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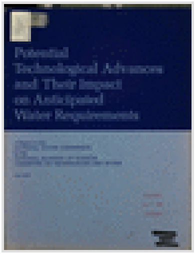

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POTENTIAL TECHNOLOGICAL ADVANCES

AND THEIR IMPACT

ON

ANTICIPATED WATER REQUIREMENTS

A Report
to the
National Water Commission
by the
National Academy of Sciences
Committee on Technologies and Water

Washington, D. C.
June 1971

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PREFACE

The charge which the National Academy of Sciences' Committee on Technologies and Water received from the National Water Commission is documented in the Introduction. Members of the Committee were primarily concerned with conducting a study of the technical advances that are not certain of physical or economic feasibility, but still within the realm of possibility; in brief, to forecast potential technological developments and their probable impact on water demands and problems. Consequently, to project our thinking into the future, it was necessary to forego our conservatism and rid ourselves of the natural tendency to assume that a "far-out" idea would not be feasible. Economics was also given a back seat. We did not want indeterminate, unknown future cost factors to restrict our thinking. Also, political, institutional, and social conditions which may be in effect in the future were generally not considered, further enabling us to free our minds from other restraints which would have stifled our projective thinking.

The free manner in which all the members of the Committee expressed ideas was indeed remarkable. We had an invitation not ordinarily extended to the scientific community; that is, to attempt to dream up things which aren't so likely to happen, and then figure out what their effect might be if they did materialize. Although the majority of the ideas and concepts we discuss are not original, the major impact of these ideas has yet to be realized. The technical developments which we felt were worthy of consideration are listed and discussed in Chapter II and form the foundation of the report. We felt that describing and listing our ideas was not sufficient and that analysis and suggested applications were necessary to place the concepts in perspective. Thus, Chapters III and IV were developed to analyze the relationships, interactions, and feasibility of the concepts and to assign research priorities to the water-related ideas, as well as to indicate by selected examples how the concepts might be applied to particular future areas of water supply and demand.

The Committee recommendations as stated in the Introduction are matters of judgment and not matters that are supported by intensive empirical research, statistics, charts and tables. It should be emphasized that this entire study really has been one of judgment and not one of applied scientific methodology to the problems of technology. Some of the recommendations have sprung from the extended informal discussions of the group and may not appear to be adequately supported by the text of the report, but nonetheless represent the judgment of the members of the Committee regarding the important implications of technology.

Appreciation is extended to Merle A. Tuve, Home Secretary of the National Academy of Sciences, and to Joseph W. Berg, Jr., Executive Secretary of the National Research Council's Division of Earth Sciences, for their inspiration and guidance to our study. I personally wish to thank each of the members of the Committee for his enthusiastic participation in our activities and his individual contributions to this report. The representatives of the National Water Commission, V. A. Koelzer and Edwin Haycock, were most helpful throughout the study. We also wish to thank the Committee staff for their personal interest and assistance during our deliberations.

We hope that this report will be useful to the National Water Commission and that some of our ideas will prove beneficial to society in the future. Of course, we would all be most pleased if our efforts had some direct or indirect influence on increasing the national effort and expenditure for research on water-related activities in the country.

Michel T. Halbouty
Chairman
June 1971

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CHAPTER I

INTRODUCTION

The National Academy of Sciences established a Committee on Technologies and Water on behalf of the National Water Commission to evaluate potential technological advances and their impact on anticipated water requirements. The Committee was asked to consider all technological developments that may have future potential, even those not at all proven at the present. The Committee was not to be concerned with the effect of government policies on water demand or use. The charter for the Committee is as follows:

> "The Committee will study and report to the National Water Commission on potential scientific and technological advances which would affect water requirements and supply in the future, including possible new uses of water, and will accentuate innovative concepts regarding these matters during the course of study. Particular attention will be devoted to those areas where water use is heavy. An attempt will be made to provide general information on the anticipated order in which such innovations will arrive and on the conditions necessary for their realization. Research will be recommended, where possible, on new concepts resulting from deliberations of the Committee when it is deemed they have the potential of decreasing water requirements and/or increasing water supply for the future. When deemed necessary, the group will consider possible ecological or social consequences that may result from such potential scientific and/or technological advances."

This study was also intended to complement a study by Resources for the Future, which looked at technological advances and policy changes which are presently indicated to be in the realm of physical and economic feasibility.[1]

It has proven difficult to keep deliberations free from economic considerations when a future technology is being imagined. New technologies don't just happen. Their development involves economic considerations and political decisions. In order not to put unnecessary constraints of possible future technologies on the report, it was decided that the first thing to do was to look at various potential technologies in isolation; i.e., the technology would be considered only from the point of view of scientific feasibility.

The method used by the Committee was first to develop a list of technological advances or concepts that could be imagined to come into being in the future. In Chapter II, Descriptions of Technical Developments, each concept has been described and the importance of each concept in terms of future water use and/or availability considered. Emphasis was placed on those technical developments which would directly or indirectly affect major water uses. Important areas of concern included power generation, energy transport, irrigation and alternative ways to produce food, and technologies improving water treatment and reuse.

Although this study was not concerned with present or projected aggregate regional or national water use, base data on present and projected water use were compiled for our review. These data permitted

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[1] Charles W. Howe, Clifford S. Russell, and Robert A. Young, Future Water Demands: The Impacts of Technological Change, Public Policies, and Changing Market Conditions on the Water Use Patterns of Selected Sectors of the United States Economy, 1970-1990, a study for the National Water Commission by Resources for the Future, Inc. (Washington: June, 1970), 102 pp. Available from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia.

those areas in which new technologies could have the greatest impact to be identified. The data on various projections of water use were compiled for the Committee by the International Research and Technology Corporation in two 1970 reports, Forecast of Long-Range Factors Relating to the Future Supply and Demand for Water and Future Technologies and Water Demand, which have been turned over to the National Water Commission.

Technological developments in Chapter II are grouped into five categories: (A) Technical developments which will increase or decrease future demand for water; (B) Technical developments which should increase usable supplies of fresh water; (C) Technical developments which extend the usefulness of impure water; (D) Technical developments which could have an influence on future water demands and supplies; and (E) Considerations which could influence technical achievements. A complete list of these technical developments or concepts is given on pages 16 through 18.

In Chapter III, Analysis of Technical Developments, a table is presented in which we have made estimates of the years until each concept might be feasible on a theoretical or pilot operation basis and years until it might be realized as a full-scale operation. Further, it is usually not possible for a new technology to be developed and introduced without some changes in the institutions involved in water planning and development. Therefore, some consideration is given to institutional changes that might be necessary before the various technologies could be developed. This has been done even though it is well recognized that the actual calendar date of these occurrences will depend on many uncertain factors, including commitments to pursue the necessary research and development. For those technologies whose application depends on research and development specifically directed to influencing water supply and demand, the Committee has assigned research priorities to be used as a guide for emphasis and effort essential for the technical achievement to be realized.

These technical concepts are listed by research priorities on pages 165 and 166 following the table in Chapter III. Since many of the specific technical developments being considered are dependent on other related developments, consideration is given to these other developments in the discussion on Trends and Interactions Concerning Future Technologies, also in Chapter III.

In Chapter IV, Application of Technologies to Future Water Supply and Demand, four scenarios describing possible future sets of compatible technologies in selected problem areas are presented. In these projections an identification of the major political, social and economic factors that might dominate the use of water is given special consideration. These examples are given to illustrate how the various technologies might interact in a consistent future set of conditions. It was beyond the scope of this study to carry the question of future implementation of the technologies and the interaction among them to a satisfactory end. This would have entailed more detailed planning studies and consideration of non-technical questions which were beyond the resources of this Committee. Also, the charge from the National Water Commission suggested that the Committee concentrate on ". . . the technical advances that are less certain of physical or economic feasibility, but still are within the realm of possibility." Therefore, the examples given in Chapter IV should be viewed as possible futures, not predicted futures.

This entire study has really been one of judgment and not one of applied scientific methodology to the problems of technology. As a result of the Committee's study and deliberations, eight specific recommendations have been formulated. These recommendations are directed towards the fundamental importance of considering research and changing technologies in water planning and water management practices and policies. Some of the recommendations have sprung from the extended informal discussions of the group and may appear not to be adequately supported by the text of the report, but nonetheless represent the judgment of the members of the Committee regarding the important implications of technology. These recommendations are matters of judgment and not matters that are supported by intensive empirical research.

Recommendation #1 Technological change and impacts must be brought explicitly into water planning.

Past procedures for water planning have always taken a conservative stand toward technology; i.e., they have worked almost completely within existing technologies and have not counted on new technologies being available. This treatment of water technology is particularly inconsistent since river-basin economic-base studies and other water plans have for years taken into account anticipated economic change in water-using industries. Undoubtedly, ignoring likely future changes in water technologies stems both from a lack of market pressures on water agencies to introduce new technologies, and also from the fact that water planners have perceived that the costs of failing to meet even rare peak demands are extremely high in comparison to those costs incurred in excess construction or costs of carrying excess capacity.

The criticality of water quantity and quality problems in some regions, the inadequacy of existing regional, surface and ground supplies, and the high costs of importing water from great distances makes it mandatory for planning to consider technologies which do not exist at present but which can reasonably be counted on in the future under the explicit stimulus of planned research and development.

Current concern with the environment, both physical and social, also makes it mandatory to weigh all impacts of particular water technologies on the total environment.

Recommendation #2 Technical changes likely to occur outside the immediate area of water technology but which will affect the demand for or the supply of water must similarly be taken into account in water planning, as must the possibility of utilizing non-water technologies as ways of solving water-related problems.

The critical problems of the water sector are partly the product of economic decisions made by various categories of users that create the demands for water. Under some circumstances, the quality or quantity of the basic water supply is altered via return flows from non-consumptive uses which restrict further use by others.

Clearly, important technological changes in water-using industries must be anticipated if water demands are to be correctly forecast. It is also clear that in some circumstances, the best solution to a water problem may be explicit sponsoring of research or the subsidization of a non-water technology. For example, the best way to attack a water quality problem may be to improve the production process of a water-polluting industry.

Recommendation #3 Water planning must be continually reassessed to consider the benefits of new technology.

Water planning efforts must be timed in such a way that the effect of future technologies can be considered and brought to bear on water problems. Since it is not possible to predict when a technological breakthrough might occur, it is essential that reassessments be carried out on a continuing basis. This requires that the water planning process remain closely keyed to new and impending technical developments so that the benefits of these technologies are realized at the earliest possible time.

Recommendation #4 Water planning must have a built-in flexibility.

Too often water plans intended to be implemented over a period of years, often several decades, are cast so rigidly that changes cannot be made in response to altered circumstances. The continuing planning process must have sufficient built-in flexibility to accommodate unforeseen events or conditions. These changes may result from new technologies of importance to the water scene, or perhaps changes in the goals of society. The important thing is that the water planning group be cognizant of changes as they occur, and have available "feedback" mechanisms to consider them.

All this implies the need for some form of formalized systems analysis which considers a host of relevant factors, some of which will certainly relate to new technologies, before irreversible decisions are made. Appropriate analytical procedures may involve operations research techniques with some subjective quantification of social values and possible future technology effects included along with more easily quantifiable current data. Other useful approaches might include cross-impact analyses, such as described in Chapter III, since it is imperative that interactive effects of technologies be considered whether they be mutually reinforcing or antagonistic.

Any plan or projection which does not have the built-in flexibility to respond to the future changes that are certain to occur will not be adequate.

Recommendation #5 Research and development must be specifically programmed as part of a water-development plan.

Research and development must be programmed as an integral part of water planning. This programming provides the necessary lead time so that each new technical development can be evaluated and, if desirable, incorporated in the plan. Failure to program research and development into long-term water development projects which are to be implemented over a period of years or decades results in failure to consider technical factors which could be so pervasive in time as to totally change the original purpose or conditions of the plan.

Recommendation #6 Technological trends, the interactions of technological developments with each other, must be subjected to continuing formalized analysis.

Technological trends, the interactions of technologies and the cross-impact reference analysis of technologies must be formally incorporated in the continuing process of technological analysis by water-planning agencies. Analysis must be made on the relative effects of various technological developments on the future water picture based on different explicit assumptions concerning future research levels. This will permit judgments to be made on the expected benefits to be accrued from research in future water supply and/or water demand terms. Only in this way can the synergistic effects of different technologies be recognized and incorporated in planning.

Recommendation #7 Changes in social goals, demands and objectives, as well as physical objectives must be considered in water development planning.

In keeping with this conclusion, the Committee wishes to underscore the importance of making the assessment of environmental and social effects a part of each new technological proposal and of including and identifying necessary research to accomplish such assessment among research objectives of water resource agencies.

Recommendation #8 The research funds for water and related activities must be substantially increased in the future. These research funds must be appropriated when new projects are authorized.

To properly assure that the benefits of technical breakthroughs are realized in water projects, it is necessary that the research expenditure be substantially increased in the future and that these research funds be appropriated when new projects are authorized.

Economy will be achieved when future water planning has programmed research as an integral part of its activity. The Committee recommends that future authorizations for water development programs have research funds specifically earmarked to be sure that technological developments are accomplished and that potential technologies related to water are in fact realized.

As a possible assistance to water resources planners and others interested in pursuing at greater length elements related to future water technologies, a selected Bibliography has been included at the end of this report.

CHAPTER II

DESCRIPTIONS OF TECHNOLOGICAL DEVELOPMENTS

INTRODUCTION

The National Water Commission's request to the National Academy of Sciences for an evaluation of potential technological advances and their effect upon water requirements and the future supply (with due consideration of their ecologic and social value) seems particularly relevant at this time. Despite Ackerman and Löf's work of twelve years ago,[1] consideration of technological advances is at present involved only indirectly or incidentally in water management. The consideration of new and innovative technologies is not even now mentioned in the United States Water Resources Council's Policy Statement on Water and Related Land Resources Planning, July 22, 1970. Technology must become a factor of increasing significance in improving sources of supply, in the evolution of processes adding to the usefulness and efficiency of present supplies, and in the evolution of developments that will affect the future demands for water. The prospects for technological change appear so pervasive that they must not be ignored in planning.

The need for increased technological inputs and their explicit consideration in planning is made clear by the historical record. Water-supply works, for example, have been basically unchanged for a century. A dam and aqueduct or a well and pump that account for most sources of supply today would have been recognizable a century ago. Even Frontinus,

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[1] E. A. Ackerman and George O. G. Löf, Technology in American Water Development, published for Resources for the Future, Inc., by the Johns Hopkins Press, Baltimore, 1959.

to whom we are indebted for his description of water supply for imperial Rome where he served as an efficient and literate water commissioner, would have little background reading to do before he could effectively assume the duties of the water commissioner for a major American city. Today he would be faced with the same problems of leakage, wastage, quality and shortage. Even new technologies such as pressure aqueducts, equalizing basins, treatment works, and the deep-well pump are new only in a sense relative to ancient Rome. They have been with us for some decades. The old technologies of supply now being used are increasingly unable to cope with demand. The emphasis has too long rested on increasing hydrologic development within an existing technology. A reverse emphasis might now be in order -- bringing new technology into play concerning existing sources of supplies, or sources not previously feasible under the old technologies.

Equally ancient in concept, single-use, once-through technologies have shaped demand. A very high percentage of water is used to transport organic, chemical and thermal wastes. Any process that requires water for the dilution, transport or the treatment of wastes, correspondingly increases the demand for water and thereby increases the desirability and often the feasibility of recycling. In principle the net demand upon the environment for water can be reduced to the amount consumed in manufacturing, evaporation, or amounts so degraded in quality as to be unusable. The current change in social values attached to avoiding environmental deterioration will also stimulate the development of technologies that will tend to recycle water in closed systems, reducing the demand for water and thus isolating it from the natural hydrologic cycle.

There are some prospective technologies that will be induced by particular water problems. In addition, there will be exogenous technologies -- those in non-water fields -- that will affect the demand for water.

The generation of power, for example, requires large amounts of coolants for which water is an ideal substance. Increasingly efficiency in power production itself would reduce the thermal waste load upon water, while the solution of fuel problems through gasification of coal would increase the consumptive demand for water. Food production, one of the major consumptive uses of water, may change in ways that will greatly increase or decrease the gross demand for water.

In our review of technologies emphasis has been placed on those technical developments which would directly or indirectly affect major water uses. In general, technologies affecting only minor water uses were not considered. Important areas of concern included power generation, energy transport, irrigation and alternative ways to produce food, and technologies improving water treatment and reuse.

The Committee has tried to avoid placing value judgments upon the several technological possibilities and has refrained from pleading their special merits or issuing dire warnings of portending evil. It was decided to look at various potential technologies only from the point of view of scientific feasibility. The effort to be impartial, however, is not to be considered indifference to the imperative need for objective evaluations of benefits and risks that may ensue from adoption or neglect of the various technologies.

Important in the descriptions of the technological concepts are statements of the possible risks to the environment. The Committee believes that an assessment of risks to the environment is as much a responsibility of science as is the development of technology.

At the first Committee meeting ideas on the future of technology from technical or scientific viewpoints were freely exchanged without a consideration of policy constraints or economic factors. It has proven difficult to keep deliberations free from economic considerations. New technologies don't just happen: their development involves economic considerations and political decision.

In order to view the prospective technologies in relation to specific water problems, the Committee grouped the technical developments into five categories of demand and supply:

A. <u>Technical developments which will increase or decrease future demand for water</u>

Here are identified a diverse group of potential technical developments that will affect the demands for water to a significant degree and, where possible, we have noted the direction of this effect. These technologies of demand will often be external to the field of water development itself and, since many are judged to involve principles now already known, they require careful consideration in any present projections of water demand.

B. <u>Technical developments which should increase usable supplies of fresh water</u>

On the supply side of the water economy, the Committee finds a number of potential developments that offer opportunity to increase supplies of usable water. Some of these technologies involve altering the hydrological cycle and some the improved conservation of existing supplies, or new innovative applications of existing technologies.

C. <u>Technical developments which extend the usefulness of impure water</u>

A further set of technologies that needs to be involved in assessing usable supplies of water are those that extend the usefulness of impure water. Here the Committee has identified five technological developments that will significantly improve the future supply of usable water.

D. Technical developments which could have an influence on future water demands and supplies

There are several technical developments whose influence on future demands and supplies cannot be identified. Nevertheless, the Committee believed it essential to list four of these whose influence in magnitude, as well as direction, needs to be considered in each particular assessment of demands and supplies of water.

E. Considerations which could influence technical achievements

Other factors involve considerations which, although not necessarily technological, may exert considerable effect upon water planning. Recognizing that such considerations may be quite numerous, the Committee enumerated six such factors exemplifying areas which merit attention in the formulation of water policy.

Lists of potential technological developments are subject to errors of commission and of omission. The former include technologies that may prove irrelevant or impractical. Omission of technologies which may prove to dominate the future is the forecaster's fear. Who would have predicted in 1930 the impact of nuclear power on the United States energy and water picture now, only 40 years later?

The Committee's list and description of concepts or technical developments are presented in this Chapter. A brief narrative of each technical development is given describing the concept with attention to its importance in terms of water use and/or supply, additional scientific developments and research required for the technology to be realized, and in many cases, the probability of the technology coming into being.

In this report the demand for water is based on present technology. Demand is defined in relative terms such as water demand per unit production or per capita. Although each technological development was placed in a particular category, several developments may have an effect in more than one category. For example, a given development for better removal of impurities from water could increase usable supplies of fresh water and also extend the usefulness of impure water. A given development was placed in the section where its impact was judged to be greatest.

For those technologies judged to require research and development implemented from a water resources point of view, research priorities have been assigned. These research priorities are noted under the title of each concept, where applicable, throughout Chapter II. The research priorities are discussed and listed in the Introduction to Chapter III.

A complete list of the Committee's selected technical developments as assigned to the five basic categories follows.

DIRECTORY TO CONCEPT DESCRIPTIONS

Concept	Page
A. Technical Developments Which Will Increase or Decrease Future Demand for Water	19
1. To increase future demand for water	
a. Gas production from coal	21
b. Electric power generation by conventional nuclear reactors	22
c. Surface transportation using electric power	24
d. Transport of solids by water slurry pipeline	26
e. Fire hazard area irrigation	27
f. Forest and rangeland irrigation	30
g. Solution mining	32
2. To decrease future demand for water	34
a. Electric power generation by gas-cooled nuclear reactors	35
b. Electric power generation by nuclear fusion	36
c. Electric power generation by fuel cells	38
d. Electric power generation by magneto-hydrodynamics	39
e. Electric power generation in open-cycle engines	40
f. Electric power generation by use of wind and water power	42
g. Recirculation cooling pond development	43
h. Cooling tower design and utilization in industry	45
i. Industrial cooling systems using air	47
j. Water as diluent for wastes	49
k. No-rinse washing/laundry technology	50
l. Bioprocessing to provide food	51
m. Artificial anti-transpirants	55
n. Genetic development of plants to withstand drought and salinity	56
o. Subirrigation and unsaturated leaching strategy	58
p. Landscaping with artificial materials	60

Concept	Page
3. To increase and/or decrease future demand for water, direction uncertain or different directions in different regions	62
a. Conversion of solar energy to heat and power . . .	62
b. Power generating units for meeting peak demands .	64
c. Electric power transmission over long distances . .	66
d. Oil shale conversion to liquid fuels	67
e. Advanced communications systems	69
f. Central electric vs. on-site total energy systems .	70
g. Geothermal energy	71
h. Regional environmental management of bays and estuaries	73
i. Vegetation management	74
B. Technical Developments Which Should Increase Usable Supplies of Fresh Water	77
1. By making new sources available where needed	78
a. Desalting of seawater and brackish water	78
b. Compact water desalting units for residential use .	80
c. Precipitation increase through cloud seeding . . .	81
d. Long-term seasonal precipitation forecasting . . .	82
e. Augmenting fog drip	83
f. Artificial ice fields	84
g. Deliberate snow/ice avalanching	86
h. Melting of ice caps to create lakes	87
i. Iceberg towing	88
j. Collapsible bladders for transport of liquids . . .	89
k. Underseas aqueducts	90
l. Offshore reservoirs	92
m. Large-scale canal systems to carry water from regions of surplus	94
n. Nuclear explosives for canal, tunnel and reservoir construction	96
o. Service tunnel use in urban areas for electric power distribution, sewage, water services, and storm drainage	97

Concept	Page

2. By conservation of existing sources 99

   a. Evaporation reduction from lakes and reservoirs . 99
   b. Phreatophyte control 100
   c. Runoff water control using rock tunnels and galleries 103
   d. Groundwater storage and management. 105
   e. Groundwater recharge using craters created by nuclear devices 107
   f. Soil and rock reservoir modification 108
   g. Watershed management: surface water harvesting . 110

C. Technical Developments Which Extend the Usefulness of Impure Water 113

1. Advanced waste treatment: improved processes for purification and reuse 114
2. Instream aeration for water quality improvement . . . 116
3. Waste water renovation by surface spreading 117
4. Water recycling in manufacturing industry 119
5. Increased use of seawater by industry 121

D. Technical Developments Which Could Have an Influence on Future Water Demands and Supplies 123

1. Reservoir bottom water use 124
2. Subsurface and marine waste disposal 125
3. Crop production by use of residual heat and other by-products 127
4. Reducing contaminants from watershed areas 129

E. Considerations Which Could Influence Technical Achievements 131

1. Populating the desert 132
2. Rationalizing the market for water services 133
3. Residential water demand modification 136
4. Water-based recreation trends 138
5. Reservoir role in water management 139
6. Effects of bioconcentration of toxic materials 141

A. TECHNICAL DEVELOPMENTS WHICH WILL INCREASE OR DECREASE FUTURE DEMAND FOR WATER

Introduction

The concepts and technologies discussed in this section are grouped into three categories: those technical developments which will increase future demand for water; those technical developments which will decrease future demand for water; and some technical developments which may affect future demand for water, but for which the direction of the effect is not now evident or for which opposite directions will be observed in different regions. In this section water demand is based on present technology. Demand is defined in relative terms such as water demand per unit of production or per capita.

Those developments which will increase future water demand are primarily those which involve use of water which heretofore did not exist to any appreciable extent. An exception might be power generation by conventional nuclear reactors which have large cooling water requirements; an increase in power generation by this method will increase the cooling water requirement.

Developments decreasing demand per unit of production are those which tend to use water more efficiently than existing ways of doing the same task. Various new ways of power generation with less waste heat rejection loom as very important in the future. Alternative ways of producing foods through microbial agriculture could also be very significant. Others include an array of water conservation techniques.

Some technical developments which will occur may either increase or decrease future water demand, depending on other related factors. Some may even increase demand in one region and decrease it in another depending on local circumstances and related factors. In some cases, a large requirement for water may be shifted from one region to another, as with long-distance electric power transmission. Most are new activities in which the water use is not sufficiently clear to confidently predict what the future impact will be. Therefore close follow-up on water use impact of these developments is essential in future water planning programs.

1. TO INCREASE FUTURE DEMAND FOR WATER

a. Gas Production from Coal

Definition and significance. As natural gas supplies are depleted, synthetic gaseous fuel will have to be substituted. Coal will be the most important raw material for gas manufacture. Regardless of the particular process employed, large quantities of water will be required. Some processes will employ water or steam in the chemical reaction, with the water being consumed and transported away from the site in the form of combined hydrogen in the gas itself. Cooling water will also be a large requirement.

The manufacture of gas will be in areas where coal is cheap and abundant. To achieve economies, the manufacturing plants should be of large capacity and will thus require large supplies of water. Water for cooling, waste handling, and for actual conversion to methane and hydrogen will be needed. The impact on the water supply in the immediate vicinity is expected to be very large, particularly in view of the fact that the portion which combines with carbon and is transported away from the region represents a net consumption. To produce a billion cubic feet of gas per day, 5-10 million gallons of water would be consumed in the reactions. At the present average natural gas consumption rate of about 50 billion cubic feet per day, at least 25 million gallons of water would be consumed in the production of equivalent gaseous fuel.[2] With the very large projected demands for gaseous fuel, it is evident that large concentrated water demands will develop in the coal-producing regions of

[2] Hans H. Landsberg, Leonard L. Fischman, and Joseph L. Fisher, Resources in America's Future: Patterns of Requirements and Availabilities, 1960-2000 (Baltimore: Johns Hopkins Press, 1963), p. 204.

the country. These demands may become so critical and concentrated that they could conceivably take precedence over nearly all other requirements in the region.

Developments required and research recommendations. The additional developments required to make this technology practical largely involve reducing manufacturing costs. Several methods for coal gasification have been developed, including the old system for city gas manufacture by destructive distillation of coal to produce coke. The new processes provide opportunity for considerably cheaper gas, but further improvements will be required for large-scale application.

Research into possible alternate processes for coal gasification will be important in the development of the most practical system. Different types of coal may need somewhat different treatment processes for maximum economy. The pressure for this activity will mount as supplies of natural gas are reduced and are finally exhausted.

The probability that this source of gaseous fuel will become important or perhaps even dominant in this century is high. Natural gas is being consumed at an ever-increasing rate, and new discoveries are not keeping pace with consumption. It is very likely that large coal gasification plants will be in operation in this country within ten years. Substantial impact on water use will occur by the year 1990.

b. Electric Power Generation by Conventional Nuclear Reactors

Definition and significance. Conventional nuclear reactors, employing the pressurized water-heat transfer system, operate at substantially lower temperatures than do modern fuel-fired plants. As a result, overall conversion efficiencies are lower, and the amount of heat which must be discarded into cooling water per kilowatt hour generated is higher. Typical figures are 30 percent overall thermal efficiency (the percentage of the energy liberated by the fuel which is delivered as electric power) for nuclear plants versus 40 percent for coal and oil-fired plants.[3] As a consequence, the nuclear plant requires at least half again as much cooling water as does the conventional fuel-fired plant.

Developments required and research recommendations. The main reason for the lower temperature requirement in the conventional nuclear reactor is the limited capability of the reactor materials to withstand temperature and pressure. There appears to be no likely system for altering the present limitation unless the reactor design is changed and a different coolant is employed. This has been accomplished in the gas-cooled reactor which has efficiencies approaching those of fossil-fuel plants. The gas-cooled reactor is just beginning to be commercially utilized. But nearly all of the existing and planned nuclear power plants are of the low-efficiency type, so water requirements for these systems will continue to be higher than for fuel-fired systems and for the advanced design nuclear plants employing gas-cooled reactors. The overall result is that the development of atomic power and its substitution for fuel-generated power has been accompanied by an increased water demand. This trend will continue until high-temperature nuclear reactors begin to predominate over lower temperature reactors.

During the next decade or two, low-temperature nuclear power plants will continue to be built, increasing the average water demand per kilowatt hour generated. As high-temperature reactors become more widely utilized, average water requirements per unit of output should reach a peak and then decline.

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[3]Based on figures in "Economics of Thermal Pollution Control," Water Pollution Control Federation Journal, 42 (December, 1970), 2102.

c. Surface Transportation Using Electric Power

Definition and significance. One of the areas of potential substantial growth in electrical power demand is electrification of surface transportation.

Electrification of horizontal surface transporation has decreased somewhat in the past 30 years as trolleys have been almost entirely replaced by buses. However, the use of elevators has continuously increased, and the use of "horizontal" elevators (or people movers) is beginning to grow rapidly. It is not unlikely that high-capacity electric conveyor-type systems will be widely installed in downtown areas (as well as airports, shopping centers, etc.) to reduce automotive congestion and at the same time improve the efficiency of internal circulation in the area. The use of rechargeable battery-powered U-drive electric cars or dual-mode vehicles and "electric highways" is another possibility.

Electrified conveyor-type systems are a natural extension of existing elevator and escalator technology and no new technology is required. The electric-car alternative would be more similar to existing automotive technology and could be an extension of existing technology. However, the system of energy distribution would be radically altered; much less liquid fuel would be sold for consumption in vehicles, and more heat energy would be converted to electric power at either centralized (or decentralized on-site) generation plants. To the extent that central generating plants were involved -- regardless of whether the fuel is coal, oil, natural gas or uranium -- water cooling would be required.

Including elevators, it is conceivable that electrified urban systems could by 2020 account for as much as 20 percent of all energy used in surface transportation. This presumes continued urbanization. At this level of use, transportation might also account for up to 15 to 20 percent of all utility electric power used -- depending upon the use of utility electricity for space heating and air conditioning. If all automotive travel (as of 1970) were converted to electric vehicles with the present pattern of use remaining substantially unchanged, the demand for utility electric power would roughly double. However, this is probably an extreme upper limit since it presumes vehicle sizes, utilization rates, ownership patterns, costs and other factors which are not likely to remain stable indefinitely.

Developments required and research recommendations. Electrified horizontal transportation systems of the conveyor-type exist now. The major breakthrough required to increase their use dramatically would be a safe method of entrance and egress from a continuously moving means of transport. Exclusion of conventional automotive vehicles from congested downtown areas and their replacement by special purpose electric minicars would require a major political effort (in the United States at least) but perhaps less so in the next decade as the idea is tried out on an experimental basis in Europe. Antipollution legislation may have a major role in bringing about a change in attitudes toward the role of automobiles in cities.

As far as the technology is concerned, major breakthroughs would be needed before a practical electric car could be developed for a significant range of automotive applications. Both high energy storage batteries and compact, inexpensive high-performance motors are needed. Improvements of an order of magnitude would be required in some key technological performance parameters such as energy, power and cost per unit weight (related to range, acceleration, and charging time). The entire area should be reviewed from the standpoint of economic feasibility and environmental impact.

