IIT Waste Energy Management Project

Technical Report TR-79-2

Beneficial Use of Waste Heat for Surface Irrigation

by

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August 1979

Prepared for
U. S. Department of Energy
Contract EC 77-S-02-4531

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ABSTRACT (SUMMARY)

The feasibility of utilizing once-through cooling water discharge from large steam-electric power plants for surface irrigation was investigated. Advantages for the power plant include reduced turbine back pressure with greater power output and thermal efficiency, as well as reduced cost and environmental impact, as compared with closed-cycle cooling systems. Crops could benefit from moderately elevated water temperatures of irrigation which tend to increase yield for certain species.

As an example, a 2000 MW(e) fossil-fueled plant was analyzed. It was determined that about 178,000 acres would be required under typical optimal average spray-irrigation rates of 1.5 inches/week and the optimal field crop, corn. For this size system, water temperatures would be in near natural equilibrium at the average crop location. Thus no thermal advantage can be claimed for crop growth. Considering the irrigation system investment and return, the net cost of cooling in 1980 dollars was estimated as 4 mills/kWh as compared with 0.7 and 1.7 for wet and dry mechanical-draft towers, respectively. In the case of tomatoes, a net profit of 3 mills/kWh might be achieved assuming that the market could absorb the enormous yield, which is unlikely. During non-irrigation periods, a conventional cooling system, or the irrigation distribution system with a bypass return to the plant or the natural water body would have to be employed at additional cost. The prospects of using hot-water blowdown for more limited surface irrigation appears more practical and may be viable as a system zero-discharge alternative.

INTRODUCTION

The need to conserve energy in the U. S. is generally recognized. Of particular interest are techniques for converting energy more efficiently and reducing its consumption through more effective utilization. The beneficial use of waste heat from steam-electric power plants offers opportunities in both of these areas.

Present day energy conversion technology in central stations is such that approximately two units of energy have to be rejected as heat for every unit of output. Even though the heat rejection is unavoidable,

this energy is certainly not unusable. As water is a better heat exchange medium than air, enormous quantities of water are involved in the rejection process, usually in closed-cycle systems that transfer the waste heat directly to the atmosphere in order to alleviate aquatic environmental impact. Unfortunately, it is not economical to design enormous cooling systems that return the cooling water to near ambient water temperatures before their re-intake into the plant. As a consequence, cooling-water temperatures tend to elevate 15-40 F above ambient water temperatures at the intake, thereby raising the steam-side temperature and turbine back pressure in the condenser. Thermal efficiency drops, and fuel requirements and reject heat both increase. It would be highly desirable both to find a beneficial use of the reject heat and to utilize once-through cooling.

Nominal characteristics of typical large power plants along with the quantities of effluent associated with them are presented in Table 1.

Table 1. Nominal Power Plant Characteristics

			Fossil Fueled	Nuclear Fueled
Rated Output	-	MW(e)	2000	2000
Thermal Efficiency	-	%	40	30
Stack Losses	-	%	15	0
Population Served	-	(10^6)	2	2
<u>At Full Load</u>				
Coolant Flow	-	gpm	0.6×10^6	1.27×10^6
Coolant Temp. Rise	-	F		
Closed-Cycle			25	25
Once-Through			25	25
Intake Temperature	-	F		
Closed-Cycle			75-95	75-95
Once-Through			32-85	32-85

The enormity of the discharges involved is driven home by the fact that annual withdrawals of water currently amount to about 10-15% of the total fresh-water runoff in the coterminous U. S. By the end of the

century, this figure is expected to become as large as 30% [Clarke (1970)]. Several investigators have discussed in detail the thermodynamic, metallurgical and economic constraints that limit the efficiency of thermal power generation and also the environmental and ecological impact of the effluents [Parker & Krenkel (1970), Beall (1970) and Rimberg (1974)]. The temperature of the condenser discharge is rarely above 120 F and hence it does not find much use in the process industry. Potential beneficial uses are therefore limited to agriculture, aquaculture, livestock farming, airport defogging and deicing, deicing of waterways, sewage and wastewater treatment, district heating and municipal water supply. The objectives in the present investigation are to study the various aspects of combining a condenser cooling method with a beneficial use for the effluents in irrigated agriculture for improvement of crops.

