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Power - Follow up

1974 (Feb.-March)

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INTERNATIONAL DEVELOPMENT ASSOCIATION | INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT | INTERNATIONAL FINANCE CORPORATION

OFFICE MEMORANDUM

TO: Utility Staff Regions and CPS

DATE: February 28, 1974

FROM: Y. Rovani

SUBJECT: Index of Public Utility Papers

Please find attached an index of public utility papers prepared for your information. They can be obtained from Miss Phyllis Peter who answers on Ext. 5459 at least until our current move, within the 7th Floor of the "D" building, is completed.

Attachment

cc: Miss Peter

YRovani:em

PUBLIC UTILITIES DEPARTMENT

DOCUMENTS INDEX

~~March 1, 1974~~

May 13, 1974

Prepared by: Phyllis Peter

RESEARCH SERIES

The Research Series includes those research papers which have been prepared for or by the Public Utilities Department. They represent the result of analytical and expository studies which are considered to be of interest to operational staff. They are in no way intended to be statements of Bank Policy.

RES 1 Economic Analysis of Electricity Pricing Policies: An Introduction -- January 9, 1974 -- 14 pages

"Electricity pricing policies have been dominated by financial questions; in particular by the need to maintain tariffs at levels that will help finance the large capital requirements of contunually expanding systems; and also by a questionalbe accounting approach to the design of tariff structures. But how fast should expansion be? How should output be distributed between homes and industry and between rich and poor? Can capital be utilized more fully? These neglected questions of economics and equity also need to be worked into pricing policy. A balanced approach is needed: finance to spur expansion; economics and equity to contain and direct it. This paper discusses how pricing policies can be formulated which are efficient while satisfying the constraints of finance and equity. Additional constraints set by the need for simple tariffs, risk, ignorance about consumer reactions and by the costs and technical difficulties of accurate metering are also discussed. The paper is an introduction to a series of case studies, research papers and quidelines designed to help Bank staff, utilities and their consultants adopt a new point of view and start solving the difficult but worthwhile problems of implementation that it poses."

Estimation of the Economic Benefits of Water Supply and Sewerage Projects -- Warford, Bahl, & Coelen -- October 1973
**Report presented by the Syracuse University Research Corporation, Maxwell School of Citizenship and Public Affairs

OTHER RESEARCH PAPERS PREPARED WITHIN THE DEPARTMENT BUT NOT PRESENTLY FINALIZED ARE AS FOLLOWS:

Electricity Pricing Case Studies - Tunisia - Sudan -- Anderson & Turvey
(Sudan - June 1973 - 46 pages)
(Tunisia - October 1972 - 32 pages) Available in DRAFT form.

The Economic Return on Electric Power Investments -- Anderson
January 1973 -- 31 pages. Available in DRAFT form.

RES 2 __Village Water Supply and Sanitation in Less Developed Countries__ -- Warford & Saunders -- ** ~~To be issued shortly.~~ issued

RES 2A Summary + Conclusions of The Full Report

RES 3 ~~How to Study Electricity Tariffs~~ -- Turvey Framework for Electricity Tariff Studies
~~** To be issued shortly.~~ Issued

__Village Electrification: The El Salvador Study__ -- Anderson
** In progress; due this fiscal year.

POLICY PAPERS

At present the only published "Policy Papers" are three Sector Working Papers (Water Supply & Sewerage, Telecommunications, and Electric Power). These papers describe the distinctive economic, financial, and institutional characteristics of each sector; outline the role played by each sector in the general process of economic development; review the scale and approach of World Bank operations in the sector; and summarize the Bank's philosophy about how its own operations, together with the activities of other aid donors, can contribute to building up each sector - physically, financially, and institutionally - in its member countries.

Water Supply and Sewerage Sector Working Paper - October 1971
13 pages (available in translation - French & Spanish)

Telecommunications Sector Working Paper - November 1971
18 pages (available in translation - French & Spanish)

Electric Power Sector Working Paper - December 1971
17 pages (available in translation - French & Spanish)

Operational Policy Memorandum - No. 2.36 - Public Utilities
* See Operational Manual

Under preparation:

PPA -- Economic Evaluation of Public Utilities Projects

This paper is presently awaiting review in the Department. It is under the responsibility of Messrs. Anderson, Howell, and Warford. ~~To Policy Review Committee (PRC) Staff Review - April 1974~~. Postponed

PPA -- Lending for Village Water Supply

This paper is in a first draft form and has been circulated among the utility staff. It is being prepared by Harold Shipman. To Rural Development Panel April 1974, PRC Staff Review ~~April~~ May 1974.