Earliest feasible date for the first installation of "next generation " electrified horizontal conveyors is 1975-1980. Extensive use of electric minicars in central cities, based on current (lead-acid) battery technology can be expected by 1975 at the earliest. The earliest feasible date of next generation batteries is 1980-1985 depending on intensity of research effort. The probability of extensive use of horizontal conveyors in downtown areas by 1990-2000 is very high, while the estimated probability of extensive urban use of electric vehicles by 1990-2000 is low to moderate. However, fossil fuel scarcity and cost will force this technology into being by 2020 or 2050 at the latest.

d. Transport of Solids by Water Slurry Pipelines
(Research Priority, 3)[4]

Definition and significance. The transfer of pulverized solids by means of water slurry pipelines is likely to expand rapidly in the future, since it represents a very efficient form of transport for bulk commodities. Coal is currently the largest commodity being shipped by this means, but other materials, including concentrated ores could possibly be transported by this method. While water is the medium for carrying other commodities, the transport of water itself could be a purpose of the slurry pipeline; the water being separated and filtered at the end.

Potentially, this method could replace huge volumes of coal currently being carried by barge and rail. Ore concentrations being transported by pipeline could substitute for the carriage of less concentrated ore by ship. The natural drawback to the method is its inflexibility

[4]For an explanation of research priorities, see Introduction to Chapter IV.

and large initial investment. Such pipelines must be used to a high percentage of capacity to be economical.

Pipelines have natural environmental drawbacks caused by forest clearing and other defacing of the visual environment if they are not buried. The water transported in the process may be a detriment as well as a benefit of the process, since the water may be difficult to dispose of or may be needed in the area of origin.

Developments required and research recommendations. No further developments or research are needed to make this method feasible, but much work is yet to be done on methods for processing commodities to prepare them for this method of transport.

e. Fire Hazard Area Irrigation
(Research Priority, 4)

Definition and significance. Damages from forest fires occur almost everywhere forests exist. High fire hazard is typical of the arid West and Southwest, but high fire hazards occur even in the East and South. Fire risk increases with increase in population and travel through the high hazard areas. In an average year in the United States, forest fires start in 125,000 places, burn 5 million acres, consume 113 million tons of wood, put out 165 cubic miles of smoke, emit 364,000 tons of smog-producing hydrocarbons, burn 25 Americans to death and injure 1,350 more. Forest fires are costly to suppress. Expenditures for forest fire control activities average about $316 million per year. A single large fire may cost as much as $10 million to suppress. In southern and central California during 1970, forest fires burned over 900 square miles, destroyed over 900 homes and other structures.[5]

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[5] J. J. Barrows, "Forest Fire Research for Environmental Protection," Journal of Forestry, 69 (January, 1970), 17-20.

Direct damages from forest fires are high, but the aftermath of forest fires, floods and sedimentation often cause even greater damages and expenditures to prevent such damages. Investment in structural storage and conveyance systems to minimize flood and sediment damages has exceeded over $1 billion in the Los Angeles area alone.[6] Their effectiveness is threatened by each incidence of large fires followed by major storms. However, nearly everywhere in the United States, water quality is impaired for some time after large forest fires, and large amounts of water are made unusable, or huge expenditures for water purification result, even under current demands for water.

Reduction of forest fires may demand additional water supplies. If water were used to irrigate areas of high fire incident or risk, damages from forest fires could be reduced. Fire hazard would be reduced by changing the succulence of the present trees or brush, by converting to more succulent types, by changing from forest types to lower growing vegetation, or by locally altering the fire risk by increasing atmospheric moisture. The amount of additional water required will vary widely between situations and will depend on the final choice of vegetation to be propagated. Minimum amounts of water might range from one-third acre-foot per acre for new vegetation forms, such as wild members of the pineapple family, twice that for present vegetation in moist sites and normal years, and up to 2 1/2 acre-feet per acre for some hydrophilic vegetation in dry sites.

Such use of water could be important both in minimizing the damages associated with the fire itself, and in minimizing the damages from flood and sedimentation originating from burned areas. Prevention of forest fires minimizes damages to water supplies by maintaining

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[6] Walter J. Wood, "Los Angeles County Flood Control," Civil Engineering, 40 (January, 1970), 58-61.

water quality and preventing sedimentation of water storage and conveyance systems.

Developments required and research recommendations. Several technological developments such as low-cost storage of water in remote areas by creating impermeable surfaces, the use of plastic sheeting, creation of storage areas by new low-cost excavation, creation of subsurface storage, or injection of chemicals which cause soil water storage behind barriers may bring about the significant use of water in reduction of fire hazard areas. Local redistribution of rainfall to selected areas is possible by use of surface sealants and coverings now being widely tested. The utilization of waste such as sewage and industrial waste water would also be useful in the reduction of fire hazard in forest areas.

Possible pitfalls in application of water to high fire hazard areas may include an increased chance of landslides if irrigation were applied to slide-susceptible areas. Also, a false sense of security from the danger of floods could be created by the presence of improved vegetation resulting from irrigation of fire hazard areas, because floods can occur despite the improved and increased vegetation.

Considerable research will be required to determine the ecological responses of present vegetation to artificial watering, to develop species with resistance to fire under applied additional water, and to improve prediction of vegetational adaptation and succession under various conditions. The hydrological significance of applying additional water on water supplies, on floods and sedimentation, and on the preservation of water quality, together with the maintenance of slope stability and prevention of erosion need continued research both before and after various ecological techniques are developed. Considerable research in fire physics will be needed in order to predict the best location, extent, and operational techniques for fire hazard reduction for the various weather, topographic, and vegetation conditions. Lastly, and most importantly, the economics of the reduction of fire hazards by irrigation versus other techniques need research.

The probability of the future application of irrigation in the prevention of forest fires seems high in certain localized areas. We may expect prototype application within the next five years and rather extensive application of the technique to the highest fire hazard and high value areas within the next ten years.

f. Forest and Rangeland Irrigation

Definition and significance. Future demands for water could increase if more water is used in forests and rangelands which are now primarily considered as water sources. The irrigation of uncultivated primitive areas could increase plant growth and permit substitution of plant types.

Such use of water would be important because water demand could impinge on water now available for other uses. The demand for water for irrigation of wildlands could be large because of the extent of such lands and because of the enormous amount of water that could be used. For example, irrigation would maintain grass and other range forage green for greater yields and longer season of use. Additional water might also make possible economic use of fertilizers, selective herbicides, and more intensive management. Yet, whether such irrigation is ever applied on any significant scale would depend on economics. The additional water needed for irrigation of rangelands will vary from one-half acre-foot per acre for the higher cooler sites and wetter years to two acre-foot per acre for the drier sites and drier years.

In forests, supplemental irrigation with fertilization will produce maximum growth of trees for timber products. Irrigation of the hybrid poplar for rapid production of fiber is already competing for water in water deficient areas of southern Europe. Irrigation of coniferous forests is under test in Sweden and northwestern United States.

Developments required and research recommendations. Some technological developments which will make the use of water for irrigation of forests and rangelands more economical, and hence bring about additional demands for water, involve both the technical feasibility of supply and demand for the products of rangelands and forests. Low cost storage of water in remote areas is already underway with the use of new materials to create impermeable surfaces which collect and store water. Developing methods of low cost excavation of storage areas will also make irrigation of forests and rangelands more economical.

The projected increased demands for wildland ranges, as domestic pastures are occupied by urban development and other uses, will call for more extensive conversion of wildland ranges to irrigated pasture. Shortage of wood fiber brought about by extensive conversion of fiber to animal or human food, as well as increases in the present uses of fiber, will increase the demand for forest products and hence justify use of water in augmenting forest growth.

Demands for park-like outdoor scenic and recreation areas in low-rainfall areas near cities and by highways can make small but significant demands on local water supplies. However, some of such increased demand may be offset by reuse of present water supplies. Over-irrigation of wildlands for purifying sewage, industrial waste water, and polluted or sediment-laden streamflow may enhance both rangeland and forest growth, without increasing present demands on water in those areas. The total impact, however, is likely to be an increased demand for forest and rangeland use of water.

Development of the use of irrigation of forest and rangelands requires research largely into economic feasibility. The application of sewage and other waste waters to range and forest lands requires ecological research to determine the adaptability of various species of plants to such treatments and the ultimate impact on water quality delivery from areas over-irrigated with waste water.

The probability of widespread development of irrigation of forests for increased production of fiber is not great. However, local extended demand for water to enhance areas of forests for local recreation purposes seems likely. Use of over-irrigation of forest and rangelands for purifying waste waters also may be expected to expand. However, neither of these last two demands are likely to make a serious impact on water needed for other purposes.

g. Solution Mining

Definition and significance. Mining is still in a relatively primitive technological state. Opportunities for technological advancement lie in *in situ* mobilization of the desired elements or minerals by selective solution and extraction through bore holes. This method will require a large volume of water to manufacture solvents. Elements and minerals that are readily soluble (potash and sodium salts) are now being mined by solution mining. Uranium and copper are being mined by solution methods in experimental projects in some districts. Other less soluble elements and minerals await new technology. Water requirements will be local.

Conventional mining now requires water for drilling operations and on-site milling and concentrating. How much additional water will be required for conversion to solution mining is not known. In some operations where the solvent can be reclaimed and re-cycled, water requirements may be decreased over those required for a conventional operation.

Developments required and research recommendations. Widespread use of solution mining will depend upon the success of research in progress to develop efficient solvents, to effectively use subsurface microbes to render the desired elements soluble, to contain the solvent within the ore body, to condition the ore body so to assure pervasive contact with the circulating solvent, to recover the pregnant solution, and to recognize and recycle the solvent. The date that the technology will be fully operational depends on the commodity being mined, the local geologic conditions, and economics. The solution mining method should be in more widespread use in the major districts in 25 years.

2. TO DECREASE FUTURE DEMAND FOR WATER

Substantial breakthroughs in power generation by such methods as atomic fusion, fuel cells, or magnetohydrodynamics, or perhaps by some currently unknown method, could greatly reduce the enormous demand for cooling water in power generation plants. The primary motivation for developing such systems is to reduce fuel costs by increasing thermal efficiency. The higher the efficiency of converting fuel to electricity, the lower the consumption of fuel per kilowatt hour generated. Concomitantly, since more of the fuel energy is being converted to electric energy, there is a smaller fraction which has to be discarded in the cooling water, and cooling water requirements are thereby decreased.

Certain energy conversion systems, such as electro-chemical fuel cells and magnetohydrodynamics do not employ the "heat engine." Therefore, their efficiencies are not constrained by the usual temperature limitations encountered in steam cycles. Fuel cells require practically no water, magnetohydrodynamics probably very little water, and atomic fusion might or might not require water depending upon whether a heat engine will be required. Gas turbines and internal combustion engines may also be used to drive electric generators, and they involve practically no water consumption.

The nature of the interrelationships between these and other potential power generation methods is not foreseeable at present. It is probable, however, that if the development of one of these systems is tremendously successful, the others would not be expected to become important. On the other hand, several methods might be used simultaneously in different areas and for different types of service (base load versus peaking, large versus smaller plants, nuclear versus other energy sources).

It is therefore evident that if one or more of these methods for generating electric power should become important or possibly dominant, the potential effect on water use could be very great. In virtually all cases, the effect would be a large reduction in water demand for power generation. The characteristics and prospects of each of the methods having some possibility for use are described below.

a. Electric Power Generation by Gas-Cooled Nuclear Reactors

Definition and significance. Nearly all atomic power plants in use in the United States at the present time operate at considerably lower temperature than do modern oil-fired and coal-fired plants. This is necessitated by the temperature limitations of the nuclear reactor itself. As a result, the efficiency of converting heat to electricity is substantially lower than in the best fossil fuel plants -- roughly 30 percent as against 40 percent. Considerably more heat therefore must be discarded into the cooling water. This, in turn, requires a greater withdrawal of cooling water either in a once-through system or in a recirculation system (see Section A-1-b).

Nuclear reactor developments have led to a design involving the transfer of heat from the reactor to steam by means of a circulating gas at temperatures closely approaching those in conventional fuel-fired plants. The overall efficiency of conversion in this type of atomic power plant is therefore very near the best efficiencies in new coal and oil-fired plants. Accordingly, water requirements per kilowatt hour generated in these installations are about the same as those in fossil fuel-fired units.

The impact of this new type of nuclear reactor on water should be substantial. The expansion of nuclear power capacity by use of high-temperature reactors rather than low temperature units will permit water requirements to remain at levels comparable to those in fossil fuel-fired power plants.

Developments required and research recommendations. Very large research and development programs are being conducted in the field of gas-cooled power reactors, and such efforts may be expected to continue. The result anticipated is a thermal efficiency capability in advanced nuclear reactor design approximately equal to that in fossil fuel-fired plants.

Thus, water use per kilowatt hour generated can be expected to follow the same downward trend in the entire complex of U. S. power generation capacity as in the fossil fuel-fired capacity alone. Gas-cooled reactor design may be expected to predominate by the year 2000 and to assume an increasing portion of total U. S. electrical generating capacity thereafter. Although the demand for cooling water will continue to rise, the rate of rise should decline as average plant efficiency continues to increase.

b. Electric Power Generation by Nuclear Fusion

Definition and significance. The concept of fusion power is based on the nuclear reactions known to occur in the sun, basically the conversion of hydrogen to helium with the liberation of enormous quantities of energy. Unlimited supplies of hydrogen on earth in the form of water could provide an almost infinite quantity of energy, provided methods can be devised for achieving and maintaining the extremely high temperature (millions of degrees) required for the reactions to occur.

Developments required and research recommendations. There is now fairly general agreement that a self-sustaining, controlled fusion reaction is technically feasible and that the next generation of experiments may demonstrate this phenomenon on a modest scale. In other words, the next generation of fusion power research devices will be prototypes of an actual future fusion power plant. If successful they will demonstrate that the major problems of instabilities, leaks, heat losses from contamination by heavy ions, and some of the other technical problems can be overcome.

At this stage it is not known whether a fusion power system will have to involve a heat engine -- a steam cycle and turbine -- or whether some sort of direct conversion of energy from the high temperature plasma to electricity can be devised. If the heat engine is required, there will probably not be a large change in the cooling water requirements per kilowatt hour generated from the best plants using other energy sources. This is because the steam cycle itself, regardless of the temperature of the heat source, is governed by the second law of thermodynamics, metallurgical considerations and properties of water as a working fluid to efficiencies in the range of 40 to 45 percent. Water withdrawals for cooling and net evaporation losses in recirculation systems would therefore approximate the present values in the best power plants, even with nuclear fusion heat sources. If, however, some direct conversion energy methods can be developed in which the heat engine cycle will not be required, water usage could probably be greatly reduced and perhaps nearly eliminated in fusion power plants. In such circumstances, the importance of this development to the nation's water resources would be tremendous.

Research and development needed for fusion power development are of massive proportions. Large effort is being devoted in this direction and should be expected to continue. Only by such effort can the development be achieved. (It is even possible that the ultimate outcome could be a negative finding; that is, more energy will be required to sustain the fusion reaction than can be usefully delivered as output.)

There is little likelihood that a practical fusion power generation system will be available during the present century. Speculation indicates some possibility of application well after the year 2000. The impact on water requirements is impossible to foresee at the present time, but either the water requirements will remain about the same as at present, per unit of electricity generated, or they will substantially decrease.

c. Electric Power Generation by Fuel Cells

Definition and significance. The objective in a fuel cell is to combine a reactant, preferably a hydrocarbon, with oxygen from the air in an electrolytic medium, possibly in the presence of a catalyst, so that the exothermic reaction produces a flow of electric current rather than heat. In principle this can be more efficient than a heat engine since it does not involve rejecting energy as low grade heat at the low temperature end of a thermal cycle. Instead, under theoretically ideal conditions, it would be possible to obtain complete conversion of fuel energy to electricity.

In practice, some energy is lost in the form of heat because most fuel cells must operate at an elevated temperature, some of the fuel therefore being used to overcome heat losses. Hydrogen has been successfully used with oxygen in fuel cells, but hydrocarbons such as natural gas have generally required preliminary decomposition for effective conversion.

Developments required and research recommendations. A great deal of research and development has to be done if fuel cells are to become practical for large scale power generation. Development of existing cells as well as exploration of new possibilities should be useful. Substantial effort will be required to develop fuel cells which can utilize hydrocarbon fuels directly.

At the present, it does not appear probable that fuel cells will make sizable inroads in large-scale power generation in the U. S., even in the next century. A breakthrough of some sort, however, might bring this system into the picture, consequently reducing cooling water requirements.

d. Electric Power Generation by Magnetohydrodynamics

Definition and significance. Research has shown that electric power can be generated by passing an ionized high temperature gas through a magnetic field. The principle is similar to the operation of a conventional electric generator where a conductor, in that case an electrical winding, is rotated in a magnetic field, thereby inducing a flow of current in the conductor. In a magnetohydrodynamic (MHD) system, ionization of very high temperature furnace gases can be accomplished by addition of vapors such as sodium chloride or other salts.

Since the magnetohydrodynamic system avoids the use of a conventional heat engine, and since it operates at a very high temperature, overall efficiencies of conversion to electric power can possibly be double those of conventional efficiencies. Estimates are as high as 60-70 percent of the energy in the fuel being converted to electrical output.[7] In addition, there is the possibility of employing the exit gases from the MHD generator in a conventional steam power cycle, with additional energy recovery.

The consequence of successful application of MHD would be the generation of increased amounts of electric power with very little water use. Since more energy is converted to useful electric output, less is

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[7] P. Harris and G. E. Moore, "Combustion: MHD Power Generation," paper presented at IEEE meeting, New York, February, 1971 (in print).

dissipated in cooling water. Cooling requirements could be reduced to possibly one-fifth of the present average. Requirements for power plant location on large water courses would no longer exist, and more flexibility in siting would result. Since power plant cooling is now the largest industrial user of water, it is evident that if MHD can be successfully and widely applied, the impact on water demand would be great.

Developments required and research recommendations. Although MHD has been demonstrated on a small scale, a large amount of research and development must be devoted to this process if it is to become practical. Problems of gas ionization, containment at very high temperatures, generator design, and numerous other questions require solution. Development needs, materials for the system, cost reductions, and recovery of ionizing materials also must be worked out.

Estimates of the commercial prospects of MHD are very speculative in this early stage of development. However, since the principle has been demonstrated successfully, there is reasonable expectation that practical designs will eventually be developed. The pressure for increasing efficiency of fuel utilization will further increase as fuel prices continue to rise. This is true even insofar as nuclear fuels, which may also be considered potential sources of heat for the MHD process, are concerned. Accordingly, there is a reasonable prospect for limited application of MHD by the year 2000. If economically attractive, increased use of this process could be realized in the ensuing decades.

e. Electric Power Generation in Open-Cycle Engines

Definition and significance. Examples of open-cycle engines are the conventional internal combustion engines based on the Otto and Diesel principles and the gas turbine engine in which hot compressed air and combustion products are expanded through rotating blades and discharged to the atmosphere. Several other types and modifications of these once-through gas flow engines exist, and it is unlikely that all possibilities along this line have been exhausted.

The cost of generating electricity by use of these open-cycle engines is presently greater than that of steam power generating systems because of higher investment requirements and lower thermal efficiencies. It should be possible, however, to increase efficiencies and perhaps reduce investment requirements by concentrating effort specifically pointed toward large-scale power generation use. In past decades, however, the main thrust in developing open-cycle engines has been in the application of these systems to transportation uses. The possibilities for improvements directed toward power plant use have therefore not been fully realized. Since all these engines use very little cooling water, and some of them use none at all, the potential for water savings is great.

Developments required and research recommendations. A wide variety of research and development requirements would have to be met if there is to be substantial substitution of open-cycle systems for conventional steam electric generation facilities. It appears that some sort of breakthrough would be required if this substitution were to occur in other than small systems and in installations used as peaking units. One possible application could be in conjunction with MHD operation, the hot gas from the MHD generator passing through some sort of open-cycle engine for additional power generation. Studies of this sort are currently in progress, primarily undertaken by the organizations which manufacture internal combustion engines, but such efforts could undoubtedly be augmented.[8]

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[8] Ibid.

The likelihood of open-cycle engines dominating the power generation field appears remote during the present century. There will be some use for peaking and for small capacity plants, and in these situations water requirements will be minimal.

f. Electric Power Generation by Use of Wind and Water Power

Definition and significance. Wind power has been used for centuries on a small scale for ship propulsion, water pumping, materials processing (e.g., grinding grain), and electricity generation. Its use requires no water. The prospects for large-scale electricity generation by use of very large wind machines have been theoretically and experimentally studied in the U. S. and abroad, with generally unfavorable findings.[9] High equipment cost, variable wind speed and dependability, and few suitable sites are serious drawbacks. Moreover, the absolute amount of dependable energy available in the wind which could be utilized is small in urban regions. Accordingly, virtually no possibility for this power source on a large scale can be foreseen. If it should achieve limited use in favorable locations, however, water need not be a consideration in site selection because none is required.

Production of electricity using water power has steadily decreased over the years relative to other methods. In 1920, water power capacity was about 25 percent of the total electrical capacity in the country. Present capacity is about 15 percent of the total, and of this power capacity, nearly half is at federal multipurpose dams.[10] The private

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[9] Proceedings of the UN Conference on New Sources of Energy, August, 1961.

[10] Based on annual reports of the Federal Power Commission.

water power component has grown very little over the years, although pumped storage for peaking purposes on thermal systems is becoming a significant factor.

Developments required and research recommendations. To some extent the future role of water power may depend upon technological improvement such as dam construction, tunneling, turbine design, electrical transmission lines, and automation which would make small sites feasible. Water power does not pollute the air or water, even though it exerts direct and indirect effects on the environment that may affect a public now sensitive to all new works. Impoundments for water power may affect recreation, converting rapids to slack water and assisting those who look to lake sports (boating, water skiing, fishing from boats) at the expense of those who enjoy fishing and canoeing on swift streams. There is a corresponding shift in aesthetic values as drowned valleys replace open valleys. The migration of fish may be affected. An impoundment results in evaporation -- a loss of water that may be especially significant in the arid regions and to that extent an increase in salt concentration. A dam or reservoir changes the temperature regimen and removes prime land from cultivation and other uses.

The general conclusion is that even though electrical power demand may continue to increase about 25 percent a decade, the rate of increase is considerably less than the anticipated growth in total electrical capacity and water power will not become a significant factor in the power economy.

g. Recirculation Cooling Pond Development
(Research Priority, 3)

Definition and significance. Cooling ponds for removal of heat from power plant condenser water have the same function as cooling towers (see A-2-h), but occupy considerably more land area -- an acre of pond surface per megawatt of power plant capacity is often used as a rule of thumb. Primarily for this reason, they are in much more limited use than cooling towers. Somewhat more water evaporation occurs from artificial cooling ponds than from cooling towers because of the absorption of solar radiation in the ponds.

Developments required and research recommendations. New developments which directly or indirectly increase the applicability of cooling ponds in water recirculation systems are improved excavating and land filling machinery and methods, improved linings for reservoirs to prevent water loss, and external effects such as restrictions on thermal discharge and the aesthetic drawbacks (and costs) of cooling towers. Additional developments which would minimize solar energy absorption in the water while permitting dissipation of the power plant heat could increase the use of this type of cooling system. The possibility of reflective floating particles or porous solid or liquid films on the water surface might be of future importance. Methods to increase the area of contact between air and water, by spraying or other means, can reduce the pond area requirements. Apart from technical considerations, the recreational opportunities afforded by the warm water environment in cooling ponds may enhance their future use.

Whether cooling towers or cooling ponds are used in a water recirculation system will make very little difference in the nation's usable water supply. Slightly higher demand will be imposed by those plants using cooling ponds over those using cooling towers, but the difference is very small. A more important impact will be in situations where cooling ponds are used rather than once-through cooling. In these situations, water withdrawal for power plant cooling can be reduced to a few percent of the once-through requirement.

No new research or development is needed for this system of recirculation cooling, because it is already practiced to a considerable extent. However, if some improvements in performance and reductions in construction cost can be effected by further development, applicability of the system should be increased.

The use of cooling ponds can be expected to grow nominally during the next decades. However, with the growing demands for land area, cooling towers will undoubtedly be used to a greater extent than ponds, particularly in urban and suburban areas. Impact on the national water picture will probably not be appreciable even into the next century.

h. Advances in Cooling Tower Design and Utilization in Industry
(Research Priority, 2 -- research in progress)

Definition and significance. Cooling towers are employed for cooling and condensing purposes (for removing the heat from water which has been used) in conjunction with thermal power plants and other industrial facilities. This is accomplished by allowing water to cascade down through a lattice work inside a tall vertical shaft through which air is rising, either by virtue of a blower system or by use of natural draft and very tall towers. A portion of the warm water evaporates into the air, thereby cooling the balance of the water for recirculation and reuse. Recent developments in the United States have been mainly in the direction of increasing the size and capacity of the natural draft type of cooling tower for use in very large power plants. Limitations being imposed on thermal discharge have forced increased use of cooling towers, thereby indirectly stimulating manufacturing and construction economies.

The impact of this development on water demand and use is very large. The use of cooling towers as contrasted with once-through cooling results in a reduction in water withdrawal to less than 5 percent of the once-through requirement. Cooling towers are already widely used in the west and southwest United States mainly because stream flows are not adequate for once-through cooling of power plants. As temperature standards are imposed on streams in other parts of the country, it is virtually certain that cooling towers will be used in most new power installations. Unless a power plant is located on an extremely large river or on the open ocean, it appears unlikely that "once-through" cooling will be permitted. The net result of this trend will be a very large reduction in the quantity of water withdrawn for cooling purposes in power plants and other industrial facilities. It is considered possible that the reduction may be of such magnitude that the use of water for cooling purposes will no longer be the great industrial requirement it is now.

A possible deterrent to uninhibited growth of cooling tower installations is the aesthetic aspect of huge concrete shafts (natural draft towers) and fog plumes (most troublesome at low levels from mechanical draft towers). Where these factors may be particularly objectionable, as in or near cities, for example, other solutions may be dictated. Siting of power plants at greater distances from the cities and the use of cooling ponds (see A-2-g) may have to be more widely employed.

Developments required and research recommendations. Cooling tower technology is mature, and it is unlikely that additional developments will be of more than marginal importance. No additional developments are really required for this technology to be widely applied, and no new research is required for the concept to become widely used.

Cooling tower technology is already being practiced, and application of cooling towers will certainly continue to grow. Implementation of this concept simply involves the gradual increase in the proportion of power plant and industrial cooling being accomplished with cooling tower systems. Most new power plants will employ cooling towers, and as the proportion of new power plant capacity to existing capacity continues to increase, so will the proportion of cooling water that is recirculated. There is little doubt that by the year 2000, well over half the power generating capacity in the United States will be using cooling towers.

i. Industrial Cooling Systems Using Air
(Research Priority, 1)

Definition and significance. Under suitable conditions, air may be used for the dissipation of heat from manufacturing operations and power generation plants. Such systems completely eliminate the need for water withdrawal and avoid temperature increases in rivers and evaporation loss. Lower heat transfer rates through air-cooled equipment result in higher cost than in water-cooled systems, particularly when the waste heat is at temperatures only slightly above atmospheric. High temperature industrial operations can be conveniently air-cooled, and intermediate temperature operations such as in petroleum refining are often provided with coolers and condensers through which air is circulated directly.

There is very limited use of air-cooling in steam electric power generation. Only one large plant in the world is actually in existence. In this English power plant, water is used for condensing the steam from the turbines, then the heated water is cooled by air in a completely closed water circulation system so that no evaporation takes place. A so-called "dry cooling tower" is used for the transfer of heat from water to air.

Greater application of direct air-cooling and non-evaporative water cooling could have substantial impact on water demand and use. The only major deterrent is the cost of the equipment. In areas where the availability and cost of fresh water are extremely critical, direct and indirect air-cooling could have a significant influence on demands.

Developments required and research recommendations. Additional developments which might be required for wider application of direct air-cooling of industrial operations are mainly those which would reduce the capital cost of the equipment. If there would be substantial progress in this direction, through design changes, materials substitution, and so on, wider application might be expected. Cheap, corrosion-resistant materials for heat exchangers would be an important development. Aesthetic factors, such as the appearance of very large dry cooling towers and noise from large high speed air fans, would require consideration. On the favorable side, however, is the absence of a water cloud or plume which is occasionally objectionable when conventional cooling towers are used.

This concept is already feasible, so research would be needed only in the sense of effecting improvements and economies. Investigations in heat transfer, materials of construction, fabricating methods, and the like, would be in this direction.

In the present view, it does not appear highly likely that widespread application of this existing technology will develop insofar as United States power plants are concerned. However, favorable progress in research and development effort such as those outlined above could alter this view. Complete freedom in power plant site selection, without any regard to water availability, would be an indirect and valuable result of such developments. In such an event, considerable use of the concept might be envisaged in the year 2000. Direct air cooling of high temperature industrial operations is already practiced, and it is considered very likely that the use of air for moderate temperature cooling requirements will increase in the next decades.

j. Water as Diluent for Wastes
(Research Priority, 4)

Definition and significance. Reducing the use of water as a diluent for wastes can be accomplished in two ways. First, water can be entirely replaced by another inert fluid such as Freon 131, which can readily be reclaimed and recycled. Second, saline and/or recycled wash waters can be used as waste diluents, particularly for domestic sewage. Either method would require a second system of pipes and storage tanks.

The importance of the concept lies in the magnitude of the water savings. One-third to one-half of the water used inside homes, offices, hotels, and hospitals is required for carrying wastes. Thus, the potential impact of either scheme is significant in the long run.

Developments required and research recommendations. Both total replacement and recycling will require a complete plumbing system including a method of reclamation and purification of the alternate fluid, preferably a very inexpensive, inert fluid. Otherwise, the major requisite is capital investment which can only be justified by significant charges for urban withdrawals and contaminated returns.

The technology for implementing the alternate fluid concept exists. A number of specific concepts should be analyzed for technical and economic feasibility. These would include (but not be limited to) the following:

(a) Use of untreated or partially treated domestic bath/wash water for toilet flushing.

(b) Use of sea water or brackish water for toilet flushing (dual sewage system).

(c) Domestic treatment and recycling of bath or wash water, perhaps in combination with low-water use toilet and/or items (a) and (b).

(d) Use of an inert, heavy, non-aqueous fluid (such as Freon 131) for carrying sewage from toilets to separators where the waste could be removed and the carrier fluid recycled. This might be combined with (c).

Retrofitting a secondary system of plumbing into most existing structures is unlikely. Where water costs are high, especially in large complexes, dual systems are now economically feasible. This condition exists currently in certain locations (e.g., St. Thomas, V. I.) and will probably exist on the mainland, perhaps in southern California, before the year 2000.

k. <u>No-Rinse Washing/Laundry Technology (Research Priority, 4)</u>

<u>Definition and significance.</u> A large amount of water is used in both commercial and home laundries. This water is used both in the cleansing action and subsequent rinsing, with the latter being predominant. Rinsing is second only to sewage disposal in terms of current domestic and commercial consumption of water. One can conceive of a washing technique which would require less water for rinsing than is currently the case. The problem is to separate efficiently the dirty (possibly soapy) water from materials or objects being cleaned without excessive dilution. The public associates cleansing effectiveness with sudsiness, which leads to excessive use of soap and detergent, a tendency by manufacturers toward high-suds formulations, and a need for more rinse water to remove suds.

Two laundry technologies could affect water use. One is a no-suds washing technology and the other a no-rinse technology.

<u>Developments required and research recommendations</u>. No-suds technology now exists, but there is little incentive for its rapid adoption. Adoption of this practice would depend on public information

programs and cooperation of the manufacturers to educate the people to the fact that high suds are not necessary for effective cleansing and may even impede the washing action. The effect of adoption of this technology on water use would be relatively small, coming primarily from a reduced rinsing requirement because of no suds and improved rinsing techniques such as filtration, countercurrent rinsing and internal recirculation.

