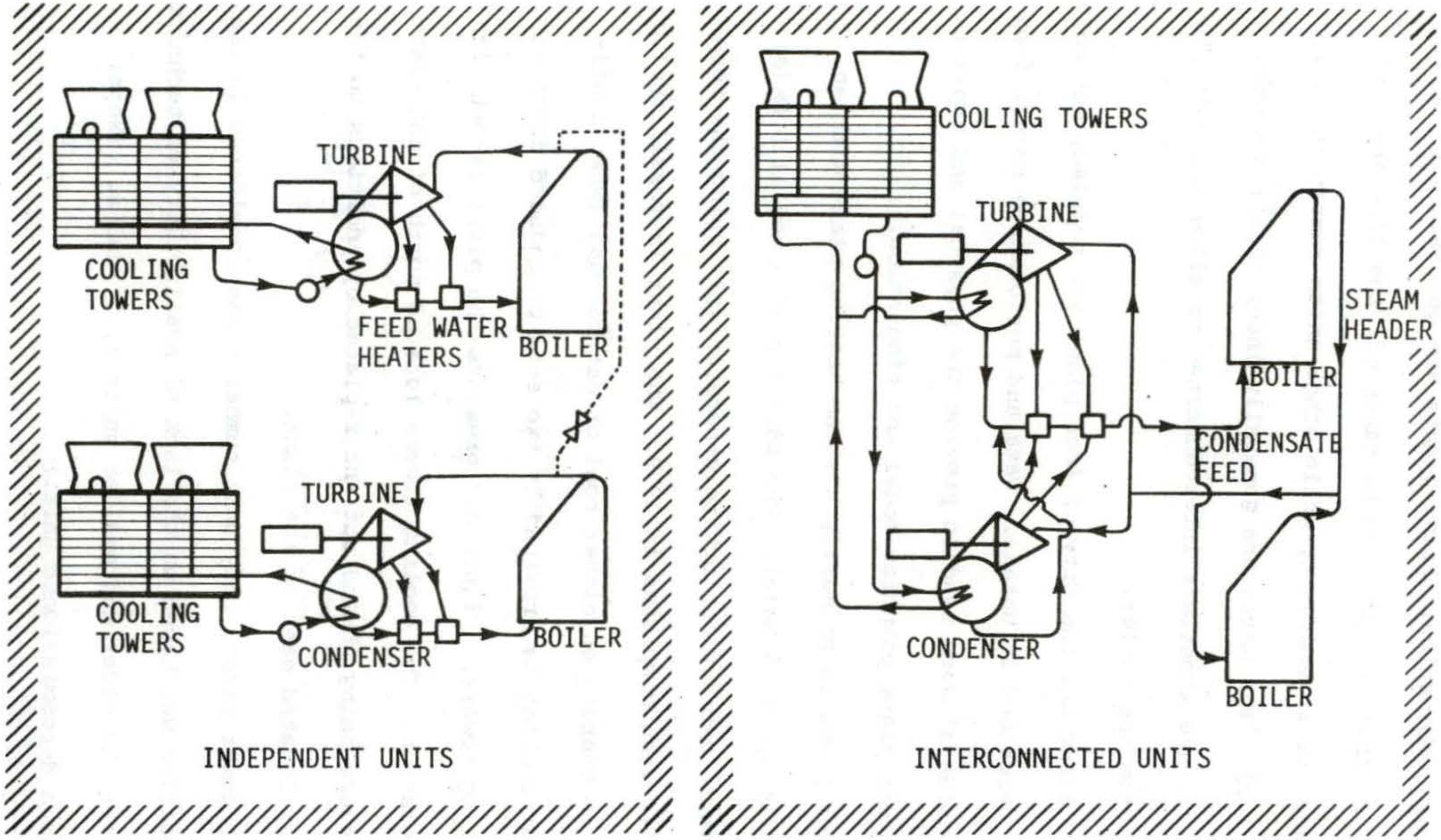


Figure A.2. Independent and interconnected configuration for multiple unit power plants

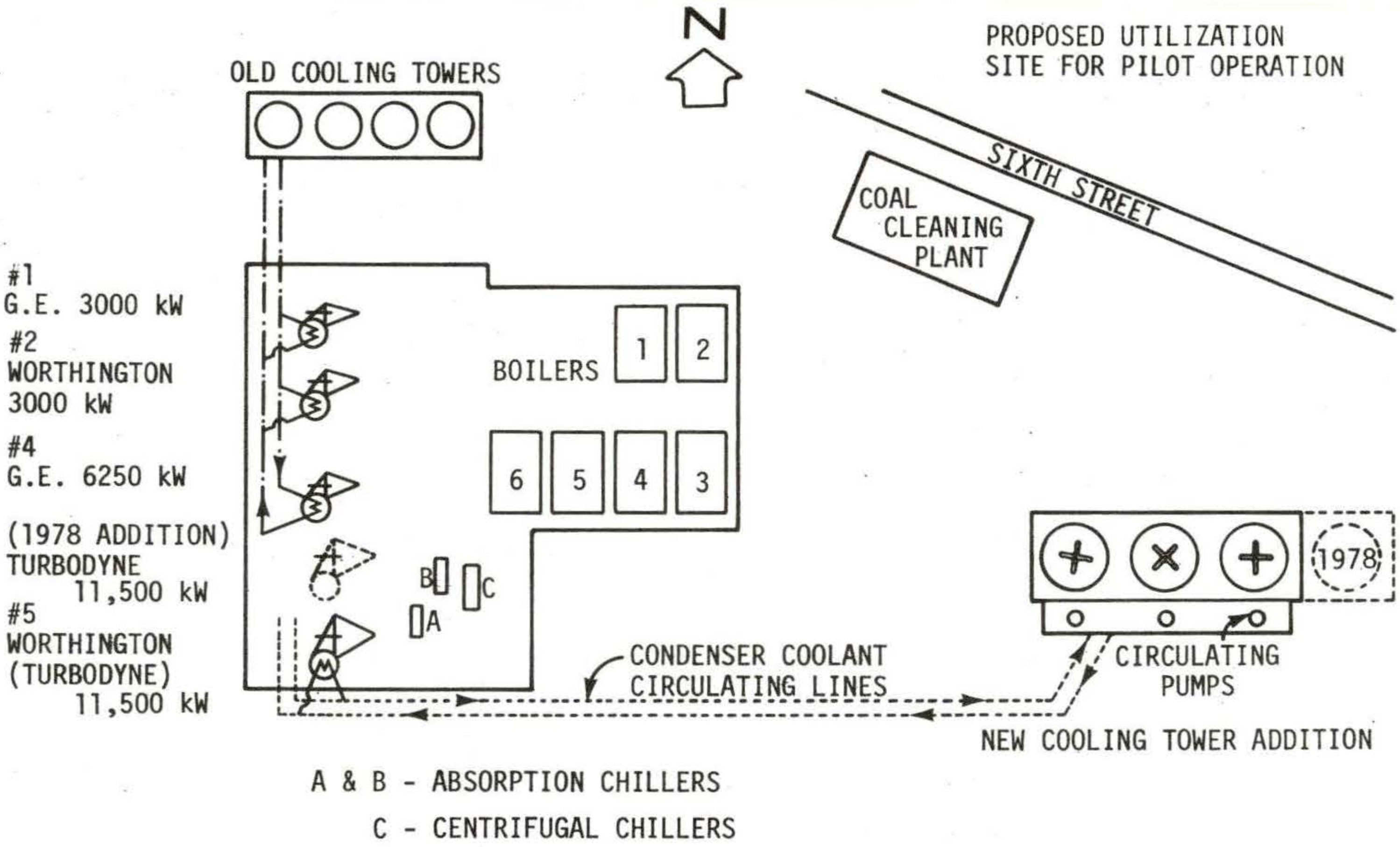


Figure A.3. ISU power plant layout and cooling tower location

An accurate means of predicting condenser steam flow for various conditions of KW load and steam extraction was not available so for the purpose of keeping the simulation as simple and accurate as possible, only unit number 5 was considered. Another drawback in getting data for the ISU plant is that no instrumentation is available for measurement of Btu/hr input or tons of coal burned per hour. The Btu/hr figure is needed to determine the heat rate for the unit being considered, where heat rate = Btu/KWhr and its inverse, KWhr/Btu is a measure of the unit or plant efficiency. To overcome this problem, heat rate curves for a similar turbine were used to describe the performance for ISU unit number 5. Refer to Appendix G.

The performance of an automated extraction steam turbine is generally presented as a plot of the throttle steam flow vs the kilowatt load for various extraction conditions. This turbine performance curve is presented for ISU unit number 5 in Figure G.5 in Appendix G. In a similar manner, condenser performance is described by a plot of the condenser loading (Btu/hr) vs the absolute pressure (of the steam-water mixture being condensed) for various cooling water inlet temperatures. Condenser performance curves for ISU unit number 5 are provided in Figures G.3 and G.4, Appendix G, representing the two flow conditions of 7,800 GPM and 12,000 GPM, respectively.

A heat balance cycle diagram was not available for unit number 5. This was due to the fact that the units were set up for steam extraction for various space heating functions and only a small portion of the extraction was used for common feedwater heating (for all units). Therefore, individual heat balance diagrams were not prepared when new units were added. An approximation for the unit number 5 heat balance diagram is presented in Figure A.4.

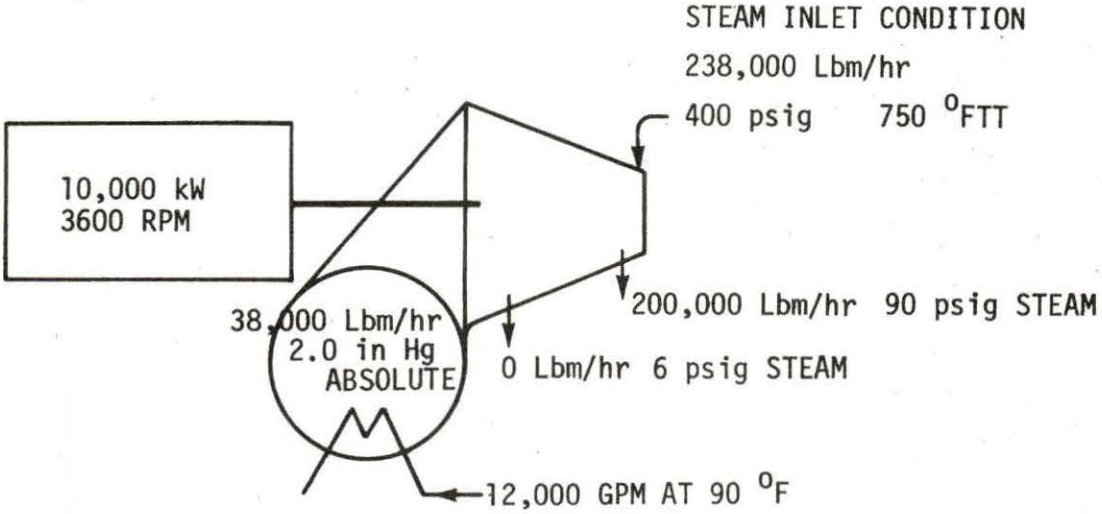


Figure A.4. Assumed heat balance configuration for ISU unit number 5

The cooling towers used for unit number 5 are located east of the power plant and consist of three bays of Marley class 600 industrial crossflow induced draft wet evaporative cooling towers. One bay is used primarily for unit number 5 condenser cooling (during the winter). The second and third bays are used during the summer for condenser cooling on unit number 5 and three water chillers (one centrifugal and two absorption chillers). Note that the centrifugal chiller and the two absorption chillers are used mainly during the summer. (The absorption chillers are sometimes run during winter months to provide for a small cooling requirement.) All three components generate waste heat which adds to that normally dumped by the turbine. The waste heat contributions from these sources were not included as part of the power plant model used in this study.

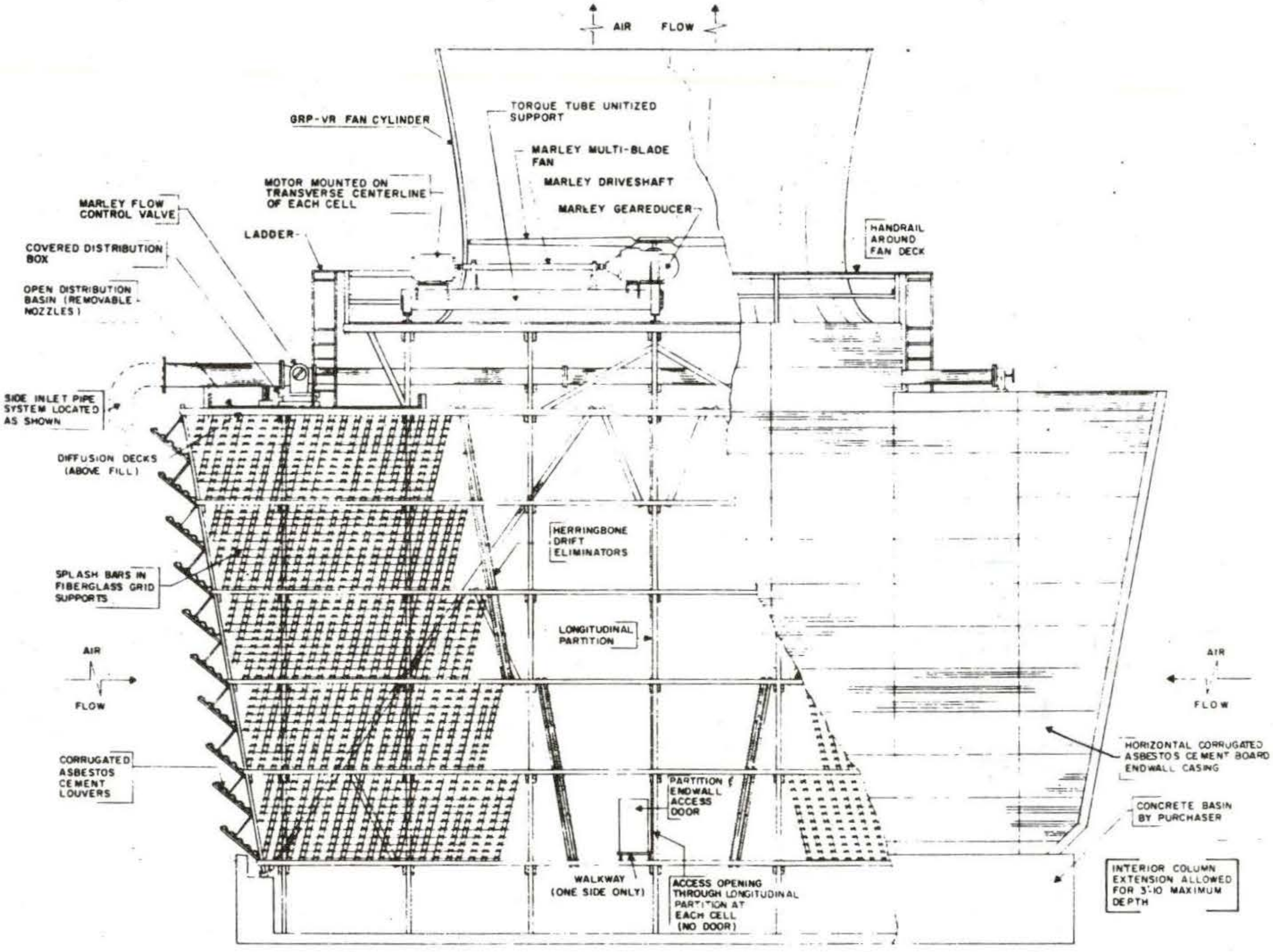
Figure A.5 presents a cross-section view of the cooling tower. Each bay is designed to handle 10,000 GPM of cooling water and has its own circulating pump and riser pipe. The circulating pump withdraws water from the cold water basin, pumps it through the condenser in the power plant via a four foot diameter buried pipe and returns to empty into the hot water distribution basin on top of the cooling tower. Figure A.6 presents the circulation scheme. Each bay of the tower is equipped with its own circulating pump and a two speed fan. The hot water distribution system that dumps the water into the warm water basin is set up to allow a single circulation pump to serve more than one bay.

During a typical year one, two, or three bays can be used along with one, two, or three pumps and zero to three fans in service (high or low speed operation). An assumed typical annual history is given in Table A.2.

A circulating water pump performance curve is provided in Figure G.6 in Appendix G. This plot shows how the total head developed varies with the flow.

Greenhouse

The greenhouse to be modeled is assumed to be a rigid frame permanent structure of the arched roof type with a floor space of 5000 ft^2



TRANSVERSE CROSS SECTION OF CLASS 600 DOUBLE-FLOW TOWER

Figure A.5. Cross-section view, induced draft cross-flow wet evaporative cooling tower for ISU unit number 5

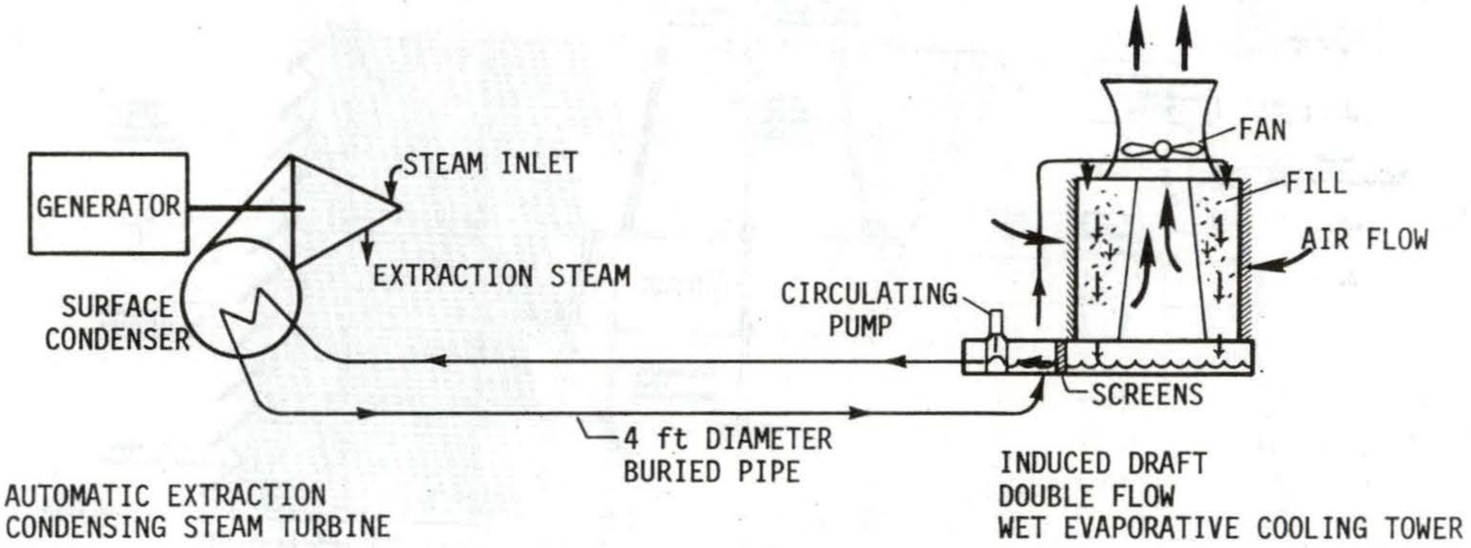


Figure A.6. Coolant circulation scheme, ISU unit number 5

Table A.2. ISU cooling tower equipment data and operating schedule

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Vertical turbine pump: 300 HP - 460 Volts - 348 Amps

2-speed fan motor: High 125 HP - 1780 RPM - 147 Amps - 460 Volts

Low 31 HP - 880 RPM - 72 Amps - 460 Volts

Approximate hours of motor operation per year:

One pump: 8760 Hrs (continuous year round)

Second pump: 5040 Hrs (approximately 7 months total)

Third pump: 2880 Hrs (approximately 4 months total)

Single fan: (speed) High - 7200 Hrs (approximately 10 months total)

Low - 720 Hrs (approximately 1 month total)

Fan not in operation approximately 1 month per year

Second fan: (speed) High - 4320 Hrs (approximately 6 months total)

Low - 720 Hrs (approximately 1 month total)

Fan not in operation approximately 3 months per year

Third fan: (speed) High - 2160 Hrs (approximately 3 months total)

Low - 720 Hrs (approximately 1 month total)

Fan not in operation approximately 8 months per year

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of growing area, and approximately 6552 ft^2 of roof with a heat transfer U value of 0.8 Btu/hr $ft^{2}{}^\circ F$, and 1448 ft^2 of side and end wall with a heat transfer U value of 0.8 Btu/hr $ft^{2}{}^\circ F$. This gives an overall surface area of 8000 ft^2 with a U value of 0.8 Btu/hr $ft^{2}{}^\circ F$. The roof glazing material is assumed to be plastic, with a double inflated layer and a one inch airspace separation. The end and side walls are assumed to be double glazed fiberglass or double glazed plastic both with a one inch airspace separation. This is a common and inexpensive type of structure widely used in the present greenhouse industry and suitable for operation under Iowa winter conditions.

A disadvantage of the plastic as a glazing material is that it must be replaced every two years. However, the advantage of the higher insulating value of the double plastic resulting in a lower annual fuel bill combined with the low cost of the structure tend to make it a good choice for either a long or short term installation. The 1.5 acre Ames Greenhouse, Inc. installation located one mile east of Ames, Iowa makes use of this type of structure.

The greenhouse heating system is assumed to include both soil and space heating. The space heating requirement was determined by assuming a worst case condition. The condition assumed was night, with a 5 mph wind, and an outdoor ambient air temperature of 5°F (-15°C). The maximum heating requirement was then calculated to be 325,907 Btu/hr, which agreed well with the number recommended by a local greenhouse heating equipment representative[1] (320,000 Btu/hr). The small difference

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[1] B. G. Peterson Co., Inc., Manufacturer's representative (heating), Des Moines, Iowa. Personal communication, 1977.

between these figures confirms that the simplified energy balance used to describe the energy requirement of the greenhouse will adequately serve as a model for predicting the greenhouse energy requirement. Note the air temperature to be maintained in the greenhouse is 60°F (15°C).

The greenhouse space heating requirement was assumed to be accomplished by using Modine hot water unit heaters in combination with a polytube air distribution system. Performance curves and cost figures for various hot water unit heaters were supplied by Modine.[1] The Modine HS 1235 unit heater was selected as the standard unit heater based on its heat output and unit price. (The entire greenhouse space heating requirement can be met by using one or more of these unit heaters set up in a parallel hot water flow arrangement.) An alternate space heating configuration using finned tube heating pipe along the perimeter, beneath benches and in an overhead installation could also have been simulated but performance curves were not available, so this alternative was not included. However, it could be easily added to the model when performance data become available. Figure A.7 presents the two alternate schemes for greenhouse space heating.

Greenhouse cooling, if required during the summer operation, would be accomplished using a conventional fan and evaporative pad system. An ORNL report (Olszewski and Hillenbrand, 1976) revealed that attempts to cool a greenhouse using a wet evaporative pad system and power plant waste heat resulted only in a further heating and humidification of the greenhouse air. Thus, waste heat <u>cannot</u> be used to cool

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[1] B. G. Peterson Co., Inc., Manufacturer's representative (heating), Des Moines, Iowa. Personal communication, 1977.

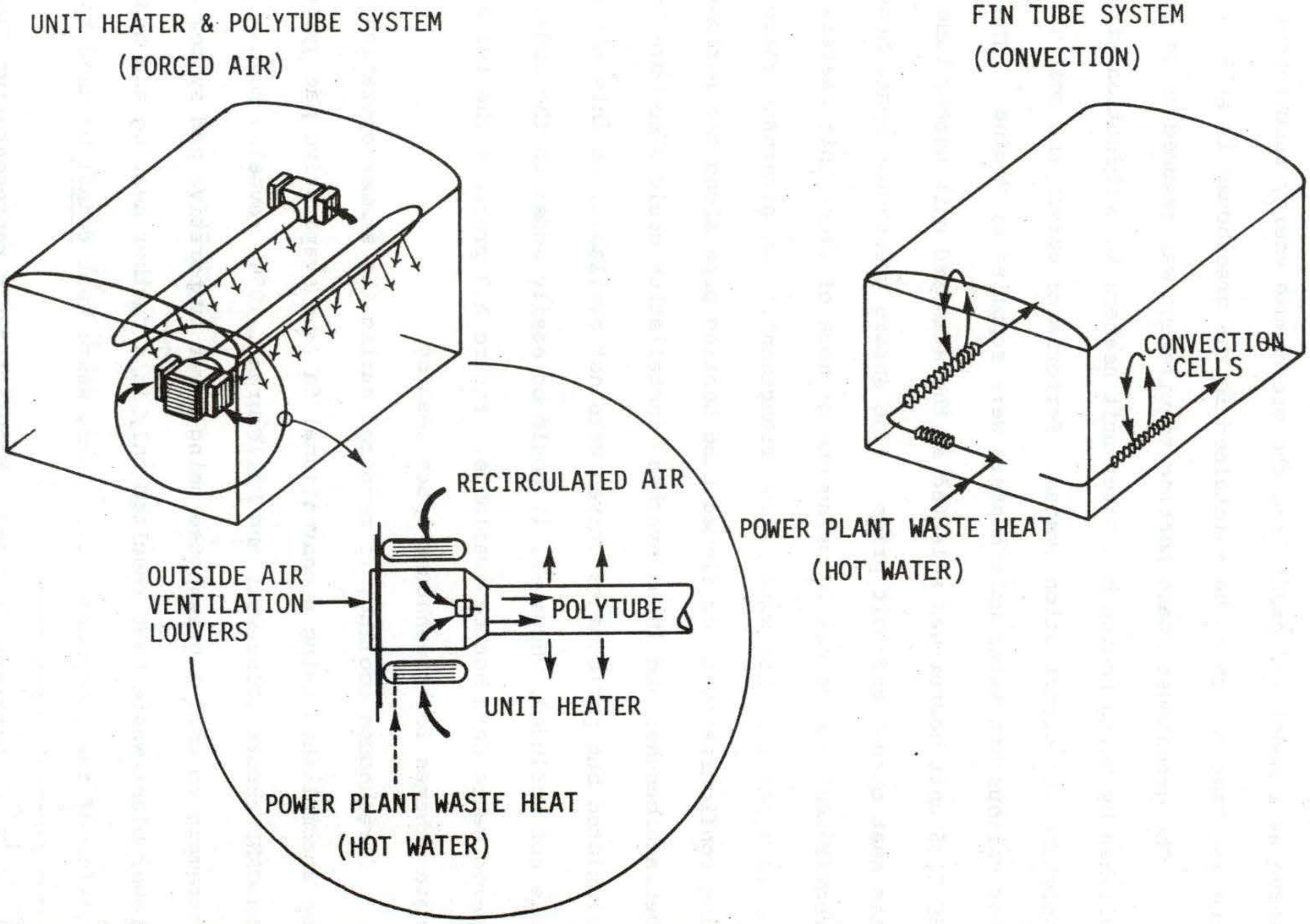

Figure A.7. Alternate schemes for greenhouse space heating with power plant waste heat a greenhouse using conventional evaporative pad techniques. (Excessively high humidities were also reported to be a problem.) Humidification during the winter was assumed to be controlled by normal greenhouse watering/misting or other irrigation techniques.

The soil heating system for the greenhouse assumes the use of buried plastic pipe as the subsoil heat source. The assumed layout is presented in Figure A.8. This configuration is patterned after the installation used by Stewart and Winfield (1973) in soil heating for tomato plant production. Review of literature has shown that soil heating will not contribute significantly to the space heat requirement unless very high temperatures are used (Stewart and Winfield, 1973). High temperature subsoil heating would result in excessive drying of soil and have an adverse effect on growth. Therefore, the soil heat system described for the greenhouse is assumed to make no contribution to the space heating requirement.

The greenhouse environmental considerations are dependent on the species of plants being produced. For the purpose of this investigation, a high cash crop such as the tomato was considered to be the best choice for potential production.[1] For greenhouse tomato production, the minimum night air temperature is 68°F (20°C) and the minimum day temperature is 78°F (25.6°C). This is presented in Figure A.9, superimposed with the seasonal outside air temperatures and a typical power plant condenser discharge temperature. Because solar input generally

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[1] Charles V. Hall, Professor and Head, Department of Horticulture, Iowa State University, Ames, Iowa. Personal communication, 1976.

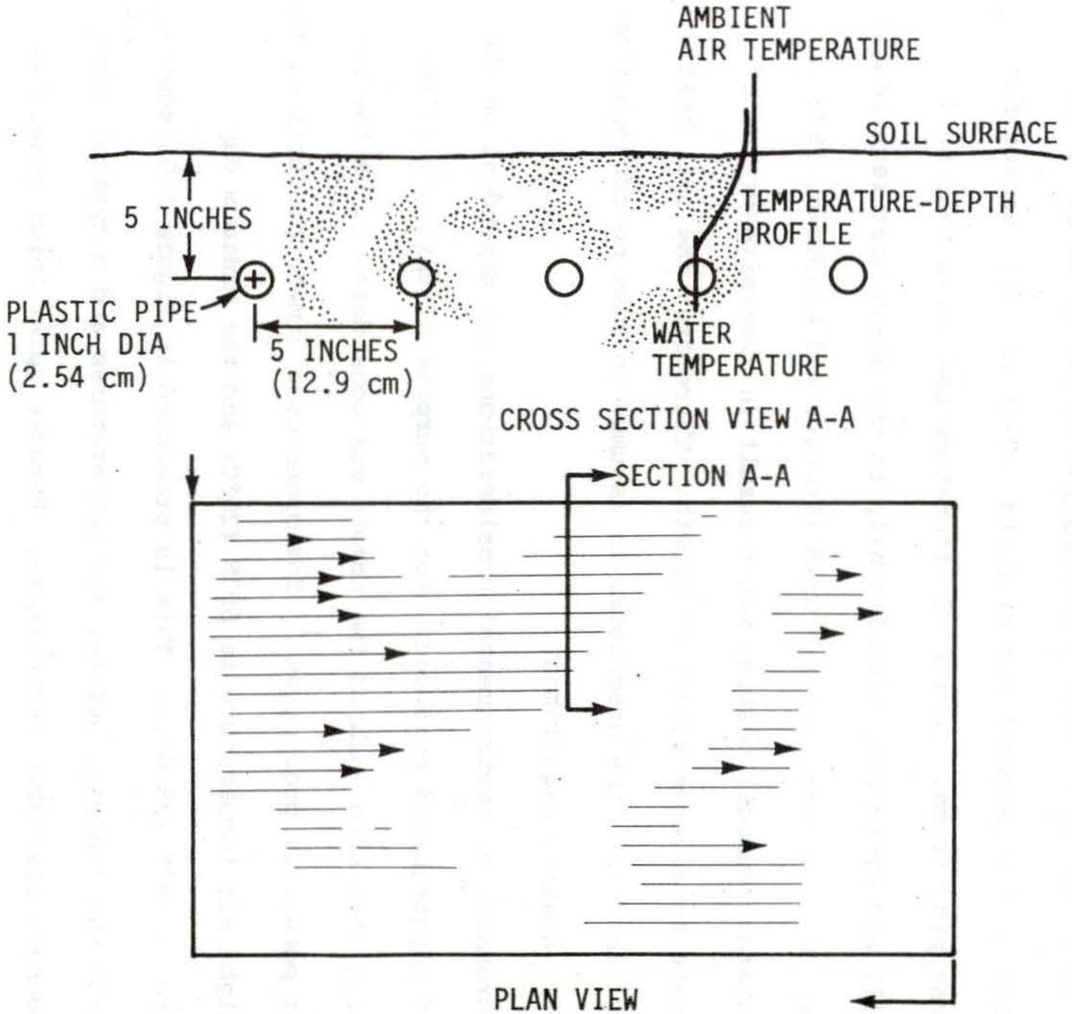

Figure A.8. **Assumed** piping layout for greenhouse and field soil heating

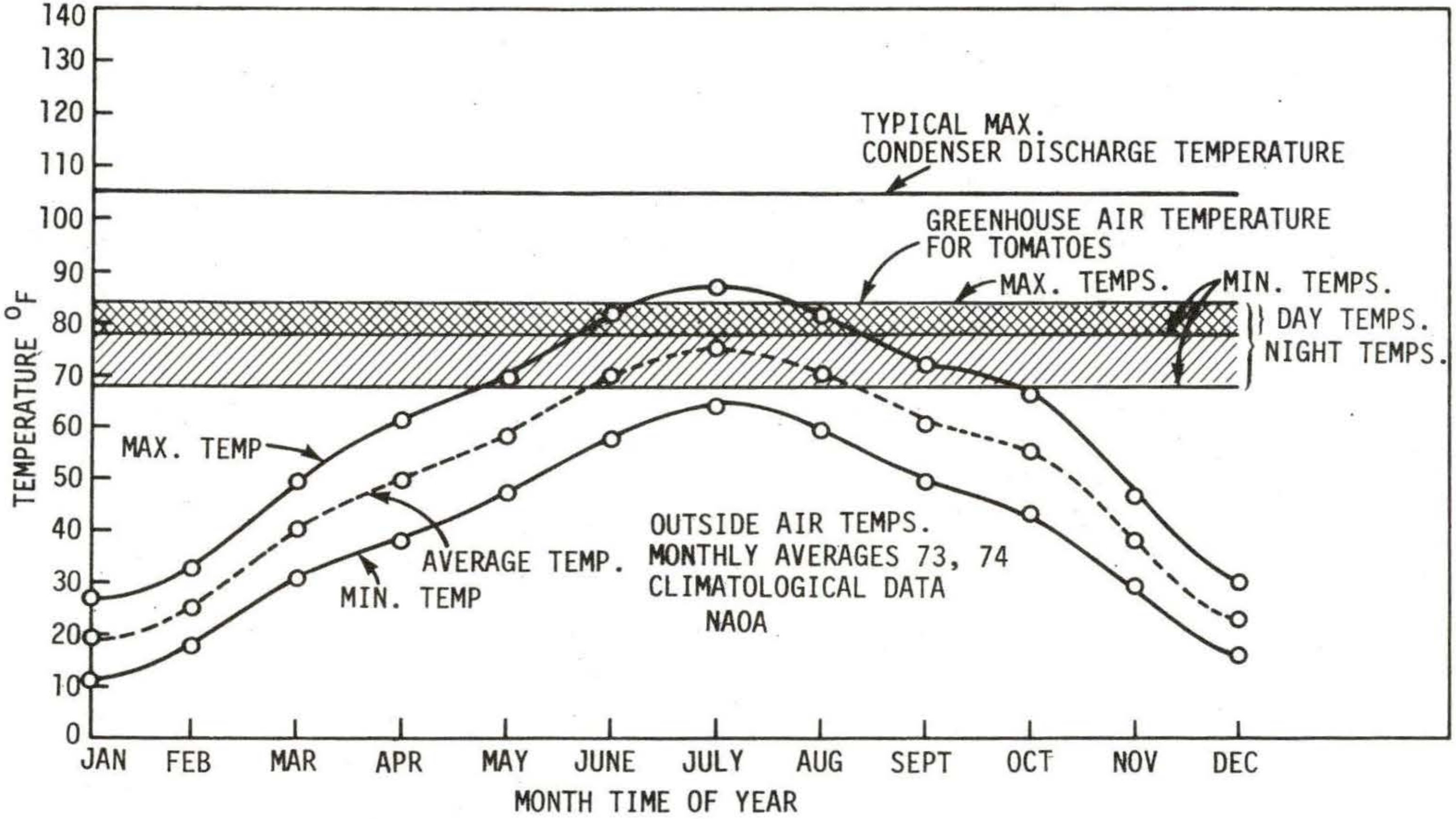

Figure A.9. Seasonal outside air temperatures and temperature requirements for greenhouse tomato production reduces the daytime heating requirement, the heating system for this study will be designed to maintain the greenhouse air temperature at 60°F (15°C) for nighttime conditions, with an outside air temperature of 5°F (-15°C) and a wind of 5 mph. Some consideration should also be given to greenhouse orientation for multiple gutter connected units. This consideration is important for this type of structure with respect to wind loading and roof snow loads. Experience from large commercial installations tends to favor a north-south orientation for the longitudinal axis of the greenhouse. This is because wind out of the north will generally remove snow from roofs and prevent the large accumulation that may occur for an east-west orientation. This type of orientation is used for the 1.5 acre installation of Ames Greenhouse, Inc. east of Ames, Iowa. The difference in solar gain or loss is negligible for the north-south orientation vs that of the east-west.

Additional general background information on the effects of heat and temperature on plant growth covering optimum temperature range, optimum night temperature range, phases of growth, optimum day and night temperature ranges in greenhouse production, and unfavorable effects of temperature are presented by Roberts and Bahr (1978) in their final report to the Iowa Energy Policy Council.

Aquaculture

The proposed catfish production unit would consist of eight circular tanks, 8 ft in diameter and 3 ft deep. The tanks are assumed to be constructed of fiberglass, insulated, and have center drains. Figure A.10 presents the tank layout and water flow configuration. A 2 ft

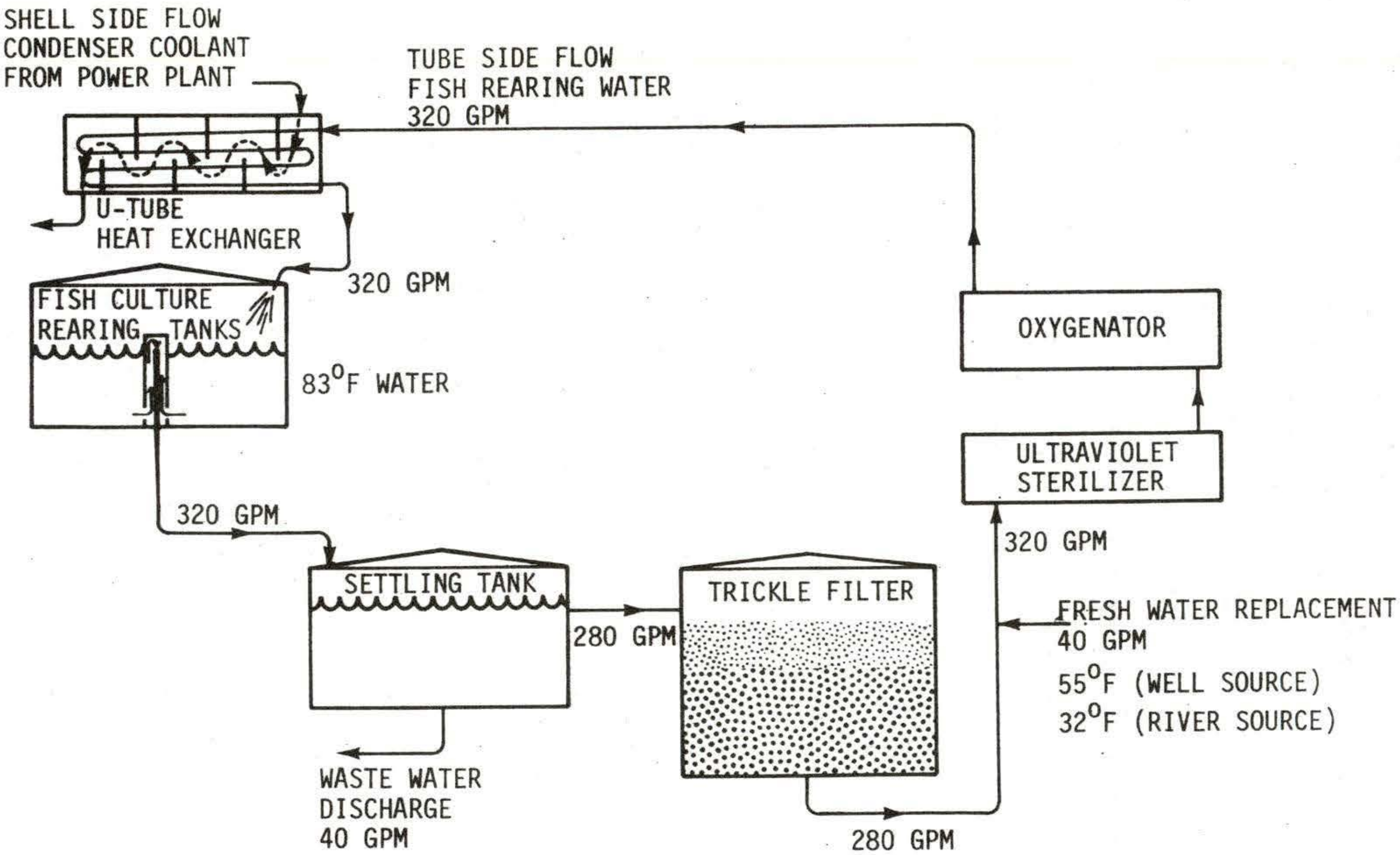

Figure A.10. Tank layout and water flow scheme for catfish production unit water depth will provide a volume of approximately 100 ft^3 of water per tank. For the case in which the power plant uses recirculated water, such as for cooling tower operation, the circulated water would transfer heat to the fish unit through a heat exchanger. This is necessary to prevent the addition of toxic chemicals from the makeup water used for cooling tower operation to the fish rearing water. (Some typical chemicals added to cooling water for recirculating tower systems are chlorine for algae control, microbiocides to control growth of microorganisms, sulfuric acid to control pH, and inhibitors to prevent scaling.) The heat exchanger would be sized to maintain the rearing water in the tanks and the 5% per minute replacement water (320 gal/min) at 83°F (28°C). Because it was desired to use off the shelf equipment for the heat exchanger, a commercial heat exchange manufacturer was selected at random and equipment specifications, performance curves, and cost data were then obtained. Bell and Gossett, Buffalo, New York provided information on their line of industrial heat exchangers. Heat exchanger parameters such as flow rates, heat transfer area, and cost were then placed in the computer model.

It was assumed that the fresh water replacement makeup was from a well water source with a year round constant temperature of 55°F (12.8°C). A fresh water input rate of 0.05 gallons per minute per cubic foot of volume was assumed, which corresponds to a complete replacement turnover every 2.5 hours. A recirculation rate of 0.4 gallons per minute per cubic foot of volume was also assumed which would correspond to a recirculation turnover every 20 minutes.

The water flow rates corresponding to these conditions are 40 gallons per minute fresh water replacement input (5 GPM per tank) and 320 gallons per minute recirculation. These circulation figures are based on research conducted by Andrews et al. (1971).

Additional equipment required for the operation of the fish production unit is presented in Figure A.10. Major components consist of a settling tank, roughly 0.5 ft^2 surface area per GPM of flow;[1] therefore, a 160 ft^2 area was used with dimensions of 16 ft by 10 ft by 5 ft. A trickle filter would also be required. An assumed 0.2 ft^2 area per GPM of flow gives an area of 56 ft^2 or a tank 8 ft in diameter and 8 ft deep. An ultra-violet radiation sterilizer would also be required. This could consist of a standard commercial model such as a unit with uv light tubes immersed in the recirculation flow. In addition, aeration equipment would be required to add dissolved oxygen to the recirculation water as needed. This would again consist of standard commercial equipment which is readily available in the fish farming industry.

