ENERGY AND ENVIRONMENTAL CHARACTERISTICS OF ALTERNATIVE THERMAL ELECTRIC GENERATING PLANT COOLING ARRANGEMENTS

by

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INTRODUCTION

Steam electric generating plants are the largest industrial users of water in the world. In 1968 the total water usage for the steam electric generating plants of the United States was approximately 4×10^{13} gallons. This amount of water is approximately 10% of the total runoff of the nation's rivers. In the recent past, growth of the steam electric generating industry has occurred at an annual rate of approximately 8%. This growth rate has resulted in doubling the installed capacity for each of the past several decades. The implications which are clearly derived by extrapolating such growth history into the future is a large reason for the present regulatory concern for controlling thermal discharges from electric generating plants. Any exponential growth of a physical system continued far enough into the future will result in an unsatisfactorily large condition. However, it is presently becoming apparent that factors such as shortages and economics will prevent the indefinite doubling of electric generating capacity in the future for each ten year period as has occurred in the recent past. At the time the initial nation wide concern for thermal discharges was becoming clear (perhaps some 6 or 8 years ago), the limited nature of the resource base available for the production of goods and for pollution abatement was not as generally recognized as is the case at present. Also, until very recently, meaningful data on the thermal effects of power generating stations has been lacking. Thus neither the electric generating industry nor the responsible regulatory agencies could estimate accurately the effects of thermal discharges on receiving water bodies. The Environmental Protection Agency has tended to rely on extrapolation of laboratory thermal tolerance experiments in identifying possible detrimental thermal effects and as a consequence has treated the thermal discharge problem in a very conservative manner. The electric generating industry perhaps aided in the establishment of a nation wide urgency in the coining of such terms as "thermal enrichment".

1972 WATER LAW

Thermal discharge regulation entered a new era with the passage of the 1972 Federal Water Pollution Control Act Amendments. This act specifically treated heat as a pollutant. However, the act recognized the unusual nature of treating heat as a pollutant by requiring a report under Section 104(t). This section required the following:

"In evaluating alternative methods of control the studies shall consider (1) such data as are available on the latest available technology, economic feasibility including cost-effectiveness analysis, and (2) the total impact on the environment, considering not only water quality but also air quality, land use, and effective utilization and conservation of fresh water and other natural resources."

The law also provided for promulgation of effluent limitations under Section 304(b) and Section 301 for pollutants including heat which could be obtained by application of the best practicable technology by 1977 and best available technology economically achievable by 1983. At the present time the Environmental Protection Agency has published a draft of effluent limitation guidelines for steam electric generating plants required under the above sections of the law. Basically the guidelines as presently proposed envision for both best practicable and best available technology the use of closed cycle cooling towers as the bench mark of thermal discharge control in the electric generating industry. Cost of application of this bench mark to the existing thermal electric generating plants of the nation is estimated by the Environmental Protection Agency at 4.1 billion dollars annually. In a time of increasing recognition of the finite nature of the nation's resources, the most serious consideration of these costs and resulting benefits is appropriate to assure that the limited resources of the nation are properly allocated and that benefits returned are commensurate with the resources expended. The 1972 Water Law itself specifically requires such a balancing. Section 304(b)(1)(b) states that "factors relating to the assessment of best practicable control technology currently available to comply with Subsection (b)(1) of Section 301 of this act should include consideration of the total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application". Thus it is not enough to simply evaluate the cost of implementing proposed effluent limitation guidelines. The law requires specifically that the cost be considered in relation to the benefits obtained and requires consideration of other factors such as energy consumption.