Owing to the safety aspects of nuclear plants, we consider only the fossil-fueled plant of Table 1. While water associated with cooling is generally not contaminated with radiation in a nuclear plant, the possibility of accidental leakage and the psychological impact of such a system probably would exclude nuclear stations from the present application. Fossil plants also have the benefit of reduced flow rates (Table 1) which turn out to be desirable in the current application.

Agricultural Use of Waste Heat

Crop production in many areas is limited by unfavorable climate and lack of irrigation water. The ecological significance of soil thermal environment and water deficit on plant life is the topic of many excellent books and articles in the literature [Hagan, et al (1967), Chang (1968)]. Rimberg (1974) also describes the important concepts involved in his discussion on waste heat utilization. Agricultural applications for waste heat from power plants have been suggested since as early as 1957.

Heating greenhouses was considered forty years ago in the U.S.S.R. and about ten years ago in the U.K. More recently, studies have been made under the auspices of Oak Ridge National Laboratory (ORNL), the TVA, University of Arizona and others. Yields as much as ten times the open field output have been realized in small areas using waste heat. Cash crops like tomatoes, lettuce, cucumbers and flowers have been found to yield economic returns. But, in order to use a sizeable fraction of the waste heat from a power plant, the size of the greenhouse involved is

clearly an order of magnitude larger than any existing operation.

Currently fossil fuels are being used for heating. Cheap or even free heat supply does not appear to be enough attraction for operations near power plant sites. As scarcity of fuel gets stronger, such undertakings might be necessitated. Another suggestion has been to use the exclusion zones of nuclear plant sites for greenhouse horticulture. But again, utilities at present are not favorably disposed to having a second party on their cooling system particularly in view of possible radioactive contamination.

Combination of environment control of livestock shelter with greenhouse vegetable production has also been found feasible with power plant waste heat [Williams (1972)]. Such a scheme can supply a city of about 5 million people with enough produce. Once again, large undertakings like these do not appear to be attractive at present. With total-energy and energy-center concepts gaining acceptance such beneficial applications might receive serious consideration in the future.

A second approach is to use open field agriculture. The possibility of using heated cooling water directly for heating and/or irrigation is attractive for its simplicity.

There are various ways of irrigating land. With surface irrigation like flooding, efficiencies are low, water losses and soil erosion are high, and since considerable land preparation is called for, labor costs are high. However, soil warming up to the root zone by direct application of hot water is not very effective since the water is cooled very quickly. The irrigation intensity required to maintain optimum soil temperatures is so high that land stays flooded. In sprinkler or spray irrigation, even though efficiency and uniformity of application are high, the water droplets get cooled to ambient temperature or lower by the time they reach the ground [Cline, et al (1969)]. In both these methods water is used consumptively.

In order to impart heat to the soil more effectively, circulation of the warm water in buried pipes has been suggested [Boersma (1973)]. Subirrigation through buried pipes results in formation of dry soil cores around the pipes. Hence water should be allowed to seep through the walls by making the latter porous. In addition, sprinkler or direct irrigation may also be used to supply the water deficit. Rykboost (1976),

Allred (1974), Skaggs, Sanders and Willey (1975) have reported experiments in which considerable improvement in quality and yield of several crops like corn, beans, potatoes etc. were realized. The area of land involved was in the range of 4000-15,000 acres. The cost of land, labor and the distribution system is very high and the return from crops is not adequate to offset the additional costs incurred. An agro-power-waste water complex in which municipal waste water was used for spray irrigation has been investigated by Dewalle (1974). Preliminary system design and cost analysis indicated that the new concept was less expensive than dry cooling towers but more expensive than wet towers.