The technology for no-rinse washing does not now exist. This technology, if developed, could significantly reduce laundry water requirements because only small amounts of wash water would be needed. Some methods for no-rinse technology with potential are ultrasonics and chemical additives. The adoption of this technology could come in 20 years if research and development is undertaken. In areas of extreme water deficiency, the water savings could be important. Incentives to undertake any research and development in this area are also lacking at present. A more rational water pricing policy (see concept E-2) could alter this situation.

No-rinse washing/laundry technology will eventually attain widespread application. However, before economic incentives can be instituted, several broad research programs including a survey of technical possibilities for soapless washing, a public education program and some form of "anti-suds" legislation are needed.

1. Bioprocessing to Provide Food
(Research Priority, 1)

Definition and significance. Bioprocessing involves alternative ways of providing the basic nutritional needs of mankind. It extends beyond traditional agriculture production as practiced today in that many raw products, not palatable in their present form, will be bioprocessed into edible protein, carbohydrates and fats. The raw material for these food products include unconventional plant sources such as nonedible leaf material, cellulose, petroleum materials, and various wastes. The micro-organisms which use these various carbon and energy sources will usually result in a single cell protein food material which will be further processed through new food technologies and blended to form a satisfactory food source.

There is a projected need for greater food production on a worldwide basis because of burgeoning population. Since most nutrition deficiencies, both present and projected, are protein deficiencies, the critical need is for expanded protein production. Production of animal protein is inefficient when compared with direct protein production from plants or using micro-organisms to convert nonedible materials into protein sources. Therefore, the trend will be to get greater efficiency in protein production using these new bioprocessing technologies.

Agriculture is a large user of water, and to provide food production through irrigation agriculture involves a large water requirement per unit of protein production. This is particularly true if higher animals such as beef cattle are in the protein production chain. Calculations based on recent data indicate that direct extraction of protein from leafy material such as alfalfa is over 12 times as effective in terms of recoverable food protein as processing leaf protein through beef cattle.[11] Even greater overall efficiency in food protein production is obtained when yeasts are grown on available carbohydrate sources, but the end product is not acceptable as a human food in most places. Torula yeast has successfully been used as a human food supplement.

The widespread use of bioprocessing to provide food will have several important impacts on the water use picture. In the first place,

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[11] N. W. Pirie, "Leaf Protein as a Human Food Source," Science, 152 (1966), 1701.

there might be very little incentive for expensive new irrigation projects. Trees are capable of utilizing whatever water is available and trapping water in the soil for efficient future use. If water is in short supply, photosynthesis and carbon fixation is severely reduced, but the crop is not lost. Considering all this and the higher calorie conversion efficiency, cellulose culture could be considerably more efficient in terms of water use and would be ultimately more efficient in terms of edible calories produced per unit of fresh water supply than the existing agricultural food production system.

Secondly, tropical forests would be economically more valuable. The drier parts of the country where food grains are grown could become comparatively less important agriculturally, and the forests along the Gulf Coast and in the humid subtropics more important because of the climatic advantage of a long growing season.

Thirdly, waste materials from agricultural production and processing operations, urban wastes, and certain industrial waste liquors would themselves become energy sources for food production. The whole problem of water reuse would become technologically and economically easier to solve.

The above procedures will permit at least a ten-fold increase in production of adequate dietary protein from a given land source with a corresponding savings in water requirement. Also, production can occur in those areas of the country where water supply is not so critical.

Developments required and research recommendations. Since conversion of cellulose will involve certain yeasts not totally palatable, certain modifications will have to be made in proteins for suitable digestability when they are a major source of protein for human diets. While it will be some time before the hydrocarbon-based yeasts will be accepted as a direct human food source, they are now becoming increasingly important as an animal food. One of the major problems which will have to be overcome will be related to the overall acceptance of these new food sources by the general populace. Technical developments needed will include improved ways of restructuring, flavoring, and combining protein molecules from many sources into better synthetic meats and foods through advanced food science technology.

Research should be strengthened and expanded on the technologies related to the potential of microbial food resources. This will include studies of toxicology, microbial genetics, bioengineering, process chemistry, and the biochemistry and food technology of these food bioprocessing systems. Finally, research will be needed to evaluate the systems analysis aspects of these food production concepts so they can tie in directly with other functions, be they industrial manufacturing providing waste energy sources or space nutrition.

The technical feasibility of bioprocessing technology has already been established. However, additional work is needed on the food technology aspects to insure that the products are flavorful and universally palatable before the bioprocessed materials will enjoy widespread acceptance as a human food.

After the turn of the century, there will be a significant amount of human nutrition needs satisfied through bioprocessing technology where nonedible energy sources are converted into edible human nutrition sources. Initially this bioprocessing technology will be used to provide enriched feed sources for animals, but after the year 2000, much of the conversion will be directly to human food sources. The extent to which this source of human nutrition will replace traditional agricultural production will be dependent on food supplies available and the comparative cost of this food source. By the year 2000 food from bioprocessed nonedible materials will be a significant source of food in this country and will be a part of the basic human diet.

m. Artificial Anti-transpirants
(Research Priority, 2)

Definition and significance. Most of the water used by vegetation is transpired because of a diffusion gradient of vapor between the inside and the outside of the leaves through leaf surface openings called stomata. The leaf also takes in carbon dioxide for photosynthesis through these openings, but in the opposite direction. Any means which could be found which would decrease the effective diffusivity of water vapor through the stomata without affecting the input of CO_2 into the leaf would result in a decrease in water use without a decrease in growth.

On small areas of free water surface, the diffusivity for water vapor can be greatly reduced by the use of monomolecular layers of long-chain alcohols such as hexadecanol. These layers apparently have little effect on the inward diffusion of oxygen and carbon dioxide. Such substances have not proved effective for evapotranspiration suppression, however, since they wash off the leaves easily and are difficult to apply to the underside of the leaf where the stomata are located. The increased plant temperatures resulting from lower evaporation can increase rates of growth.

A successful low cost, persistent anti-transpirant could make a dramatic change in the water supply and water use problems of all parts of the United States. During periods of deficient water supply or when precipitation on watershed must percolate to the deep soil reservoir or groundwater, certain plant communities such as forests or bushy species will be treated to reduce transpiration and perhaps make the plant temporarily dormant to conserve water. This could increase the rainfall appearing as base flow runoff by a very significant amount. At a proper time the effect of the anti-transpirant will naturally wear off or an antidotal chemical may be applied.

Developments required and research recommendations. Proper nontoxic materials will have to be developed for this purpose. Many of the present anti-transpirants are toxic; therefore, new materials will be necessary for the method to be feasible. At present the mechanism of natural stomate control is not understood, and the secrets of the stomate nerve center must be unlocked for effective transpiration control to occur.

Although the potential exists, the meager amount of research to date has not been overly encouraging. There has not yet been developed a quick evaluation procedure for the many compounds that might be suitable. Research will be slow until such procedures can be devised. Since some plants appear to have reasonably good photosynthesis with less water use, there may be some value to studying the biochemistry of these leaf surfaces.

Anti-transpirants could be developed any time from five years to a century depending on the level of effort and the potential for the development of a quick evaluation procedure. At present rates of research, only a lucky break would make it available within the next forty to fifty years. Once developed, it could be implemented as fast as production facilities could be provided.

n. Genetic Development of Plants to Withstand Drought and Salinity
(Research Priority, 2)

Definition and significance. Today's Green Revolution, which allows new high-yield varieties of plants developed in one part of the world to be transplanted in another, is a reminder that genetic differences in plant populations can be identified, isolated and recombined to synthesize new varieties with specific desirable characteristics. Geneticists are attempting to develop plants which use water more efficiently through genetic breeding. These plants will be more drought resistant and most likely will be deep rooted and have a leaf structure such that transpiration losses are greatly reduced. In many cases the plant material produced will not be used directly because of some undesirable characteristics, but instead it will become a new material for further processing into food and other products.

A second genetic development will be the breeding of plants which can use water of lower quality, particularly in terms of mineral content in the irrigation water. This latter will not necessarily save water but will use water of lower quality which is not otherwise usable. The genetic development of specialized plant species is very important because it will help develop some of the water deficient wastelands. As an indication only, barley has been grown in laboratory experiments using irrigation water containing 24,000 parts per million total dissolved solids.[12]

The fact that many of our present staple crops appear to have originated under arid or semi-arid conditions suggests that genetic material should be available which could permit the use of much more saline water for irrigation purposes or for dry farming under lower rainfall conditions than can presently be practiced.

Either of these genetic developments would substantially reduce the amount of water needed for food production. Salinity tolerance would permit greater reuse of drainage waters and other brackish waters.

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[12] Hugo Boyko, "Salt-Water Agriculture," Science, (June, 1967), 89-96.

Drought resistance would extend the useful range of dry farming. Major areas of water deficient wastelands could be made productive.

Developments required and research recommendations. A fairly long period of research will be required for these objectives. The Green Revolution had its inception in the early thirties and has been the subject of a concerted research and development program by the Rockefeller Foundation and the Government of Mexico since 1942. Basic research is needed to identify and quantify the particular characteristics to be sought and refined. This will be more difficult than was the case with the development of high yielding hybrids, however, since the reaction of the plants to both drought and salinity is quite different at different phases of growth.

At the present time there is essentially no work being done on drought resistance, and salinity tolerance has not been the subject of any significant amount of genetic research. Forty years might be required to develop varieties with sufficiently high production for commercial use. On the other hand, a concerted research effort could shorten this time substantially.

o. Subirrigation and Unsaturated Leaching Strategy
(Research Priority, 3)

Definition and significance. Subirrigation and unsaturated leaching are methods for markedly reducing the amount of water required to accomplish required tasks. In subirrigation the water is applied below the soil surface reducing the water losses occurring in irrigation. The unsaturated leaching concept provides a means for leaching excess salts from soils with a minimum amount of water. By managing the system so downward flow in the soil occurs in the unsaturated state, more salt is removed from the soil per unit of water used. The water flows along soil particle contact points and through minute crevices where salt particles tend to accumulate, dissolving and removing the salt with a minimum of water.

Subirrigation is not new, but widespread application of the method has usually not been economical in the past because appropriate low cost materials for the subirrigation pipes had not been developed. In subirrigation the root zone of the plants is kept at the optimum moisture content. Fertilizers and other materials such as systemic insecticides can be efficiently applied with the water below the surface, avoiding any possibility of runoff and uncontrolled pollution. Since the soil surface is not wetted, evaporation from the soil surface and growth of noxious weeds tend to be eliminated. Water use efficiency in terms of vegetative material produced per unit water consumed can be increased by a factor of three to six over conventional sprinkler or surface irrigation. This has a tremendous potential impact on water use for irrigation and can significantly extend the productive life of groundwater supplies in many regions.

Trickle or drip irrigation is similar to subirrigation in that water is applied only as the plants can use it. Trickle irrigation is particularly useful for orchard crops since water can be dripped at a few points under each tree and not totally wet the soil or the foliage which causes large evaporation losses. Soils must be of sufficiently fine texture so adequate unsaturated flow in the soil will carry the water throughout the plant foot zone. Water savings similar to subirrigation can likely be achieved.

An unsaturated leaching strategy provides an efficient way to reclaim saline soil or to maintain a desirable soil salinity balance in irrigation agriculture in arid areas. This is extremely important since leaching is an essential adjunct to irrigation agriculture if the water quality is not perfect as is normally the case. This technique can increase leaching efficiencies by a factor of four under proper conditions.

Developments required and research recommendations. The subirrigation concept will become increasingly practiced when suitable materials for the subirrigation distribution system become readily available. Additional developmental research is needed on low cost, durable porous tubes which can be easily installed in these systems. The unsaturated leaching strategy is dependent on careful management of the system in terms of drainage and water application rates. More research is needed on this practice particularly in terms of problems in non-homogeneous soils.

Both technologies have been developed and will be expanded continuously. Subirrigation will come into general practice for high valued crops in water deficient areas by 1990. The same time scale will apply to the leaching strategy. Neither of these concepts will be adopted widely until the availability and/or cost of water necessitates the more efficient water use practice.

p. Landscaping with Artificial Materials

Definition and significance. In arid and sub-humid areas, landscape vegetation accounts for a very large fraction of the water consumptively used. As an approximation, an acre of vegetation in an urban environment will consumptively use about five percent more water annually than an acre of crops. To some extent, this vegetation serves to reduce air temperature (and increase humidity). For the most part, however, its purpose is aesthetic. Replacement of lawns and shrubs by xerophytic vegetation has not proved popular. The advent of artificial turf, however, would suggest a major potential for reducing urban water requirements while maintaining an aesthetically pleasing, serviceable surface with greatly reduced maintenance as an added attraction.

A very large fraction of the total consumptive use of water by an urban area could be eliminated if all urban landscaping used artificial material. Lawns may very well be replaced to a significant extent within a decade or two, particularly if mass production brings the cost down. Shrubs, flowers and trees are less likely to be replaced, however, as is suggested by the present continued use of higher cost fresh flowers in the home. If lawns only were replaced perhaps as much as one half the consumptive water use could be eliminated.

Developments required and research recommendations. This technology is available now and would require only small modifications (other than cost) to adapt artificial turf from playing fields to home lawns. Further research will be required, however, if the use of these materials is to avoid more problems than it solves. They are presently impermeable. If installed throughout residential districts, flood drainage systems would quickly be overloaded even with small storms. Permeability equivalent to natural grass would be a very desirable characteristic to be developed. This could also reduce installation costs since the requirement for an even subsurface would be eliminated.

Cost is apparently still a deterrent to widespread landscaping with artificial materials, and there may be a shortage of competent installation personnel. Adoption of this development will most likely occur because of the superiority of the artificial materials and the reduced maintenance requirements rather than the savings in water costs. The technology could, if extensively introduced, reduce suburban water requirements on the order of 25 percent.

3. TO INCREASE AND/OR DECREASE FUTURE DEMAND FOR WATER, DIRECTION UNCERTAIN OR DIFFERENT DIRECTIONS IN DIFFERENT REGIONS

a. Conversion of Solar Energy to Heat and Power

Definition and significance. The practically unlimited energy received from the sun can be converted to heat or to electric power by numerous techniques. The amount of energy available would be sufficient for all man's needs, and only the cost of conversion to useful forms limits the use of this energy resource.

Conversion to heat at temperatures sufficient for house heating, water heating, and for operating some types of air conditioners can be simply accomplished by use of glass-covered blackened metal surfaces in contact with circulating air or water. Higher temperature applications can be met with greater difficulty and cost by use of focusing reflectors. Electric power can be generated by using the high temperature heat in a reasonably conventional steam-electric system, or the solar radiation may be converted directly to electricity by means of solid state devices, such as silicon solar cells.

The importance of large-scale development of solar energy insofar as water supply and demand are concerned would be the alteration of the location of demand, and for some applications, increased water requirements. If large amounts of electric power are generated from solar energy by direct conversion techniques employing no cooling water whatever, corresponding reductions in water demand per unit of generation would result. This effect might be expected to be most important in areas of abundant sunshine, particularly in the Southwest. Direct conversion of solar radiation to electricity on a very large satellite and transmission of the power to a receiver on the earth by microwave system has been studied.[13]

If, however, the technology moves in the direction of using solar heat to operate steam-electric generating systems, cooling water would be required, and the demand for water would be intensified in the areas of most abundant sunshine, again the Southwest. Prediction of the ultimate technology employed, when and if used, is not now possible. The ultimate effect on water demand may therefore be a decrease in total quantity, or the total may stay about the same with the location of demand shifted to sunny areas.

The widespread replacement of fuel-fired units by individual household units for low temperature heat applications would have virtually no effect on water demand. However, if the solar energy source supplants or replaces electrical power for home uses there would be a reduction in electrical demand and hence in the demand for cooling water by electrical generating plants located in the sunny parts of the United States.

Developments required and research recommendations. In order for any of these technologies to become widely used, much research and development would be required for investment costs to decrease materially. If a determined effort were mounted, substantial use of solar heat for domestic purposes could be realized in 10 to 20 years. The future of solar power is more uncertain. It is dependent on a number of competing energy sources, such as nuclear fusion of hydrogen, and the technology of low cost solar power has not yet been worked out. It is considered likely in the very long range view (100 years) that electricity

[13] A paper on this subject was presented at the IEEE meeting, New York, February, 1971, by Glaser and Löf.

from solar energy will have to be widely utilized because of insufficient sources of other forms of energy.

Assuming that considerable effort is devoted to the development of economical systems for collecting and using solar energy for heating and cooling, there could be widespread application in the year 2000. Some easing of water demands for electricity generation might therefore be envisaged in sunny areas of the United States (the west, southwest, the southeast, and parts of the central states). Solar power on a large scale is not likely to be employed in the next half century unless major economic breakthroughs in the technology should take place.

b. Power Generating Units for Meeting Peak Demands

Definition and significance. Electricity demand is highly variable both through a twenty-four hour day and through the seasons of the year. Since capacity must be adequate to meet the most severe demands, portions of the electric generating systems are idle for much of the time. In typical systems, total power generation per year may be about one-half of the system capability. The cost of idle power generating equipment is high, and means for its reduction are being developed.

In addition to the cost of idle equipment, there is the added problem of variable water demand for cooling and the usual unfortunate combination of maximum system load (due to air-conditioning demands) at times when river flows are lowest and river temperatures are the highest. These factors combine to place severe demands on both the power generating system and the water required for cooling.

Alternatives to steam electric power plants operating on a highly variable or intermittent basis are hydroelectric units, electric generators operated by large diesel engines, gas turbine engines (similar to airplane jet engines) and pumped storage of water utilizing off-peak power to pump water to an elevated reservoir for subsequent energy supply by hydroelectric generators during peaks. The latter system may also employ surface and underground reservoirs in a similar fashion. These alternatives involve no consumptive use of water (evaporation), and only the first involves stream flow requirements. However, the energy losses in the pumped storage system require the generation of about one-third more power during off-peak periods, thus total cooling water use must be proportionately increased.

Large-scale use of peaking power units not requiring water should reduce the water throughput and water evaporation in the nation's power plants. The higher cost of these systems precludes their use for base load applications, so their importance will be limited in scope. Probably the main result of using these systems for peaking will be a modest decrease in the use of cooling water during periods when demands on the water sources are highest. This should mean a net benefit in the nation's water picture.

Developments required and research recommendations. Application of this technology does not depend on further research and development being performed, because the systems are already available. Moderate cost reductions through engineering development will lead to increased application.

Flexible systems for meeting power system peaks are already in use, and they may be expected to increase in the years ahead. By the end of this century, it is likely that most of the electric power system peaks will be met by non-water consuming generating units rather than by conventional steam plants.

c. Electric Power Transmission over Long Distances

Definition and significance. The transmission of electric power over long distances -- hundreds or perhaps even a thousand miles -- will have an indirect influence on water demand. Until recently, it has not been economical to transmit power over such distances because of excessive losses in the lines. Power generation facilities therefore have had to be located reasonably near the electrical load centers. Large power plants in or near large cities have been the general practice. Recent developments, particularly in Europe, in the transmission of very high voltage direct current with the associated equipment for AC-DC conversion have made it possible to send power over hundreds of miles with very moderate losses. A few long lines employing such systems have actually been built in the United States. The effect on water demand can readily be seen as a reduction near the load centers and an increase in the construction of plants where abundant supplies of water are available, as on the seacoast.

An even newer and not yet applied technology is the transmission of power through cryogenically cooled conductors, probably located underground, over virtually unlimited distances with practically no loss. Maintaining the temperatures of the conductors near absolute zero by using liquified gases could make this possible.

Both of these power transmission developments can be very important in relocating the demand for water in the cooling of power plants. The total demand would not be changed, but the construction of new plants on the seacoast or where other abundant supplies exist and the relaxation of demand on scarce inland supplies would have substantial benefits. For example, instead of using scarce supplies for power plant cooling in the arid southwest, power could be generated on the shore of the Pacific Ocean and then transmitted to this region by these new techniques. Water thus saved in the inland region could then be applied to other uses.

Aesthetic factors are also involved in these developments. Intensified construction of long overhead power lines will encounter opposition because of unsightly damage to the countryside, whereas underground cryogenic conductors will have no detrimental effects on the regions through which they pass. This difference may have considerable influence on the extent of use of the two systems.

Developments required and research recommendations. Additional research and development needed for these systems to become fully practical relate to the specific electrical technology utilized. Research programs in these areas are underway, and application of the high voltage DC system is growing.

It is probable that these technologies for long distance power transmission will result in appreciable shifting of power plant locations to regions of water abundance. By 1980 there should be several long DC transmission lines in the United States, and by the year 2000 very long distance power transmission by cryogenic conductors is considered likely. Both of these developments will tend to concentrate new power plants in areas where supplies of water and fuel are abundant and cheap.

d. Oil Shale Conversion to Liquid Fuels

Definition and significance. Very large reserves of oil shale in the central Rocky Mountains are potential sources of gasoline and other liquid fuels. The technology for mining and processing this mineral to yield liquid and gaseous fuels has been developed, and full scale production plants could now be built and operated. Economic factors, however, are not yet favorable to this development; petroleum and natural gas being cheaper sources of these products. As reserves of petroleum are consumed and the remaining crude oil becomes more expensive, oil shale will probably be brought into use as a raw material for motor fuels.

The impact of this development on water demands will not be widespread, but in the region where oil shale is located, mostly in Colorado, Wyoming, and Utah, requirements for water will be severe. In most of the areas where good shale deposits occur, water supplies are very limited. Exceptional water conservation measures will therefore have to be employed in the development of this resource. It has been estimated that if a high degree of water recirculation is provided, a shale oil plant of 100,000 barrel daily capacity would require the withdrawal of 10 million gallons per day, mostly for cooling. A large shale oil complex producing 2 million barrels per day might require about 400,000 acre-feet per year, a quantity greater than can be supplied unless some new sources of water can be found. The potential for water pollution from the shale processing industry is also severe, and effective pollution control measures will have to be provided.

Developments required and research recommendations. Research and development needed for shale oil to become fully commercial are mainly in the direction of engineering progress toward production economies. Several processes are being investigated experimentally, and improved or even new processes may be found. Water conservation and pollution control will need to be incorporated into these further studies.

It is considered likely that by the year 2000, shale oil will be produced in substantial quantity in the central Rocky Mountains. The effect on the national water supply picture will be minor, but the impact in the region where the industry is located will be large. The development of new water supplies such as by precipitation augmentation and long distance diversion may have to enter into the picture. A factor that may delay the introduction of shale oil is the development of economical methods for producing liquid fuels from coal.

e. Advanced Communications Systems

Definition and significance. Today's society is based primarily upon a home-work station relationship with the physical location of the latter dictating the limits on both. A large portion of the work stations presently require an absolute physical presence of the employee. However, an increasing number of work stations could require only highly efficient communications between people.

Developments required. A substantial amount of decentralization has already been made possible by the development of improved multi-channel long distance telephone systems, and this trend can be expected to continue. Those systems will not suffice to provide the "presence" effect of direct person to person communication. Until such presence can be communicated at least as well as voice and flat image, the effects of improved communications on the dispersion of the working force will be limited in its potential for decentralization of governmental and industrial organizational units.

Depending upon the degree to which physical presence (e.g., equivalent of a staff meeting) could be simulated, the development of improved business, industrial and governmental communications systems would permit and perhaps even encourage a much greater rate of decentralization of working units with corresponding major impact on population distribution and regional water requirements. These could involve major increases to the extent that attractive places to live and work might also involve shortages of urban water supplies. On the other hand, shortage of water might also force decentralization of some portions of industry in order to preserve the supplies for investment in non-mobile physical facilities.

Such a new technology can be expected to grow during the coming decades.

f. Central Electric vs On-Site Total Energy Systems

Definition and significance. The present pattern of distribution of energy to domestic and commercial establishments typically involves transmitting electric power from a central generating plant for lighting and electric appliances (commonly including air conditioners) and delivering fossil fuel (oil or natural gas) by truck or pipeline for space heating. This pattern may be altered by either one of two ways: (1) there may be greater reliance on central generation of electric power for space heating, thus eliminating the need for a furnace and hot water or hot air heating system; or (2) there may be on-site generation of electric power, utilizing low-grade waste heat for space heating or absorption-type air conditioning. The latter alternative is known as the total energy approach.

The advantages of central generation of electric power are reduced construction costs and greater convenience and flexibility for users. The disadvantages are higher operating costs and greater vulnerability to central power failure. The advantages and disadvantages of the total energy approach are the reverse.

If greater reliance were placed upon central power generation, the demand for central utility electricity would increase substantially. If all space heating were electric, demand would probably triple present levels due to less efficient use of the heat energy or fuel. Overall fuel consumption would rise and requirements for water cooling would increase correspondingly. Should the total energy system be used, the demand for central utility electricity would decrease significantly from present levels and overall fuel consumption would drop. Water-cooling requirements for central power stations would decrease by about 30 percent.

Developments required and research recommendations. No prerequisites are needed for an increase in the "all-electric" approach. This is occurring now. Improved reliability and systems integration are prerequisite to widespread adoption of on-site generators. Also, electric utilities which are economically powerful would have to accommodate themselves to the new approach (or even adopt it as their own). Before significant advances occur in implementation of this technology, the technical and economic feasibility and environmental impact of the total electric technology must be determined.

The increase of "all-electric" building for large complexes will reach a peak by 1980 and decline thereafter. There will be increased use for individual houses in low-density areas until 2000. Use of total energy systems will increase slowly until 1980 and rapidly thereafter as technical problems are solved and cost of utility electricity continues to rise due to environmental problems.

g. Geothermal Energy

Definition and significance. A storehouse of thermal energy is represented by high temperature rocks lying at varying distances below the earth surface. Where this distance is small this energy is already being tapped for the production of electricity by means of high pressure steam from wells drilled into the formation. Plants are in operation in northern Italy, New Zealand, and in northern California. Another possible use of geothermal heat is for desalting brackish water and sea water, either in a single purpose installation or in a combination water and power complex.

High pressure steam may be obtained directly from wells penetrating the heated rock strata if there is a natural source of underground water in the formation or if water can be pumped down to the formation through injection wells. For power production alone, use of this source of energy could increase water requirements in the geothermal region, mainly for cooling as in power plants employing conventional fuels. If suspected geothermal sources in the western and southwestern United States are developed in this way, water conservation by recirculation will probably be necessary. In comparison with the quantity of power generated by use of conventional and nuclear fuels, this geothermal source will probably remain small.

Another potential use of geothermal heat is in water desalting. Salt water, from the sea or from brackish ground water sources, would be pumped into the hot rock strata, from which it would return through wells to the surface in a super-heated state. On relieving the pressure, part of the heated salt water would evaporate, or "flash" into steam, which could then be condensed to pure water. If the steam, at adequate pressure, were passed through a turbine prior to condensation, power would be obtained in addition to pure water. The remaining brine could be returned to the ground for reheating, a portion being discarded to prevent salt accumulation.

Developments required and research recommendations. The technology of deep rock drilling, with conventional rotary tools or with "heat" drilling to melt or spall the rock in the well, is important to the successful development of this concept. Fracturing of the heated underground zones by conventional or nuclear explosives may also be involved.

Additional research and development will be required to improve the technology of well drilling into formations of this type. In addition, considerable research will be required on the characteristics of concentrated saline solutions at high temperatures and pressures, with particular attention given to solubilities of the common saline water constituents and the separation of salt and water as pressures are reduced in various cycles.

Assuming a directed program for this purpose, geothermal power and desalted water at reasonable costs might be achieved in twenty years, but sufficient work to demonstrate feasibility could be accomplished in ten years. Practical use might follow the schedule for development of other commercial desalination processes, with fully operational systems within twenty years.

h. Regional Environmental Management of Bays and Estuaries (Research Priority, 1)

Definition and significance. The flows of major United States' rivers are increasingly controlled by expanding state and regional water plans that include construction of large numbers of dams. Within the river system there is increased consumptive use, increased evapotranspiration, increased pollution, and decreased flow to the terminal bay or estuary. This results in increased salinities in the estuary and a deleterious effect on the estuarine food chain and the food production capability of the estuary. It is desirable to insure a controlled optimum flow of fresh water to the estuary. Fresh water used to maintain the salinity of the estuary within certain limits may produce more food than the same amount of water used for irrigation. The questions arise: What is the value of fresh water used in this way, and what minimum flow of each major river should be reserved to the bay or estuary system?

There appear to be two alternatives: (1) The regulation of fresh water flows to "wild" estuaries to avoid extremes of hyper-fresh and hyper-saline conditions and thereby to improve survival of wild species in estuarine nursery grounds; and/or (2) The carefully controlled distribution of fresh water to and within the estuary in developed mariculture.

Developments required and research recommendations. Development of mariculture technology depends on the economic advantage of maximizing bay and estuary productivity. Economic feasibility remains to be demonstrated. Depending on successful experimentation, control mechanisms already in effect on the river system for flood control and reservoirs, and institutional decisions on water allocations, widespread use of mariculture is 20-30 years in the future.

The potential scope and impact of this concept on water supply and demand is extremely difficult to evaluate. The further establishment of regional authorities for rivers, bays, and estuaries is very important in order to develop the necessary multiple-objective planning and management capabilities required for the control and protection of the total water system under consideration. Many commercial and sports interests, as well as municipal and industrial requirements must be considered along with improvements in systems planning and management capabilities. Primary research on ecological balances and sensitivities to environmental changes in rivers and estuaries as well as study of water-use patterns are needed. Significantly, the greatest needs are changes in thinking, planning, and water use patterns as well as the myriad institutional constraints already imposed on estuary terminating rivers.

i. Vegetation Management
(Research Priority, 2 -- research in progress)

Definition and significance. Vegetation management for purposes other than water harvesting may change water demands or water supplies by affecting the amounts of water yielded, by changing the timing of water yield with respect to other area demands, or by affecting the usability of water yielded to downstream users. Water supply may be affected by vegetation management changes ranging from a simple change in crop rotation on agricultural land to clearcutting of an entire forested watershed. This discussion is confined primarily to the effects of water supply and/or yield resulting from change in vegetation characteristics, vegetation type, or vegetation environment.

The rise and decline of many civilizations is said to have resulted largely from their vegetation management. For example, the decline of civilization in the countries around the Mediterranean resulted largely from denudations of watershed lands by goats. In this country the breaking of the prairie and resultant dust bowl is an obvious example. Not so obvious, but perhaps more crucial to future water supplies and demands, is management of the present vegetation and the application of vegetation management as a tool of water supply management.

Developments required and research recommendations. Several developments might bring about significant differences in the use of water vegetation:

(1) Low water using vegetation suitable to forest and brushland sites might be discovered. For some soils a shallow-rooted grass vegetation has shown promise. Exploration may show that some species, such as relatives of the pineapple, may have very low water use and yet be adaptable to sites where current water use is high.

(2) The defoliation of all or part of trees or brush stands may reduce water losses during critical periods of downstream water demands. However, some defoliators may have adverse affects on other forest values, and thus be unacceptable.

(3) Application of more effective cutting patterns of forest, type conversions of brushlands, and vegetation management specifically aimed at a particular desiderata of water supply or water amount and quality control may be expected from future research results. It is now evident that natural vegetation types are using much more water than had formerly been thought. It follows that management may be devised to reduce this water use and result in saving of water beyond present expectations.

Since vegetation management is both a threat and a promise with regard to important aspects of water supply, the impact of each vegetation management technique on the water supply must be known. To determine these requires research beyond the present general guidelines for vegetation management.

