velopment and are meeting with some success. Scrubbing efficiencies of 90% have been achieved. The marketing problems of the large quantities of sulfur and/or sulfuric acid are under study. Because of high and rising transportation costs, such systems are economical only if adequate local markets can be developed.

The 1000 MWe Power Plant—The magnitude of the solid waste problem produced by particulate and SO_2 (limestone scrubbing) as it relates to the reference 1000 MWe plant is shown in Table 4 which gives the input/output solids relationship as it would exist for typical sulfur contents. It is clear that even for 2% sulfur coal, provision must be made to transport and landfill a mass approaching one-third that of the coal used. This is a problem of major proportion.

Even if a recoverable scrubber system is used and useful by-products are obtained, fly ash is produced at about 55 tons/hr/1000 MWe from coal of 15% ash content. The disposal of this solid waste is in itself a major problem.

III. ENVIRONMENTAL IMPACT OF HEAT DISSIPATION*

More than two-thirds of the energy used in the generation of electricity is rejected at the site as waste heat. The use of natural water bodies in the dissipation of that heat can, in some instances, adversely affect aquatic biota. The use of other methods of heat dissipation, such as cooling towers, substantially reduces the influence on aquatic biota but can produce other undesirable effects. An objective of the site evaluation is to determine as quantitatively as possible the consequences of the use of feasible cooling systems.

Background

The thermodynamic efficiency of a modern, fossil-fueled power plant is approximately 40%; that of a nuclear plant is 33%. Thus, for every kilowatt of electrical energy produced, 1.5 to 2 kilowatts of energy are rejected to the environment as heat in the generation process. Most of the waste heat is rejected from the power plant working fluid through the cooling systems. The cooling fluid receives its heat through conductive transfer at the condenser, where the low temperature vapor to liquid phase change of the working fluid assures a continuous pressure gradient across the turbines which drive the generator.

The waste heat is eventually transferred to the atmosphere through conduction, radiation, and primarily, evaporation. A variety of techniques can be used to accomplish this transfer. At present, the two most common types of heat rejection systems use water as a coolant. In the so-called "once-through" or open system, a large flow of water is withdrawn from a large body of water, it is passed once through the condenser where it undergoes a temperature rise, and then it is returned to the water body at a point physically removed from the intake. In other systems cooling is accomplished by the circulation of essentially the same mass of water which is alternately heated at the condenser and then cooled by some heat transfer device such as a cooling tower or pond. Such systems are frequently referred to as "closed" systems in spite of the fact that in most systems some water is continuously added to and removed from the circulating flow. In cooling ponds and wet cooling towers, evaporation is the primary cooling mechanism so most of the waste heat is absorbed in the latent heat of vaporization.

* In addition to the authors, Mr. T. W. Eagles, Dr. K. L. Warsh, Dr. W. D. Stanbro, Mr. J. H. Meyer, and Mr. J. A. Kagan of the Power Plant Site Evaluation Staff made substantive contributions to the experimental tests, modeling, and the general study work reported in Chapter III.

Major responsibilities in the areas of hydrology resided with Dr. Donald Pritchard and Dr. Alan Elliott of the Chesapeake Bay Institute. The marine biology work was performed by a team from the Department of Geography and Environmental Engineering under the leadership of Dr. Loren Jensen.

Water must be drawn into the cooling system to replace both the evaporated water and that discharged from the tower (blowdown) to control the concentration of dissolved solids in the circulating cooling water. However, the amount of water that must be withdrawn from natural waters is typically in the range of 0.5 to 2% of that necessary for a once-through cooling system. The blowdown is generally returned to the natural water body. While blowdown temperatures range from about 40° F greater than ambient water temperatures in winter to about 12° F greater than ambient in summer, the relatively small volume of the blowdown markedly reduces the significance of the discharge of heat.

Another form of closed system, the dry cooling tower, provides no physical contact between the cooling medium and the atmosphere and depends almost solely on conductive heat transfer as utilized in an automobile radiator. At present, such systems are inefficient and expensive to operate and have not found broad acceptance. Wet-dry towers are hybrids, usually being predominantly evaporative, with only a modest portion of the heat being transferred to the atmosphere by dry cooling.

Wet cooling towers, the principal closed cooling system, are of two general types. Natural draft towers use chimneys typically 100 to 140 meters tall and 80 meters in diameter at the top to propel the air mass carrying the waste heat into the atmosphere. One tower would serve one 1000 MWe generating unit. Mechanical draft towers use fans to draw air flow through the heated water; they are made up of a number of identical cells, each with its own fan. Each cell is usually less than 25 meters tall and is grouped with 8 to 16 other cells to form a bank. Typically, 36 cells would be required to serve a 1000 MWe coal-fired generating station. A mechanical draft tower circulating cooling system, with parameters for the 1000 MWe coal-fired plant, appears as Fig. 5. The 22.5° F temperature rise in the circulating water is typical.

Once-through cooling has been used in most large power plants until recent years when concern for the impact on aquatic biota began to constrain the use of such systems. There are several mechanisms by which a once-through cooling system can adversely affect life in a river or estuary. Small biota, including fish eggs and larvae, phytoplankton, and zooplankton, can be