PPA -- Lending for Nuclear Power

This paper is in second DRAFT form and is being prepared by Mr. Howell and Mr. Friedmann. It is scheduled for distribution to the PRC Staff Review March 1974.

PPA -- Lending for Village Electrification

First DRAFT being prepared. To PRC Staff Review ~~April~~ May 1974.

GUIDELINES SERIES

The Guidelines Series includes a variety of papers on economic, financial and technical subjects. Some of them will result from the natural sequence of PBP's innovative tasks - Research, Policy Papers, Guidelines; others will result from PBP studies of operational techniques, methods, or procedures; others will reflect changing Bank practices in the utility sectors. Guideline papers are circulated in draft to the Division Chiefs and a selected panel of staff in the Regions and other Departments. Any disagreements of substance are thoroughly discussed. For those Guidelines which prescribe actions, procedures, or methods, staff are expected to observe the Guidelines unless there are convincing reasons to support a departure.

GAS 1 WHO/IBRD Cooperative Program - May 1973 - 4 pages plus annexes
* Note: to be reissued shortly.

GAS 2 UNDP/Special Interest Project Procedures: Water & Sewerage - August 1973 - 5 pages
* Note: to be reissued shortly.

GAS 3 Guidelines for Project Monitoring System for Public Utilities Projects - November 8, 1973 - 2 pages plus annexes

"This paper introduces guidelines for a monitoring system which should be applied in all Public Utilities projects.

The system provides for presentation in appraisal reports of general indicators selected by the appraisal teams as being representative of key factors in the success of the project and the enterprise. Progress as measured by these indicators would be checked during project execution, and reflected in supervision reports.

Two annexes list examples of indicators which may be applicable in the Power and Water/Sewerage sectors. Suggested indicators for Telecommunications will be issued later."

GAS 4 Guidelines for Sector Work in the Water Supply and Waste Disposal Sector - November 9, 1973 - 18 pages plus annexes

** Available in French Translation ~~shortly~~

* Spanish translation in progress - due July '74

" These guidelines suggest the means for acquiring the information about the water supply and waste disposal sector needed in order to prepare plans for its development. Sector studies are primarily for the benefit of decision makers at the national and local level, but they also benefit outside agencies interested in efficient development of the sector. To be effective, sector work must involve both appropriate officials and the sector specialists in the country in question, and be seen as part of a continuous process for building up knowledge and improving decisions in the sector. Several typical sector issues are discussed, along with a number of practical considerations for organizing sector work. Detailed planning of sector work is emphasized. Annexes provide, among other things, checklists which help to assure that important aspects are not overlooked."

GAS 5 Guidelines for Sector Work in the Power Sector - November 20, 1973 - 13 pages plus annexes

" These guidelines suggest why studies of the power sector in developing countries should be carried out, point out that decisions affecting the sector's evolution reach across the whole economy, and caution that a mere inventory of facilities does little to illuminate the problems and prospects associated with the assurance of a long-term dependable supply of power appropriate to the needs of the country's development. A general approach is outlined, supplemented by reminders of specific information sought. The Annexes are offered as Aides Memoire in this connection."

GAS 6 Guidelines for Estimating Costs of Tunnel Construction - January 17, 1974 - 4 pages

" This paper deals with the problems of estimating costs to execute underground works where uncertainties may be great. It suggests areas to which special attention should be given, and advocates the routine collection of data on costs as experience is gained so that the basis for judging estimates may be broadened."

Previously Written Papers which may be of interest:

Handbook for Appraisal -- Jennings -- November 1970

Part A   Checklist for Appraisal Missions
"Designed to help plan and organize the work of Appraisal Missions."

Part B   Outline for Appraisal Reports
"Designed to aid preparation of appraisal reports."

Under Preparation --

Telecommunications Handbook

GAS 7   Part I   An Outline of Telecommunications
Issued
~~(to be issued March 1)~~
"Summarizes basic telecommunications technology in simplified technical terms, concluding with a shorter chapter on management of telecommunications enterprises. It is designed to be a source of general information about the nature and organization of telecommunications, the physical and cost structures of networks, and the basic engineering and management functions of an operating authority."