B. TECHNICAL DEVELOPMENTS WHICH SHOULD INCREASE USABLE SUPPLIES OF FRESH WATER

Introduction

There presently exists in nature polluted water (including naturally saline and degraded waters) and unpolluted water. Within limits, however, both have economic usefulness. The technical developments discussed in this section address the current state of usable fresh water supplies from two points of view: developments which will make new sources of fresh water available where needed; and developments for the conservation of existing fresh water sources. New sources of fresh water are obtained through developments which alter the hydrologic cycle in controlled ways, developments which create fresh water from salty or polluted water, or developments which transfer and store water so needs can be met. Developments treating the conservation of existing fresh water sources are approached with concepts which improve the management of hydrologic processes such as the reduction of evaporation from lakes and reservoirs, control of phreatophytes, and watershed modifications.

1. BY MAKING NEW SOURCES AVAILABLE WHERE NEEDED

a. Desalting of Seawater and Brackish Water
(Research Priority, 1 -- research in progress)

Definition and significance. Substantial progress on several fronts in desalting technology is gradually improving the prospects of application in regions of fresh water scarcity and salt water abundance. Most of the developments are improvements in known processes, but technical breakthroughs leading to new processes and major cost reductions may still be possible. Either the steady improvements or the breakthroughs will certainly result in increased desalting operations and fresh water replacements.

If the cost of desalting can be reduced to around 25 cents per kilogallon, there should be a large impact on most areas where salt water is abundant and fresh water is scarce. Although not as cheap as most fresh water supplies, water at this price would be competitive with some municipal and industrial supplies. Since the cost of new fresh supplies is steadily rising, future use of desalted water would be intensified. Present desalting costs, at the one million gallon per day capacity now frequently used, are about one dollar per kilogallon, and designs for much larger plants indicate cost in the 40 cent vicinity. Some of the situations in which desalted water will probably find increased use are:

a. Locations where economic activity is required but no suitable alternative fresh water supplies exist.

b. Locations where the quantity of water required is too small to justify long distance transport.

c. As a means of temporarily deferring investment in surface transport systems during demand buildup stages (5 - 15 years).

d. As an insurance source, thus increasing the "firm" capability of a supply exposed to drought.

e. As a means of verifying the economic viability of virgin areas to be developed (even though cost of water is not covered by productivity at the lower use levels).

Multiple purpose systems involving water desalting may also become significant. The combination of large nuclear power stations and salt water evaporation plants offers cost advantages over the separate facilities. The possibilities of profitable by-products, aquaculture, utilization of waste heat, and so on, may enhance the economic potential of the system.

Developments required and research recommendations. The developments most likely to bring about increased water desalting are improvements and modifications in evaporation processes, reverse osmosis systems, electrodialysis equipment and materials, and possibly freezing processes as well as significant reduction in energy costs. More durable equipment, large unit sizes, methods for increasing output per unit of energy required, and automation techniques should continue to receive major attention. Multipurpose plants providing water, power, and possibly food production and recreation through related facilities may be envisaged. Effective and economical methods for disposal of brines from inland desalting plants must also be developed. Substantial effort is being devoted to these problems, and such work must be continued if desalting is to become a significant factor in those areas where it can be theoretically applied.

Although desalination by numerous processes is already feasible, research on possible new methods or major modifications in existing methods might lead to large reductions in the cost of water desalting. This type of research is therefore needed if all alternatives are to be considered.

In ten to twenty years, there should be numerous desalting installations in the southwestern coastal regions. Brackish water desalting in inland areas will probably not develop as rapidly, mainly because of the brine disposal problem. If that difficulty can be economically dealt with, moderate sized plants in many locations in the western United States may be envisaged in twenty years.

b. Compact Water Desalting Units for Residential Use (Research Priority, 4)

Definition and significance. Although most of the development effort is concentrated on large-scale desalting facilities for communities and cities, there is some effort to develop individual household-size units for use in situations where saline water might be distributed to family units or where dwellings are located in rural areas having only saline water sources. Rural use is considered the more likely because it would usually be more economical to have a large central desalting facility in a municipal system than to distribute salt water to each household with its own small purification unit. An exception might be the situation in which only saline water would be distributed throughout the community, each residential unit then purifying only the small fraction of the water needed for drinking and cooking. Sanitary uses could be met by the saline supply.

Utilization of these individual desalting units will probably not be great enough to significantly affect the national water supply situation. The availability of small desalting devices, some already developed and others potentially practical, could open up settlement in rural areas now undesirable because only brackish water is available. To a considerable extent, this development would resemble the application of water softeners in individual homes, now common in hard water areas.

Developments required and research recommendations. Research and development efforts appear to be of only marginal need and influence in this application. Equipment already exists for this use, and although cost reductions can probably be achieved by additional investigation, incentives for such action are generally limited to the suppliers of the equipment itself.

Some units are already in use, and it may be expected that during the next 10 to 30 years, there will be increased application of these home water desalting units. Effects on the water supply and demand nationally will probably not be significant in the foreseeable future.

c. Precipitation Increase Through Cloud Seeding (Research Priority, 2 -- research in progress)

Definition and significance. It may not be possible to augment storm snowfall in mountain areas of the west by introducing ice nucleating particles into the atmosphere. An increased snowfall of 10 to 20 percent is indicated. This represents valuable water storage which will probably be depended upon in the decades ahead. This technology, however, applies mainly to storms already generated by natural causes. When the number and intensity of storms is reduced as is characteristic of drought years, augmentation during the snow season will not likely be effective and will not decrease the natural precipitation variability.

Developments required and research recommendations. Despite optimistic claims, several long series of tests have demonstrated that artificial nucleation has no noticeable effect on summer rainfall. The explanation of this is complex, but it is related to the sporadic showery nature of summer rains, the rapidity of cloud build-up and intense cloud energy, and the lesser role of ice nucleation.

Even if some unanticipated technology should develop in the next decades, the first requisite is the presence of clouds. Drought periods are notable for their absence of clouds.

The potentialities of this technology have been reported on by the NAS Committee on Atmospheric Sciences. The tone of the report is one of cautious optimism. It is difficult to foresee the development of technologies that will augment precipitation significantly more than is being done at present. Research should be continued to improve the techniques which could augment snow storage in mountain areas. If an important breakthrough should occur in this research, it could have far-reaching effects.

d. Long-term Seasonal Precipitation Forecasting
(Research Priority, 3)

Definition and significance. California and the adjacent deserts are deficient in rainfall because they are under or downwind from one of the great atmospheric sinks represented by the Pacific anticyclone. (Other such areas characteristically on the western margin of continents include North Africa extending into the Middle East, Southwest Africa, most of Australia and western South America.) Rainfall is mostly confined to the winter season, but varies considerably from one season to the next. Since the Pacific Ocean is a major winter heat source, the circulation of a large part of the atmosphere is driven or influenced by the temperature differences between the heat sources in the Pacific and the heat sink of the winter-chilled continents. It may be possible to predict West Coast winter precipitation by examining temperatures in the tropical and subtropical Pacific, although this is admittedly a simplified picture. Rainfall comes as a result of major disturbances in the general circulation which are only loosely tied to the thermal distribution. Perturbations in troughs break up the subsiding Pacific anticyclone.

The value of accurate long range precipitation forecasting is obvious. Normal water supply, planning and management decisions, as well as flood forecasting would be measurably improved. Arid region agricultural programs could be modified to suit the expected conditions. Accurate long-term precipitation forecasts would dictate water use, availability, and reservoir management decision. The impact of this technology will greatly affect water use patterns and planning trends along the western margin of continents.

Developments required and research recommendations. Numerous technological breakthroughs will be needed before long-term forecasting can be trusted. Research on applied statistical and numerical methods for evaluating discrete perturbations in the overall thermal and atmospheric patterns is needed. Vastly improved observational and real time relay methods are also prerequisite to accurate long-range precipitation forecasting. International scientific cooperation will be required for comprehensive observations.

The Global Atmospheric Research Program now underway among the nations of the world is expected to provide numerical methods for predicting the general circulation. The progress being made suggests that within the next decade or so useful forecasts applicable to water management will be made.

e. Augmenting Fog Drip
(Research Priority, 4)

Definition and significance. When low lying clouds or fog intercept the earth's surface, condensation of water occurs, and the ground and covering surfaces become wet. This phenomena has variously been called horizontal precipitation, cloud interception, or fog drip. Such interception occurs naturally in several places of the world, including the famous Green Belt in the desert-like climate of coastal Peru and the coniferous forests along the coastal shores and mountains of California and Oregon.

Developments required and research recommendations. The prototype planting of Norfolk Island Pine on a cloud swept ridge on the island of Lanai in Hawaii suggests that vegetation management might augment the water received as fog drip. On Lanai 100 acres of planted trees are intercepting an additional 400 acre feet of water each year -- enough water to supply supplemental irrigation to several thousand acres of pineapple plantations in the neighboring valleys. Other development possibilities using fog drip include planting crops under trees so the crops could utilize drip water, or using impervious surfaces under trees to collect fog drip water for delivery to crops. Additional research would be required to test the most effective trees and other vegetation for collecting and using fog drip and to test other methods of intercepting fog. If, for example, electrical charges could be induced on the fog particles different from the charges on the receiving surfaces, more efficient condensation could be obtained. If coalescence could be initiated by chemical seeding, for example, condensation on the trees might be more efficient.

Although the total impact may be small, the feasibility of developing additional water supplies in certain areas utilizing fog drip has already been demonstrated. The full development of its use, however, will require another 20 years of research and development.

f. Artificial Ice Fields
(Research Priority, 4)

Definition and significance. Water may be stored as artificial glaciers by creating masses of ice on or beneath the surface soil to meet the demand for water in seasons when normal streamflow is low but water demand is high. Such ice fields could be created by utilizing the cold winter air and radiation to the winter sky to freeze water stored in reservoirs or diverted from streams.

The yield from mountainous watersheds in the western United States does not coincide with the peak demand seasons. Year to year holdover of water in reservoirs utilizes space which might serve to store additional water if a means of auxiliary storage of reservoir water would be devised. One such method would be to release the water from reservoirs on winter nights and spray it on shaded terraces on northern slopes. The water would freeze as it falls, forming an ice field. In the late spring and early summer this ice would melt slowly, supplying water for downstream use when streamflow is at a minimum. Such accumulations of ice occur naturally under waterfalls. Deliberate flooding of frozen lakes has also proven effective in storing water in the frozen form.

In areas where summer water supplies are deficient or in years when a deficit in water supply could be crucial, water could be stored in reservoirs and then released to create artificial ice fields. In effect, this would afford year to year hold-over capacity in reservoirs which might normally be able to store only single year supplies.

The use of the ice in these artificial glaciers to offset thermal pollution is one of the benefits the water derived from these ice fields offers. Thermally polluted water introduced directly to the ice fields could be effectively cooled. The artificial glacier concept might find dual use in both late season water supply and control of avalanching, either as check dams in the snowfield or by forming ice dams to slow or divert avalanches. They may also be used to offset adverse effects on soil surfaces by creating artificial icebergs in lakes or reservoirs.

Developments required and research recommendations. Care would have to be taken in the selection of sites for artificial ice fields to avoid damaging aesthetic values, significant and unique environments, or aquatic habitats. Conjunctive planning of reservoir locations at high elevations and design of reservoir capacities including artificial ice fields as part of the design capacity might be considered.

Technique and procedure tests will have to be made before the creation of artificial glaciers becomes feasible. Considerable investigation of present and future sites for application should be preceded by basic studies of the heat budget for the creation and management of ice fields. Studies of the effects on the local environment and downstream aquatic habitats is likewise required.

Studies for utilizing the ice in offsetting thermal pollution -- to bring the ice to the plant (say as a crushed ice slurry) or to bring the thermally polluted water to the ice fields -- are needed. The first means seems more efficient since cooling water could be recycled almost indefinitely.

The impact of creating artificial ice fields on future water supply will probably be small and highly location-dependent.

g. Deliberate Snow/Ice Avalanching
(Research Priority, 4)

Definition and significance. Water can be stored in deep snow piles by deliberately avalanching selected snow fields. Snow in these deep piles would melt slowly and yield water late in the spring to meet increased water demands or replenish reservoir storage.

As much as 10 to 15 percent of some high mountain areas consist of avalanche paths, some of which do not avalanche with any consistency. It may be possible to deliberately induce avalanching repeatedly at selected sites, resulting in massive amounts of snow piled up at downhill terminal sites.

Advantage could be taken of the reduced area of large amounts of snow at the terminal site by applying snow melt retardants to further delay the melt and prolong the water yield. Snow melt retardants such as albedo augmenters or insulators might then prove to be economically feasible.

Care need be taken that the avalanche snow is not situated in an area so warm that the total melt rate is faster than at the unavalanched site. It is likewise necessary to insure that the avalanches do not block live streams, or cause temporary lakes with subsequent flood surges and downstream damages. Also, snow avalanche paths frequently become paths for torrents, so torrent control may discourage perpetuation of avalanche paths by deliberate avalanching.

Developments required and research recommendations. Although some techniques of deliberate avalanching have already been worked out, additional developments will be needed before deliberate avalanching for water storage will become feasible. More importantly the heat and water budgets of snow piled up by avalanching will have to be thoroughly explored in order to permit prediction of the most effective areas for avalanching and the water supply conditions under which avalanching would be desirable and economically feasible.

Widespread use of deliberate avalanching to augment temporary storage of water is location-dependent, and the probability of its use is low. However, within 10 years the prospect of delivering prolonged yields of cold water from such treatments may make the technique locally feasible in offsetting adverse thermal quality in streams.

h. Melting of Ice Caps to Create Lakes
(Research Priority, 4)

Definition and significance. There are sufficiently large enclosed basins of ice of considerable depth, which, if melted, would create lakes for water storage. In theory, a nuclear plant generating electrical energy might be installed in a polar region where heat could be released for melting ice, thereby avoiding thermal pollution. If economically feasible, the electric power could be transmitted over great distances, and the water conveyed to storage in reservoirs on land to increase the water supply for long-distance transportation to international and national water systems.

Developments required and research recommendations. Techniques exist for melting ice caps. However, feasibility studies must first be undertaken by engineers and meteorologists to determine the environmental effects of a massive ice melt, and whether it might add sufficient volumes of water to circulation in the hydrologic cycle to increase the volume of the oceans and inundate coastal areas. Economic feasibility must also be examined to determine whether there would be sufficient capital incentives for acquiring ice reserves.

i. Iceberg Towing
(Research Priority, 3)

Definition and significance. Iceberg towing would involve capturing or quarrying floating icebergs and towing them to a suitable offshore point where they could be broken up into manageable pieces (perhaps by means of explosives). The fragments would be hauled onshore by means of a continuous conveyor belt or some other system. The bulk ice would then be granulated and utilized either for cooling large power plants or large central air conditioning plants, such as the New York subway system. Water from the melted ice would be added to the municipal supply. In a humid area, the melting slush would theoretically condense additional moisture from the air, to augment water yield.

Iceberg towing might be significant for certain large cities, particularly Boston, Long Island, New York City, and Philadelphia in the

East, and possibly the Los Angeles basin. From the economic standpoint, the "cooling" value of the ice may exceed the value of the water per se.

Developments required and research recommendations. This technology is non-existent in practice, although the problems do not appear insurmountable. A technological and economic feasibility study is prerequisite to development. Technological research and development could be undertaken later if the results of the feasibility study were sufficiently promising.

The institutional responsibility here is very unclear. To successfully implement such a scheme would undoubtedly require collaboration among many diverse organizations.

j. Collapsible Bladders for Transport of Liquids (Research Priority, 3)

Definition and significance. Petroleum products can be transported through waterways and the sea by using very large water-tight bags or bladders fabricated from strong sheet materials of reinforced synthetic rubber or some types of plastic films. The folded or rolled empty bladder is moved to the point of loading, partially immersed in the waterway, loaded with the liquid to be transported, and then towed by ship to its destination. It can then be pumped out, collapsed, and returned for reuse. Quantities exceeding 100,000 gallons could be readily transported in this way. This method could also be used for transporting fresh water. Very large bladders could be loaded at the fresh water source, perhaps at a river mouth, and towed to cities or industrial users located on tidewater or navigable inland watercourses where fresh water supplies are scarce.

Developments required and research recommendations. Research and development efforts required to make this transport system feasible include the designing of bladders of materials which are durable and strong as well as economical and serviceable. Hydrodynamic factors and towing vessel design would also be important considerations. Operational and economic studies will be needed to appraise the usefulness of this method for supplying water in specific locations.

The materials necessary for implementing this technology already exist. Water towing will probably not be extensively used unless other techniques for augmenting water supply were to fail or become excessively expensive. It may, however, provide a water source competitive with desalted water, or with water transported over very long distances by pipeline.

k. Underseas Aqueducts
(Research Priority, 3)

Definition and significance. Very large quantities of fresh water could be transmitted for long distances to serve coastal cities and adjacent inland areas using underseas aqueducts. Since fresh water has a lower density than salt water, salt water will support a buoyant fresh water aqueduct. Foundation problems are thereby limited to the simple problem of holding down the aqueduct. The density of the sea water also acts to reduce the strength required to withstand the pressures required to produce flow.

In principle, a large diameter flexible or semi-rigid plastic pipe could be laid from a specially designed vessel, leading from a pumping station near the mouth of a river such as the Rouge or the Columbia, along the coast on the continental shelf to its destination. Additional pumping stations can be provided along the route as needed.

Taking fresh water at the mouths of the great rivers of the Northwest after all local uses have been met has considerably more political feasibility and a higher chance for environmental quality acceptance than upstream diversion and the construction of surface aqueducts, pumping stations, etc. On the basis of materials needed, such an aqueduct should be substantially less expensive to construct and, unlike its surface counterpart, might be retrieved and installed elsewhere.

An extension of undersea aqueduct technology to provide either large-size submersible pumps capable of operating in a high pressure environment or rigid low cost pipelines could permit drawing deep cold ocean water for cooling purposes, discharging it at or near ambient surface temperatures. Thermal efficiencies of steam generating systems could be increased. A further application could be the controlled updraft of nutrient rich deep ocean waters to produce major new fisheries. Control of nutrient updraft would permit a optimum balance between photosynthesis and the higher food chain elements as a function of season, light availability, and water temperature.

The injection of water provided by waste heat into deep cold layers would result in both mixing and thermal updraft. By using a specially designed flexible or rigid wall channel from the point of discharge to a point 50 to 100 feet below the surface the warm water could activate a low velocity high volume "jet" pump to accomplish the controlled nutrient updraft without conventional pumping systems. In either event the result could be highly productive controlled fish protein production not subject to the vagaries of natural nutrient upwelling.

It may be anticipated that underseas aqueducts of this type may first be developed for use for deep ocean outfalls for the effluent of municipal and industrial waste treatment plants along the coast. Properly designed and placed, they could enhance rather than harm the environment for marine life. This use would provide a beneficial market for experimental development in the early stages.

Developments required and research recommendations. Underseas aqueducts will require a number of technological developments and considerable basic and applied research. An entirely new technology will be required for the placement of the pipe. The manufacturing technology might also prove to require further development for the sizes and wall thicknesses that will be required. Anti-fouling characteristics of the material will be required. For long systems such as this, techniques for welding joints will be required. The possibility of extruding the plastic continuously from the mother ship exists, in effect a mobile pipe factory.

Techniques for crossing the many submarine canyons need to be developed. Perhaps the pipe could be floated across as an "inverted suspension bridge." The possibilities of damage by sea animals must be evaluated. Methods for locating leaks or breaks and for making rapid repairs will need research and development. Thought would have to be given to problems of security of the aqueduct from enemy action in the event of a war.

Approximately twenty years would be required to bring the development to a 1000 mile long, 2 million acre feet per year system. Within 10 years, however, enough experience could be obtained to evaluate the potential of much longer systems with much larger capacity.

l. Offshore Reservoirs
(Research Priority, 4 for bladders, 2 with environmental considerations for dams)

Definition and significance. Large fresh water reservoirs can be created in ocean water near major centers of water use, utilizing techniques similar to those for underseas aqueducts (see B-1-k). The offshore underwater reservoir would provide a means for coastal cities with combined sewers to hold the flood discharges in a sanitary, inoffensive, non-polluting way until they could be processed through a waste treatment plant (see B-2-c). Elsewhere they could also be used to temporarily store fully reclaimed effluent from waste treatment systems until these waters could be recycled. Many waste treatment plants near the ocean have no satisfactory reservoir sites in the vicinity. The use of such reservoirs as afterbays to aqueduct systems will also be possible in cases where reservoir sites are inadequate or land is too costly for this purpose. Its use as a terminus of an underseas aqueduct is readily apparent.

These reservoirs might take two forms depending on whether the ocean surface can be reserved for the exclusive use of the reservoirs or not. If such reservation is possible and enforceable, the fresh water reservoir can be floating. In this case the technology would consist of the construction of a very large balloon of flexible but fairly thick walled plastic or impregnated fabric. The balloon would expand when filled and be collapsed by the weight of the sea water when empty. By making the material denser than sea water it will sink to the bottom when not in use and float when filled.

Developments required and research recommendations. A submerged fresh water reservoir will require sufficient ballasting (perhaps with sand) to hold it down when completely filled. This represents a much more difficult technology, but the reservoir could be located so as to avoid practically all interference with ocean surface uses.

Obviously there will be major fabrication problems associated with offshore reservoirs of large capacity. Installation technology will also be more difficult. Protection against accidental damage and in-place (submerged) repair techniques are additional problems. Much of the research and development needed, however, can be combined with that required for underseas aqueducts.

The technology for offshore reservoirs could become available in 20 to 40 years depending on the level of effort provided. It should be approximately coincident with medium scale, medium distance underseas aqueduct technology.

m. Large-scale Canal Systems to Carry Water from Regions of Surplus
(Research Priority, 2 -- with environmental considerations)

Definition and significance. The technology of large-scale interbasin transfer of water to arid regions generally involves scaling-up of well established pumping, storage, and aqueduct systems to move water from basins of origin to basins of use, often with significant amount of power recovery. Recent proposals range from one which would transfer 2.5 million acre-feet per year from the Snake River to the Colorado River to another which would transfer Yukon waters to all parts of North America in amounts upward of 100 million acre-feet per year. The scale of the proposals is generally far above any currently operating systems. Large-scale implies the possibility of ecological impacts which have not been experienced in smaller systems and which are difficult to predict.

The major attainment of these projects would be to permit the continuation of past patterns of economic expansion of the arid and semi-arid areas of the western United States. This would mean a continued heavy reliance upon irrigated agriculture with as much as 90 percent of regional consumptive water use by field crops. In a few instances, large-scale importations could prevent the eventual decline of irrigation areas where economic viability is dependent mainly upon agriculture and agri-business. Whether or not the public sector has a responsibility to undertake these projects is an important policy matter not yet determined.

Another possible advantage of large-scale interbasin transfers could be the expansion of inland barge or even ship transportation. Projects of this scale would, however, very likely have serious ecological and environmental drawbacks.

<u>Developments required and research recommendations</u>. The technology required is currently available, although there is some uncertainty about problems of pump and turbine design in sizes far in excess of present scales. The conditions required to make large transfers attractive are largely economic and political, since vast amounts of subsidy would be required in one form or another. Considerable ecological research would be a prerequisite of any large transfer project.

Present agricultural and water policies highly subsidize irrigation agriculture through price supports for commodities and the pricing of water far below its cost. If these policies are continued, western irrigation will continue to use a very high proportion of available supplies. Expanding urban and industrial activities will experience increasing difficulty in obtaining supplies of water. Regional political pressures will continually mount for federally subsidized large-scale transfers into the southwest. Some intra-United States transfers could be started within a 20 to 40 year period.

The adoption of economically more rational agricultural programs, the pricing of water closer to cost, and improved ways of handling the sale of existing water rights would greatly increase the efficiency of current water use. The political feasibility of maintaining large price and water subsidies for agriculture is likely to diminish in the future, and it appears likely that agriculture will be put on a free market basis. It is possible that as much as 1/3 of the water currently being used in irrigation in arid areas will become available for sale to expanding municipal and industrial uses. Should this occur, there would be little pressure for transfers with the possible exception of the "rescue" type of operation in areas solely dependent on irrigation agriculture.

n. Nuclear Explosives for Canal, Tunnel and Reservoir Construction
(Research Priority, 4)

Definition and significance. It is now possible to construct very large surface and underground hydraulic works at low cost by the use of nuclear explosives. Excavations by use of nuclear explosives can be made at costs far below conventional methods and made many times larger than those of conventional structures. The blasting of reservoir sites (throw-out craters), the excavation of very large canals, and the construction of tunnels by phased charges are all possible applications of nuclear explosives. Utilizing such structures, large quantities of water could thus be made available in areas where needed. Interbasin diversion and even international transfers of water could similarly be accommodated. The importance and value of the concept of using nuclear explosives is tied to the economics of nuclear devices and the great magnitude of energy available for useful work.

Developments required and research recommendations. Although nuclear craters have already been used as reservoirs in the Soviet Union and conceptually employed in the United States, technological breakthroughs are still required to minimize the amount of environmental contamination from explosion-produced radioactivity. Radiation containment will involve research on device shielding and radiation entrapment within the explosion zone. Research along these lines indicates that boron and cadmium shielding and clathrate stemming can all be used to minimize the radioactivity distributed to the environment. Additional side effects associated with the nuclear method include the seismic responses from the explosion and the air blast associated with a near surface detonation. Seismic responses will require proper site selection and institutional arrangements to allow such uses within certain distances of metropolitan areas. Air blasts can be minimized by firing on meterologically safe days.

Since 100 to 300 years are required for decay of radioactivity associated with nuclear detonations, their use requires long-term planning, which will take into account their irreversible effects. The containment of radioactivity, however, may minimize this problem. The probability of the technology being utilized and having a large impact on water resources will be determined by the state of the technology, treaty restrictions limiting its use and public concern over avoiding radioactive contamination of the environment.

o. Service Tunnels in Urban Areas for Electric Power Distribution, Sewage, Water Services, and Storm Drainage
(Research Priority, 4)

Definition and significance. The use of service tunnels in urban areas to house all utilities would provide easy access for locating leaks and repairing or laying in new services. Electricity, water, telephone, cable TV, sewerage, steam for heating, airconditioning, and possible systems for solid waste disposal could be placed in the tunnel. With appropriate protections for these installations, the tunnels could also be used to convey storm runoff. They could be utilized to provide additional storm sewer storage capacity which would alleviate urban flooding, temporarily store storm runoff, and possibly be utilized in other programs for channeling runoff into storage for future use. At present, most utilities are distributed through entirely independent systems which are generally underground or on utility poles. This practice is quite inefficient, imposing high access costs for repairs, damaging other utilities during repairs, creating unsightly operations, and imposing high costs through disruption of traffic.

A recent study for the National Water Commission estimated that 12 percent of total urban water production is lost annually through leaks (940 billion gallons in 1965) and that 9 percent of total production could economically be saved through leak detection and repair programs (about 786 billion gallons or 2.4 million acre feet as of 1965 of water already captured, transported, treated, and distributed).[14] At least 50 percent of existing losses occur through cracked mains and blown joints which could be quickly detected and easily repaired if the line were located in utility tunnels.

Developments required and research recommendations. The major technological development required is cheap, fast methods for tunneling. Large advances are being made in this direction, but additional research and development are necessary. In new areas, the service tunnel scheme could easily be installed, but in established areas the problems of existing utility systems, existing building foundations, and reluctance to change must first be overcome.

Even if water services were combined with other utility services in utility tunnels resulting in some economies of scale and reducing water loss due to poor maintenance, this would probably have no direct impact upon water consumption or demand.

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[14] Charles W. Howe, Clifford S. Russell, and Robert A. Young, Future Water Demands: The Impacts of Technological Change, Public Policies, and Changing Market Conditions on the Water Use Patterns of Selected Sectors of the United States Economy, 1970-1990, a study for the National Water Commission by Resources for the Future, Inc. (Washington: June, 1970), 120 pp. Available from Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia.

2. BY CONSERVATION OF EXISTING SOURCES

a. Evaporation Reduction from Lakes and Reservoirs (Research Priority, 2 -- research in progress

Definition and significance. Large losses of water from lakes and reservoirs reduce the quantities of water available for use, particularly in the drier western sections of the country. Solar energy and advected atmospheric heat can provide sufficient energy to evaporate several feet of water per year in dry, sunny regions. Some success has been achieved in reducing this loss by use of small amounts of certain chemical compounds as very thin films on the water surface. This chemical film may be visualized as a coating which reduces the actual contact between air and water.

Evaporation losses from reservoirs might be cut in half if it were possible to obtain a high degree of coverage of large water surfaces with evaporation suppressants such as hexadecanol. Water savings in the West alone could be in the millions of acre feet per year. The impact of this development could thus be extremely large. There would probably be little advantage in the use of such techniques in the eastern part of the United States where net evaporation losses are small.

Developments required and research recommendations. Very limited success has been obtained to date by use of evaporation suppressants on comparatively small ponds and lakes. Difficulties in maintaining film coverage have decreased the effectiveness of this technique on large bodies of water. New research and developments which could aid the full realization of this concept would include such things as more effective new compounds, new techniques for spreading and maintaining the chemical on the water surface, and particularly, materials which would reflect a large fraction of the incidental solar energy. Possible problems and undesirable side effects of this technique would also have to be avoided. There could be an increase in water temperature which partially offsets the evaporation-retarding effect of the suppressant and possibly changes the ecology of the lake. Toxic effects of the chemical would have to be completely avoided, as well as any aesthetic problems which the thin chemical film might create.

Other proposed techniques for reducing evaporation involve the suppression of surface temperature rise by using air bubbles or pumps to mix the warm surface water with the colder water below or by skimming off the warm surface layer and discharging it to the streams. Studies along both lines could have important benefits if successful.

The prospects for widespread application of evaporation reduction methods in water conservation do not appear particularly favorable at present or in the near future primarily because of the difficulties mentioned above. Although concerted research and development effort has been devoted to these problems, it appears that some new ideas will have to evolve before significant application of evaporation control methods on reservoirs and lakes occurs. Perhaps in a 10 to 20 year time period, this technology could be developed to its fullest potential, but the extent of its ultimate use is virtually impossible to predict.

b. Phreatophyte Control
(Research Priority, 1 for biological controls, 2 for chemical controls)

Definition and significance. Phreatophyte control involves the elimination or reduction of plants which grow on or near watercourses and which tap underground water storage in arid areas. Juniper, salt cedar, mesquite and chaparral cover vast areas of river bank or cover shallow aquifers in the arid areas of the western United States. These plants have high rates of evapotranspiration, their root systems are generally able to penetrate to great depths to tap groundwater sources, and they have no beneficial use beyond the harboring of wildlife.

The Senate Select Committee of 1960 estimated that phreatophytes transpire 1.2 million acre-feet per year in the Lower Colorado Basin alone, while the Geological Survey has estimated that the West loses 6.1 million acre-feet per year from salt cedars alone. When water budgets are prepared for various areas, particularly the arid areas, it becomes clear that one of the major water losses is through transpiration from vegetation which has no direct economic value. If phreatophytes could be eliminated, a direct saving of water would result in increased runoff and streamflow.

T. W. Robinson (1952) estimated that these non-utilitarian water consuming plants covered 15 million acres in the 17 western states and wasted from 20 to 25 million acre-feet per year.[15] Van Hylckama (1966) estimated a total loss of 24 million acre-feet per year in the semi-arid zone of the southwestern United States.[16] Much of the loss is from salt cedar (Tamarix) which T. W. Robinson (1965) has forecast to cover 1.3 million acres by 1970, with consumptive waste of groundwater rising to 5.0 million acre-feet by 1970.[17]

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[15] T. W. Robinson, "Phreatophytes and Their Relation to Water in Western United States," Transactions, American Geophysical Union, 33 (February, 1952).

[16] T. E. A. van Hylckama, "Effects of Soil Salinity on the Loss of Water from Vegetated and Fallow Soil," International Association of Scientific Hydrology, Proceedings of the Wageningen Symposium, June, 1966, pp. 635-644.