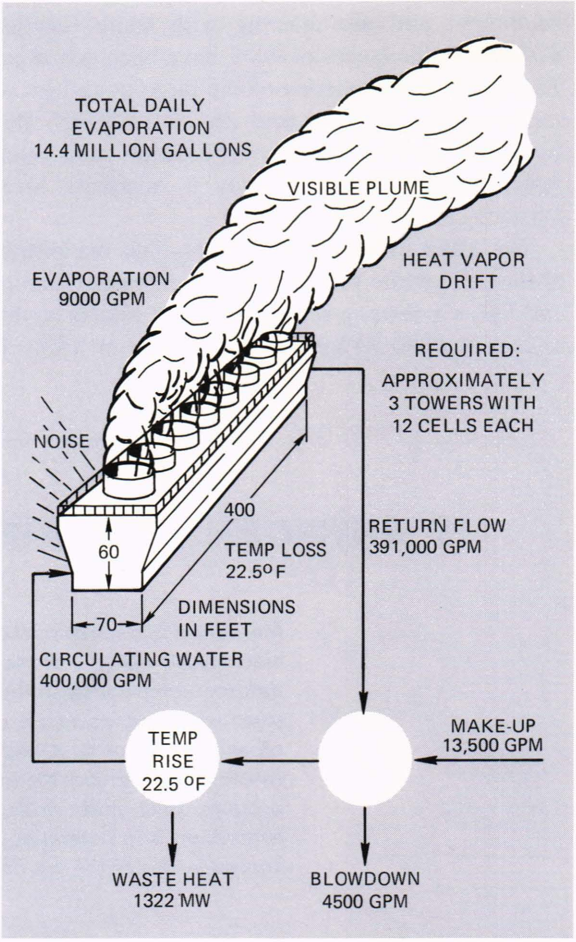

Fig. 5—Water flow chart for mechanical draft cooling tower—1000 MWe coal-fired power plant.

drawn into the cooling system (entrainment) with the cooling water and subjected to sudden temperature increases and decreases, high temperatures, biocides, and mechanical injury. There is some evidence that the latter effects may be more significant than those associated with temperature. Larger organisms such as juvenile or adult fish may be trapped (entrapment) or impinged (impingement) on screens at the intake. High temperatures, temperature transients, and toxic chemicals in the natural water body due to the discharge of cooling water can be detrimental.

Problems of aquatic biological impact can be substantially alleviated, although not eliminated, by the use of a closed cooling system. Cooling towers make it possible to operate power plants at sites on which once-through cooling could not be used; even so, some proposed sites are sufficiently biologically sensitive or vulnerable that the aquatic impact of a cooling tower can be significant. Problems of entrainment, impingement, and entrapment therefore must be considered.

In addition, closed systems have problems of their own. The large size of natural draft towers can have an impressive visual impact. The cloud-like plume of warm, moist air from the tower can, under some meteorological conditions, extend for considerable distances adding to the visibility of the tower. The plumes from mechanical draft towers will, under some conditions, remain close to the ground producing low-level visible plumes and sometimes ground level fog and, in cold weather, ice near the tower. When brackish water is used in the cooling tower, salt can be caught in the rising plume and deposited in the surrounding area with a potential effect on vegetation, soil, and structures. Salt fallout is more likely to occur in concentrations high enough to be of concern with mechanical draft towers than with a natural draft tower.

The role of site evaluation is to evaluate, as quantitatively as possible, all of the consequences of the use of the various available cooling systems and the design proposed for the particular site in question.

Overview of the Sites Evaluated to Date

The significance of the strengths and weaknesses of each type of cooling system depends on the site and type of plant in question. This can be illustrated by a brief review of some of the sites and plants that have been encountered in the site evaluation program. Because the nature of much of the aquatic impact can be similar for nuclear and fossil fuel installations, the sites proposed for both types of plant will be reviewed.

At Brandon Shores, on the Baltimore Harbor, mechanical draft wet-dry cooling towers will be used. The make-up water for the tower is to be taken from the discharge canal of a once-through cooling system of an existing plant so the additional aquatic impact from the new plant will be negligible. However, the choice between types of cooling tower was a difficult one involving principally choosing between the aesthetic impact of natural draft towers versus the salt deposition and low level plumes from mechanical draft towers. Predictive models of moist plume rise and salt transport and deposition played an important role in this evaluation. Once-through cooling could be considered and, in fact, was reasonably competitive at this site. Both hydrological and biological studies were necessary to address the once-through alternative.

The Perryman site is on the Bush River, a shallow estuarine tributary to the Chesapeake Bay. Once-through cooling cannot be used at this site. Make-up water for cooling towers can be obtained from the Baltimore City water supply aqueduct for which water is obtained from the Conowingo Reservoir on the Susquehanna River. Intake problems are not significant. However, the dilution available from the Bush River is sufficiently small that both the dilution and the potential aquatic effects of the discharge of cooling tower blowdown must be examined carefully. Piping the blowdown to other bodies of water for discharge is being considered. The biological and hydrological characteristics of this site are quite important. The nearness of small airfields and major highways complicates the selection of the type of cooling tower.

The Dickerson site is on the Potomac River above Washington. Summertime flows are inadequate to support a once-through system. The consumptive loss of water which could otherwise be used in Washington's water supply was an issue which, after an analysis of water demand and supply, was resolved by a requirement that the Potomac Electric Power Co. (PEPCO) maintain a reservoir of water to eliminate the plant's dependence on the Potomac for a 16-day period under low flow conditions. Make-up water for the cooling towers will be withdrawn from the discharge canal of an existing plant, and there will be no significant additional impact on aquatic biota; however, the effect of the existing plant on the biota is of concern. The site lies in a scenic section of Montgomery County, and the aesthetic impact of natural draft towers is of considerable concern to residents of the area. Various wet-dry mechanical draft towers were evaluated in order to assess the potential for alleviating moist plume problems from mechanical draft towers. Table 5 shows a brief summary of the results of the evaluation of alternative cooling towers at Dickerson on the basis of the study.[7] The State Power

[7] *Power Plant Site Evaluation Report—Dickerson Site,* Addendum to PPSE 3-1, The Johns Hopkins University, Applied Physics Laboratory, Jan. 1974.