Multipurpose projects that include additional beneficial applications like waste water treatment, district heating etc., appear promising enough to merit further investigation. Since some form of auxiliary cooling system appears unavoidable, another possibility [Marmer (1978)] is to investigate beneficial uses in irrigated agriculture for the blowdown water from evaporative cooling systems. Since the quantities of blowdown water are much smaller than the condenser coolant flow, the land areas to be irrigated are expected to be smaller and more easily managed.

Present Study

In the present investigation we consider direct discharge of heated cooling water into a large spray irrigation system without subsurface heating. This concept is consistent with multiple use of water resources but does not incorporate the full urban-agricultural-industrial complex approach that has been proposed by some investigators.

In the next section we discuss agricultural and thermal aspects of the proposed system. Then a system and economic analysis is presented.

AGRICULTURAL and THERMAL ASPECTS

Crop Characteristics

As an example, special consideration was given to the North Central Region in consultation with the College of Agriculture, University of Illinois. Members of the faculty in the departments of Agronomy, Plant Science, Agricultural Engineering, Agricultural Economics and the Agricultural Experiment Station were consulted regarding various aspects

of the proposed beneficial application of condenser cooling water and waste heat in irrigation of cropland. Their comments, criticisms and opinions were sought with the purpose of devising an agriculture-oriented waste heat management scheme, in accord with opinions of the experts and scholars in the area. The following personnel were consulted:

Prof. M. D. Thorne	Agronomy/Plant Science
Prof. W. Lemke	Agriculture Engineering
Prof. P. Walker	Agriculture Engineering
Dr. B. A. Jones (Jr.)	Associate Director of Agricultural Experimental Station
Mr. R. A. Hinton	Agricultural Economics

The following important aspects were given due consideration. Additional details are provided in the special bibliography of Table 2.

(1) In the so-called North Central Region, of which Illinois is a member, irrigated crop production is rather small but is expected to increase. A large percentage of soils is wet and therefore requires drainage. While this precludes irrigation for some soils and crops, it brings out the fact that drainage could be a principal factor to be accounted for while designing an irrigation project. Also, in locations removed from water bodies like rivers or lakes, considerable amount of irrigation water, where it is employed, is derived from wells that are drilled for this purpose.

(2) When large quantities of irrigation water are available as in our project, sandy and sandy-loam soils, like those found in Mason County, Illinois, are the best candidates for growing irrigated crops. This is due to the fact that their infiltration capacities are high and hence they will not develop conditions of excessive soil moisture. Such a soil profile may also call for the provision of suitable drainage arrangement.

(3) Corn and soybeans are the principal crops in Illinois. Supplemental irrigation is necessary in periods of inadequate seasonal rainfall and drought and also in certain stages of crop growth like the silk emergence stage in corn during late July and August which often coincides with hot, dry spells. Such irrigation will definitely improve crop quality and yield. Irrigated sweet corn is supposed to have better

Table 2. Special Bibliography on Irrigation in the North Central Region

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- 1) "Irrigation Guide for Illinois" Prepared Jointly by University of Illinois Co-Op Extension Service, Agricultural Experimental Station, and U.S.D.A. Soil Conservation Service, Agricultural Engineering Report 866, January 1965.
 - 2) "Irrigation Principles and Costs for Illinois", Pamphlet by Prof. M. D. Thorne, Extension Agronomist, University of Illinois.
 - 3) B. E. Downey (Jr), Section on Irrigation, Chapter 3, 6, Project Report - Ohio River Basin Water Resources Study, 1978.
 - 4) "Report of Illinois Advisory Commission on Sludge and Wastewater Utilization on Agricultural Land", February, 1975.
 - 5) "Utilizing Municipal Sewage Wastewaters and Sludges on Land for Agricultural Production", North Central Region Extension Publication No. 52, November, 1977.
 - 6) "The Use of Land as a Method of Treating Wastewater - C-SELM Wastewater Management Study", Department of the Army, Chicago District, Corps of Engineers, 219 South Dearborn Street, Chicago, IL 60604, December 1972.
 - 7) "Wastewater - Is Muskegon County's Solution Your Solution," USEPA, Region 5, Chicago, IL, September 1976.
 - 8) Pratt P. F., Thorne, M. D. and Wiersma, F., "Future Direction of Waste Utilization", Chapter 25 of Soils for Management of Organic Wastes and Wastewaters, American Society of Agronomy, 1977.
 - 9) "Application Sludges and Wastewaters on Agricultural Lands - A Planning and Educational Guide", North Central Regional Research Publication No. 235, October 1976.
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taste. But this also means that utilization of the water on a continuous basis is difficult. Alternative uses or storage devices may be required.