[17] T. W. Robinson, Introduction, Spread, and Areal Extent of Saltcedar (Tamarix) in the Western United States, Geological Survey Professional Paper 491-A, Washington, D. C.: U. S. Government Printing Office, 1965.

How much of this water could be saved economically is not known, but Robinson (1952) estimated that in Nevada, 25 percent probably could be.[18] To date efforts to suppress phreatophytes have been costly, and the ecological effects of different suppression techniques have not been evaluated. Clearly, much additional research is called for by the large water-saving potential.

Experiments by the Forest Service in cooperation with the Salt River Valley Water Users Association (Arizona) have shown increased runoff of 0.2, 3.0, and 24.0 acre-inches per acre per year as a result of the eradication of juniper, chaparral, and other riparian vegetative types, respectively, as well as increase in stream bank erosion. Indicated costs of the above control programs are roughly $57, $26, and $2 per acre-foot of water, respectively.[19] Most efforts, however, have been costly and only partly successful.

Developments required and research recommendations. Methods of phreatophyte control include physical destruction through burning, chaining or cutting, deprivation of water through diversion of streamflow or lowering of the water table, and the application of herbicides and defoliants. Additional research is needed to increase the effectiveness of present phreatophyte removal programs and for the development of new methods.

Inexpensive biological controls are needed to avoid the repetition of costly programs of physical destruction. Research should be intensified

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[18] T. W. Robinson, "Phreatophytes and Their Relation to Water in Western United States."

[19] William L. Warskow, "The Salt River Valley Water Users' Association Watershed Rehabilitation Program: A Progress Report," a paper presented at the Range Weed Research Meeting, Las Cruces, New Mexico, August 1967.

on selective pathogens which would attack the nuisance plants without spreading to beneficial species. Transpiration inhibitors might be developed to reduce the water loss and still permit some plants to remain for whatever esthetic or ecological value they may have. This may be important since conflicts have developed between conservation groups who have fought the eradication of phreatophytes since they provide a "natural" environment for birds and other wildlife. Chemical methods of control through herbicides and defoliants may have promise, but there must be absolutely no pollution potential from these materials.

In spite of the lack of progress to date, the amounts of water involved are so great that supply and economic pressures will eventually force greater emphasis on reducing phreatophyte losses. Mechanical methods of control exist now and will continue to be more widely used as water becomes more valuable. Chemical control will not likely expand in usage because of legislated controls on the use of chemicals. Biological control, which is the ideal method, will require a major technological breakthrough, and this will likely not occur until after the year 2000.

c. Runoff Water Control Using Rock Tunnels and Galleries (Research Priority, 3)

Definition and significance. Storm runoff water in many urban areas constitutes a particularly important problem because of the large amounts of street and yard refuse it usually carries with it. In some of the older cities, the storm drains and sanitary sewers are combined. As a result, excessive sedimentation occurs from the sanitary waste during periods of low storm runoff flows. This sediment is then flushed out by storm waters making the pollution problem extremely difficult to resolve.

There are two alternatives: (1) It may be possible to store runoff waters temporarily until they can be passed through a waste treatment plant; or (2) A treatment plant capable of treating the maximum flow could be constructed. The second alternative is clearly uneconomical. Thus temporary storage may be required even if sanitary and storm runoff are separated.

Sites for conventional surface storage reservoirs of sufficient capacity are usually not available near waste treatment plants. Furthermore, the nuisance and safety hazards involved in treating storm runoff suggest either underground or underwater storage systems (see B-1-1). The latter can be used for this purpose wherever there is sufficient underwater volume available. The requirements for river flood flows must be respected if the water volume must come from a river or narrow estuary.

Underground storage excavated well below ground surface can provide both lower cost storage and greatly increased hydraulic gradients. The former prevents untreated sewer system spills from entering the waterways. The latter increases the system capacity, thereby preventing overflow at various points along the sewer system due to high outfall water surface elevations.

The deep underground conveyance system would consist of tunnels, perhaps cross-connected, leading to the main storage. The excavated underground storage might approximate the present room and pillar systems employed in large-scale underground mining or other such techniques as may be feasible for the particular geology involved.

When viewed in a systems context, the use of reversible pump-turbines between the underground reservoir and a small surface reservoir would permit the unit to be used as a pumped storage or "hydraulic battery" system, permitting electric energy generating systems to operate at efficient high load factors. A deep storage volume designed for the infrequent flood event could be used for this supplementary purpose at little additional cost for all but a few days in a century. In addition, the water stored during flood runoff can be reclaimed for direct beneficial use.

Developments required and research recommendations. Application of this technology is highly feasible. It will also be highly desirable for a number of non-water related applications. The value of surface land in cities continues to rise. The cost of disruptions by conventional near surface excavation techniques has already become excessive. The complementarity of the multiple-purpose approach is attractive.

Tunneling and deep underground excavation research should be accelerated greatly so that the potential application of this technology to water systems, transportation systems, utility distribution systems, and other urban systems can be realized at the low end rather than the high end of the technology development sequence.

The technology for underground runoff water storage will be available within a decade and very much improved by the end of the century. The deep rock tunnel technology will probably be developed in connection with other tunneling needs. Although tunneling research and development has been discussed, little actual research has been initiated. The technological developments required for very large diameter deep rock tunneling may be far off, and unless subsidiary considerations unrelated to this technology encourage earlier development, may require fifty years.

d. Groundwater Storage and Management
(Research Priority, 1 -- research in progress)

Definition and significance. The principal means for managing the nation's surface water resources has been the surface storage reservoir. Several thousands of reservoirs have been constructed for municipal water supply, irrigation, flood control and other purposes. Using present technology, the development of enough dependable streamflow to meet the water supply and waste dilution needs of the year 2000 and beyond (more than 900 billion gallons per day) would require usable storage capacity 5 to 9 times the present surface storage total of 400 million acre-feet in surface reservoirs. It is unreasonable to expect to develop any such capacity in surface reservoirs. Economical reservoir sites are becoming increasingly scarce as good ones are used up and remaining sites are preempted for other preferred uses. Consequently, it is most unlikely that future storage needs can be met unless a massive share of the water is placed underground.

Subsurface storage capacity is orders of magnitude greater than surface storage and offers several significant advantages: freedom from evaporation, no loss through siltation, availability "on site" (i.e., under the place of use), and the enhancement of quality of reclaimed water.

Subsurface aquifers have storage capacities of many billions of acre-feet, a substantial fraction of which lies near enough to the land surface to be economically accessible and usable. Of particular interest are sand and gravel aquifers in those parts of the country where holdover storage of surplus surface water offers promise of relief to water supply; and fissured and cavernous rock such as limestone and basalt which have been relatively neglected. As long as storage is our principal means of evening out the fluctuations of water availability over time and space, aquifers are an attractive target for investigation and exploitation. Many aquifers have a tremendously high capacity for storing and releasing water which can be used in conjunctive management of surface and groundwater and for capture of flood water for use as water supply.

Developments required and research recommendations. Although methods of withdrawal of water from subsurface reservoirs are widely developed and applied, recharge into permeable formations is not so well developed. Presently, this practice is concentrated on recharging small volumes of good or excellent quality water into a few ideal aquifer environments. The technology for recharging very large volumes of seasonal storm flow or melt water into aquifers of wide variety and character does not yet exist, although it is feasible in principle. Before extensive subsurface storage capacity can be put to use, its hydrologic properties have to be explored and defined. Special effort is needed to enlarge upon the existing technology of recharge; specifically, the design of recharge structures, the chemistry and biology of groundwater recharge, the degree and kind of water treatment before recharge, exploration of areas favorable to recharge (artificial and induced), and identification of practical methods of recharge. Basic processes are known, but research can bring the technology to a level for practical consideration in water resources planning.

There are some institutional constraints upon this development because unlike surface reservoirs, the management and exploitation of subsurface reservoirs has been a local rather than a federal program. Because of this, the responsibility has been diffuse among cities and other local governments where research and development has rarely been undertaken. Unless the research program is vigorously pursued at the federal level and subsurface reservoir alternatives considered actively in federal water resources planning, the technology will be limited severely to spot applications.

e. Groundwater Recharge Using Craters Created by Nuclear Devices
(Research Priority, 4)

Definition and significance. Large craters created by nuclear devices can serve as gravity recharge pits and can be located beneath or beside rivers. These craters could be located to alleviate ground mining as well as a means for improving groundwater quality. Large-scale groundwater recharge could increase groundwater availability in previously overpumped areas or arid regions. Construction of large craters or basins for underwater recharge can be created by using nuclear explosives which have the advantage of being inexpensive and effective.

The crater formed by a nuclear explosion depends on the depth of burial, the yield of the nuclear device, and geology of the area. There are two types of craters which can be created by nuclear explosions, and either type could be used to form a large-scale gravity recharge pit. The first type is a "throw-out" crater which is formed when a buried nuclear device explodes near enough to the ground surface to excavate a crater by throwing out the overlying materials. The second type, a subsidence crater, is formed when the chimney of an underground nuclear explosion extends to the surface, causing the ground to sink.

Developments required and research recommendations. Developments are required which will assure elimination of seismic damage and contamination of the environment before the concept of using nuclear devices for cratering could have a large impact on water use and supply (see B-1-n). The basic technology presently exists. It is, however, extremely limited and unproven. Water resources applications using nuclear technology have been tried only in the Soviet Union where open experimentation with nuclear devices has been permitted.

f. Soil and Rock Reservoir Modification
(Research Priority, 2 -- research in progress)

Definition and significance. The water retention and delivery characteristics of the soil and rock reservoirs of watersheds may be modified by changing the physical or chemical characteristics of the soil or rock. Such changes may increase water stored or reduce the use of water from this reservoir and hence increase total water delivery, and change the rate of delivery from an area.

Management might be aimed at restricting the capacity of the soil or rock to retain water, restricting the ability of roots to reach water stored in soil and rock, or modifying the rate of spill from this reservoir.

Such management techniques might increase the usefulness of the water supply originating from the area.

Watershed soil and rock mantles constitute a huge reservoir, exceeding the capacity of man-made reservoirs by 10 to 100 times. Water losses from the soil constitute from 25 to nearly 100 percent of the water entering the soil reservoir. The management of that soil and rock reservoir for water supply is an almost completely neglected field of hydrology.

The capacity of the soil reservoir might be reduced by sealing off the lower part of the soil, leaving only the upper foot or so for vegetation growth to prevent erosion and for supplying a limited amount of forage fiber. By successive application of chemicals, a layer of material which would inhibit root growth might be created at a depth of one to two feet in the soil. This would effectively reduce water use by vegetation, but would allow the whole soil mantle to be used for temporary storage and transmittal of water from the watershed.

Chemicals might be applied to the soil to reduce the retention capacity of the soil particles and hence increase the proportion of the water which would percolate through the soil rather than be retained for vegetation use. Hexadecanol applied to soil has been found to do this in a minor way; other treatments might be more effective.

The storage capacity of rock might be increased by fracturing the rocks by blasting. The construction of large-volume underground storage using nuclear techniques might be considered as an extreme example of rock blasting techniques. Widespread applications of simple fracturing of rock might be more feasible.

Barriers may be created within the soil or rock to temporarily store water, restrict the rate of flow, or divert the flow along more desirable paths-- for example, away from areas of high transpiration use.

Agents to reduce permeability and porosity could be injected to prevent leakage around dams and might be effective in creating artificial barriers in soils.

Great care would be needed in the choice of techniques and selection of sites for any of the above soil reservoir treatments in order to avoid the creation of undesirable water quality characteristics in the original or augmented water supply. In some areas, adverse effects such as increased floods and erosion would have to be carefully appraised and guarded against.

The research needed to make treatment of soils feasible has a firm foundation in soil physics. The means of effecting the desired water supply through management of soils on natural watersheds, however, are practically unknown. A whole package of basic research and development aimed at this very promising technology needs to be initiated.

The prospects for soil reservoir management are not immediate, but new technologies that would make such management possible seem worth pursuing for the potential water saving is tremendous. The economic feasibility will depend on the costs and effectiveness of the techniques developed.

g. Watershed Management: Surface Water Harvesting
(Research Priority, 1 -- research in progress)

Definition and significance. Water harvesting may create additional water supplies by increasing watershed yield, by improving the timing of water yield with respect to demand, or by enhancing the usability or utility of water yielded from natural areas.

The possible future of water harvesting in "natural areas" has not been fully appreciated. Vast amounts of precipitation are never used for beneficial purposes because from 25 to nearly 100 percent of the precipitation is lost through evaporation or transpiration near the point where it falls. Savings resulting from water harvesting may add 10 percent to present water supplies where supplies are already large; in arid regions special techniques may harvest 60 to 90 percent of total rainfall.

Several technological developments promise significant increases in the effectiveness of water harvesting. Systems analyses and economic evaluations comparing this method with other methods of producing additional water have shown water harvesting to be economically feasible. More effective techniques for reducing water use and improving water delivery from forests and brushlands have come from recent research results. The vegetation cover on watersheds may be changed to increase water yield or control time of delivery. In other areas, century-old techniques of creating impervious areas to catch rainfall have been improved by new soil sealants and stabilizers, resulting in high quality water and the elimination of erosion. The collected water may be fully used by storing it in enclosed reservoirs, in tanks, or underground. Other techniques include water saving by evaporation suppression which has proven technically feasible, both on snow surfaces and in small reservoirs.

The areas where water harvesting techniques might be applied have expanded because of other technological and social developments. Increased public appreciation that extensive dense forests or extensive brushfields are neither as aesthetically pleasing nor as productive of good water as managed forests or brushfields promises to further expand water harvesting. As systems are developed which take full account of probabilities of critical water deficits, efficient operating schedules for reservoirs will be possible as well as efficient scheduling of water harvesting on watersheds above reservoirs.

Conjunctive application of water harvesting and cloud seeding, reduction of evaporation from soil and snow surfaces, or other management techniques may make various combinations of these economical where each separately would not be.

Developments required and research recommendations. Care in applying water harvesting is necessary to minimize side effects. Since water harvesting deliberately changes the hydrologic regime, the possible consequences of increased erosion, loss of soil stability, increased local floods, and degrading of water quality must be guarded against, and research is needed on these. Efforts to select non-critical sites and to apply means of offsetting adverse effects may be necessary for applied water harvesting.

Although many of the techniques of water harvesting are generally known, diversity of conditions where harvesting might be attempted and wide differences in the sensitivity of the ecosystems to any particular technique requires extensive research and testing. Research is needed for low cost stabilization and sealing of soil surfaces. Since water harvesting will usually be used conjunctively with other practices, such as improved water transport and storage, and groundwater recharge technology, research on these technologies will be required.

The prospects for immediate expansion of water harvesting by known techniques are good from the technological point of view; widespread deliberate applications of the techniques may take 20 years. The social restraints brought about by questions of who owns the water, how to compensate for water increases incidental to other management operations and who pays for added costs, will restrict the most efficient water harvesting, especially from private lands.

C. TECHNICAL DEVELOPMENTS WHICH EXTEND THE USEFULNESS OF IMPURE WATER

Introduction

Water quality renovation and improved efficiencies of use in the energy, industrial, and population-use sectors, will significantly improve the future water supply picture. The examples of technologies discussed in this section are principally those which improve water quality for reuse or which find economic uses for impure water. Since there will be increasing demands on water, it will be necessary to use, purify and reuse water many times. Greater use of degraded water will have to be made. Technical developments such as recycling and advanced waste treatment may have far greater impact on the future water picture than most developments in the preceding section (B).

1. Advanced waste treatment: Improved processes for purification and reuse
2. Instream aeration for water quality improvement
3. Waste water renovation by surface spreading
4. Water recycling in manufacturing industry
5. Increased use of seawater by industry

1. Advanced Waste Treatment: Improved Processes for Purification and Reuse
(Research Priority, I -- research in progress)

Definition and significance. When sewage is treated by the conventional primary and secondary treatment processes, an effluent results which has been reasonably acceptable for discharge into streams and lakes. There remains, however, a minor portion of the original biochemical oxygen demand and suspended solids content, and nearly all of the dissolved phosphates, nitrogen compounds, and other dissolved salts. The purity of this water is too low for most industrial use and for all municipal purposes. Processes are being tested, however, in which one or two chemical and physical procedures yield high purity water suitable even for potable supply by tertiary treatment of the secondary effluent. Some of the leading methods include chemical addition, coagulation, settling and filtration of the sludge, activated carbon adsorption of remaining impurities, incineration of sludge, recycling of chemical additives, and land spreading (see C-3). When perfected, these processes will result in a major increase in efficiency of water use by making possible the use of the same water more than once for the same purpose.

Advanced waste treatment processes can remove 95 to 100 percent of the deleterious materials in waste waters excepting highly soluble inorganic salts. Nearly all of the phosphates and the major portion of the nitrates can be removed. Thus, these new treatments will produce waste waters undiminished in quality (except for mineral salts increase), and in many situations the quality of the effluent will be higher than that of the original supply. Under these circumstances, repeated use of the same water supply is practical.

This development can be of major importance in industrial (see C-4), municipal, and possibly agricultural applications (see C-3).

Conservation of water supplies by the effective reduction in withdrawal demand would be significant. Only the salinity increase will limit the extent of reuse -- possibly three cycles in municipal supply and up to ten or more in industrial applications. Agricultural reuse would be limited mainly by economics and the presence of dissolved salts leached from the soil and concentrated in the water through evaporation.

Developments required and research recommendations. Development and testing of advanced waste treatment processes are presently being actively pursued. These efforts must be continued in order to make the systems fully dependable and economical. Cost reductions are particularly important, but no major obstacles appear in this direction. Probably the most important factor will be diligence in developing a full-scale system at the earliest possible date in order that new treatment plants soon to be built will not be based on obsolescent processes.

Research is needed for the development of economical processes for the removal of dissolved salts (see B-1-a). Assuming that effective removal of other contaminants will result from present development efforts, the extent of water reuse will be limited only by dissolved salts accumulation. If inexpensive methods for removing relatively small amounts of solutes from water can be devised and perfected, there will be virtually no limits to the utilization of advanced waste treatment.

Advanced waste treatment, in one of its forms, will be widely used when it is perfected. Limited, semi-experimental use is now being practiced, and in another ten years there should be many fully practical systems in operation. Whether municipal reuse will be practiced within this time will depend on institutional decisions and public acceptance of the idea, but the technology should not be limiting. By the turn of the century, advanced treatment and extensive reuse should be commonplace.

2. Instream Aeration for Water Quality Improvement (Research Priority, 2)

Definition and significance. The volumetric space required for aeration for biological decomposition of organic wastes represents much of the cost of waste treatment systems. Although much less efficient, the same biological decomposition reactions occur in natural waters and reduce oxygen levels. If organic loads are heavy, oxygen levels may fall below those necessary to support fish and other aquatic life. Aeration technology might be developed to cope with the diffuse sources of organic pollution which reach streams such as leaves and other forest and crop residue. Artificial aeration of lakes and streams has been practiced in several locations.

The instream aeration system usually consists of a long, weighted plastic tube of small diameter with tiny holes every few feet. The tubing is laid along the bottom of the stream and compressed air is fed into the tube to seep out into the water. The buoyancy of the compressed air creates a circulation pattern which brings more deaerated water to the surface. The latter action is of lesser importance in turbulent streams than in lakes, estuaries and sluggishly moving rivers.

Surface aerators may also be used, particularly where turbulent diffusion such as that encountered in flowing water will provide the necessary deep mixing. Surface aerators require less mechanical energy than that used by deeper subsurface aerators. Both types of aerators may be utilized to enhance natural aeration and therefore would be located at or near the points where the oxygen sag (deficit) is the greatest.

Developments required and research recommendations. An instream aeration technology will require the solution of a number of additional problems including protection against flood damage, damage by vessels, submergence by silt, control of the rate of supply of oxygen when the depth of water is variable, and many others. However, such a technology would be the most promising method of protecting streams against diffuse sources of non-pathogenic organic wastes. For this reason alone it is probably worth development for lakes and slow moving rivers.

There do not appear to be any insurmountable obstacles to the development of this technology within the next decade. Presuming the necessary research (including an assessment of any adverse consequences of the system) is undertaken, use of the technology in lakes and low velocity streams could be widespread before the turn of the century.

3. Waste Water Renovation by Surface Spreading (Research Priority, 1)

Definition and significance. The nutrient load in most treated waste water remains high. This load must be reduced before the water is returned to streams or lakes or injected into the groundwater. Otherwise eutrophication will occur in the lakes and streams, and the groundwater will become contaminated. The disturbance of the natural ecology of streams and lakes will be lessened if the natural capacity of the soil for removal and utilization of nutrients is used instead of dumping the nutrients directly into these waters.

In one system the byproduct value of these nutrients will probably be captured through highly developed production operations in conjunction with the vast capacity of most soils to hold nutrients. Usually the waste water will be used in irrigation schemes, and the water and nutrients will be used to produce agricultural or forest crops. Water will be cleaned in the process and excess water percolating through the soil will be of adequate quality to be suitable for groundwater recharge provided the systems are properly managed.

In another type system the soil alone will be used for renovation of waste water for recharge without crops being grown to utilize partially the nutrients. Carefully managed basins with alternate flooding, then drying and aeration will remove nitrogen through nitrification-denitrification cycles. Phosphorus is removed by fixation in the soil profile. Microorganisms will also be removed, and the water will move on to recharge the groundwater for subsequent safe reuse.

Surface spreading to renovate waste water is important because much of the water pollution problem is related to excess nutrient enrichment of waters through waste discharge. Chemical removal of phosphorus and volatilization of nitrogen are expensive. By using surface spreading, the nutrients are put to a beneficial use and/or the water is recharged for reuse.

The impact of this technology is potentially very great. Not only will it permit safe recycling of a given water supply, it will also help avoid stream pollution. In coastal areas, where seawater encroachment occurs because of groundwater overdraft, this treatment method can be used to curtail encroachment through proper location of the waste water treatment-recharge basins.

Developments required and research recommendations. If the irrigation technique is used, and nutrient removal is accomplished primarily through uptake by vegetation then large areas of land are required adjacent to cities. They may take the form of greenbelts around cities or parks or adjacent forest areas. Since the sewage water is pretreated, it can safely be used for park irrigation. The basin technique will require less land but greater management of the system. In northern climates where extended subfreezing periods occur, there will be a need to store the effluent for periods of time while the ground is frozen.

Research is especially required concerning the use of these techniques on different kinds of soils including sands. The effects of climate on the efficiency of the system need to be determined so that appropriate system management procedures can be determined. The possibility of an essentially closed loop where the treated waste water from a city is recharged, using the basin technique, directly into the water supply aquifer for the city needs further study.

By 1980 this technique will be practiced in many locations. By 2000 practically all desert and coastal cities (with available adjacent land areas) may be using the method for final waste treatment. It will likely remain one of the least expensive ways to obtain final treatment of waste water except when land becomes totally unavailable or the cost disproportionally high.

4. Water Recycling in Manufacturing Industry
(Research Priority, 1 -- research in progress)

Definition and significance. Industry uses a large amount of water for washing raw materials and products, for transporting materials from one stage to another, for physical and chemical treatment of materials, and for inclusion in the products. In all uses except the last, waste water contaminated by substances removed from the main stream of materials is produced. The pressures of pollution control legislation, river quality standards, and often the cost and limited availability of fresh water supply have stimulated the development of systems for industrial water recirculation and reuse. Usually these systems involve either sequential use of water in various plant operations which tolerate progressively lower water quality, or removal of the impurities picked up by the water and recirculation of the purified water with only small water losses.

The development of effective processes and equipment for purifying waste waters is responsible in part for the increased use of recirculation in industry. These developments include sedimentation processes and equipment, economical, physical, and chemical processes for removal of specific dissolved contaminants, activated carbon adsorption units for final "polishing" of waste water to purities equivalent to the fresh water supplies, and the redesign of manufacturing processes to permit use of less water.

The probable impact of widespread industrial water reuse is very great. Recycling systems such as those above will enable industries to reduce their intake water requirements to a small fraction of the once-through demand. Not only do such measures reduce fresh water requirements, but they also decrease waste water discharge and, usually, the discharge of the waste substances themselves. Along with recirculation cooling in power plants and changes in agricultural water use, this development will probably have the largest of all effects on water demand and use in the next several decades.

Developments required and research recommendations. Additional research and development is required for the full implementation of these recirculation systems. The methods themselves require improvement mainly through chemical processing and physical equipment design. Also the cost of the systems and their operation must be reduced. Efforts are now being made to achieve both of these aims. There appears to be no desperate requirement for a breakthrough in waste treatment technology, but rather a need for steady improvement in methods through a concerted research and development effort. Problems unique to each industry require specific attention in order that methods for purification of particular types of waste water can be effectively developed.

It is certain that industrial water recirculation and reuse will become almost universal. With increasing quality requirements for industrial waste water discharge, it is obvious that these purified waste waters will be reused to the maximum practical extent simply as a cost-saving measure. By 1980 it is likely that major industries will recirculate a substantial portion of their process and cooling water. Furthermore, in their design and planning, new industries will incorporate extensive recirculation and purification systems for plant water supplies.

5. Increased Use of Seawater by Industry
(Research Priority, 2 -- research in progress)

Definition and significance. Seawater is highly corrosive to most metals, particularly the common grades of steel used widely in industrial equipment. This property of metals has limited the use of seawater for cooling, washing, and waste carrying operations. Industrial plants have therefore tended toward locations where fresh water is plentiful. The development of strong plastics and corrosion-resistant alloys of iron and other metals for tubing, piping, and other industrial equipment has altered this situation somewhat by permitting salt water use for numerous industrial purposes at tolerable increases in capital cost. Further metallurgical developments along these lines and the growing demands for fresh water will stimulate the growth of factories where salt water can be used for all or part of the plant operations.

This development of corrosion-resistant materials is such that modern steam electric power plants will be able to employ seawater for cooling. Petroleum refineries, metallurgical plants, chemical factories, and other industries could be located near seawater supplies, thereby releasing fresh water for other uses in regions near seacoasts. This could have considerable impact on fresh water supplies in these regions. This development could also enable the widespread adoption of siting large power plants on tidewater or the open seacoast, and thus have a significant impact upon new technologies in long distance power transmission (see A-3-c).

Developments required and research recommendations. Additional developments and research activities required to increase the potential of direct use of seawater are probably not too formidable, since application is already being made. Increases in durability and decreases in the cost of plastics, glass, protective coatings, and corrosion-resistant alloys will provide added inducements for the industrial use of seawater. Improved methods for reducing the fouling of equipment by marine organisms of many types are needed.

Growth in the direct use of seawater for cooling and other industrial needs will probably be stimulated more by pressures on water availability than by technological factors. It is virtually certain that this existing technology will be generally used in coastal areas. Power plants, in particular, will probably be concentrated in coastal regions where cooling water supplies are available. A negative factor, however, is the possible ecological damage by heated discharge from these plants into the sea, but suitable designs should minimize this hazard. The availability of coastal land may also be somewhat restricted by competing uses, but residential and recreational requirements are usually sufficiently different from industrial needs to minimize conflicting demands. By the year 2000 heavy use of seawater for industrial purposes is a strong possibility.

D. TECHNICAL DEVELOPMENTS WHICH COULD HAVE AN INFLUENCE ON FUTURE WATER DEMANDS AND SUPPLIES

Introduction

The four sample technologies discussed in this section relate to both water and non-water oriented developments. While these concepts could all be significant, one which considers food production using waste heat and other by-products could be extremely significant in that it entails a food factory concept. And this could have major impact on future water requirements for conventional irrigation agriculture food production. The developments dealing with waste disposal and pollution control are also potentially important.

1. Reservoir bottom water use
2. Subsurface and marine waste disposal
3. Crop production by use of residual heat and other by-products
4. Reducing contaminants from watershed areas

1. Reservoir Bottom Water Use
(Research Priority, 4)

Definition and significance. Reservoir bottom water can be used instead of near surface (top) water from all or part of a reservoir for the purpose of maintaining shoreline elevations for recreation, scenic, wildlife or aquatic habitat purposes. Part of the total reservoir storage could be displaced by substituting air in inflatable pillows (or some other substance heavier than water slurry) thereby rendering the displaced volume of water available for use. The displacement pillow would be regulated in conjunction with the overall reservoir system.

Alternately, a double dam system might be used to withdraw water from the deeper downstream parts of the reservoir, leaving a smaller upper part at nearly full stage. A low secondary dam, with a temporary plastic riser such as is now commonly used as a flashboard, might be one technique which would minimize loss of overall capacity of the system.

These techniques could be valuable because they allow the maintenance of shoreline elevations and at the same time permit harvesting of additional water. This is significant because demands for water-related recreation facilities promise to increase at an accelerated rate as leisure and population rise, and legal restrictions prohibit reducing shoreline elevations in many reservoirs and lakes. The greatest impact will be the extended availability of water during periods of low flow or drought. During critical water shortages, as in the recent New York water crisis, the technique of bottom water displacement might be used to take water from lakes not ordinarily used for water supply. During that critical water shortage over half of the mountain lakes in the New England area were nearly full.

Developments required and research recommendations. The bottom water displacement techniques presuppose several technological developments. There do not now exist inflatable pillows or bladders of the size envisioned. In addition, structural stability and inflation/deflation mechanisms must be developed. Before a technique is employed, the ecological impact of the concept must be fully measured. Research is required to evaluate the effect of the bladders and dams on lake stratification, temperature profiles, increases in potential evaporation, nutrient levels, and the combined effects of the aforementioned on aquatic life, recreation, and the potential for eutrophication. Finally, the integrated effects of the technology on the efficiency of the system must be determined so that appropriate system management procedures can be developed.

2. Subsurface and Marine Waste Disposal
(Research Priority, 1 -- with environmental considerations)

Definition and significance. One of the major factors influencing the use of water concerns the disposal of wastes. Regardless of treatment, desalination or other process of water beneficiation, at some point the residual mineral or chemical matter must be removed from the environment. Water requirements eventually center upon this minimum quantity of water required for transport of the mobile residual matter. Moreover, public concern for the safe disposal of concentrated toxic, hazardous, or otherwise undesired and unwanted materials is increasing. In some locations the cost of treating waste to meet the standards for discharge into surface water may necessitate a choice between serious economic dislocation of the community or industry involved or the relaxation of standards. Either alternative is obviously undesirable. Under such conditions interest in utilizing both the marine environment and underground as possible mediums of waste disposal is great. The situation is potentially dangerous, for the information necessary to determine what wastes can be stored safely underground or in the marine environment, and how and in what amounts, is largely lacking.

Nevertheless, the potential for successful waste disposal exists, and there are certain kinds of wastes for which there appears to be no logical means of storage or disposal. Among these are radioactive materials and certain highly toxic organic and inorganic chemicals. Where can such wastes, including waste brines from desalination, be stored safely underground? What wastes can be so stored? How must they be treated or neutralized before injection? What data are necessary to assure confinement where intended? What are the risks and possible costs of a "breakout," and how can these be evaluated in comparison to those involved in alternative methods of waste management?

Although the oceans and large lakes are not inexhaustible sinks for the disposal of heat or material wastes, under certain circumstances such disposal could be highly beneficial. The key to useful disposal lies in placement of wastes in relation to thermal gradients, density gradients, circulation patterns, and geologic stability.

In the case of marine disposal, the development of an underseas aqueduct technology (B-1-k) would permit a rational offshore deep water placement of the waste heat from electric generating systems or other waste materials provided the location of the point or points of discharge are selected on the basis of sound information on the characteristics of the receiving waters. The technology for these lines, running perpendicular to the shore instead of parallel, would be considerably simpler to develop since they would avoid the problem of submarine canyon crossings and would be much shorter. In most other respects the installation and maintenance technology would be the same as for the underseas aqueduct.

