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THE USE OF SIMULATION IN THE DEVELOPMENT
OF REGIONAL PLANS FOR PLANT SITING AND
THERMAL EFFLUENT MANAGEMENT*

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INTRODUCTION

As the nation moves in search of a rational policy for carrying out the important job of providing energy of the future, a number of aspects of the management of the common pool resources involved has been brought to sharp focus. Among these are the questions of institutional arrangements, the relative roles of the owners and operators and the need for improved means of applying systems technology to support policy. Adding to the problem is the multitude of agencies and interactions involved in the marketing, distribution, manufacture and operation of the energy technology system. As recently stated by President Nixon, "The various agencies often trip over one another as they move to meet a common problem," and sometimes, "step on one another's toes."

While there can be no completely permanent solution to the institutional problems associated with common pool resources, nor is it necessarily even desirable, a breakthrough is needed in the mix of institutional facilities which will permit a more optimal outcome while still responding to public thinking. This mix will contain a large variety of public and quasi-public bodies of differing powers and boundaries. It will include means for developing relatively unchallenged sources of reliable, unbiased information, and will of necessity, include the utilization of diverse forms of pricing or user charges where appropriate. (1) In addition to institutional methodology there is needed the basic concept of a common pool resources plan and some effective systems tools for examining alternatives in advance of commitment.

THE REASONS FOR A PLAN

From a purely technical standpoint, the reasons are involved principally in the development of boundaries over which traditional optimization processes operate. While engineers can be justly proud of the technical scope of the optimization system, the developments of recent years clearly indicate that a weakness in the system exists in the selection of boundary conditions. The engineer traditionally attempts to limit the scope of his optimization to the most deterministic level, thereby undervaluing interactions which are not included. The engineering technology system is understandably reluctant to assume responsibility for undefined spillover because of the emphasis on determinism in the value system pertinent to engineering. Branscomb⁽²⁾ has stated, "Mankind must react rationally to the opportunities as well as the problems created by technology. On one side lies a harmonized world of interdependent societies, enjoying decentralized power and shared wealth, leisure, and learning. On the other is a despoiled planet of charred earth, dead lakes, and an acid atmosphere."

The need for a plan for energy development can be summarized as follows:

- All energy eventually degrades to heat whether or not used efficiently or usefully. Accordingly, planning must include questions related to total energy release to the atmospheric environment.
- Since water is 4.5 times more effective than air by weight and 42 times as effective as air on a volume basis as a heat transfer medium, there are technological advantages in the planned use of water to remove thermal effluent from metropolitan centers subject to heat island effects.

- Other policies which indicate attention to previously unvalued opportunities are national policy on population dispersal, the new cities program and related social innovations regarded as essential in the most recent summaries of nationally desirable objectives.⁽³⁾ Policies which tend to preserve inelastic considerations do not appear to offer any chance of long range success.
- The recreational needs of man and the tastes of society need careful study and modeling for inclusion into the planning process. More attention to these factors can allay many of the fears of the most potent opponents of a planning policy.
- The final essential is the protection of the individual initiative system. Without a rational policy with regard to planning of facilities which involve lead times of from 5 to 7 years, no amount of proper initiative can survive without the guiding perspective of an institutional policy designed to enhance the social values of decentralized operation.

THE ESSENTIALS OF A SUCCESSFUL PLAN

Accordingly, on the basis of the discussion above, a number of basic essentials to support a successful plan or planning method can be listed. In the aggregate they constitute a new concept, impracticable in the pre-computer era, which can be called dynamic planning.

- A successful plan must have high visibility and capable of clear translation to a heterogeneous populace.