TABLE 5

SIMPLIFIED COMPARISON OF COOLING TOWER ALTERNATIVES FOR PROPOSED DICKERSON, MARYLAND, POWER PLANT EXPANSION

	Natural Draft Tower	*Mechanical Draft Wet-Dry Tower*		
		Design I	*Design II*	*Design III*
Size	Height 400 ft Top Dia. 180 ft Bottom Dia. 375 ft	Each cell: height 70 ft, length 38 ft, width 67 ft		
Number of Towers	1 per generating unit.	26 cells per generating unit.	32 cells per generating unit.	40 cells per generating unit.
Ground Level Fog Induced Off-Site	None	Less than 19 hours per season at any particular off-site location.	Slightly less fog than for Design I (less than 10% reduction).	Not calculated but less than for Design II.
Elevated Visible Plume Lengths (percent of time exceeding indicated distance)	(Feb. thru July) 500 meters: 13% 1500 meters: 2.6%	(Dec. thru Aug.) 500 meters: 27% 1500 meters: 2.7%	(Dec. thru Aug.) 500 meters: 16% 1500 meters: 0.1%	(Dec. thru Aug.) 500 meters: 9% 1500 meters: 0%
Ice	None	Occasionally near tower. None off-site.	Occasionally near tower. None off-site. Less than I.	Less than II.
Land Use	Can be put on presently allotted land.	Can be put on presently allotted land.	Can be put on presently allotted land.	Either modification of site utilization or loss in plant efficiency under some wind conditions.
Noise from Towers Serving 1 unit	at 4000 ft 40 dBA (see p. 23).	Slightly less than Design II.	At 4000 ft: 4 dBA > natural draft but increases noise from complex by only 1 dBA.	Slightly more than Design II.
Relative Capital Cost (rough estimate)	1	0.85	1.15	1.45

500 meters = 1640 ft   1500 meters = 4921 ft

Plant Siting Program recommended wet-dry mechanical draft towers. The utility, while agreeing with the findings of the evaluation, concluded that natural draft towers were indicated. The Public Service Commission ruled that natural draft towers should be used.

The Douglas Point site is on the Potomac estuary in the vicinity of one of the two principal striped bass spawning grounds in the State. Cooling towers have been proposed because of the biological sensitivity of the estuary. Natural draft towers have been proposed by the utility because the large size of the facility, 2200 MWe, would necessitate a large number of mechanical draft tower cells and, as a consequence, high capital and operating costs, larger land requirements, on-site induced fog and ice and higher levels of salt deposition off-site. Because Douglas Point is in a tobacco growing area and tobacco is extremely sensitive to salt, the latter issue is significant. Methods of minimizing entrainment of fish eggs and larvae and the assessment of the significance of that entrainment are receiving considerable attention in the ongoing evaluation. Modification of the proposed cooling system design is being considered in order to minimize the cooling tower make-up water requirement. A revised design would reduce to a third the water intake during the spawning and early nursery period. The location and design of the water intake system to both minimize the entrapment of fish and maintain the nuclear safety-related integrity of the water flow, without undue cost, is an important consideration. A need to understand the dispersion of chemical and radioactive effluents, as well as movement of planktonic organisms, has necessitated major hydrological studies. The need for an understanding of the biological resource and of fish and larvae behavior patterns at the site necessitated a major biological field program. An analysis is being made of both the fraction of eggs and larvae that would be entrained by the plant under a variety of hydrological and biological conditions and also of the long-term significance of various levels of such cropping to the striped bass's population.

In short, the selection of the cooling system alternatives for consideration and the assessment of the advantages and disadvantages of those alternatives is very much a site specific and plant specific process.

Evaluation of the Potential Aquatic Impact

The study of the potential impact of cooling systems on aquatic biota in the Maryland site evaluation program typically involves biological and hydrological field studies to assess the characteristics of the site and modeling of pertinent hydrological and biological systems, together with a study of the characteristics and potential effects of all applicable plant design technology.

The biological studies have been conducted by the Department of Geography and Environmental Engineering, The Johns Hopkins University. Typically, 12 to 15 month field programs are involved in which systematic samplings of fish, ichthyoplankton (fish eggs and larvae), phytoplankton (primary producers—the "grasses" of the water), zooplankton (the grazers), benthic organisms (bottom dwellers), and water quality are made. The surveys, together with a review of the pertinent literature, determine to the extent possible the inhabitants of the water body, their spatial and temporal distribution and the ecological health of the area, and identify any relatively unusual or unique characteristics or ecological roles of the region. The biological program must seek to obtain data which resolve specific questions that are the key to the prediction of the direct impact of the power plant. For example, at the Douglas Point and Chesapeake & Delaware Canal (nuclear plant) sites, where the impact on striped bass is of concern, the uncertainty about the behavior patterns of striped bass larvae needs to be resolved. The transport and distribution of larvae, and hence the length of time for which they are vulnerable to a plant, depend upon whether the larvae concentrate near the river bottom or are distributed throughout the water column, whether and at what age they seek refuge in the marshes, and whether they rise to the surface at night to feed.

Even more difficult are questions related to the long-term significance of a given level of damage to the health of the ecosystem. For example, the significance of a given level of entrainment of striped bass eggs and larvae is not resolved until the long-term effect on the striped bass fishery in the Chesapeake Bay and Atlantic coast can be predicted. This, in turn, requires an understanding of the mechanisms currently regulating the population. While the present understanding of fishery population dynamics is not adequate to unequivocally resolve such an issue, the program must attempt to bound the answer as closely as possible.

The hydrological studies are conducted by the Chesapeake Bay Institute with collaboration from staff of the Applied Physics Laboratory. Field studies are conducted to provide the basis for models of the far-field water dispersion processes. Parameters measured include temperature and salinity distribution, and flow magnitude and direction. Dye studies are usually conducted to determine the dispersion characteristics of the region. Salt is usually used as the tracer for the development of the estuarine models; the models once developed are then evaluated by comparing their predictions to measured dye concentrations.

The models developed vary in complexity with the site. A simple one-dimensional, six-segment dynamic model was developed for the shallow, slowly flushing Bush River. Simple inter-segment exchange coefficients were used to model the net effect of density-induced and wind-induced flow. A two-layered equilibrium model has been developed for the entire Potomac estuary as part of the Douglas Point site evaluation. This model permits the calculation of concentrations of an effluent from the proposed plant which would result throughout the estuary under steady-state conditions from releases at the site. The estuarine flow developed from this model for a spring period is shown in Fig. 6 normalized to fresh water flow, R. A dynamic model of the Potomac is now under development which will treat transient circulation and dilution. At Dickerson and Brandon Shores, hydrological models were not needed because the characteristics of the discharge from existing plants could be measured directly. Both dynamic and equilibrium models are being developed for the Chesapeake & Delaware Canal for the Chesapeake City evaluation.