All components and piping are assumed to be insulated so as to minimize heat loss. The heat loss from these components was not calculated from individual energy balance equations because the individual components and piping are not specified in great enough detail at this stage. Detailed component specification would take place in the pilot construction phase. However, when sizing the heat exchanger for this study a large heat loss (temperature drop) was assumed for the recirculating water. This allows for a worst case consideration in determining the size and cost of the heat exchanger.

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[1] J. C. Young, Department of Civil Engineering, Iowa State University, Ames, Iowa. Personal communication, 1977.

The building housing the fish production complex was not specified in any great detail for the feasibility study. However, all components are assumed to fit into a building of roughly 30 ft by 50 ft. This structure would probably consist of a well-insulated metal building. The building space heat required could also be supplied by waste heat. Due to the fact that the heating requirement for the building would be very small when compared to the Btu requirement for heating the fish rearing water, it was not included in the model. Thus, the heating requirement for the aquaculture component is assumed to consist of two parts, the heat required to raise the replacement water (well water) from 55°F (13°C) to 83°F (28°C) and the component required to replace heat lost from tank surfaces.

The environmental requirements for the fish production unit are dependent on the species of fish being raised. For this study, channel catfish (Ictalurus punctatus) was chosen as the species to be raised. This choice was made because of the relatively abundant knowledge and experience which has already been gained through intensive catfish pond-farming in the southern United States and the fact that a good market has been established for this fish.

Consideration of both the optimum temperature for growth and the optimum temperature for digestive enzyme secretion suggest that the optimum water temperature for rearing is about 83°F (28°C).[1] The upper lethal temperature is 102°F (39°C) and the lower limit is 32°F (0°C).

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[1] Ross V. Bulkley, Associate Professor, Department of Animal Ecology, Iowa State University, Ames, Iowa. Personal communication, 1976.

Although meeting the heating requirements for the fish system is the primary concern of this investigation, a discussion of other factors involved in fish culture is presented by Roberts and Bahr (1978) in the final report to the Iowa Energy Policy Council. Effects of physical parameters such as temperature, dissolved oxygen level, and light intensity are considered along with the effects of such biological and chemical parameters as stocking density, water turnover rate, metabolic wastes, and waste production from intensive culture systems.

Pilot System Location

The proposed site location for the ISU pilot waste heat utilization research complex is shown in plan view in Figure A.11. The complex could be conveniently located close to the ISU power plant, by utilizing the presently unused field directly east of the horticultural garden and north of the new cooling tower addition along Sixth Street. The proposed site has adequate land available for those components originally suggested for the pilot study and for certain additional utilization schemes identified in the investigation. In addition, the site is conveniently close to the main university campus so that maximum exposure to various other interdisciplinary study efforts is possible. The technical and managerial expertise available from EMRRI, the Energy and Minerals Resource Research Institute, the Agricultural Experiment and Home Economics Research Station and ERI, the Engineering Research Institute, when combined with the information dissemination and communication capabilities of the Agricultural and Engineering Extension services seem to suggest that the proposed ISU location for a pilot

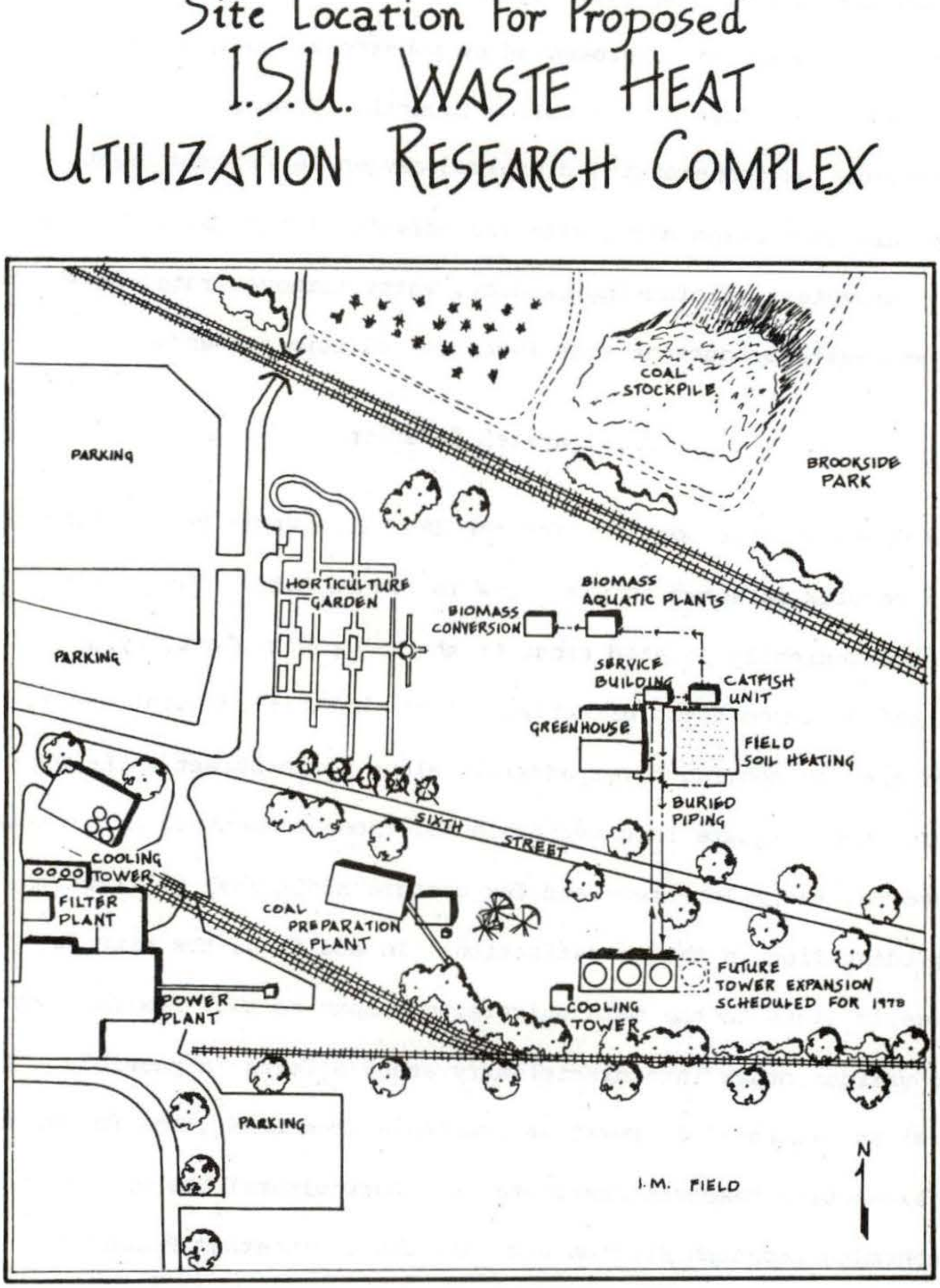

Figure A.11. Site location for proposed waste heat utilization complex study operation would be the best choice, offering a maximum potential return to the State's economy and to Iowa industry and utilities.

Pilot System Production

The 5000 ft^2 greenhouse and field subsoil heat plot and the 8 tank (800 ft^3) fish production unit were selected for the feasibility study because they were considered to be adequately sized to allow for reasonably accurate extrapolation of parameters to commercial scale, i.e., a 10 to 20 acre greenhouse installation or a 50,000 lb/yr fish production unit.

Production from the greenhouse, assuming tomatoes at two crops per year, would be 20,661 lb/yr.[1] The fish production unit would yield an estimated 2500 lb market size per four months or 7500 lb/yr.[2] Production from larger acreages or a larger volume fish unit can be assumed to be a linear extrapolation for cost, income, and production.

Pilot Location Climatological Factors

The climate of Ames can be classified as temperate and continental. It is subject annually to a wide seasonal range in both temperature and precipitation. Typically, the mean temperature varies from a low of 20°F (-6°C) in January to a high of 75°F (24°C) in July. The average minimum for January is about 10°F (-12°C) and the average maximum for

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[1] Charles V. Hall, Professor and Head, Department of Horticulture, Iowa State University, Ames, Iowa. Personal communication, 1976.

[2] Ross V. Bulkley, Associate Professor, Department of Animal Ecology, Iowa State University, Ames, Iowa. Personal communication, 1976.

July is about 87°F (30°C). However, the temperature extremes may range from a low of -20°F (-29°C) to a high of 105°F (41°C) for January and July, respectively.

Winter months are generally dry with about 1 in. of precipitation each month. June is generally the wettest month, with over 5.5 in. of precipitation, normally in the form of frequent thunderstorms. The mean temperature and precipitation are presented in Figure H.1 in Appendix H. Wind frequencies, direction, and velocities are provided in Figures H.2, H.3, H.4, and H.5 in Appendix H. From these figures it can be noted that strong winds are most frequently from the northwest and occur during the winter and spring months with maximum velocities reaching 40 mph. The highest velocities occur in March and April and the lowest in August. During the summer and fall, a large percentage of wind comes from the south and southeast at lower velocities, with a maximum of 25 mph. Figure H.2 shows that 85% of the wind speed is less than 15 mph; the average is 12 mph. A table of current climatological data (1975, 1976) is provided in Table H.1. This provides monthly data for maximum and minimum air temperatures, degree days, soil temperatures, and precipitation norms.

For building design heating loads, the extreme worst case condition will be taken as -20°F (-29°C) outside air temperature with a 15 mph wind, but a more conservative design figure of 5°F (-15°C) with a 5 mph wind is recommended.

APPENDIX B. SITE SELECTION AND DATA FOR LARGE SCALE INSTALLATIONS

General

The following five sites were visited and some data describing each plant were collected: Neal Stations 1, 2, and 3 (Iowa Public Service, Port Neal), Des Moines Station (Iowa Power and Light, Des Moines), Ames Electric Plant (Municipal, Ames), Muscatine Electric Plant (Municipal, Muscatine) and the Fair Station (Eastern Iowa Light and Power, Montpelier). A preliminary survey of a few power plants was conducted to permit an assessment of the survey techniques. The identification and selection of these plants for visitation and data collection were based on previous knowledge of each respective power plant's location, type of plant, and land availability. All power plants throughout the state should be surveyed in order to determine the optimum sites for commercial utilization of power plant waste heat. This survey would include land use, environmental assessment, with emphasis on geohydrologic considerations, and marketing studies, that is, for each particular application, where a certain commercial unit could be set up, what size it could be, and where it could market its product.

Some physical parameters identified as good indicators for potential utilization sites are the following: multiple unit power plants, plant locations near population centers, close proximity to agricultural land or to an industrial, commercial, or residential complex. Experience gained from visitation to the previously listed plants has revealed that a dual survey technique would yield the greatest amount of information, that is, through a combination of aerial photo-reconnaissance and surface inspection tour. Aerial photography records the greatest density of information of any survey technique. To obtain the same information using conventional surface techniques would require a great deal of time. The information recorded on the photograph must be accompanied by data obtained from a personal inspection tour. The combination can then be used to evaluate the utilization potentials for that particular site.

The following example further illustrates the importance of aerial photography in site survey analysis. Referring to the Neal Station photo (Figure B.1), note the surface hydrologic feature indicated by the arrow (marsh oxbow) forming a large arc east of the power plant. This marsh may have gone totally unnoticed during the surface inspection tour because during the surface inspection, only a small portion of the surrounding site can be seen from any given vantage point. The marsh is significant in that it may have some waste heat utilization potential of benefit to the power plant.

General plant information was gathered at each station visited. This included plant unit layout, heat balances diagrams, cooling system-type, flow rates, coolant temperature, operating backpressures, and condenser and turbine data (when available). Land utilization practices characteristic of the individuals or communities associated with each site were recorded in general detail (as permitted by limited observation), that is, the type of land use such as industrial, residential, commercial, or agricultural.

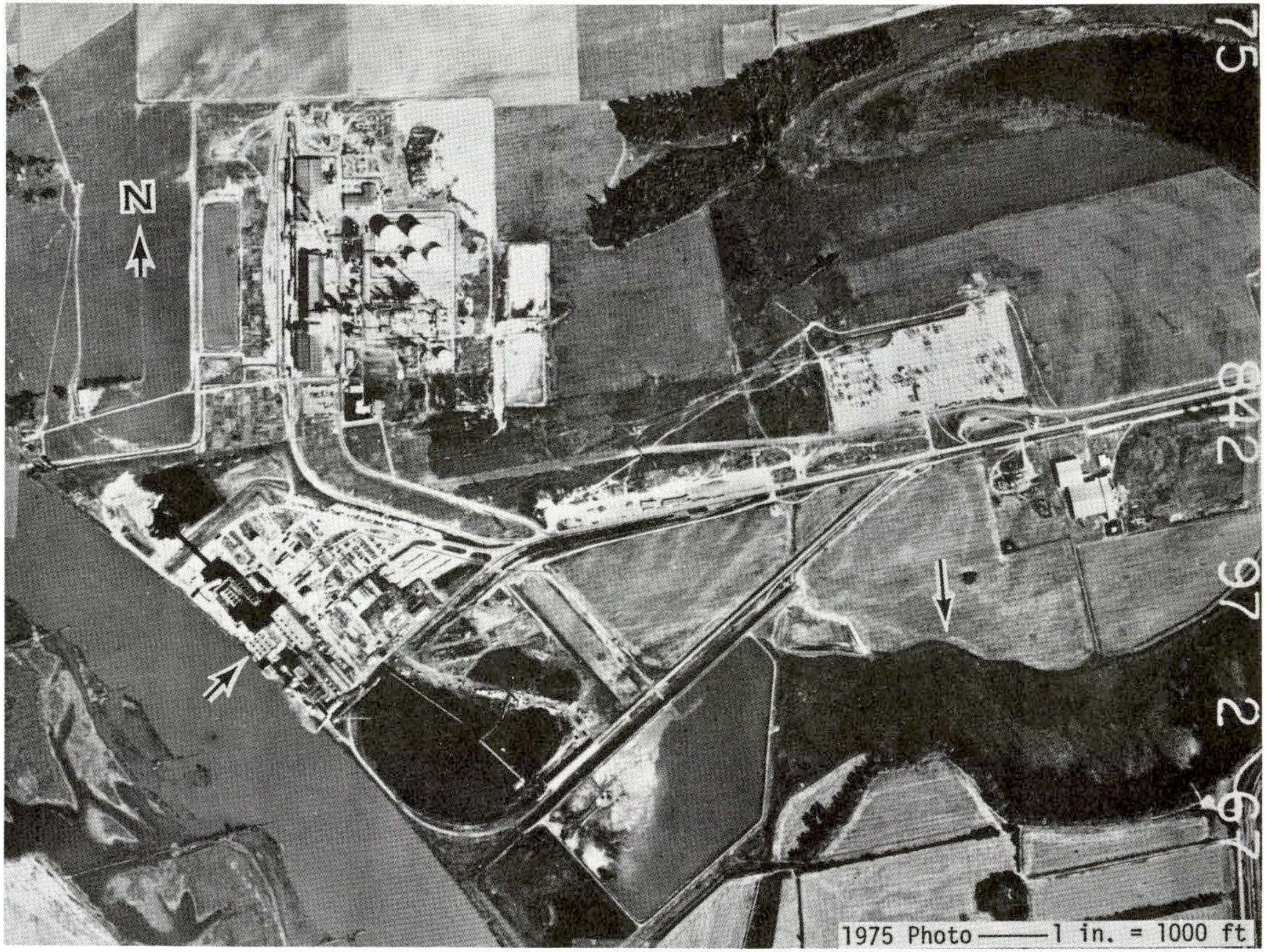


Fig. B.1. Aerial photo, Neal Station 1,2 & 3, Port Neal, Iowa.

Neal Station 1, 2, and 3

The Neal Station is located at Port Neal on the Missouri River just south of Sioux City. Neal Station 1, 2, and 3 has a total output of 1000 MW(e). The plant consists of three independent units. Each is fossil fueled using coal and each is cooled using once through river water. Refer to Table B.1.

Table B.1. Condenser flow rates, Neal Station

	Circulating water in GPM	
	Summer	Winter
Unit 1	71,300	50,750
Unit 2	119,600	100,000
Unit 3	3,275,200	250,000

From Figure B.2 it can be seen that the land surrounding the plant is almost entirely agricultural. (An exception is a chemical plant located north and adjacent to the power plant.) The turbine backpressure differs by about 1 inch Hg from summer to winter operation. Typical summer and winter values are 3 inches Hg abs. and 2 inches Hg abs., respectively. A 20°F (11°C) temperature rise through the condensers is typical for summer conditions and a 10°F (6°C) rise is characteristic for winter operating conditions. Discharge temperatures are typically 90°F (32°C) in the summer and 70°F (21°C) in the winter. For summer operations, two circulating pumps are used whereas only one pump is required for winter conditions. For deicing purposes in the winter, some warm water may be discharged upstream from the intake. Plant heat balance diagrams were not available; however, condenser

Fig. B.2. Aerial photo, Neal Station 1,2 & 3 and surrounding land, Port Neal, Iowa.

specifications and performance curves were obtained and are provided in the final report to the Iowa Energy Policy Council (Roberts and Bahr, 1978).

Des Moines Station

The Des Moines station is located in the southeast corner of Des Moines (Figure B.3). (Arrow indicates location of the power plant adjacent to the Des Moines River.) The station is fossil fueled using coal and employs a combination of cooling towers and once through river water for condenser cooling. The station consists of four units, two older units and two newer units. The two older units have been all but phased out due to their low efficiencies and the difficulty in meeting current air pollution emission standards. Therefore, only data pertaining to the newer units were obtained. The two newer units are referred to as unit 6/10 (turbine/boiler) with an output of 7 MW(e) and unit 7/11 (turbine/boiler) with an output of 120 MW(e). Unit 6/10 uses river water cooling when flows are adequate; otherwise, cooling towers are used. For a typical January river inlet temperature of 40°F (4°C), the condenser coolant discharge temperature is 52°F (11°C) and the corresponding operating backpressure in 1.6 inches Hg abs. Summer discharge temperatures are typically in the upper 90's°F (32's°C) with a corresponding turbine backpressure of 3.5 inches Hg abs. Unit 7/11 uses wet evaporative induced flow cooling towers. For a winter condenser inlet temperature of 48°F (8°C) the outlet temperature is 79°F (26°C) with a corresponding backpressure of 1.8 inches Hg abs. Summer outlet temperature in the 80's or 90's°F (26 to 32°C) correspond to

Fig. B.3. Aerial photo, DesMoines station, DesMoines, Iowa.

backpressures of 2.8 inches Hg. Table B.2 presents the summer and winter flow rates.

Table B.2. Condenser flow rates, Des Moines Station

	Circulating water in GPM	
	Summer	Winter
Unit 6/10	65,000	50,000
Unit 7/11	61,000	55,500

Condenser specifications and performance curves are provided in the final report to the Iowa Energy Policy Council (Roberts and Bahr, 1978).

Ames Municipal

The Ames Power Plant is located along the eastern margin of the city (Figure B.4) and is surrounded by the downtown business district to the west and south, by residential dwellings to the north, and agricultural land to the east. The station is fossil fueled, burning coal or natural gas. The unit also has a solid waste refuse burning addition. The plant consists of three main units plus a gas turbine for peaking. Detailed information was collected on the largest unit, number 7, 33 MW(e). All three units use induced draft wet evaporative cooling towers. The condenser circulating water flow rates are 16,200 GPM in the winter and 26,600 GPM during the summer, with winter inlet and outlet temperatures of 70°F (21°C) and 90°F (32°C), respectively, and corresponding summer temperatures of 79°F (26°C) and 99°F (37°C), respectively. Corresponding backpressures of 2.5 inches Hg abs. for winter and 3.2 inches Hg abs. for summer operations are common. A heat

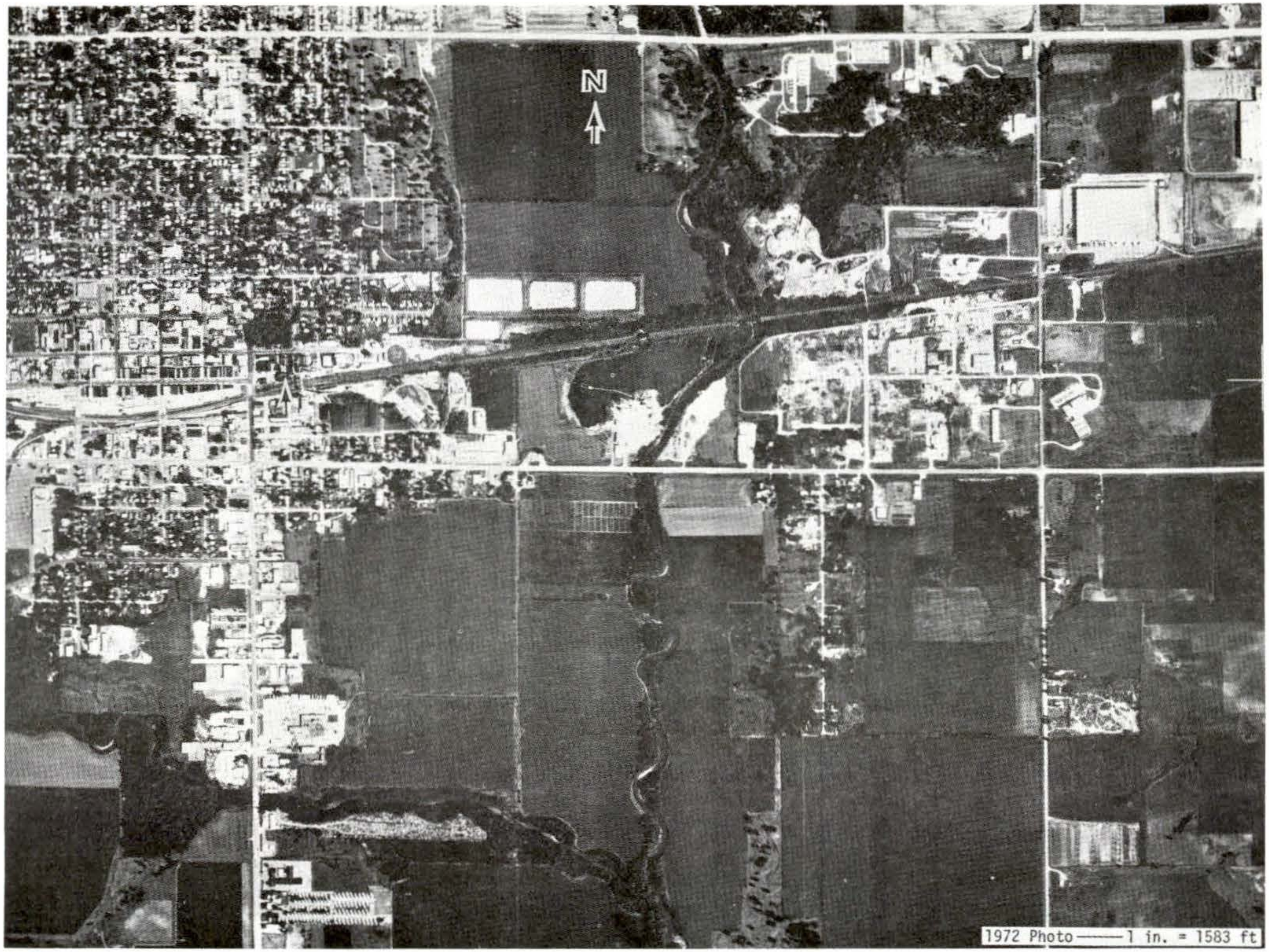


Fig. B.4 Aerial photo, Ames station, Ames, Iowa.

balance diagram, turbine and condenser specifications, and condenser performance information are provided in Appendix G.

Muscatine Municipal

The Muscatine power plant is located at the southeast edge of the city of Muscatine. The plant is adjacent to the Mississippi River and is bordered on the north by chemical and grain industries and to the west and south by agricultural land. The station consists of four coal burning units. All four units use once through river water for cooling. Data were taken on only the two newer larger units, 7 and 8. Unit 7 is 22 MW(e) with a cooling water flow rate of 37,000 GPM in the summer and approximately 30,000 GPM in the winter. Unit 8 has an output of 81 MW(e) with typical cooling water flow rates for summer and winter operations of 75,000 GPM and 65,000 GPM, respectively. Unit 8 exhaust hood over temperature alarm sounds at 145°F (63°C) or 5 inches Hg absolute pressure. Winter inlet temperatures to condensers are in the range of 38 to 40°F (3 to 4°C) with discharge temperatures ranging from 55 to 60°F (12 to 15°C). Summer inlet temperatures are in the range of 80°F (26°C) and outlet temperatures are about 91°F (32°C). These figures are representative values for unit 8 and correspond to turbine backpressures of 0.5 inch Hg abs. and 2.2 inches Hg abs. for winter and summer, respectively. The condenser and turbine specification data obtained for units 7 and 8 are presented in the final report to the Iowa Energy Policy Council (Roberts and Bahr, 1978).

Fair Station

The Fair Station is located along the Mississippi River just west of Montpelier, Iowa. The station consists of two coal fired units, number 1, 22 MW (e) and number 2, 33 MW(e). Condenser cooling is provided by using once through river water. Condenser flow rates for two pump operations for Unit 1 is 20,500 GPM and for Unit 2 is 28,600 GPM. An example of a winter operating condition for Unit 2 would be an inlet water temperature of 35°F (2°C) and a discharge temperature of 58°F (14°C) for a turbine backpressure of 0.9 inch Hg abs. and a load of 30.3 MW. Typical summer operating conditions for a 40.5 MW load are an inlet temperature of 82°F (27°C) and a discharge temperature of 88°F (31°C) with a corresponding backpressure of 2.3 inches Hg abs. Turbine and condenser specification data are provided in the final report to the Iowa Energy Policy Council (Roberts and Bahr, 1978).

APPENDIX C. ADDITIONAL POTENTIAL WASTE HEAT USERS

General

The following applications requiring temperatures from 70 to about 100°F (21 to 38°C) may be considered as potential waste heat users. Figure C.1 presents a sequence of low temperature waste heat users located adjacent to their respective operating temperature range (note that some applications have a wider temperature use range than indicated, such as greenhouse space heating).

Refuse Drying

Drying of solid waste for incineration as a power plant fuel may hold some potential for utilization, especially from power plants with dry cooling tower systems.

Space Heating

A wide variety of space heating applications could be developed to use waste heat. These applications range from apartment, to industrial plant, to greenhouse heating. The users should be located relatively near the power plant heat source. The temperature utilization range for space heating applications, such as for greenhouse heating, could start about 70°F (21°C). All space heating applications would be seasonal with peak demands during winter and with little or no demand during the summer depending on geographic location.

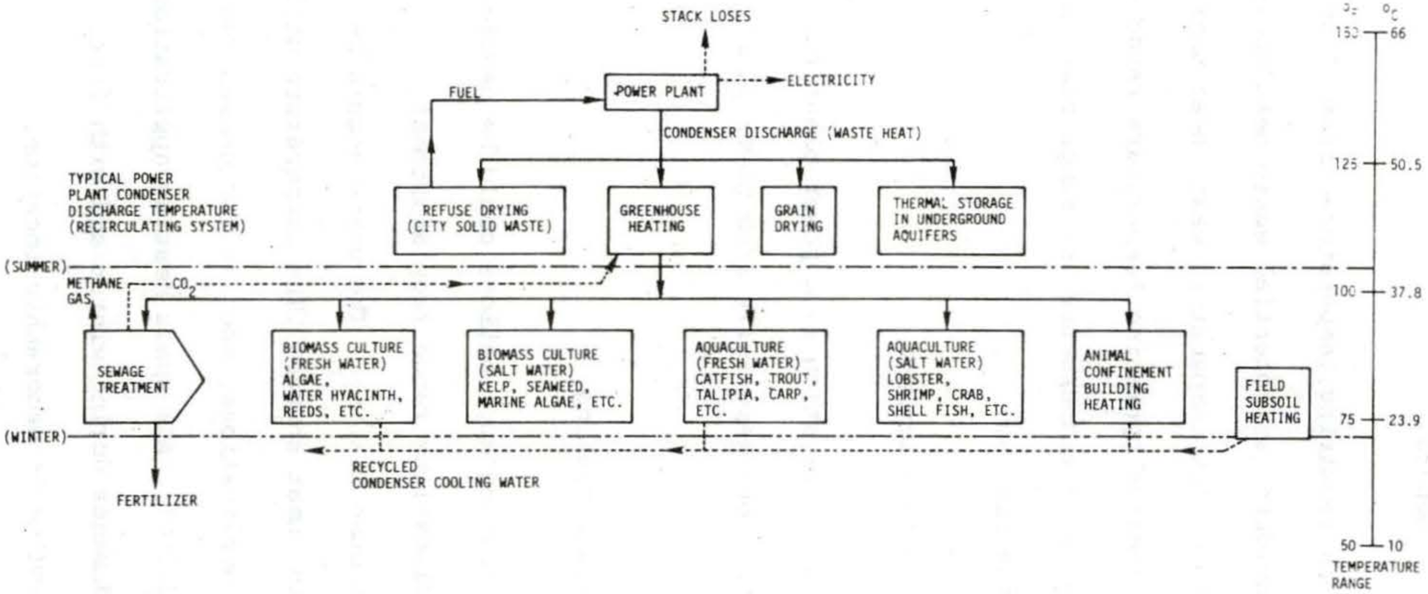


Figure C.1. Sequence of potential low temperature waste heat users

Grain Drying

This application is similar to that of any space heating application but has a narrow utilization time span, that is, a fall or post-harvesting heating demand only.

Thermal Storage

Thermal energy storage is not an application in the usual sense of the word but a technique for improving the efficiency of true applications by storing useful heat from the time it is produced until the moment when it is needed. Thus, heat produced in the summer could be made available for use in the winter.

The storage of low temperature waste heat in underground aquifers is a relatively new and unexplored concept. One possibility might be the use of heat pumps to remove heat from the warm water and use it for some space heating application or possibly direct recovery by pumping. Some studies have been conducted on the feasibility of high temperature water storage in confined underground aquifers (Meyer and Todd, 1973a,b). This technique showed favorable results.

Sewage Treatment

Waste heat can be used in a variety of ways in sewage and waste water treatment. Waste heat can be used to increase the temperature and facilitate anaerobic fermentation for methane production. A 95°F (35°C) temperature is suitable for the operation of an anaerobic digester using animal wastes or similar sewage waste. Warm water can provide the needed thermal environment for an alternate waste water treatment scheme involving the use of various aquatic plants to help purify water to a recyclable level (Duncan, 1976). Use of aquatic plants such as water hyacinth (to remove heavy metals) along with single cell proteins (algae) has received attention in recent waste water treatment studies (Wolverton and McDonald, 1976; Queijo, 1977). Algae, used to remove nutrients from waste water (Devik, 1974), can then be harvested and used as a protein source or converted to a fuel such as methane. Similarly, other aquatic plants can be grown, harvested, and converted to useful products.

Biomass Production

The most effective scheme for use of power plant waste heat during the summer may be that of a biomass production evaporative cooling marsh. This concept may have a good potential for efficient year round use of large quantities of power plant waste heat. Figure C.2 presents a plan view of an idealized biomass production evaporative cooling marsh. This example presents the case where an existing old river oxbow can be developed into a cooling marsh with biomass production. The warm water from the power plant is discharged into the marsh where it cools by evaporation, radiation, and conduction to the overlying air. Suitable aquatic emergent plants could then be established in the marsh to provide a variety of useful benefits. The emergent aquatic plant community would act to provide a vegetative canopy to receive and utilize (store as biomass material) the incoming solar radiation and thus the solar heat normally received by the water. The resultant

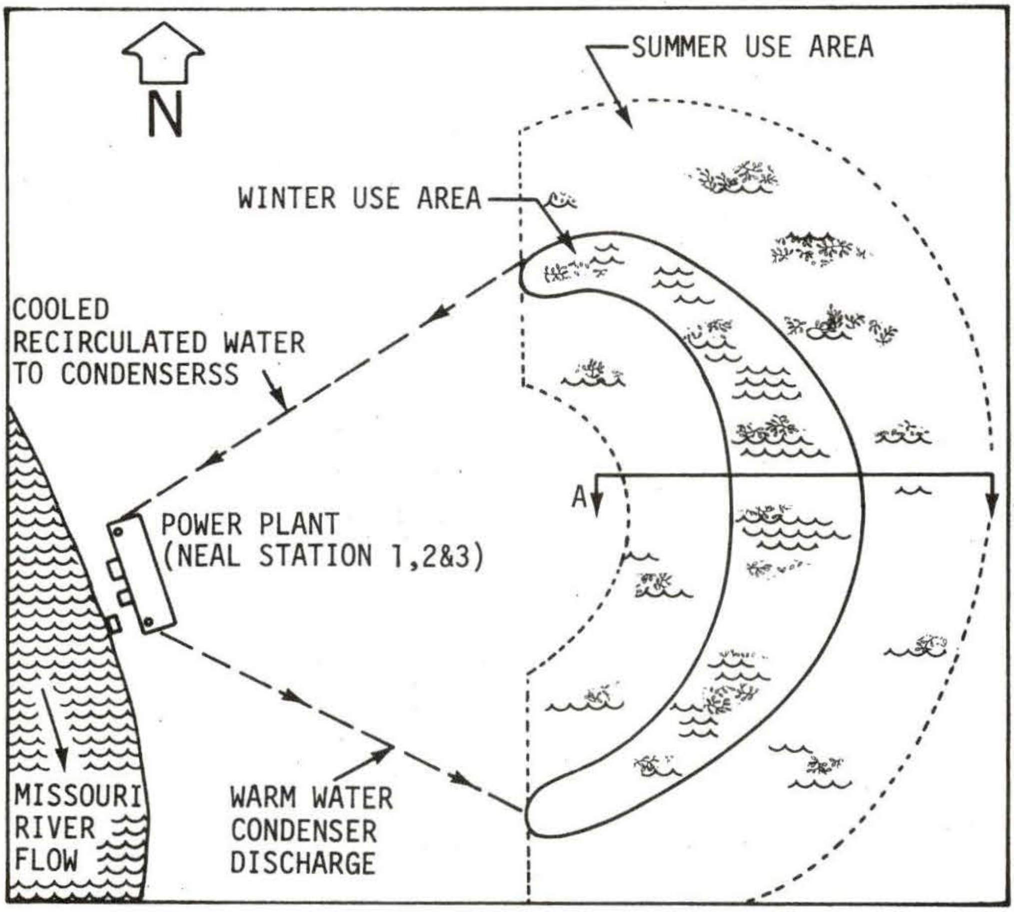


Figure C.2. Idealized plan view of a biomass production evaporative cooling marsh, Port Neal, Iowa shading of the water aids in the exchange of energy for cooling since the water experiences a 70% reduction in solar heat load. The reduced total heat load permits a reduction in the marsh area required for power plant cooling. A second benefit of growing the emergent plants is that the biomass (the plant material) can be harvested and either burned as a clean fuel or converted to some other desirable product such as protein, methane, glucose, etc.

The present cost of land in some areas has made the conventional cooling pond concept uneconomic. Therefore, if the area required can be reduced by the development of an effective plant canopy, then the investment could become competitive in capital cost and performance with conventional wet cooling towers. Another benefit of the marsh cooling concept is that it provides a return from the capital investment whereas the conventional cooling techniques do not. Additional waste heat use could be obtained from the marsh cooling system, by using the warm water environment for sewage treatment, fertilizer recovery, single cell protein production, fish aquaculture, or as a wildlife refuge. Figure C.3 presents an example of a potential site for a biomass production evaporative cooling marsh for the City of Ames power plant. The power plant location and adjacent Skunk River flood plain could be developed into a site for city sewage treatment, fertilizer recovery and water recovery, as well as biomass production and water cooling. The site is close to existing city sewage lines and treatment facilities on the Skunk River flood plain (Figure B.2). The biomass production evaporative cooling marsh seems to be environmentally desirable because an entire aquatic ecosystem could be set up based on the waste heat

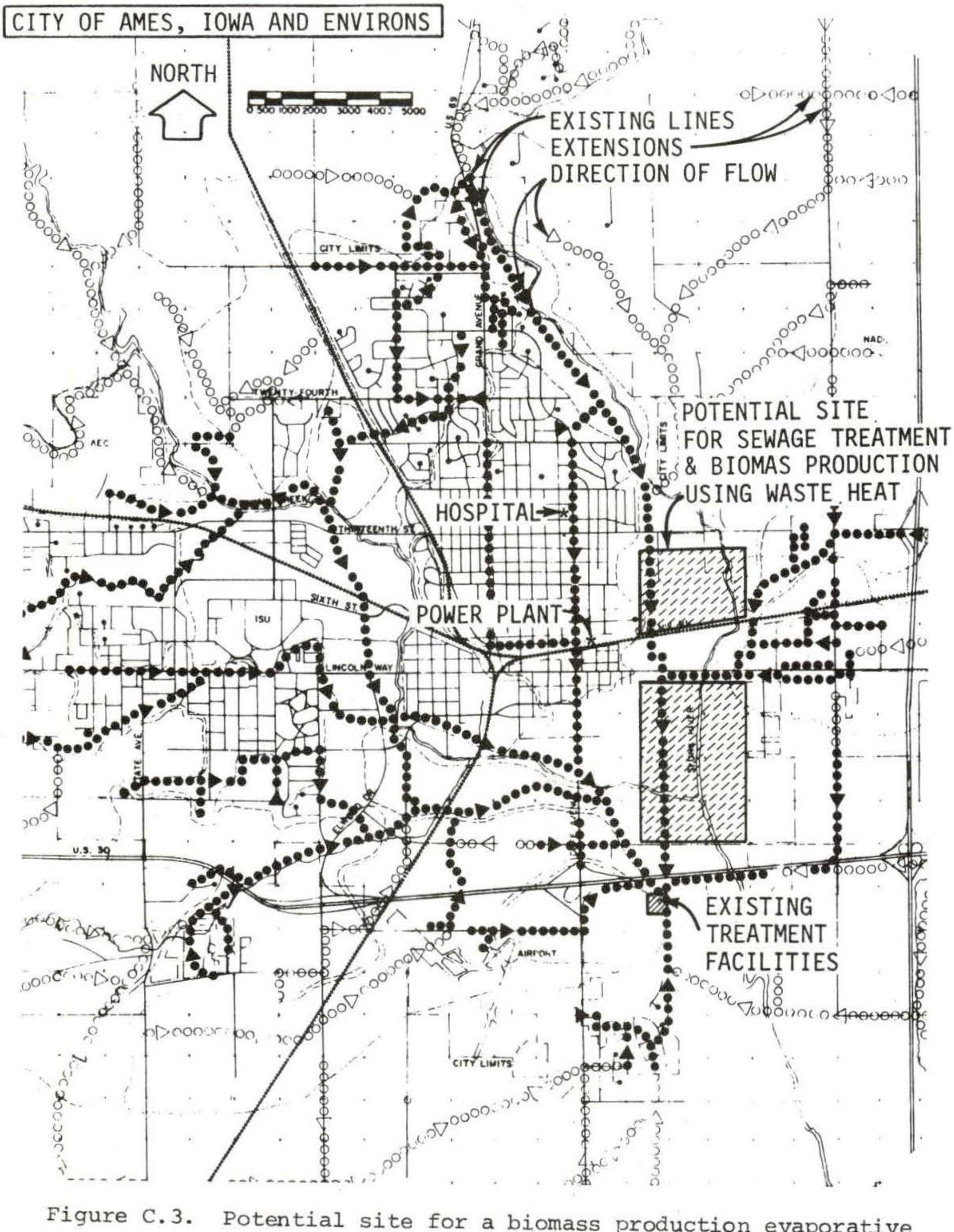


Figure C.3. Potential site for a biomass production evaporative cooling marsh for the City of Ames power plant discharged from the power plant. In this manner the discharge is not introduced as a thermal pollutant but rather becomes a natural part of an elevated temperature artificial marsh ecosystem (this could be either fresh or salt water environment).

Aquaculture

The intensive culture of catfish, trout, talipia, and other species of fish may have a great potential for development in the United States with power plant waste heat supplying the heating requirement. Aquaculture is not limited to freshwater species as lobster, shrimp, and other shell fish are already being raised at various locations (Roberts and Bahr, 1978). Use of the waste heat is desirable in aquaculture because it is already in the form required for the fish, that is, warm water, and it can be used to heat water during winter operation at northern locations. The United States lags behind other advanced nations in developing aquaculture as an efficient low cost high protein food industry and it remains a vast untapped potential resource.

Animal Confinement

Some potential may exist for use of waste heat in the heating of animal confinement buildings. This space heating application is similar to that of greenhouses and the confinement structures would need to be located relatively close to the power plant. The animal space heating demand is also a winter seasonal heat requirement. Use of the waste heat could also be applied to conversion of animal wastes from the confinement complex to other useful products such as methane or fertilizer.

Subsoil Heating

The circulation of waste hear warmed water through pipes buried in the ground below growing plants provides a number of potential benefits (Slegel, 1976). The growing season can be extended, crop quality can be improved, growth can be promoted, and some control of certain diseases and pests may be possible.

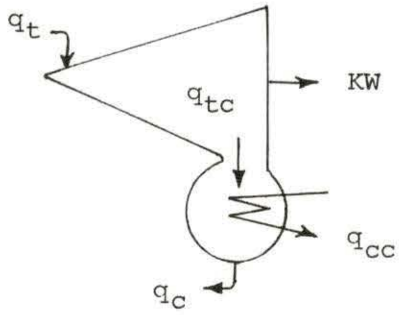
Potential advantages and reality are not necessarily the same. Much more research is needed to study problems of elevated temperature in the root zone, disease, and drying of soil (Schisler and Bakker-Arkema, 1975).

APPENDIX D. ENERGY BALANCE FOR COMPUTER MODELS

General

Using a block diagram input-output approach, the energy balance for each major component of the assumed system is presented. The block diagrams represent a simplified description of the energy balance equations and energy flow for each major component of the overall model. The actual equations employed are presented in the computer program in Appendix I.