Developments required and research recommendations. This technology could be developed with a concerted research and development program over the next fifteen to twenty years or perhaps sooner on a crash program basis, which may be needed for waste heat disposal. In association with the research and development on waste disposal technology, a corresponding research program on the consequences of deep water and underground waste heat disposal is essential. Since the marine disposal sites will experience secondary currents, vertical mixing effects need to be analyzed. Underground disposal may initiate seismic responses. Heat transfer through disposal connecter walls also needs to be determined. This research will be essential to the design and placement of these systems.

The savings in water spared from contamination by disposal of concentrated chemicals gives urgency to the development of this technology. Although the injection of unwanted waste waters into the marine environment and underground has several points of research common with artificial recharge of relatively pure river or reclaimed water, the objectives are obviously different.

Ultimately, domestic and international legal constraints will influence the implementation of such waste disposal techniques.

3. Crop Production by Use of Residual Heat and Other By-Products
(Research Priority, 2)

Definition and significance. Use of residual heat and other manufactured by-products must be viewed in a systems context, in that it must be an integral part of other activities, such as power generation and desalination, which use by-product heat and other materials. A simple case would be to use heated water from power generation for irrigation, thereby extending the crop growth season and providing early germination and rapid initial growth. This procedure can markedly improve the timing of harvest.

A more complex case would be a closed food factory production system. Inputs into the system would be heated water of regulated fertility from desalting works and related fertilizer manufacturing plants. The sun's energy would be augmented and the natural carbon dioxide levels enriched for increased photosynthesis efficiency. Waste heat from power generation would be used to maintain environmental conditions. Insects and pests would be excluded from the closed system with chemical controls applied in the water with systemic materials. New varieties of high protein plants would be grown in the food factory with all parts of the plant used and processed in adjacent facilities. Cleaning and processing waste water would be returned to the irrigation system for crop use of nutrients.

The use of waste heat and other by-products from power generation plants and other factories is simply another case of recycling energy and other materials. Pollution, thermal and otherwise, is reduced. Water which might otherwise be lost is put to beneficial use, and environmental quality is enhanced.

Developments required and research recommendations. Research is needed on the use of heated water in irrigation and on many aspects of food factory production. The economic efficiency of the system components requires research in order to evaluate the overall economic efficiency of a food factory system coupled with other enterprises.

Irrigation of crops with heated water from power generation will probably increase beginning in 1975. By 1990 it may be a common practice in areas where existing irrigation occurs in proximity to power plants. The food factory concept may not come into widespread use until after the turn of the century. By 2000 numerous highly efficient food factories, coupled with other enterprises, might be in operation.

4. Reducing Contaminants from Watershed Areas
(Research Priority, 3 -- research in progress)

Definition and significance. The use and management of watershed lands for a wide variety of purposes can be expected to add contaminants to water supplies in lakes or streams and to groundwater. Such contaminants result from natural elements in the watersheds, from contaminating materials brought into the watershed system, or from stimulation of contaminants by release of natural or introduced materials.

Accumulating evidence suggests that the impact of land use and development in watersheds on water quality is being underestimated because dilution has been obscuring their effects. In the western United States a major portion of the water supply comes from wildland areas. These areas are being increasingly modified as high elevation timber is harvested, roadways and power lines are cleared, brushfields are converted to forests or grass, and fires, insects, disease and gale winds devastate the forest. Pesticides, herbicides, fertilizers, organic and chemical wastes, and other compounds are added to the environment without adequate knowledge of their secondary effects or ultimate destiny. The cumulative effects of these compounds on future water quality must be evaluated to permit rational watershed management decisions.

The demand for pure water from virgin watersheds for municipal use, for fish habitat, and for irrigation is increasing. Protectors of the environment may demand that where water is pure, water must remain pure.

Multiple use of forests and other wildlands is increasing, and each increase may be expected to bring about problems of pollution and sediment control from watershed areas. Sediment constitutes ninety percent of the present water pollution problem in the United States. Road construction and maintenance on roads in mountain areas are a major source of sediment in streams.

Developments required and research recommendations. Forest areas are major sources of water supply. Clearcutting of forests starts a cycle of nitrogen and phosphorus release, increases in-stream turbidity and a whole chain of effects which may be detrimental to stream habitats, fishing, and the usefulness of water. Types of forest harvesting other than clearcutting may have less impact on watershed erosion and may be justified in some areas to prevent pollution of water supplies. Other uses, such as mining, grazing, and recreation use, have their impacts on water pollution; these must be assessed and measures to minimize them developed. More intensive management with the application of pesticides, herbicides and fertilizers has also added to pollution problems and may be expected to increase. The impact of management on water quality must be studied.

Some general guidelines for pollution control in watershed management have been established, but the conflicts between uses of watersheds and the impacts of such uses on water quality have already created a demand for knowledge extending beyond general guidelines. Research into the whole ecosystem of watersheds, as well as research into the physics of natural and artificial water pollutants within each ecosystem, is needed. Development and testing of alternatives to present management techniques and means of offsetting the adverse effect on water quality of present uses and techniques must be intensified.

Many of the problems of pollution of watershed areas are already with us. The probability that the problem will grow is nearly certain.

E. CONSIDERATIONS WHICH COULD INFLUENCE TECHNICAL ACHIEVEMENTS

Introduction

The six concepts discussed in this section are examples of developments which could have a significant influence on the direction of water planning in the future. These non-technical developments can potentially be very important in the future water picture. They are only illustrative of a host of non-technical factors which might have been given which could have impact on future water problems.

These concepts have been included even though they are somewhat outside the Committee's specific charge. The rationale for their inclusion is largely based on the fact that these needs and trends were often involved in the Committee's discussion of the potential impact of technical developments in water demand and supply. Other factors, population control for example, may have equal or greater influence on motivating and stimulating technical developments relating to water. Accordingly, the Committee felt that a representative selection of these non-technical concepts should be included, showing mainly how they might influence the direction of future technological effort.

1. Populating the desert
2. Rationalizing the market for water services
3. Residential water demand modification
4. Water-based recreation trends
5. Reservoir role in water management
6. Effects of bioconcentration of toxic materials

1. Populating the Desert
(Research Priority, 2 -- to determine impact of adoption on technical water problems)

The land area of the continental 48 states is nearly one-third subarid to arid. Present use of this land is limited to dry farming or low density grazing, except for the growing oasis cities and farms centered along perennial streams. The burgeoning "people pressure" has inspired occasional proposals to create new desert towns apart and distinct from those now existing, which would be devoted to industry, communications, and transport, as well as to recreation. Requirements for water supply and waste disposal will be significant problems in these new towns. In some cases, the new communities may be able to obtain initial supplies by converting water use from irrigation to industrial use (one acre of irrigated land uses about the same quantity of water as 20 persons). However, this conversion may not be sufficient for growing municipal and industrial use, as it tends to create even greater demands for water.

Innovative, unconventional sources of water such as partial or complete recycling may be needed. Desalination to prevent the continuous build-up of salt may be an essential part of recycling schemes. Mineral constituents must be continuously removed even where wastes are completely treated or oxidized.

In addition to the severe technological difficulties of water supply and waste disposal, critical social and ecological problems will have to be surmounted. Landscaping, for example, would necessarily emphasize features that do not use water. Further, one must recognize that desert landscape is very fragile, and its dense occupation may introduce severe erosion and ecological imbalance. Although it will be through technology that desert lands will be used, the land itself may not be ignored. Considerable care and study must precede development of new towns in order to "design with nature."

The arid lands may look toward industrial rather than pastoral or agricultural expansion. The historic progression of waste land, farm-land, city land, and factory is not appropriate to the development of the arid lands in this century. Present population projections for the year 2000 apparently assume little "filling up" for the arid lands, but that the percentage of population in this region will not change. The rate of movement toward new desert communities will depend on an increasing productivity, and as technology offers an alternative to the scarcity of water, water can be shifted to more productive uses. Technology will respond to the demand, but the growth of true desert communities is not likely to have great influence on the total water situation. It is more likely to create a land rather than a water problem.

2. Rationalizing the Market for Water Services
(Research Priority, I -- to determine impact of adoption on technical water problems)

The traditional systems for defining riparian and appropriate water rights currently make the transfer of water rights quite difficult. An individual desiring to sell his water rights to others is usually severely constrained by the physical difficulties of effecting the transfer and by the impacts which the transfer will have on other parties downstream. The impacts on others (externalities), combined with the fact that rights frequently have been poorly defined (usually being stated in terms of cubic feet per second permitted to be withdrawn and requiring the demonstration of "beneficial use" of the water so diverted) have resulted in complex legal procedures which must be followed in the attempt to transfer rights. The outcome is usually quite uncertain in terms of whether or not the transfer will be permitted, and, if transfer is permitted, it is uncertain how much water can be transferred. For these reasons, markets in water rights are imperfect, uncertain, and tend to discourage transfer to new uses.

However, active, continuous markets for water do exist on limited scales. Seasonal rentals of water among users occur within the membership of particular ditch companies and on a wider scale among companies in the same irrigation district. Examples are found in northeastern Colorado and Utah. A market for the permanent sale of rights is maintained by the Northern Colorado Conservancy District through a process of resale to the District and hence to other users. In all of these instances, the existence of a continuous market coincides with (1) both buyers and sellers being located within the same physical distribution system so the "downstream" effects of a transfer can be compensated for, and (2) water rights being represented by shares in a ditch company or by a contract either of which clearly specifies the nature of the right. Transfers occurring when both buyers and sellers are not located within the same physical distribution system are complicated by the large capital cost of physical transfer systems.

The existence of market arrangements like those mentioned above leads to much more efficient use of water than would take place in the absence of having a market stimulus to save water. While the above market arrangements do not work with complete efficiency (i.e., the decisions to sell water may not reflect secondary income impacts on parties related to the seller on a business basis), they are worthy of emulation on a more extensive and large scale.

New water market arrangements might take two forms. The first would vest property rights in the form of "use certificates" which would be transferable and saleable in the open market. A use certificate would be valid for uses only at a particular point on the dendritic water distribution system or upstream from it. The initial sale price of certificates would represent the capital cost of the corresponding share of the system's output at the specified point and would also include an amount for perpetual system maintenance. Transfer of use certificates would be at the option of the holder as for any other personal or real property.

A second, somewhat more popular form would have the water agency (e.g., the United States Government) own all the water and sell it on periodic supply contracts, f.o.b. point of delivery. Two factors affect the optimum length of the contract period. As the contract period is lengthened, the system becomes more rigid, and as the contract period becomes indefinite, the system would be exactly equivalent to the present system of water wholesaling from federal projects. As the contract period becomes shorter, the uncertainties associated with the ability to obtain the needed water cause less capital-intensive and often less productive uses to be made of the water than would be made under greater certainty. This causes a necessary lower bound to be placed on contract lengths.

The effect of either plan would depend upon public policy with respect to water supply development, as it does at the present time. If it were public policy to provide additional water supplies (wholesale) so long as the average unit cost of doing so is less than the equivalent current price of certificates in a district, water use would probably not be greatly curtailed in cities and most industries. Agriculture and food production would be affected by the rising price of water. Agricultural use of supplies relatively remote from cities would be least affected. Those agricultural supplies drawn from the same system as municipal and industrial water would be highly curtailed unless they were represented by certificates confirming rights at the "heart of the ditch."

The value of certificates would probably tend to fluctuate considerably with the proximity in time (and the cost) of new supplemental supplies. Since economies of scale require new supplies to occur in a few major steps 20 to 30 years apart rather than a large number of minor increments, there might be cycles of feast and famine. Such fluctuations would not be in the interests of optimum use of water for reasons stated above; hence, on construction of new projects the certificates would probably be released according to a schedule which would maintain relatively constant prices until the entire supply had been purchased at a price at least equal to construction costs. Certificates would then increase in value to the point where their price justified new projects.

These procedures would require, for all new sources of supply, a management agency which would issue water certificates or otherwise manage the sale of water. The agency would be physically able to compensate for the downstream effects of transfer, and it would probably be desirable to authorize the agency to add a "tax" or "bounty" to the auction price of a certificate to reflect income externalities.

The real challenge in the use of this concept comes in extending it to regional water systems. A regional water agency could supervise transfers over a wide area, compensating for externalities either by physical controls over flows or by its own purchase of certificates to permit such compensation. The agency could, over time, acquire existing water rights and incorporate them into the scheme.

Schemes like this are vital to the efficient use of water. Efficient regional transfers will avoid the needless expenditures of billions of dollars in the future for very long distance transport of water and the construction of desalting plants.

3. Residential Water Demand Modification
(Research Priority, 3 -- to determine impact of adoption on technical water problems)

The amount of water physiologically required for human survival is so small that consideration of attempting to change those requirements is not at all worthwhile from a national water management viewpoint.

The discretionary amounts of water demanded for the amenities of home life, however, are quite large and cover a wide range. These amounts frequently can be affected by technology and by public policies.

Residential water demands range from less than 50 to more than 150 gallons per capita per day, depending upon the affluence of the person, the type of housing, and climatic factors.[20] These rates of use are divided between in-house uses and outdoor uses in about an 80-20 ratio in arid areas. These uses can be affected through the adoption of water-saving technologies, metering and pricing policies, land use regulations, housing densities, and new gardening and lawn practices.

Estimated domestic use for 1965 in the United States was between 15 and 18 million acre-feet per year.[21] It has been estimated that these figures will, under current policies, increase by 12 million acre-feet per year by 1990. Naturally, only a part of this use, 30 to 40 percent, is consumptive, the remainder returning to streams or aquifers in a state of reduced quality.

While not a large item in total national water use when compared with, say, irrigation uses (75 million acre-feet consumed per year), these residential demands constitute a large part of the total water produced and delivered by public (urban) systems (26 maf diverted, 5.8 maf consumed in 1965).[22] This accounts for a very large part of public water supply system investment.

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[20] F. P. Linaweaver, Jr., John C. Geyer, and Jerome B. Wolff, Final and Summary Report on the Residential Water Use Research Project, for the Federal Housing Administration, Johns Hopkins University, Department of Environmental Engineering Science, Baltimore, June 1966.

[21] Ibid.

[22] Ibid.

It is presently a feasible and widely established practice to meter residential users and charge according to use. More complete metering and higher prices would depress use considerably.

Water saving models of toilets, automatic washing machines, shower heads, and air conditioners are currently available which would save 30 percent of in-house uses without decreasing the quality of the associated services. Since these devices generally cost more and since water prices are fairly low (on average about 40¢ per thousand gallons), there is no financial incentive for adopting them. Building codes could require them in water-short areas.

Outdoor uses account for from 20 to 50 percent of residential use, depending upon climate.[23] These demands are strongly affected by water pricing. Programs of education on arid area landscaping could do much to alleviate these demands as could the development of better grasses and shrubs.

Peak-period and summer season pricing have been suggested as ways of reducing demands during the dry season. The reduction of peak demands permits large savings in distribution system investment. Water rate schedules which increase with use rather than falling as most do at present, would encourage conservation and might serve to reduce peak demands.

4. Water-Based Recreation Trends
(Research Priority, 2 -- to determine impact of adoption on technical water problems)

Water-based recreation is the fastest growing type of leisure activity. Vast amounts of water are impounded in federal multi-purpose

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[23] United States Water Resources Council, The Nation's Water Resources, Part 4, Washington, D. C., 1968, Chapters 1 and 4.

projects to provide recreational opportunity. As a result, large volumes are lost through evaporation, and the functioning efficiency of reservoirs intended for water supply is reduced.

If the requirement for water becomes critical in certain areas, consideration could be given to diverting increasing demands away from water-based opportunities to other types of activity. Certainly, the prevailing public policies (federal, state and local) of free access to water bodies for recreation have stimulated high demands for water recreation. The development of attractive alternatives such as hiking trails, camp sites, tennis, and golf could reduce the pressure for water developments.

From the viewpoint of national water supply, a reduction in water-based recreation would have little effect. In fact, since recreation is usually compatible with water supply and navigation, if not with flood control and power generation, its reduction might eliminate economies of scale and cost-sharing arrangements which presently help to keep water costs down.

A related issue on which research is needed is the rapidly growing outdoor recreation use for natural areas and white water streams. The values which a stream would yield in these uses should be considered one of the costs of reservoir construction on the stream.

5. Reservoir Role in Water Management
(Research Priority, 3 -- to determine impact of adoption on technical water problems)

Reservoirs are the dominant tool of water resources development and control, storing the variable flow of rivers for such diverse purposes as municipal supply, electrical power, irrigation, flood damage abatement, impoundment of sediment, farm and ranch uses, and recreation. The technology is among the oldest available, having a history going back more than a thousand years. Reservoirs have become prominent features of the American landscape. Yet rivers still fluctuate greatly. If the complete regulation of rivers becomes a natural objective, that is, if the evening out of the variations in river flow is a prime objective, then reservoir capacity more than tenfold that existing may be required.

There are numerous reasons why reservoir technology may be increasingly questioned in the years ahead. The following are but examples among many:

1. Water loss. Reservoir evaporation is a significant item in the western water economy, and evaporation suppression may be difficult to achieve in large open bodies of water.
2. Capacity loss from sedimentation. A significant portion of the reservoir storage capacity can be expected to be lost due to watershed erosion and reservoir sedimentation.
3. Aesthetic values. Dam sites occupying valley constructions often inundate places of great scenic appeal with reservoir slack water substituting for free-flowing rivers.
4. Obsolescence. Because they are capital-intensive and of long life, reservoirs commit one to the existing technology. Less capital-intensive technologies permit and even encourage the exploitation of new and more advantageous techniques.
5. Irreversibility. Reservoirs impose irreversible decisions on large parts of the land surface and remove prime agricultural land from cultivation.

Alternative technologies such as underground storage and recycling avoid these problems and may have considerable appeal for these reasons. Alternate objectives such as flood-damage abatement, power generation, and the use of stored water for dilution of wastes may prove uneconomical and may not be fully achieved by other means. However, there are some purposes, including irrigation supplies, power peaking, recreational (boating, swimming) and real estate enhancement, for which there are no practical alternatives.

6. Effects of Bioconcentration of Toxic Materials
(Research Priority, 1 -- to determine impact of adoption on technical water problems)

A problem of utmost importance now entering the water picture with great frequency is the bioconcentration of certain toxic materials, particularly certain forms of mercury, other heavy metals, and toxic substances such as DDT. Through bioprocesses in the organism, these substances can be concentrated by several orders of magnitude when they enter the food chain in water bodies. The end result is known to all.

Several factors should be considered in relation to this problem. First, technologies must be developed to better identify all materials that might pose a future hazard through biological concentration to dangerous levels. Secondly, technologies must be developed to absolutely prevent these potentially dangerous materials from entering bodies of water. The technologies to achieve these objectives may be many, but their development should receive a high research priority. Finally, the mechanism through which biological concentrations occur must be completely understood.

Two critical reasons for understanding the bioconcentration mechanism are immediately apparent, and both could result in new technologies. If the process is fully understood, it might be possible to develop ways to counter this biological concentration process using some innoculation process or chemical to neutralize the reaction. On the other hand, the bioconcentration process could be utilized to remove target materials from the aqueous system. For example, special ponds might impound waste effluent from a factory which had a bioconcentrating compound in the waste water. A selected lower life form might be cultured to concentrate the compound for ultimate removal and disposal. This would provide removal of selected toxic materials from water prior to discharge to the larger ecosystem of natural waters.

The impact of these ideas, in both direction and magnitude on the water picture is difficult to predict, but it could be of major importance.

CHAPTER III

ANALYSIS OF TECHNICAL DEVELOPMENTS

INTRODUCTION

In the table in the following section, each technical development described in Chapter II has been listed and estimates have been made concerning the timespan required for its implementation. First, estimates are given of the number of years until the technology will be feasible in terms of a laboratory or pilot-plant demonstration.

The Committee is concerned that the estimates given in the table not be misused by being taken out of context, since there is considerable subjective judgment involved in estimating when a future event might occur. The data given in the table are more accurately described as "least surprising" estimates than as predictions. This is necessary since each technological development is dependent on a host of interrelated factors, many of which are not concerned with technology.

A second item in the table gives the Committee's estimate of the years until the development will be fully operational, where fully operational means being technically and economically viable with some systems in commercial use. In every case where a timespan until the technological development is feasible or operational is given in the table, the estimate is conditioned on the assumption that the necessary research and development will take place. It must be recognized that if research and development on any technology is not accomplished, the date of feasibility will be delayed.

Since each technical development given is judged to have an impact on water supply and/or demand, it is necessary to assess its effect on the water economy. For example, some developments such as landscaping with artificial materials (A-2-p) will likely develop as a result of general technological progress. Yet, widespread use of this concept could affect the hydrologic relation of an area if the artificial turfs are impermeable, so this factor must be considered.

Some developments may never be applied because of economic or institutional restrictions, and others may never prove to be technically feasible. Some developments given are mutually exclusive; so if one is successfully implemented, there will be no impetus for the other to be pursued. Along with the estimate of years until fully operational, information is given on whether the Committee believes that implementation will be controlled by future institutional factors (designated by I), technical considerations (designated by T) or both (designated by I&T). The term "institutional" as used here includes all factors which are not strictly technical. Therefore, factors such as political considerations and socioeconomic factors are grouped in this institutional category.

A third item of the table concerns the Committee's judgment on whether application of the given technology would depend on research and development specifically directed to influencing water supply and/or demand. Therefore, this column delineates those technologies whose application the Committee believes will depend on research and development implemented primarily from water supply or use considerations. For those technologies whose application does depend on research and development specifically directed to influencing water supply and demand, a <u>yes</u> is given in the third column.

For those technologies with a <u>yes</u> in the third column, the Committee has assigned in Column 4 a <u>research priority</u>. Research priorities, which are the collective judgment of the Committee, are assigned on a scale of 1 to 4, with 1 indicating the greatest research need (extremely critical), and 4 indicating a low research requirement (least critical). For those items given a research priority of 4, a feasibility study is the least action acceptable. In the case where significant research is already in progress, the research priority is followed by an asterisk. If the research may have special significance to environmental and other considerations, then the research priority has a superscript e (as 2^e). A double asterisk is used where the Committee felt that research on special considerations is needed to determine the impact that adoption of those considerations would have on technical developments related to water. The Technical Concepts identified by the Committee are listed by research priority on pages 165 and 166 following the table.

The final and fifth column in the table indicates those developments which will result, at least partly, from technological progress not directly related to water considerations.

Section C of this Chapter, Trends and Interactions Concerning Future Technologies, gives a synopsis of factors which enter technology prediction and outlines a procedure for analyzing the cross-impact of related technologies. The nature of problems that lie ahead in assuring that the required amount and quality of water is available for future use make technology a factor of importance. In this section, the Committee reviews the role of research and the effects of natural limits on water quality and availability, noting that while the feasibility of an invention may be based upon scientific and engineering principles, the application is often more complex than the fundamental technology, owing to the cross-impacts and interrelationships among technological, social and economic developments, circumstances and policies.

Potential Technological Advances and Their Impact on Anticipated Water Requirements
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CHAPTER III

SECTION A

TABLE RELATING FEASIBILITY AND OPERATIONAL UTILITY OF TECHNICAL DEVELOPMENTS WITH TIME

Potential Technological Advances and Their Impact on Anticipated Water Requirements
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TABLE RELATING FEASIBILITY AND OPERATIONAL UTILITY
OF TECHNICAL DEVELOPMENTS WITH TIME

	1	2	3	4	5
Technical Development	Years Until Feasible	Years Until Fully Operational*	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority+	Application depends upon technological progress on subjects other than water
A. Technical Developments Which Will Increase or Decrease Future Demand for Water					
1. To increase future demand for water					
a. Gas production from coal (21)**	Present	15 T			Yes
b. Electric power generation by conventional nuclear reactors (22)	Present	10 T[1]			Yes

*"Fully operational" means technically and economically viable, with at least several systems in commercial use. T or I indicates that implementation is controlled by Technological Capabilities (T) or Institutional Decisions (I).

**Numbers in parentheses refer to page numbers in Chapter III.

+Research priorities are given only for those technical developments which are judged to be dependent upon R&D specifically directed to influence water supply and demand. Priorities are assigned on a scale of 1 to 4 with 1 indicating the greatest research need (extremely critical) and 4 indicating a low research requirement (least critical). For those items receiving a research priority of 4, a feasibility study is the least action acceptable.

[1] For peak effect. Mix of high efficiency fossil fuel plants and high efficiency gas-cooled nuclear plants with low efficiency conventional nuclear plants estimated to change in such a way as to maximize cooling water demand per unit generation in about ten (10) years.

(A)(1)(a) - (A)(1)(b)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
c. Surface transportation using electric power (24)	Present	20 T[2]			Yes
d. Transport of solids by water slurry pipeline (26)	Present	10 T[3]	Yes	3	Yes
e. Fire hazard area irrigation (27)	Present	10 T&I	Yes	4	
f. Forest and rangeland irrigation (30)	Present	20 I			Yes
g. Solution mining (32)	Present[4]	25 T			Yes
2. To decrease future demand for water					
a. Electric power generation with gas-cooled nuclear reactors (35)	Present	10 T[5]			Yes
b. Electric power generation by nuclear fusion (36)	30	60 T			Yes
c. Electric power generation by fuel cells (38)	15[6]	30 T			Yes

[2] For major effect, including moving sidewalks, electric cars, etc.

[3] For numerous systems to be in use

[4] For some minerals and elements

[5] For numerous installations

[6] For conventional fuel sources

(A)(1)(c) - (A)(2)(c)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
d. Electric power generation by magnetohydrodynamics (39)	20	30 T			Yes
e. Electric power generation in open-cycle engines (40)	Present	30 T[7]			Yes
f. Electric power generation by use of wind and water power (42)	Present	Unlikely for large-scale use			Yes
g. Recirculation cooling pond development (43)	Present	10 T&I[8]	Yes	3	
h. Cooling tower design and utilization in industry (45)	Present	10 I[9]	Yes	2*	
i. Industrial cooling systems using air (47)	Present	25 I	Yes	1	

[7] For large impact, mainly for economical peaking plants

[8] For large-scale, multi-purpose use

[9] For major impact

* Significant research already in progress

(A)(2)(d) - (A)(2)(i)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
j. Water as diluent for wastes (49)	Present[10]	25 T&I	Yes	4	
k. No-rinse washing/laundry technology i. No suds	Present	5 I			Yes
ii. No rinse (50)	10	20 T	Yes	4	
l. Bioprocessing to provide food (51)	Present	30 T	Yes	1	Yes
m. Artificial anti-transpirants (55)	10	30 T	Yes	2	
n. Genetic development of plants to withstand drought and salinity (56)	30	50 T	Yes	2	
o. Subirrigation and unsaturated leaching strategy (58)	Present	20 T&I[11]	Yes	3	
p. Landscaping with artificial materials (60)	Present	15 T&I[12]			Yes

[10] Dual sewage system replacing water in ten years

[11] For selected locations

[12] For widespread use

(A)(2)(j) - (A)(2)(p)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
3. To increase and/or decrease future demand for water (direction uncertain or different directions in different regions)					
a. Conversion of solar energy to heat and power					
i. Heat	Present[13]	20 T&I			Yes
ii. Power (62)	30	50 T			Yes
b. Power generating units for meeting peak demands (64)	Present	20 I[14]			Yes
c. Electric power transmission over long distances					
i. D. C.	Present	15 I			Yes
ii. Cryogenic (66)	10	20 T&I			Yes
d. Oil shale conversion to liquid fuel (67)	Present	25 T&I			Yes

[13]For small-scale heating

[14]For significant impact

(A)(3)(a) - (A)(3)(d)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
e. Advanced communications systems (69)	Present	25 T&I[15]			Yes
f. Central electric vs on-site total energy system (70)	Present	10 I[16]			Yes
g. Geothermal energy (71)	10	20 T			Yes
h. Regional environmental management of bays and estuaries (73)	10	20 T&I	Yes	1	
i. Vegetation management (74)	Present	10 T&I	Yes	2*	

*Significant research already in progress

[15] Will not be a significant factor in urban planning for 50 years or more

[16] Total electric converts to total energy system

(A)(3)(e) - (A)(3)(i)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
B. Technical Developments Which Should Increase Usable Supplies of Fresh Water					
1. By making new sources available where needed					
a. Desalting of seawater and brackish water (78)	Present	20 T&I[17]	Yes	1*	
b. Compact water desalting units for residential use (80)	Present	20 T[18]	Yes	4	
c. Precipitation increase through cloud seeding (81)	Present[19]	10 T&I[20]	Yes	2*	
d. Long-term seasonal precipitation forecasting (82)	20	30 T	Yes	3	

*Significant research already in progress

[17] In selected areas

[18] Limited use in rural situations

[19] Quantitative effects not yet clear

[20] In limited areas

(B)(1)(a) - (B)(1)(d)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
e. Augmenting fog drip (83)	Present	30 T[21]	Yes	4	
f. Artificial ice field (84)	5	20 T	Yes	4	
g. Deliberate snow/ice avalanching (86)	10	20 T&I	Yes	4	
h. Melting of ice caps to create lakes (87)	30	70 T&I	Yes	4	
i. Iceberg towing (88)	20	50 T&I	Yes	3	
j. Collapsible bladders for transport of liquids (89)	Present	30 T	Yes	3	
k. Underseas aqueduct (90)	20	40 T&I	Yes	3	
l. Offshore reservoirs					
i. Using flexible bladders	20	40 T&I	Yes	4	
ii. Using dams in estuaries to create fresh water reservoirs (92)	Present	25 I	Yes	2[e]	

[e] Significant environmental and other considerations

[21] Impact limited

(B)(1)(e) - (B)(1)(l)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
m. Large-scale canal systems to carry water from regions of surplus (94)	Present	40 I[22]	Yes	2[e]	
n. Nuclear explosives for canal, tunnel and reservoir construction (96)	20[23]	40 I[23]	Yes	4	Yes
o. Service tunnel in urban areas for electric power distribution, sewage, water services, and storm drainage (97)	Present	20 T&I	Yes	4	Yes
2. By conservation of existing sources					
a. Evaporation reduction from lakes and reservoirs (99)	Present[24]	20 T	Yes	2*	

[e]Significant environmental and other considerations

*Significant research already in progress

[22]Highly dependent upon ecological, sociological, and economic factors

[23]Dependent upon treaty restrictions and whether radioactive contamination of environment can be avoided

[24]On a small scale

(B)(1)(m) - (B)(2)(a)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
b. Phreatophyte control					
i. Mechanical	Present	Present			Yes
ii. Chemical	Present	Questionable[25]	Yes	2	
iii. Biological (100)	15	30 T&I	Yes	1	
c. Run-off water control using rock tunnels and galleries (103)	Present	25 I	Yes	3	Yes
d. Groundwater storage and management (105)	Present	20 T&I	Yes	1*	
e. Groundwater recharge using craters (107)	20[26]	40 T&I[26]	Yes	4	
f. Soil and rock reservoir modification (108)	10	20T	Yes	2*	
g. Watershed management: surface water harvesting (110)	Present	15 T&I	Yes	1*	

*Significant research already in progress.

[25]Doubtful due to ecological considerations.

[26]Dependent upon treaty restrictions and whether radioactive contamination of environment can be avoided.