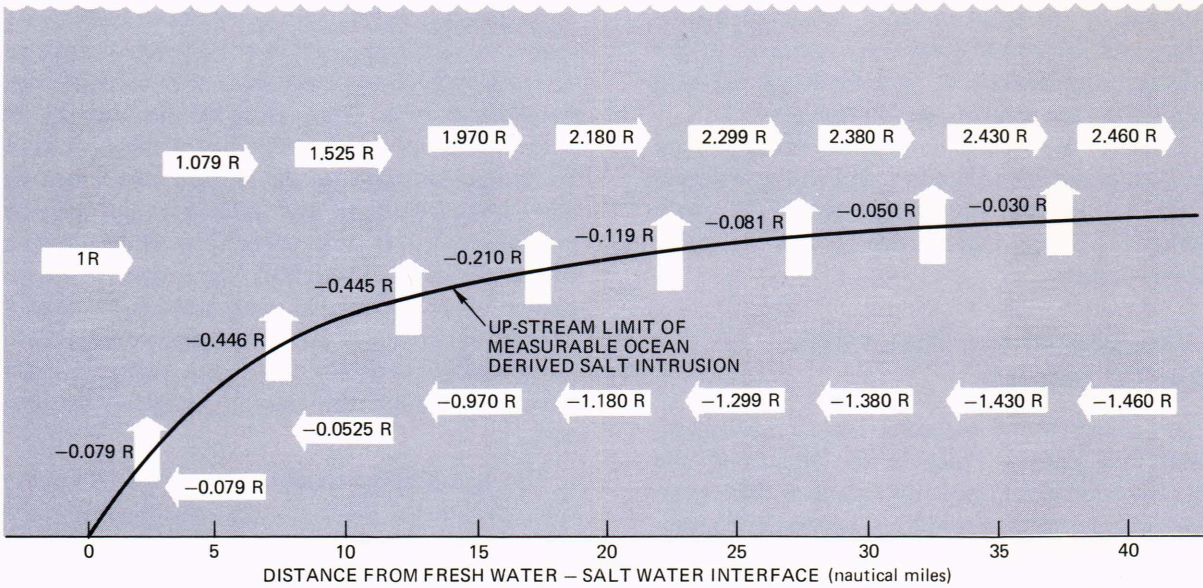

Fig. 6—Model of estuarine circulation in Potomac River normalized to fresh-water flow (*R*) under representative spring conditions (data taken April 1974). The upstream limit of ocean-derived salt intrusion typically occurs at Maryland Point in the spring.

Concentrations of effluents near the discharge where the dilution is dominated by characteristics of the discharge system are predicted using models of these near-field processes. A semiempirical jet model developed by Dr. Pritchard of CBI is used to model discharge systems having a single opening.[8] Models drawn from the literature are used to evaluate discharge systems with multiple openings as ports. The near-field models must be adjusted to account for the local topography and flow conditions. Concentrations of effluents which build up in the vicinity of the site reduce the near-field dilution available because the water which is drawn into the discharge plume and dilutes it already contains a finite concentration of the effluent. This background concentration is estimated from dye studies and far-field models and used to modify the predictions of near-field dilution. Dilution in the intermediate range, beyond the direct influence of the discharge but short of the distance where far-field predictions are appropriate, is the most difficult to estimate. The results of dye studies are used directly to predict dilution within this region.

Among the plant design technologies that must be evaluated are the design and location of water intake systems which can moderate the entrapment and entrainment losses, and plant design which affects cooling water requirements. For the Douglas Point site several plant designs affecting cooling water intake requirements were studied. Data on the distribution and behavior of striped bass eggs and larvae and of the hydrological characteristics of the Potomac were used in a model to predict the fraction of a striped bass spawn that would be entrained by existing and proposed plants at different locations on the estuary for the various plant designs and for a range of river flow conditions. Preliminary results are shown in Table 6. Cases A and B are for river flow equal to the average spring flow. Cases C and D are for a river flow equal to half of this value; the lower flow was found to maximize the entrainment loss at Douglas Point. The lower entrainment at Morgantown, downstream from Douglas Point under lower flow conditions is due in large part to the slower rate of downstream transport under low flow conditions coupled with the ability of young fish to avoid entrainment after a number of weeks. The model is currently being revised to include more elaborate characterizations of the hydrological transport and dispersion, and of the behavior of the striped bass larvae and fry.

[8] *Power Plant Site Evaluation Report—Douglas Point Site,* PPSE 4-1, Vol. 1, The Johns Hopkins University, Applied Physics Laboratory, May 1974.

TABLE 6
ENTRAINMENT BY EXISTING PLANTS ON THE POTOMAC WITH ONCE-THROUGH SYSTEMS (POSSUM POINT, MORGANTOWN) AND THE PROPOSED DOUGLAS POINT PLANT WITH WATER INTAKE REQUIREMENTS FROM TWO POTENTIAL COOLING SYSTEM DESIGNS.

	Entrainment of Striped Bass Eggs & Fry			
	Case A %	*Case B* %	*Case C* %	*Case D* %
Possum Point	1.5	1.5	3.7	3.7
Morgantown	8.5	8.5	0.7	0.7
Douglas Point	1.4	0.5	2.6	0.9
Above Combined*	11.1	10.3	6.9	5.3
Douglas Point Intake (cfs)	240†	80‡	240†	80‡
River Flow	43-Year Average		50% of 43-Year Average	

* The entrainment for the combination of two or more plants is less than the sum of the entrainment of the individual plants since each plant can potentially entrain only what is passed along from the plants upriver.
† Present cooling system design.
‡ Alternative cooling system design under evaluation.

Alternative sources of water, such as sewage treatment plants, other industrial plants, or other less biologically-sensitive water bodies, can be viable at some sites. The discharge design and location can influence concentrations of heat and biocides in the vicinity of the plant as well as the potential for recirculation of discharged water into the intake. Plant operation must be modeled to determine the chemical and physical characteristics of water returned to the river. In the present site evaluations, this need has led to a laboratory and field study of the chemistry of chlorine within an operating cooling tower system. Present understanding is not adequate to predict the quantities of toxic chlorine derivatives that would be present under varying water conditions and with candidate biocide administration practices.