Figure D.1 represents a simplified turbine-generator-condenser energy flow scheme. A more detailed treatment can be found in the computer model description and program listing in Appendices E and I.



q_t = heat into turbine

q_{tc} = heat into condenser from turbine

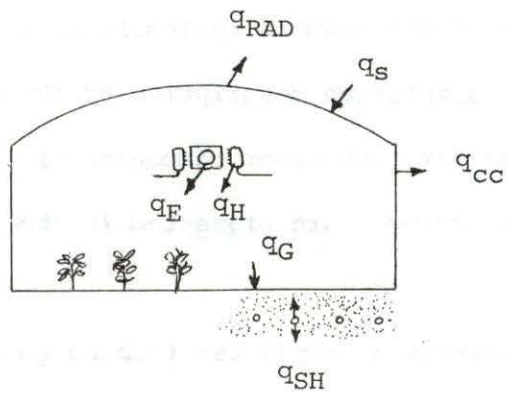
q_c = heat (condensate) leaving condenser

q_{cc} = heat transferred to condenser coolant

KW = generator kilowatt output

Figure D.1. Energy balance for a condensing steam electric power plant

The factors affecting the steady state energy balance for the greenhouse are presented in Figure D.2. The figure can be simplified by assuming night conditions; therefore, $q_S = 0$, also let $q_{SH} = q_G$ by assuming the heat added by soil heat just equals that lost to the soil from space heat.



q_S = solar radiation gain

q_{RAD} = radiation loss

q_{cc} = conduction-convection loss

q_E = heat added by equipment

q_H = heat added by space heating system

q_{SH} = heat added by soil heat system

q_G = space heat lost to ground

Figure D.2. Assumed steady state energy balance for a greenhouse

The parameters can then be summed into an energy balanced and arranged to solve for q_H, the space heating requirement for given outside climatic conditions. The energy balance equations are provided in the greenhouse subroutine of the computer program listing in Appendix I.

Figure D.3 provides a simplified steady state energy balance for the assumed fish production unit. Since it was assumed that the building space heat requirements were small and its temperature relatively constant, then the main parameter to be determined from the energy balance would be the size of the heat exchanger. The size would be mainly determined by the heat load required to raise the temperature of the replacement water to 83°F (28°C) plus replacement of heat lost from tank and pipe surfaces. The actual energy balance and heat exchanger equations are provided in the fish subroutine of the computer program listing in Appendix I.

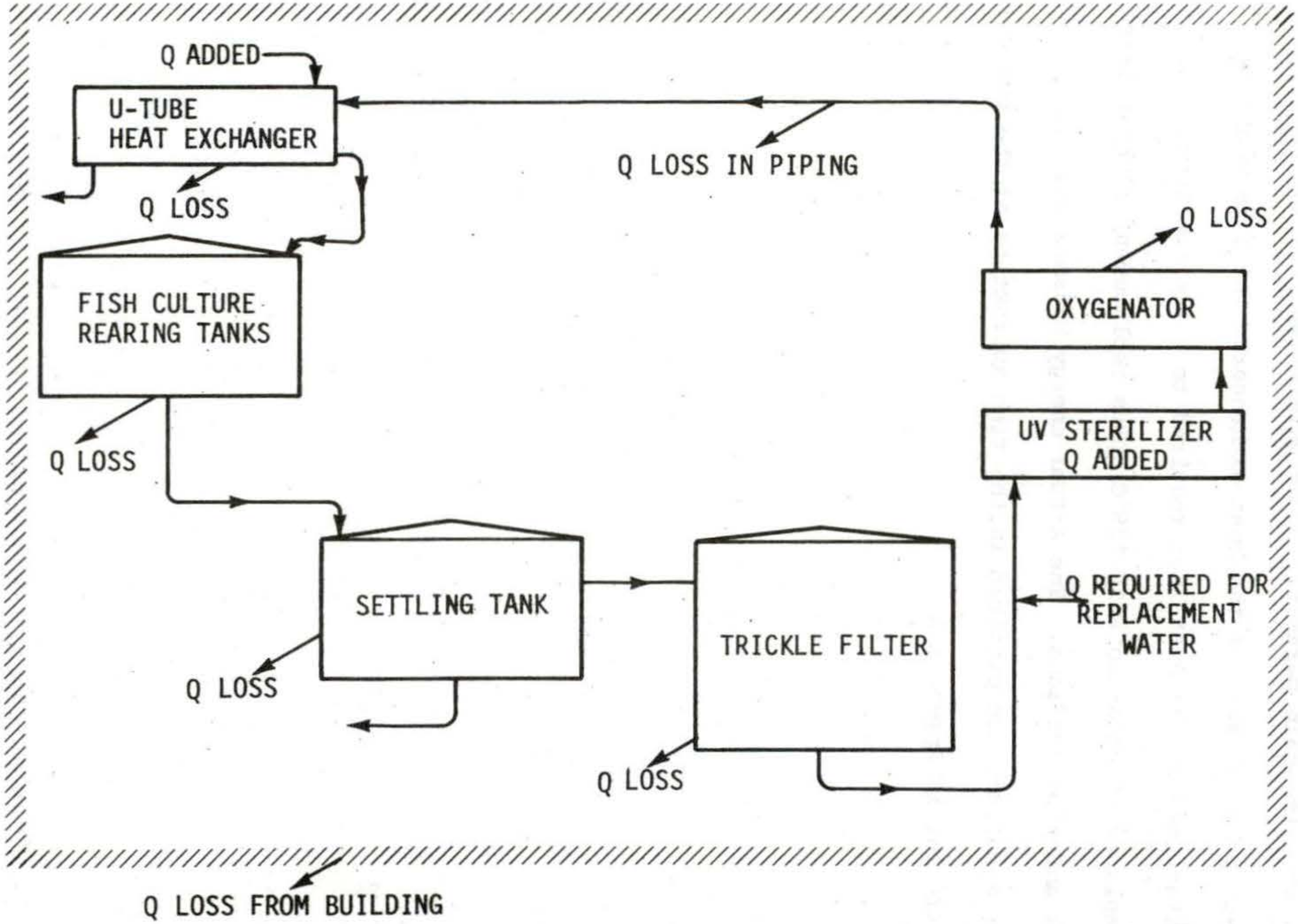


Figure D.3. Fish production unit steady state energy balance

APPENDIX E. COMPUTER MODEL

General Power Plant Considerations

Most of the present day generation of condensing steam turbines are designed for operation at exhaust temperatures of 134°F (57°C) corresponding to an exhaust pressure of 5 inches Hg absolute. This line of turbine equipment was designed to meet the requirements associated with condenser coolant water from wet evaporative cooling towers, rivers, lakes, or cooling ponds. The upper limit for the turbine exhaust condition is fixed by material consideration. These include overheating of the last stage turbine blades, possible flutter damage to the last stage blades at high exhaust pressures and low loads; possible water damage due to recirculation from the condenser; rapid exhaust temperature changes due to load fluctuation which cause cyclic thermal stresses; distortion of the exhaust hood and bearing supports; and difficulties in providing the required adequate clearance control.[1] Therefore, to operate the existing present day units at exhaust conditions higher than 134°F (57°C) or 5 inches Hg absolute would require major design changes. It should be noted that these design changes have been incorporated into the new line of high backpressure turbines designed for operation with dry cooling towers. These high backpressure units are suitable for operation at exhaust pressures up to 14 inches Hg absolute and a corresponding temperature of 180°F (82°C).

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[1] General Electric Marketing Information Letter No. 922, June 28, 1971.

One possible approach to recovering power plant waste heat is to use the condenser coolant water at the existing temperatures. This recovery method implies no modification of the power plant or cooling towers and thus no loss of electric generating capacity. Figure E.1 presents a simplified power plant flow diagram.

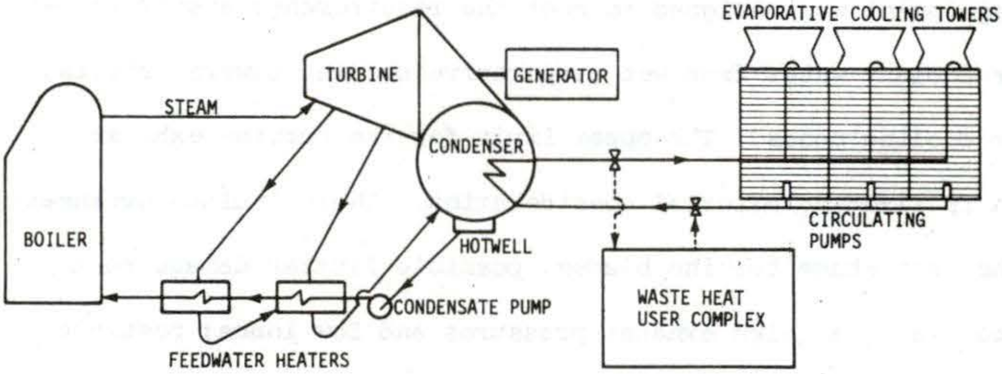

Figure E.1. Power plant waste heat recovery method, Case 4, no modification of condenser coolant temperature

Referring to Figure E.1, the no temperature elevation approach would make direct use of the heated water before it passes through the cooling towers. The temperature of the condenser coolant (79-120°F) (26-49°C) will then be determined by the temperature and loading from the turbine exhaust and by the ambient air effect on cooling tower performance. This assumes a constant circulation rate of coolant through the condenser and specified tower configuration. The temperature of the condenser coolant will also be dominant in sizing the heat exchangers for the waste heat users and since this approach does not consider the possibility of controlled increased temperature, then the required heat exchanger area would be larger and consequently more costly.

An alternate scheme considers elevation of the temperature of the condenser coolant discharge. In this case, the temperature of the condenser coolant is raised by modification of cooling tower performance parameters. This could be accomplished by reduction of fan operation or the number of cooling tower bays in service or some combination to achieve the desired coolant temperature out of the condenser. This assumes a given Btu loading condition from the turbine exhaust and also a fixed coolant circulation rate. As the temperature of the condenser coolant rises, so does the turbine exhaust pressure. The limiting temperature of the condenser coolant is determined by the maximum turbine exhaust temperature as specified by the turbine manufacturer. This condition is usually expressed in terms of absolute pressure and, for most present day turbines, 5 inches Hg absolute with a corresponding temperature of 134°F is accepted as a suitable upper limit for continuous operation. However, from an economic standpoint, operation at the lowest possible exhaust pressure (limited by the turbine heat balance) is desired so as to achieve maximum fuel economy.

The turbine exhaust pressure rise associated with the increased temperature in the condenser will result in a reduced electrical output. The reduction of kilowatts generated due to exhaust pressure rise is very small (1%) and corresponds roughly to the normal loss experienced by steam electric power plants during summer operation. During summer months, the exhaust pressure increases due to the adverse effect of higher ambient air temperature and humidity on cooling tower performance. Since utilities are familiar with a loss in generation capacity during the summer, then perhaps they will consider and accept a loss in generation revenue during the winter months if the loss can be balanced by the sale of "waste heat". Thus, any loss in generation revenue due to an increased condenser coolant temperature must be offset by a charge for the waste heat delivered to the users. Referring again to Figure E.1, the only modification to the power plant would be to alter the cooling tower operation by shutting down one or more bays or by reduced fan operation. It should be pointed out here that utilities normally do shut down one or more cooling tower bays during winter months in order to keep the temperature of the condenser coolant within an acceptable operating range (to prevent subcooling of the steam condensate). In addition, the practice of shutting down cooling towers and reduced operation also helps save on tower maintenance and pumping costs.

Figure E.2 presents a power plant layout with two possible modifications to provide the heat required to increase the temperature of the condenser coolant.

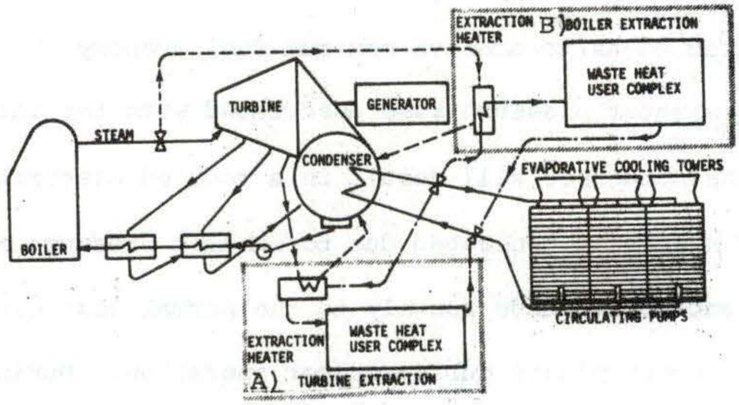

Figure E.2. Case A and B. Increased condenser coolant temperature by thermal enrichment

In Figure E.2, Method A takes extraction steam from the turbine and passes it into a heater through which the condenser coolant is circulated. Method B takes steam directly from the boiler and passes it to a heater which increases the temperature of the condenser coolant. At some elevated temperature, the condenser coolant is then circulated to the user complex where it dumps the heat. Ideally, in both cases, the coolant is then pumped directly back through the condenser (assuming all of the heat that would normally be dumped in the cooling tower can be transferred to the environment of the user complex). Again any loss in generation capacity and its associated revenue loss would have to be offset by a charge for the waste heat at the higher temperature. The technique described in Figure E.2 by Method B (boiler extraction) will not be included in the model. This technique is less desirable because the very high temperature is not needed and some mechanical work could be done with the high temperature boiler steam by expansion through the turbine before utilization of the steam's heating capability at a lower temperature.

Computer Model Flowcharts

The logic structure for interfacing the main program with the subprograms is presented in Figure E.3. From this figure it can be seen that the main program consists of a read input data statement and a series of call subprogram statements. One set of input data is read for each power plant considered. This input data is used in the two power plant subprograms for calculation of waste heat production. This determines various waste heat production parameters for summer and winter conditions, such as quantity, flow rates, condenser coolant

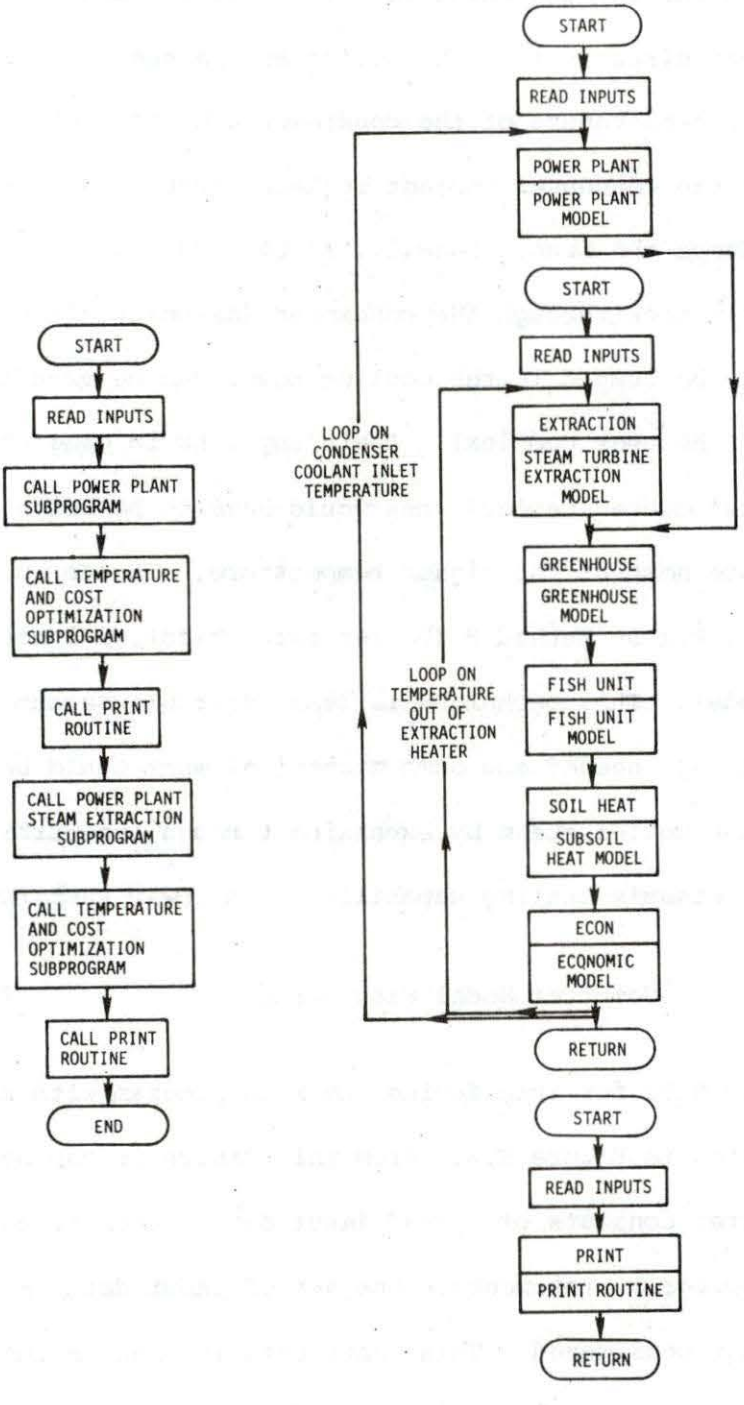

Figure E.3. Computer program flowchart

discharge temperatures, condenser pressure, plant losses, and so on. The program and printout results appear in Appendices I and J, respectively.

Figure E.4 presents the power plant subprogram flowchart. The model computes a steady state condenser discharge temperature which is an input to each subprogram (set up as a parallel temperature input). After performing calculations in each respective subprogram the condenser coolant temperature is increased by a selected value and input to the power plant model where an iteration is carried out until the new equilibrium discharge temperature is reached. This new discharge temperature then goes through the same process in each subprogram and the temperature return is increased again until a preselected limit is reached. The steam extraction subprogram is presented in Figure E.5. In this subprogram the external loop for discharge temperature elevation is the same as for Figure E.4 and the internal dynamics of the extraction technique is as described in the flowchart.

The greenhouse subprogram is presented in Figure E.6. Tables of selected output parameters are presented in Appendix J. Figure E.7 presents the fish unit subprogram flowchart. Results of selected output parameters are presented in Tables J.9 and J.10. Similar flowcharts and computer simulation could be accomplished for the biomass production and the soil heat concepts; however, these were not included in the simulation.

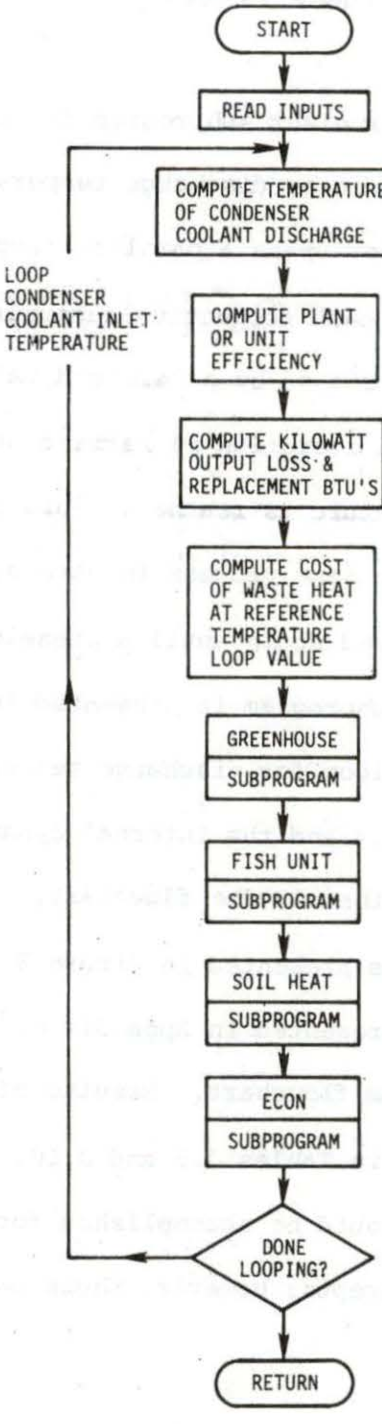

Figure E.4. Power plant subprogram flowchart

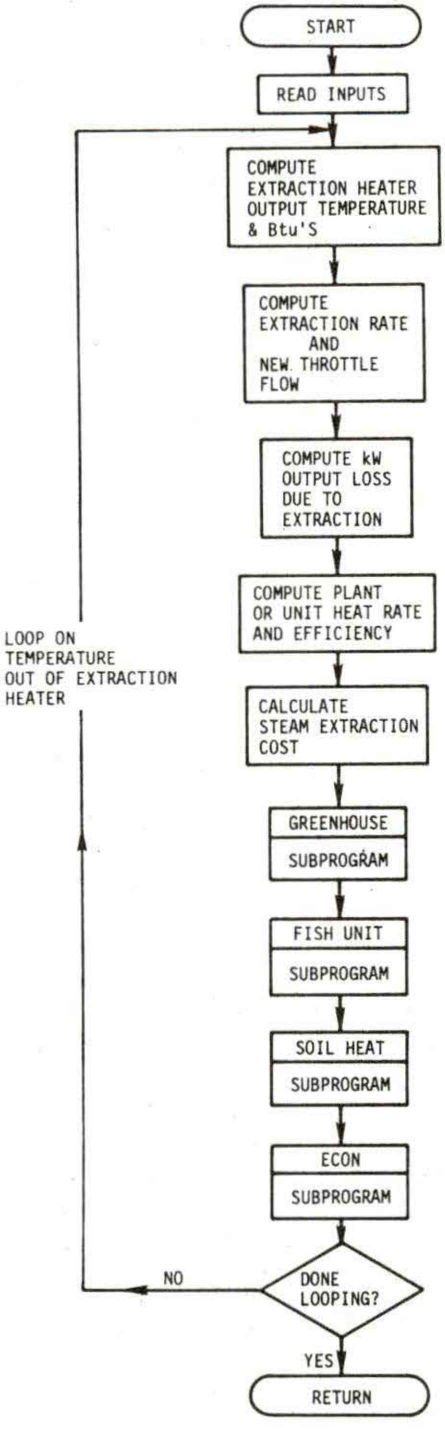

Figure E.5. Steam extraction subprogram flowchart

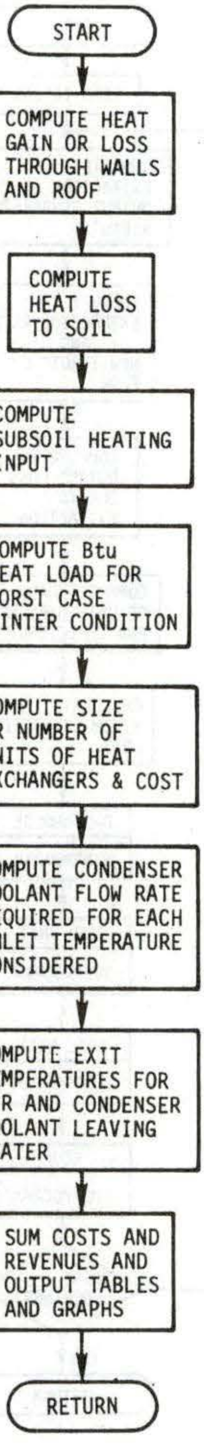

Figure E.6. Greenhouse subprogram flowchart

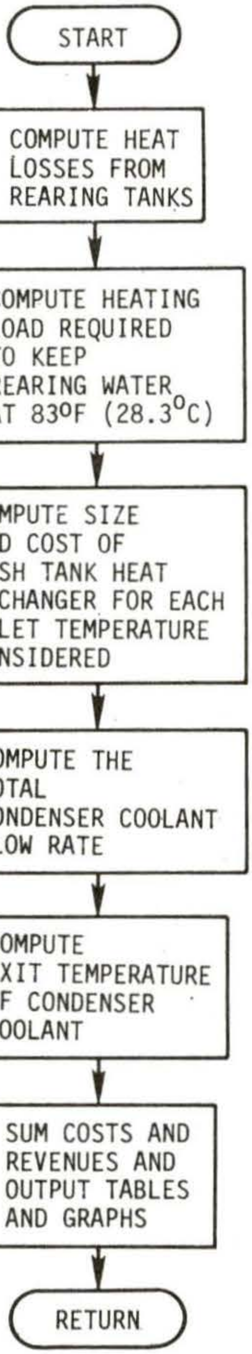

Figure E.7. Fish unit subprogram flowchart

APPENDIX F. HYDROGEOLOGIC CONSIDERATIONS

General

It is necessary to consider the hydrogeologic aspects for two major reasons: first, water availability for plant cooling requirements and, second, prevention of contamination (by surface runoff or direct input) of surrounding ground water resources. These will be discussed in general terms and further references provided for the interested reader.

A recent survey of the water cooling requirements for electric power production in Iowa (Butterfield and Dougal, 1975) has indicated that the two major rivers bordering the state will play a major role in meeting future power plant cooling requirements. In addition, the growing demand on ground water use combined with its reduced availability will most likely result in increased restrictions on withdrawal and consumptive use of water for power plant cooling. In the near future the water allocation problem may force power plant designs to feature dry cooling towers. This is certainly to be expected for large power plants located within the state and away from the major rivers. Also, as plant generating capacities increase, so do cooling water requirements to the extent that with existing thermal discharge regulations, once through river cooling systems will be prohibited simply because adequate river flows will not be available. These restrictions will tend to force power plant designs to consider wet cooling towers or cooling ponds and, eventually, dry cooling towers.

As previously stated, the two most important considerations with respect to hydrogeology are water availability and prevention of ground water contamination. When an alternate cooling scheme such as a cooling pond or an evaporative cooling marsh is to be used, the preceding considerations and additional hydrogeologic parameters must be evaluated. For example, when considering a site for either a cooling pond or a cooling marsh, it must be assumed that makeup water will be available, that the site under consideration will hold water (low infiltration), and that it will not act as a potential point source of pollution in hydrogeologic connection to an important ground water aquifer.

Figure F.1 presents the six major Iowa river basins and Figure F.2 presents the alluvial aquifers of Iowa. Superimposed on both of these figures are the site locations of various power plants visited in a sample survey across the state. Note from Figure F.1 that each power plant site is located alongside a river capable of providing an adequate supply of cooling water. In Figure F.2 note that the power plants are located over alluvial material (alluvial deposits underly the flood plains and terraces of Iowa's principal rivers). These alluvial deposits act as surficial aquifers and are composed of glacial outwash and fluvial deposits called alluvium. They are found as buried river or stream channels along present water courses and as discontinuous sand bodies in glacial drift.

The alluvial deposits constitute productive aquifers and are currently important sources of water. Because of the near surface location of the aquifer and its high permeability, great care must be taken to prevent contamination.

Consideration of alternative power plant cooling schemes, such as the use of a biomass production evaporative cooling marsh, provides an

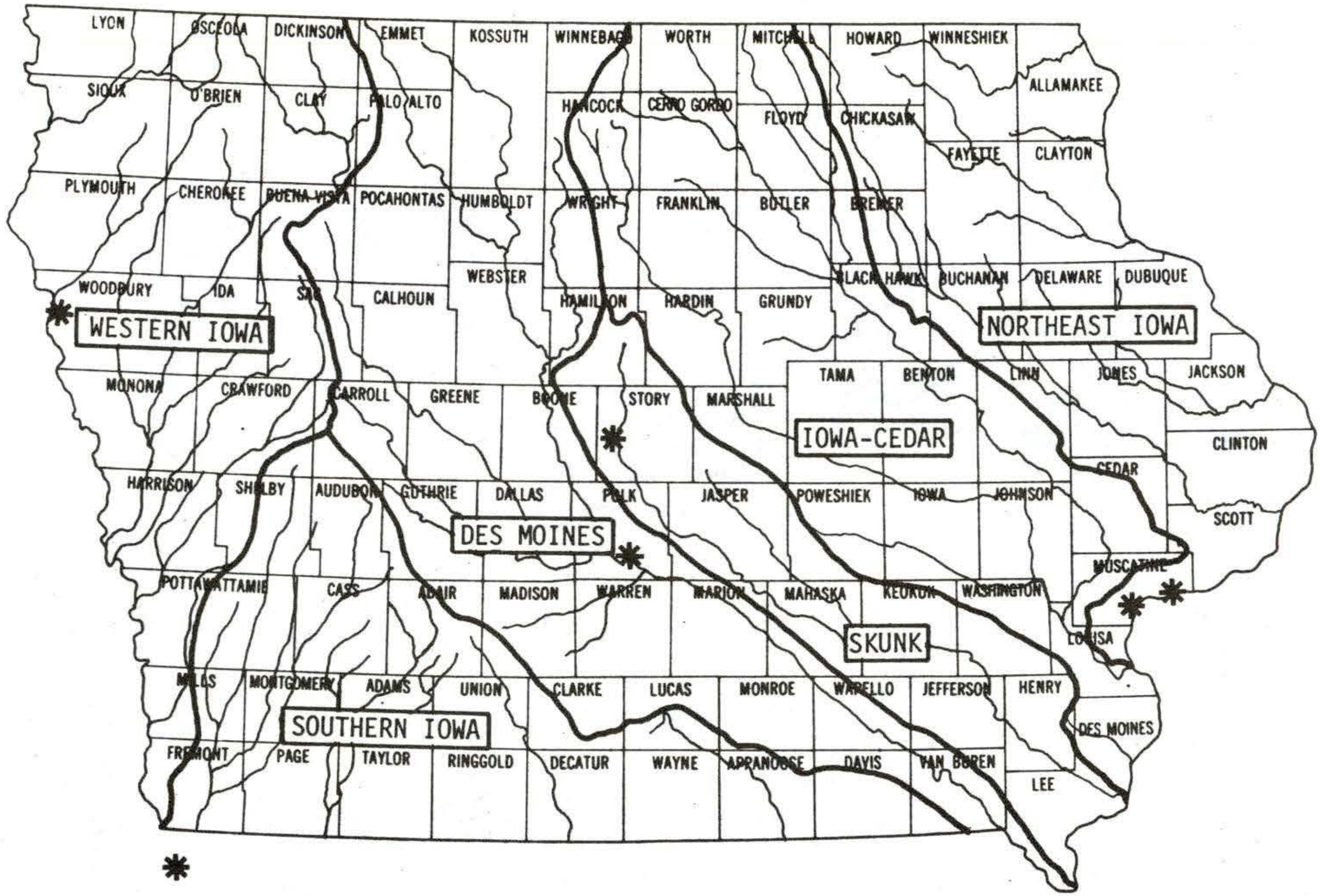

Figure F.1. Six major Iowa river basins

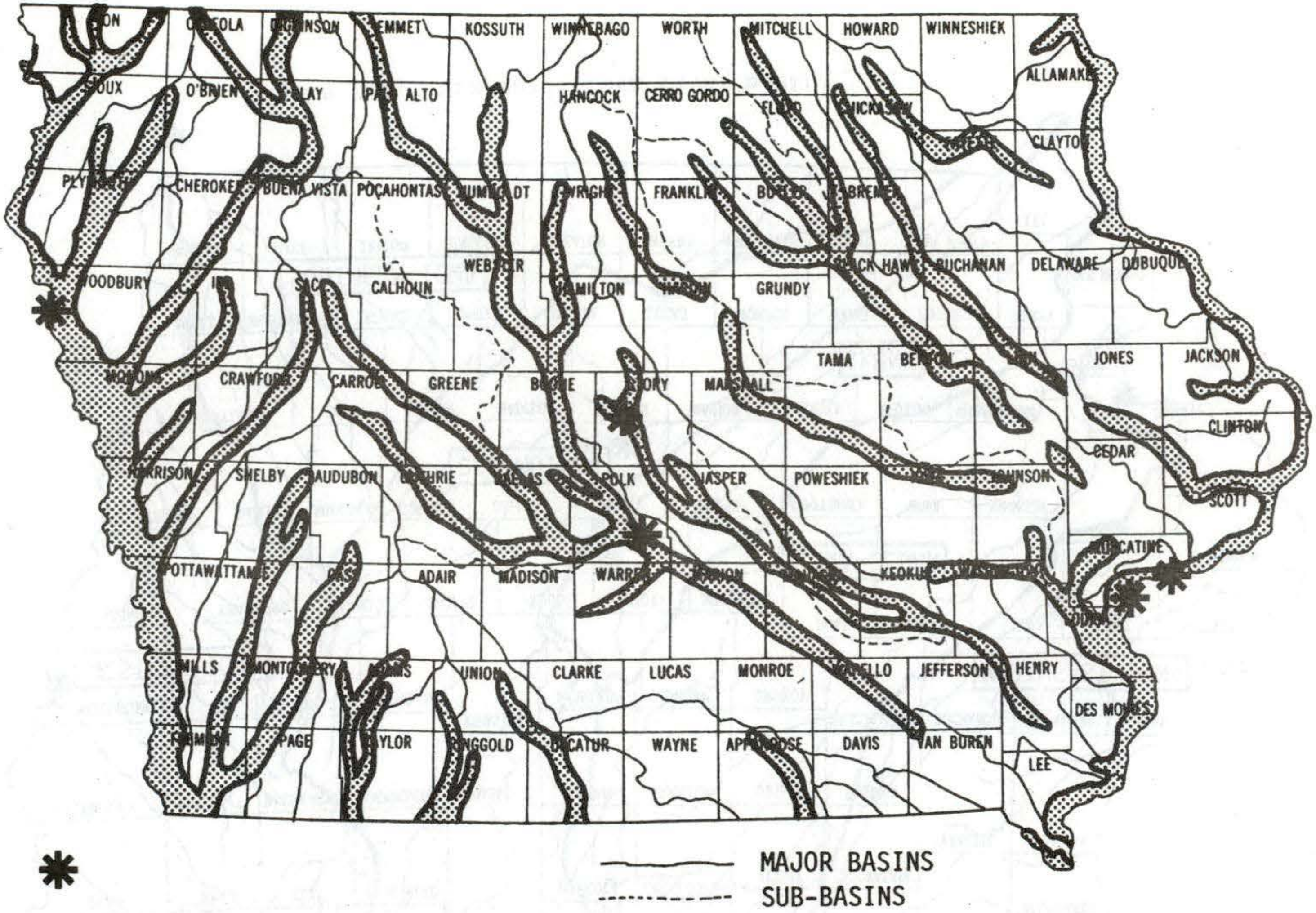

Figure F.2. Alluvial aquifers of Iowa

additional possibility for solving the conflict between growing power plant cooling needs and water resource conservation. The alternative is greater use of dry cooling towers.

An idealized plan view of a biomass production evaporative cooling marsh was presented in Figure C.2 for the Iowa Public Service Neal Station 1, 2, and 3 at Port Neal, Iowa. The important hydrogeologic considerations can be explained in Figures F.3 and F.4. Recall from Figure F.2 that the power plant is located on a flood plain and that the deposits underlying the plant are alluvial. The upper material described in Figure F.3 is alluvial and acts as a surficial ground water aquifer. The high permeability of the alluvial material will readily transmit water from the surface into the ground water flow already present within the system. The marsh could therefore easily contaminate the ground water system beneath it.

The potential for contamination can be seen in Figure F.4 which presents a generalized view of the cross-section A-A from Figure C.2. If the marsh is to be used solely for biomass production and evaporative cooling of power plant waste heat, then no problems of contamination would be expected. However, if greater utilization of the marsh and warm water is attempted, such as sewage effluent treatment, then some consideration would need to be given toward prevention of ground water pollution. This would be especially important if sewage effluent was to be introduced into the marsh to clean the effluent water to a recyclable state.

Because the sewage generally contains toxic heavy metals and inorganic chemicals, great care would need to be taken to prevent these from

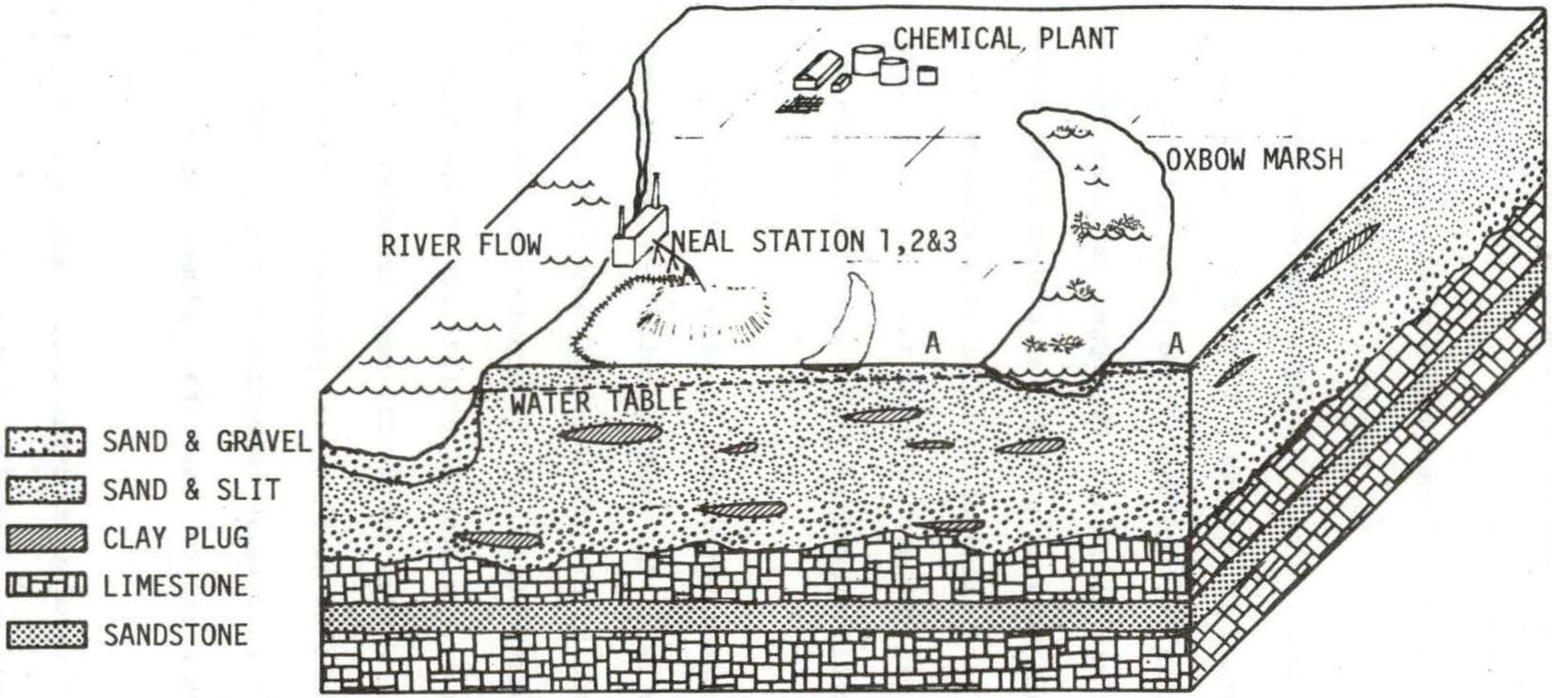

Figure F.3. Generalized geologic section, Port Neal, Iowa

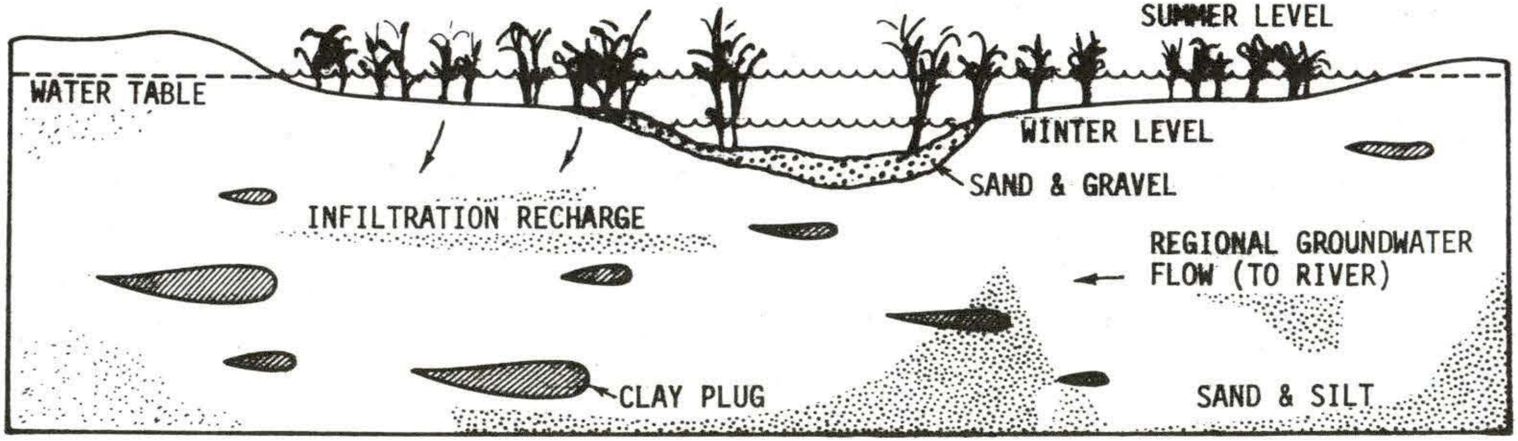

Figure F.4. Generalized section A-A, biomass production evaporative cooling marsh entering the ground water system by infiltration from the marsh. This could be prevented with the conventional engineering techniques presently used at treatment facilities, such as using a plastic liner at the base of the marsh to prevent infiltration. If the warm water marsh was to be used to clean waste water from an intensive fish raising complex or waste from a feedlot operation, a liner would probably not be necessary, since the organics would tend to be filtered out during the infiltration process. Therefore, the liner would be necessary only if toxic materials were introduced into the marsh with the sewage effluent.

Iowa Ground Water Resources

Iowa's ground water reservoir systems are summarized in Table F.1 and Figures F.5 and F.6, adapted from Horick (1970). A Precambrian cystalline complex makes up the basement which reaches a depth of 5200 feet in the southwest part of the state and outcrops at the surface in the extreme northwestern and to within 800 feet of the surface in the northeastern corner of the state. The system is composed of Paleozoic age consolidated sedimentary strata. The strata are dominated in the lower level by sandstones and dolomites and in the upper level by shales, dolomites, and limestones. Downwarping of the strata (Figure F.6) has allowed erosion to expose some older units and thus form extensive recharge zones in northeast Iowa and southern Minnesota.

From Table F.1 and Figure F.6, the principal aquifers (highly productive) can be divided into one category consisting of alluvial and shallow carbonate rock aquifers (in hydrologic connection with principal streams) and a second category, deep artesian aquifers with distant

Table F.1. Geologic and hydrogeologic units in Iowa[a]

AGE		ROCK UNIT	DESCRIPTION	HYDROGEOLOGIC UNIT	WATER-BEARING CHARACTERISTICS
Cenozoic	Quaternary	Alluvium	Sand, gravel, silt and clay	Surficial aquifer	Fair to large yields
		Glacial drift (undifferentiated)	Predominantly till containing scattered irregular bodies of sand and gravel		Low yields
		Buried channel deposits	Sand, gravel, silt and clay		Small to large yields
Mesozoic	Cretaceous	Carlile Formation Graneros Formation	Shale	Aquiclude	Does not yield water
		Dakota Group	Sandstone and shale	Dakota aquifer	High to fair yields
Paleozoic	Pennsylvanian	Virgil Series Missouri Series	Shale and limestone	Aquiclude	Low yields only from limestone and sandstone
		Des Moines Series	Shale; sandstones, mostly thin		
	Mississippian	Meramec Series	Limestone, sandy	Mississippian aquifer	Fair to low yields
		Osage Series	Limestone and dolomite, cherty		
		Kinderhook Series	Limestone, oolitic, and dolomite, cherty		
	Devonian	Maple Mill Shale Sheffield Formation Lime Creek Formation	Shale; limestone in lower part	Devonian aquiclude	Does not yield water
		Cedar Valley Limestone Wapsipinicon Formation	Limestone and dolomite; contains evaporites in southern half of Iowa	Silurian-Devonian aquifer	High to fair yields
	Silurian	Niagaran Series Alexandrian Series	Dolomite, locally cherty		
	Ordovician	Maquoketa Formation	Shale and dolomite	Maquoketa aquiclude	Does not yield water, except locally in northwest Iowa
		Galena Formation	Limestone and dolomite	Minor aquifer	Low yields
		Decorah Formation Platteville Formation	Limestone and thin shales, includes sandstone in SE Iowa	Aquiclude	Generally does not yield water; fair yields locally in southeast Iowa
		St Peter Sandstone	Sandstone	Cambrian-Ordovician aquifer	Fair yields
		Prairie du Chien Formation	Dolomite, sandy and cherty		High yields
	Cambrian	Jordan Sandstone	Sandstone		
		St Lawrence Formation	Dolomite	Aquiclude (wedges out in northwest Iowa)	Does not yield water
		Franconia Sandstone	Sandstone and shale		
		Dresbach Group	Sandstone	Dresbach aquifer	High to low yields
Precambrian		Sioux Quartzite	Quartzite	Base of ground-water reservoir	Not known to yield water except at Manson cryptovolcanic area
		Undifferentiated	Coarse sandstones; crystalline rocks		

[a]Source: Horick (1970).