(4) Truck and vegetable crops which yield high cash returns are grown mostly in the southern parts of Illinois. Soybeans as a cash crop may not provide enough yield increase to offset the additional costs incurred in irrigation. Silage corn might be a good candidate. Land costs are between \$650 - \$2000 per acre in Illinois and high levels of management and fertilizer application might be necessary to make irrigated crop production economically attractive.

(5) In utilizing cooling tower blowdown at high concentrations (TDS greater than 1000 ppm), dilution water may be required if it is not feasible to grow crops which are salt tolerant.

(6) In studying multipurpose beneficial uses like Agro-Power-Wastewater Treatment schemes, the Muskegon and Chicago-South End of Lake Michigan (C-SELM) projects could be used as models or guides since part of the nutrient requirement and all or part of the irrigation water could be obtained from the wastewaters while effecting water reclamation and crop production simultaneously. Such a project might be beneficial for reclaiming strip-mined land through application of waste-heat consolidated sludge, and spray irrigation using cooling tower blowdown and/or treated wastewater. This would be suitable especially for power plants situated in the vicinity of coal mines.

(7) In general, open field irrigation and sub-surface soil warming with spray irrigation are both not expected to be economically viable methods of producing crops on the scales envisaged by the cooling water usage owing to high land costs, high levels of cultural and management practice, crop yields, marketing and other related aspects involved.

With regard to the design of an actual irrigation and drainage system, details to be examined concern monthly and peak water usage of crops, soil profile characteristics (infiltration and percolation capacities, drainage and runoff), crop-soil combinations, culture and management considerations, fertilizer requirements, yield and cash return expected, water storage, conveyance, distribution and application schemes and associated thermal and hydraulic characteristics (amount of cooling, evaporation loss, pumping requirements, storage capacity, etc.).

Specific plant locations should be studied for their suitability to

an agricultural application of the kind proposed. Soil characteristics, local climatological conditions, general water resource characteristics, proximity to centers of population and consumption, etc., must also be investigated for a design-oriented study that will offer insight into site-specific factors and their influence on the planning and design of an agro-power system.

In the present project, less detail was considered in order to determine whether further analysis that might lead to a demonstration project is in fact desirable.

Irrigation Characteristics

Soil warming and irrigation can result in enhanced plant growth and yield. The growing season can be extended to raise more than one crop. With improved soil environment, plants normally not suited to a region could be grown. In saline soils, water can be used as a leaching agent to maintain a favorable salt balance. Evapotranspiration in plants results in consumptive use of water. When the consumptive need is not met in full by precipitation, the resulting water stress can cause the plant to wilt. The water deficit can be avoided by irrigation. Many methods have been proposed to relate consumptive use to climatological variables. Based on data gathered in the Western U. S., Blaney and Criddle (1962) have suggested the following formula

$$U = \sum_i k_i T_i P_i \quad (1)$$

where U = total seasonal consumption of water in inches

T_i = monthly average air temperature

k_i = monthly crop use coefficient (tabulated)

P_i = monthly average percentage of day time hours of the year

The amount, I, of irrigation water to be supplied is

$$I = (U - P)/\eta \quad (2)$$

where P = total precipitation for the period concerned (monthly or for the entire growing season depending on how U is calculated)

η = overall irrigation efficiency to account for conveyance, distribution and farm losses

Appropriate percentage corrections may be applied to I to allow for leaching, drainage and other requirements. The area of land that can be irrigated with a given volume of coolant flow may be estimated, after a crop suited to the soil is selected.