The 1972 Water Law, although it does provide for application of best practicable and best available technology, does not require that a uniform effluent reduction scheme be applied nation wide. Investigations conducted around existing power plants nation wide in the past two or three years have emphasized the site dependent nature of thermal effects. The Environmental Protection Agency itself has specifically recognized this site uniqueness when determining the effects of thermal discharges. In October 1973, it published proposed criteria for water quality parameters including temperature. This document was in response to the 1972 Water Law Sections 304(a) 1 and 2. In the section on thermal criteria the following language appears: "Because temperature changes may effect the composition of an aquatic community, and induce change in the thermal characteristics of an eco-system they may be detrimental. On the other hand, altered thermal characteristics may be beneficial as evidenced in some of the newer fish hatchery practices and at other aquacultural facilities. The general difficulty in developing suitable criteria for temperature (which would limit the addition of heat) is to determine the deviation from natural temperature a particular body of water can experience without adversely affecting its desired biota ..... In view of the many variables it seems obvious that no single temperature requirement can be applied uniformly to continental or large regional areas; the requirements must be closer related to each body of water and to its particular community of organisms, especially the important species found in it." By EPA's own determination, effluent reduction benefits as reflected by the well-being of fish, shellfish, and wildlife are related to heated discharge on a site specific basis. It seems straightforward that effluent limitations for heat must likewise be a site specific determination if the cost of effluent reduction is to be properly balanced with reduction benefits as required by the law. Application of a uniform effluent reduction technology nation wide (such as closed cycle cooling towers) straight jackets the consideration of alternatives and does not allow the utilization of site specific characteristics in a particular area of the country. In the southeastern United States there are unique characteristics which tend to emphasize the penalty to the region and to the environment of the region if application of thermal discharge control is interpreted to mean only closed cycle cooling towers. The greatest good to the region and to the nation requires wise utilization and protection of the unique water resources of the Southeast.

ALTERNATIVE COOLING SCHEMES CONSIDERED

Three methods of dissipating the rejected heat from electric generating plants are shown by Figure 1. These are forced draft cooling towers, cooling ponds, and power plant utilization of deep stratified reservoirs. Application of each of these schemes is feasible at many sites in the southeastern United States.

Cooling tower construction requires only a sufficient source of water either from a flowing stream or from an impoundment to provide for the consumptive loss of water produced by evaporation and drift from the cooling tower.

Cooling ponds are particularly feasible in the southeastern United States for several reasons. First, compared with other regions of the country, land cost may be considerably lower. Second, the abundant rainfall and runoff of the region provides for feasible cooling ponds on much smaller water sheds than in the western part of the United States. In the southeast cooling ponds provide for the dissipation of the waste heat with less consumptive use of water than evaporative cooling towers. This is true because the heat transfer mechanisms of convection and radiation are effective in addition to evaporation which is essentially the sole mechanism in the cooling tower. In the southeast evaporation from a lake surface may approximately equal the evapotranspiration which would have occurred if the lake were not constructed. Therefore, construction of a lake in water abundant areas may not reduce total watershed runoff. In fact, when evapotranspiration exceeds lake evaporation, total runoff is increased by lake construction. This is not true in some other parts of the country, particularly the west. Where cooling