Part II   Telecommunications in Developing Countries
(due FY74)
"An attempt to relate the basic concepts of Part I to the special problems of developing countries and will be of particular assistance to new telecommunications staff."

Part III   Economic Issues in Telecommunications
(due FY 74)

PUBLIC UTILITIES NOTES

Public Utility Notes are notes of information or "state of the art" papers on utility sector related subjects. They are used to: provide perspective on subjects of current interest (Petroleum Notes); disseminate information on the operational significance of on-going research (Village Electrification); explain the origin of current research and help retrieve past work (Utility Pricing); summarize, for the benefit of a broad audience the contents of bulky research papers (Village Water Supply); or draw attention to innovative operational work (Finland's Pollution Control). These notes are issued under the sole responsibility of the Public Utilities Department and do not represent statements of Bank policy.

PUN 1 Petroleum Notes - January 24, 1973 -- 19 pages

"The purpose of these Petroleum Notes is to provide some basic information and understanding of the most important factors related to the supply, demand, and pricing of this commodity. They would serve as background to further notes and guidelines aimed at improving energy-related sector work. This would include, in due course, notes on Energy and the Environment, Nuclear Power Technology and Economics, Guidelines on Energy Aspects of Power System Planning, etc. It is also hoped that the Notes may be of some interest for country, transportation and industry economic work."

PUN 2 The Problems of Estimating Costs of Tunnel Construction -- January 1973 -- Issued as a Board Paper (SecM73-32) -- Reissued by PUD as Guidelines (See GAS 6above)

PUN 3 Generating Plant Reserve Margins - June 20, 1973 - 9 pages

"This note describes some practical approaches to determining the amount of spare generating plant capacity that should be planned for in order to achieve an optimum standard of security for a particular electrical supply system."

PUN 4 Standards of Urban Electricity Distribution - June 28, 1973
6 pages

"This paper is topical in that it deals with some of the newer emphasis in the Bank's operational work, e.g., emphasizing that part of the service nearest to the consumer (distribution) as distinct from the more "traditional" wholesale parts of the service (generation and distribution). It also deals with that aspect of access to service which considers trade-offs between the standard of existing service and the expansion of access to service."

PUN 5 Pricing in Power and Water Supply -- July 1973 -- 10 pages

"This Note brings the reader up-to-date with respect to Bank work in Public Utility Pricing, indicating what lessons have been learned, what information is now available for operational use and what further work is being done. It suggests that economic, social and fiscal aspects of utility pricing be more systematically considered in all phases of operational work."

PUN 6 The Appraisal of Village Electrification Projects -- August 1973
7 pages

"The object of this Note is to report on some of the operational lessons and indicators which have emerged from the Bank's research work on village electrification, mainly in El Salvador. The topics covered include the criteria for judging the merits of village electrification projects; the measurements that must be made in order to assist investment decisions; tariffs, finance and fiscal effects; and income distributional aspects."

PUN 7 The Changing Energy Scene -- issued December 1973 in DRAFT
29 pages

This DRAFT prepared in December 1973 to complement Petroleum Notes and which incorporates much of the talk given by Mr. Friedmann at an earlier Staff Lunch Seminar will not be finalized.

PUN 8 Finland's Water Pollution Control Program: The Role of Economic Analysis - February 20, 1974 - 24 pages

"This note is the report of a mission which examined the role that economic analysis should play in the evaluation of a project designed to improve the quality of Finland's lakes and rivers. The project, consisting of the installation of effluent treatment works in industrial plants, is part of the first nationwide environmental improvement program with which the Bank has been involved, and for this reason the report is circulated for the general interest of staff members.

The paper contains some rather controversial recommendations on such issues as the subsidization of polluters, effluent charges versus standards, and the role of benefit-cost analysis in pollution control. As in the case of other notes, the report which was originally prepared for the DFC's Division of EMENA, is not to be interpreted as a policy statement or as a working instruction. In fact, it is to be sent to the Finnish authorities, the final position to be taken by the Bank being the outcome of the ensuing dialogue between us."

PUN 9 Water Desalination - February 20, 1974 - 11 pages
Also issued as a Board paper SecM74-6.