- Such a plan should have a very high degree of rational determinism. It should be isolated from political bias, but contributory to the political process. Its essential duty is to provide information.
- Dynamic planning must be flexible to continuous change in response to new conditions, both technical and social. Both new opportunities and constraints should be sought and tested.
- The plan must offer protection of the most appropriate alternatives. Such protection would place heavy emphasis on social values and life styles while properly evaluating the corresponding costs.
- A successful plan must integrate the competing requirements of need and taste in a way that a self evident means of improvement for the plans exists and is functionally viable.
- The plan must include a direct means to inform a number of levels of a heterogeneous public, institutional systems and agencies.
- Finally the planning system must be constantly seeking new technological means to gauge, simulate and predict the long range needs of the social system to the extent that inputs to the planning options are available and deviations estimated.

Technical-Economic Analyses

Advanced technology would be utilized to study the technical and economic factors concerned with water quality and ecological imbalances. The planning program would consist principally in applying predictive technology, identifying and comparing management options, and developing evaluative procedures. Hierarchical simulation models would be developed and used to represent the

physical, chemical, biological, and engineering properties of water bodies under consideration. The methodology would incorporate in-depth detail for the many interactions between components of resources utilization, which heretofore defied analytical treatment. The primary role of the technological sector is to provide for the capability base to accomplish the following six major objectives:

- Advance basic research in analysis techniques for field and laboratory data pertinent to the technology of the water resources system.
- Develop unified data format and handling systems, common computer languages, and highly advanced information-retrieval and distribution capability
- Develop processes for the evaluation of the impact of physical aspects of technology on the course of human affairs
- Develop engineering subprograms involving structural innovation and control of the primary elements of the hydrologic cycle
- Improve the predictive capability in forecasting future industrial technology applicable to identification of new waste streams, management options, and alternative prime-mover systems in conversion and energy industries and municipal waste treatment.
- Utilize new technological developments in computers, information systems, communications, and related research in order to use the best combination of tools for the accomplishment of the resources-management objectives.

The hierarchical systems-analysis approach is an efficient method of obtaining operationally adequate simulation models for complex problems. This concept is limited only by the accuracy of scope of the individual phenomena determined by field test to be the key factors in the chain of relevance. Ranging from the highest level to lower levels, models are employed to explore the individual phenomena in more and more detail, and at varying levels of activity, as the emphasis shifts. At the lower level in the relevance chain, quite rigorous mathematical representations and corresponding closed-form solutions might be used in a totally deterministic

framework. Valid simplifications would be sought at every level such that higher echelon models do not delve into unnecessary detail in a subarea, thereby keeping the investigating team oriented to the concept that individual details of lower levels appear in simplified or simulated form at the highest levels of investigation pertinent to the specific problem at hand.

Simulation models will have to be extensively validated and the output and the input data will require specific accuracies, depending on the sensitivity of a given parameter. Because of the potential difficulty of achieving full acceptance, it is incumbent on simulation-model technology to also provide means of testing the accuracy of the methodology and comparing alternative ways of determining the sensitivity of a given subarea. This must be done in a fully auditable way. An investigation of the criteria for satisfaction yields four important points for consideration:

- Were the data measured in a standard manner and was the population sampled representative of the entire sample?
- Were the mathematical tests that were applied sufficiently objective to preclude built-in bias or subjectivity?
- Would the model system be subject to exterior bias, such as sabotage, electronic malfunction, or inquiry from unauthorized persons without the ability to detect or abort such influences?
- Is the use of electronic simulation with the possibility of compensating error ever tractable in terms of legal or quantitative proof in cases involving institutional systems such as law where statistics are often inadmissible in testimony?

The supporting analyses would be considered as a linkage between technological factors and model representations on the one hand and institutional factors and modification on the other. Information on the nature of the physical problem and how it might be modified by the technological factors is taken as basic input. Through economic analysis, this basic input is

transformed into information that can be used directly by public decision makers. More specifically, the analyses would develop information needed to answer two basic questions about prospective use of water resources systems in the siting of utility plants:

What programs should be undertaken?

How should they be economically integrated into the time frame?