Evaluation of Airborne Environmental Effects of Cooling Towers

Evaporative cooling towers may adversely affect the environment because of the large amounts of moisture they add to the air which at times does not have the capacity to absorb it without condensation occurring. Fogging, icing, or the formation of visible clouds may result. In addition, droplets of the circulating water that escape from the tower, called drift, carry with them the concentrated chemicals present in the make-up water (water taken in to replace evaporated water) as well as any chemicals added to the water to control biological or chemical effects in the cooling system. If salt water is used for make-up, the concentrated salt present in the drift can be deposited on the ground in significant amounts downwind from the towers. There is also a possible effect on aircraft flying through the plume because of turbulence and icing. These effects—fog formation, icing on the ground and on aircraft, visible plume formation, drift deposition, and turbulence—need to be quantified for use in evaluating the desirability of a cooling system, as well as for comparing alternate cooling methods. An analysis has been made for three plants; methods and representative results are outlined here. Each of these effects depends upon the behavior of the moist cooling tower plumes. Efforts to monitor this behavior will first be discussed.

Moist Plume Behavior

Buoyant plumes from stacks have been studied by numerous investigators over many years. Such studies, while providing a starting place for the prediction of cooling tower plume behavior, are far from adequate for such predictions. The differences in the size of the exit opening and in the temperature, water content, velocity, and turbulence of the emerging gases make cooling tower plumes significantly different from stack gas plumes. Even among cooling towers, the differences in the exit geometry and characteristics of the emerging air make data or models of natural draft towers poor characterizations of mechanical draft towers.

Little data on cooling tower plume behavior has been published. A series of studies at the Keystone Plant in Pennsylvania has provided most of the data available on natural draft towers. A study has been conducted on natural draft tower plumes by the TVA and their data will soon be published. The Maryland Power Plant Siting Program has begun a major study of a natural draft tower soon to become operational at the Chalk Point Plant on the Patuxent River. This investigation will provide insight not only on plume trajectory, but on salt transport, deposition, and impact on natural vegetation and crops.

Even less information has been published on mechanical draft tower plumes. Because plumes from mechanical draft towers start closer to the ground and rise shorter distances than those of natural draft towers, they are more likely to produce adverse ground level conditions. Consequently, it is quite important to be able to accurately predict plume behavior from such towers. As part of the site evaluation program, APL has conducted a study of an existing mechanical draft tower at PEPCO's Benning Road generating station.[9] Measurements were made of the characteristics of the plume leaving the tower, including profiles of velocity, temperature, and humidity across the exit. Local meteorology was determined using ground level measurements and rawinsonde (radio wind sonde) flights. Plume trajectories were recorded photographically and quantified with photogrammetric techniques. Data have been reported from 21 days with approximately four observation periods per day collected over the fall and winter of 1973–74. Aerial photographs and instrumented flights are made on occasion. Figure 7 shows a photograph of a plume with points indicated at which profiles of temperature and humidity were measured; Fig. 8 shows the corresponding water vapor densities. These data provide the principal characterization of mechanical draft tower plume behavior available today. They are being used within the APL/JHU program and elsewhere to define and tune models of the trajectory, extent of visibility, and salt transport of mechanical draft tower plumes. The data are also being used to characterize the occurrence of downdraft, when the plume is pulled down into the wake of the tower, as a function of meteorological conditions.

Fog

Fog occurs primarily because the moisture content of the air exceeds the saturation value. At times when the ambient relative humidity is high, the addition of a small amount of moisture from a cooling tower can saturate the air, inducing fog. In general, natural draft towers induce little or no ground level fog because of the height of the towers and substantial rise of the plumes. The characteristics of the plume leaving the mechanical

Fig. 7—Mechanical draft cooling tower plume at Benning Road as viewed from 305 meter altitude. The black dots indicate various altitude penetrations of the plume by aircraft.

draft towers frequently induce ground level fog near the towers, particularly during the winter. They will induce spotty fog on occasion beyond the site boundaries. The unexpected nature of fog which occurs in a small patch can contribute to the traffic hazard posed by the fog.

In each site evaluation, the frequency with which a visible plume would reach the ground (i.e., produce fog in spots) is predicted for each season of the year. The analysis for the Dickerson site will be reviewed. As a first step, the seasonal frequency of occurrence of natural fog as a function of relative humidity was determined from five years of meteorological data compiled at Dulles International Airport. The sensitivity of the Dickerson environment to fog inducement was then obtained by calculating sensitivity functions (again based on the Dulles data) expressing the increased probability of fog as a function of added moisture.

The characteristics of the plume leaving the tower were calculated for representative temperature/humidity conditions for each season. The plume rise and dispersion of water vapor was calculated for six wind speeds and six atmospheric stability classes. For natural draft towers, Briggs plume rise formulation (Ref. 5) was used. For mechanical draft towers, a modification of the formula indicated by the preliminary analysis of the Benning Road data was used. Pasquill-Turner dispersion formulations (Ref. 6) were used. For each combination of conditions, the water vapor added by the tower was determined as a function

[9] J. H. Meyer, *et. al.*, "Mechanical Draft Cooling Tower Visible Plume Behaviors: Measurements, Models, Predictions," *Proceedings of the Cooling Tower Environment, 1974 Symposium,* U. S. Atomic Energy Commission (to be published—will be available from APL).