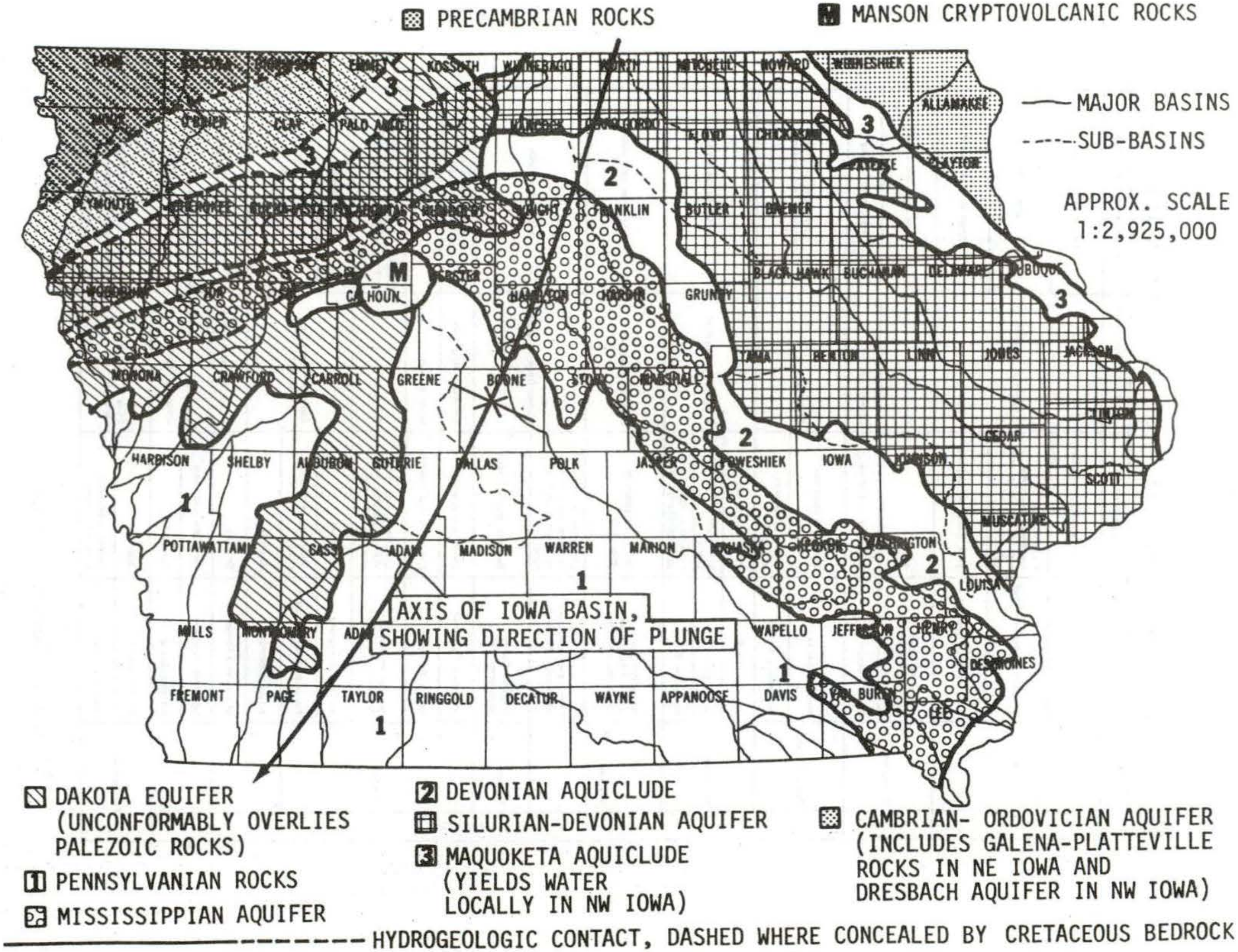

Figure F.5. Hydrogeologic map of Iowa

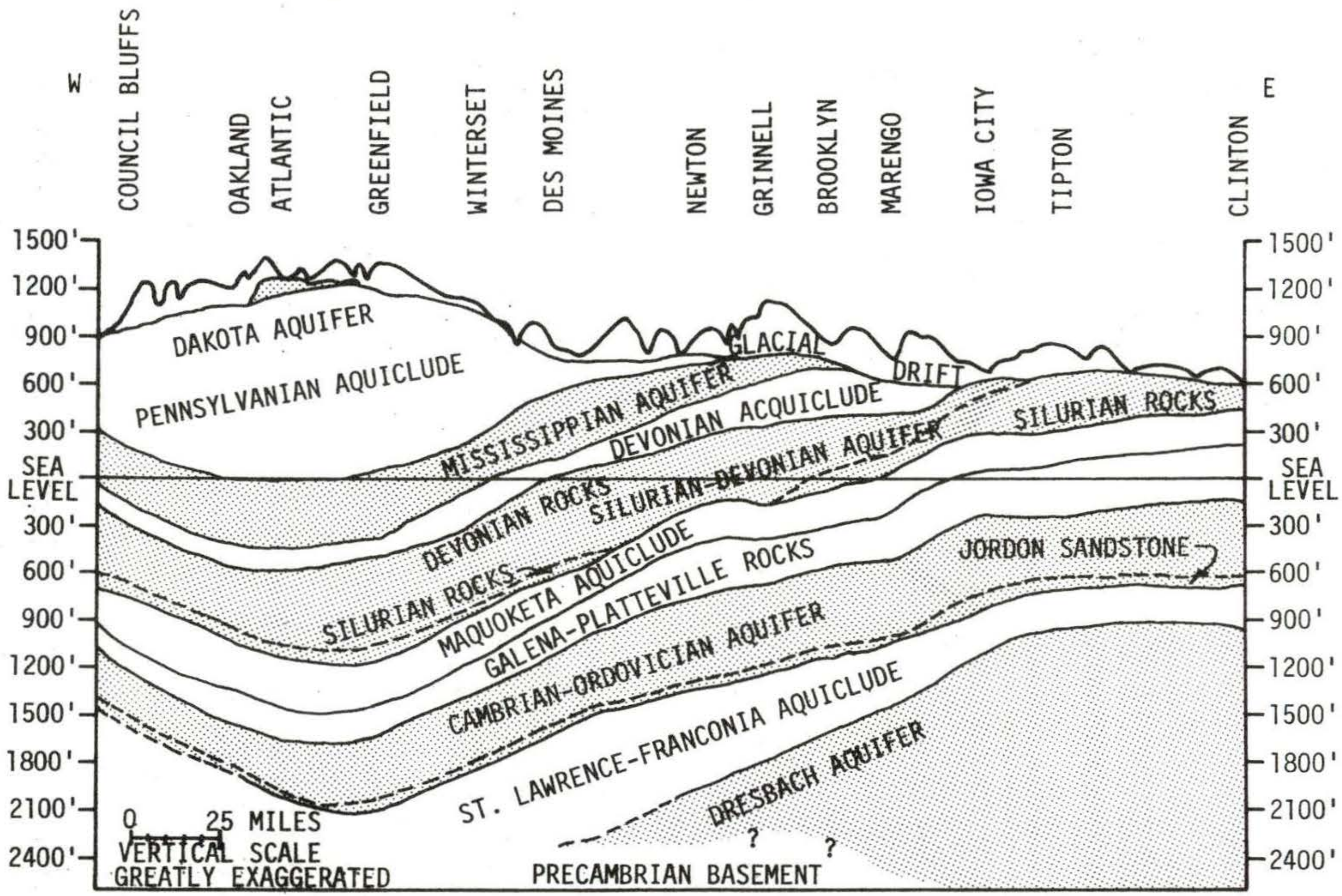

Figure F.6. Generalized hydrogeologic section of Iowa recharge zones. (The deep aquifers may carry water from recharge zones hundreds of miles from the point of discharge.) It should also be noted that the water velocity in these aquifers is extremely small; however, the large storage volume available allows large withdrawals with little impact on depletion of supply. It can also be noted that the use of the deep aquifer sources is less desirable due to the expense of pumping from the greater depth.

In addition to the deep aquifers, there are a great number of interstratified aquicludes (vertical movement of water restarted by impermeable units). Therefore, the aquifer in any location of the state will be dependent on the local geology and can differ substantially over short distances (see Figure F.4).

Iowa's surficial aquifers can be seen in Figure F.2 and are composed of fluvio-glacial outwash deposits and fluvial deposits of Quarternary age, commonly called alluvial deposits. Alluvial deposits are generally found along present watercourses, and also as buried stream channels and as discontinuous sand bodies in glacial drift. Alluvial deposits are considered to be very important sources of (moderate to large) water supplies; however, their occurrence is restricted to pre-glacial drainage patterns. The alluvial reservoirs have large storage capacities and are generally recharged at frequent intervals with recharge occurring from local precipitation and infiltration from streams and rivers.

The principal water-yielding bedrock aquifers in Iowa are described by Horick (1970) and will not be presented here. The physiographic features of the state following glacial activity and periods of erosion are presented in Figure F.7. The bedrock was modified by the advance and retreat of four great glaciers, the Nebraskan Kansan, Illinoin, and Wisconsin. Subsequent erosion in recent geologic time has determined the present surface features of Iowa's six major river basins. (The dashed line in Figure F.7 indicates the outline of the Skunk River basin.)

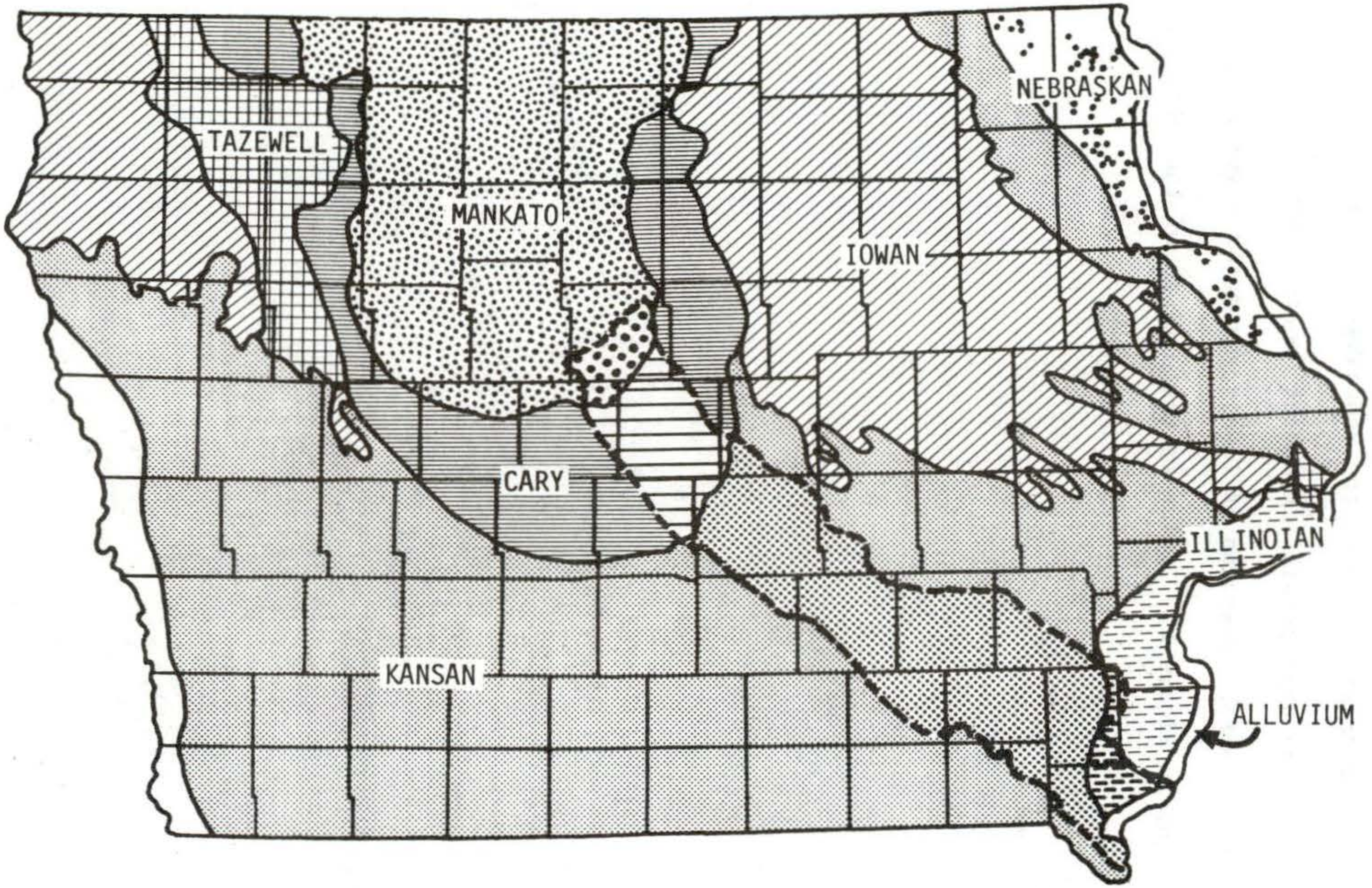

Figure F.7. Glacial geology of Iowa

APPENDIX G. POWER PLANT AND EQUIPMENT DATA

General

Information describing equipment performance is provided in the following figures. For the ISU unit number 5 this includes Figures G.1 through G.6 and Tables G.1 and G.2, and for the Ames unit number 7, Figures G.7 through G.11 and Tables G.3 and G.4. Additional information for other power plants included in the survey is reported in Roberts and Bahr (1978).

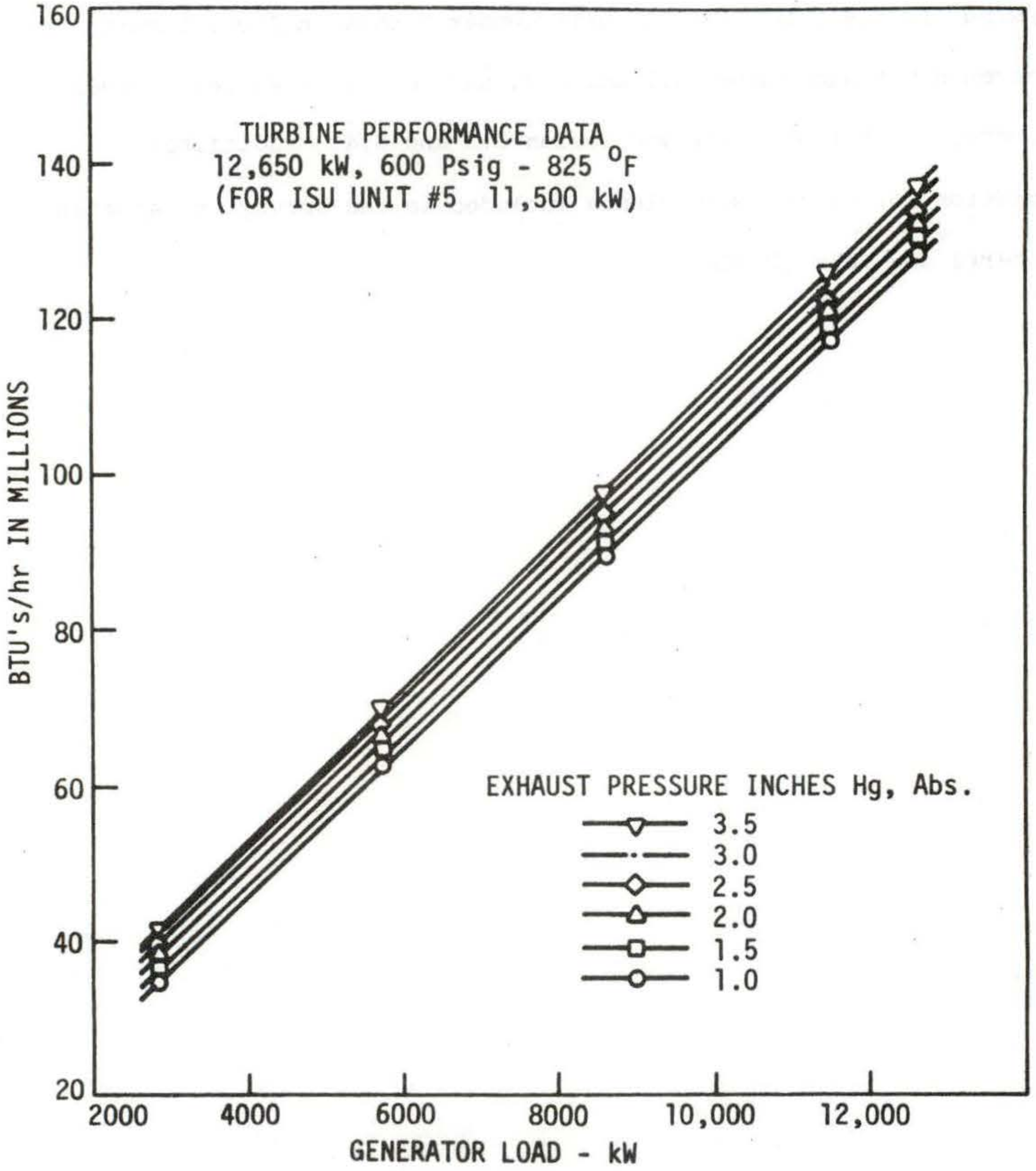

Figure G.1. Turbine performance curve, Btu/hr vs generator load for ISU unit number 5

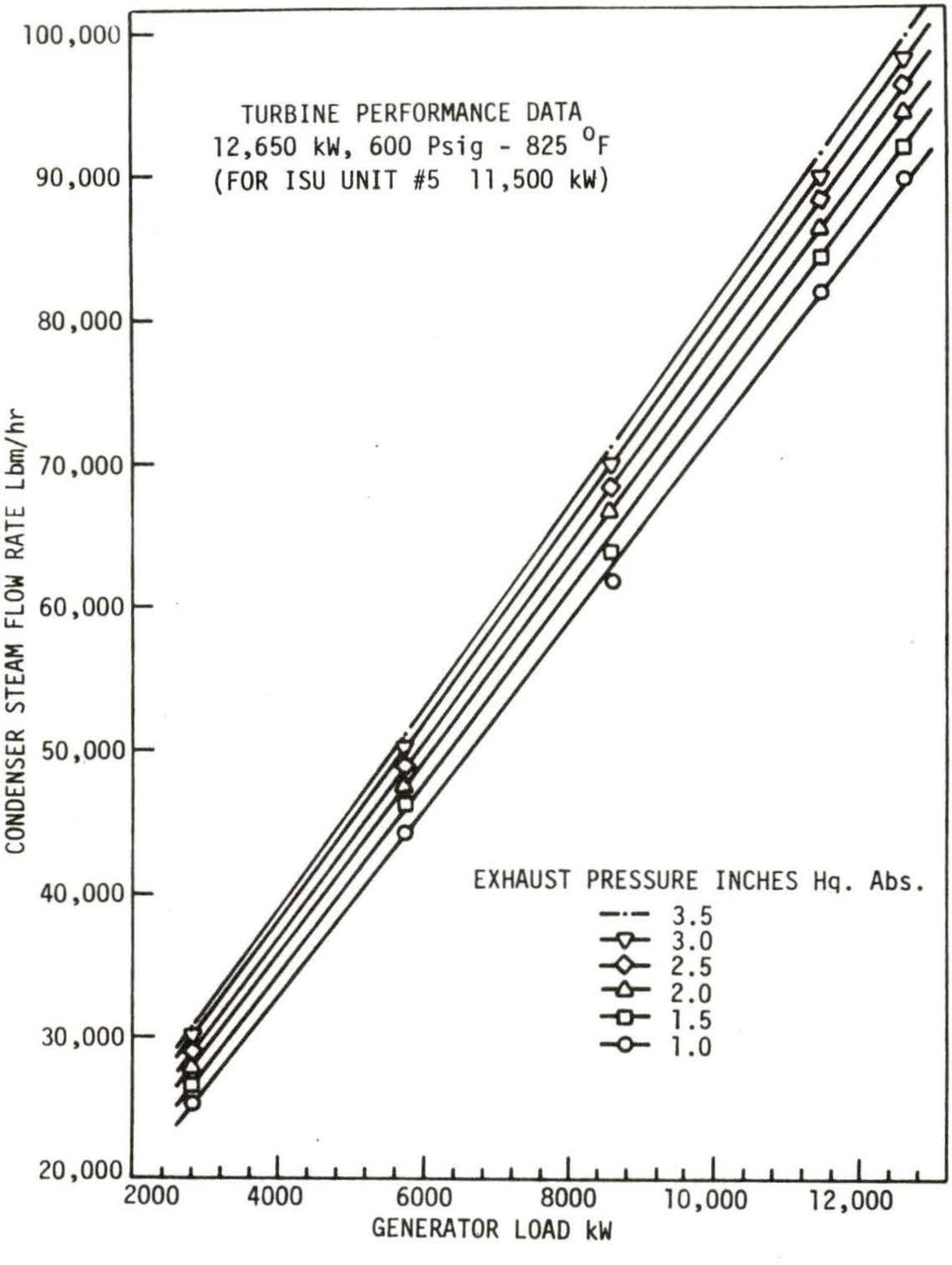

Figure G.2. Turbine performance curve, condenser steam flow vs generator load for ISU unit number 5

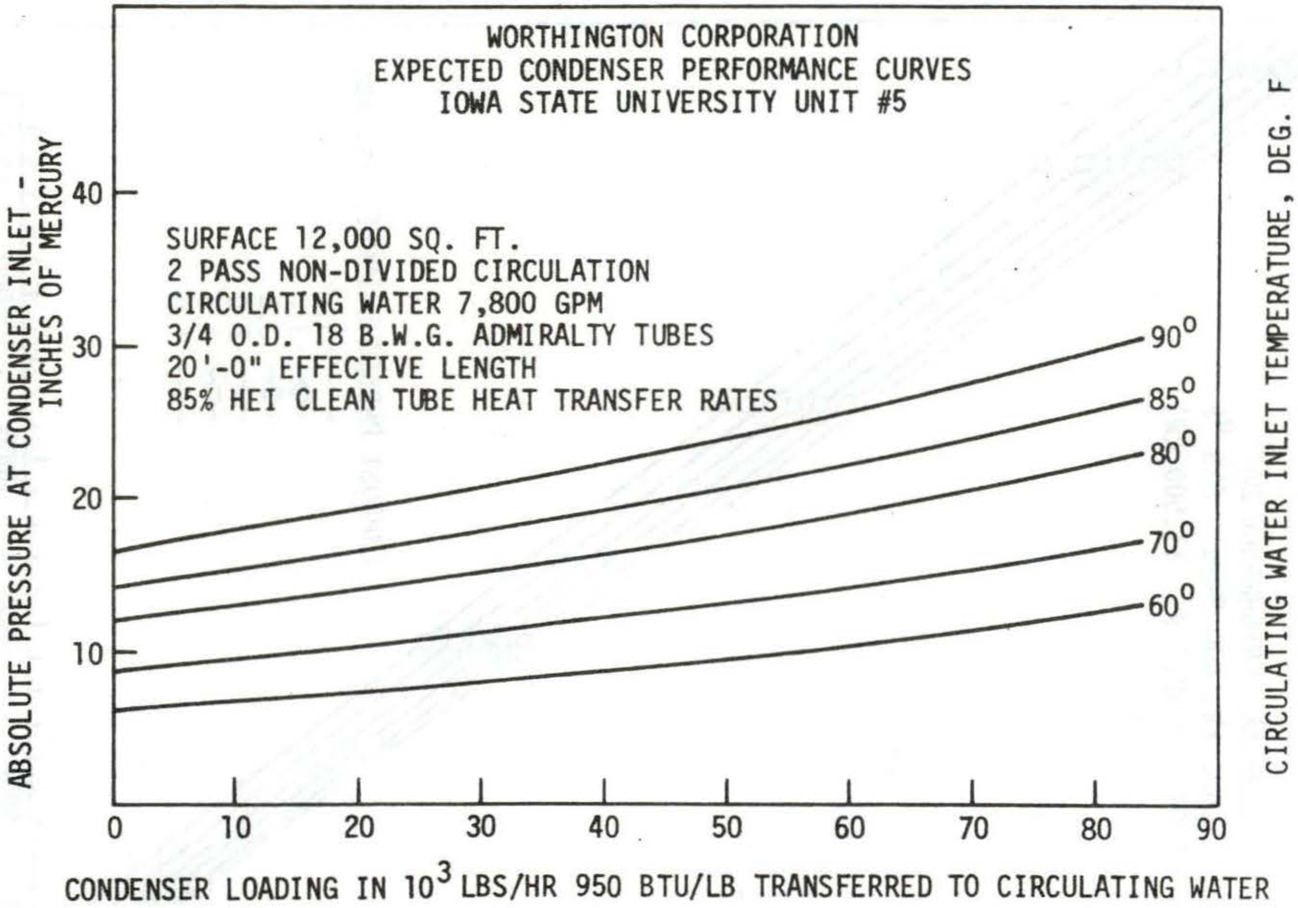

Figure G.3. Condenser performance curve winter condition, condenser pressure vs condenser loading for ISU unit number 5

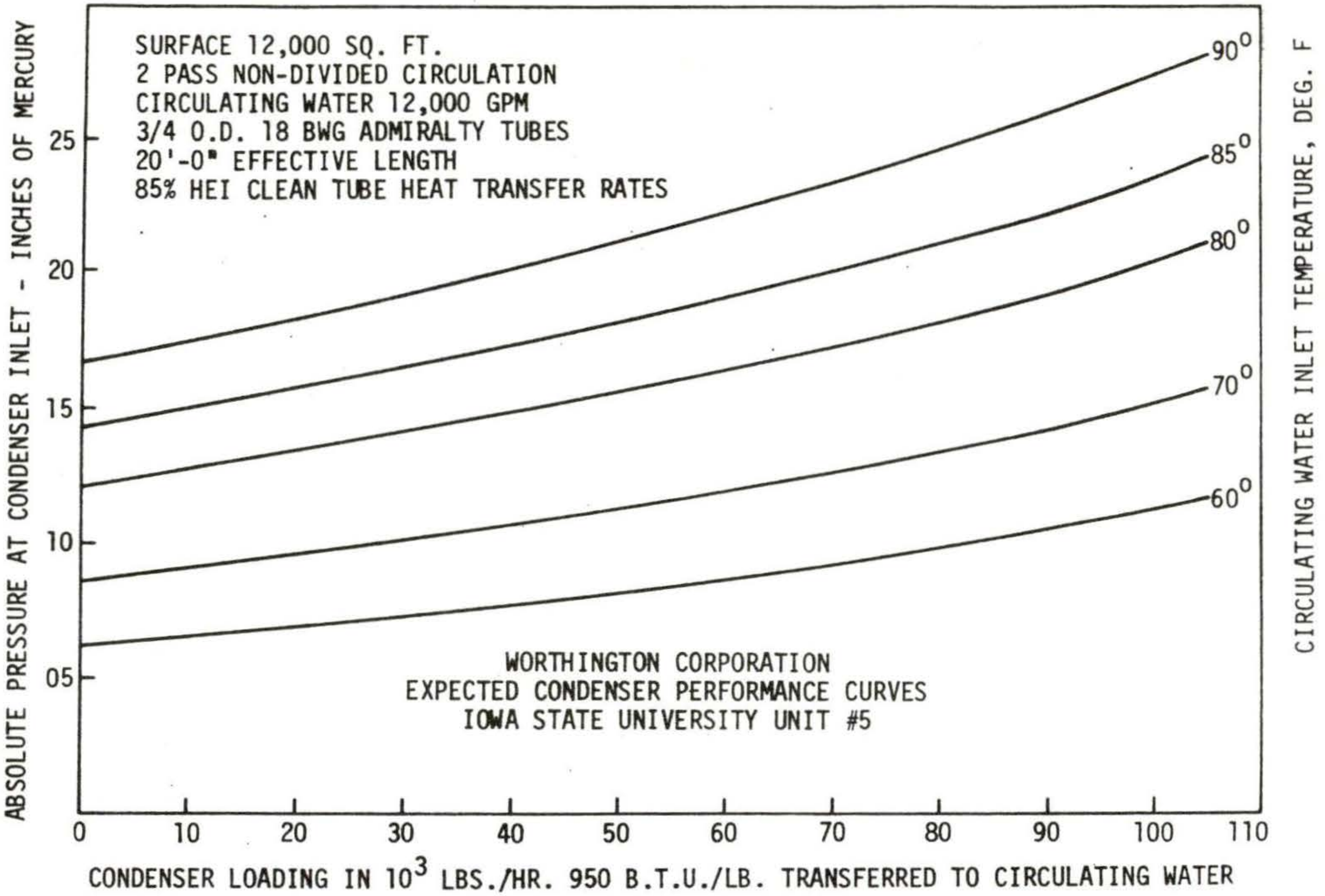

Figure G.4. Condenser performance curve summer condition, condenser pressure vs condenser loading for ISU unit number 5

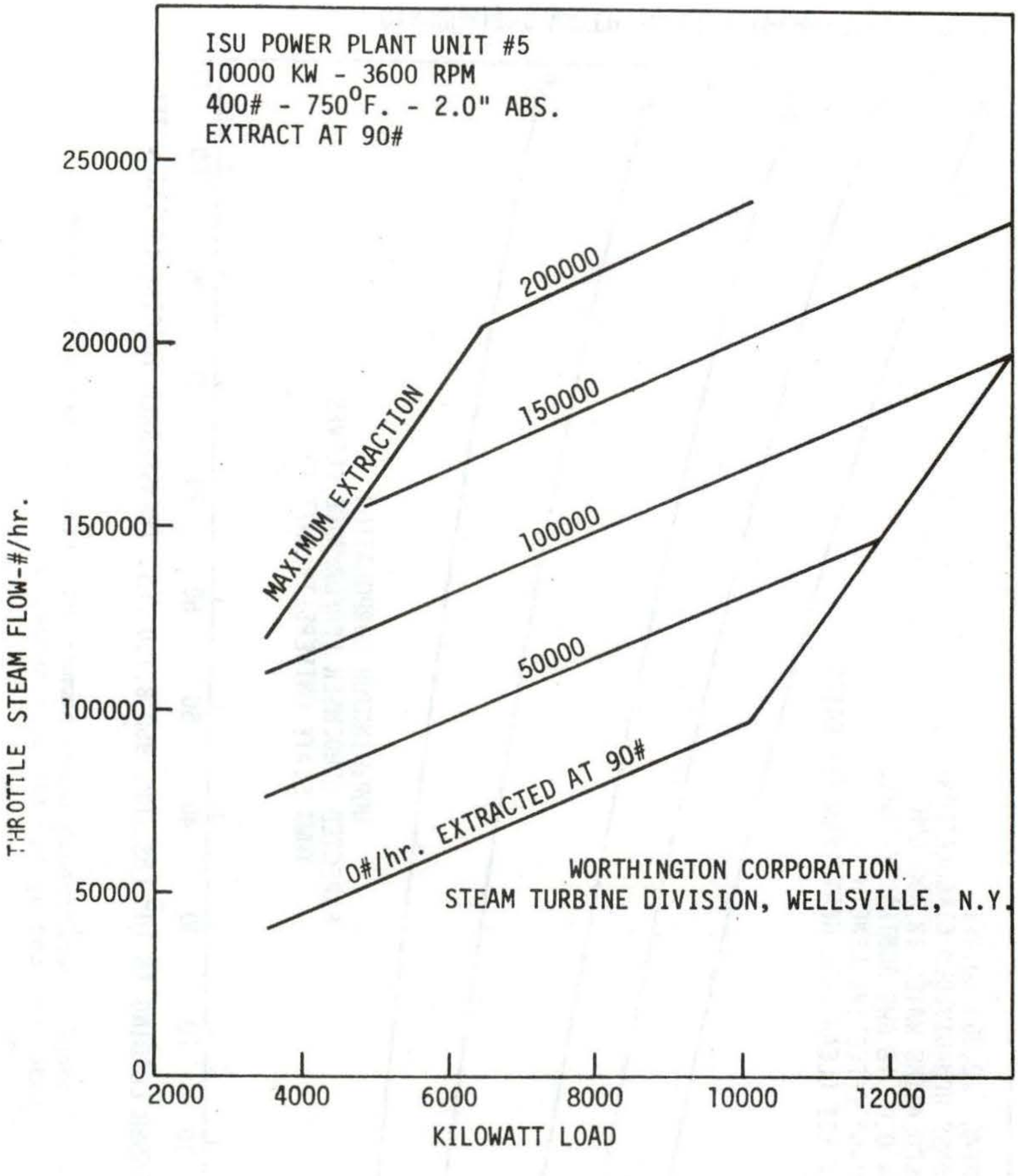

Figure G.5. Throttle steam flow vs kilowatt load for extraction at 90 psiq for ISU unit number 5

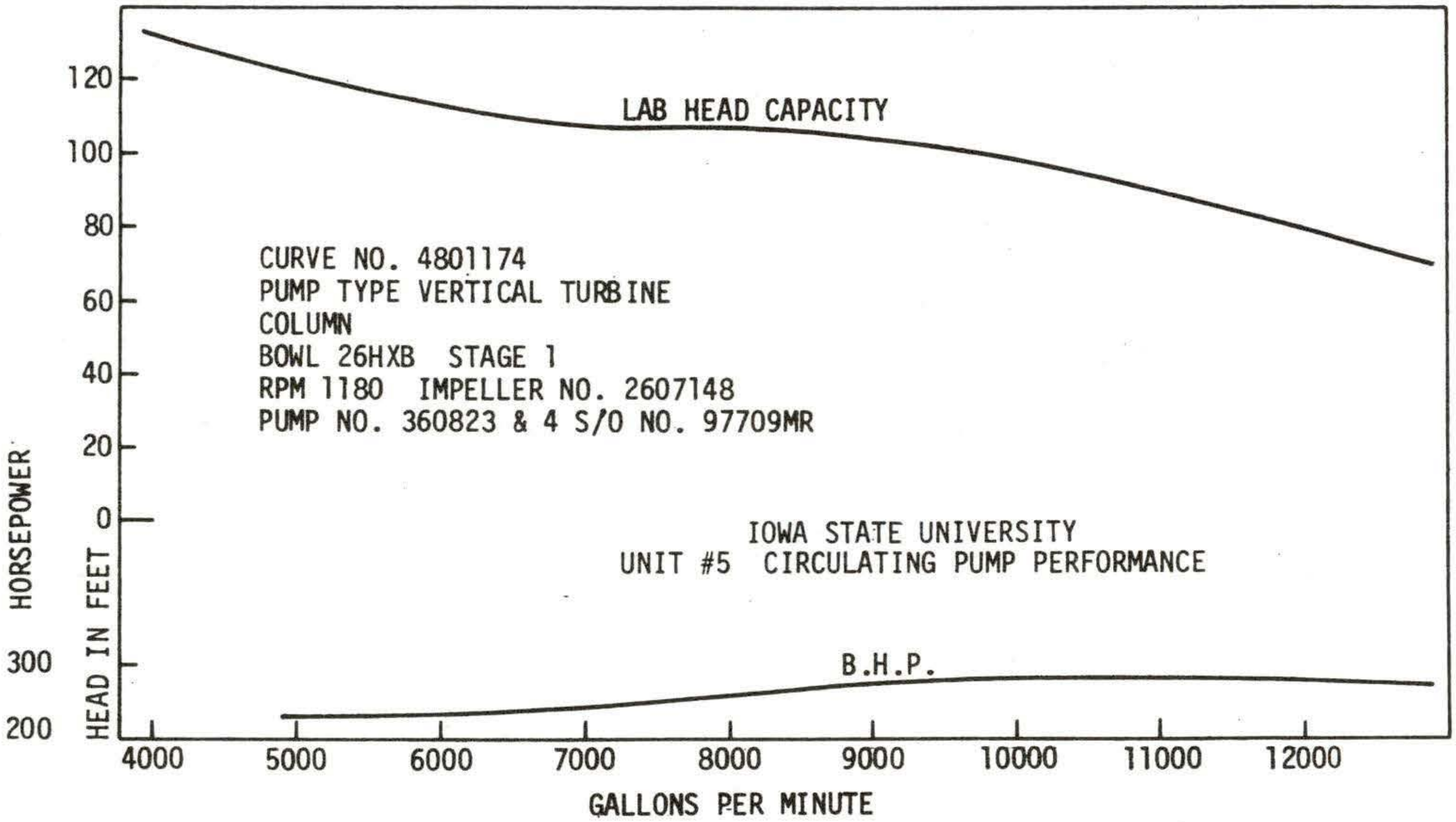

Figure G.6. Circulating pump performance curve, heat, and horsepower vs gallons per minute for ISU unit number 5

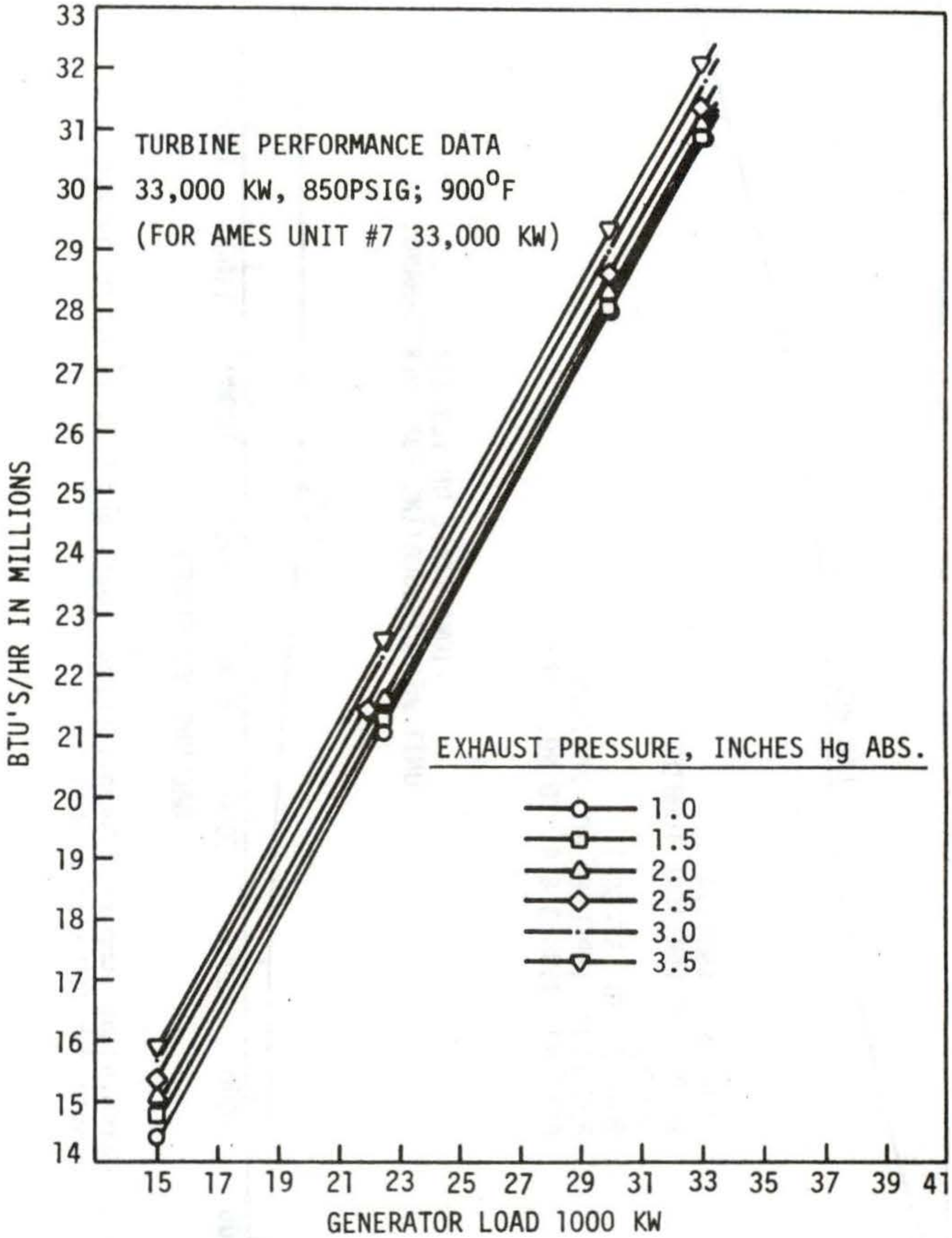

Figure G.7. Turbine performance curve, Btu/hr vs generator load for Ames unit number 7