"Desalination is increasing in importance in areas of the world where the need for domestic and industrial water approaches or outstrips economically available fresh water supplies. At present there are about 800 desalting plants in operation; they produce an aggregate of 4 million m^3/d, equivalent to the daily consumption of 20 to 30 million people. The paper reviews salinity tolerance levels for various water uses, desalination technology, operation and maintenance problems, and the importance of the cost of energy on overall production costs. Noting that desalination costs are 10 to 15 times greater than the cost of conventional water production processes and that scientific breakthroughs to dramatically reduce costs are unlikely, it discusses the prospects of effecting savings through dual purpose plants, better plant utilization and economies of scale. Criteria for evaluating desalting processes and comparing them with alternative water supply projects are presented along with a guideline suggesting that desalination may be a viable option if alternative fresh water must be piped more than 200 km. Because of high costs and the large quantities required, the paper concludes that desalination for irrigation is unlikely to prove economic except for a very few specialized situations."

NOTES UNDER PREPARATION --

PUN 10 Status and Outlook of Geothermal Energy - To be issued in March

"This Note examines the values and prospects of geothermal development: potential reserves, actual and planned installations, available cost data, technological constraints, research needs and programs of national and international agencies, including those of the UN Resources and Transport division.

It forms part of a series of papers reviewing the principal sources of energy -- nuclear power and coal are next -- designed to serve the needs of energy and power sector work and to be used also as inputs to the work of the Energy Task Force.

It reproduces a reprot commissioned by the Department from Dr. Glenn Coury in connection with last summer's utility staff seminar on geothermal energy. Dr. Coury's report was prepared under the guidance of Mr. Efrain Friedmann."

PUN 11 ~~Village Water Supply and Sanitation in Less Developed Countries~~ ~~To be issued in March~~ Urban Water Supply + Sewerage Pricing
March 22, 1974

PUN 12 First Approach to Energy Sector Surveys

* The preparation of this paper has been postponed indefinitely due to work on the Energy Task Force.

EDI DOCUMENTS

Please note that in addition to the Department documents, the following are available from recent EDI Seminars:

Water Supply Case Studies and Work Exercises:

Volume I -- pages 1-358

Volume II - pages 359-659

Edited by Lamson-Scribner and Burnett. 1973. Economic Development Institute.

P. U. Department No. PUN 11

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

INTERNATIONAL DEVELOPMENT ASSOCIATION

PUBLIC UTILITIES DEPARTMENT

PUBLIC UTILITIES NOTES

URBAN WATER SUPPLY AND SEWERAGE PRICING POLICY

March 22, 1974

Central Projects Staff
Public Utilities Department

URBAN WATER SUPPLY
AND SEWERAGE PRICING POLICY

A B S T R A C T

This note discusses the various objectives of pricing policy as applied to urban water supply and sewerage. Revenue-raising, equity, and administrative simplicity are important criteria to use in evaluating pricing policy, but the paper emphasizes an aspect that is usually neglected, namely, the role of price as means of influencing consumer behavior. The paper outlines an approach to tariff policy that recognizes all four objectives, and indicates the type of compromise that often has to be made between them.

Prepared by: R. Turvey (consultant) and J. Warford

March 22, 1974

URBAN WATER SUPPLY AND SEWERAGE PRICING POLICY

I. INTRODUCTION

1. As communities exhaust convenient sources of water supply and have to go further afield for additional supplies, and as surface and ground-water pollution increases, unit costs of water supply and of sewage disposal can be expected to rise. This necessitates efforts to ensure that ever scarcer water resources are not used wastefully. An important means of doing this is to apply pricing policies that reflect, not the historic costs of a utility's operations, but the real resource costs that are incurred as a result of additional consumption. If consumers are willing to pay prices reflecting these real resource costs, it will be demonstrated that those costs are worth incurring.

2. This general objective is necessarily subject to a number of constraints. The choice of the appropriate tariff structure in any particular case will involve judgements about equity and income distribution, about its financial and fiscal implications, and about the cost of implementing the tariff structure itself. There are, that is to say, multiple objectives of tariff policy, this being evidenced by the wide variety of tariff structures in use. Particular problems arise in charging for disposal of waste water, willingness to pay not being as effective a criterion of the value of sewerage as of the value of water supply.