Typical irrigation rates are about 2 in/week. On this basis, the 2000 MW(e) fossil-fueled plant of Table 1 would require 111,000 acres to receive 600,000 gpm. Actually, about 20% more area is required for associated distribution. Thus, about 134,000 acres would be required.

Thermal Effects

In order to use all the once-through cooling water discharged from the power plant, the area of crop-land required is clearly enormous. It is therefore important to know how much cooling can be expected in distributing the hot water. It is assumed that distribution occurs in open channels. For this purpose, the flow-through cooling pond model of Lorenzi and Porter (1978), based on Edinger and Geyer (1971) may be employed:

$$(T_1 - E)/(T_H - E) = \exp [- KA/(\dot{m} c_w)] \quad (3)$$

where

T_1 = water temperature after distribution

E = natural equilibrium temperature

T_H = hot-water temperature

K = surface exchange coefficient

A = surface area of distribution

$\dot{m}$ = water mass flow rate

c_w = specific heat of liquid water

Typical weather conditions are given in Table 3 for the purpose of computing K and E . While these represent the average growing season, greater temperature drops would occur in cooler weather.

With the resultant natural equilibrium temperature of 82.5 F and a surface exchange coefficient of 240 B/ft²-day-F, it is estimated that approximately 1750 acres of surface area would reduce the water temperature from 95F to 83.5 F, within 1 F of natural equilibrium. This is

Table 3. Weather Conditions for Estimating the Cooling Effect in Irrigation Distribution

Net Solar Radiation	1920 B/ft ² - day
Dry Bulb Temperature	73 F
Wind Speed	8.6 mph
Cloud Cover	58%
Relative Humidity	65%
Equilibrium Cooling Pond Temperature	82.5 F
Surface Exchange Coefficient	240 B/ft ² -day - F

equivalent to about 1440 miles length of a 10-ft wide canal. A distribution canal of this size would cool the discharge to nearly the ambient water temperature that would occur without heating in the power plant. Because this area is only 1% of the total irrigation area and would likely be exceeded in an actual distribution system, it is concluded that the cooling water would cool to near ambient conditions before reaching the crops or even the irrigation sprinklers.

Further cooling would occur after spraying. Using the NTU model of Porter, et al. (1976,1977) and Chaturvedi and Porter (1978)

$$(T_2 - \bar{T}_{WB}) / (T_1 - \bar{T}_{WB}) = \exp (-NTU b_f / c_w) \quad (4)$$

where

T_2 = water temperature after spraying

$\bar{T}_{WB}$ = local wet-bulb temperature

NTU = number of transfer units = 0 (1)

or greater for fine sprays of
order-mm drop diameter or less

b_f / c_w = thermodynamic property ratio
of order unity

However, similar cooling would occur with and without the use of

condenser water, because the latter would be cooled to near ambient conditions before spraying. Therefore, it is unnecessary to perform further thermal analysis for the present case. Of course, if heated blowdown were supplied to a much smaller surface area of the order of a few thousand acres or less, it would be necessary to consider spray cooling in order to include the effect of a heated discharge.

In the present case, only once-through cooling was analyzed. Therefore, further consideration of heat and mass transfer to the atmosphere was not required nor was incorporation of the effect of temperature on crop growth. In effect, the agro-power complex constitutes simply a multiple use of the same water, as envisioned here. Alternatively, the irrigation-system distribution channels may be considered to serve a second use as a flow-through cooling pond for the power plant.

The basic question to be answered is whether the increased investment and return of irrigated agriculture can offset the ordinary cost of cooling of a closed-cycle cooling system such as a mechanical-draft wet cooling tower. This question is considered in the next section for a hypothetical system operating under near-optimal conditions.