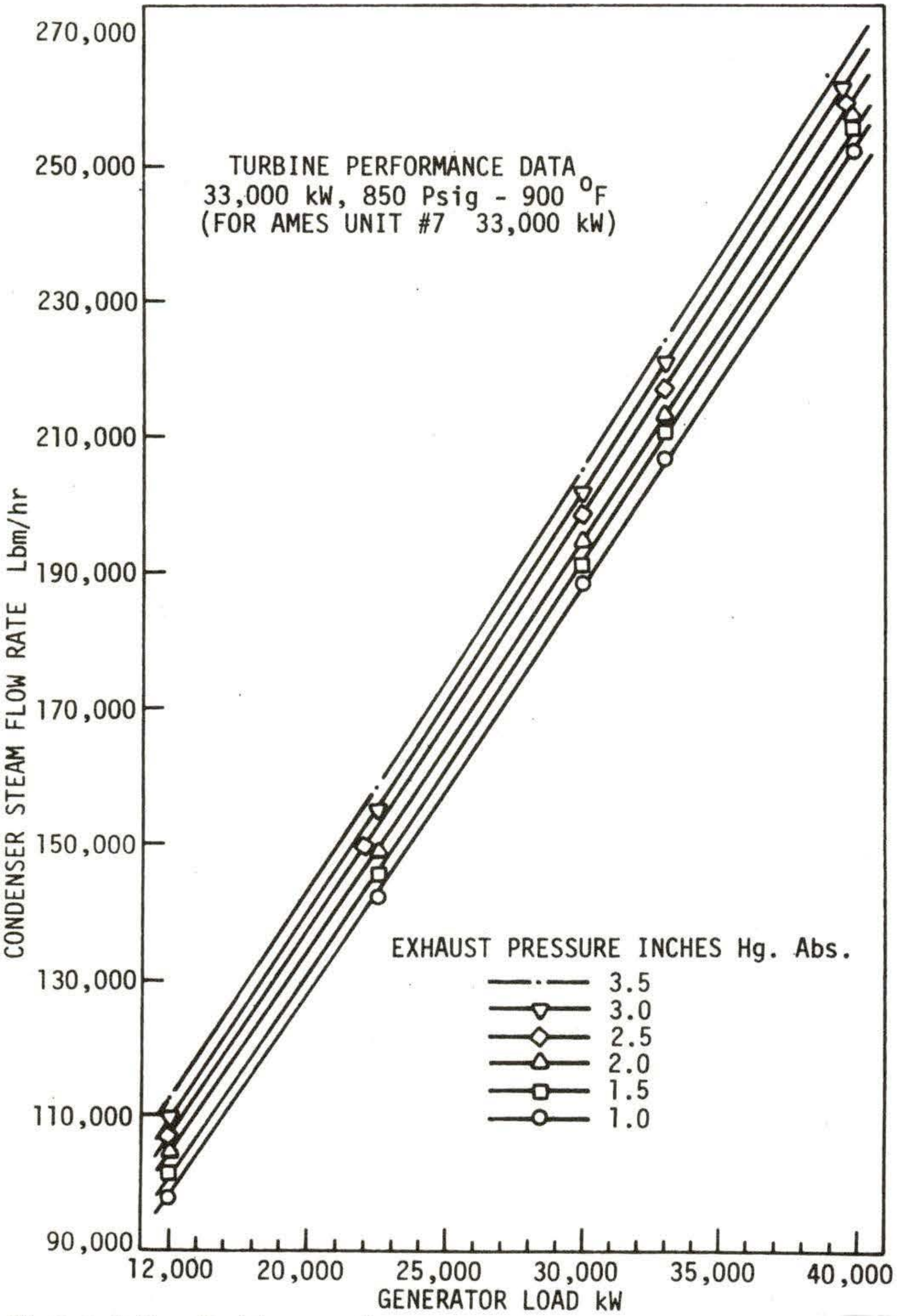

Figure G.8. Turbine performance curve, condenser steam flow vs generator load for Ames unit number 7

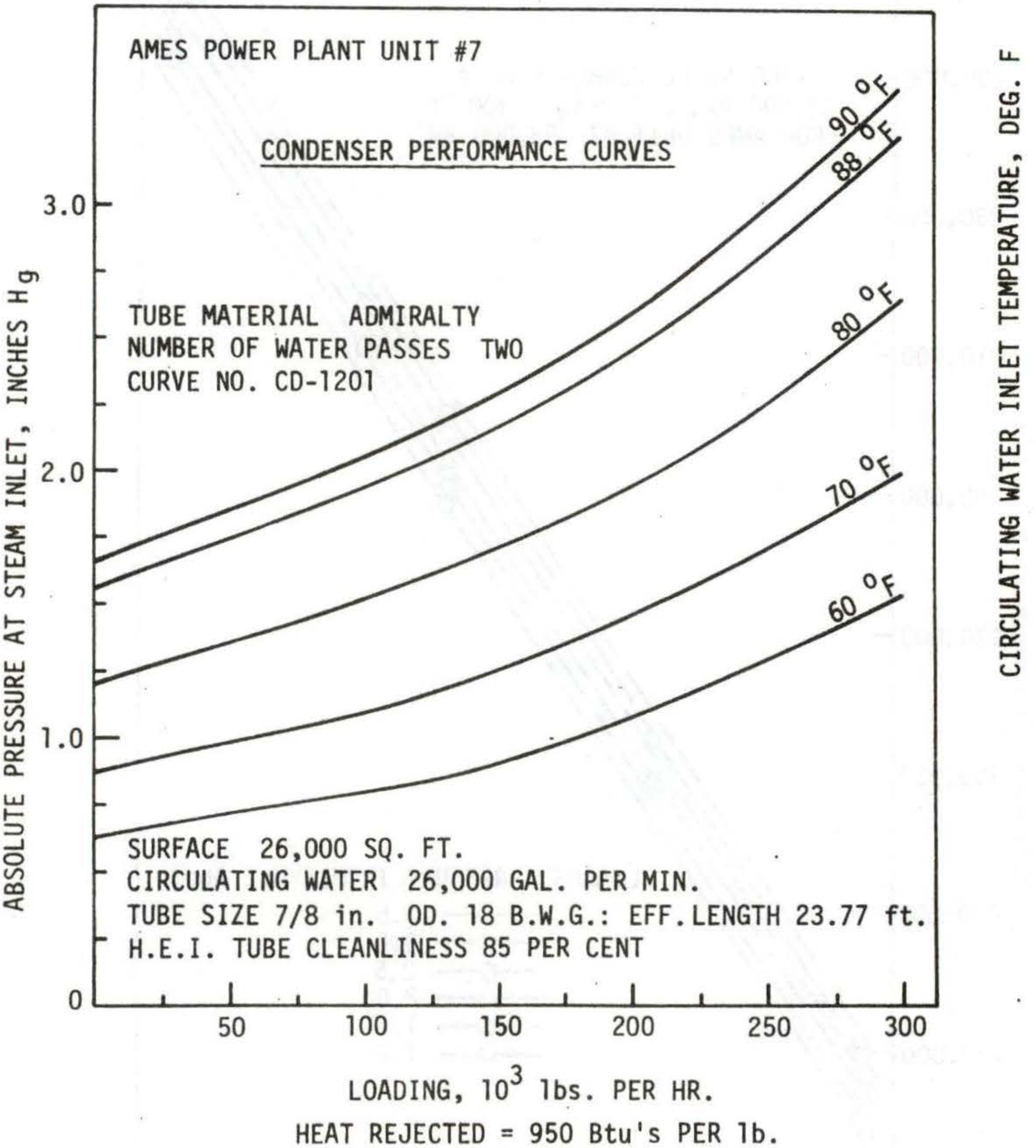

Figure G.9. Condenser performance curve winter condition, condenser pressure vs condenser loading for Ames unit number 7

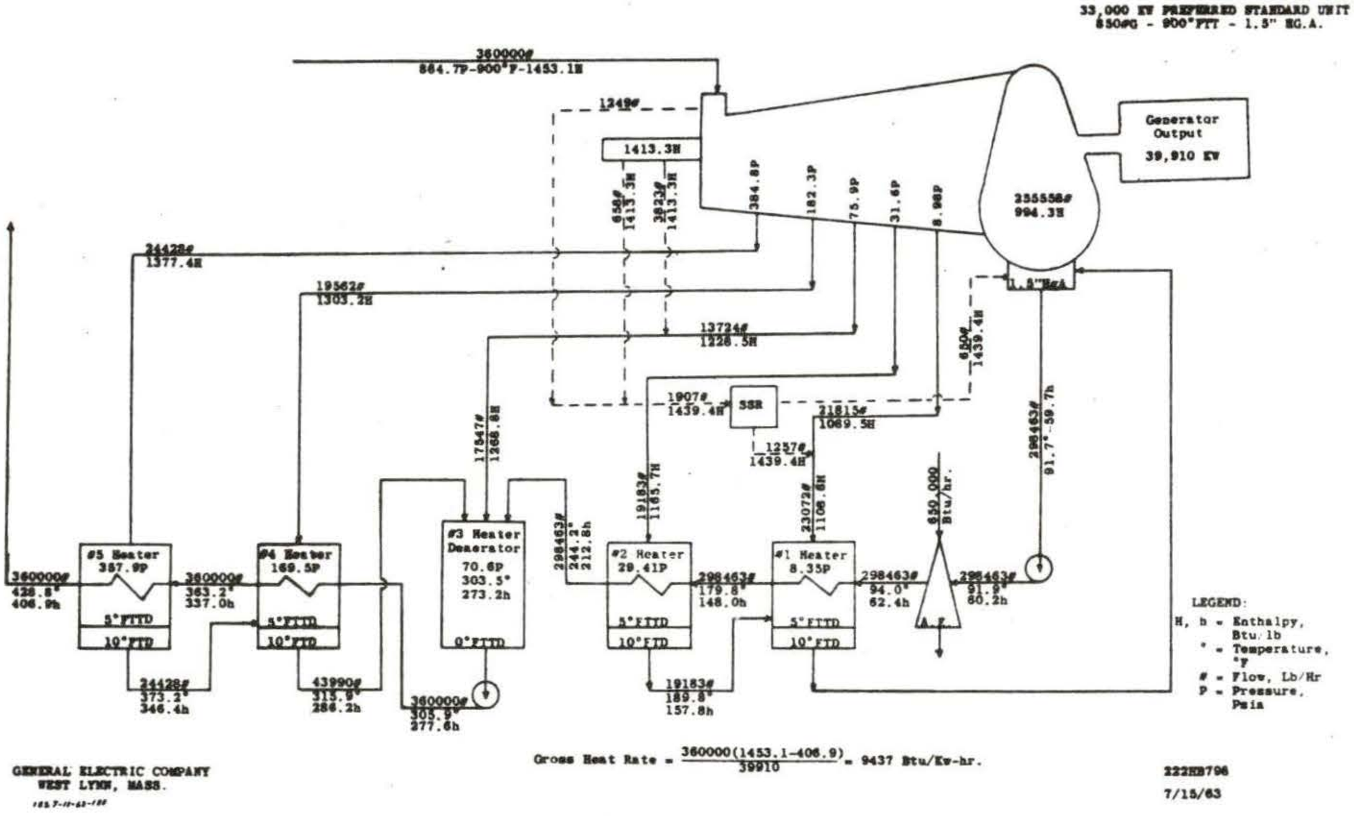

Figure G.10. Heat balance diagram for Ames unit number 7

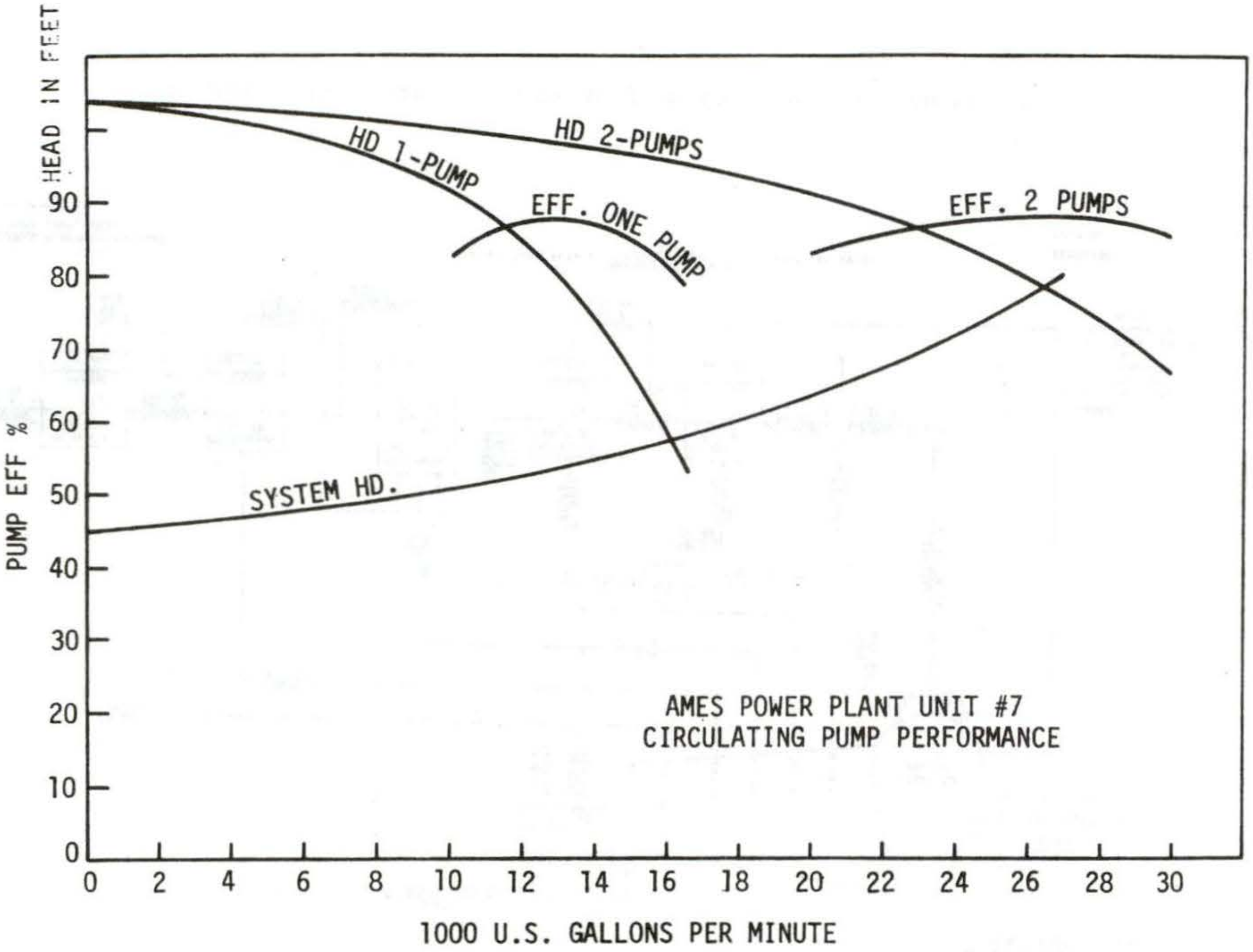

Figure G.11. Circulating pump performance curve, head, and efficiency vs gallons per minute for Ames unit number 7

Table G.1. Turbine description, ISU power plant unit number 5

Worthington Corp., Steam Turbine Div. (name change to Turbodyne Corp.)

11,500 Kw condensing automatic extraction

Wellsville Works order number U-15705

Turbine generator unit number 27212

Turbine frame T4BV1X5Y3

Number of stages: 1 Curtis, 13 Rateau

Turbine rating: 11 500 Kw at 3600 rpm

Inlet steam condition: 400 Psig at 750° FTT (Turbine throttle)

Exhaust condition: 2 in. Hg abs.

Controlled extraction condition: 200,000 lb/hr at 90 Psig at 10,000 Kw

Uncontrolled extraction condition: 15 000 lb/hr at 6 Psig

Low vacuum alarm switch sound at 15 in. Hg vacuum

Low vacuum switch shut turbine down at 10 in. Hg vacuum

Number of steam inlet valves: 7 automatic venturi

Number of extraction valves: 4 automatic venturi; 90 Psig (Note: 90 Psig steam is only taken from one valve)

Number of uncontrolled extraction openings: 1 (5th stage)...6 Psig (Note: 6 Psig steam is not taken from this unit)

Rupture discs set to provide relief at 10 Psig exhaust pressure

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Table G.2. Condenser description, ISU power plant unit number 5

Worthington surface condenser

12,000 ft^2 (1115 m^2) effective tube surface (includes air cooling sections)

Horizontal tube type with two internal air cooling sections

Two Pass, nondivided waterboxes

Folded tube layer design

3057 tubes, 20 ft exposed length

O.D. 3/4 in., No. 18 B.W.G.

Tubes: admiralty metal

Water source, cooling towers

Steam condensed (at 950 Btu/Lbm)...75,000 Lbm/hr

Duty (net heat transferred to circ. water)...71 250,000 Btu/hr

Circulating water quantity: 12,000 gpm

Circulating water inlet temperature: 85°F (29°C)

Cleanliness factor: 85%

Water velocity through tubes: 7.56 ft/sec (2.30 m/sec)

Absolute pressure steam inlet to condenser: 2.05 in. Hg (5.2 cm Hg)

Condensate temperature depression (no subcooling): 0°F (-18°C)

Condenser friction head drop: 17.5 ft (39.2 cm Hg)

Table G.3. Condenser data Ames power plant unit number 7 (33 MW)

Rectangular type-direct flow surface condenser	
Surface area	26,000 ft^2
Number of passes	2
Tube material	Admiralty
Tube size O.D.	7/8 inch
Effective tube length	23 feet 9 1/4 inches
Number of tubes	4310 Admiralty
Guarantee Conditions based on exhaust enthalpy of 950 Btu/Lbm	
a) loading	235.3 x 10^6 Btu/hr
b) exhaust steam pressure	2.93 inches Hg absolute
c) condensate temperature	114.1°F
d) inlet cooling water temperature	88°F
e) tube cleanliness factor	85%
f) circulating water rate	26,000 GPM
g) velocity in tubes	7.3 ft/sec
h) circulating water rise	19°F
i) heat transfer rate	649 Btu/hr ft^3 °F
j) friction loss	15.94 feet

Table G.4. Turbine data Ames power plant unit number 7 (33 MW)

G.E. nonreheat steam turbine	
Turbine rating	33,000 KW
Steam pressure	850 Psig
Steam temperature	900°FTT
Exhaust pressure	2.5 inches Hg absolute
Rated speed	3600 RPM
Refer to Heat Balance diagram, Figure G.10	

APPENDIX H. AMES CLIMATOLOGICAL DATA

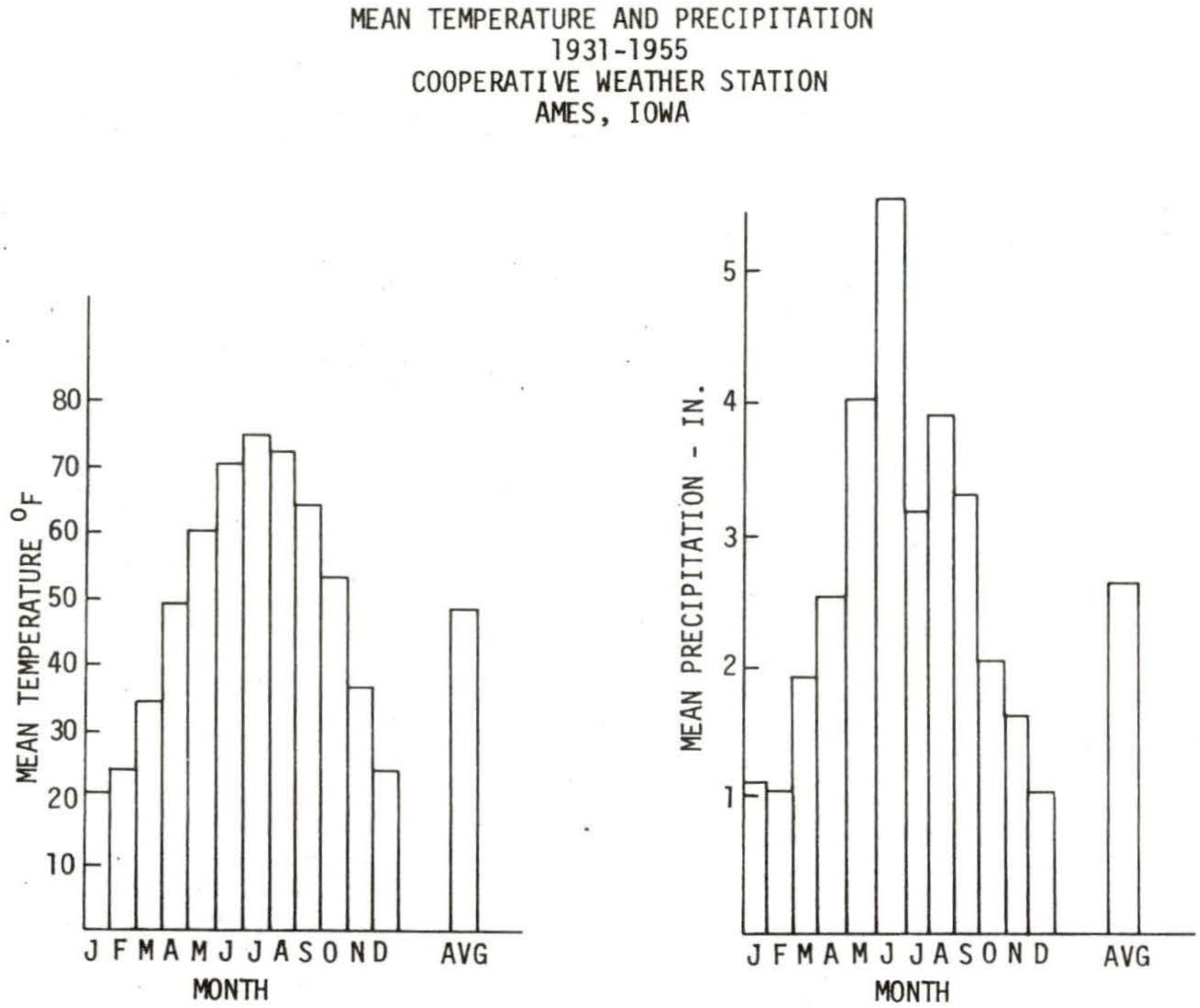
General

Table H.1 and Figures H.1 through H.5 provide a brief description of accumulated weather data for the Ames, Iowa area. A discussion of the figures is presented in Appendix A.

Table H.1. Ames climatological data[a]

1976					Soil Temperature								
	Outside Air Temperature °F			Degree Days	Depth 2.25 in.		4 in.		8 in.		40 in.	Precipitation in inches	
	Av Max	Av Min	Av		Av Max	Av Min	Av Max	Av Min	Av Max	Av Min	Av Max	Norm	Dev
Jan	33.6	10.1	21.9	1331	30.2	24	28.8	26.5	29.9	28.9	40.2	Trace	- .88
Feb	45.0	21.2	33.1	919	36.5	31.1	32.8	31.0	31.7	31.3	37.7	2.51	1.65
Mar	48.0	28.6	38.3	817	43.5	36.3	40.1	37.5	38.7	37.4	36.8	3.90	1.83
Apr	66.7	40.6	53.7	349	66.4	47.5	57.9	50.6	53.3	51.0	44.1	5.66	2.50
May	71.3	46.6	59.0	202	75.6	53.7	66.3	57.6	61.1	58.0	49.7	2.97	-1.52
Jun	82.2	56.2	69.2	9	89.4	65.9	79.7	70.1	73.9	70.2	57.3	5.72	- .03
Jul	86.5	62.9	74.7	0	95.3	74.5	86.3	77.6	80.4	77.5	63.2	1.1	-2.33
Aug	84.9	57.8	71.4	5	75.3	72.3	85.9	76.5	80.5	77.1	66.8	.25	-3.38
Sep	79.0	48.9	64.0	95	83.9	64.0	76.4	68.5	72.2	69.7	66.4	.34	-2.94
Oct	59.9	33.8	46.9	571	63.0	46.3	57.3	50.7	55.9	53.1	59.2	.91	-1.28
Nov	44.0	18.2	31.1	1009	43.3	33.5	41.7	37.2	41.5	39.7	50.1	.01	-1.13
Dec	32.2	6.4	19.3	1413	29.3	24.5	29.1	27.3	30.6	29.5	42.6	.22	- .73
1975													
Jan	28.7	11.7	20.2	1382	32.1	31.8	32.9	32.6	34.9	34.8		1.31	- .43
Feb	28.8	14.0	21.4	1217	29.9	29.6	30.8	30.5	33.8	33.6		.63	- .23
Mar	36.7	19.8	28.3	1131	33.6	31.7	32.1	31.6	33.0	33.0		2.0	- .07
Apr	54.3	34.5	44.4	61	50.5	41.7	45.9	41.8	42.7	41.2		4.23	1.07
May	76.8	51.2	64.0	108	75.9	58.9	69.6	61.2	63.8	61.1		3.72	- .77
Jun	80.3	59.1	69.7	23	80.0	66.5	74.6	67.6	69.8	67.6		8.04	2.27
Jul	(not available)												
Aug	(not available)												
Sep	71.8	47.5	59.7	206	77.1	60.5	71.4	64.6	67.8	65.4	64.4	1.45	-1.83
Oct	70.5	38.5	54.5	338	68.4	52.1	62.5	55.8	60.0	57.8	59.1	.55	-1.64
Nov	50.8	31.0	40.9	716	50.0	42.8	49.7	45.9	49.4	47.3	54.5	2.87	1.73
Dec	35.4	19.7	27.6	1153	34.4	30.1	34.1	32.4	35.8	34.9	45.7	1.03	.08

[a]Climatological Data National Oceanic and Atmospheric Administration.



MEAN TEMPERATURE AND PRECIPITATION
1931-1955
COOPERATIVE WEATHER STATION
AMES, IOWA

Figure H.1. Mean temperature and precipitation vs month

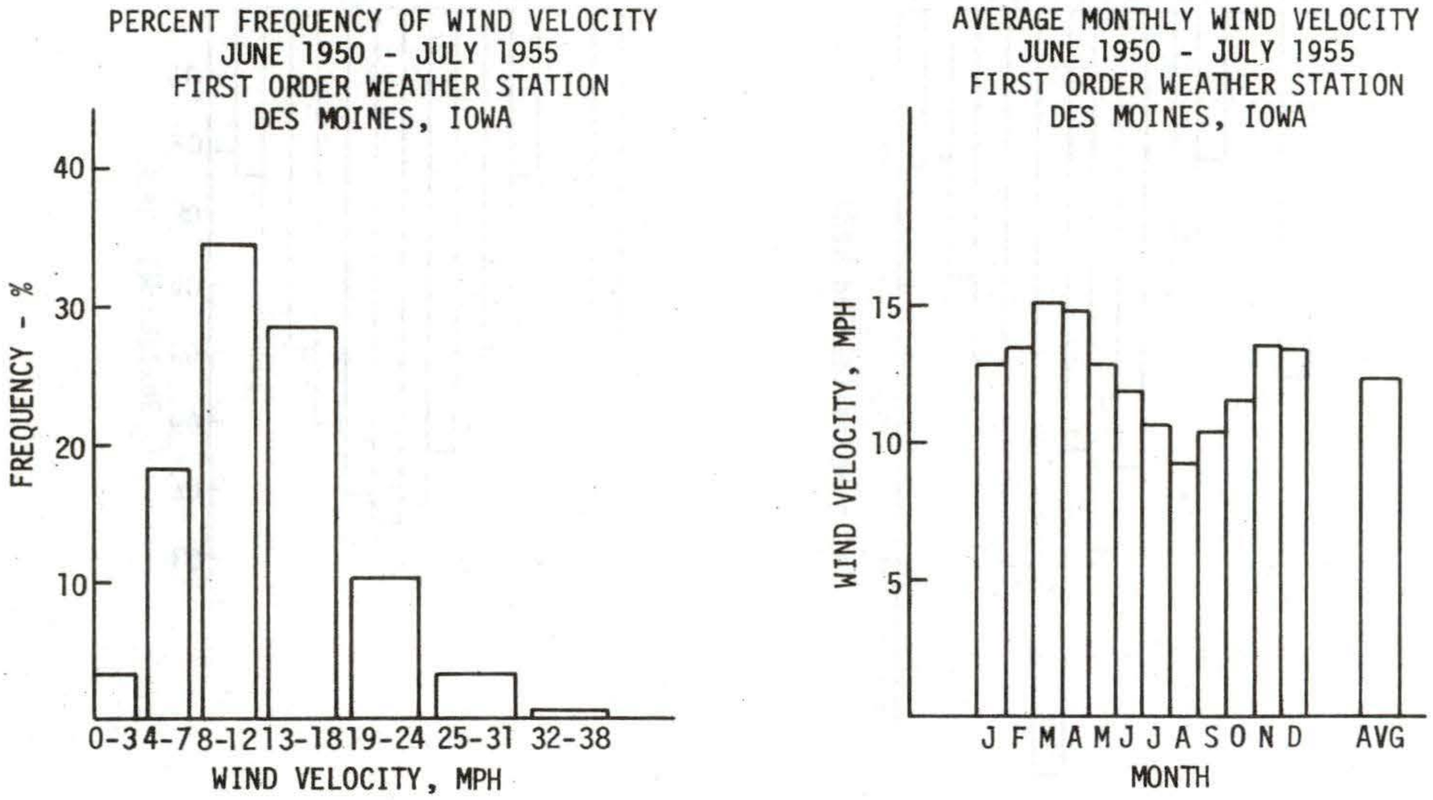


Figure H.2. Frequency of wind vs velocity and velocity vs month

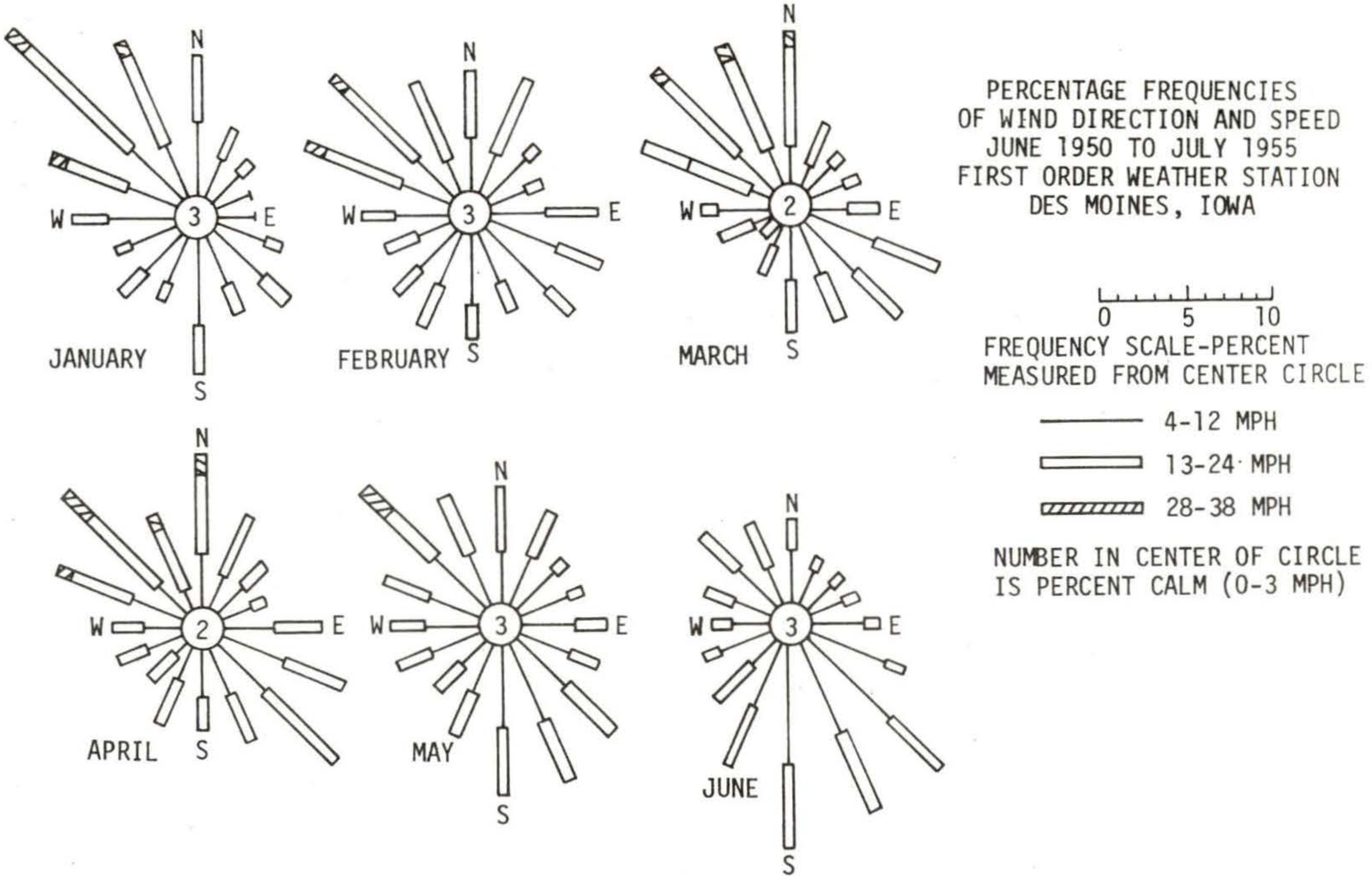


Figure H.3. Percentage frequency of wind direction and velocity, January to June

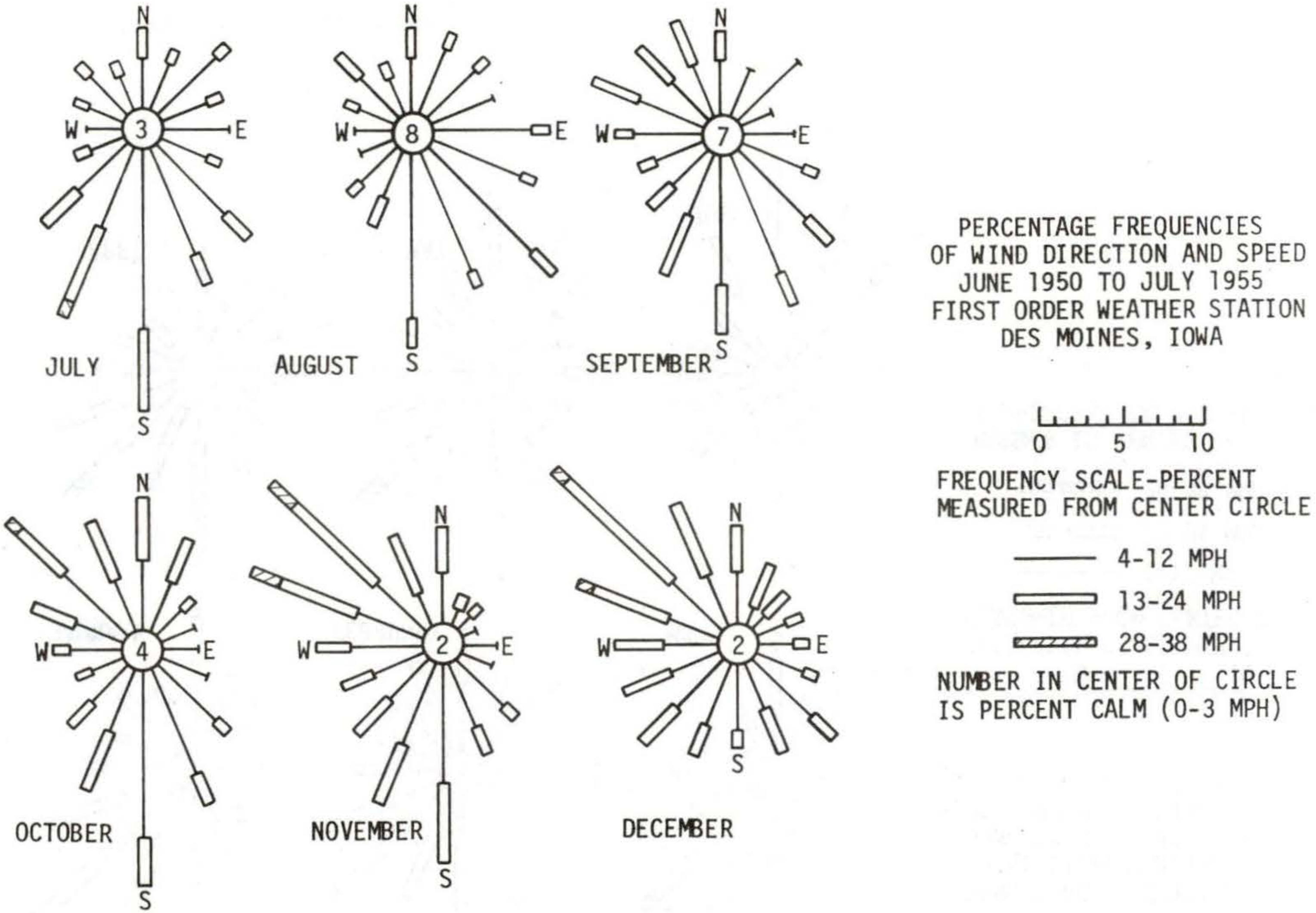
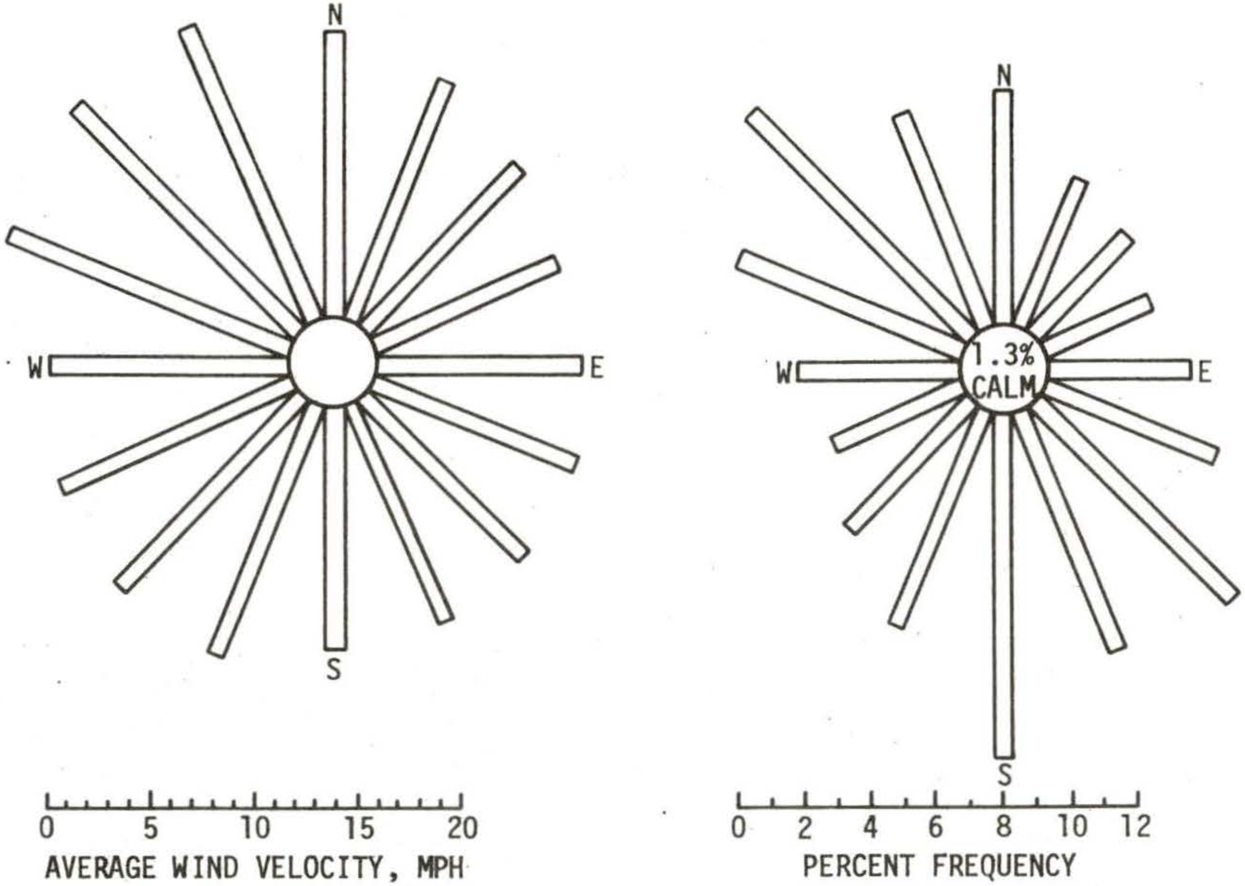


Figure H.4. Percentage frequency of wind direction and velocity, July to December



ALL VALUES ARE MEASURED FROM THE CENTER CIRCLE
AVERAGE WIND VELOCITY AND FREQUENCY OF WIND DIRECTION
FROM JUNE 1950 TO JULY 1955 (43,824 OBSERVATIONS)
DES MOINES, IOWA