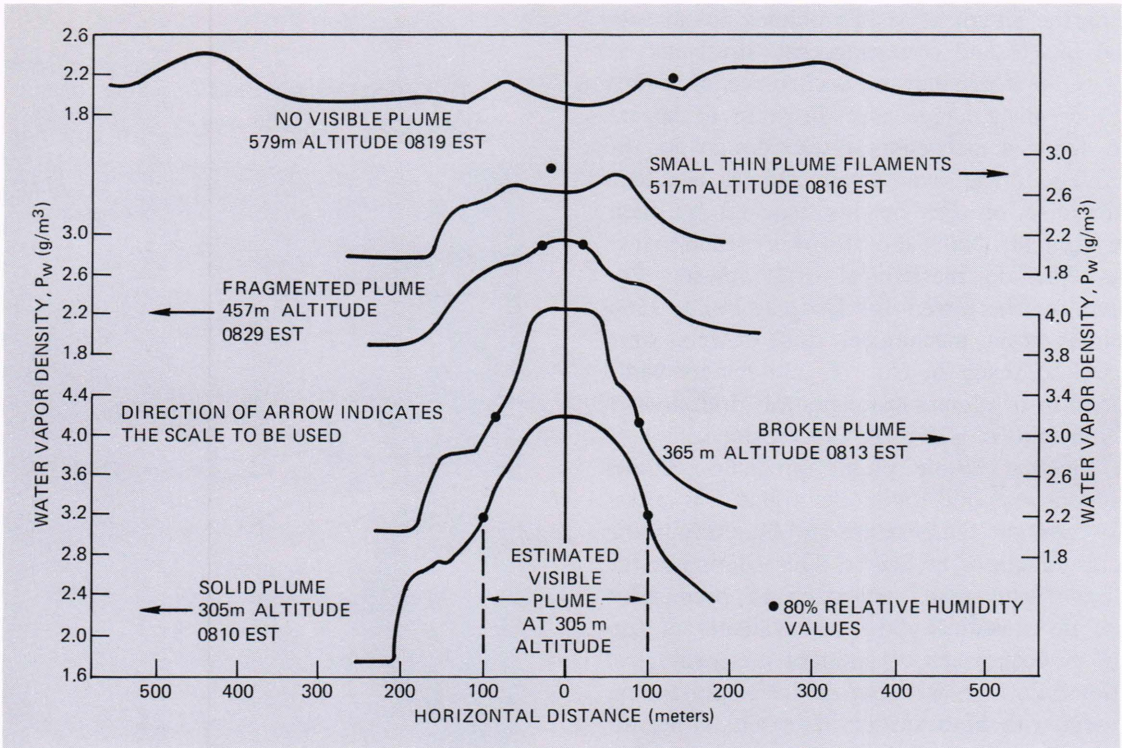

Fig. 8—Aircraft-measured horizontal water vapor density profiles of mechanical draft cooling tower plume at various altitudes, Benning Road, February 6, 1974, 8:00 to 8:30 EST.

of distance from the tower. Data giving probability of occurrence of each combination of wind speed, wind direction, and stability class is routinely available from the National Climatic Center, and such data (called a "stability-wind rose") were obtained from Dulles Airport. Finally, the water vapor added for each representative condition, the probability of occurrence of each condition, and the fog sensitivity functions were combined to calculate the incidence of induced fog at ground level. This analysis was carried out for natural draft towers and for four wet-dry tower designs.

The predictions indicate that although fog would be induced by mechanical draft towers on occasion in all areas within a few miles of the towers, no one area would be expected to experience ground level fog more than four hours per season. Interestingly, the inclusion of dry heat exchange in the mechanical draft towers did not reduce the incidence of induced fog because the effect of the reduction in evaporation was offset by a reduction in the plume rise obtainable from the wet-dry designs. The induced fog would likely occur as an extension of natural fog. The frequency of occurrence of induced fog can be compared to that of natural fog which is on the average 340 hours per winter season.

Elevated Visible Plumes

The length of the visible portion of plumes which do not reach ground level is of interest primarily for aesthetic reasons, although in certain situations the influence of visible plumes on aircraft must be examined. Visible plumes frequently extend several thousand meters downwind; on rare occasions they may extend for miles. In the Douglas Point site evaluation, an analysis of visible plume length was made for a natural draft tower, a wet mechanical draft tower, and four wet-dry mechanical draft towers with differing percentages of dry cooling. It was found that while natural draft towers tend to have fewer plumes reaching distances comparable to 1000 meters or greater, they produce more of the relatively long plumes than do mechanical draft towers. Wet-dry designs were quite effective in reducing the length of visible plumes but at substantial capital and operating cost. Illustrated in Fig. 9 is the frequency of occurrence of visible plumes of given length and direction to be expected from a particular tower design in the winter. The range over which plumes are seen depends also on the heights reached by their visible segments. Natural draft towers reach higher heights than do mechanical draft towers. For example, for the towers for Douglas Point, 25% of plumes from mechanical draft towers were predicted to reach heights of 220 meters while this fraction of plumes from natural draft towers reached heights of 520 meters or greater.

An elevated visible plume prediction model differs from a ground-fog model in that it is necessary to know the temperature and humidity in the plume as functions of height. This eliminates the statistical "wind rose" approach to predictions because no statistical data are available of frequency of occurrence of ambient meteorological conditions aloft. It is therefore necessary to use the model with both surface data and upper air data combined for each instance being evaluated. In our evaluations, predictions were made for each three-hour interval in a one-year period. At the end of this process, statistics were compiled on frequency of occurrence of plumes of given length as illustrated in Fig. 9.

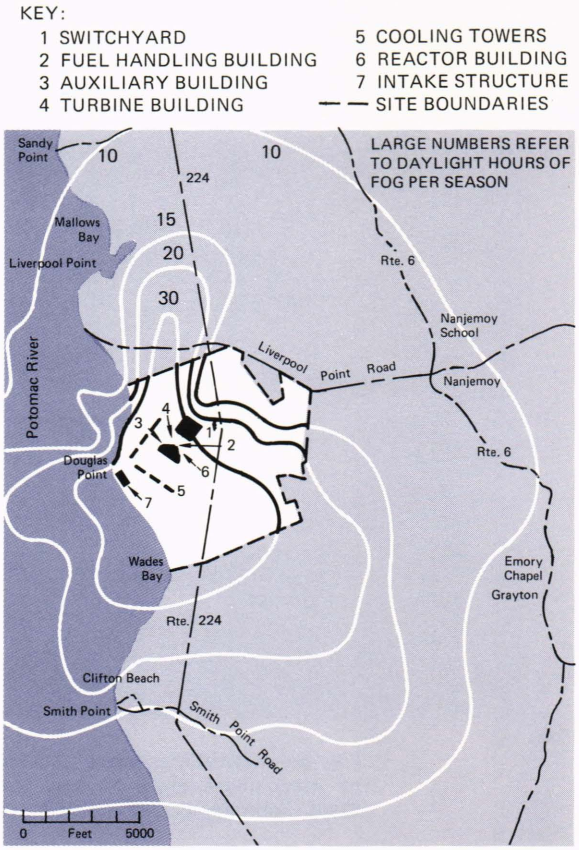

Fig. 9—Contours of equal frequency of occurrence of visible plumes—full-wet mechanical draft tower, winter season.