(B)(2)(b) - (B)(2)(g)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
C. Technical Developments Which Extend the Usefulness of Impure Water (More Use Out of Given Amount of Water)					
1. Advanced waste treatment: Improved processes for purification and reuse (114)	Present	10 T&I	Yes	1*	
2. Instream aeration for water quality improvement (116)	Present	10 T&I	Yes	2	
3. Waste water renovation by surface spreading (117)	Present	15 T	Yes	1	
4. Water recycling in manufacturing industry (119)	Present	10 T&I[27]	Yes	1*	
5. Increased use of seawater by industry (121)	Present	15 T&I[28]	Yes	2*	Yes

*Significant research already in progress

27 For substantial decrease in industrial water withdrawal per unit of product

28 For major impact

(C)(1) - (C)(5)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
D. Technical Developments Which Could Have an Influence on Future Water Demands and Supplies					
1. Reservoir bottom water use (124)	20	40 T&I	Yes	4	
2. Subsurface and marine waste disposal (125)	15	30 T&I	Yes	1[e]	
3. Crop production by use of residual heat and other by-products (127)	15	30 T	Yes	2	
4. Reducing contaminants from watershed areas (129)	Present	20T	Yes	3*	

[e]Significant environmental and other considerations

*Significant research already in progress

(D)(1) - (D)(4)

Technical Development	Years Until Feasible	Years Until Fully Operational	Application depends upon R&D specifically directed to influencing water supply or demand	Research Priority	Application depends upon technological progress on subjects other than water
E. Considerations Which Could Influence Technical Achievements					
1. Populating the desert (132)	N. A.*	N. A.	Yes	2**	Yes
2. Rationalizing the market for water services (133)	N. A.	N. A.	Yes	1**	Yes
3. Residential water demand modification (136)	N. A.	N. A.	Yes	3**	Yes
4. Water based recreation trends (138)	N. A.	N. A.	Yes	2**	Yes
5. Reservoir role in water management (139)	N. A.	N. A.	Yes	3**	Yes
6. Effects of bioconcentration of toxic materials (141)	N. A.	N. A.	Yes	1**	Yes

*Not applicable

**Research is needed on these considerations to determine the impact that their adoption would have on technical developments related to water

(E)(1) - (E)(6)

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CHAPTER III

SECTION B

LIST OF RESEARCH PRIORITIES FOR THOSE TECHNOLOGIES WHOSE APPLICATION DEPENDS ON RESEARCH AND DEVELOPMENT SPECIFICALLY DIRECTED TO INFLUENCING WATER SUPPLY AND DEMAND

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RESEARCH PRIORITIES

First Priority (Critical need for research)

Industrial cooling systems using air (A)(2)(i), p. 47, 151.
Bioprocessing to provide food (A)(2)(l), p. 51, 152.
Regional environmental management of bays and estuaries (A)(3)(h), p. 73, 154.
*Desalting of seawater and brackish water (B)(1)(a), p. 78, 155.
Phreatophyte control, biological (B)(2)(b), p. 100, 158.
*Groundwater storage and management (B)(2)(d), p. 105, 158.
*Watershed management: surface water harvesting (B)(2)(g), p. 110, 158.
*Advanced waste treatment: improved processes for purification and reuse (C)(1), p. 114, 159.
Waste water renovation by surface spreading (C)(3), p. 117, 159.
*Water recycling in manufacturing industry (C)(4), p. 119, 159.
+Subsurface and marine waste disposal (D)(2), p. 125, 160.
**Rationalizing the market for water services (E)(2), p. 133, 161.
**Effects of bioconcentration of toxic materials (E)(6), p. 141, 161.

Second Priority

Cooling tower design and utilization in industry (A)(2)(h), p. 45, 151.
Artificial anti-transpirants (A)(2)(m), p. 55, 152.
Genetic development of plants to withstand drought and salinity (A)(2)(n), p. 56, 152.
*Vegetation management (A)(3)(i), p. 74, 154.
*Precipitation increase through cloud seeding (B)(1)(c), p. 81, 155.
+Offshore reservoirs, dams (B)(1)(l), p. 92, 156.
+Large-scale canal systems to carry water from regions of surplus (B)(l)(m), p. 95, 157.
*Evaporation reduction from lakes and reservoirs (B)(2)(a), p. 99, 157.
Phreatophyte control, chemical (B)(2)(b), p. 100, 158.
*Soil and rock reservoir modification (B)(2)(f), p. 108, 158.
Instream aeration for water quality improvement (C)(2), p. 116, 159
*Increased use of seawater by industry (C)(5), p. 121, 159.
Crop production use of residual heat and other by-products (D)(3), p. 127, 160.
**Populating the desert (E)(1), p. 132, 161.
**Water-based recreation trends (E)(4), p. 138, 161.

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*Significant research already in progress
**Research is needed on these considerations to determine the impact that their adoption would have on technical water problems
+Significant environmental and other considerations

Third Priority

Transport of solids by water slurry pipeline (A)(1)(d), p. 26, 150.
Recirculation cooling pond development (A)(2)(g), p. 43, 151.
Subirrigation and unsaturated leaching strategy (A)(2)(o), p. 58, 152.
Long-term seasonal precipitation forecasting (B)(1)(d), p. 82, 155.
Iceberg towing (B)(1)(i), p. 88, 156.
Collapsible bladders for transport of liquids (B)(1)(j), p. 89, 156.
Underseas aqueducts (B)(1)(k), p. 90, 156.
Run-off water control using rock tunnels and galleries (B)(2)(c), p. 103, 158.
*Reducing contaminants from watershed areas (D)(4), p. 129, 160.
**Residential water demand modification (E)(3), p. 136, 161.
**Reservoir role in water management (E)(5), p. 139, 161.

Fourth Priority (Minimum requirement would be feasibility study)

Fire hazard area irrigation (A)(1)(e), p. 27, 150.
Water as diluent for wastes (A)(2)(j), p. 49, 152.
No-rinse washing/laundry technology (A)(2)(k), p. 50, 152.
Compact water desalting units for residential use (B)(1)(b), p. 80, 155.
Augmenting fog drip (B)(1)(e), p. 83, 156.
Artificial ice field (B)(1)(f), p. 84, 156.
Deliberate snow/ice avalanching (B)(1)(g), p. 86, 156.
Melting of ice caps to create lakes (B)(1)(h), p. 87, 156.
Offshore reservoirs, flexible bladders (B)(1)(l), p. 92, 156.
Nuclear explosives for canal, tunnel and reservoir construction (B)(1)(n), p. 96, 157.
Service tunnels in urban areas for electric power distribution, sewage, water services, and storm drainage (B)(1)(o), p. 97, 157.
Groundwater recharge using craters created by nuclear devices (B)(2)(e), p. 107, 158.
Reservoir bottom water use (D)(1), p. 124, 160.

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*Significant research already in progress
**Research is needed on these considerations to determine the impact that their adoption would have on technical water problems

C. TRENDS AND INTERACTIONS CONCERNING FUTURE TECHNOLOGIES

Trends in Technology

Systematic examination of technological trends is a recent development. Such trend analysis is based upon a study of the technical and socioeconomic factors that lead to technological invention and innovation. The object is to forecast the direction of technological developments for consideration in long-term planning but not necessarily to predict outcomes uniquely.

There is keen awareness of a need for skill in trend analysis for long-range planning in industry, manufacturing and defense. This type of analysis has not been applied in water-resources development. Its absence in this field is not because of lack of social significance of technology, but rather that there is virtually no market stimulation in water-resources development. As will be shown, the nature of problems that lie ahead in assuring that the required amount and quality of water is available for future use will make technology a factor of importance. High social value of technology related to water in the past has not proved a sufficient motivation for technological innovation. There must also be substantive advantage. For instance, trend analysis could identify the requirement for specific research directed toward a realistic and operational future technology.

Role of Research

The Committee sees two direct uses of an analysis of technological trends in water resources. The first is that the forewarned planner can adjust his policies today to profit by those technologies that may be favorable and to minimize the effects of those technologies that may prove adverse. The second use is assessment of technological possibilities as the basis for guiding technology itself towards socially useful purposes through research. The Table in III-A lists those technological possibilities that have been identified which may occur as a result of research and development specifically directed to influencing water supply or demand or which may occur as a result of technological progress on subjects other than water. Of those listed, two-thirds are in the latter group. This leads to the conclusion that considerable research and development outside of the direct water resources field will have a major impact on the development of the necessary techniques to assure that the required amount and quality of water is available in the future.

Effects of Natural Limits

The water economy of the past and continuing into the present, based essentially on a once-through pattern of use, is limited closely to the natural hydrologic cycle. To improve this situation, it is necessary that those technological developments that yield new supplies or increase the efficiency of use of present supplies are promoted. Many such technological possibilities are listed in Chapter II-B. For example:

Precipitation increase through cloud seeding
Long-term seasonal precipitation forecasting
Iceberg towing
Underseas aqueducts
Phreatophyte control
Groundwater storage
Watershed management

Although the natural operation of the hydrologic cycle will continue as a dependable source of fresh water, over the long run two emerging limits appear with converging influence upon technology. The first is the limited nature of the water resource itself; and the second is the finite capacity of the water and earth environment to assimilate wastes--the residuals of man, farm, factory and power. These limits, especially the second, will encourage those technological trends that tend to separate the water economy from the hydrological cycle.

Modifying residential demands and water-use patterns over the next thirty years will greatly enhance the feasibility of recycling and reduction of the use of water as a diluent for wastes. Technical developments that extend the usefulness of impure water will have an immediate impact on lessening the pure water requirement for industry and municipalities.

Food and power production, now among the major users of water, will tend to lessen the intensity of their technical requirements for water. Advances in agriculture and food production will improve the efficiency of agricultural water use. Population growth, coupled with international aid policies should assure the research needed to make bioprocessing of food (Item A-2-1) operational by the year 2000. A major impact on the future water picture can also be expected to come from the energy-demand sector. Electric power generation by several methods, as discussed in Items A-2-a through A-2-f, should reduce the demand for water in the power generation process. However, an investment in research in alternate cooling methods for power plants and alternate fuel sources should shorten the predicted 10-40 year development period. Conversely, such developments would reduce the need for investment in technologies such as creation of artificial ice fields, melting of ice caps to create lakes, iceberg towing, creation of artificial anti-transpirants and the genetic development of plants to withstand drought and salinity; all of which are part of the once-through technology.

Technological Factors

The table on technological possibilities notes two dates in the development of each possibility--"years until feasible" and "years until fully operational." Of the 70 items listed, about 60 percent are feasible now or feasible, on the average, within five years, indicating that these concepts are based on what is already known. By contrast, the estimated period before the concepts become fully operational (average of about 25 years) suggests that the application of invention involves the greater length of time, and therefore, the greater hazard in forecasting. Technical feasibility of an invention is based upon scientific and engineering principles, but application is often more complex than the fundamental technology owing to cross impacts and interrelationships among technological, social, and economic circumstances and policies.

Cross Impact

One of the major sources of ambiguity in any attempt to analyze alternative future possibilities (technological or otherwise) is the fact that each time a possibility becomes an actuality, the inherent probabilities of other events are altered. That is, when event A actually occurs, the probability of some other event (B) may increase while the likelihood of a third possibility (C) may decline either for technological, economic, or social reasons. In other words, A may have been a prerequisite for B and a competitor of C.

In very general terms the possible relationships between the joint probabilities of ordered pairs of hypothetical futures may be expressed as probability-enhancing (i. e., synergism or potentiation) or probability-reducing (i. e., antagonism or depotentiation). Thus, technology A might accelerate the development of B while the sequence B-A might be simply impossible. Or if B did come about independently, it might have no effect on the possibility of A occurring later on; or if B came first, it might even preempt A if work on A was being pursued largely in the hope of arriving at B.

There are several ways that one development may influence another. In the negative direction, a very successful development may entirely preempt the field, thereby effectively stifling other developments directed toward the same objective. Somewhat less decisive would be a development which would result in capture of only part of the market, competition then becoming a factor in deterring to some extent other developments. This competition can be in the form of demands for the same resources or in supplying similar or identical products or services.

In some instances, developments result in a new technology which can also be utilized by related or competing developments, thereby stimulating the latter. Sometimes a new development creates a large demand for a product which provides a sufficient market to stimulate new techniques for making the product. Another stimulus can be the demand for a new component or service related to new development, which in turn brings about a technical development to meet the need.

Analysis of these complex alternatives can be facilitated by utilizing a form of cross-impact matrix. This type of cross-impact analysis can be applied to any number of elements and what follows represents a preliminary effort by the Committee to express relationships between some of the technological possibilities described in the area of power generation and cooling. The number of possibilities listed below could obviously be expanded, but the Committee believes that most of the relevant trade-offs for power generation and cooling would be covered by these 16 items.

Power Generation and Cooling

Item	Relevant Technological Possibilities	Concept	Page
1	Air cooling towers	A-2-h	45
2	Electric power generation by conventional nuclear reactors	A-1-b	22
3	Electric power generation by gas-cooled nuclear reactors	A-2-a	35

Item	Relevant Technological Possibilities	Concept	Page
4	Electric power generation by nuclear fusion	A-2-b	36
5	Electric power generation by fuel cells	A-2-c	38
6	Electric power generation by MHD	A-2-d	39
7	Electric power generation in open-cycle engines	A-2-e	40
8	Electric power generation by wind and water power	A-2-f	42
9	Conversion of solar energy to heat & power	A-3-a	62
10	Geothermal energy	A-3-g	71
11	Central energy vs. on-site total energy systems	A-3-f	70
12	Power generating units for meeting peak demands	A-3-b	64
13	Transmission of electric power over long distances	A-3-c	66
14	Transport of solids by water slurry pipeline	A-1-d	26
15	Gas production from coal	A-1-a	21
16	Oil shale conversion to liquid fuels	A-3-d	67

After making a list, the next step is to set up a 16 x 16 matrix, as shown on the next page. The horizontally cross-hatched matrix element corresponding to the fourth row (fusion power) and the third column (high-temperature gas-cooled reactor) refers to the case where fusion power is assumed to exist already. The entry describes a judgment as to the increase or decrease in the probability of the high-temperature gas reactor (HTGR), given the existence of fusion. It was judged that a successful fusion plant would reduce the chances of the HTGR, hence the entry is a negative number. The reverse situation, where the HTGR is assumed to exist first, is shown in the vertically cross-hatched matrix-element which is located symmetrically across the diagonal of the matrix. In this case the Committee judged that the probability of a successful fusion plant would be slightly (but not greatly) enhanced since it might utilize some of the HTGR technology.

GIVEN THESE DEVELOPMENTS		1. AIR COOL TOWERS	2. CONV. REACTORS	3. HTGR	4. FUSION	5. FUEL CELL	6. MHD (CONV.)	7. OPEN CYCLE (AIR) ENGINES	8. WATER POWER	9. SOLAR	10. GEOTHERMAL	11. T/E	12. SPEC. PEAK POWER	13. LD POWER TRANSMISSION	14. LD SLURRY TRANSPORT	15. COAL GASIFICATION	16. OIL SHALE → GASOLINE	COMMENTS
AIR COOL	1.		+1	-1	0	-1	-1	-1	NA	0	0	-1	0	+1	0	0	0	
CONV. REACTOR	2.	+3		-2	-1	-1	-2	-2	NA	0	0	+1	+2	+2	-1	-1	0	WATER-COOLED/SODIUM-COOLED BREEDER
HTGR	3.	-1	-2		+1	-1	+2	-1	NA	0	0	+1	+2	+2	-1	-1	0	
FUSION	4.	+2	-4	-4		-1	-4	-4	NA	-1	0	+1	+2	+3	-1	-1	0	USES MHD FOR CONVERSION
FUEL CELL	5.	-1	0	-1	-1		-1	-1	NA	-1	0	0	+2	+1	+1	+2	0	HIGH TEMP. ONLY
MHD	6.	-1	-1	+1	+2	-1		-1	NA	-1	0	0	+2	+1	+1	+1	0	FOSSIL OR NUCLEAR FUEL
OPEN CYCLE (AIR) ENGINE	7.	-1	0	0	0	0	0		NA	0	0	+2	0	0	0	+1	+1	GAS TURBINE TYPE
WATER	8.	-1	0	0	0	0	0	0		0	0	0	-1	+2	-1	-1	0	EXISTING TECHNOLOGY
SOLAR	9.	0	0	0	0	0	0	0	NA		0	+2	+2	0	-1	-1	0	
GEOTHERM.	10.	-1	0	0	0	0	0	0	NA	0		0	0	+2	-1	-1	0	
T/E	11.	-1	-2	-1	0	-1	-1	+2	NA	0	-1		-2	-1	0	+3	+1	UTILIZES OPEN CYCLE OR STEAM ENGINE
PEAK POWER	12.	+1	0	0	0	0	0	+4	NA	+1	0	-1		+2	0	0	0	PUMPED STORAGE IN REMOTE AREAS
LD TRANS-MISSION	13.	0	+1	0	0	+1	+1	0-	NA	+1	+2	-1	+2		-1	-1	0	ASSUMED E4V OR CRYOGENIC
LD SLURRY	14.	0	-1	-1	0	+1	+1	0+	NA	0	0	0	0	-1		-1	0	
COAL GASIF.	15.	0	-1	-1	0	+3	+2	+1	NA	0	0	+2	0	-1	-1		+2	
OIL SHALE	16.	0	-1	-1	0	0	0	+1	NA	0	0	+1	0	0	0	+2		

NA: **NOT APPLICABLE (IF ITEM IN COLUMN IS ALREADY WELL ESTABLISHED, IT CANNOT BE PRECEDED BY ANOTHER EVENT.)**

Potential Technological Advances and Their Impact on Anticipated Water Requirements
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The matrix elements have been filled in with numbers ranging from minus 4 to plus 4, where minus 4 would imply strong antagonism (or de-potentiation), plus 4 would imply strong synergism (or potentiation) and zero would imply no effect either way.

A matrix such as the above as may be constructed for other problem areas offers the possibility of tracing chains of interrelations. For example, one may identify some symbiotic chains. Coal gasification (A-1-a) induces positively the fuel cell (A-2-c), MHD (A-2-d), total energy systems (A-3-f) and oil shale conversion (A-3-d), each of which is shown symmetrically to have a positive effect on the gasification of coal. One may surmise that there is strong technological inducement for coal gasification; moreover, that although it will increase the intensity of a regional demand for water, some of the related processes have an opposite or off-setting effect on water demands.

Similarly one may note that the long-distance power transmission (A-3-c) would be positively induced by several technologies and in turn would induce other technologies such as geothermal power (A-3-g) and special peaking capacity (A-3-b).

On the other hand the development of fusion power would discourage the development of several other energy technologies; for example, MHD (A-2-d) and open-cycle engines (A-2-e). While it in turn would be only weakly discouraged by conventional reactors and fuel cells. The development of MHD, however, would contrariwise give inducement to fusion power.

Thus the interactions among the several possible technologies favor certain combinations and discourage others. In Chapter IV, prospective development of technologies in several fields--food, power, urban, and waste disposal--are traced, based on recognition of the relationships among the technologies and the other factors outlined in this Chapter. The discussions in Chapter IV serve to emphasize the interrelationships among technological developments and their impacts on a few of the sectors of the water economy.

CHAPTER IV

APPLICATION OF TECHNOLOGIES TO FUTURE WATER SUPPLY AND DEMAND

INTRODUCTION

In this chapter the Committee has reviewed the technological concepts in Chapter II and examined them as they apply to the following areas: (A) Food Production, (B) Electric Power Generation and Cooling, (C) Urban Water Demand and Supply, and (D) Municipal Waste Disposal. In these four scenarios, we have attempted to describe possible future sets of compatible technologies in selected problem areas. In the projections an identification of the major political, social and economic factors that might dominate the use of water are given special consideration. These examples illustrate how the various technologies might interact in a consistent set of conditions and should be viewed as possible futures, not predicted futures.

The direction of water use and control over the years will depend to a large extent on the opportunities provided by technological invention and innovation and upon the judgment used in choosing among them to realize their benefits and to avoid their destructive potentials. Some of the technologies affecting water use and/or availability will come about as a spin-off result of technological progress which is not specifically water related. However, specific research undertaken to solve water problems will be the controlling factor in developing many of the technologies. The value of research on technological developments related to water use and/or supply cannot be overemphasized.

Consideration of potential technology as it affects water is rather new in water planning. Few significant changes in water technology have occurred, and plans for developing and using water in the past have been implemented without regard for the effects of technological development. The fact is that technological changes have occurred, but in ways not anticipated. The deep-well pump and sprinkler irrigation systems that have revolutionized irrigation by promoting the development of otherwise inaccessible groundwater and nonirrigable land were not parts or results of river-basin planning.

The usefulness of long-range forecasts in water planning is complicated by the great difficulty of assigning probabilities of an event occurring within a practical term of years since technology responds to an ever-changing environment and requires continuous consideration. There are two recent reports which suggest that technology should be considered in a timely manner for man's benefit. One by the National Academy of Sciences, Technology: Processes of Assessment and Choice,[1] and another by the National Academy of Engineering, A Study of Technology Assessment.[2] We share with these reports a high regard for sensitivity to the risks, as well as the benefits of technological innovation.

The Committee wishes to underscore the suggestion that assessment of environmental and social effects should be part of each new technological proposal and that the research necessary to accomplish such assessment be included and so identified among research objectives of the water resource agencies.

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[1]National Academy of Sciences, Technology: Processes of Assessment and Choice, A report by the Committee on Science and Public Policy to the Committee on Science and Astronautics, U. S. House of Representatives (Washington: U. S. Government Printing Office, 1969), 163 pp.

[2]National Academy of Engineering, A Study of Technology Assessment, A report to the Committee on Public Engineering Policy to the Committee on Science and Astronautics, U. S. House of Representatives (Washington: U. S. Government Printing Office, 1969), 208 pp.

A. FOOD PRODUCTION

Future Food Needs

To predict future food needs is indeed uncertain with various predictions of future population growth having been made ranging from the cataclysmic growth of the world population leading to disaster predicted by some to the utopian zero population growth dreamed by others. To be sure, the world's population will continue to grow in the foreseeable future, likely growing from the present three billion plus to six or seven billion by the year 2000, or soon thereafter. United States' population will continue to increase, but estimates of future population vary considerably depending on the assumptions made and the conditions prevailing at the time of the forecast. In 1968 the Water Resources Council adopted the projection reflecting the past trend that population would reach 337 million by 2000 and 468 million by 2020.[1] More recent Bureau of the Census estimates of future population growth are much smaller, reflecting a current slower rate of increase. These estimates range downward to 266 to 321 million by 2000 and 300 to 440 million by 2020.[2]

Regardless of which estimate of world food needs is accepted, there will be an increased need for food production. This food need may well become critical in many parts of the world, but in the United States there will be no shortage of food supplies. These food supplies will come from both increased productivity from conventional agriculture and also from new food sources which are grown in an artificial

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[1] Water Resources Council, The Nation's Water Resources, 1968, Table 3-1-1.

[2] Bureau of the Census, Population Estimates and Projections, Series P-25, No. 448, August 6, 1970.

environment. To consider world food needs and how the United States might help supply those needs involves future international policy and other factors. The view given herein is restricted to the United States situation.

By the turn of the century there will be some well-established changes in the kinds of foods used by many. Per capita food consumption in the lower income groups will continue to be determined more by the economic status and ability to buy than by available food supplies. In general there will be a trend toward higher protein diets, and these will initially include more meat and meat analogs manufactured from vegetable protein sources. While the gross consumption of fresh fruits and vegetables and specialty crops will increase slightly, the per capita consumption will be reduced because of the improved technology of processing foods which in many cases will make the processed product more desirable to the average person.

<u>Technological Ways of Meeting Needs</u>

In addition to the production of traditional agronomic and fruit and vegetable crops with concurrent farm animal production, there are ways the basic nutritional needs (particularly protein) can be met through technology. For many of these, the basic technology already exists, but the bottleneck hindering their wider use is palatibility of the food materials and personal acceptance of the food tastes. Also, there has been no real need for aggressive research in the direction of developing the food science and technology to overcome these barriers. The United States has never been a food deficient nation on any major scale. However, worldwide concern for food shortages will help provide the spark for increased research on new food sources and the spin-off will provide information on new food types in this country which will be made esthetically pleasing, tasty, nutritious and economical.

Some of the new foods will include greater use of fish and other marine food sources, often from carefully designed aquaculture and mariculture enterprises. The potential for using whole fish in preparing fish protein concentrate will be realized. Protein production from microorganisms is feasible now but the extent of this technology is now in its infancy. Torula yeast, which contains 50 percent protein, has been produced and used as human food, but in general has not proved acceptable. There are thousands of fungi and bacteria with similar protein content that could be a suitable food source, and these along with algae could feed on waste materials. Wholly synthetic foods will be developed by modern food science which are nutritious base materials for building new and tasty "snythetic meats."

Another new food source which will come into importance will be food factory complexes which use residual heat and other by-products for crop production (D-3). These operations will utilize heat and other materials that could potentially become pollutants in a controlled food production operation. High value crops, many developed from genetic research, will be grown in these food factories.

None of these ways of producing foods will replace agriculture which also will become more efficient. Vegetative production through the photosynthesis reaction will remain a basic renewable resource using the sun's energy plus mineral nutrients to fix carbon and thereby provide the major base material for human food needs. However, there will be some changes in the upward trend in productivity which has existed in recent decades. In many cases future increases in productivity will be slower than in the past because of reduction in the use of production inputs such as pesticides and fertilizers out of concern for their deleterious side effects.

Least Surprising Situation--Year 2000

The relative importance of western irrigation will decrease although it will have expanded some in areas where water can be provided. The specialty crops will remain a water user which can pay high prices for water. However, future expansion of irrigation will face critical scrutiny because the food materials can be produced less expensively elsewhere and the motivation to subsidize projects when irrigation is a primary use will be reduced. Irrigation will continue to use available water from multipurpose projects until other users of waters, such as municipal and industrial users, catch up with the total supply provided.

Irrigation will expand in the central and southeastern United States where adequate water supplies are available. This expansion will be on a localized basis rather than project-type developments, but many producers will have eliminated water as a potential production controlling factor, particularly for food crops.

Large, highly efficient mariculture operations will be producing high-quality sea foods along the coasts particularly in the warmer climates of the Southern Pacific, Gulf and Southern Atlantic coasts. Also aquaculture production in the southern United States will have become big business providing a significant amount of high protein food. These operations will be comparable to large cattle feedlots of today using scientifically formulated fish rations resulting in high feed conversion efficiency.

Food factories where specially bred agricultural crops are grown in controlled environmental systems using waste heat, carbon dioxide enrichment and sophisticated water, fertility and pest control systems should be making a commercial impact, but the relative amount of food produced will be small at this time. These food factories may be tied to power generation operations where heat rejection has been an environmental problem and will have in several cases totally eliminated thermal pollution.

Microbial food sources will be at a level of development comparable to the food factories. However, the problems of public acceptance of these products will be essentially solved because the final food products from these sources will be tasty, pleasing and highly nutritious. Many will consider these foods a desirable part of a good diet.

By 2000, there will be a major trend by some people toward the artificial meats developed from non-animal protein spun into protein fibers from plant and microbial proteins. The acceptance of new and innovative kinds of foods will be well established.

Potential Impact on Water Use

Future food production will come from many sources including all the presently known agricultural production techniques as well as new ones resulting from technology. However, as demand for water continues to increase in water deficient regions there will be a strong trend toward the water users having to pay all costs of the water. Competing uses for limited water which can pay more will ultimately win out and be the user and the available supplier. This means that irrigation of cereal, forage and fiber crops will become comparatively less important in the arid regions. The slack in production will be taken up by the agricultural regions in the midwest and the south where the natural conditions are more favorable for production, and by the new food production technologies mentioned before. Specialty agricultural crops of the arid areas will remain important and competitive because of their high value and productivity in the arid climates.

Irrigation water use will not decline in total amount because some new supplies will be economically developed, particularly in the central and southeastern United States. Yet, there will be reduction in those areas such as the arid southwest where population density is great and competing demands use up the supplies. To assume that the increasing needs for human food in the United States in the next half century will have to be met to any major degree by increased irrigation in arid regions would be to ignore the potential food producing technologies which will be developed.

B. ELECTRIC POWER GENERATION AND COOLING

Future Power Needs

In the last few decades, electric power generation and use in the United States has roughly doubled every ten years. Most of the credible forecasts of electric power generation are based on a similar exponential growth, but some with a slightly smaller factor. In the thirty years remaining in this century, an eight-fold expansion in electric power generation would appear to be an upper limit, with perhaps five-fold as a lowest projection. Other than perhaps population, there are very few factors that would materially upset these projections of great increase in the generation of electrical power.

Because practically all of the electric capacity expansion will be based on the use of fuels (including nuclear), the quantities of heat dissipated to the environment will greatly increase. Present and foreseeable technological and economic factors dictate the use of water as the principal medium of waste heat disposal. There will be, accordingly, a greatly increased demand for cooling water in the nation's electric power plants.

Technological Ways of Meeting Needs

As indicated in Chapters II and III, there are several possible methods for generating electric power which could materially reduce the requirements for cooling water per unit of electric energy produced. The primary incentive for developing these processes is the possibility of reducing fuel requirements per unit of electric energy generated. However, simultaneously with a reduction in fuel input, there are reductions in heat dissipation and cooling requirements. The degree to which one or more of these new, very efficient power generation systems is utilized in the future will have a direct effect on cooling water demand and use.

There are some new power generation methods which might almost eliminate the need for cooling, whereas others, if successful, would permit substantial reductions in cooling water requirements. Direct conversion systems, not involving a steam cycle, such as fuel cells (A-2-c) and perhaps magnetohydrodynamics (MHD) generation (A-2-d) might require very little, if any, water cooling. Gas-cooled nuclear reactors operating at high temperature (A-2-a) and certain dual systems such as MHD coupled to a conventional steam cycle would permit considerably decreased water use.

There are also some potential power generation systems which might increase or decrease water use, depending upon circumstances and locations. These include such possibilities as power from solar and geothermal energy sources (A-3-a). Although not specifically methods for power generation, other technological developments could also influence water use in presently uncertain direction or in different directions in various locations. These methods include techniques for long-distance transmission of electric power (A-3-c) and the storage of power by off-peak water pumping (A-3-b). Other peaking systems, such as small and large hydroelectric stations, and generators operated by internal combustion engines, employ water in special ways or use no water at all.

Still another development in electric power generation systems is increasing water demand per unit of electric output. This is the "conventional" nuclear power plant (A-1-b) employing pressures and temperatures in the steam cycle which result in overall thermal efficiencies considerably below those experienced in modern fossil fuel plants. Reductions in cooling water use in electric power generation will therefore be contingent on the gradual phasing out of this type of nuclear plant and the substitution of plants having considerably higher efficiencies, such as the gas-cooled reactors.

Superimposed on the new and potential methods for electric power generation are the technologies of power plant cooling. The almost universal use of water for this purpose is expected to continue. The large variable, however, is the extent of water reuse for power plant cooling, as permitted by the operation of cooling towers (A-2-h), spray ponds, and cooling lakes (A-2-g). Although not a new technology, these systems are being increasingly used even in water-abundant regions with the combined benefits of reduced withdrawal requirements and decreased thermal pollution. By far the majority of power plants and the power generated in the United States is based on once-through cooling systems which withdraw and return to the stream, typically, about forty gallons of water per kilowatt hour generated. A recirculation system requires only one-to-two gallons of makeup water for a kilowatt hour of generation.

Another method for heat dissipation from power generating plants is by air cooling, directly or indirectly, without any water loss whatever (A-2-h). Although more costly, these systems can be employed if water is unavailable. Technological development can be expected to reduce the cost of air cooling systems, thereby making them more attractive for future use.

In ideal circumstances, the waste heat in the condenser water from a power plant may be beneficially used (D-3). Warm water can increase crop yields when used under proper conditions. Problems of matching availability of warm water with yearly agricultural needs may severely restrict application, so it is unlikely that this will be a large factor in future power plant cooling systems.