Figure H.5. Average wind velocity and percent frequency of wind direction

APPENDIX I. COMPUTER PROGRAM

General

The following is a printout of the entire computer program, complete with symbol dictionary. Note each major subprogram is described by its respective call statement, such as subroutine GREEN.

```
C##############################################################################
C *                            SYMBOL DICTIONARY
C *
C * NAME   DEFINITION                                                        UNITS
C *
C * AA     VARIABLE SYMBOL.
C * ABS    FORTRAN SYMBOL FOR ABSOLUTE VALUE.
C * ABSLOP DATA LIST FOR SLOPE IN ST LINE EQN FOR BTU'S REQ FOR AN
C          ASSUMED KW OUTPUT  FROM AMES UNIT # 7 (DEPENDENT VARIABLE).
C * AC     CORRECTED AREA OF HEAT EXCHANGER FOR FISH SYSTEM.                   SQ FT
C * ACBTU  DATA LIST FOR CONSTANT IN ST LINE EQN FOR BTU'S REQ FOR
C          AN ASSUMED KW OUTPUT FROM AMES UNIT # 7 (DEPENDENT VARIABLE).
C * ACRES  GREENHOUSE FLOOR AREA IN ACRES FOR SCALED UP SYSTEM.                ACRES
C * ADDCST ADDITIONAL COST OF WASTE HEAT EQUIPMENT.                            $
C * AGLAZE SURFACE AREA OF GREENHOUSE GLAZING MATERIAL.                        SQ FT
C * AREA   SURFACE CONDENSER HEAT TRANSFER SURFACE AREA.                       SQ FT
C * ASMR   DATA LIST FOR CONSTANT IN ST LINE EQN FOR STEAN MASS RATE
C          TO CONDENSER FOR AMES UNIT # 7 (DEPENDENT VARIABLE).
C * ASSLOP DATA LIST FOR SLOPE IN ST LINE EQN FOR STEAM MASS RATE
C          TO CONDENSER FOR AMES UNIT # 7 (DEPENDENT VARIABLE).
C * B1     VARIABLE SYMBOL.
C * B2     VARIABLE SYMBOL.
C * B3     VARIABLE SYMBOL.
C * B4     VARIABLE SYMBOL.
C * B5     VARIABLE SYMBOL.
C * BB     VARIABLE SYMBOL.
C * BSLOPE INTERPOLATED SLOPE FOR ST LINE EQN FOR CONSTANT KW
C          (FROM IBSLOP OR ABSLOP DATA LIST) BTU VS KW.                        BTU/HR/KW
C * BTUREF BTU REFERENCE VALUE AT REFERENCE HG BACKPRESSURE.                   BTU/HR
C * BTUREF REFERENCE BTU INPUT FOR EXTRACTION SUBPROGRAM.                      BTU/HR
C * BTUREQ BTU HEATING REQUIRED FOR SCALED UP FISH OR GREENHOUSE UNITS.BTU/HR
C * BTUSS  BTU STEADY STATE VALUE FOR CONSTANT KW.                             BTU/HR
C * CC     VARIABLE SYMBOL.
C * CCEXT  FLOW OF CONDENSER COOLANT THROUGH EXTRACTION HEATER.                LBM/HR
C * CCGPM  CONDENSER COOLANT CIRCULATING WATER FLOW RATE.                      GAL/MIN
C * CCMRC  CONDENSER COOLANT MASS FLOW RATE THROUGH CONDENSER                  LBM/HR
C * CCSS   FLOW RATE CONDENSER COOLANT SHELL SIDE FISH HEAT EXCHANGER. GPM
C * CF     CONVERSION FACTOR GPM TO LBM/HR FISH SUBPROGRAM.               MIN LBM/HR GAL
C * CF     CORRECTION FACTOR FOR CONDENSER U VALUE WITH TEMPERATURE.
C * CFGHA  CORRECTION DATA FOR GREENHOUSE HEATER 60 F AIR INLET.
C * CFGHAA INTERPOLATED CORRECTION FACTOR FOR GREENHOUSE HEATER.
C * CFGHB  CORRECTION DATA FOR GREENHOUSE HEATER 70 F AIR INLET.
C * CFTIN  CORRECTION FACTOR TABLE FOR UVAL BASED ON TEMP CC IN.
C * CHREF  GREENHOUSE CONVENTIONAL HEATER REFERENCE OUTPUT.                     BTU/HR
C * CH1    COEF. 1  IN ENTHALPY EQN. H = CH1*TS+CH2                          BTU/LB/DEGF
C * CH2    COEF. 2  IN ENTHALPY EQN. H = CH2*TS+CH2.                           BTU/LBM
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C * CHQREF REFERENCE HEAT OUTPUT SCALED UP FISH & GREENHOUSE SYSTEMS   BTU/HR
C * CHUNTS NUMBER OF CONVENTIONAL BOILER-HEAT TRANSFER UNITS REQUIRED.
C * CLNF   CLEANINESS FACTOR FOR TUBES .                               %
C * CONBTU INTERPOLATED CONSTANT FOR ST LINE EQN FOR CONSTANT KW
C          (FROM ICBTU OR ACBTU DATA LIST) BTU VS KW.                  BTU/HR
C * CONEX  DATA LIST FOR CONSTANT IN ST LINE EQN FOR KW VS THROTTLE
C          FLOW FOR EXTRACTION OPERATION ISU #5 (DEPENDENT VARIABLE).  LBM/HR
C * CONEXT INTERPOLATED CONSTANT FOR ST LINE EQN FOR CONSTANT KW       LBM/HR
C          OUTPUT (FROM CONEX LIST) FOR KW VS THROTTLE FLOW PLOT.
C * CPAR   SPECIFIC HEAT OF AIR AT CONSTANT PRESSURE.             BTU/LBM DEG F
C * CPCC   SPECIFIC HEAT OF CONDENSOR COOLANT.                    BTU/LBM DEG F
C * CS     VARIABLE SYMBOL.
C * CSMRC  INTERPOLATED CONSTANT FOR ST LINE EQN FOR STEAM FLOW
C          TO CONDENSER (FROM ISMR OR ASMR DATA LIST) FOR CONSTANT KW. LBM/HR
C * DELBTU DELTA BTU INCREASE FROM REF TO MAINTAIN KW WITH HIGHER HG   BTU/HR
C * DELEXT EXTRACTION STEAM FLOW REQUIRED BY HEATERS.                  LBM/HR
C * DELHG  DELTA INCHES HG PRESSURE IN CONDENSER(TURBINE BACKPRESSURE).INCHES HG
C * DELKW  DELTA KILOWATT LOSS DUE TO HIGHER EXHAUST BACKPRESSURE.     KW
C * DELTCC DELTA TEMPERATURE CHANGE ACROSS SHELL SIDE OF EXCHANGER.    DEG F
C * DELTCG DELTA TEMPERATURE LOSS FROM CONDENSER TO GREENHOUSE.        DEG F
C * DELTCF DELTA TEMPERATURE LOSS FROM CONDENSER EXIT TO FISH UNIT.    DEG F
C * DELTHR DELTA THROTTLE FLOW  REQUIRED FOR CONSTANT KW OUTPT.        LBM/HR
C * DELTM  LOG MEAN TEMP FOR GREENHOUSE SPACE HEATER.                  DEG F
C * DLQCND DELTA HEAT TO CONDENSER(DECREASE) FROM  TURBINE EXHAUST.    BTU/HR
C * DLSMRC DELTA STEAM FLOW INTO CONDENSER.                            LBM/HR
C * DTIN   DELTA TEMP CC IN FOR CFTIN.                                 DEG F
C * DVEL   DELTA VELOCITY FOR UVAL.                                    FT/SEC
C * DX     DELTA FOR INDEPENDENT VARIABLE (MUST BE CONSTANT).
C * E      EMISSIVITY OF GREENHOUSE GLAZING MATERIAL.
C * ECON   SUBPROGRAM FOR ECONOMICS EXTRAPOLATION OF GRENNHOUSE & FISH
C          SYSTEM DATA TO LARGE SCALE INSTALLATIONS.
C * EFFIC  EFFICIENCY OF TURBINE.                                      %
C * ELECST COST OF ELECTRICITY.                                        $/KWHR
C * EMISIV EMISSIVITY OF INSULATION COVERING TANKS.
C * EX     EXPONENTIAL E TO THE X.
C * EX1    VARIABLE SYMBOL.
C * EXSLOP DATA LIST FOR SLOPE IN ST LINE EQN FOR KW VS THROTTLE FLOW
C          FOR EXTRACTION OPERATION ISU #5 (DEPENDENT VARIABLE).       LBM/HR/KW
C * EXTCST EXTRACTION COST FOR 1000 LBS OF 6 PSIG STEAM BASED ON ISU
C          POWER PLANT OPERATING DATA.                                 $/1000LBM
C * EXTFLO TOTAL EXTRACTION FLOW FROM UNIT.                            LBM/HR
C * EXTREF REFERENCE STEAM EXTRACTION RATE FOR EXTRACTION SUBPROGRAM.  LBM/HR
C * F      CORRECTION FACTOR FOR AREA OF HEAT EXCHANGER FROM AREA EQN.
C * FBTURF REFERENCE BTU HEATING REQUIREMENT FOR FISH UNIT.            BTU/HR
C * FISH   SUBPROGRAM FOR FISH SYSTEM HEATING USING WASTE HEAT.
C * FXRT   FISH SYSTEM HEAT EXCHANGER COST FOR 20/YR LIFE.             $/HR
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C * GAFREF GREENHOUSE FLOOR AREA REFERENCE.                            SQ FT
C * GAFREQ GREENHOUSE FLOOR AREA REQUIRED FOR SCALED UP SYSTEM.        SQ FT
C * GAL    GREENHOUSE SIDE WALL SURFACE AREA FOR REF FLOOR AREA.       SQ FT
C * GASREF REFERENCE GREENHOUSE HEAT TRANSFER SURFACE AREA.            SQ FT
C * GASREQ GREENHOUSE SURFACE AREA SCALED UP SYSTEM.                   SQ FT
C * GATOP  GREENHOUSE ROOF SURFACE AREA FOR REF FLOOR AREA.            SQ FT
C * GAW    GREENHOUSE SIDE WALL(WIDTH) SURFACE AREA FOR REF FLOOR AREA.SQ FT
C * GBTURF GREENHOUSE HEATING REQUIREMENT FOR REFERENCE AREA.          BTU/HR
C * GMCCSS GPM CONDENSER COOLANT FLOW THROUGH SHELL SIDE OF EXCHANGER. GPM
C * GMFWR  GPM FRESH WATER REQUIRED FOR FISH SYSTEM.                   GPM
C * GMFTUB GPM REARING WATER FLOW THROUGH TUBE SIDE OF EXCHANGER.      GPM
C * GMRECW GPM RECIRCULATED WATER FOR FISH SYSTEM.                     GPM
C * GPMCCE CONDENSER COOLANT FLOW RATE THROUGH EXTRACTION HEATER.      GPM
C * GRBTU   SUBPROGRAM FOR CALCULATION OF GREENHOUSE HEATING REQUIREMENTS.
C * GREEN  SUBPROGRAM FOR GREENHOUSE WASTE HEAT HEATING SYSTEM.
C * GTD    GREAT TEMPERATURE DIFFERENCE FOR LMTD.                      DEG F
C * GXRT   GREENHOUSE HEATER COST OVER 20 YR TIME PERIOD.              $/HR
C * HFILMI HEAT TRANSFER FILM COEF FOR TANK-WATER INTERFACE.   BTU/HR SQFT DEG F
C * HFILMO HEAT TRANSFER FILM COEF FOR TANK-AIR INTERFACE.     BTU/HR SQFT DEG F
C * HG     INTERPOLATED VALUE FOR HG CONDENSER PRESSURE FROM HGIN TABLE.
C * HRBTU  HEAT RATE FOR STEAM EXTRACTION SUBPROGRAM.                  BTU/KWHR
C * HGI    LOOP INCREMENT BACKPRESSURE VALUE(BEFORE STEADY STATE).     INCHES HG
C * HGIN   TABLE FOR INCHES OF HG (DEPENDENT VARIABLE).                INCHES HG
C * HGREF  REFERENCE TURBINE BACKPRESSURE((CONDENSER PRESSUREABSOLUTE).INCHES HG
C * HGSS   INCHES OF HG STEADY STATE CONDENSING OPERATION.             INCHES HG
C * HR     HEAT RATE.                                                  BTU/KWHR
C * HRADSK RADIATION COEFF                                        BTU/(HR*SQ FT)
C * HTUREX ENTHALPY OF STEAM EXITING TURBINE AND INTO CONDENSER.       BTU/LBM
C * I      LOOP PARAMETER OUTSIDE AIR TEMP FOR GRBTU TABLE.
C * IBSLOP DATA LIST FOR SLOPE IN ST LINE EQN FOR BTU'S REQ FOR AN
C          ASSUMED CONSTANT KW OUTPUT,ISU #5 (BTU VSKW PLOT) .         BTU/KW
C * ICBTU  DATA LIST FOR CONSTANT IN ST LINE EQN FOR BTU'S REQ FOR
C          AN ASSUMED KW OUTPUT FROM ISU UNIT # 5 (DEPENDENT VARIABLE).
C * IE     LOOP COUNTER FOR ECON SUBPROGRAM.
C * IEF    TEMPORARY FILE FOR SCALED UP FISH UNIT ECON PARAMETERS.
C * IEG    TEMPORARY FILE FOR SCALED UP GREENHOUSE ECON PARAMETERS.
C * IERR   =ERROR FLAG
C * IERR   = 0   OK
C * IERR   =  1 X VALUE OUT OF RANGE. NOTE: R=0 IN THIS CASE.
C * IFS    TEMPORARY FILE FOR FISH UNIT
C * IGR    TEMPORARY FILE FOR GREENHOUSE
C * IM     SCALE MULTIPLIER FOR ECON SUBPROGRAM.
C * IN     LOOP PARAMETER INSIDE AIR TEMP FOR GBTU TABLE.
C * IPE    TEMPORARY FILE FOR STEAM EXTRACTION.
C * IPP    TEMPORARY FILE FOR POWER PLANT
C * IRF    TEMPORARY FILE FOR POWER PLANT REFERENCE PARAMETERS.
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C * ISH    TEMPORARY FILE FOR SOIL HEATING
C * ISMR   DATA LIST FOR CONSTANT IN ST LINE EQN FOR STEAM MASS RATE
C          TO CONDENSER  FOR ISU UNIT # 5 (DEPENDENT VARIABLE).
C * ISSLOP DATA LIST FOR SLOPE IN ST LINE EQN FOR STEAM MASS RATE
C          TO CONDENSER FOR ISU UNIT # 5 (DEPENDENT VARIABLE).
C * J      LOOP PARAMETER WIND VELOCITY FOR GRBTU TABLE.
C * J      LOOP PARAMETER FOR OUTLET TEMP CC FROM EXTRACTION HEATER.    DEG F
C * JI     LOOP COUNTER FOR MAIN PROGRAM, JI=1 FOR ISU, JI=2 FOR AMES.
C * JJ     LOOP COUNTER FOR MAIN PROGRAM FOR STEAM EXTRACTION CALL.
C * JK     LOOP PARAMETER FOR GPM FLOW THROUGH EXTRACTION HEATER.      GPM
C * JKE    LOOP COUNTER FOR POWER PLANT STEAM EXTRACTION SUBPROGRAM.
C * JP     LOOP COUNTER FOR POWER PLANT BACKPRESSURE SUBPROGRAM.
C * JPE    LOOP COUNTER FOR POWER PLANT STEAM EXTRACTION SUBPROGRAM.
C * KVALI  THERMAL CONDUCTIVITY OF FIBERGLASS TANKS.              BTU/HR FT DEG F
C * KVALO  THERMAL CONDUCTIVITY OF INSULATION COVERING TANKS.     BTU/HR FT DEG F
C * KWREF  REFERENCE KILOWATT LOAD, ASSUMED CONSTANT.                   KW
C * KWSS   KILOWATT STEADY STATE VALUE.                                 KW
C * LMTD   LOG MEAN TEMPERATURE DIFFERENCE.                             DEG F
C * LTD    LITTLE TEMPERATURE DIFFERENCE FOR LMTD.                      DEG F
C * MCCSS  MASS FLOW RATE CONDENSER COOLANT SHELL SIDE.                 LBM/HR
C * MFTUBE MASS FLOW RATE TUBE SIDE.                                    LBM/HR
C * MFWREP MASS FLOW RATE FRESH REPLACEMENT WATER FOR FISH TANKS.       LBM/HR
C * MRECIR MASS FLOW RATE RECIRCULATED WATER FOR FISH TANKS.            LBM/HR
C * N OR NPUMP  NUNBER OF CIRCULATING PUMPS IN OPERATION.
C * NY     NUMBER OF VALUES IN Y .
C * POWER  SUBPROGRAM FOR POWER PLANT NORMAL CONDENSER BACKPRESSURE OPERATION.
C * POWERE SUBPROGRAM FOR ISU UNIT# 5 STEAM EXTRACTION.
C * PRINT  SUBPROGRAM FOR PRINTING OF RESULTS
C * PROD   PRODUCTION FROM SCALED UP FISH OR GREENHOUSE SYSTEM.         LBM/YR
C * PRODRF REFERENCE PRODUCE OUTPUT FROM FISH UNIT OR GREENHOUSE.       LBM/YR
C * QADDED HEAT ADDED TO REPLACEMENT WATER PLUS HEAT LOSS REPLACEMENT. BTU/HR
C * QAIRHT GREENHOUSE HEATER BTU OUTPUT CORRECTED TO NEW INLET CONDITIONS.BTU/HR
C * QAHEAT HEAT REQUIRED FROM GREENHOUSE SPACE HEATING SYSTEN.          BTU/HR
C * QCOND  HEAT LOSS DUE TO CONDUCTION(WIND).  (GREENHOUSE)             BTU/HR
C * QCOND  HEAT TO  CONDENSER FROM TURBINE EXHAUST.                      BTU/HR
C * QEQUIP HEAT GIVEN OFF BY FANS LIGHTS MOTORS ETC.                    BTU/HR
C * QEXT   BTU'S FROM EXTRACTION HEATER.                          MILLION BTU/HR
C * QHRYR  HEATING HOURS REQUIRED /YR FOR FISH OR GREENHOUSE SYSTEM.    HR/YR
C * QOUT   BTU'S DISCHARGED FROM EXTRACTION HEATER.                MILLION BTU/HR
C * QOUT   BTU'S PER HOUR DISCHARGED FROM CONDENSER.                    BTU/HR
C * QRADSK HEAT LOSS DUE TO RADIATION FROM GLAZING TO SKY.              BTU/HR
C * QREF   REFERENCE GREENHOUSE HEATER PERFORMANCE.                     BTU/HR
C * QSDIR  DIRECT SOLAR RADIATION.                                   BTU/HR SQ FT
C * QSDIF  HEAT INPUT BY DIFFUSE SOLAR RADIATION.                       BTU/HR
C * QSOLHT HEAT INPUT BY SOIL HEATING SYSTEM.                           BTU/HR
C * QSOLAR HEAT INPUT DUE TO SOLAR RADIATION.                        BTU/HR SQFT
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C * QSOLOS HEAT LOSS BY SOIL CONDUCTION.                                BTU/HR
C * QTLOSS HEAT LOSS FROM TANK WALL SURFACE AREAS.                       BTU/HR
C * R      RESULT OBTAINED BY LINEAR INTERPOLATION.
C * RATMAR MASS FLOW RATE OF AIR THRU GREENHOUSE SPACE HEATER.          LBM/HR
C * RATMCC MASS FLOW RATE CONDENSER COOLANT THRU GREENHOUSE HEATER.    LBM/HR
C * REFKW  REFERENCE KW OUTPUT FOR EXTRACTION SUBPROGRAM.               KW
C * SAREA  HEAT TRANSFER SURFACE AREA FROM FISH TANKS ETC.              SQ FT
C * SMRC   STEAM MASS FLOW RATE INTO CONDENSER FROM TURBINE             LBM/HR
C * SMRCRF REFERENCE STEAM FLOW INTO CONDENSER.                         LBM/HR
C * SOIL   SUBPROGRAM FOR SUBSOIL HEATING WITH WASTE HEAT.
C * SSLPOE INTERPOLATED SLOPE FOR ST LINE EQN FOR STEAN FLOW            LBM/HR/KW
C          TO CONDENSER (FROM ISSLOP OR ASSLOP DATA LIST)FOR CONSTANT KW.
C * SUMCST TOTAL HOURLY COST=CAPITAL/20YR + WASTE HEAT COST/HR.         $/HR
C * SUMFF  SUM OF COST/HR FOR FISH SYSTEM EQUIP + HEATING COST/HR.      $/HR
C * TAIR   INSIDE AIR TEMPERATURE ASSUMED CONSTANT FOR FISH SYSTEM.     DEG F
C * TAIRIN TEMPERATURE OF AIR ENTERING GREENHOUSE SPACE HEATER.         DEG F
C * TAIROT TEMPERATURE AIR LEAVING GREENHOUSE HEATER.                   DEG F
C * TCCINC TEMPERATURE CONDENSER COOLANT AT CONDENSER INLET.            DEG F
C * TCCING TEMPERATURE CONDENSER COOLANT INTO GREENHOUSE HEATER.        DEG F
C * TCCINF TEMPERATURE  CONDENSER COOLANT AT INLET TO FISH UNIT.        DEG F
C * TCCEHO TEMPERATURE CONDENSER COOLANT OUT OF EXTRACTION HEATER.      DEG F
C * TCCOTC TEMPERATUTE CONDENSER COOLANT AT CONDENSER DISCHARGE.        DEG F
C * TCCOTG TEMPERATURE CONDENSER COOLANT OUT OF GREENHOUSE SPACE HEATER.DEG F
C * TCCREF REFERENCE INLET TEMP CONDENSER COOLANT SS OPERATION.         DEG F
C * TCCSSI TEMPERATURE CONDENSER COOLANT SHELL SIDE INLET.              DEG F
C * TCCSSO TEMPERATURE CONDENSER COOLANT SHELL SIDE OUTLET.             DEG F
C * TCIRIN TEMP OF RECIRCULATED WATER INTO TANKS(OUT OF HEAT EXCHANGER) DEG F
C * TFWREP TEMPERATURE OF FRESH REPLACEMENT WATER FOR FISH UNIT.        DEG F
C * TGLAZE TEMPERATURE OF GREENHOUSE GLAZING MATERIAL.                  DEG F
C * THRFLO THROTTLE FLOW REQUIRED FOR CONSTANT KW.                      LBM/HR
C * THRREF REFERENCE THROTTLE STEAM FLOW FOR EXTRACTION SUBPROGRAM.     BTU/HR
C * TIN1   TEMP CC IN CORRESPONDING TO FIRST VALUE IN CFTIN.            DEG F
C * TISDB  GREENHOUSE INSIDE AIR TEMPERATURE DRY BULB.                  DEG F
C * TLOOK  SUBPROGRAM FOR LINEAR INTERPOLATION.
C * TOSDB  AIR TEMPERATURE OUTSIDE DRY BULB                             DEG F
C * TOTGPM TOTAL GPM CONDENSER COOLANT FOR GREENHOUSE SPACE HEATING.    GPM
C * TOTMCC TOTAL MASS FLOW RATE OF CONDENSER COOLANT FOR GREENHOUSE     LBM/HR
C * TOUTRF REFERENCE DISCHARGE TEMP CONDENSER COOLANT SS OPERATION.     DEG F
C * TREARW TEMPERATURE OF REARING WATER IN FISH TANKS.                  DEG F
C * TRECIR TEMPERATURE OF RECIRCULATED WATER ENTERING HEAT EXCHANGER.   DEG F
C * TSKY   EFFECTIVE SKY TEMPERATURE                                    DEG F
C * TSOTUR TEMPERATURE OF STEAM AT TURBINE EXIT AND INTO CONDENSER      DEG F
C * TWALL  TEMPERATURE OF TANK WALL.                                    DEG F
C * U      OVERALL HEAT TRANSFER COEF FOR FISH HEAT EXCHANGER .BTU/HR SQFT DEGF
C * U      OVERALL HEAT TRANSFER COEF POWER PLANT          BTU/(HR SQ FT DEG F)
C * UA     PRODUCT OF HEAT TRANSFER AREA & U COEF FOR GREENHOUSE.       BTU/DEG F
```

```
C * UC     CORRECTION FACTOR FOR CONDENSER U VALUE WITH WATER VELOCITY.
C * UNITS  NUMBER OF GREENHOUSE SPACE HEATER UNITS REQUIRED.
C * UVAL   OVERALL HEAT TRANSFER COEF TABLE  FOR CONDENSER(DEPENDENT VARIABLE).
C * UVALW  DATA LIST FOR GREENHOUSE GLAZING UVALUE WITH WIND.
C * VEL1   VELOCITY CORRESPONDING TO FIRST VALUE IN UVAL.             FT/SEC
C * VWIND  WIND VELOCITY.                                             MI/HR
C * WATVEL COOLANT VELOCITY THROUGH TUBES OF CONDENSER.               FT/SEC
C * WHUNTS NUMBER OF WASTE HEAT -HEAT TRANSFER UNITS REQUIRED.
C * WUVAL  INTERPOLATED UVAL FOR GREENHOUSE GLAZING FROM UVALW LIST.
C * X      VARIABLE SYMBOL.
C * X      INDEPENDENT VARIABLE.
C * X1     VALUE OF INDEPENDENT VARIABLE CORRESPONDING TO FIRST VALUE OF Y.
C * XSLOPE INTERPOLATED SLOPE FOR ST LINE EQN FOR CONSTANT KW
C          OUTPUT (FROM EXSLOP LIST) FOR KW VS THROTTLE FLOW PLOT.    LBM/HR/KW
C * Y      ARRAY OF DEPENDENT VARIABLES.
C * $BTU OR BTUCST  REPRESENTS THE BTU FUEL COST .                $/MILLION BTU
C * $CHBTU COST OF PROPANE FUEL.                                      $/BTU
C * $CHHR  CONVENTIONAL HEATING COST/HR (BY PROPANE FUEL).            $/HR
C * $CHSYS COST OF CONVENTIONAL BOILER-HEAT TRANSFER UNITS REQUIRED.  $
C * $CHYR  CONVENTIONAL HEATING COST PER YEAR(BY PROPANE FUEL).       $/YR
C * $CHUNT COST OF CONVENTIONAL BOLIER-EXCHANGER FOR FISH & GREENHOUSE. $
C * $DLBTU INCREMENTAL BTU COST TO MAINTAIN KW OUTPUT WITH HIGHER HG.  $/HR
C * $ELECT OR ELECST  COST OF ELECTRICITY.                            $/KWHR
C * $EXT   EXTRACTION COST (STEAM REQUIRED).                          $
C * $GI    GROSS INCOME FROM PRODUCE.                                 $/YR
C * $GIACH GROSS INCOME AFTER CONVENTIONAL HEAT COST.                 $/YR
C * $GIAWH GROSS INCOME AFTER WASTE HEAT COST.                        $/YR
C * $HTXER UNIT COST FOR GREENHOUSE SPACE HEATER.                     $
C * $LOSS  REVENUE LOSS FROM ELECT SALE FOR CONSTANT BTUREF.          $/HR
C * $MBTU  COST OF EXTRACTION HEAT PER MILLION BTU'S.             $/MILLION BTU
C * $PRODU ASSUMED MARKET VALUE OF PRODUCE.                           $/LBM
C * $PUMP  COST OF PUMPING.                                           $/HR
C * $THTXR TOTAL COST OF GREENHOUSE SPACE HEATERS.                    $
C * $WH    WASTE HEAT COST(COST OF ADDED BTU'S TO MAINTAIN REFERENCE
C          BACKPRESSURE CONDITION)-COST IS FOR ENTIRE COOLANT FLOW.   $/HR
C * $WHSAV DOLLAR HEATING COST SAVINGS OF WASTE HEAT OVER CONVENTIONAL.$/YR
C * $WHSYS COST OF WASTE HEAT HEATERS FOR SCALED UP SYSTEM.           $
C * $WHYR  COST OF WASTE HEAT PER YEAR (ENTIRE COOLANT FLOW RATE).    $/YR
C * $WHUNT COST OF WASTE HEAT GREENHOUSE SPACE HEATERS.               $
C * $XCHG  DATA LIST COST TABLE FOR FISH HEAT EXCHANGER FOR WASTE HEAT.
C * $XCHGR INTERPOLATED COST FOR FISH HEAT EXCHANGER FROM $XCHG TABLE. $
C###############################################################################
C  *****************************************************************************
      REAL * 4 KWREF,ISMR,ICBTU,KWSS,ISSLOP,IBSLOP,N
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /INCR/JI,JJ,JP,JPE,IE
```

```
      COMMON/COST/  $WH,$XCHGR,$HTXER
      COMMON /HEAT/ QAIRHT,QADDED,GMCCSS,AC
      COMMON/TCC/ TCCINC,TCCOTC,TCCING,TCCOTG,TCCSSI,TCCSSO,
     1           DELTCC,DELTCG,DELTCF
      COMMON /PPLANT/ KWREF,BTUREF,SMRC,CCMRC,WATVEL,
     1HGREF,AREA,BTUCST,ELECST
      NAMELIST/PPLNT/ KWREF,BTUREF,SMRC,CCMRC,WATVEL,
     1HGREF,AREA,BTUCST,ELECST
C    ******************************************************************
C
C     MAIN PROGRAM
C
      JJ=0
      JI=0
   20 CONTINUE
      READ(5,PPLNT,END=900)
      JI=JI+1
      CALL POWER
      CALL PRINT
      JJ=JJ+1
      IF(JJ.EQ.2) GO TO 7
      GO TO 20
 7    CALL POWERE
      CALL PRINT
  900 CONTINUE
      STOP
      END
C    ******************************************************************
      BLOCK DATA
      REAL * 4 KWREF,ISMR,ICBTU,KWSS,ISSLOP,IBSLOP,N
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /INCR/JI,JJ,JP,JPE,IE
      COMMON /PPLANT/ KWREF,BTUREF,SMRC,CCMRC,WATVEL,
     1HGREF,AREA,BTUCST,ELECST
      DATA IPP/1/
      DATA IGR/2/
      DATA IFS/3/
      DATA ISH/4/
      DATA IPE/10/
      DATA IRF/11/
      DATA IEG/12/
      DATA IEF/13/
      END
C    ******************************************************************
      SUBROUTINE POWER
      REAL * 4 KWREF,ISMR,ICBTU,KWSS,ISSLOP,IBSLOP,N
```

```
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /INCR/JI,JJ,JP,JPE,IE
      COMMON/COST/ $WH,$XCHGR,$HTXER
      COMMON /HEAT/ QAIRHT,QADDED,GMCCSS,AC
      COMMON/TCC/ TCCINC,TCCOTC,TCCING,TCCOTG,TCCSSI,TCCSSO,
     1               DELTCC,DELTCG,DELTCF
      COMMON /PPLANT/ KWREF,BTUREF,SMRC,CCMRC,WATVEL,
     1HGREF,AREA,BTUCST,ELECST
      DIMENSION UVAL(9),CFTIN(9),HGIN(8),ACBTU(6),ASMR(6)
      DIMENSION ICBTU(6),ISMR(6),IBSLOP(6),ABSLOP(6),ISSLOP(6),ASSLOP(6)
      DATA CH1/-.57/
      DATA CH2/1094.37/
      DATA CLNF/.85/
      DATA CFTIN/.5,.66,.8,.91,1.0,1.04,1.08,1.1,1.14/
      DATA TIN1/30./,DTIN/10./
      DATA UVAL/400.,460.,530.,590.,650.,700.,750.,790.,830./
      DATA VEL1/2./,DVEL/1./
      DATA HGIN/.4854,.6900,.9663,1.3346,1.8193,2.4493,3.2594,4.2894/
      DATA ISMR/6325.,7475.,8471.,9315.,9873.,10426./
      DATA ISSLOP/6.57,6.67,6.76,6.85,6.95,7.04/
      DATA IBSLOP/9531.,9560.,9616.,9669.,9750.,9830./
      DATA ICBTU/7820000.,9322666.,1058000E1,1167633E1,1235100E1,
     1          1302566E1/
      DATA ASMR/6878.,10461.,14025.,16500.,18333.,19800./
      DATA ASSLOP/6.082,6.073,6.045,6.08,6.111,6.2/
      DATA ABSLOP/9094.17,8970.,8901.,8900.,8942.,8984./
      DATA ACBTU/7947500.,1303500E1,1735250E1,2043250E1,2252250E1,
     1          2461250E1/
      DATA N/1./
      $BTU=BTUCST
      $ELECT=ELECST
      IF(JI.EQ.2) GO TO 22
      TCCINC=46.
      GO TO 23
22    TCCINC=39.
23    CS=CCMRC/SMRC
1     CALL TLOOK(TCCINC,CFTIN,9,TIN1,DTIN,CF,IERR)
      CALL TLOOK(WATVEL,UVAL,9,VEL1,DVEL,UC,IERR)
      U=UC*CF*CLNF
      X=U* AREA /CCMRC
      EX=EXP(X)
      EX1=CH1/(EX-1.)
      TCCOTC=(TCCINC*(EX1-CS)-CH2)/(EX1*EX-CS)
      TSOTUR = (TCCOTC*EX-TCCINC)/(EX-1.)
      CALL TLOOK(TSOTUR,HGIN,8,58.,10.,HG,IERR)
26    IF(ABS(HG-HGREF).LT..01) GO TO 3
```

```
      IF (HG.LT.HGREF) GO TO 2
      TCCINC=TCCINC-.01
      GO TO 1
2     TCCINC=TCCINC+.01
      GO TO 1
3     TCCREF = TCCINC
      SMRCRF=SMRC
      TOUTRF=TCCOTC
      JP=0
      NPUMP=N
C     LOOP ON TEMPERATURE OF CONDENSER COOLANT INTU CONDENSER
4     TCCINC = TCCINC+1.
      JP=JP+1
      CALL TLOOK(TCCINC,CFTIN,9,TIN1,DTIN,CF,IERR)
      U=UC*CF*CLNF
      X=U* AREA /CCMRC
      EX=EXP(X)
      EX1=CH1/(EX-1.)
      CS=CCMRC/SMRC
      TCCOTC=(TCCINC*(EX1-CS)-CH2)/(EX1*EX-CS)
      TSOTUR = (TCCOTC*EX-TCCINC)/(EX-1.)
      CALL TLOOK(TSOTUR,HGIN,8,58.,10.,HGSS,IERR)
      IF(NPUMP.EQ.1) GO TO 20
      IF(JI.EQ.2) GO TO 15
      IF(NPUMP.EQ.2) GO TO 31
      IF(NPUMP.EQ.3) GO TO 32
15    IF(NPUMP.EQ.2) GO TO 33
31    NPUMP=2*N
      WATVEL=7.56
      CCMRC=6018997.
      GO TO 19
32    NPUMP=3*N
      WATVEL=9.4
      CCMRC=7483938.
      GO TO 19
33    WATVEL=7.
      NPUMP=2*N
      CCMRC=13013780.
19    CALL TLOOK(WATVEL,UVAL,9,VEL1,DVEL,UC,IERR)
      U=UC*CF*CLNF
      X=U* AREA /CCMRC
      EX=EXP(X)
      EX1=CH1/(EX-1.)
      CS=CCMRC/SMRC
      TCCOTC=(TCCINC*(EX1-CS)-CH2)/(EX1*EX-CS)
      TSOTUR = (TCCOTC*EX-TCCINC)/(EX-1.)
```

```
      CALL TLOOK(TSOTUR,HGIN,8,58.,10.,HGSS,IERR)
20    IF(JI.EQ.2) GO TO 21
      $PUMP=223.71*$ELECT*NPUMP
      GO TO 25
21    $PUMP=223.71*$ELECT*NPUMP
25    IF(HGSS.GT.3.5) GO TO 14
      IF(JI.EQ.2.) GO TO 5
      CALL TLOOK(HGSS,ISMR,6,1.,.5,CSMRC,IERR)
      CALL TLOOK(HGSS,ISSLOP,6,1.,.5,SSLOPE,IERR)
      GO TO 6
5     CALL TLOOK(HGSS,ASMR,6,1.,.5,CSMRC,IERR)
      CALL TLOOK(HGSS,ASSLOP,6,1.,.5,SSLOPE,IERR)
6     SMRC=SSLOPE*KWREF+CSMRC
      CS=CCMRC/SMRC
      TCCOTC=(TCCINC*(EX1-CS)-CH2)/(EX1*EX-CS)
7     TSOTUR = (TCCOTC*EX-TCCINC)/(EX-1.)
      CALL TLOOK(TSOTUR,HGIN,8,58.,10.,HGI,IERR)
      IF(ABS(HGI-HGSS).LT..01) GO TO 9
      IF(HGI.LT.HGSS) GO TO 8
      TCCOTC=TCCOTC-.01
      GO TO 7
8     TCCOTC=TCCOTC+.01
      GO TO 7
9     DELHG = HGSS - HGREF
      IF (JI.EQ.2.0) GO TO 10
      CALL TLOOK(HGSS,ICBTU,6,1.,.5,CONBTU,IERR)
      CALL TLOOK(HGSS,IBSLOP,6,1.,.5,BSLOPE,IERR)
      GO TO 11
10    CALL TLOOK(HGSS,ACBTU,6,1.,.5,CONBTU,IERR)
      CALL TLOOK(HGSS,ABSLOP,6,1.,.5,BSLOPE,IERR)
11    BTUSS=BSLOPE*KWREF+CONBTU
      DELBTU= BTUSS -BTUREF
30    HR = BTUSS/KWREF
      EFFIC = 1./HR*341300.
      QOUT=(CCMRC*(TCCOTC-TCCINC))/1000000
      $DLBTU= $BTU*DELBTU/(.83*1000000.)
      $WH=$DLBTU
      KWSS=(BTUREF-CONBTU)/BSLOPE
      DELKW=KWREF-KWSS
16    $LOSS = $ELECT*DELKW
      CCGPM=CCMRC/500.53
      IF(JP.GT.1) GO TO 17
      WRITE(IRF) HGREF,TCCREF,TOUTRF,KWREF,$ELECT,BTUREF,$BTU,SMRCRF,
     1          CCGPM
17    WRITE(IPP) TSOTUR,HGSS,EFFIC,HR,TCCINC,TCCOTC,DELKW,$LOSS,DELBTU,
     1          $DLBTU,QOUT,SMRC,CCGPM,$PUMP
```

```
 50   CONTINUE
      IF(JI .EQ.2) GO TO 12
      IF(NPUMP.EQ.2.) GO TO 34
      IF(NPUMP.EQ.3.) GO TO 13
      AA=ABS($DLBTU-4.94)
      IF(AA .LT..10.OR.AA.EQ..10) GO TO 31
      GO TO 13
 34   BB=ABS($DLBTU-5.97)
      IF(BB .LT..16.OR.BB.EQ..16) GO TO 32
      GO TO 13
 12   IF(NPUMP.EQ.2.) GO TO 13
      CC=ABS($DLBTU-8.95)
      IF(CC .LT..30.OR.CC.EQ..30) GO TO 33
 13   DELTCG=0
      TCCING = TCCOTC-DELTCG
      IF(TCCING.GT.70.) GO TO 100
      GO TO 200
 100  CALL GREEN
      IE=0
      IE=IE+1
      CALL ECON
      TCCINF=TCCOTC
      IF(TCCOTC.LT.83.0.OR.TCCOTC.EQ.83.0) GO TO 200
      CALL FISH
      IE=IE+1
      CALL ECON
 200  CONTINUE
      GO TO 4
 14   CONTINUE
      RETURN
      END
C*****************************************************************
      SUBROUTINE POWERE
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /INCR/JI,JJ,JP,JPE,IE
      COMMON /HEAT/ QAIRHT,QADDED,GMCCSS,AC
      COMMON/COST/ $WH,$XCHGR,$HTXER
      COMMON /PPLANT/ KWREF,BTUREF,SMRC,CCMRC,WATVEL,
     1HGREF,AREA,BTUCST,ELECST
      COMMON/TCC/ TCCINC,TCCOTC,TCCING,TCCOTG,TCCSSI,TCCSSO,
     1           DELTCC,DELTCG,DELTCF
      DIMENSION  EXSLOP(5)
      DIMENSION CONEX(5)
      DATA REFKW/11500./
      DATA BTUREF/1.21164E8/
      DATA THRREF/144500./
```

```
      DATA SMRCRF/94500./
      DATA EXTREF/50000./
      DATA $BTU/1.05/
      DATA CONEX/9933.33,46901.31,80162.79,111391.3,144533.3/
      DATA EXSLOP/8.66667,8.48684,8.60465,8.98551,9.3333/
      DATA EXTCST /1.87/
      DATA ELECST/.02/
      $ELECT=ELECST
      JPE=0
      JKE = 0
      DO 81 JK = 100,500,400
      JKE = JKE + 1
      CCEXT = JK*60./.11987
      DO 80 J=96,120,2
      TCCEHO = J
      JPE=JPE+1
      QEXT = (CCEXT*(TCCEHO-94.))/1000000.
      DELEXT=QEXT*1000000/(1188.2-(TCCEHO-32.))
      EXTFLO = DELEXT+ EXTREF
      CALL TLOOK(EXTFLO,CONEX,5,0.,50000.,CONEXT,IERR)
      CALL TLOOK(EXTFLO,EXSLOP,5,0.,50000.,XSLOPE,IERR)
      DELKW = REFKW-(THRREF-CONEXT)/XSLOPE
      DELTHR = (XSLOPE*REFKW+CONEXT)-THRREF
      THRFLO = THRREF + DELTHR
      HR = -.0107*EXTFLO + 11000.
      SMRC=THRFLO-EXTFLO
      BTUSS=1044*THRFLO+6532514.
      DELBTU=BTUSS-BTUREF
      DELHR=DELBTU/REFKW
      HRBTU=BTUSS/REFKW
      EFFIC=1./HRBTU*341300.
      $DLBTU=$BTU*DELBTU/(.80*1000000.)
      DLSMRC=SMRCRF-SMRC
      DLQCND=DLSMRC*1037.
      QCOND=SMRC*1037.
      $EXT = DELEXT*EXTCST/1000.
      GPMCCE = CCEXT*(.11987/60.)
      $LOSS = $ELECT*DELKW
      QOUT = (CCEXT*(TCCEHO-70.))/1000000.
      $MBTU = $EXT/QOUT
      WRITE(IPE) GPMCCE,QEXT,TCCEHO,DELEXT,$EXT,$MBTU,DELTHR,THRFLO,
     1            DELKW,$LOSS,SMRC,DLQCND,QOUT
80    CONTINUE
81    CONTINUE
      RETURN
      END
```

```
C  ******************************************************************************
      SUBROUTINE GREEN
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /INCR/JI,JJ,JP,JPE,IE
      COMMON /HEAT/ QAIRHT,QADDED,GMCCSS,AC
      COMMON/COST/ $WH,$XCHGR,$HTXER
      COMMON/TCC/ TCCINC,TCCOTC,TCCING,TCCOTG,TCCSSI,TCCSSO,
     1             DELTCC,DELTCG,DELTCF
      DIMENSION CFGHA(17),CFGHB(7)
      DATA QEQUIP/2000./
      QSOLAR = 0.
      DATA QAHEAT/403504./
      DATA QREF/235000./
      DATA UA/2212./
      DATA $HTXER/690./
      DATA RATMCC/6002./
      DATA RATMAR/21184./
      DATA TISDB/60./
      DATA CFGHA/.001,.071,.143,.214,.286,.357,.429,.500,.517,
     1.643,.714,.786,.857,.929,1.,1.071,1.143/
      DATA CFGHB/0.,.071,.141,.212,.283,.353,.424/
      DATA AGLAZE/8297./
      DATA CPAR/0.24/
      DATA CPCC/1./
      TAIRIN=TISDB
      B1 = UA/(RATMAR*CPAR)
      B2 = (RATMAR*CPAR)/(RATMCC*CPCC)
      B3 = B2*(1.-EXP(-B1))
      TCCOTG = TCCING-(TCCING-TAIRIN)*(1.-EXP(-B3))*1.0293
      TAIROT = TAIRIN+(1./B2)*(TCCING-TAIRIN)*(1.-EXP(-B3))*0.95901
      B4 = (TCCING-TCCOTG)/(TAIROT-TAIRIN)
      B5 = (TAIROT-TAIRIN)/(TCCING-TAIRIN)
      DELTM=(TAIROT-TAIRIN)/ALOG((B4)/(B4+ALOG(1.-B4*B5)))
      CALL TLOOK(TCCING,CFGHA,17,60.,10.,CFGHAA,IERR)
      QAIRHT = QREF*CFGHAA
      UNITS=QAHEAT/QAIRHT
      TOTMCC= UNITS*RATMCC
      TOTGPM = TOTMCC*0.11987/60.
      $THTXR= UNITS*$HTXER
      GXRT=$THTXR/175200.
      SUMCST=GXRT+$WH
      WRITE(IGR)    TCCING,TCCOTG,TAIRIN,TAIROT,DELTM,QAIRHT
     1,   UNITS,$THTXR,TOTMCC,TOTGPM,$WH,SUMCST
      IF(JP.GT.1) GO TO 1
      IF(JJ.EQ.1.OR.JJ.GT.1) GO TO 1
      CALL GRBTU(QEQUIP,AGLAZE)
```

```
 1    CONTINUE
      RETURN
      END
C   ****************************************************************************
      SUBROUTINE GRBTU(QEQUIP,AGLAZE)
      COMMON /INCR/JI,JJ,JP,JPE,IE
      DIMENSION JWIND(5),ITOSDB(19),QAHEAT(19,5),UVALW(6)
      DATA E/.95/
      DATA UVALW/.529,.711,.766,.8,.821,.836/
      DO 500 IN=60,75,5
      TISDB= FLOAT(IN)
      TOSDB=65.
      DO 100 I=1,19
      TOSDB = TOSDB-5.
      ITOSDB(I) = TOSDB
      VWIND=-5.
      DO 50 J=1,5
      VWIND = VWIND+5.
      JWIND(J) = VWIND
      TGLAZE = (TISDB+TOSDB)/2.
      CALL TLOOK(VWIND,UVALW,6,0.,5.,WUVAL,IERR)
      HW=WUVAL
      QCOND = HW*(TGLAZE-TOSDB)*AGLAZE
      TSKY=TOSDB
      HRADSK = (((TGLAZE+460.)**4 - (TSKY+460.)**4))*0.174E-8
      QRADSK = HRADSK*E*AGLAZE
      QSDIR = 0.
      QSDIF = 0.
      QSOLHT = 0.
      QSOLOS = QSOLHT
      QAHEAT(I,J) = QCOND+QRADSK+QSOLOS-QEQUIP-QSDIR-QSDIF-QSOLHT
   50 CONTINUE
  100 CONTINUE
      WRITE(6,38)
 38   FORMAT('1')
      WRITE(6,39)
 39   FORMAT('0')
      WRITE(6,40)
 40   FORMAT('0')
      WRITE(6,8000) TISDB
 8000 FORMAT(1H ,5X,'GREENHOUSE HEATING REQUIREMENT(5000 SQ FT FLOOR ARE
     1A',T61,F3.0,' DEG F INSIDE AIR TEMPERATURE)')
      WRITE(6,9000)
 9000 FORMAT (1H ,5X,'MAX HOUR DESIGN HEATING LOAD FOR WINTER:(NIGHT CON
     1DITIONS, SOLAR=0) BTU/HR')
      WRITE(6,9001) (JWIND(I),I=1,5)
```

```
9001 FORMAT (/,10X,'WIND'/,10X,'VELOCITY',2X,5(I10,2X)/,10X,'(MI/HR)')
     WRITE(6,9002)
9002 FORMAT (/,1H ,'TEMP',/1H ,'OUTSIDE',/1H ,'DRY BULB',01H ,'(DEG F)'
    1)
     DO 200 I=1,19
     WRITE(6,9005) ITOSDB(I),(QAHEAT(I,J),J=1,5)
9005 FORMAT(/,1H ,7X,I3,10X,5(F10.0,2X))
 200 CONTINUE
 500 CONTINUE
     RETURN
     END
C**************************************************************************************
C
     SUBROUTINE FISH
     COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
     COMMON /INCR/JI,JJ,JP,JPE,IE
     COMMON /HEAT/ QAIRHT,QADDED,GMCCSS,AC
     COMMON/COST/ $WH,$XCHGR,$HTXER
     COMMON/TCC/ TCCINC,TCCOTC,TCCING,TCCOTG,TCCSSI,TCCSSO,
    1           DELTCC,DELTCG,DELTCF
     REAL*4 MFWREP,MRECIR,MCCSS,LTD,LMTD,MFTUBE,HFILMI,HFILMO,KVALI,
    1KVALO
     DIMENSION $XCHG(7)
     DATA $XCHG/8000.,11000.,12400.,13000.,13400.,13600.,13650./
     DATA CCSS/2280./
     DATA SAREA/1400./
     DATA MFWREP/19959./
     DATA MRECIR/139711./
     DATA HFILMI/100./
     DATA HFILMO/1.5/
     DATA TAIR/65./
     DATA KVALI/.021/
     DATA KVALO/.016/
     DATA EMISIV /.8/
     DATA TFWREP/55./
     DATA TRECIR/80./
     DATA TREARW/83./
     DATA F/.9/
     DATA U/200./
     TCCSSI=TCCOTC
     CF=60.*0.1337*62.2
     MCCSS=CCSS*CF
     MFTUBE=MFWREP+MRECIR
     TCIRIN=(MFWREP*TFWREP+MRECIR*TRECIR)/MFTUBE
     TWALL=(TREARW+TAIR)/2.
     QTLOSS=SAREA*(TREARW-TAIR)/((1./HFILMI)+(.02/KVALI)+(.25/KVALO)+
```

```
     1(1./HFILMO))+.00000000174*SAREA*EMISIV*(TWALL**4.-TAIR**4.)
      QADDED=MFWREP*(TREARW-TFWREP)+MRECIR*(TREARW-TRECIR)+QTLOSS
      TCCSSO=TCCSSI-(QADDED/MCCSS)
      GTD=TCCSSO-TCIRIN
      LTD=TCCSSI-TREARW
      LMTD=(LTD-GTD)/ALOG(LTD/GTD)
      AC=QADDED/(U*F*LMTD)
      IF(AC.GT.1399.OR.AC.LT.529.) GO TO 9
      CALL TLOOK(AC,$XCHG,7,529.,145.,$XCHGR,IERR)
 3    DELTCC=TCCSSI-TCCSSO
      GMFWR=MFWREP/CF
      GMRECW=MRECIR/CF
      GMFTUB=MFTUBE/CF
      GMCCSS=MCCSS/CF
      FXRT=$XCHGR/175200.
      SUMFF=FXRT+$WH
      WRITE(IFS)   GMFWR,GMRECW,GMFTUB,GMCCSS,TCCSSI,TCCSSO,DELTCC,
     1TCIRIN,TREARW,QTLOSS,QADDED,AC,$XCHGR,$WH,SUMFF
 9    CONTINUE
 4    RETURN
      END
C*******************************************************************************
      SUBROUTINE ECON
      COMMON /INCR/JI,JJ,JP,JPE,IE
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /HEAT/ QAIRHT,QADDED,GMCCSS,AC
      COMMON/COST/ $WH,$XCHGR,$HTXER
      COMMON/TCC/ TCCINC,TCCOTC,TCCING,TCCOTG,TCCSSI,TCCSSO,
     1              DELTCC,DELTCG,DELTCF
      DATA $CHBTU/3.804E-6/
      FBTURF=1000000.
      QHRYR= 8760.
      $CHUNT= 10000.
      CHQREF= 1000000.
      PRODRF= 7500.
      $PRODU= .5
      IF(IE.EQ.1) GO TO 1
      IF(AC.GT.1399.OR.AC.LT.529.) GO TO 6
      DO 4 IM=1,10,1
      BTUREQ=FBTURF*IM
      $CHHR=$CHBTU*BTUREQ
      $CHYR=$CHHR*QHRYR
      $WHYR=$WH*QHRYR
      WHUNTS=BTUREQ/QADDED
      $WHSYS=WHUNTS*$XCHGR
      CHUNTS=BTUREQ/CHQREF
```

```
      $CHSYS=CHUNTS*$CHUNT
      ADDCST=$WHSYS-$CHSYS
      TOTGPM=WHUNTS*GMCCSS
      PROD=PRODRF*IM
      $GI= PROD*$PRODU
      $GIAWH=$GI-$WHYR
      $GIACH=$GI-$CHYR
      $WHSAV=$GIAWH-$GIACH
      TCCINF=TCCOTC
      WRITE(IEF) TCCINF,
     1         $WH,$CHHR,$CHYR,$WHYR,WHUNTS,$WHSYS,CHUNTS,$CHSYS,
     2   ADDCST,          TOTGPM,PROD,$GI,$GIAWH,$GIACH,$WHSAV
    4 CONTINUE
      GO TO 6
    1 GAFREF=5000.
      GBTURF=403504.
      GAL=1248.
      GATOP= 6552.
      GAW= 200.
      RATMCC= 60002.
      CHQREF=235000.
      QHRYR= 1700.
      $WHUNT= $HTXER
      $CHUNT= 3400.
      PRODRF= 20661.
      $PRODU= .35
      GASREF= 8000.
      DO 5 IM=1,10,1
      GAFREQ=GAFREF*IM
      GASREQ=GATOP*IM+2*GAL + 2*GAW*IM
      ACRES=GAFREQ/43560.
      BTUREQ=(GASREQ/GASREF)*GBTURF
      $CHHR=$CHBTU*BTUREQ
      $CHYR=$CHHR*QHRYR
      $WHYR=$WH*QHRYR
      WHUNTS=BTUREQ/QAIRHT
      $WHSYS=WHUNTS*$WHUNT
      CHUNTS=BTUREQ/CHQREF
      $CHSYS=CHUNTS*$CHUNT
      ADDCST=$WHSYS-$CHSYS
      TOTGPM=WHUNTS*RATMCC/500.53
      PROD=PRODRF*IM
      $GI= PROD*$PRODU
      $GIAWH=$GI-$WHYR
      $GIACH=$GI-$CHYR
      $WHSAV=$GIAWH-$GIACH
```

```
      SUMCST=$WHSYS/175200.+ $WH
 3    WRITE(IEG) GAFREQ,
     1   GASREQ,ACRES,BTUREQ,SUMCST,
     2     TCCING,$WH,$CHHR,$CHYR,$WHYR,WHUNTS,$WHSYS,CHUNTS,$CHSYS,
     3     ADDCST,         TOTGPM,PROD,$GI,$GIAWH,$GIACH,$WHSAV
 5    CONTINUE
 6    RETURN
      END
C***********************************************************************
      SUBROUTINE TLOOK(X,Y,NY,X1,DX,R,IERR)
      COMMON /INCR/JI,JJ,JP,JPE,IE
      DIMENSION Y(NY)
      IERR =0
      F=(X-X1)/DX + 1.0
      I=IFIX(F)
      IF(I.GE.NY.OR.I.LT.1) GO TO 800
      R=Y(I)+(F-FLOAT(I))*(Y(I+1)-Y(I))
      RETURN
  800 CONTINUE
      WRITE(6,100)
  100 FORMAT(' ','TABLE LOOKUP INDEX OUT OF RANGE')
      IERR=1
      R=0.
      RETURN
      END
C***********************************************************************
      SUBROUTINE PRINT
      COMMON/IO/ IPP,IGR,IFS,ISH,IPE,IRF,IEG,IEF
      COMMON /INCR/JI,JJ,JP,JPE,IE
      DIMENSION EFDATA(16)
      DIMENSION EGDATA(21)
      DIMENSION GDATA(12)
      DIMENSION FDATA(15)
      DIMENSION RDATA(9)
      DIMENSION PDATA(14)
      DIMENSION EDATA(13)
      DIMENSION SDATA(21)
      IF(JJ.EQ.2.) GO TO 320
      REWIND IRF
      WRITE(6,100)
 100  FORMAT('1')
      IF(JI.EQ.2) GO TO 99
      WRITE(6,101)
 101  FORMAT('0',T6,'ISU POWER PLANT UNIT # 5, NORMAL CONDENSER OPERATIO
     1N')
      GO TO 103
```

```
99    WRITE(6,102)
102   FORMAT('0',T6,'AMES POWER PLANT UNIT # 7, NORMAL CONDENSER OPERATI
     1ON')
103   WRITE(6,104)
104   FORMAT(' ',T6,'HGREF',T13,'T INREF',T24,'T OUTREF',T37,'KWREF',T46
     1,'$ELECT',T58,'BTUREF',T70,'BTUCOST',T82,'CONDENSER LOAD',T99,
     2          'CIRCULATION')
      WRITE(6,105)
105   FORMAT(T6,'INCHES',T14,'DEG F',T25,'DEG F',T38,'KW',T46,'$/KWHR',T
     158,'BTU/HR',T70,'$/MEGABTU',T86,'LBM/HR',T103,'GPM')
106   READ(IRF, END=107) RDATA
      WRITE(6,108)  RDATA
108   FORMAT(' ',4X,F5.3,3X,F5.2,6X,F5.2,7X,F6.0,4X,F5.3,7X,F10.0,4X,F4.
     1       2,10X,F7.0,8X,F6.0)
      GO TO 106
107   CONTINUE
      REWIND IRF
      REWIND IPP
98    WRITE(6,109)
109   FORMAT('0',T6,'EXIT TEMP',T17,'INCHES',T25,'EFFIC',T33,'HEAT',T3
     19,'COOLANT',T48,'COOLANT',T57,'DELTA',T64,'$KW',T73,'DELTA',T82,
     2'DELTA',T92,'QOUT',T99,'CONDENSER',T110,'COOLANT',T119,'PUMPING')
      WRITE(6,110)
110   FORMAT(T7,'STEAM',T19,'HG',T27,'%',T33,'RATE',T40,'T IN',T49,'T OU
     1T',T58,'KW',T64,'LOSS',T73,'BTU',T82,'BTU COST',T92,'MEGA',T100
     2,'LOAD',T111,'GPM',T120,'COST')
      WRITE(6,111)
111   FORMAT(T7,'DEG F',T18,'ABS',T31,'BTU/KWHR',T40,'DEG F',T49,' DEG F
     1',T64,'$/HR',T73,'BTU/HR',T83,'$/HR',T91,'BTU/HR',T100,'LBM/HR'
     2,T120,'$/HR')
112   READ(IPP, END=113)  PDATA
      WRITE(6,114) PDATA
114   FORMAT(6X,F5.1,5X,F5.3,3X,F5.2,2X,F6.0,2X,F5.1,3X,F5.1,4X,F5.0,2
     1X,F5.2,2X,F9.0,2X,F6.3,3X,F7.3,2X,F7.0,3X,F6.0,2X,F5.2)
      GO TO 112
113   CONTINUE
      REWIND IPP
299   REWIND IGR
      WRITE(6,300)
300   FORMAT('1')
      WRITE(6,301)
301   FORMAT('0',T7,'GREENHOUSE HEATING, 5000 SQ FT FLOOR AREA, INSIDE A
     1IR =60 DEG F, OUTSIDE AIR=0 DEG F, 5 MPH')
      WRITE(6,302)
302   FORMAT('0',T7,'TCCING',T15,'TCCOTG',T23,'TAIRIN',T31,'TAIROT',T39,
     1'DELTM',T49,'QAIRHT',T58,'NUNITS',T67,'HEATER',T76,'TOTMCC',T84,
```

```
     2'TOTGPM',T92,'WHCOST',T101,'SUMCOST')
      WRITE(6,303)
303   FORMAT(T7,'DEG F',T15,'DEG F',T23,'DEG F',T31,'DEG F',T39,'DEG F',
     1T49,'BTU/HR',T67,'DOLLARS',T76,'LB/HR',T84,'GAL/MIN',T93,'$/HR',
     2T102,'$/HR')
304   READ(IGR,END=306) GDATA
      WRITE(6,307) GDATA
307   FORMAT(1H ,4X,5(F5.1,3X),F9.0,1X,F7.2,3X,F7.0,1X,F8.0,2X,F6.0,1X,
     1F6.3,4X,F6.3)
      GO TO 304
306   CONTINUE
      REWIND IGR
      REWIND IFS
      WRITE(6,400)
400   FORMAT('1')
      WRITE(6,401)
401   FORMAT('0')
      WRITE(6,402)
402   FORMAT('0',T5,'AQUACULTURE(CATFISH PRODUCTICN UNIT HEATING REQUIRE
     1MENTS')
      WRITE(6,403)
403   FORMAT(T5,'REARING WATER TEMP=83 DEG F, ROOM AIR TEMP=65 DEG F, RE
     1PLACEMENT WATER =55 DEG F')
      WRITE(6,405)
405   FORMAT(' ')
      WRITE(6,406)
406   FORMAT(T5,'FRESH',T12,'RECIRC',T20,'TUBE',T26,'SHELL',T32,
     1'SHELL OUT',T41,'SHELL OUT'
     2                 ,T52,'DELTCC ',T60,'CIRC IN',T69,'TANK',T76,'QLOSS
     3',T83,'QADDED',T92,'AREA',T99,'EXCOST',T107,'WHCOST',T115,'SUMCOST
     3')
      WRITE(6,407)
407   FORMAT(T6,'GPM',T12,'GPM',T20,'GPM',T26,'GPM',T33,'DEG F',T43,'DEG
     1 F',T53,'DEG F',T61,'DEG F',T70,'DEG F',T76,'BTU/HR',T83,'BTU/HR',
     2T92,'SQ FT',T101,'$',T108,'$/HR',T116,'$/HR')
408   READ(IFS, END=410) FDATA
      WRITE(6,409) FDATA
409   FORMAT(5X,F3.0,4X,F4.0,3X,F4.0,2X,F5.0,2X,F5.1,4X,F5.1,5X,F5.3,4X,
     1F4.1,5X,F4.1,2X,F5.0,2X,F7.0,2X,F5.0,2X,F6.0,2X,F6.3,2X,F6.3)
      GO TO 408
410   CONTINUE
      REWIND IFS
      REWIND ISH
      REWIND IEF
      WRITE(6,12)
12    FORMAT('0',T2,'TCCINF',T9,'$WH',T15,'$CHHR',T23,'$CHYR',T31,
```

```
     1 '$WHYR',T39,'WHUNTS',T46,'$WHSYS',T53,'CHUNTS',T60,'$CHSYS',
     2          T72,'ADDCST',                   T81,'TOTGPM',T88,'PROD',T96,
     3'$GI',T105,'$GIAWH',T112,'$GIACH',T119,'$WHFUELSAV')
32    READ(IEF,END=33) EFDATA
      WRITE(6,13)(EFDATA(I),I=1,16)
13    FORMAT(T2,F5.1,1X,2(F6.3,1X),2(F7.0,1X),F5.0,2X,F8.0,1X,F3.0,2X,F7
     1      .0,5X,F8.0,1X,F9.0,1X,F7.0,1X,F8.0,1X,2(F8.0,1X),F8.0)
      GO TO 32
33    CONTINUE
      REWIND IEF
      REWIND IEG
      WRITE(6,16)
16    FORMAT('0',T39,
     1      'GAFREQ',T48,'GASREQ',T57,'ACRES',T63,'BTUREQ',T75,'SUMCST')
36    READ(IEG,END=37) EGDATA
      WRITE(6,17)(EGDATA(I),I=1,5)
17    FORMAT(T39,2(F7.0,2X),F4.1,2X,F10.0,2X,F5.2)
      GO TO 36
37    CONTINUE
      REWIND IEG
      WRITE(6,18)
18    FORMAT('0',T2,'TCCING',T9,'$WH',T15,'$CHHR',T23,'$CHYR',T31,
     1 '$WHYR',T39,'WHUNTS',T46,'$WHSYS',T53,'CHUNTS',T60,'$CHSYS',
     2          T72,'ADDCST',                   T81,'TOTGPM',T88,'PROD',T96,
     3'$GI',T105,'$GIAWH',T112,'$GIACH',T119,'$WHFUELSAV')
38    READ(IEG,END=39) EGDATA
      WRITE(6,21)(EGDATA(I),I=6,21)
21    FORMAT(T2,F5.1,1X,2(F6.3,1X),2(F7.0,1X),F5.0,2X,F8.0,1X,F3.0,2X,F7
     1      .0,5X,F8.0,1X,F9.0,1X,F7.0,1X,F8.0,1X,2(F8.0,1X),F8.0)
      GO TO 38
39    CONTINUE
      REWIND IEG
      GO TO 310
320   REWIND IPE
      WRITE(6,200)
200   FORMAT('1')
      WRITE(6,201)
201   FORMAT('0',T5,'HEATER STEAM EXTRACTION FROM ISU POWER PLANT UNIT #
     15, 90 PSIG STEAM, 11.5MW, 2.0 INCHES HG')
      WRITE(6,202)
202   FORMAT('0',T5,'CONDENSER',T16,'QEXT',T23,'T OUT',T30,'DELTA',T38
     1     ,'STEAM',T45,'COST
     1',T53,'DELTA',T62,'THROTTLE',T72,'DELTA',T79,'KWHR',T86,'CONDENSER
     2',T97,'DEL  Q',T108,'HEATER')
      WRITE(6,203)
203   FORMAT(T16,'MEGA',T30,'EXTRACT',T38,'COST',T45,'$ PER'
```

```
     1,T53,'THROTTLE',T64,'FLOW',T79,'$LOSS',T86,'STEAM FLO',T97,'CONDEN
     2SER',T108,'Q OUT')
      WRITE(6,204)
 204  FORMAT(T7,'GPM',T16,'BTU/HR',T23,'DEG F',T30,'LBM/HR',T38,'$/HR',T
     145,'MEGABTU',T54,'LBM/HR',T63,'LBM/HR',T73,'KW',T79,'$/HR',T87,'LB
     2M/HR',T98,'BTU/HR',T108,'MBTU/HR')
 205  READ( IPE, END=206) EDATA
      WRITE(6,207) EDATA
 207  FORMAT(6X,F4.0,5X,F4.1,2X,F5.1,2X,F6.0,3X,F5.2,2X,F4.2,4X,F6.0,
     1         3X,F7.0,3X,F4.0,2X,F5.2,3X,F6.0,5X,F9.0,2X,F4.1)
      GO TO 205
 206  CONTINUE
      REWIND IPE
 310  RETURN
      END
C********************************************************************************
C
 &PPLNT
 BTUREF=1.192665E8, KWREF=1.15E4, SMRC=8.418E4, HGREF=1.5EC,
 WATVEL=5.0,CCMRC=3.904134E6,AREA=12.E3,
 BTUCST=1.05E0, ELECST=.02E0
 &END
 &PPLNT
 BTUREF=3.09045E8, KWREF=3.3E4, SMRC=2.1087E5, HGREF=1.5E0,
 WATVEL=6.E0,CCMRC=8.00848E6, AREA=26.0E3,
  BTUCST=1.05E0, ELECST=.04E0
 &END
```