DEVELOPMENT OF AN EXAMPLE OF THE CONCEPT

As an illustration of the practical application of the concept, a brief example of the development of the interaction matrix for plant siting is outlined below. (Figure 1). A fundamental in the game strategy is the ability to model developing ranges of consumer demands in response to a number of planning alternatives which themselves result from policy and public taste. Using the methods described above, and considering the management optimization options as superimposed common pool resource models without identification as to individual ownership, listings of potential plants and supporting transmission would be created. Next a time frame or construction sequence would be set forth for the entire Plant construction series in the form of an interaction matrix. Each matrix intersection would then consist of a sub-model which would consider additional detail of engineering design, coolant type, reactor or fossil fuel options and other technical features. As the time frame changes from left to right, all of these options might be changed and the net cost of the plant represented by the value of X_{ij} in each intersection.

	1	2	3	4	5 +... j	
Plant A	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{1j}
Plant B	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{2j}
Plant C	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	X_{3j}
Plant D	X_{41}	X_{42}	X_{43}	X_{44}	X_{45}	X_{4j}
Plant E	X_{51}	X_{52}	X_{53}	X_{54}	X_{55}	X_{5j}
+...						
Plant i	X_{i1}	X_{i2}	X_{i3}	X_{i4}	X_{i5}	X_{ij}

FIGURE 1. Time Sequence Matrix for Plant Construction Optimization

The filled matrix then consists of a series of sub-optimal choices subject to dynamic analyses for the optimal path. Each owner would then exercise initiative on an individual basis with full knowledge of the common pool matrix of values established in common and proceed to the erection of facilities which are most suitable to the time sequence and investment consideration of the individual utility. As each plant is constructed its relative position would be filled by choices from the lower echelons of the time frame. All such analyses would be conducted in a public context, and the planning information would be available for public inspection at each step of the process. Each of the sites for the individual plants would be under investigation and license procedure in advance. The right to venture leadership would be preserved by full documentation of available options and cost-benefits resulting from the continuous planning study. Sites, once certified by a regional or state planning agency, would be protected from encroachment for a reasonable period of time, however, not indefinitely.

Such a planning method has been under development under ad hoc sponsorship of public and investor owned utilities in the Pacific Northwest. Plant sequencing, either private or non-private has been determined as a result of regional transmission optimization and load growth studies. Sites and site development costs have been determined and publicized in advance, (4) although the reference study has not been continuously brought up to date in response to changing institutional requirements, loads, interest rates, and other factors which would be considered in the dynamic planning process described above.

It is suggested that such a process could best be carried out by industry sponsored, regional study centers operated in conjunction with the emerging Regional Reliability Council organization currently under development to study interconnection and interchange problems in the utility industry.

LONGRANGE CONSIDERATIONS

Figure 2 has been provided to show the total growth of energy including reject heat from electrical power generation.⁽⁵⁾ Figure 2 shows energy demand in British Thermal units, the heat equivalent of the various input energy sources to which they all decay after useful work is performed.

The growth, shown in Figure 2, will occur primarily in the use of electricity to replace traditional heat sources in the conversion industries and for space heating. Because of the high cost of air-conditioning and lighting of large buildings, better design is expected to reduce the percapita consumption largely by elimination of incandescent lighting, low efficiency fluorescent lighting, and employment of regenerative systems to reduce heating and cooling loads. Table I is included as a general guide to the understanding of the relative input of people related activities. Of note is the considerable energy release of the private motor car. Even conversion to a total electric automobile economy would only cut the total energy release to the environment by a factor of two because, at projected efficiency growth rates in the electrical industry, 50% thermal efficiency appears a barely achievable goal under current energy policies by 2000 AD.

TABLE 1HEAT REJECTION RATES OF INTEREST
(Btu/hr)

One human being	450 (At Rest)
Electric lighting for a typical office	
Incandescent	2500
Fluorescent	900
Theoretical, 100% efficient	82
Air-conditioning for typical office	600
Heating to maintain 25°F ΔT for typical office	
Electrical resistance*	1000
Heat pump*	350
Furnace, oil or gas	1600
4000 lb automobile at 70 mph	
I.C.	750,000
Electric*	150,000

*Does not include generation or transmission losses.