FIGURE I

THREE CONDENSER COOLING WATER ARRANGEMENTS

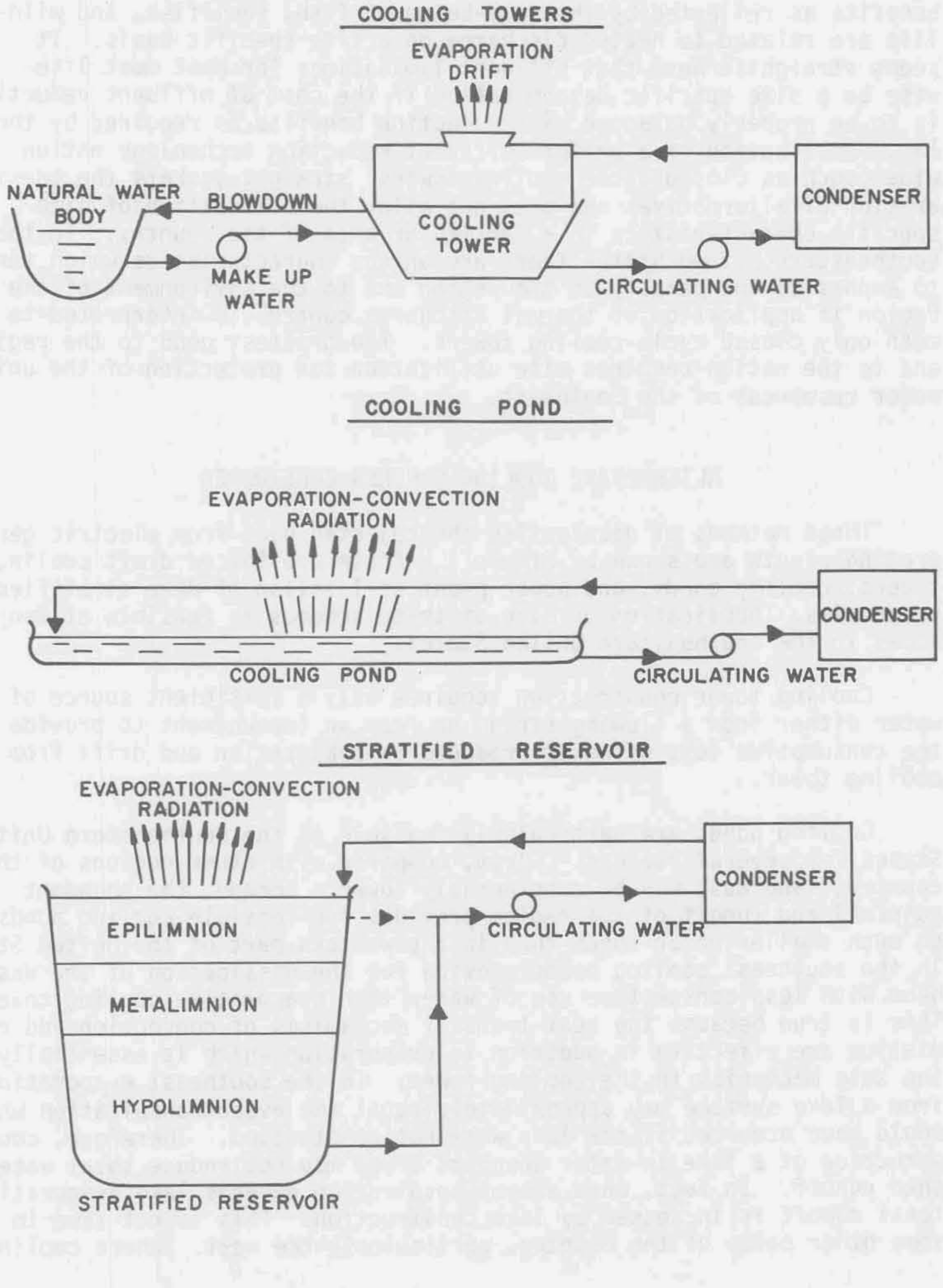
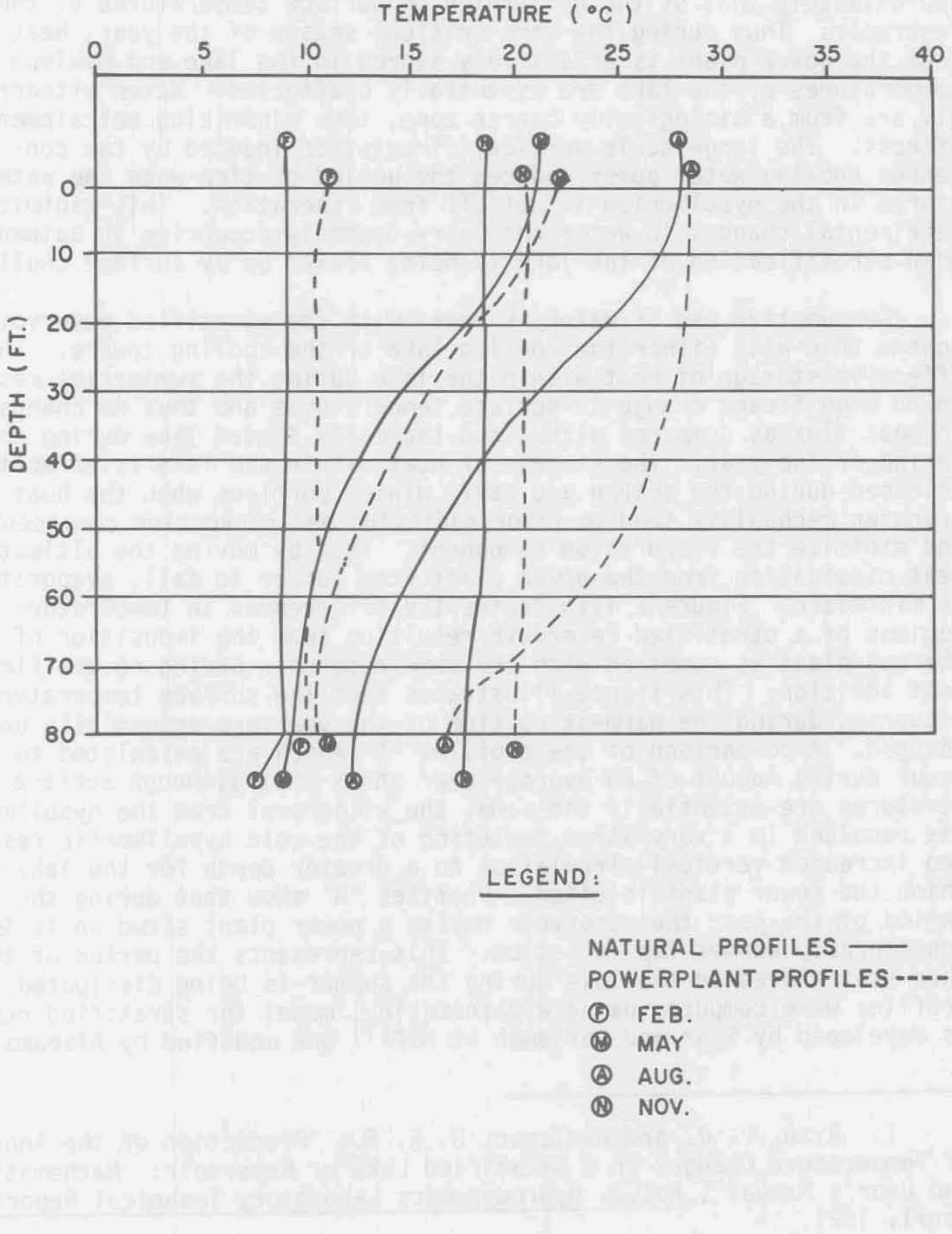