APPENDIX J. COMPUTER SIMULATION RESULTS

General

The computer simulation results are presented in Tables J.1 through J.14. Initial conditions and important parameters are listed at the top of each table. A discussion of the tables is presented in the Results section of this report.

Table J.1. ISU power plant unit #5 normal condenser operation 1.0 inches Hg reference backpressure

HGREF INCHES	T INREF DEG F	T OUTREF DEG F	KWREF KW	$ELECT $/KWHR	BTUREF BTU/HR	BTUCOST $/MEGABTU	CONDENSER LOAD LBM/HR	CIRCULATION GPM
1.000	46.57	68.58	11500.	0.020	117426400.	1.05	81880.	7800.

EXIT TEMP STEAM DEG F	INCHES HG ABS	EFFIC %	HEAT RATE BTU/KWHR	COOLANT T IN DEG F	COOLANT T OUT DEG F	DELTA KW	$KW LOSS $/HR	DELTA BTU BTU/HR	DELTA BTU COST $/HR	QOUT MEGA BTU/HR	CONDENSER LOAD LBM/HR	COOLANT GPM	PUMPING COST $/HR
79.3	1.015	33.41	10216.	47.6	69.6	6.	0.12	55200.	0.070	85.976	81949.	7800.	4.47
80.1	1.041	33.38	10224.	48.6	70.6	16.	0.32	152128.	0.192	86.069	82071.	7800.	4.47
80.8	1.069	33.35	10233.	49.6	71.6	27.	0.53	253200.	0.320	86.167	82197.	7800.	4.47
81.6	1.098	33.32	10242.	50.6	72.7	38.	0.76	360368.	0.456	86.270	82331.	7800.	4.47
82.5	1.129	33.29	10252.	51.6	73.7	50.	0.99	472144.	0.597	86.378	82471.	7800.	4.47
83.3	1.159	33.26	10262.	52.6	74.7	61.	1.23	584960.	0.740	86.487	82613.	7800.	4.47
84.1	1.190	33.23	10272.	53.6	75.7	73.	1.46	698544.	0.884	86.596	82755.	7800.	4.47
85.0	1.221	33.19	10282.	54.6	76.8	85.	1.70	812960.	1.028	86.706	82898.	7800.	4.47
85.8	1.253	33.16	10292.	55.6	77.8	97.	1.94	928048.	1.174	86.817	83043.	7800.	4.47
86.7	1.284	33.13	10302.	56.6	78.8	109.	2.19	1043808.	1.320	86.928	83188.	7800.	4.47
87.5	1.316	33.10	10312.	57.6	79.9	122.	2.43	1160272.	1.468	87.039	83333.	7800.	4.47
88.4	1.352	33.06	10323.	58.6	80.9	135.	2.71	1292688.	1.635	87.171	83499.	7800.	4.47
89.3	1.395	33.02	10337.	59.6	81.9	152.	3.03	1448848.	1.833	87.333	83695.	7800.	4.47
90.2	1.439	32.97	10351.	60.6	83.0	169.	3.37	1610400.	2.037	87.500	83897.	7800.	4.47
91.1	1.483	32.93	10365.	61.6	84.0	186.	3.71	1775120.	2.246	87.671	84104.	7800.	4.47
92.1	1.528	32.88	10380.	62.6	85.1	203.	4.07	1944176.	2.459	87.827	84295.	7800.	4.47
93.0	1.573	32.83	10395.	63.6	86.1	221.	4.42	2114928.	2.676	87.972	84478.	7800.	4.47
93.9	1.618	32.79	10410.	64.6	87.1	239.	4.77	2285504.	2.891	88.117	84660.	7800.	4.47
94.8	1.663	32.74	10425.	65.6	88.2	256.	5.13	2456400.	3.107	88.262	84843.	7800.	4.47
95.8	1.708	32.69	10439.	66.6	89.2	274.	5.48	2627744.	3.324	88.408	85026.	7800.	4.47
96.7	1.753	32.65	10454.	67.6	90.3	292.	5.84	2799584.	3.542	88.553	85209.	7800.	4.47
97.6	1.799	32.60	10469.	68.6	91.3	310.	6.20	2971744.	3.759	88.699	85393.	7800.	4.47
98.6	1.851	32.55	10487.	69.6	92.3	330.	6.61	3172496.	4.013	88.876	85607.	7800.	4.47
99.6	1.913	32.48	10507.	70.6	93.4	355.	7.09	3407792.	4.311	89.088	85859.	7800.	4.47
100.6	1.978	32.42	10529.	71.6	94.4	380.	7.60	3652240.	4.620	89.308	86120.	7800.	4.47
101.6	2.042	32.36	10548.	72.6	95.5	403.	8.07	3881072.	4.910	89.517	86369.	7800.	4.47
93.3	1.603	32.80	10405.	72.6	87.4	233.	4.65	2227680.	2.818	88.054	84598.	12025.	8.95
94.1	1.628	32.78	10413.	73.6	88.2	243.	4.85	2324144.	2.940	88.152	84701.	12025.	8.95
95.1	1.676	32.73	10429.	74.6	89.2	261.	5.23	2503600.	3.167	88.303	84893.	12025.	8.95
96.1	1.724	32.68	10445.	75.6	90.3	280.	5.61	2686992.	3.399	88.458	85089.	12025.	8.95
97.1	1.772	32.63	10461.	76.6	91.3	299.	5.99	2870592.	3.631	88.614	85285.	12025.	8.95
98.1	1.821	32.58	10477.	77.6	92.3	318.	6.37	3055456.	3.865	88.771	85482.	12025.	8.95
99.1	1.883	32.51	10497.	78.6	93.4	343.	6.86	3294288.	4.167	88.986	85738.	12025.	8.95
100.1	1.947	32.45	10519.	79.6	94.4	368.	7.36	3536368.	4.474	89.205	85996.	12025.	8.95
101.1	2.011	32.38	10539.	80.6	95.4	392.	7.85	3774496.	4.775	89.420	86252.	12025.	8.95
102.1	2.075	32.33	10558.	81.6	96.5	415.	8.30	3991760.	5.050	89.619	86491.	12025.	8.95
103.1	2.138	32.27	10577.	82.6	97.5	437.	8.74	4208240.	5.324	89.816	86730.	12025.	8.95
104.1	2.201	32.21	10596.	83.6	98.5	459.	9.18	4424720.	5.598	90.013	86968.	12025.	8.95
105.1	2.265	32.15	10615.	84.6	99.6	481.	9.62	4641152.	5.871	90.210	87206.	12025.	8.95
102.0	2.080	32.32	10560.	84.6	96.5	417.	8.33	4009888.	5.073	89.645	86511.	14952.	13.42
103.0	2.131	32.27	10575.	85.6	97.6	435.	8.69	4185600.	5.295	89.797	86705.	14952.	13.42
104.0	2.194	32.22	10594.	86.6	98.6	457.	9.13	4399440.	5.566	89.991	86940.	14952.	13.42
105.0	2.257	32.16	10612.	87.6	99.6	479.	9.57	4615088.	5.838	90.187	87178.	14952.	13.42
106.0	2.320	32.10	10631.	88.6	100.6	501.	10.01	4830832.	6.111	90.383	87415.	14952.	13.42
107.0	2.384	32.05	10650.	89.6	101.7	523.	10.45	5046608.	6.384	90.578	87653.	14952.	13.42
108.0	2.448	31.99	10669.	90.6	102.7	545.	10.90	5264432.	6.660	90.775	87893.	14952.	13.42
109.1	2.530	31.92	10693.	91.6	103.7	573.	11.45	5539008.	7.007	91.032	88192.	14952.	13.42
110.1	2.613	31.85	10716.	92.6	104.8	600.	11.99	5807696.	7.347	91.275	88477.	14952.	13.42
111.1	2.697	31.78	10739.	93.6	105.8	626.	12.53	6075712.	7.686	91.517	88762.	14952.	13.42
112.1	2.780	31.71	10763.	94.6	106.8	653.	13.06	6343616.	8.025	91.758	89047.	14952.	13.42
113.2	2.864	31.64	10786.	95.6	107.9	680.	13.59	6611568.	8.364	92.000	89332.	14952.	13.42
114.2	2.947	31.57	10809.	96.6	108.9	706.	14.12	6879408.	8.703	92.240	89617.	14952.	13.42
115.2	3.030	31.51	10832.	97.6	109.9	733.	14.65	7146608.	9.041	92.473	89895.	14952.	13.42
116.3	3.114	31.44	10856.	98.6	111.0	759.	15.18	7412192.	9.377	92.693	90159.	14952.	13.42
117.3	3.197	31.37	10879.	99.6	112.0	785.	15.70	7677072.	9.712	92.911	90423.	14952.	13.42
118.3	3.284	31.30	10903.	100.6	113.0	812.	16.25	7956528.	10.065	93.144	90701.	14952.	13.42
119.3	3.389	31.22	10932.	101.6	114.1	845.	16.89	8288800.	10.486	93.431	91032.	14952.	13.42
120.3	3.494	31.14	10961.	102.6	115.1	877.	17.55	8624464.	10.910	93.721	91366.	14952.	13.42

Table J.2. ISU power plant unit #5 normal condenser operation 1.5 inches Hg reference backpressure

HGREF INCHES	T INREF DEG F	T OUTREF DEG F	KWREF KW	$ELECT $/KWHR	BTUREF BTU/HR	BTUCOST $/MEGABTU	CONDENSER LOAD LBM/HR	CIRCULATION GPM
1.500	61.62	84.10	11500.	0.020	119266400.	1.05	84180.	7800.

EXIT TEMP STEAM DEG F	INCHES HG ABS	EFFIC %	HEAT RATE BTU/KWHR	COOLANT T IN DEG F	COOLANT T OUT DEG F	DELTA KW	$KW LOSS $/HR	DELTA BTU BTU/HR	DELTA BTU COST $/HR	QOUT MEGA BTU/HR	CONDENSER LOAD LBM/HR	COOLANT GPM	PUMPING COST $/HR
92.1	1.532	32.88	10381.	62.6	85.1	12.	0.25	117248.	0.148	87.839	84309.	7800.	4.47
93.0	1.576	32.83	10396.	63.6	86.2	30.	0.59	284016.	0.359	87.980	84487.	7800.	4.47
94.0	1.620	32.78	10411.	64.6	87.2	47.	0.95	454304.	0.575	88.125	84669.	7800.	4.47
94.9	1.665	32.74	10425.	65.6	88.2	65.	1.31	625264.	0.791	88.270	84852.	7800.	4.47
95.8	1.711	32.69	10440.	66.6	89.3	83.	1.66	796624.	1.008	88.415	85035.	7800.	4.47
96.7	1.756	32.64	10455.	67.6	90.3	101.	2.02	968464.	1.225	88.561	85219.	7800.	4.47
97.7	1.801	32.60	10470.	68.6	91.3	119.	2.38	1140656.	1.443	88.706	85403.	7800.	4.47
98.6	1.854	32.54	10488.	69.6	92.4	140.	2.80	1344096.	1.700	88.886	85620.	7800.	4.47
99.6	1.917	32.48	10508.	70.6	93.4	165.	3.29	1580384.	1.999	89.099	85872.	7800.	4.47
100.7	1.981	32.41	10530.	71.6	94.5	190.	3.80	1824960.	2.309	89.320	86134.	7800.	4.47
101.7	2.045	32.35	10549.	72.6	95.6	213.	4.27	2052432.	2.596	89.527	86382.	7800.	4.47
102.7	2.110	32.29	10569.	73.6	96.6	236.	4.72	2271568.	2.874	89.727	86623.	7800.	4.47
103.7	2.174	32.24	10588.	74.6	97.7	258.	5.17	2490288.	3.150	89.926	86864.	7800.	4.47
104.7	2.238	32.18	10607.	75.6	98.7	281.	5.62	2708976.	3.427	90.125	87105.	7800.	4.47
105.7	2.302	32.12	10626.	76.6	99.8	303.	6.07	2927712.	3.704	90.324	87346.	7800.	4.47
106.8	2.366	32.06	10645.	77.6	100.8	326.	6.52	3146464.	3.980	90.522	87587.	7800.	4.47
107.8	2.430	32.01	10664.	78.6	101.9	348.	6.97	3365264.	4.257	90.720	87828.	7800.	4.47
108.8	2.507	31.94	10686.	79.6	102.9	375.	7.50	3626576.	4.588	90.965	88115.	7800.	4.47
109.8	2.591	31.87	10710.	80.6	104.0	402.	8.05	3895440.	4.928	91.208	88401.	7800.	4.47
101.5	2.050	32.35	10551.	80.6	95.7	215.	4.30	2066656.	2.614	90.951	86397.	12025.	8.95
102.2	2.080	32.32	10560.	81.6	96.5	225.	4.51	2169696.	2.745	89.637	86511.	12025.	8.95
103.2	2.141	32.27	10578.	82.6	97.5	247.	4.94	2379808.	3.011	89.827	86742.	12025.	8.95
104.2	2.205	32.21	10597.	83.6	98.6	269.	5.39	2595936.	3.284	90.023	86980.	12025.	8.95
105.2	2.268	32.15	10616.	84.6	99.6	292.	5.83	2812336.	3.558	90.220	87219.	12025.	8.95
106.2	2.332	32.09	10634.	85.6	100.6	314.	6.28	3028896.	3.832	90.417	87457.	12025.	8.95
107.2	2.395	32.04	10653.	86.6	101.7	336.	6.72	3245392.	4.106	90.613	87696.	12025.	8.95
108.2	2.461	31.98	10673.	87.6	102.7	359.	7.18	3470976.	4.391	90.819	87944.	12025.	8.95
109.2	2.543	31.91	10696.	88.6	103.8	387.	7.73	3741504.	4.733	91.070	88237.	12025.	8.95
110.2	2.626	31.84	10719.	89.6	104.8	414.	8.27	4006976.	5.069	91.310	88519.	12025.	8.95
111.3	2.709	31.77	10743.	90.6	105.8	441.	8.81	4274736.	5.408	91.551	88804.	12025.	8.95
112.3	2.793	31.70	10766.	91.6	106.9	468.	9.35	4544384.	5.749	91.795	89091.	12025.	8.95
113.3	2.877	31.63	10790.	92.6	107.9	495.	9.90	4814144.	6.090	92.037	89378.	12025.	8.95
110.2	2.636	31.83	10722.	92.6	104.9	417.	8.34	4041296.	5.112	91.577	88556.	14952.	13.42
111.2	2.702	31.78	10741.	93.6	105.9	438.	8.77	4252816.	5.380	91.533	88781.	14952.	13.42
112.2	2.785	31.71	10764.	94.6	106.9	465.	9.30	4517648.	5.715	91.771	89062.	14952.	13.42
113.2	2.868	31.64	10787.	95.6	107.9	492.	9.84	4785408.	6.054	92.012	89347.	14952.	13.42
114.3	2.951	31.57	10810.	96.6	108.9	519.	10.37	5053280.	6.393	92.253	89632.	14952.	13.42
115.3	3.035	31.50	10834.	97.6	110.0	545.	10.91	5320368.	6.731	92.485	89908.	14952.	13.42
116.3	3.118	31.44	10857.	98.6	111.0	572.	11.44	5585888.	7.066	92.704	90173.	14952.	13.42
117.3	3.201	31.37	10880.	99.6	112.0	598.	11.96	5850800.	7.402	92.922	90437.	14952.	13.42
118.3	3.290	31.30	10904.	100.6	113.1	626.	12.52	6133680.	7.759	93.159	90718.	14952.	13.42
119.4	3.394	31.22	10933.	101.6	114.1	659.	13.18	6466176.	8.180	93.446	91049.	14952.	13.42
120.4	3.499	31.13	10962.	102.6	115.1	692.	13.84	6801824.	8.605	93.736	91384.	14952.	13.42

Table J.3. Ames power plant unit #7 normal condenser operation 1.0 inches Hg reference backpressure

HGREF INCHES	T INREF DEG F	T OUTREF DEG F	KWREF KW	$ELECT $/KWHR	BTUREF BTU/HR	BTUCOST $/MEGABTU	CONDENSER LOAD LBM/HR	CIRCULATION GPM
1.000	39.99	67.18	33000.	0.040	308055000.	1.05	207570.	16000.

EXIT TEMP STEAM DEG F	INCHES HG ABS	EFFIC %	HEAT RATE BTU/KWHR	COOLANT T IN DEG F	COOLANT T OUT DEG F	DELTA KW	$KW LOSS $/HR	DELTA BTU BTU/HR	DELTA BTU COST $/HR	QOUT MEGA BTU/HR	CONDENSER LOAD LBM/HR	COOLANT GPM	PUMPING COST $/HR
79.8	1.031	36.55	9337.	41.0	68.2	7.	0.27	60672.	0.077	217.944	207785.	16000.	8.95
80.4	1.054	36.55	9338.	42.0	69.2	12.	0.47	105984.	0.134	218.030	207936.	16000.	8.95
81.0	1.077	36.54	9340.	43.0	70.2	17.	0.67	151552.	0.192	218.115	208088.	16000.	8.95
81.7	1.100	36.54	9341.	44.0	71.2	22.	0.88	198656.	0.251	218.202	208243.	16000.	8.95
82.3	1.125	36.53	9342.	45.0	72.2	27.	1.09	246528.	0.312	218.290	208403.	16000.	8.95
83.0	1.150	36.53	9344.	46.0	73.3	33.	1.31	295680.	0.374	218.381	208567.	16000.	8.95
83.7	1.175	36.52	9345.	47.0	74.3	38.	1.53	346112.	0.438	218.474	208734.	16000.	8.95
84.4	1.201	36.51	9347.	48.0	75.3	44.	1.76	397568.	0.503	218.568	208904.	16000.	8.95
85.1	1.227	36.51	9349.	49.0	76.3	50.	1.99	449536.	0.569	218.665	209077.	16000.	8.95
85.8	1.254	36.50	9350.	50.0	77.3	56.	2.23	502784.	0.636	218.762	209254.	16000.	8.95
86.6	1.283	36.49	9352.	51.0	78.3	62.	2.49	560896.	0.710	218.868	209446.	16000.	8.95
87.4	1.313	36.49	9354.	52.0	79.3	69.	2.75	619520.	0.784	218.976	209641.	16000.	8.95
88.3	1.345	36.48	9356.	53.0	80.3	76.	3.04	684032.	0.865	219.102	209856.	16000.	8.95
89.1	1.386	36.47	9358.	54.0	81.4	85.	3.39	762880.	0.965	219.276	210118.	16000.	8.95
89.9	1.425	36.46	9361.	55.0	82.4	94.	3.75	843008.	1.066	219.453	210384.	16000.	8.95
90.8	1.467	36.45	9363.	56.0	83.4	103.	4.12	923904.	1.169	219.632	210652.	16000.	8.95
91.6	1.508	36.44	9366.	57.0	84.4	114.	4.56	1021440.	1.292	219.801	210911.	16000.	8.95
92.5	1.549	36.42	9371.	58.0	85.4	133.	5.31	1189888.	1.505	219.926	211129.	16000.	8.95
93.3	1.590	36.40	9376.	59.0	86.5	152.	6.06	1357568.	1.717	220.050	211346.	16000.	8.95
94.2	1.632	36.38	9381.	60.0	87.5	171.	6.82	1526528.	1.931	220.175	211564.	16000.	8.95
95.0	1.674	36.36	9387.	61.0	88.5	190.	7.61	1701632.	2.153	220.304	211791.	16000.	8.95
95.9	1.718	36.34	9392.	62.0	89.5	210.	8.40	1877760.	2.375	220.433	212019.	16000.	8.95
96.8	1.751	36.32	9397.	63.0	90.5	230.	9.20	2054400.	2.599	220.563	212248.	16000.	8.95
97.7	1.804	36.30	9403.	64.0	91.5	250.	10.00	2231808.	2.823	220.693	212477.	16000.	8.95
98.6	1.857	36.27	9409.	65.0	92.6	274.	10.96	2444544.	3.092	220.869	212752.	16000.	8.95
99.5	1.914	36.25	9416.	66.0	93.6	301.	12.02	2678272.	3.388	221.072	213055.	16000.	8.95
100.5	1.971	36.22	9423.	67.0	94.6	327.	13.09	2913536.	3.686	221.276	213359.	16000.	8.95
101.4	2.029	36.18	9432.	68.0	95.6	360.	14.42	3208192.	4.059	221.540	213722.	16000.	8.95
102.3	2.083	36.14	9443.	69.0	96.7	401.	16.02	3565056.	4.510	221.866	214147.	16000.	8.95
103.3	2.147	36.10	9454.	70.0	97.7	441.	17.65	3926272.	4.967	222.196	214577.	16000.	8.95
104.3	2.210	36.06	9466.	71.0	98.8	484.	19.37	4310272.	5.453	222.547	215035.	16000.	8.95
105.3	2.273	36.01	9477.	72.0	99.8	528.	21.11	4696320.	5.941	222.900	215495.	16000.	8.95
106.3	2.337	35.97	9489.	73.0	100.9	571.	22.84	5082368.	6.430	223.252	215955.	16000.	8.95
107.3	2.400	35.92	9501.	74.0	101.9	614.	24.58	5468928.	6.919	223.603	216415.	16000.	8.95
108.3	2.468	35.88	9513.	75.0	103.0	661.	26.43	5880064.	7.439	223.984	216905.	16000.	8.95
109.3	2.550	35.81	9530.	76.0	104.0	721.	28.85	6421504.	8.124	224.393	217423.	16000.	8.95
110.3	2.632	35.75	9547.	77.0	105.0	785.	31.40	6993920.	8.848	224.753	217893.	16000.	8.95
101.4	2.045	36.17	9435.	77.0	94.2	372.	14.86	3306496.	4.183	224.422	213839.	26000.	17.90
102.1	2.076	36.15	9441.	78.0	95.0	393.	15.70	3493888.	4.420	221.804	214062.	26000.	17.90
103.1	2.137	36.11	9452.	79.0	96.1	434.	17.37	3864320.	4.889	222.141	214504.	26000.	17.90
104.1	2.199	36.06	9464.	80.0	97.1	477.	19.08	4244480.	5.370	222.488	214956.	26000.	17.90
105.1	2.262	36.02	9475.	81.0	98.1	520.	20.79	4624896.	5.851	222.835	215410.	26000.	17.90
106.1	2.324	35.98	9487.	82.0	99.1	562.	22.50	5005056.	6.332	223.183	215863.	26000.	17.90
107.1	2.387	35.93	9498.	83.0	100.2	605.	24.21	5385728.	6.813	223.530	216316.	26000.	17.90
108.0	2.449	35.89	9510.	84.0	101.2	648.	25.92	5766400.	7.295	223.875	216770.	26000.	17.90
109.0	2.529	35.83	9525.	85.0	102.2	706.	28.22	6280704.	7.945	224.306	217307.	26000.	17.90
110.0	2.610	35.77	9542.	86.0	103.2	768.	30.73	6844928.	8.659	224.661	217771.	26000.	17.90
111.0	2.691	35.70	9559.	87.0	104.3	830.	33.22	7404032.	9.367	225.012	218230.	26000.	17.90
112.0	2.771	35.64	9576.	88.0	105.3	893.	35.70	7963392.	10.074	225.362	218690.	26000.	17.90
113.0	2.852	35.58	9593.	89.0	106.3	954.	38.18	8522496.	10.781	225.711	219149.	26000.	17.90
114.0	2.932	35.51	9610.	90.0	107.4	1016.	40.65	9081856.	11.489	226.061	219609.	26000.	17.90
115.0	3.014	35.45	9628.	91.0	108.4	1079.	43.18	9653248.	12.212	226.462	220123.	26000.	17.90
116.1	3.097	35.39	9645.	92.0	109.4	1143.	45.71	10228220.	12.939	227.080	220851.	26000.	17.90
117.1	3.182	35.32	9663.	93.0	110.5	1208.	48.30	10816000.	13.683	227.714	221596.	26000.	17.90
118.2	3.268	35.25	9681.	94.0	111.5	1274.	50.95	11418110.	14.445	228.364	222359.	26000.	17.90
119.2	3.375	35.17	9704.	95.0	112.6	1356.	54.24	12167680.	15.393	229.073	223309.	26000.	17.90
120.3	3.486	35.09	9727.	96.0	113.7	1440.	57.59	12932090.	16.360	229.930	224277.	26000.	17.90

Table J.4. Ames power plant unit #7 normal condenser operation 1.5 inches Hg reference backpressure

HGREF INCHES	T INREF DEG F	T OUTREF DEG F	KWREF KW	$ELECT $/KWHR	BTUREF BTU/HR	BTUCOST $/MEGABTU	CONDENSER LOAD LBM/HR	CIRCULATION GPM
1.500	56.49	83.94	33000.	0.040	309044900.	1.05	210870.	16000.