FIGURE 2. Projected Total Energy Demand in the United States

Since the electrical energy requirements for the entire United States are expected to be the predominant growth factor in the next 30 years rising from a present 21.5% of all energy requirements in 1965 to 52% of all requirements by the year 2,000, the primary emphasis on the analysis of future needs is largely determined by that sector of the growth function. It is also in this area where because of the legislative history, research and development in the multi-purpose use of related materials involved in the production of electrical energy has been delayed the greatest extent. Despite the fact that the number of large operating utility companies is slowly decreasing and that less than 250 firms now control over 99% of the generating capacity in the United States compared to 1,000 in 1945, integration has been largely vertical. The Holding Company Act of 1935⁽⁶⁾ limited the effectiveness of mergers in the utility field as a means of integrating the transmission system of the industry. The Act has also served to concentrate R&D in the industry on conversion processes which are single purpose and are limited to the direct interest of the industry as constituted under the Act of 1935. In other areas of industry, aggressive development of related business opportunities have permitted wide distribution of the cross fertilization of technology in comparison to the utility field. In the latter area, the developments which have occurred have been narrow in scope.

SUPPORTING MODEL TECHNOLOGY

While a number of excellent models for the prediction of the physical regimes of rivers and lakes used for once-pass cooling exist, the application of these models to systematic evaluation of water resources planning has been hindered by the lack of clear policy regarding the role of such systems in the description and adjudication of competing needs. Because of the regional emphasis on the planning of utilities facilities, an early start

on such technology was experienced in the Tennessee Valley Authority and among the agencies involved in development of the Columbia River. The reader is encouraged to examine the details of four of these modeling systems as typical of the state of the art at the present time⁽⁷⁾⁽⁸⁾⁽⁹⁾⁽¹⁰⁾. In each case some unpublished development has continued. A brief review of the system developed under direction of the author, the COL HEAT model is included as it forms the basis for the regional evaluations discussed later in this paper.

The COL HEAT simulation model, which was first utilized to simulate a reach of the Columbia River in August 1965 applies a heat budget to a given section of a river, as follows:

$$\Sigma Q = Q_T = (Q_s - Q_r) - Q_b - Q_e \pm Q_h + Q_v$$

where

Net insolation

Q_s = incoming short wave radiation

Q_r = reflected short wave radiation from the water surface

Back radiation

$$Q_b = 0.970 \sigma (T_w^4 - \beta T_a^4) \text{ Btu/ft}^2/\text{hr}$$

σ = Stefan Boltzmann radiation constant

β = atmospheric radiation factor derived from cloud cover and vapor pressure

T_w = temperature of water surface in °K

T_a = temperature of air in °K

Evaporation

$$Q_e = 13.8 u (l_w - l_a) \text{ Btu/ft}^2/\text{hr}$$

u = wind speed in mi/hr

l_w = vapor pressure of water in inches of mercury

l_a = vapor partial pressure in inches of mercury

Conduction

$Q_h = 0.00466 \text{ kpu } (T_a - T_w) \text{ Btu/ft}^2/\text{hr}$; 0.00466 is a constant derived from the Bowen ratio for quiescent lakes

k = correction factor varying between (1-3) for rapid streams

u = wind velocity in mi/hr

p = atmospheric pressure in inches of mercury

T_a = mean air temperature in °C

T_w = mean water surface temperature in °C

Advected energy

Q_v = varies with heat source

(Term used to input discharge heat from thermal effluents, and and in special cases to handle ice, sleet, rain, etc.)

The water temperature for a river section is determined by means of the equation

$$T_w = \left[\frac{1}{V_r} \frac{Q_t A \theta}{62.5} + V_i (T_i - T_w) \right]$$

where

V_r = mean river section or reservoir volume

A = mean river section or reservoir surface area

θ = time increment

V_i = inflow volume per time increment

T_i = mean temperature of inflowing water

T_w = mean temperature of water in a given section of river or reservoir

Q_t = the net heat transport per time.