Some of the foregoing concepts have a direct or indirect bearing on the possible location of new power plants. Efficient long-distance transmission of electric power (A-3-c) would permit plant location where abundant supplies of water are available, particularly on the seacoasts. Ocean water for power plant cooling can be employed if suitable protective measures are utilized (C-5). Nuclear plants, involving no problem of flue gas dissipation as in fossil fuel plants, could even be located beneath the sea, near the shore line. Underground locations may also be practical. If, of course, methods of power generation requiring no cooling water are developed, desolate areas, such as the deserts, might be advantageously used as sites. In the foreseeable future, however, it appears that ample supplies of water for makeup of recirculation cooling systems will be prime requisites of suitable power plant sites.

At least into the next century, the United States power generation industry will depend very heavily on fossil fuel, mainly coal, for its energy source. The greatly increased size of new power installations, upwards from one million kilowatts, means enormous fuel tonnages. Location of these plants near the fuel source may therefore be expected to grow. Water supplies, even only for makeup in recirculation systems, can be expected to become critical in certain favorable locations insofar as fuel and power load centers are concerned. If, for a one-million kilowatt plant, a dependable water supply of one-to-two million gallons per hour could not be assured, such a plant would have to be located elsewhere, or nonevaporative cooling; i. e., air cooling, would have to be employed. Even with the $10-to-$20 per kilowatt capital cost penalty of air cooling versus water cooling assuming a total power plant investment of $150 per kilowatt of capacity, fossil fuels might have sufficient economic advantages from other standpoints to justify air cooling.

Predictions of water requirements for future electric power generation involve many uncertainties. The principal ones are the total amount of electric power generated, the mix of plant types employed (equivalent to power generation efficiency and total heat dissipation), and the mix of cooling systems employed. In more detail, regional considerations will be important, including distribution of population, distribution of power generation stations which involves, in turn, power transmission system types, and the other factors outlined immediately above.

Given a total amount of electric energy generation, cooling requirements will be highly dependent on power plant type and efficiency. If, for example, a breakthrough in fuel cell technology occurs, cooling requirements in plants of that type will practically disappear. If MHD can be successfully developed, the need for cooling will be reduced to one-half or possibly one-third of the present best plants. Power from nuclear fusion, if it can be developed, might involve cooling requirements similar to those now prevailing, or if some type of direct conversion system is successful, cooling would be only a fraction of the present.

Most Probable Situation--Year 2000

Since it is not possible to predict at this stage which, if any, of the radically new systems for electric power generation will be widely introduced, it is not possible to make credible forecasts of cooling water needs. There is, however, some basis for projecting over the near term--say thirty years. This is because existing power plants and those being planned and under construction, and those which will be planned prior to any possible radical change in power generation techniques will total a large fraction of all the electric power generation facilities in the next ten-to-twenty years, and they will also represent a significant portion of the total capacity even at the turn of the century. Cooling water requirements for these plants are fairly predictable, provided that some confidence can be placed in estimates of the proportion of total cooling which will be met by recirculation systems.

Potential Impact on Water Use

Figures gathered from numerous sources by Löf and Ward indicate that of all United States power plants of 500 megawatts and larger capacity estimated to be in operation by 1990, about 40 per cent will involve recirculation cooling.[1] It is probable that this proportion will materially increase as restrictions on thermal discharge become more severe. A 1990 total electricity generation of four-to-five trillion kilowatt hours per year, produced in plants totalling about one billion kilowatts capacity, will require the rejection of about five trillion Btu. per hour, assuming about half the power is from fossil fuel and high-temperature nuclear reactors, and half from moderate-temperature nuclear reactors. If all cooling were in once-through systems, about four billion gallons of water per hour would be required for heat dissipation. However, with about half the total generation involving recirculation systems, something on the order of two billion gallons per hour of cooling water intake will be necessitated. This is equivalent to about twenty-five trillion gallons (75 million acre feet per year).

It is clear that a much more significant factor in cooling water use in the future than the particular type of electric generation system employed is the degree of water recirculation in the nation's power plants. Water withdrawal for cooling, if recirculation were universally practiced,

[1] G. O. G. Löf and J. C. Ward, "Economics of Thermal Pollution Control," Journal WPCF, Vol. 42 (December, 1970), p. 2102.

would be only a percent or two of the once-through requirements (or two-to-four percent of the last figures stated above on the assumption of half the nation's plants using recirculation). It may therefore be fair to say that regardless of the type of power generation systems which may be evolved in the next half century, cooling water demands can be kept within reasonable bounds by the simple process of recirculation. Plants located directly on the seacoast will not need to reuse their cooling water because satisfactory provisions for discharging heated condenser water to the open sea can be established. It appears, then, that the overriding trend in water use for electric power generation will be in continually increased use of recirculation cooling, primarily by use of cooling towers, almost regardless of power generation system employed. In limited instances, there may be the use of direct or indirect air cooling, without evaporation, thereby completely eliminating water withdrawal requirements in these cases.

It is clear that total water requirements for electric power generation will increase during the next half century, regardless of other developments. It is improbable that the total demand could be met by once-through cooling of conventional power plants. Therefore, until some new type of power plant requiring very little cooling is developed, reliance will have to be placed in the future on recirculation cooling and on nonevaporative, direct air cooling. Singly, or in combination, these types of cooling systems will keep cooling water demand within reasonable capabilities. They will, in addition, prevent thermal pollution of America's rivers, lakes, and estuaries. Evaporation will, of course, represent an appreciable water requirement, but in the aggregate, this will be a relatively small factor in the nation's water use.

Power Plant Location

Power plant location in the next half century merits a few comments. Traditionally located near load centers, but also with a cooling water supply and a not-too-expensive fuel transport situation, power plants have proliferated in and near large cities. Several types of pressures are very probably going to change this pattern. Public opposition to large nuclear facilities near population centers, and large smoke emitters in the case of fossil fuel plants is forcing power companies to locate new plants away from the cities. Secondly, water availability is becoming more and more critical in otherwise favorable sites. Thirdly, the trend toward extremely large power plants (for reasons of scale economies) is making the transport and handling of enormous tonnages of coal increasingly difficult, thereby increasing the frequency of construction of power plants at or very near the coal mines supplying their fuel. Finally, progress toward efficient transmission of power over longer and longer distances is decreasing the need for locating the plants near the load centers. Still experimental developments in very long-distance transmission at high efficiency will probably further this trend. High-voltage direct-current transmission is already being employed on a limited scale, and the possibilities of almost loss-free transmission in underground cryogenically cooled conductors are attractive.

The above circumstances may result in a considerably changed pattern of power plant location in the future. One possibility is the heavy concentration of power plants at the seacoasts where unlimited supplies of salt water for cooling are available. Economical fuel transport facilities may also be utilized. Long-distance transmission of the power to load centers should be possible through use of the systems being developed. The nuisance aspects of large power plants may be minimized by locating them at adequate distances from population centers. Even further, the possibilities for locating nuclear plants on the sea bottom near the shore may completely avoid some of the objections now frequently interfering with their construction in more conventional sites. Underground locations (but provided with ample cooling water) may also be utilized.

The technical prospects for transmission of power over very long distances may make international and intercontinental power transfers possible. A global power network is not beyond imagination. Generation of power in countries where fuel and water are plentiful and export of electric energy, rather than fuels, to countries needing it should be economically feasible in a few decades. This development could greatly alleviate some of the concentrated demands for cooling water, but at the same time demands elsewhere could become severe.

It should not be inferred from the above discussion of power plant location that large generation stations will not also continue to be built near large lakes, rivers, and even comparatively small streams. With recirculation cooling, very limited water supplies will suffice for a million kilowatt plant.

Solar Energy

In the very long-range picture, attention will of course have to be given to the use of solar energy for virtually all of our electric power needs. If nuclear fusion can be developed to a practical stage, the day of solar power will be postponed at least by centuries, but as yet, there is no assurance that nuclear fusion can be utilized for these purposes. Therefore, if and when solar energy is used for large-scale electric power generation, enormous areas of the ground or possibly large-area satellites, will be needed to capture the solar energy and convert it to electricity. If heat engines are employed (steam engines being a specific example), cooling will have to be provided at a level equal to or even greater than in present-day power plants. Most of the sunny areas of the United States have limited water supplies, so great economy in water use would have to be the rule if solar power were to be generated on a large scale in these areas. Non-water consumptive cooling might have to be utilized, at a modest cost penalty. If economical direct conversion systems can be developed, either for terrestrial use or for generating power in space (to be beamed to earth receivers), the need for cooling water would disappear. Accordingly, electric power from the sun, when needed, does not appear to be unduly constrained by water availability.

Role of Technology in the Future

The role of technology in the future of water as an input in electric power generation appears to be mainly in the areas of minimizing water demand through conservation, reuse, and substitution of air cooling. Technology will have a powerful influence on the nature and degree of use of new power-generation systems, but the primary incentives here appear to be fuel conservation and overall cost economy through improved and more efficient generation systems. Cooling requirements become somewhat incidental to the other factors. So where technology can influence water requirements directly is in improvements in recirculation cooling design, cost reduction techniques, improvements in the aesthetic aspects of recirculation cooling structures and their environmental effects, and in the improvement and cheapening of cooling systems employing no water consumption.

Since it is generally cheaper to cool a power plant by use of a once-through system rather than a recirculation system, only limitations in water supply and in the temperature permitted in the discharge will cause a power plant to employ recirculation cooling. The former constraint is one imposed by nature; whereas the latter is imposed by law or public pressure. The combination of these factors is the primary potential for bringing about technical improvements in cooling water use in America's power plants.

C. URBAN WATER DEMAND AND SUPPLY

Introduction

The planning of water-resource development should take into account likely technological change, and research and development must be embedded in the planning process; i.e., as new problems are encountered and old problems reoccur, research and development should be counted on to provide new approaches and should be built into the "critical path" of the planning and development process.

Naturally, research and development will be more important at higher levels of government where research capabilities are greater and where there is greater capability to speed the benefits of research and development. State water resource departments should be developing research capacity and developing close working contact with federal river basin authorities to be sure that all technical knowledge is fully shared. Naturally, the same should be done by municipalities in their relationship to state and federal agencies.

Here we present a sequence of technological changes which are likely to affect the urban water supply-demand situation one way or another, whether or not they are planned for. If these changes are planned for, then adverse impacts can be minimized and their advantageous impacts maximized. The following scenario of possible technological changes is, naturally, hypothetical and in a probability sense can best be described as "not likely."

Factors Affecting Demand

A major factor in the urban water quality picture will be electric power generation. Methods of generation have substantially different cooling requirements, so the methods used will greatly affect diversions for cooling. Thermal pollution will also be directly dependent on generating techniques and cooling technology, whether once-through or recirculation.

Electric power generation by conventional nuclear reactors (A-1-b) is currently expanding in the environs of cities and will expand as shortages get worse. The next ten years will see a large expansion of conventional nuclear capacity, with peak impacts being felt within twenty years. Gas-cooled nuclear reactors (A-2-a) will increase in use in the next ten years with peak impacts coming within twenty years. This technology will be more efficient and tends to decrease diversions for cooling and thermal pollution.

Another factor which will tend to decrease cooling demands in city environs is the improvement of long-distance power transmission, permitting power plants to be located on coasts or generally in areas where pollution will be minimized. Improvements of direct-current transmission (A-3-c) will reach a peak within ten-to-twenty years. Beyond twenty years cryogenic methods will be widely introduced.

During the period ten-to-twenty years in the future total energy packages (A-3-f) will start to be used in residential and commercial complexes, reducing loads on central generating stations and greatly increasing the efficiency of heat use by combining localized power generation, space heating, cooling, and waste disposal. Beyond ten years, open-cycle engines (A-2-e) and, after twenty years, generation by magnetohydrodynamics (A-2-d) may substantially reduce cooling needs.

The handling of waste will affect urban water use. Tending to increase water use in the period ten-to-twenty years in the future will be the use of water slurry pipelines (A-1-d) or the transport of total wastes away from the urban area and into landfill or deep-sea disposal. Tending to offset this, however, there may be a move toward sewage systems using reusable substitutes for water and liquids which can carry wastes and be separated from the waste without dilution of the latter. This will permit much more efficient waste treatment for those wastes being treated within the urban area as well as reducing water use.

A very large use of water in urban areas is for irrigation of lawns, gardens, parks, golf courses, etc. Landscaping with drought-resistant and native arid-land plants is currently becoming popular and will have significant impacts in new areas a decade hence. This move will be supplemented by the development of new species of plants and grasses (A-2-n) and by the development of superior artificial substitutes (A-2-m) ten-to-twenty years in the future.

There has been talk of policies of population dispersal (E-1), particularly into the desert. While some social incentives for dispersal currently exist and are likely to increase substantially within ten years, new towns are more likely to be established where water supplies are adequate. The effect on water demands could be up or down but will not be large overall. Reinforcing the social rationales for dispersal of population will be improvements in communications (A-3-e) which will permit much business to be carried on "at home." This is likely to be important, starting in about twenty years.

Tending to restrict water demand will be more sophisticated metering and charging schemes (E-3), especially during peak periods of demand. All new areas are currently being metered, and new peak period meters registering higher charges as incentives to reduce peak demands have been designed by some meter suppliers. It is estimated that they will become important, starting in about ten years.

New Sources of Water

Desalination (B-1-a and b) is currently being used in isolated situations where alternatives do not exist. Costs are high and it appears that they will remain high. It will be used in the form of multiple-purpose (water and power) plants in coastal areas, starting in ten years or so to supplement conventional water supplies. New types of plants designed to operate only during periods of peak demands will be developed, partly as insurance against infrequent drought. Desalting seems unlikely to become a major source nationally.

Underseas aqueducts (B-1-k) to transport fresh river water along coasts will play some role after twenty years, as will plastic offshore reservoirs (B-1-l) as a way of catching runoff and river outflow.

Conservation of Water

Within fifteen or twenty years, maintenance costs will require that service tunnels (B-1-o) be in wide use in urban areas. This will avoid leaks and facilitate repairs. Capture of urban runoff (B-2-c) with recharge into aquifers is currently used in some areas and will increase in importance. In general, better coordination of ground water storage and surface water supplies will become increasingly important.

Water Reuse

Superior methods of advanced treatment (C-1) will become available within the next decade, having a peak impact within twenty years. The major impact will be to permit municipal water recycling. Recycling in manufacturing independent of general municipal recycling will become widespread within ten years and dual systems (lower quality water for certain uses) (C-4) will become widespread in urban industry. This will be facilitated by reducing contaminants of urban and water shed areas (D-4) as part of water reuse programs on which emphasis will be placed within ten or fifteen years.

D. MUNICIPAL WASTE DISPOSAL

Introduction

The use of water as a means of transporting and treating urban and industrial wastes is essentially universal. If it is presumed that past trends will continue, an increasing per-capita use of water for this purpose may be anticipated from the demand point of view. On the other hand, there are alternative technologies involving closed-system recycling and alternative fluids which could result in a very substantial reduction in demand.

With respect to new urban developments, including new additions and major renovation of old urban districts, these two alternatives are probably mutually exclusive. Either the economics or the environmental effectiveness or both will favor closed-systems disposal or these factors will act to continue the present collection and central treatment route.

The most likely path to be taken will largely be governed by governmental policy and the related institutional arrangements for implementation of that policy. For example, current policy and institutions, if continued, could very well preclude the development of the closed-cycle alternative. Central-waste collection and treatment has its economic advantages due to economies of scale. Full-treatment costs are a few pennies per day per capita. Because the present capacities or urban-water distribution systems will very likely continue to be required to meet fire-protection objectives, there will be little reduction in the final cost of the distributed supply owing to any possible reductions in water use. (An important factor will be the institutional arrangements for paying the costs of centralized waste treatment.) At present this is largely a municipal obligation with capital costs underwritten by general obligation bonds. Current costs are usually borne by taxation. Under these conditions, economic incentives all oppose the introduction of any new closed-system technology for waste disposal which is based on individually owned installations even though the latter might be more efficient from the overall national point of view.

Should these arrangements be modified, as for example by a general policy of full cost user charges based on waste water volume and quantities of waterborne waste, the closed-system technology could be developed and used by any householder at whatever time it proved to be less costly than the going user charges. Should there be a desire for the ultimate in the preservation of the quality of natural streams, user charges could be further increased to accelerate closed-system installation or direct subsidy could be offered on the basis of the value to the nation of water-quality enhancement.

Two possible alternative futures are outlined below. The first presumes that either policy remains unchanged or that despite policy changes no closed-cycle waste system proves too economically competitive. The second presumes that the enabling policies and institutional arrangements are adopted and that closed-cycle waste treatment is the most economical or the only effective alternative.

Aqueous Disposal System

An aqueous disposal system, returning water to natural watercourses must eventually cope with a number of problems. The first is the provision for treatment facilities sufficiently complete to allow the water to be returned without unacceptably adverse effects on the receiving waters. This appears to be the target for the 1970-1980 decade and it will be presumed that, with respect to "normal" sewage and waste flows it will be accomplished. The second problem relates to peaking loads, best exemplified by the current combined sewer problem but in reality much broader. Whether storm and sanitary sewers are combined or not, flood waters clearly represent a threat to the maintenance of water-quality standards. These sewers carry the litter from natural vegetation, urban streets, and urban vegetation. The third problem relates to the secondary biological production induced under certain conditions by the high nutrient levels in biologically treated waste waters. The fourth problem relates to the increase in total dissolved solids which characteristically accompany each urban-use cycle. A fifth problem relates to toxic materials in both treated and untreated waste water, particularly those in a form which result in bioconcentrations to levels which are unacceptable.

In combined sewer systems, the peaking-load problem will result in a need for low-cost storage of storm runoff from urban-industrial areas and from agricultural or "natural" areas which are identified as major diffuse sources of pollution. Possible new technologies which could meet this demand are outlined in B-2-c, Runoff Water Control Using Rock Tunnels and Galleries, and A-3-i, Vegetation Management. The underground storage technology (B-2-c), except perhaps for some further reduction in costs, is already available. What remains to be developed is the acceptance and refinement of the total-systems concept needed to make this alternative economically feasible. It may be expected that demonstration systems of this type could be constructed by 1980 followed by increased use thereafter. This development is particularly attractive for cities with very little gradient in the drainage system since it would greatly increase existing storm-drainage capacity.

The use of inflatable plastic reservoirs (with storm water providing the inflation) (B-1-l), is another prospect. The principal problems relate to fabrication and installation of very large units plus rip and puncture protection. These can be installed underground or above ground, near runoff sources or at central locations. Smaller units near sources could provide the maximum flexibility and security against failure.

Instream aeration (C-2) can be utilized to minimize the adverse effects of those peak biochemical-oxygen-demand loads which cannot be satisfactorily held and treated by one of the above technologies. This aeration could be introduced into storm drains as well as the receiving waters, particularly where grade levels are such as to impose a fairly large detention time in the drains. Artificial aeration might also be incorporated into any of the peak flow collecting and/or holding systems whether surface reservoirs, subsurface reservoirs or inflatable holding units.

In coastal cities, storm waters might be most effectively disposed of through large diameter flexible plastic pipes leading to deep-ocean outfalls (B-1-k) either with or without preaeration. This procedure would be particularly suitable for large volumes of relatively low-strength waste water such as storm runoff, provided the point of release is at a sufficient depth for adequate dilution with aerated ocean water prior to reaching the photosynthetic zone near the surface. These outfalls can also be used to dispose of treated or partially treated normal effluents.

Although the problems of waste heat disposal are discussed elsewhere in this chapter, the use of deep-ocean outfalls for this purpose, and the possibility of drawing much colder water for cooling from these depths should be mentioned. In particular, an important possibility is the potential for adjusting flow rates, underwater storage and points of discharge so as to be able to produce a controlled upwelling of nutrients (natural or man-delivered) in precise balance with the best photosynthesis-zooplankton-to-commercial fish food chain, thus producing a stable "fish farm."

Secondary biological pollution will continue to be a major problem for aqueous waste disposal to natural lakes and those few streams where the only limitations on photosynthetic production of algae are the supplies of nutrients. Many receiving waters are naturally turbid to such an extent as to make light the limitation on the growth of algae. These waters will not require special consideration, at least for this particular problem. Most clear water lakes and some estuaries, however, will produce secondary biological pollution unless action is taken to limit the critical nutrient inputs (D-4) or to provide for sufficient artificial aeration so as to alleviate at all times the unacceptable adverse effects (C-2).

The presently favored policy of developing technologies which control nutrient input face uncertainties concerning the effects of uncontrolled nutrient sources. It should be noted that the very limited research on this particular question has produced controversial opinions. Research, particularly broadly based multi-variable systems considering the complex nutrient relationship is needed.

An additional technology now being given some research attention is the integration of organic waste disposal and food production systems (A-2-1). Presuming the research problems associated with this technology can be solved, it represents a major possibility, particularly in arid and semiarid areas where the resources in waste water are put to an economic advantage. There is strong need for extensive research on this because some of the current estimates of the amount of land required, hence the extent of the distribution system needed, may be underestimated. Also the problems associated with toxic materials such as heavy materials in sewage sludge may cause unforeseen problems by getting in the food chain if the sludge is used as a nutrient source for food production. Once again research from an overall systems point of view is badly needed.

The fourth problem is the increase in total dissolved solids in water which passes through present urban-use systems. It turns out that the added dissolved solids in each urban-use cycle is approximately equal to the total dissolved solids limit recommended by the Public Health Service for drinking water. There is a need to address this dissolved-solids problem now.

Aside from preventing the salts from entering the water in the first place, desalination offers the only potentially practical technology for reducing the absolute amount of dissolved solids in the water (B-1-a). Even here, lacking a technology for extraction of salts only, desalination results in two streams of water of high and low concentrations, respectively. The former still represents a problem for disposal.

The primary use of desalination can thus be expected to occur more often for water-supply treatment than for waste-water treatment. When desalination is used for treating waste water, it will probably be limited to systems in which water is recycled.

Dilution could be an important means for coping with increases in salt content of natural streams. However, with the expected ever-increasing competition for water for consumptive use, dilution will be competitive with other uses. Once again, integrated multiple-use systems research will be essential at levels far above those now devoted to these subjects.

The problem of bioconcentration of toxic materials (E-6) has only recently come to light with the discoveries of bioaccumulation of DDT, certain forms of mercury and other heavy metals. Many others will doubtless be identified. Extensive research will be needed to identify these materials and to explain the mechanisms by which it occurs. Action might then take the form of altering the compounds to preclude bioaccumulation, to render it unstable in the biosystem, or to limit it at some point in the food chain, etc. At present the only technological alternative is to eliminate any bioaccumulative compounds which might reach toxic levels. Even this is a major task, as reports of mercury from coal combustion would suggest.

The probability of extensive use of any or all of the above technologies will depend very much on the commitment to the accomplishment of the related research. Most of the alternatives, if developed, have their place in the alleviation of water-quality problems in one situation or another. For some problems, for example bioaccumulation, current research is so inadequate as to virtually preclude any suggestions for a scientifically based technology. To a lesser, but still important extent, lack of research has limited technological possibilities severely. If the most effective and least costly technologies for the resolution of these problems are to be identified and developed, substantial increases in research will be required.

Closed-Cycle System and Other Management Innovations

As a possible complete alternative to the open-system waterborne waste-disposal technologies described above, modifications in institutional arrangements could pave the way for the development and introduction of closed-cycle liquid-waste disposal (C-1 and C-4). Until the economic externalities of existing systems have to be removed by adjustment of institutions, the closed-cycle systems will most likely be owned and maintained by individuals or relatively small groups of people.

Presuming user charges are adopted in a carefully structured way, new urban centers could adopt this technology by 1980 with more gradual replacement of existing systems. The closed-cycle systems could use water, reclaimed and reused, or a liquid other than water in which the wastes are insoluble.

The impact of this technology on water withdrawals and on water-quality maintenance could be highly significant. For the most part, however, wastes in wash water would continue to require some form of central treatment and disposal. The latter requirement would suggest the concurrent development of nonaqueous cleaning agents (A-2-k) which can be more efficiently stripped and recycled; hence, these technologies should be considered complementary.

Special consideration should be given to total-systems technologies which might combine a number of the above alternatives to utilize water-borne wastes for productive purposes, particularly for food, wood and fiber production. Such a system could combine partial treatment, storage, transport and controlled release to agricultural areas, woodlands, lakes, rivers and oceans to produce stable optimum environments for substantially increased production. In effect a very large-scale closed-nutrient cycle would be created. With modern emphasis on the systems approach, this multiple-technology has a high probability of development and introduction within the next two decades, provided the necessary comprehensive research program is initiated in the near future.

While not strictly a technology, the optimal management of salinity will require very carefully researched and designed institutions with sufficient authority and responsibility to manage. Salt reaches fresh water streams largely through natural processes. The consumptive use of water without a corresponding extraction of salt results in an increase in the salt concentration. Unless this salt continues to move toward the sea or other natural or safe artificial sink at the rate at which it enters the fresh water system, accumulation sooner or later becomes intolerable.

Saline management consists of those actions which will assure the continued transfer of salt in such a way as to prevent such excessive accumulation. Virtually all water management systems at present ignore this basic equilibrium requirement and, for the most part, are legally incapable of treating it.

Other interactions must be considered. What is solid waste for one technology may be liquid waste in another and vice versa. Disposal of solid wastes can become water pollution at a later date. The end product of effective water-treatment systems has been more solid waste or more airborne waste. The technology of the future will very likely consider the suppression of the exchange of one pollution problem for another. How successful the attempts will be will be determined by the success of this institutional-political-legal research and development.

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INDEX

Anti-transpirants, artificial - 55, 152, 169, 198

Bays and estuaries, regional management - 73, 154

Bibliography - 211-239

Bioconcentration of toxic materials - 141, 161, 205-207

Bioprocessing to provide food - 51, 152, 169

Canal systems to carry water from region of surplus - 94, 157

Central electric system vs. on-site total energy system 70, 154

Cloud seeding - 81, 155, 168, 233

Collapsible bladders for transport of liquids - 89, 156, 203

Communications systems, advanced - 69, 154, 198

Cooling
- Alternate methods for power plants - 169, 189
- Industrial systems using air - 47, 151, 187-189, 191
- Pond, recirculation development - 43, 151, 187, 190
- Tower, advances in design and utilization in industry 45, 151, 185

Crop production by use of residual heat and other by-products 127, 160

Desalting
- Seawater and brackish water - 78, 155, 199, 206, 221
- Units, compact for residential use - 85, 155, 199, 221

Desert, populating the - 132, 161, 198

Economic considerations - 2, 12, 143-144, 177-209

Electric power
  Generation - 185-195, 237
    conventional nuclear reactors - 22, 149, 170-176
    gas-cooled nuclear reactors - 35, 150, 170-176, 187
    nuclear fusion - 36, 150, 170-176, 189
    fuel cells - 38, 150, 170-176, 189, 197
    magnetohydrodynamics - 39, 151, 170-176, 186, 189, 197
    open-cycle engines - 40, 151, 170-176, 197
    units for meeting peak demands - 64, 153, 186
    use of wind and water power - 42, 151, 170-176
  Transmission over long distances - 66, 153, 170-176, 186
    189, 192-193, 197

Energy
  Geothermal - 71, 154
  Solar - 62, 153
  Systems
    central electric vs. on-site total energy - 70, 154

Environmental considerations - 5, 11, 12, 145, 154, 178,
    182, 201

Evaporation reduction - 99, 157

Fire-hazard area irrigation - 27, 150

Fog drip - 83, 156

Food production - 169, 179-184

Forest and rangeland irrigation - 30, 150

Fuel cells - 38, 150, 170-176, 186, 189

Gas production from coal - 21, 149

Genetic development of plants to withstand drought and
  salinity - 56, 152, 169, 180, 198

Geothermal energy - 71, 154, 186

Groundwater
  Recharge - 107, 158, 216
  Storage - 105, 158, 168, 199, 216

Hydrologic cycle - 109

Iceberg towing - 88, 156, 168

Ice cap melting - 87, 156, 168

Ice field, artificial - 84, 156, 168

Institutional changes - 3, 144, 147-161, 201, 207-209

Instream aeration for water-quality improvement - 116, 159, 204, 221

Landscaping with artificial materials - 60, 144, 152

Long-term seasonal precipitation forecasting - 82, 155, 168, 233

Magnetohydrodynamics - 39, 151, 170-176, 186, 189, 197

Marine and subsurface waste disposal - 125, 160

Municipal waste disposal - 201-209

Nuclear
  Conventional reactors - 22, 149, 170-176, 185-195, 197
  Explosives for canal, tunnel and reservoir construction 96, 157
  Fusion - 36, 150, 170-176, 189
  Gas-cooled reactors - 35, 150, 170-176, 187, 197

Offshore reservoirs - 92, 156, 199, 204

Oil-shale conversion to liquid fuel - 67, 153

Open-cycle engines - 40, 151, 170-176

Phreatophyte control - 100, 158, 168

Precipitation
  Augmenting fog drip - 83, 156
  Increase through cloud seeding - 81, 155, 168, 233
  Long-term seasonal forecasting - 82, 155, 168, 233

Recreation trends, water-based - 138, 161, 238

References (selected related reading) - 213-239
  Water management
    general - 213
    groundwater - 216
    reservoirs and rivers - 217
    water resources development - 218
  Water quality
    aeration - 221
    desalination - 221
    general - 219
    pollution sources and control - 223
    waste and water treatment - 224
  Water research and technology - 227
  Water resources - 230
  Water supply - 213
    evaporation and phreatophyte control - 233
    general - 231
    weather modification - 233
  Water use
    agriculture - 236
    general - 234
    power generation - 237
    recreation - 238

Research priorities - 3, 144-161, 163-166

Reservoir
  Role in water management - 139, 161
  Use of bottom water - 124, 160

Residential water demand modification - 136, 161, 169, 234

Runoff water control using rock tunnels and galleries
    103, 158, 199

Seawater
  Desalting - 78, 155, 199, 206, 221
  Increased use by industry - 121, 159

Service tunnel use in urban areas - 97, 157, 199

Snow/ice avalanching - 86, 156

Soil and rock reservoir modification - 108, 158

Solar energy conversion to heat and power - 62, 153, 193-194

Solution mining - 32, 150

Subirrigation and unsaturated leaching - 58, 152

Subsurface and marine waste disposal - 125, 160

Surface transportation using electric power - 24, 150

Surface water harvesting - 110, 158

Technology
  Application - 167-173, 177-109
  Analysis - 143-167
  Change - 2, 5-7, 10
  Concepts - 10-142
  Considerations which could influence - 131-142, 144, 149
  Cross impact - 8, 145, 170-176
  Future - 177-209
  Research and development - 5-9, 143, 147-161, 163-166,
    167-176, 177-178, 196, 207-209, 227
  Trends - 8, 145, 167-176

Underseas aqueduct - 90, 156, 168

Vegetation management - 74, 154, 203

Washing/laundry technology - 50, 152, 208

Water
  Demand - 19-76, 123-130, 143, 149, 161, 196-200
  Diluent for wastes - 49, 152, 169, 206

Water
  Evaporation reduction from lakes and reservoirs - 99, 157, 233
  Management - 139, 161, 207-209
  Planning - 5-9, 20, 167, 177-178
  Quality - 5-6, 113-122, 159, 169, 204, 208, 219, 236
  Recreation trends - 138, 161
  Recycling in manufacturing industry - 119, 159, 199, 206
  Runoff control using rock tunnels and galleries - 103, 158, 199, 203
  Services, rationalizing the market - 133, 161
  Slurry pipelines for transport of solids - 26, 150, 197
  Supply - 77-112, 123-130, 143, 169, 196-200, 231
  Waste treatment/disposal - 224
    improved processes for purification and reuse - 114, 159, 196-200
    renovation of waste water by surface spreading - 117, 159
    subsurface and marine waste disposal - 125, 160

Watershed management
  Modifying soil and rock reservoirs - 108, 158
  Reducing contaminants - 129, 160
  Surface water harvesting - 110, 158

Wind and water power - 42, 151, 170-176

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