EXIT TEMP STEAM DEG F	INCHES HG ABS	EFFIC %	HEAT RATE BTU/KWHR	COOLANT T IN DEG F	COOLANT T OUT DEG F	DELTA KW	$KW LOSS $/HR	DELTA BTU BTU/HR	DELTA BTU COST $/HR	QOUT MEGA BTU/HR	CONDENSER LOAD LBM/HR	COOLANT GPM	PUMPING COST $/HR
92.0	1.529	36.43	9369.	57.5	84.9	13.	0.54	119808.	0.152	219.868	211025.	16000.	8.95
92.9	1.570	36.41	9374.	58.5	86.0	32.	1.27	285184.	0.361	219.989	211239.	16000.	8.95
93.7	1.611	36.39	9379.	59.5	87.0	51.	2.03	453376.	0.574	220.114	211457.	16000.	8.95
94.6	1.653	36.37	9384.	60.5	88.0	70.	2.80	625408.	0.791	220.240	211679.	16000.	8.95
95.5	1.696	36.35	9389.	61.5	89.0	90.	3.58	801024.	1.013	220.369	211907.	16000.	8.95
96.4	1.740	36.33	9395.	62.5	90.0	109.	4.38	977664.	1.237	220.499	212135.	16000.	8.95
97.3	1.783	36.31	9400.	63.5	91.0	129.	5.17	1154560.	1.461	220.629	212364.	16000.	8.95
98.2	1.829	36.29	9406.	64.5	92.1	150.	6.01	1340928.	1.696	220.770	212605.	16000.	8.95
99.1	1.885	36.26	9413.	65.5	93.1	176.	7.06	1572864.	1.990	220.971	212905.	16000.	8.95
100.0	1.943	36.23	9420.	66.5	94.1	203.	8.12	1807872.	2.287	221.176	213209.	16000.	8.95
100.9	2.001	36.20	9427.	67.5	95.1	230.	9.19	2045184.	2.587	221.382	213516.	16000.	8.95
101.9	2.059	36.16	9438.	68.5	96.2	269.	10.78	2397952.	3.034	221.703	213936.	16000.	8.95
102.8	2.118	36.12	9449.	69.5	97.2	310.	12.40	2758400.	3.490	222.034	214366.	16000.	8.95
103.8	2.179	36.08	9460.	70.5	98.3	352.	14.07	3131392.	3.961	222.375	214810.	16000.	8.95
104.8	2.242	36.03	9472.	71.5	99.3	395.	15.81	3516672.	4.449	222.727	215269.	16000.	8.95
105.8	2.306	35.99	9483.	72.5	100.3	439.	17.54	3902720.	4.937	223.078	215729.	16000.	8.95
106.8	2.369	35.95	9495.	73.5	101.4	482.	19.28	4289024.	5.426	223.431	216189.	16000.	8.95
107.8	2.432	35.90	9507.	74.5	102.4	525.	21.01	4675072.	5.914	223.782	216649.	16000.	8.95
108.8	2.509	35.85	9521.	75.5	103.5	579.	23.15	5150720.	6.516	224.217	217192.	16000.	8.95
109.8	2.592	35.78	9538.	76.5	104.5	643.	25.71	5724672.	7.242	224.578	217664.	16000.	8.95
110.8	2.673	35.72	9556.	77.5	105.6	706.	28.24	6292992.	7.961	224.935	218131.	16000.	8.95
111.8	2.755	35.65	9573.	78.5	106.6	769.	30.76	6860544.	8.679	225.290	218597.	16000.	8.95
102.9	2.139	36.11	9453.	78.5	95.8	325.	12.99	2890240.	3.656	224.948	214523.	26000.	17.90
103.6	2.170	36.08	9458.	79.5	96.6	346.	13.83	3077632.	3.893	222.330	214746.	26000.	17.90
104.6	2.231	36.04	9469.	80.5	97.6	387.	15.50	3448064.	4.362	222.666	215187.	26000.	17.90
105.6	2.293	36.00	9481.	81.5	98.6	430.	17.21	3828224.	4.843	223.012	215640.	26000.	17.90
106.6	2.356	35.95	9493.	82.5	99.7	473.	18.92	4208896.	5.325	223.359	216093.	26000.	17.90
107.6	2.418	35.91	9504.	83.5	100.7	516.	20.63	4589568.	5.806	223.705	216547.	26000.	17.90
108.6	2.490	35.86	9517.	84.5	101.7	565.	22.59	5025280.	6.357	224.118	217066.	26000.	17.90
109.6	2.571	35.80	9534.	85.5	102.7	626.	25.06	5579008.	7.058	224.488	217544.	26000.	17.90
110.5	2.651	35.73	9551.	86.5	103.8	689.	27.55	6139392.	7.767	224.839	218004.	26000.	17.90
111.5	2.732	35.67	9568.	87.5	104.8	751.	30.04	6698240.	8.474	225.190	218464.	26000.	17.90
112.5	2.812	35.61	9585.	88.5	105.8	813.	32.52	7257600.	9.181	225.540	218923.	26000.	17.90
113.5	2.893	35.55	9602.	89.5	106.9	875.	35.00	7816960.	9.889	225.889	219383.	26000.	17.90
114.5	2.974	35.48	9619.	90.5	107.9	938.	37.51	8382464.	10.604	226.242	219847.	26000.	17.90
115.6	3.056	35.42	9636.	91.5	108.9	1001.	40.04	8954368.	11.328	226.775	220492.	26000.	17.90
116.6	3.140	35.35	9654.	92.5	110.0	1065.	42.61	9537024.	12.065	227.402	221230.	26000.	17.90
117.7	3.225	35.29	9672.	93.5	111.0	1130.	45.20	10125310.	12.809	228.036	221975.	26000.	17.90
118.7	3.323	35.21	9693.	94.5	112.1	1205.	48.21	10808570.	13.674	228.791	222841.	26000.	17.90
119.8	3.432	35.13	9716.	95.5	113.1	1288.	51.53	11566590.	14.632	229.510	223801.	26000.	17.90

Table J.5. ISU power plant unit #5 extraction operation 1.0 inches Hg reference backpressure

HEATER STEAM EXTRACTION FROM ISU POWER PLANT UNIT #5, 90 PSIG STEAM, 11.5MW, 1.0 INCHES HG

CONDENSER GPM	QEXT MEGA BTU/HR	T OUT DEG F	DELTA EXTRACT LBM/HR	STEAM COST $/HR	COST $ PER MEGABTU	DELTA THROTTLE LBM/HR	THROTTLE FLOW LBM/HR	DELTA KW	KWHR $LOSS $/HR	CONDENSER STEAM FLO LBM/HR	DEL Q CONDENSER BTU/HR	HEATER Q OUT MBTU/HR
100.	0.1	71.0	87.	0.16	3.25	60.	144560.	7.	0.14	94473.	27934.	0.1
100.	0.2	73.0	175.	0.33	2.17	121.	144621.	14.	0.28	94446.	55804.	0.2
100.	0.3	75.0	262.	0.49	1.96	181.	144681.	21.	0.43	94419.	83803.	0.3
100.	0.4	77.0	350.	0.66	1.87	242.	144742.	29.	0.57	94392.	111931.	0.4
100.	0.5	79.0	439.	0.82	1.82	304.	144804.	36.	0.72	94365.	140060.	0.5
100.	0.6	81.0	527.	0.99	1.79	365.	144865.	43.	0.86	94338.	168383.	0.6
100.	0.7	83.0	616.	1.15	1.77	427.	144927.	50.	1.01	94310.	196771.	0.7
100.	0.8	85.0	705.	1.32	1.76	488.	144988.	58.	1.15	94283.	225223.	0.8
100.	0.9	87.0	795.	1.49	1.75	550.	145050.	65.	1.30	94255.	253871.	0.9
100.	1.0	89.0	885.	1.65	1.74	613.	145113.	72.	1.44	94228.	282453.	1.0
100.	1.1	91.0	975.	1.82	1.73	675.	145175.	80.	1.59	94200.	311294.	1.1
100.	1.2	93.0	1066.	1.99	1.73	738.	145238.	87.	1.74	94172.	340136.	1.2
100.	1.3	95.0	1157.	2.16	1.73	801.	145301.	94.	1.89	94144.	369172.	1.3
100.	1.4	97.0	1248.	2.33	1.73	864.	145364.	102.	2.04	94116.	398273.	1.4
100.	1.5	99.0	1339.	2.50	1.73	927.	145427.	109.	2.18	94088.	427438.	1.5
100.	1.6	101.0	1431.	2.68	1.72	991.	145491.	117.	2.33	94060.	456799.	1.6
100.	1.7	103.0	1523.	2.85	1.72	1055.	145555.	124.	2.48	94031.	486159.	1.7
100.	1.8	105.0	1616.	3.02	1.72	1119.	145619.	132.	2.63	94003.	515713.	1.8
100.	1.9	107.0	1709.	3.20	1.73	1183.	145683.	139.	2.79	93974.	545332.	1.9
100.	2.0	109.0	1802.	3.37	1.73	1247.	145747.	147.	2.94	93946.	575017.	2.0
100.	2.1	111.0	1895.	3.54	1.73	1312.	145812.	155.	3.09	93917.	604830.	2.1
100.	2.2	113.0	1989.	3.72	1.73	1377.	145877.	162.	3.24	93888.	634838.	2.2
100.	2.3	115.0	2083.	3.90	1.73	1442.	145942.	170.	3.40	93859.	664911.	2.3
100.	2.4	117.0	2178.	4.07	1.73	1508.	146008.	178.	3.55	93830.	695049.	2.4
100.	2.5	119.0	2273.	4.25	1.73	1573.	146073.	185.	3.71	93801.	725317.	2.5
500.	0.5	71.0	436.	0.81	3.25	301.	144801.	36.	0.71	94366.	139088.	0.3
500.	1.0	73.0	873.	1.63	2.17	604.	145104.	71.	1.42	94231.	278629.	0.8
500.	1.5	75.0	1311.	2.45	1.96	908.	145408.	107.	2.14	94096.	418494.	1.3
500.	2.0	77.0	1751.	3.28	1.87	1212.	145712.	143.	2.86	93961.	558943.	1.8
500.	2.5	79.0	2193.	4.10	1.82	1518.	146018.	179.	3.58	93825.	699845.	2.3
500.	3.0	81.0	2636.	4.93	1.79	1825.	146325.	215.	4.30	93689.	841266.	2.8
500.	3.5	83.0	3081.	5.76	1.77	2133.	146633.	251.	5.02	93552.	983206.	3.3
500.	4.0	85.0	3527.	6.60	1.76	2442.	146942.	287.	5.75	93415.	1125598.	3.8
500.	4.5	87.0	3975.	7.43	1.75	2752.	147252.	324.	6.48	93277.	1268510.	4.3
500.	5.0	89.0	4425.	8.27	1.74	3063.	147563.	361.	7.21	93138.	1411940.	4.8
500.	5.5	91.0	4876.	9.12	1.73	3376.	147876.	397.	7.94	93000.	1555888.	5.3
500.	6.0	93.0	5329.	9.96	1.73	3689.	148189.	434.	8.68	92860.	1700355.	5.8
500.	6.5	95.0	5783.	10.81	1.73	4004.	148504.	471.	9.42	92721.	1845276.	6.3
500.	7.0	97.0	6239.	11.67	1.73	4319.	148819.	508.	10.16	92580.	1990715.	6.8
500.	7.5	99.0	6697.	12.52	1.73	4636.	149136.	545.	10.91	92440.	2136738.	7.3
500.	8.0	101.0	7156.	13.38	1.72	4954.	149454.	583.	11.65	92298.	2283279.	7.8
500.	8.5	103.0	7617.	14.24	1.72	5273.	149773.	620.	12.40	92156.	2430274.	8.3
500.	9.0	105.0	8079.	15.11	1.72	5593.	150093.	658.	13.15	92014.	2577787.	8.8
500.	9.5	107.0	8543.	15.98	1.73	5915.	150415.	695.	13.91	91871.	2725884.	9.3
500.	10.0	109.0	9009.	16.85	1.73	6237.	150737.	733.	14.66	91728.	2874499.	9.8
500.	10.5	111.0	9477.	17.72	1.73	6561.	151061.	771.	15.42	91584.	3023697.	10.3
500.	11.0	113.0	9946.	18.60	1.73	6886.	151386.	809.	16.18	91440.	3173349.	10.8
500.	11.5	115.0	10417.	19.48	1.73	7212.	151712.	847.	16.95	91295.	3323714.	11.3
500.	12.0	117.0	10889.	20.36	1.73	7539.	152039.	686.	17.71	91150.	3474403.	11.8
500.	12.5	119.0	11364.	21.25	1.73	7867.	152367.	924.	18.48	91004.	3625740.	12.3

Table J.6. ISU power plant unit #5 extraction operation 2.0 inches Hg reference backpressure

HEATER STEAM EXTRACTION FROM ISU POWER PLANT UNIT #5, 90 PSIG STEAM, 11.5MW, 2.0 INCHES HG

CONDENSER GPM	QEXT MEGA BTU/HR	T OUT DEG F	DELTA EXTRACT LBM/HR	STEAM COST $/HR	COST $ PER MEGABTU	DELTA THROTTLE LBM/HR	THROTTLE FLOW LBM/HR	DELTA KW	KWHR $LOSS $/HR	CONDENSER STEAM FLO LBM/HR	DEL Q CONDENSER BTU/HR	HEATER Q OUT MBTU/HR
100.	0.1	96.0	89.	0.17	0.13	62.	144562.	7.	0.29	94473.	28518.	1.3
100.	0.2	98.0	178.	0.33	0.24	123.	144623.	15.	0.58	94445.	57100.	1.4
100.	0.3	100.0	268.	0.50	0.33	186.	144686.	22.	0.87	94417.	85682.	1.5
100.	0.4	102.0	358.	0.67	0.42	248.	144748.	29.	1.17	94390.	114394.	1.6
100.	0.5	104.0	448.	0.84	0.49	310.	144810.	37.	1.46	94362.	143236.	1.7
100.	0.6	106.0	539.	1.01	0.56	373.	144873.	44.	1.76	94334.	172142.	1.8
100.	0.7	108.0	630.	1.18	0.62	436.	144936.	51.	2.06	94306.	201178.	1.9
100.	0.8	110.0	721.	1.35	0.67	499.	144999.	59.	2.35	94278.	230279.	2.0
100.	0.9	112.0	813.	1.52	0.72	563.	145063.	66.	2.65	94250.	259574.	2.1
100.	1.0	114.0	905.	1.69	0.77	626.	145126.	74.	2.95	94221.	288934.	2.2
100.	1.1	116.0	997.	1.86	0.81	690.	145190.	81.	3.25	94193.	318359.	2.3
100.	1.2	118.0	1090.	2.04	0.85	754.	145254.	89.	3.56	94165.	347914.	2.4
100.	1.3	120.0	1183.	2.21	0.88	819.	145319.	96.	3.86	94136.	377598.	2.5
500.	0.5	96.0	445.	0.83	0.13	308.	144808.	36.	1.45	94363.	142199.	6.5
500.	1.0	98.0	892.	1.67	0.24	618.	145118.	73.	2.91	94225.	284786.	7.0
500.	1.5	100.0	1340.	2.51	0.33	928.	145428.	109.	4.37	94087.	427827.	7.5
500.	2.0	102.0	1791.	3.35	0.42	1240.	145740.	146.	5.84	93949.	571452.	8.0
500.	2.5	104.0	2242.	4.19	0.49	1552.	146052.	183.	7.31	93810.	715530.	8.5
500.	3.0	106.0	2695.	5.04	0.56	1866.	146366.	220.	8.79	93671.	860062.	9.0
500.	3.5	108.0	3150.	5.89	0.62	2181.	146681.	257.	10.27	93531.	1005307.	9.5
500.	4.0	110.0	3607.	6.74	0.67	2497.	146997.	294.	11.76	93390.	1150875.	10.0
500.	4.5	112.0	4065.	7.60	0.72	2814.	147314.	331.	13.25	93249.	1297157.	10.5
500.	5.0	114.0	4525.	8.46	0.77	3133.	147633.	369.	14.75	93108.	1443763.	11.0
500.	5.5	116.0	4986.	9.32	0.81	3452.	147952.	406.	16.25	92966.	1591146.	11.5
500.	6.0	118.0	5450.	10.19	0.85	3773.	148273.	444.	17.76	92823.	1738789.	12.0
500.	6.5	120.0	5914.	11.06	0.88	4095.	148595.	482.	19.27	92680.	1887210.	12.5

Table J.7. Greenhouse heating from Ames unit #7, 33 MW 1.0 inches Hg reference backpressure

AMES POWER PLANT UNIT # 7, NORMAL CONDENSER OPERATION
GREENHOUSE HEATING, 5000 SQ FT FLOOR AREA, INSIDE AIR =60 DEG F, OUTSIDE AIR=0 DEG F, 5 MPH

TCCING DEG F	TCCOTG DEG F	TAIRIN DEG F	TAIROT DEG F	DELTM DEG F	QAIRHT BTU/HR	NUNITS	HEATER DOLLARS	TOTMCC LB/HR	TOTGPN GAL/MIN	WHCOST $/HR	SUMCOST $/HR
68.2	66.0	60.0	62.4	5.8	13722.	24.67	17020.	148045.	296.	0.076	0.174
69.2	66.8	60.0	62.7	6.5	15384.	22.00	15180.	132045.	264.	0.134	0.220
70.2	67.5	60.0	63.0	7.2	17057.	19.84	13691.	119096.	238.	0.192	0.270
71.2	68.2	60.0	63.3	7.9	18767.	18.03	12444.	108242.	216.	0.251	0.322
72.2	69.0	60.0	63.6	8.6	20478.	16.53	11404.	99199.	198.	0.312	0.377
73.3	69.7	60.0	63.9	9.3	22189.	15.25	10525.	91549.	183.	0.374	0.434
74.3	70.5	60.0	64.2	10.0	23901.	14.16	9771.	84993.	170.	0.438	0.494
75.3	71.2	60.0	64.5	10.8	25613.	13.21	9118.	79312.	158.	0.503	0.555
76.3	72.0	60.0	64.8	11.5	27325.	12.39	8547.	74342.	149.	0.569	0.618
77.3	72.7	60.0	65.1	12.2	29038.	11.66	8042.	69958.	140.	0.636	0.682
78.3	73.4	60.0	65.4	12.9	30752.	11.01	7594.	66058.	132.	0.709	0.753
79.3	74.2	60.0	65.7	13.6	32467.	10.42	7193.	62569.	125.	0.784	0.825
80.3	74.9	60.0	65.9	14.3	34177.	9.90	6833.	59437.	119.	0.865	0.904
81.4	75.7	60.0	66.2	15.0	35882.	9.43	6508.	56613.	113.	0.965	1.002
82.4	76.4	60.0	66.5	15.8	37588.	9.00	6213.	54045.	108.	1.066	1.102
83.4	77.2	60.0	66.8	16.5	39293.	8.61	5943.	51699.	103.	1.169	1.203
84.4	77.9	60.0	67.1	17.2	40997.	8.26	5696.	49550.	99.	1.292	1.325
85.4	78.7	60.0	67.4	17.9	42692.	7.93	5470.	47583.	95.	1.505	1.536
86.5	79.4	60.0	67.7	18.6	44386.	7.63	5261.	45767.	91.	1.717	1.747
87.5	80.2	60.0	68.0	19.3	46080.	7.34	5068.	44084.	88.	1.931	1.960
88.5	80.9	60.0	68.3	20.1	47776.	7.08	4888.	42520.	85.	2.153	2.181
89.5	81.7	60.0	68.6	20.8	49471.	6.84	4721.	41063.	82.	2.375	2.402
90.5	82.4	60.0	68.9	21.5	51179.	6.61	4563.	39692.	79.	2.599	2.625
91.5	83.2	60.0	69.2	22.2	52899.	6.40	4415.	38402.	77.	2.823	2.848
92.6	83.9	60.0	69.5	22.9	54628.	6.20	4275.	37186.	74.	3.092	3.117
93.6	84.7	60.0	69.8	23.6	56363.	6.00	4143.	36042.	72.	3.388	3.412
94.6	85.4	60.0	70.1	24.4	58098.	5.83	4020.	34965.	70.	3.685	3.708
95.6	86.2	60.0	70.4	25.1	59846.	5.66	3902.	33944.	68.	4.058	4.081
96.7	86.9	60.0	70.7	25.8	61606.	5.49	3791.	32974.	66.	4.510	4.531
97.7	87.7	60.0	71.0	26.6	63368.	5.34	3685.	32057.	64.	4.967	4.988
98.8	88.5	60.0	71.3	27.3	65134.	5.20	3585.	31188.	62.	5.452	5.473
99.8	89.2	60.0	71.6	28.0	66901.	5.06	3491.	30365.	61.	5.941	5.961
100.9	90.0	60.0	71.9	28.8	68647.	4.93	3402.	29592.	59.	6.429	6.449
101.9	90.8	60.0	72.3	29.5	70389.	4.81	3318.	28860.	58.	6.918	6.937
103.0	91.5	60.0	72.6	30.2	72137.	4.69	3237.	28161.	56.	7.438	7.456
104.0	92.3	60.0	72.9	31.0	73890.	4.58	3161.	27492.	55.	8.123	8.141
94.2	85.1	60.0	70.0	24.1	57446.	5.89	4065.	35362.	71.	4.183	4.206
95.0	85.7	60.0	70.2	24.7	58798.	5.76	3972.	34549.	69.	4.420	4.442
96.1	86.5	60.0	70.5	25.4	60533.	5.59	3858.	33559.	67.	4.888	4.910
97.1	87.2	60.0	70.8	26.1	62270.	5.44	3750.	32622.	65.	5.369	5.391
98.1	88.0	60.0	71.1	26.8	64008.	5.29	3649.	31737.	63.	5.850	5.871
99.1	88.7	60.0	71.4	27.5	65745.	5.15	3552.	30898.	62.	6.331	6.352
100.2	89.5	60.0	71.7	28.3	67478.	5.02	3461.	30105.	60.	6.813	6.833
101.2	90.2	60.0	72.0	29.0	69191.	4.89	3375.	29359.	59.	7.295	7.314
102.2	91.0	60.0	72.3	29.7	70915.	4.77	3293.	28646.	57.	7.945	7.964
103.2	91.7	60.0	72.6	30.4	72629.	4.66	3215.	27970.	56.	8.659	8.677
104.3	92.5	60.0	72.9	31.2	74342.	4.55	3141.	27325.	55.	9.366	9.384
105.3	93.3	60.0	73.2	31.9	76056.	4.45	3071.	26710.	53.	10.074	10.091
106.3	94.0	60.0	73.5	32.6	77769.	4.35	3003.	26121.	52.	10.781	10.798
107.4	94.8	60.0	73.8	33.3	79482.	4.26	2938.	25558.	51.	11.489	11.506
108.4	95.5	60.0	74.2	34.1	81202.	4.17	2876.	25017.	50.	12.211	12.228
109.4	96.3	60.0	74.5	34.8	82950.	4.08	2815.	24490.	49.	12.939	12.955
110.5	97.1	60.0	74.8	35.5	84711.	4.00	2757.	23981.	48.	13.683	13.698
111.5	97.8	60.0	75.1	36.3	86487.	3.91	2700.	23488.	47.	14.444	14.459
112.6	98.6	60.0	75.4	37.0	88272.	3.83	2646.	23013.	46.	15.392	15.407
113.7	99.4	60.0	75.7	37.8	90075.	3.76	2593.	22552.	45.	16.359	16.374

Table J.8. Greenhouse heating from ISU unit #5, 11.5 MW 1.0 inches Hg reference backpressure

ISU POWER PLANT UNIT # 5, NORMAL CONDENSER OPERATION
GREENHOUSE HEATING, 5000 SQ FT FLOOR AREA, INSIDE AIR =60 DEG F, OUTSIDE AIR=0 DEG F, 5 MPH

TCCING DEG F	TCCOTG DEG F	TAIRIN DEG F	TAIROT DEG F	DELTM DEG F	QAIRHT BTU/HR	NUNITS	HEATER DOLLARS	TOTMCC LB/HR	TOTGPM GAL/MIN	WHCOST $/HR	SUMCOST $/HR
69.6	67.0	60.0	62.8	6.8	16013.	21.14	14584.	126860.	253.	0.070	0.153
70.6	67.8	60.0	63.1	7.5	17726.	19.09	13175.	114600.	229.	0.193	0.268
71.6	68.5	60.0	63.4	8.2	19460.	17.39	12000.	104387.	209.	0.320	0.389
72.7	69.3	60.0	63.7	8.9	21197.	15.97	11017.	95833.	191.	0.456	0.519
73.7	70.1	60.0	64.0	9.6	22936.	14.76	10182.	88569.	177.	0.597	0.655
74.7	70.8	60.0	64.3	10.4	24675.	13.72	9464.	82327.	164.	0.740	0.794
75.8	71.6	60.0	64.6	11.1	26415.	12.81	8841.	76905.	154.	0.884	0.934
76.8	72.3	60.0	64.9	11.8	28154.	12.02	8295.	72153.	144.	1.029	1.076
77.8	73.1	60.0	65.2	12.5	29894.	11.32	7812.	67954.	136.	1.174	1.219
78.8	73.8	60.0	65.5	13.3	31634.	10.70	7382.	64216.	128.	1.321	1.363
79.9	74.6	60.0	65.8	14.0	33375.	10.14	6997.	60867.	122.	1.468	1.508
80.9	75.3	60.0	66.1	14.7	35103.	9.64	6653.	57871.	116.	1.635	1.673
81.9	76.1	60.0	66.4	15.4	36840.	9.19	6339.	55141.	110.	1.833	1.869
83.0	76.9	60.0	66.7	16.2	38580.	8.77	6053.	52654.	105.	2.037	2.072
84.0	77.6	60.0	67.0	16.9	40322.	8.39	5792.	50380.	101.	2.246	2.279
85.1	78.4	60.0	67.3	17.6	42057.	8.05	5553.	48302.	96.	2.460	2.491
86.1	79.2	60.0	67.6	18.4	43788.	7.73	5333.	46392.	93.	2.676	2.706
87.1	79.9	60.0	67.9	19.1	45518.	7.44	5131.	44629.	89.	2.891	2.921
88.2	80.7	60.0	68.2	19.8	47249.	7.16	4943.	42994.	86.	3.108	3.136
89.2	81.4	60.0	68.5	20.6	48979.	6.91	4768.	41475.	83.	3.324	3.352
90.3	82.2	60.0	68.8	21.3	50716.	6.67	4605.	40055.	80.	3.542	3.568
91.3	83.0	60.0	69.2	22.0	52471.	6.45	4451.	38715.	77.	3.760	3.785
92.3	83.7	60.0	69.5	22.8	54239.	6.24	4306.	37453.	75.	4.014	4.038
93.4	84.5	60.0	69.8	23.5	56023.	6.04	4169.	36260.	72.	4.311	4.335
94.4	85.3	60.0	70.1	24.2	57811.	5.85	4040.	35139.	70.	4.620	4.644
87.4	80.1	60.0	68.0	19.3	45894.	7.37	5089.	44263.	88.	2.818	2.847
88.2	80.7	60.0	68.3	19.9	47312.	7.15	4936.	42936.	86.	2.940	2.968
89.2	81.5	60.0	68.6	20.6	49023.	6.90	4764.	41438.	83.	3.167	3.195
90.3	82.2	60.0	68.9	21.3	50740.	6.67	4603.	40035.	80.	3.399	3.426
91.3	83.0	60.0	69.2	22.0	52476.	6.45	4450.	38711.	77.	3.632	3.657
92.3	83.7	60.0	69.5	22.7	54212.	6.24	4308.	37472.	75.	3.865	3.890
93.4	84.5	60.0	69.8	23.5	55965.	6.05	4173.	36298.	73.	4.168	4.191
94.4	85.2	60.0	70.1	24.2	57718.	5.86	4046.	35195.	70.	4.474	4.497
95.4	86.0	60.0	70.4	24.9	59471.	5.69	3927.	34158.	68.	4.775	4.798
96.5	86.8	60.0	70.7	25.7	61219.	5.53	3815.	33183.	66.	5.050	5.072
97.5	87.5	60.0	71.0	26.4	62966.	5.38	3709.	32262.	64.	5.324	5.345
98.5	88.3	60.0	71.3	27.1	64714.	5.23	3609.	31391.	63.	5.598	5.618
96.5	86.8	60.0	70.7	25.7	61369.	5.52	3805.	33101.	66.	5.073	5.095
97.6	87.6	60.0	71.0	26.4	63095.	5.36	3701.	32196.	64.	5.295	5.316
98.6	88.3	60.0	71.3	27.2	64831.	5.22	3602.	31334.	63.	5.566	5.586
99.6	89.1	60.0	71.6	27.9	66568.	5.08	3508.	30517.	61.	5.839	5.859
100.6	89.8	60.0	71.9	28.6	68289.	4.96	3420.	29747.	59.	6.111	6.131
101.7	90.6	60.0	72.2	29.3	70001.	4.84	3336.	29020.	58.	6.384	6.403
102.7	91.3	60.0	72.5	30.1	71713.	4.72	3257.	28327.	57.	6.660	6.679
103.7	92.1	60.0	72.8	30.8	73439.	4.61	3180.	27661.	55.	7.007	7.026
104.8	92.9	60.0	73.1	31.5	75162.	4.50	3107.	27027.	54.	7.347	7.365
105.8	93.6	60.0	73.4	32.2	76884.	4.40	3037.	26422.	53.	7.686	7.704
106.8	94.4	60.0	73.7	33.0	78607.	4.31	2971.	25843.	52.	8.025	8.042
107.9	95.1	60.0	74.0	33.7	80329.	4.21	2907.	25289.	51.	8.364	8.381
108.9	95.9	60.0	74.3	34.4	82051.	4.12	2846.	24758.	49.	8.703	8.719
109.9	96.7	60.0	74.6	35.1	83771.	4.04	2788.	24249.	48.	9.041	9.057
111.0	97.4	60.0	74.9	35.9	85511.	3.96	2731.	23756.	47.	9.377	9.393
112.0	98.2	60.0	75.2	36.6	87253.	3.88	2677.	23282.	47.	9.712	9.727
113.0	98.9	60.0	75.5	37.3	88997.	3.80	2624.	22826.	46.	10.066	10.081
114.1	99.7	60.0	75.8	38.0	90754.	3.73	2573.	22384.	45.	10.486	10.501
115.1	100.4	60.0	76.1	38.8	92512.	3.66	2524.	21958.	44.	10.911	10.925

Table J.9. Aquaculture heating from ISU unit #5, 11.5 MW 1.0 inches Hg reference backpressure

ISU POWER PLANT UNIT # 5. NORMAL CONDENSER OPERATION
AQUACULTURE(CATFISH PRODUCTION UNIT HEATING REQUIREMENTS
REARING WATER TEMP=83 DEG F. ROOM AIR TEMP=65 DEG F. REPLACEMENT WATER =55 DEG F

FRESH GPM	RECIRC GPM	TUBE GPM	SHELL GPM	SHELL IN DEG F	SHELL OUT DEG F	DELTCC DEG F	CIRC IN DEG F	TANK DEG F	QLOSS BTU/HR	QADDED BTU/HR	AREA SQ FT	EXCOST $	WHCOST $/HR	SUMCOST $/HR
40.	280.	320.	2280.	85.1	84.2	0.861	76.9	83.0	1484.	979469.	1309.	13619.	2.460	2.537
40.	280.	320.	2280.	86.1	85.2	0.861	76.9	83.0	1484.	979469.	1025.	13169.	2.676	2.751
40.	280.	320.	2280.	87.1	86.3	0.861	76.9	83.0	1484.	979469.	848.	12520.	2.891	2.963
40.	280.	320.	2280.	88.2	87.3	0.861	76.9	83.0	1484.	979469.	725.	11494.	3.108	3.173
40.	280.	320.	2280.	89.2	88.4	0.861	76.9	83.0	1484.	979469.	634.	10178.	3.324	3.383
40.	280.	320.	2280.	90.3	89.4	0.861	76.9	83.0	1484.	979469.	564.	8727.	3.542	3.592
40.	280.	320.	2280.	87.4	86.5	0.861	76.9	83.0	1484.	979469.	818.	12389.	2.818	2.889
40.	280.	320.	2280.	88.2	87.4	0.861	76.9	83.0	1484.	979469.	721.	11457.	2.940	3.006
40.	280.	320.	2280.	89.2	88.4	0.861	76.9	83.0	1484.	979469.	632.	10137.	3.167	3.225
40.	280.	320.	2280.	90.3	89.4	0.861	76.9	83.0	1484.	979469.	563.	8709.	3.399	3.449

Table J.10. Aquaculture heating from Ames unit #7, 33 MW 1.0 inches Hg reference backpressure.

AMES POWER PLANT UNIT # 7. NORMAL CONDENSER OPERATION
AQUACULTURE(CATFISH PRODUCTION UNIT HEATING REQUIREMENTS
REARING WATER TEMP=83 DEG F. ROOM AIR TEMP=65 DEG F. REPLACEMENT WATER =55 DEG F

FRESH GPM	RECIRC GPM	TUBE GPM	SHELL GPM	SHELL IN DEG F	SHELL OUT DEG F	DELTCC DEG F	CIRC IN DEG F	TANK DEG F	QLOSS BTU/HR	QADDED BTU/HR	AREA SQ FT	EXCOST $	WHCOST $/HR	SUMCOST $/HR
40.	280.	320.	2280.	85.4	84.6	0.861	76.9	83.0	1484.	979469.	1187.	13507.	1.505	1.582
40.	280.	320.	2280.	86.5	85.6	0.861	76.9	83.0	1484.	979469.	956.	12966.	1.717	1.791
40.	280.	320.	2280.	87.5	86.6	0.861	76.9	83.0	1484.	979469.	804.	12251.	1.931	2.001
40.	280.	320.	2280.	88.5	87.6	0.861	76.9	83.0	1484.	979469.	695.	11200.	2.153	2.217
40.	280.	320.	2280.	89.5	88.6	0.861	76.9	83.0	1484.	979469.	613.	9729.	2.375	2.431
40.	280.	320.	2280.	90.5	89.7	0.861	76.9	83.0	1484.	979469.	548.	8397.	2.599	2.647

Table J.11. Greenhouse heating requirements 60 °F inside air temperature

GREENHOUSE HEATING REQUIREMENT(5000 SQ FT FLOOR AREA 60. DEG F INSIDE AIR TEMPERATURE)
MAX HOUR DESIGN HEATING LOAD FOR WINTER:(NIGHT CONDITIONS, SOLAR=0) BTU/HR

WIND VELOCITY (MI/HR)	0	5	10	15	20
TEMP OUTSIDE DRY BULB (DEG F)					
60	-2000.	-2000.	-2000.	-2000.	-2000.
55	27844.	31619.	32760.	33465.	33900.
50	56869.	64420.	66701.	68112.	68983.
45	85100.	96425.	99848.	101964.	103270.
40	112551.	127651.	132215.	135036.	136778.
35	139240.	158116.	163820.	167346.	169524.
30	165187.	187837.	194682.	198914.	201527.
25	190407.	216833.	224819.	229756.	232805.
20	214920.	245121.	254248.	259890.	263374.
15	238741.	272718.	282985.	289332.	293253.
10	261890.	299641.	311049.	318102.	322458.
5	284381.	325907.	338456.	346214.	351006.
0	306232.	351533.	365224.	373687.	378914.
-5	327459.	376536.	391367.	400535.	406198.
-10	348079.	400931.	416903.	426776.	432874.
-15	368108.	424735.	441847.	452426.	458960.
-20	387561.	447963.	466217.	477501.	484470.
-25	406455.	470632.	490027.	502016.	509421.
-30	424805.	492757.	513292.	525987.	533827.

Table J.12. Greenhouse heating requirements 65 °F inside air temperature

GREENHOUSE HEATING REQUIREMENT(5000 SQ FT FLOOR AREA 65. DEG F INSIDE AIR TEMPERATURE)
MAX HOUR DESIGN HEATING LOAD FOR WINTER:(NIGHT CONDITIONS, SOLAR=0) BTU/HR

WIND VELOCITY (MI/HR)	0	5	10	15	20
TEMP OUTSIDE DRY BULB (DEG F)					
60	28396.	32171.	33312.	34018.	34453.
55	57962.	65512.	67794.	69205.	70076.
50	86713.	98038.	101461.	103577.	104883.
45	114669.	129770.	134333.	137154.	138897.
40	141851.	160726.	166430.	169957.	172135.
35	168273.	190924.	197769.	202000.	204614.
30	193954.	220380.	228366.	233303.	236352.
25	218912.	249113.	258240.	263882.	267367.
20	243165.	277141.	287409.	293756.	297676.
15	266730.	304481.	315890.	322942.	327298.
10	289623.	331150.	343699.	351457.	356248.
5	311863.	357164.	370854.	379317.	384544.
0	333464.	382541.	397371.	406540.	412202.
-5	354444.	407296.	423268.	433142.	439240.
-10	374820.	431447.	448559.	459138.	465672.
-15	394607.	455009.	473262.	484546.	491516.
-20	413821.	477998.	497392.	509381.	516786.
-25	432477.	500430.	520965.	533659.	541500.
-30	450593.	522320.	543996.	557396.	565672.

Table J.13. Greenhouse heating requirements 70 °F inside air temperature

GREENHOUSE HEATING REQUIREMENT(5000 SQ FT FLOOR AREA 70. DEG F INSIDE AIR TEMPERATURE)
MAX HOUR DESIGN HEATING LOAD FOR WINTER:(NIGHT CONDITIONS, SOLAR=0) BTU/HR

TEMP OUTSIDE DRY BULB (DEG F) \ WIND VELOCITY (MI/HR)	0	5	10	15	20
60	59074.	66624.	68906.	70316.	71188.
55	88358.	99684.	103106.	105222.	106529.
50	116831.	131932.	136495.	139316.	141059.
45	144513.	163389.	169093.	172619.	174797.
40	171420.	194071.	200916.	205147.	207761.
35	197573.	223999.	231984.	236921.	239970.
30	222986.	253187.	262314.	267956.	271441.
25	247680.	281656.	291923.	298271.	302191.
20	271671.	309422.	320830.	327883.	332239.
15	294975.	336502.	349051.	356809.	361600.
10	317612.	362913.	376603.	385066.	390293.
5	339596.	388673.	403504.	412672.	418335.
0	360946.	413797.	429769.	439643.	445741.
-5	381677.	438304.	455416.	465995.	472529.
-10	401805.	462207.	480460.	491745.	498714.
-15	421347.	485525.	504919.	516908.	524313.
-20	440319.	508272.	528807.	541501.	549342.
-25	458737.	530464.	552140.	565540.	573816.
-30	476615.	552118.	574934.	589039.	597751.

Table J.14. Greenhouse heating requirements 75 °F inside air temperature

GREENHOUSE HEATING REQUIREMENT(5000 SQ FT FLOOR AREA 75. DEG F INSIDE AIR TEMPERATURE)
MAX HOUR DESIGN HEATING LOAD FOR WINTER:(NIGHT CONDITIONS, SOLAR=0) BTU/HR

WIND VELOCITY (MI/HR) TEMP OUTSIDE DRY BULB (DEG F)	0	5	10	15	20
60	90035.	101360.	104783.	106898.	108205.
55	119036.	134137.	138700.	141521.	143263.
50	147228.	166104.	171808.	175334.	177512.
45	174632.	197282.	204127.	208359.	210972.
40	201263.	227689.	235675.	240612.	243661.
35	227142.	257343.	266470.	272112.	275596.
30	252286.	286263.	296530.	302877.	306797.
25	276712.	314464.	325872.	332925.	337280.
20	300438.	341964.	354514.	362271.	367063.
15	323481.	368782.	382472.	390935.	396162.
10	345857.	394934.	409765.	418933.	424596.
5	367585.	420436.	436408.	446282.	452380.
0	388679.	445306.	462419.	472998.	479531.
-5	409158.	469560.	487814.	499098.	506067.
-10	429037.	493215.	512609.	524598.	532003.
-15	448333.	516285.	536820.	549515.	557355.
-20	467060.	538788.	560464.	573863.	582139.
-25	485236.	560738.	583555.	597660.	606372.
-30	502874.	582152.	606110.	620920.	630067.