The above equation, which applies to homogeneous, isotropic media, is modified for nonhomogeneous media by incorporating it into a computational system which uses intermittent transport and mixing with respect to the ratios of mean travel times of water masses through a fixed volume. In the form of the model used in this study, the flow system is composed of

an inner and outer trough with relative volumes B and (1-B), respectively (Figure 3). The model sets up a series of difference equations and iteratively computes the downstream temperatures as a function of the input data in the following manner:

$$T_{i+1,j+1} = (1-B) \left(T_{i,j} + T_{i,j}^{(1)} + T_{i,j}^{(2)} \right) + B \left(T_{i,j-1} + T_{i,j-1}^{(1)} + T_{i,j-1}^{(2)} \right)$$

where

$T_{i,j}$ = average water temperature of the beginning of the j^{th} flow increment at the end of the i^{th} time increment (flow day) °C

$T_{i,j}^{(1)}$ = the temperature change during the first half of the i^{th} time interval in the j^{th} flow increment as determined from surface heat exchange plus advected energy (heat budget) in °C

$T_{i,j}^{(2)}$ = same as above except for the second half of the i^{th} time interval, in °C

B = the fractional part of the water in the inner fast moving trough.

At the end of an i^{th} time interval the water in the inner and outer troughs of each section is mixed and an average temperature for the section is calculated. The process is then repeated for the $i + 1$ time interval.

Operation of the COL HEAT model requires the following data:

- River or reservoir dimensions reduced to equivalent non-parallel trapesoidal cross sections
- Water temperatures at the upstream end of reach under study and also at downstream locations
- Streamflow at inlet and outlet of each river section

l VARIES AS RESERVOIR GEOMETRY AND FLOW
AND REPRESENT A RESERVOIR LENGTH FOR THAT REGION
ONE FLOW DAY IN LENGTH

FIGURE 3. Model of Channel Flow at a Translational Instant

- Meteorological data over the area of interest (wind velocity, mean air temperature, dew point, sky cover, incoming short wave radiation)
- Advected heat quantities.

As an example of the potential possibilities of the coordinated development of water resources for cooling and siting, the Atomic Energy Commission authorized Battelle Northwest to study the thermal capacity of the streams of the conterminous United States. Information⁽¹¹⁾⁽¹²⁾ is now being distributed as a result of this program and additional work is expected to be reported. Several important points have been raised by the two reports cited which can be summarized as follows:

- The present pattern of thermal plant siting is far from an optimum in the use of common pool resources, long range value to the nation, and in the minimization of regional thermal effects to both air and water.
- Large unexploited opportunities for the location of thermal plants exists on large streams such as the lower Ohio, the Mississippi and the channelized portions of the Great Lakes waterway which are subject to winter freezing and navigation stoppage.
- The natural low flows of the Ohio and the Mississippi Rivers could in the long range future be adjusted upwards by diversion projects which could effectively impound and redistribute excess run-off in a manner of benefit on a multi-purpose basis.

A CASE FOR THE OHIO RIVER BASIN

From the model simulations reported, it can be stated that under average monthly conditions, the thermal capacity of the Ohio River system (Figure 4) is limited in September and October because of natural flow

FIGURE 4. Ohio River Basin

reductions. However, during 10 months of the year, sufficient capability exists to handle the majority of needs for thermal effluent disposal for most of the forecasted power needs through the end of the century. Clearly, the power industry is faced with the problems of adapting more flexible design options which permit the advantages of low cost direct cooling during a majority of the year to be supplemented by ancillary cooling during the critical months.

Supplementary cooling could take the form of combinations of cooling ponds or cooling towers sited in such a manner as to permit optional, partial open circuit ancillary loops in order to meet summer load conditions. Such conditions could be met at operational points away from thermodynamic optima, such as high back-end loading, for these limited periods, with return to direct cooling and highly optimal cooling operation in the months with ample flow. In addition, the careful attention to scheduling of shutdowns and ancillary gas turbine systems offers additional possibilities, while strengthening system reserves.