3. This paper examines pricing policies in the sector in the light of the relevant objectives and constraints. Its emphasis is on the economic aspects of pricing policy, in other words, on the role of price as a means of influencing consumer behaviour, since this is the least familiar aspect.

II. METHODS AND OBJECTIVES OF CHARGING

4. Any charging system for water or sewerage or both must consist of one or more of the following:

1) A lump-sum payment at the time a consumer connects to the system, determined by one or more of:

    i) The cost of the connection;

    ii) The size of the connection;

    iii) Characteristics of the consumer directly relevant to the amount of water to be used or amount and type of sewage generated (such as number of taps);

    iv) Characteristics of the consumer not directly related to water use and sewage generation (such as property value or type of consumer).

2) A periodic fixed payment determined by one or more of:

   i) Characteristics of the consumer directly related to the amount and type of sewage generated (such as meter inlet size, number of taps, presence of a garden, industrial process);

   ii) Characteristics of the consumer not thus directly related (such as type of consumer or property value).

3) A periodic payment determined by metered water consumption. It may be a single rate or in blocks; it may vary seasonally, by type of consumer or property value; it may reflect the strength of sewage and it may differ between areas.

5. The choice from among these options of the structure of charges and the choice of their appropriate level has to be a compromise between four main aims. These will now be considered one at a time, after which the possible conflicts between them will be discussed.

6. The first aim is to raise some target level of total revenue. The target needs to be set so that the utility can service its debts and maintain the degree of financial independence necessary for it to be an efficient organization. This requirement is usually the dominant one, since it involves not only covering all current costs and debt service but also making some contribution to future expenditure. How large this contribution should be can only be a matter of judgement, but one relevant factor is the availability of capital from other sources. Where fiscal resources are especially limited, a high degree of self-finance will presumably be desirable.

7. Since required revenue is a cash-flow concept, the above considerations need to be looked at in cash-flow terms. But this does not mean that the target actually has to be expressed in such terms: given the depreciation rules and given the book value of assets, the gross revenue target can be translated into a target net rate of return on capital. However, it is important to realize that such an accounting rate of return on total assets is a very different concept from a calculation of the discounted cash flow rate of return on a new project. If the two are the same, it is only a coincidence.

8. Given the total target cash-flow of gross revenue, the second aim is to share out this burden fairly between the different users of the system (and also perhaps local or central government). The difficulty here is of course that what is fair is a matter of subjective political judgement. What the analyst personally feels to be fair may well be irrelevant, in which case all he can do is to get the borrower to formulate clearly what is deemed to be fair. This may entail some discussion, since clarity is not always easy. Thus a borrower who asserts that ability to pay as roughly measured by property values is a fair basis for charging should be asked why this applies to non-domestic consumers; the burden of high charges upon a firm may be borne not by its owners but by its customers. Again, the question of whether some part of the revenue should be provided by local or central government requires some thought. There may, for example, be cases where subsidy to poor consumers who use standpipes, or costs related to storm water are more fairly provided from general taxation than from user charges.

9. The third aim is that of administrative simplicity and efficiency. The strength of this consideration will naturally vary according to the competence of the utility and the characteristics of the users. Not much is said about this aim in what follows, but that is because it is obvious not because it is unimportant.

10. The fourth aim, which forms the main focus of this paper, is the one that is most generally neglected, namely that of influencing consumer behaviour. In the short-term this aim is to induce users to economize when there is a drought or when capacity is inadequate. More generally, the aim is to reflect the costs of system expansion in charges in such a way that users (apart from those who deserve subsidy) only choose to impose such costs when they are willing to bear them. A poor country needs to be very sure that it devotes scarce resources to water and sewerage only when this is at least as good a use of the resources as other kinds of investment.

III. PRICING AS AN INCENTIVE

11. The costs which are relevant to the aim of influencing consumer behaviour are the value of the resources which are made unavailable for other purposes by being devoted to water supply and sewerage. Sunk costs are thus irrelevant and it is the costs of future system expansions which matter; engineering cost estimates rather than historical accounting costs are therefore needed. The aim is to reflect these costs in the charges which affect user choices. If there is no conflict with the other three aims this would require, for example:

- low charges when additions to capacity can be provided cheaply;

- an incentive to reduce the strength of industrial effluents when this would lead to savings in treatment cost or a desirably improved standard of treated effluent from sewage works;

- a greater incentive to reduce water use in summer than in winter in cases where capacity and hence costs are predominantly summer-use related.