FIGURE 2

COMPARISON OF TEMPERATURE PROFILES



lakes are constructed in an arid climate, the presence of a free water surface guarantees that a large consumptive loss will occur. Cooling ponds also can provide considerable peripheral benefits not possible with cooling towers. Existing cooling lake sites throughout the south and southeast provide for considerable fishing and other recreational use.

Particularly in the Piedmont region of the southeast there are large stratified fresh water lakes. These lakes and potential sites for similar lakes provide an extremely valuable and unique potential for heat dissipation. Power plants sited on such a lake, withdrawing cooling water from the hypolimnion during the stratified seasons of the year, can operate to limit the temperature of the discharges to approximately that of the epilimnion or surface temperatures of the reservoir. Thus during the warm critical season of the year, heat from the power plant is effectively stored in the lake and maximum temperatures of the lake are essentially unaffected. Water withdrawals are from a biologically barren zone, thus minimizing entrainment effects. The large scale vertical circulation induced by the condenser cooling water pumps reduces the period of time when the water stored in the hypolimnion is cut off from reaeration. This minimizes detrimental changes in water chemistry commonly occurring in autumn when stratification of the lake is being broken up by surface cooling.

Consumptive use of water is lower with the stratified reservoir scheme than with either the cooling lake or the cooling towers. The effective storage of heat within the lake during the summertime results in no significant change in surface temperatures and thus no change in heat flux as compared with a non-thermally loaded lake during this period of the year. The storage of heat within the lake is effectively released during the autumn and early winter portions when the heat transfer mechanisms tend to favor radiation and convection components and minimize the evaporation component. Thus by moving the ultimate heat dissipation from the power plant from summer to fall, evaporation is minimized. Figure 2 illustrates the differences in temperature regimes of a stratified reservoir resulting from the imposition of a thermal plant as compared with the same reservoir having no artificial heat addition. This figure illustrates that the surface temperatures occurring during the warmest portion of the year are essentially unchanged. A comparison of the profiles "A" which are calculated to occur during August of an average year shows that although surface temperatures are essentially the same, the withdrawal from the hypolimnion has resulted in a very large depletion of the cold hypolimnetic resource and increased vertical circulation to a greater depth for the lake on which the power plant is sited. Profiles "N" show that during the fall period of the year the reservoir having a power plant sited on it is considerably warmer top to bottom. This represents the period of the year when heat stored in the lake during the summer is being dissipated. These profiles were computed using a mathematical model for stratified reservoirs as developed by Ryan and Harleman at MIT(1) and modified by Alabama Power

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1. Ryan, P. J. and Harleman, D. R. F., "Prediction of the Annual Cycle of Temperature Changes in a Stratified Lake or Reservoir: Mathematical Model and User's Manual", M.I.T. Hydrodynamics Laboratory Technical Report No. 137, April, 1971.

Company and Dr. John Goodling of Auburn University to provide for superimposing a thermal plant on the stratified reservoir regime.