From a technological standpoint, sufficiently detailed methods exist for defining the cooling regime of any river in relation to any set of stream standards which may be adopted by states. There is an opportunity for both the regulatory agencies and the power industries to meet on common ground in the management of thermal loadings, similar to that carried out in the management of dissolved oxygen objectives in the operation of municipal waste treatment plants. Study reveals important avenues of approach in the future management of water resources systems which will permit all interested parties to derive the maximum benefit from technology

without catastrophic impairment of traditional resources values for recreation and other uses, or the arbitrary assessment of increased operational costs throughout the year because of a short seasonal problem.

The following specific statements are derived from the study of the Ohio Basin.

Under average conditions, by 1980, the flow-through cooling requirements for single-stage, direct-cooled plants which could be sited on the Allegheny River will exceed the stream capacity in late summer and early fall. With systems using topping ponds or topping towers, a considerable extension of the time could be achieved. A ratio exceeding 3.0 between average and minimum capability exists on the Allegheny; this ratio indicates that if supplementary cooling were employed on a flexible basis, sufficient capacity exists to handle all cooling requirements for the foreseeable future.

The Monongahela River is capable of additional development on a flexible basis; however, under present once-through cooling designs, the capability is sufficient to match the 1980 requirements. Some allowance for continued use by other industry would also require factoring in a specific study directed to an actual allocation. On the basis of data collected for the study, it appears that the Muskingum River cannot attenuate present loads and remain within a 5°F differential during September and October. The development of flexible supplementary cooling methods with seasonal adjustments might permit additional use.

The Kanawha River presently receives extensive heated effluent from chemical and primary metal production facilities in addition to electrical generating plants. Additional development of the river for direct cooling on a flexible basis could be accomplished provided that supplementary cooling for the late summer and fall periods could be installed. Under normal direct-cooled operation, the critical low flow capacity is under 250 MW_T .

Conditions on the Wabash River are similar to other streams discussed. Some additional development appears possible; however, the low flow extremes in summer and fall indicate the need for use of flexible systems or scheduled operation by 1980.

For the Ohio River Basin as a whole (Figure 5) considerable additional cooling capability exists below Evansville. This is expected to total at least 10 GW_e under average conditions during the summer and fall. With supplementary ponds or topping towers, as much as 40 to 50 GW_e could be handled within the study assumptions. The middle river, largely between Huntington and Cincinnati, which has few steam electric stations at present, is also a potential area for development. Again, possibilities for flexible design or operation exist. Under the maximum condition of development and with some partial supplementary cooling, the entire needs of the area could be accommodated through the foreseeable future. Without supplementary cooling, the available siting opportunities above Louisville may be totally committed at present.

FIGURE 5.. Average Direct Cooling Capacity of Ohio River Basin

The study reveals new and important opportunities in the use of dual purpose or supplementary cooling systems in which a portion of the thermal loading is handled by off stream processes such as cooling ponds or cooling towers during times when full river flows are not available to operate at thermodynamic optima. Such dual cooling permits the utility to use a better range of design practices as an alternative to the practice of "high back-end loading" resorted to when fuel is relatively cheap and equipment costs are relatively high. Dual purpose cooling systems permit the using utility to regulate the end quantity of heat disposed to the receiving stream or atmosphere throughout a range of operating conditions instead of requiring a firm and early choice of heat disposal policy on the part of regulatory agencies. Considerable additional research is needed to investigate the operating alternative open to a successful utility operation, particularly those involving fuel costs, reserve requirements, siting, and operational flexibility. Some excellent examples of the dual use of cooling lakes and power plants exist in combination with planned public joint use of the facilities. The study suggests additional opportunities for the building of public confidence by such dual cooled facilities.