12. For consumers currently lacking piped water or main drainage, the costs which need to be ascertained are those of extending the system to provide them with service. For consumers who already have service but whose use is growing, the relevant costs are those of adding to existing capacity. In either case what has to be estimated are the additional costs resulting from additional use. The basic notion is thus that charges which vary with the use of the system should reflect the rate of change of system costs with respect to volume. This is what is meant by charges which reflect "marginal" costs.

13. Because new water supply schemes and sewage works are usually large units and because new mains and sewers may combine the purposes of reinforcement, extension and replacement, a refined analysis of marginal costs may not be possible. But this need not deter the planning engineers from deciding what sort of incentive structure would have to be provided by the charging system for it to convey a sensible message to users. Exact calculations are not required; the point is to reflect the approximate order of magnitude of

the costs of system expansion in the charges which vary with the amount of use of the system. This notion of simultaneously informing and inducing the users to economize most when economy on their part would do most to save scarce resources is, however, easily confused with the entirely different notion of allocating costs between consumers. An example will make this clear. Suppose domestic water consumption is closely related to property values. Then a fixed charge related to property value would approximately allocate costs between consumers according to consumption. Yet the incentive effects would be zero, since no consumer would save money by using less water or be charged more if he used more. Thus whatever the fairness or unfairness of such charges (a matter of the second aim) they would do nothing to realize the fourth aim. This, to repeat, is to influence user behaviour.

14. The distinction is so important that another example will be useful. Consider the collective metering of an apartment block. This makes the payment of all the families in the block vary according to their aggregate use, something which may or may not be deemed fair. But whatever subjective judgement is made on this point, and whatever the administrative advantages of collective metering, the incentive effects of the charging system are minimal. The individual family pays scarcely any more if it uses more and scarcely any less if it uses less.

IV. CONFLICTING OBJECTIVES: THE METERING DECISION

15. The last two examples illustrate very clearly the point that the aims of revenue raising, of fairness, of administrative simplicity and of influencing user behaviour can conflict with one another. This is why the choice of a charging system may involve a compromise. No general rules can be laid down about how to weigh up the achievability and the importance of the four main aims. But there are nevertheless three useful approaches to be adopted in seeking to reconcile them.

16. The first is to recognize that because judgements of fairness are subjective, sometimes reflecting no more than political expediency, they are not unique. Thus to judge one system of charging to be fair does not rule out all other possible systems. The analyst can try out various alternatives even when it is not his business to pronounce upon them.

17. The second is to recognize that while the aim of influencing user behaviour relates to the total charges payable by a potential user who is deciding for or against connection, things may well be different with existing users. Where they are extremely unlikely to seek disconnection, their behaviour will be influenced by the way their charges vary with use but not by their total level. Suppose, for example, that water and sewerage are to be jointly charged for by a semi-annual fixed charge and a charge per thousand gallons of metered water use. The aim of reflecting system expansion costs imposes limitations on the fixed charge only if it is use-related. But if it is determined by some non use-related characteristics of the consumer it will have scarcely any incentive effect and can be so chosen in relation to the metered rate as to make the consumers' total bill constitute a fair contribution towards the required revenue.

18. The third useful approach to reconciling conflicting aims relates to administrative simplicity versus influencing behaviour. The latter demands metering or ascertaining some use-related magnitude such as appliance ownership and either of these adds to administrative burdens. But most of the disadvantages of administrative complexity can be measured in cost terms; the more complex a system is, the more it costs to initiate and run it without any increase in fraud. This makes it possible to illuminate the trade-off in monetary terms. For the important choice between metering and not metering a particular group of consumers for example, the minimum reduction in their average annual water consumption which would be required for metering to be preferred can be calculated. It is that reduction which would make the saving in water and sewerage system expansion costs as large as the cost of metering. This requires information about:

i) The capital cost of procuring and installing meters;

ii) The annual cost of meter reading maintenance and billing;

iii) The future cost of expanding the water supply and distribution system, plus the corresponding operation and maintenance costs;

iv) The relationship between decrements of water use and the rate of flow of sewage;

v) The future cost of expanding the sewage collection, treatment and disposal system, plus the corresponding operation and maintenance costs.