SYSTEMS ANALYSIS

Irrigation System

Young, et al (1977) have considered the detailed cost of several irrigation systems employing flows of 1 Mgd (694 gpm). A total of 864 "modules" of this size would be required for the present 2000 MW(a) fossil-fueled plant (Table 1). These modules will be analyzed in parallel. Therefore, for the sake of analysis, the size and ownership of the parcels of land incorporated in the system are not significant. However, these factors will be considered later. The cost factors are summarized in Table 4 for two irrigation rates, 2.5 and 4.0 inches/week. Actually, the larger rate is generally excessive for agriculture but illustrates the effect of flow rate on costs. Certain costs are less because spraying would not be employed.

The agricultural return for various crops is shown in Table 5 [Young, et al. (1977)].

Table 4. Costs* of Irrigation [Young, et al. (1977)]

Item	Flow Rate (in/week)	
	2.5	4.0
Land Irrigated (acres)	103	64
Land Required (acres)	124	77
<u>Capital Costs</u>		
Land (\$500/acre)	\$62,000	\$38,500
Earthwork	10,300	64,000
Pumping Station	50,000	50,000
Transmission	132,000	132,000
Distribution	144,000	64,000
Collection	0	6,000
Total	\$398,000	\$354,500
Total/Required Acres	\$3,200	\$4,600
Amortized Cost**	\$37,000	\$34,700
Cost, \$/Kgal	\$0.101	\$0.095
<u>Operating Cost</u>		
Labor	\$10,000	\$10,000
Maintenance	19,400	12,000
Power	5,800	5,800
Total	\$35,200	\$27,800
Cost, \$/Kgal	\$0.096	\$0.076
Total Cost, \$/Kgal	\$0.209	\$0.178

* 1973 dollars

** 7% interest rate, depreciated over 15 years excluding land.

Value of land is assumed to appreciate by 7% per year.

Table 5. Agricultural Return* under Average Conditions [Young, et al. (1977)]

Crop	Return (\$/Kgal) for Flow Rates (in/week) of	
	1.5	2.0
White Pine	0.070	-
Corn, Grain	0.102	0.076
Corn, Silage	0.099	0.071
Red Clover	0.056	0.040
Grass, Fodder	0.066	0.052

* 1972 dollars

It is apparent that the most economical crop to consider is grain corn.

The net cost (\$/Kgal) is summarized in Table 6 for several flow rates, determined by interpolating and extrapolating the above figures.

Table 6. Net Cost* for Irrigated Grain Corn

	Flow Rate (in/week)		
	1.5	2.0	2.5
Cost (\$/Kgal)	\$0.230	\$0.219	\$0.209
Return (\$/Kgal)	<u>0.102</u>	<u>0.076</u>	<u>0.050</u>
Net Cost (\$/Kgal)	\$0.128	\$0.143	\$0.159
Required Acres	178 K	134 K	107 K
Utilized Acres	148 K	111 K	89 K

* 1972-3 dollars

It is apparent that light liquid loading is most favorable. Even so, the system would operate at a loss based on agricultural enterprise alone. That is, irrigated crop growth would not be generally profitable. In the present case, we compute the corresponding cost of cooling based on corn :

$$\begin{aligned}
 \text{Cost of Cooling (Corn)} &= \frac{\text{Cost per Unit Flow} \times \text{Flow}}{\text{Power Output} \times \text{Time}} \\
 &= 2.3 \text{ mills/kWh (1972-3 \$)} \\
 &= 4.3 \text{ mills/kWh (1980 \$)}
 \end{aligned}$$

where an escalation factor of 1.85 was used for 1980 dollars [Rao and Porter (1978)].