Study has shown that the tendency to aggregate thermal capacity in "super" plants of very large rating aggravates the general problem of heat dissipation because of the limitations on the local temperature rise imposed by State Standards under the Water Quality Restoration Act of 1966, especially in the upper reaches of the Ohio River

Basin. Data developed for the individual subbasins supplying the Ohio River Basin is especially useful in detailing the specific interdependence of plant size, load factor and seasonal stream capacity. These facts suggest that the optimization processes involved in plant size determination should include the entire system from water source to heat sink in the venture analysis supporting process selection. Such study should include review of such practices as high back-end loading. Though high back-end loading nominally shows advantages in leveling the sensitivity of plants to changes in condenser temperature, it does so at the cost of higher total plant heat rate with attendant increases in overall heat discharge to the total environment (Figure 6). As a corollary, study suggests the retention of lines of smaller, flexibly designed plants which could be used for regions which could incorporate direct cooling on smaller streams with appropriate electrical flexibility for low voltage regional systems.

Finally, study suggests the development of the concept of dynamic planning and management of stream temperature resources using the latest in computer simulation as an alternative to the use of rigid practices administered in an inflexible manner. Both the power industry and the regulatory agencies appear to have much to gain from the use of such practices in preservation of the quality of the environment and the low cost of power and other services to the ultimate consumer.

FIGURE 6. Range of Effects of Higher Condenser Temperatures on Plant Efficiency

A CASE FOR THE MISSISSIPPI RIVER BASIN (Figure 7)

As a general conclusion, the upper Mississippi main stem has adequate cooling capacity to assimilate and dissipate forecasted loads through the year 1990, except in the St. Paul-Minneapolis metropolitan area, if full advantage is taken of energy exchange with the atmosphere by proper spacing of thermal effluent sites. If significantly nonoptimal siting is practiced, Quad Cities and St. Louis sections would also have insufficient cooling capacities for projected 1990 loads. Tributary streams, with the possible exception of the Wisconsin River, have inadequate heat sink capacities under low flow conditions to assimilate and dissipate projected 1990 loads within a temperature envelope of 5°F above background. Partial recirculatory cooling facilities could be employed in the eight major tributary basins of interest. Table 2 summarizes cooling capacities for a broad range of conditions in the upper Mississippi Basin.

The above conclusions indicate a need of coordinated advanced planning of thermal effluent releases in the Upper Mississippi River Basin in order to quantify benefits associated with the development of a limited natural resource, cooling water supply. In addition to minimizing residual effects of upstream thermal releases upon downstream users of cooling water supply, coordinated planning could provide significant benefits to navigation, and to fish and wildlife during the winter months.

At the present time ice generally halts navigation above Hannibal, Missouri from early December to April. By 1990, thermal effluent could be significant in opening winter navigation to the Quad Cities, or possibly as far north as the confluence with the Wisconsin River. Projected 1990 thermal loads in the Twin Cities area could provide relatively open

FIGURE 7. Upper Mississippi River Basin

navigation conditions downstream to Lake Pepin. Power growth in the reach between Lake Pepin (confluence with the Chippewa River) and the confluence with the Wisconsin River, as presently projected for 1990 does not appear to be adequate for major midwinter open water conditions. Whether the benefit-cost ratio of extending a 12-month navigation season to the Twin Cities, by locating some generating plants in the above reach instead of closer to the St. Paul-Minneapolis utility market area, would be adequate is unknown. Also unknown is the benefit-cost ratio associated with conjunctive use of thermal effluent and icebreakers for winter navigation. (See also Figures 8 and 9).

CONCLUDING OBSERVATIONS

Having illustrated two principal problem areas involved in meeting the public energy needs as presently forecasted, it is necessary to examine in a general way, the overall effects of the current trend of doubling energy releases to the environment every 7 or 8 years. No clear agreement on the subject exists because the subject is too new to have accumulated the proper ratio of dispassionate observers and the data base is too small to make classic stochastic or statistical observations without a serious degree of professional risk and possibility of adverse criticism. This latter factor has a tendency to often group scientists and engineers into two overlapping groups as follows:

- A general grouping of investigators who have not been deeply involved in environmental matters and fail to react completely to new and revised requirements for integrated environmental thinking.