COMPARISON OF THREE CONDENSER COOLING SCHEMES

Table 1 gives a comparison of the stratified reservoir with the cooling lake and cooling tower for a 1,000 MW unit. Fuel consumption, evaporative water consumption, capability differences and construction cost are compared between the alternatives. Comparison items for all three alternatives are derived from analysis of actual sites within Alabama Power Company's service area. Differences in fuel consumed are calculated for the hypothetical 1,000 MW plant using the thermodynamic characteristics of large modern fossil units designed for cooling towers or cooling lake condensing conditions as applicable. Since the cooling towers operate with considerably higher condensing temperatures this temperature differential is reflected in a lower thermodynamic efficiency of the steam cycle and a consequent increase in fuel consumption for an equivalent useful power output. This same difference in condensing temperatures causing lower thermodynamic efficiencies also produces a difference in maximum capability between the alternatives. As can be seen in both the fuel consumption columns and the capability penalty columns, the stratified reservoir, because of the cool temperatures available during the stratified season produces the highest efficiency of the three alternatives considered.

Table 1 indicates that a 1,000 MW generating plant with cooling towers consumes over 43,000 tons of coal annually more than a similar plant on a stratified reservoir. This difference in fuel consumption is equivalent to a present value penalty of $5,503,000.00 considering coal costing 50¢ per million BTU and interest at 8%, for a 30 year plant life. The capability differential between cooling towers and the stratified reservoirs is equivalent to 41,180 KW. Construction cost associated with the cooling towers is estimated at approximately $4,800,000.00 more than the stratified reservoir base. Total cost differential estimated as discussed above amounts to a penalty of approximately 20.3 million dollars for the 1,000 MW unit using cooling towers as compared with the same unit on a stratified reservoir.

Figure 3 illustrates the variation in present value of fuel cost between the alternatives considered as a function of the cost of fuel. As can be seen from this figure as fuel cost increases above 50¢ per million BTU the advantages associated with better thermodynamic efficiency of the cooling lake or stratified reservoir increases markedly. All indications are that fuel cost in the foreseeable future will likely exceed 50¢ per million BTU's and in some cases by a considerable margin.

SUMMARY AND CONCLUSIONS

Present draft effluent limitations promulgated by the Environmental Protection Agency tend to force the use of evaporative cooling towers for dissipation of heat from thermal electric generating plants. The language of the Water Quality Control Act Amendments of 1972 specifically

TABLE I

DIFFERENTIAL COMPARISON OF ALTERNATIVE COOLING SCHEMES

FOR 1000 MW PLANT

	COOLING TOWERS	COOLING POND	STRATIFIED RESERVOIR
ANNUAL COAL CONSUMPTION	+43016 TONS	+6431 TONS	BASE
ANNUAL COAL CONSUMPTION AS % OF BASE	1.638%	.24%	0
ANNUAL ENERGY COST	$488,790	$75,890	BASE
ANNUAL ENERGY COST AS % OF BASE	1.638%	.24%	0
PEAKING CAPACITY PENALTY	40180KW *	10110KW	BASE
AVERAGE WATER CONSUMPTION	9.8 cfs	7.86 cfs	BASE
AVERAGE WATER CONSUMPTION AS % OF BASE	80.6%	64.8%	0
CONSTRUCTION COST	$4,779,000	$3,219,000	BASE
TOTAL CONSTRUCTION COST AS % OF BASE	101.4%	100.8%	100%
ESTIMATED COST OF PEAKING PENALTY	$10,045,000	$2,528,000	0
PRESENT VALUE OF ANNUAL FUEL COST @ 8% FOR 30 YEARS	$5,503,000	$854,000	0
TOTAL COST	$20,327,000	$6,601,000	0
TOTAL COST AS % OF BASE COST	108.1%	102.6%	100%