Other crops such as tomatoes would be more profitable. For example, Hinton (1975) reports data showing return to management and profit for tomatoes, not including charges for land, of 3.1 times that of corn. On this basis, the system would involve a cost of cooling for tomatoes of

$$\text{Cost of Cooling (tomatoes)} = -2.9 \text{ mills/kWh (1980 \$)}$$

That is, a profit would be returned. However, the annual yield from 148,000 acres of tomatoes would be about 30,000,000 tons. It is doubtful that the market could sustain this production at a favorable price. Nevertheless, the results show that the economic analysis is sensitive to the particular crop and that this factor requires detailed study if the concept were to be pursued.

Cost of Conventional Cooling

Rao and Porter (1978) estimate the cost of cooling of mechanical-draft wet towers relative to once-through cooling as 0.61 mills/kWh (1980 \$). Rossie, et al (1971) report for fossil-fueled plants in the Chicago area a value of 0.34 mills/kWh which when adjusted with an escalation factor of 2.08 [Rao and Porter (1978)] corresponds to 0.71 mills/kWh (1980 \$). For the present study, we assume for mechanical-draft wet towers (MDW)

$$\text{Cost of Cooling (MDW)} = 0.7 \text{ mills/kWh (1980 \$)}$$

Rossie, et al (1971) report an incremental cost of mechanical-draft dry cooling of 0.48 mills/kWh which we adjust to 1.0 mills/kWh (1980 \$). Thus, for mechanical-draft dry towers (MDD) we assume

$$\text{Cost of Cooling (MDD)} = 1.7 \text{ mills/kWh (1980 \$)}$$

The above figures include cost of capital, maintenance, operation and loss of capacity effects. While the specific values are open to question depending on the particular plant, location, supplier, etc., they illustrate the order of magnitude of the costs involved.

Practical Considerations

As noted above, the required acreage for a 2000 MW(e) fossil-fueled plant is estimated as 178,000. It is highly unlikely that any utility in the U.S. could assemble this acreage near a generating station, or anywhere for that matter. Indeed, one of the problems with cooling ponds is the lack of available land at a reasonable price. In this case, about 3000 acres would be needed which is a much lesser requirement.

However, it does not seem necessary for the utility to actually own the land. Instead, heated water could be distributed to individual farms under private ownership. The present estimates indicate that the utility would have to subsidize a field-crop agricultural operation because high-volume irrigated agriculture is more expensive than un-irrigated systems in the present market. Unfortunately, the net cost to the utility adjusting for the agricultural revenue is greater than conventional cooling such as mechanical-draft wet cooling towers, or even mechanical-draft dry cooling towers.

An additional problem is cooling during off growing-season periods or when irrigation is unnecessary. Storage does not seem feasible on a seasonal basis due to the sheer volume involved with a flow of 600,000 gpm. Two alternatives are suggested. First, a conventional back-up cooling system may be employed in which case the cost is increased due to both capital investment and the fraction of time operating. Second, water may be discharged into the irrigation distribution system for cooling and returned to the source bypassing the sprinklers. In this case, additional bypass and return channels would increase costs to an extent. It is conceivable that the water would be sprayed in the sprinkler mode, but this use of water would be consumptive and probably unacceptable.

Finally, perhaps the greatest limitation is the lack of availability of 600,000 gpm for a single point withdrawal for once-through cooling and irrigation without returning the flow to the water body.

An additional possibility is to use only blowdown for irrigation, from a conventional cooling system. For the 2000 MW(e) fossil-fueled plant this would involve about 15,000 gpm and a required area of about 4400 acres. The power plant could benefit by blowing down hot water rather than cold water which is presently the case in good practice. Future zero-discharge standards may make this approach very attractive. With a smaller size system, the crops may also benefit from heated water which would be cooled far less prior to spraying. Results of Skaggs, et al (1975) suggest increases in yield from 67-75% for corn using subsurface root warming. The smaller volume of production may also be suitable for more profitable crops such as tomatoes. Based on zero-discharge alternatives, agricultural irrigation may be attractive. However, as an alternative to conventional closed-cycle cooling, it does not appear to be a viable option.

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