Key to the determination of the temperature and humidity throughout the plume is the prediction of the rate of growth, or of entrainment of ambient air into the plume. This rate of entrainment is inferred from the plume trajectory model through use of the basic equations of continuity of mass, buoyancy, and momentum which are used in the development of the plume rise formula. The relative humidity of the plume, along with a visibility criterion selected through the use of field data, is used to determine the point at which the plume ceases to be visible. In cases where the plume remains visible up to its final height, a Gaussian dispersion model is used to predict plume centerline water concentrations beyond the final rise point.

Icing

Ice can be formed in the vicinity of a cooling tower when drift droplets or gaseous or condensed water vapor in the plume come in contact with cold surfaces. With natural draft towers the concentrations of water reaching the ground are too small to permit the formation of ice. Under high wind conditions, plumes from mechanical draft towers can be brought near the ground. This is particularly likely if winds are sufficiently high for the plume to be caught in the wake of the tower. If temperatures are then below freezing, the potential for icing exists. This effect is confined to the first several hundred meters; of concern is how it affects plant operations, and in some situations, transmission line or switchyard arcing. The simultaneous occurrence of moderate to high winds and freezing temperatures is required for icing to occur. For the site evaluations to date, climatological data have been used to determine the joint frequency of occurrence of freezing temperatures and representative wind speeds and directions. The data from the study of mechanical draft tower plume behavior are being examined to better determine the conditions under which plume downdraft will occur; these results will be used in the development of a model of ground level icing.

At the Douglas Point site the question has been raised of the possible interference of tower plumes through both turbulence and icing on the heavy air traffic from the Quantico Marine Base which passes over the site. These effects are now under study.

Salt Drift Deposition

The amount of drift-borne salt distributed onto the ground and other surfaces surrounding a salt water cooling tower depends on the salt emission rate and on the distance traveled by the salt-laden droplet before it strikes the ground. The salt emission rate depends on the salt concentration of the tower circulating water, which in turn depends on the ambient salinity and the degree to which dissolved solids are allowed to concentrate in the circulating water, and on the fraction of that water which escapes as drift. Downwind travel of the drift droplets is influenced by the effects of wind, ambient relative humidity, atmospheric stability, the distribution of the size of droplets, and the rate of evaporation of the droplets as they travel, first within the plume, and later after they leave the influence of the plume.

The method used by the site evaluation team to estimate potential salt drift deposition from the use of salt water cooling towers at PEPCO's proposed Douglas Point plant attempted to include all of these factors. A model based on Briggs' plume rise equations, but modified for mechanical draft towers using the Benning Road data, was used. A model of the rate of evaporation of droplets was incorporated. Both droplet fall and dispersion were treated.

Meteorological conditions of temperature, relative humidity, and atmospheric stability were determined at three-hour intervals for a one-year period (1970) as a function of height using Quantico climatological data and Dulles radiosonde soundings. Annual and seasonal salt deposition rates were computed for mechanical and natural draft towers for both typical and extreme ambient salinity conditions.

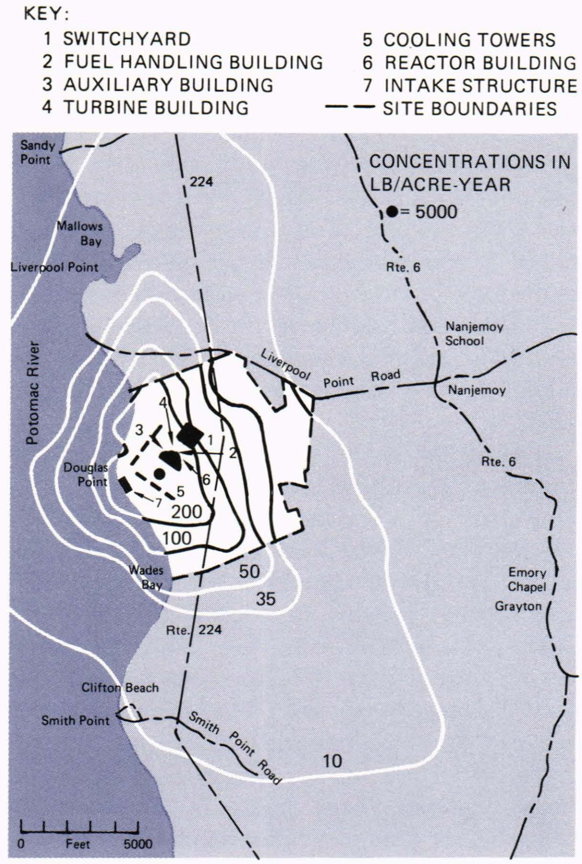

Fig. 10—Predicted contours of constant salt concentration owing to salt deposition from mechanical draft cooling towers which would occur in a year of unusually high Potomac River salinity.

In Table 7 a comparison is made of the maxi-

TABLE 7
SUMMARY OF PREDICTED MAXIMUM ANNUAL SALT DEPOSITION DUE TO DOUGLAS POINT COOLING TOWERS: ON-SITE, OFF-SITE, AND AT ANY EXISTING TOBACCO FARM

		Maximum Annual Salt Deposition (lb/acre-yr)		
Tower Type	*Potomac Salinity Conditions*	*On-Site*	*Off-Site*	*At Any Tobacco Farm**
Mechanical Draft	Extreme	5000	235	60
Mechanical Draft	Typical	2000	70	20
Natural Draft	Extreme	130	85	50
Natural Draft	Typical	50	25	15

* In every case, only one existing tobacco farm receives greater than 10 lb/acre-yr salt deposition; this farm is approximately ½ mile north of the site boundary.

mum salt deposition predicted at any location from mechanical and natural draft towers under conditions of typical and extremely high Potomac River salinities. The most significant differences occur at areas of peak deposition on-site where mechanical draft towers would result in substantially higher levels of deposition. At nearby off-site areas natural draft towers might result in about three times the salt deposition of mechanical draft towers. In Fig. 10 predicted contours of salt deposition are shown for a particular tower and river salinity condition which provides an upper bound on salt deposition for the proposed plant.