TABLE 2

SUMMARY OF AVERAGE AND LOW ANNUAL COOLING CAPACITIES
(MW_T) OF UPPER MISSISSIPPI RIVER BASIN

	<u>April,</u> <u>avg</u>	<u>Nov,</u> <u>avg, (c)</u>	<u>April,</u> <u>low (c)</u>	<u>Nov,</u> <u>low (c)</u>	<u>1970 Steam</u> <u>Generating</u> <u>Capacity,</u> <u>MWe</u>
Minnesota River (a)	4,500	350+	350+	100+	1,622
St. Croix River (a)	7,800	3,100	1,800	750+	598
Chippewa River (a)	7,300	2,900	2,800	1,100	None
Wisconsin River (a)	11,700	7,000	5,600	2,500	166
Rock River (a)	6,800	3,000	2,200	650+	570
Cedar Iowa River (a)	7,000	1,700	650+	250+	382
Des Moines River (a)	7,400	500+	250+	100+	683
Illinois River (a)	33,000	20,000	12,000	4,000	3,702
Mississippi River (a)	100,000	49,000	67,000	42,000	4,300
Upper Mississippi River Basin(b)	130,000	61,000	79,000	46,000	28,400

a. *Independent capacities*

b. *Integrated capacities*

c. *Maximum assimilative capacity given where total is less than
800 MW_T*

FIGURE 8. Low Flow Direct Cooling Capacity of Mississippi River

FIGURE 9. Upper Mississippi River Basin Local Direct Cooling Capacity Probabilities

- A general grouping of investigators who are fully involved with matters of environmental concern, but because of previous training or experience fail to include conditions of practical necessity into action plans proposed for protection of the environment. In this case we use the word environment in its broadest sense, that of the total socio-economic physical surroundings of man.

Experience has shown that the truth lies somewhere in-between, and varies in a dynamic way from situation to situation. A brief review of the major considerations concerning energy effects on the environment is contained in the following statements:

- When examined on an entirely global perspective, and with the singular exception of particulate emission in the upper atmosphere and stratosphere, troposphere and ionosphere, the foreseeable effects of the release of energy and the by-products of energy conversion do not provoke the need for crisis thinking in the institutional management of resources.
- Particulate emission and changes in the atmospheric opacity resulting from artificial cloud seeding and thermal islands are highly suspect as potential sources of serious dislocations in the weather patterns; rainfall and general surface energy budget of the earth⁽¹³⁾.
- On a regional basis of the scale of 10^6 km^2 , distinctly observable patterns of effect related to the release of products of combustion, moisture and thermal energy (the end state of all useful energy of interest to this discussion) are known to exist and to be increasing in size and intensity. Without control of accelerating urbanization,

one can predict with certainty that climatic changes will increase from a purely local scale to a regional scale and will appreciably affect not only air and water temperatures, but present ecological balance. Known changes include increased cloudiness, reduction of winds, concentration of pollutants (smog), drastic changes in runoff of rainfall, and profound, but as yet quantitatively unmodeled effects of the immense quantities of gaseous and suspended materials ejected to the metropolitan atmosphere. (14)

- In the utility field, because of its potential dominance of the energy releases to the environment, serious consideration needs to be given to the combined end effects of pollution policy on prime mover efficiency, regional weather patterns and national fuel and anti-trust policy. The available facts suggest that uncoordinated national policy is directly related to a great number of the present economic dislocations which appear as pollution of the environment. (15)
- A large number of the more useful tools for predicting effects such as simulation modeling remain relatively underdeveloped because of the present reliance on the adversary proceeding as the basis for taking action. The distribution of pollutants in relation to the planning of abatement facilities must be systematically investigated and related to local and regional goals. Clearly, institutional development and reform congruent to scale of expected energy releases is a question of highest priority. The creation of simulation and prediction centers of politically uncommitted excellence appears as an indispensable step in the arbitration of competing needs for the use of energy on the grand scale foreseen for the coming decades.

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