* INCLUDES INCREASE IN PLANT STATION SERVICE DUE TO COOLING TOWERS

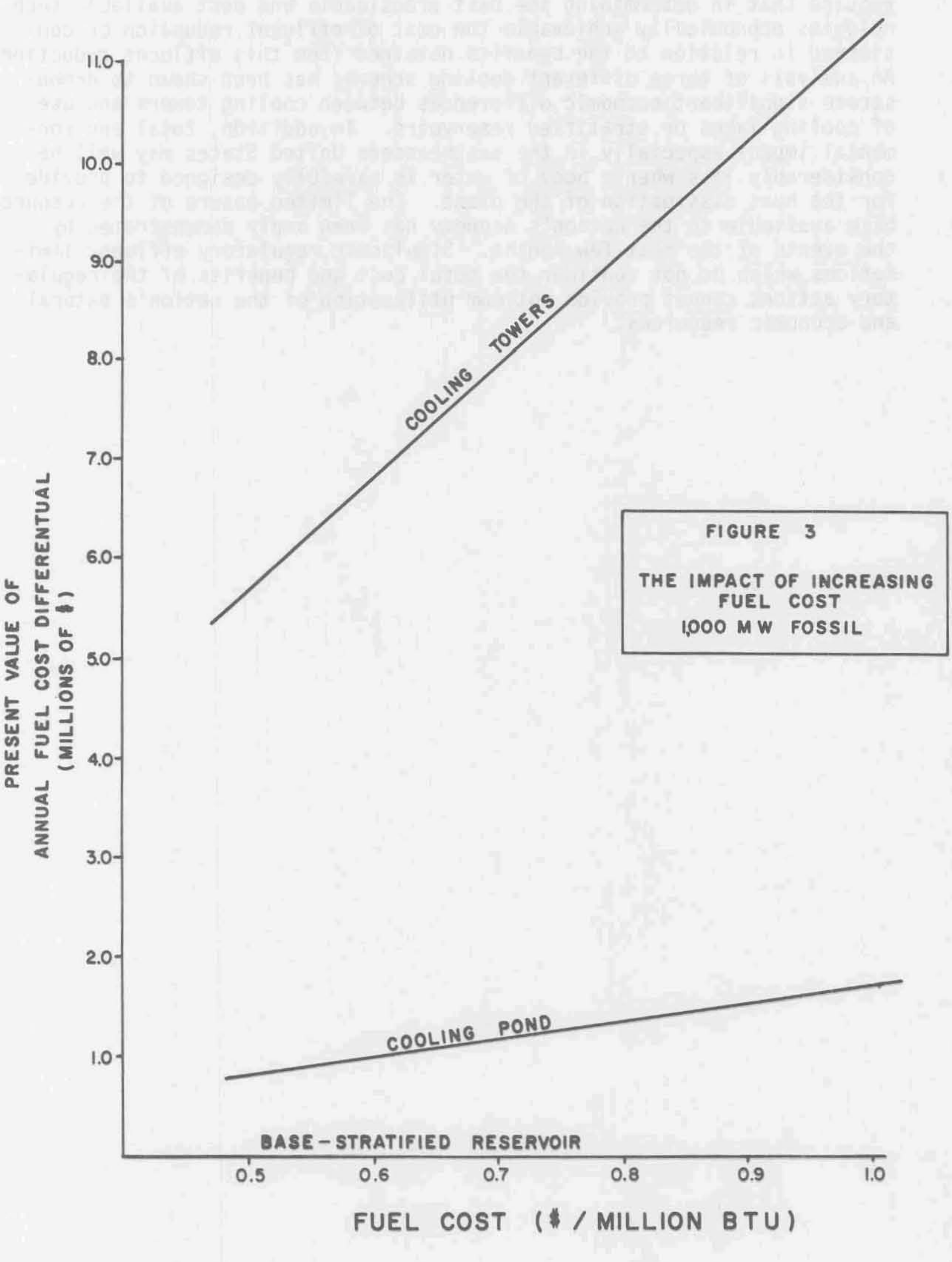
FIGURE 3
THE IMPACT OF INCREASING
FUEL COST
1,000 MW FOSSIL
PRESENT VALUE OF
ANNUAL FUEL COST DIFFERENTUAL
(MILLIONS OF $)
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
COOLING TOWERS
COOLING POND
BASE-STRATIFIED RESERVOIR
0.5
0.6
0.7
0.8
0.9
1.0
FUEL COST ($/MILLION BTU)

require that in determining the best practicable and best available technologies economically achievable the cost of effluent reduction be considered in relation to the benefits obtained from this effluent reduction. An analysis of three different cooling schemes has been shown to demonstrate significant economic differences between cooling towers and use of cooling lakes or stratified reservoirs. In addition, total environmental impact especially in the southeastern United States may well be considerably less when a body of water is carefully designed to provide for the heat dissipation of the plant. The limited nature of the resource base available to the nation's economy has been amply demonstrated by the events of the past few months. Simplistic regulatory effluent limitations which do not consider the total cost and benefits of the regulatory action, cannot provide optimum utilization of the nation's natural and economic resources.