The significance of salt deposition from cooling towers to vegetation is being investigated at the University of Maryland through the support of the Maryland Power Plant Siting Program as well as in several other places in the country. While much work remains to adequately clarify this issue, preliminary results have indicated damage to some crops from deposition rates comparable to 300 pounds/acre-year.[10] The burning quality of tobacco has been reported to be adversely affected by much smaller quantities; concern has been expressed over levels in excess of 35 pounds/acre-year in tobacco land.

Salt drift from cooling towers also has the potential to accelerate the corrosion of materials exposed to it. The amount of acceleration is dependent not only on the amount of extra salt deposited, but also on the amount of moisture available, the temperature and other atmospheric pollutants, and, of course, the materials involved. Some perspective can be obtained from a comparison with salt deposition rates in the severely corrosive environment of an ocean shore. Deposition within 30 to 50 meters of the Atlantic coast is typically at the rate of several thousand pounds per acre-year; at a distance of a thousand meters from the shore deposition typically drops to several hundred pounds per acre-year.

[10] C. L. Mulchi and J. A. Armbruster, "Effects of Salt Sprays on the Yield and Nutrient Balance of Corn (*Zea mays,* L.) and Soybeans (*Clycine,* max. L.)," presented at *Cooling Tower Environment Symposium—1974,* held at the University of Maryland, Mar. 4–6, 1974.

Evaluation of Impact on Potable Surface Water

Either a once-through cooling system or a wet cooling tower ultimately rejects its waste heat burden to the atmosphere largely by the evaporation of water. For the expansion of the Dickerson plant, the source of that water is to be the Potomac River. However, during periods of low river flow, any consumptive use of water from the Potomac would add to an already serious water supply problem for the Washington metropolitan area. A statistical study was performed to determine the number of consecutive days during which various low levels of river water would be available as a function of the length of time between occurrences of such drought conditions (recurrence interval) using flow data published by the U. S. Geological Survey. The availability of water was compared to projected water

TABLE 8
NUMBER OF DAYS CONSUMPTIVE USER OF POTOMAC RIVER WATER WOULD NEED TO DRAW FROM STORAGE TO HAVE NO ADVERSE EFFECT ON WATER SUPPLY FOR METROPOLITAN WASHINGTON (METROPOLITAN PERSPECTIVE)

	ALTERNATIVE ONE					*ALTERNATIVE TWO*				
Year	*Unaugmented Potomac River flow less 155 cfs flow to Potomac Estuary*					*Potomac River flow augmented by 212 cfs from Bloomington Reservoir less 155 cfs flow to Potomac Estuary*				
	RECURRENCE INTERVAL-YEARS									
	2	5	10	20	50*	2	5	10	20	50*
1975	—	—	<7	17	34					
1980	—	<7	13	26	56	—	—	—	7	18
1985	—	8	24	42	79	—	—	7	16	32
1990	—	18	37	66	96	—	<7	15	30	58
1995	<7	31	57	90	120	—	13	30	52	86

* Based on extrapolated low flow duration table.
— Storage probably not required assuming short term local storage provided. (Curves cannot be read for periods less than seven days.)

demand using population estimates and water demand estimates published by the Washington Area Interstate Water Resources Program. Through the graphical solution of supply and demand functions it was possible to determine the length of time for which demand would exceed supply assuming various upstream flow augmentation schemes under consideration. The results of the study are concisely presented in Table 8, which shows the number of consecutive days during which withdrawal of Potomac water would aggravate an inadequate supply as a function of recurrence interval and year. It was suggested that PEPCO could handle this problem by storage of water in an on-site reservoir; the needed capacity of the reservoir could be calculated using the Table for any recurrence interval. PEPCO has been required by the Public Service Commission to have the capability of eliminating their dependence on the river for the equivalent of 16 consecutive days through a combination of modified operating procedures and the construction of an on-site reservoir with nine days make-up capacity.

IV. OTHER POWER GENERATION IMPACTS

In addition to the major issues of air and water pollution, the power plant has potential for many other impacts. Among the more important of these are: community noise, groundwater availability, sediment and erosion control, dredging and dredge spoil disposal, visual impact, oil spill potential, and coal pile dust. These are included in our studies as required, and some are treated in this section.

Potential Noise Impact

All environments, no matter how remote from the activities of man, will have sound energy present. Such "ambient noise" often cannot be traced to any specific source. An assessment of the noise impact of a proposed power plant must start with a determination of the ambient conditions to provide a base against which potential intruding plant noise can be compared.

The magnitude of sound is generally described in terms of decibel units (dB)*, with zero dB being approximately the quietest sound a normal person can hear. To describe noise from the point of view of human perception and annoyance, it is generally necessary to describe its decibel level in individual portions of the frequency spectrum. This is important because the way people perceive sound and the manner in which they might be annoyed will depend on the frequency distribution of the noise.

Therefore, it is customary to describe sound levels in individual portions of the frequency spectrum; typically nine separate bands are used which are centered at 31, 62, 125, 250, . . . 800 Hz, each band being one octave wide. Many times a simpler description of noise is used by assigning an equivalent "dBA" rating. The term dBA indicates that the total sound energy is modified by a frequency characteristic similar to that of the human ear.

The introduction of a power plant will add noise originating from generating units, cooling towers, fuel handling facilities, and vehicular traffic. Each of these noise sources must be described in separate octave bands in order to adequately assess the noise that will be propagated off-site and its annoyance potential. In the APL/JHU noise assessment program, these source level models are determined through a combination of APL/JHU measurements, manufacturer's data, published information, and theoretical principles.

Sound levels propagated to residents surround-

* The basic unit of reference is 0.0002 dynes/cm^2