Note that (iv) and (v) are relevant according to whether reduced water usage will lower sewage collection, treatment and disposal costs, whether or not water and sewage are administered jointly. They are, of course, the same costs as are relevant to fixing the metered rate.

19. A calculation like that suggested need not be refined and accurate. If it indicates that an x% reduction in water consumption would be required for there to be a net cost saving, the analyst would only recommend the introduction of metering if:

- Metering with the proposed charges is highly likely to reduce average daily consumption by <u>more</u> than x%;

- The proposed charge per thousand gallons does not exceed the average cost of additional capacity operation and maintenance.

If, in other words, water consumption is likely to be reduced more than enough to secure a net cost-saving by a charge which is not excessive, then metering is probably worthwhile.

20. A similar kind of analysis can illuminate such issues as whether to have seasonal or area differentials in charges per thousand gallons. If forward-looking expansion plans show there to be significant differences between seasons or between areas in the costs of adding to or operating capacity, the reconciliation of the third and fourth aims requires similar calculations.

21. Metering may turn out to be of dubious value in the case of poor consumers. Even if metering is on balance cheaper than unrestricted supply, the installation of some flow-limiting device may be preferable. A Fordilla valve, for example, limits the amount of water each consumer can get and so keeps down the cost of the reticulation system as well as saving on source costs. It costs less than a meter, and the consumers can pay a single simple fixed periodic charge. Possibilities of this sort merit examination when water supply is being extended to poor urban areas.

22. The conveyance of storm water and the treatment of sewage provide collective benefits to a town rather than individual benefits to those of its inhabitants who have sewer connections. As they involve a collective decision they are not necessarily best paid for by charges which vary with individual water use; some other way of recovering the cost will very likely be preferable. It is only where a change in an individual water consumer's water use results in a change in the cost of sewerage or sewage disposal that payment for the latter should be embodied in a charge which varies with water consumption.

V. THE SUBSIDY ISSUE

23. The issue of whether or not to subsidize particular groups of consumers often arises. It can best be looked at in terms of the aims of pricing policy, since this enables one to distinguish three quite separate reasons for a subsidy. Even though more than one of these reasons may apply in any particular case, clear thinking demands that they be separated. They are:

1) The willingness to pay for water supply and/or sewerage understates the strength of the case for providing it either because the consumers are poorer than is considered desirable or because there is not only a benefit to them but also to their neighbors in terms of amenity and health. In either case they may not agree to connection or will use too little water unless they are charged less than the effect upon system costs of providing the service.

2) A reduction in charges for water and/or sewerage will constitute a transfer of income to a deserving group of consumers.

3) The cost of charging for water from standpipes or for communal waste facilities such as public latrines outweighs the benefit.

The important feature of these is that 1) relates to the aim of influencing behaviour, 2) relates to the aim of fairness and 3) to the aim of administrative simplicity. Thus in 1) the purpose of subsidy is to encourage use of the service, in 2) the aim is to leave existing consumers with more money to spend on other things, while in 3) the aim is to save administrative costs.

24. It is not sufficient to examine the case for a subsidy solely in these terms. The subsidy must come either from other users of the system or from the general taxpayer. The effects on their behaviour, the fairness of making them pay for the subsidy and any extra administrative complications in raising the money from them all need to be considered. Thus subsidy of a group of poor consumers for reasons 1) and 2) might on balance be a bad idea if it were to be financed by extra taxation of some item predominantly consumed by the poor, including those who lack piped water.

VI. SOME PRACTICAL APPLICATIONS

25. The analyst attempting to look at a charging system in the light of this paper will often find that his task is to suggest improvements to an existing system rather than to design a totally new one. The adequacy of the total revenue generated can easily be studied and views can be obtained on the fairness or unfairness of the charges. Their administration can also be studied, very often with the result that more should be spent on meter maintenance, on chasing up defaulters and so on. What is most demanding is the task of examining and evaluating the impact of the present system upon the allocation of resources. While it is impossible to provide a generally applicable checklist of matters for investigation, some examples of the kind of work that has to be done may be useful.

26. Once-and-for-all charges upon connection can have some effect upon the number of connections. If they do, then their level has to be looked at in relation to other parts of the charging structure and not in isolation. For users not judged to need a subsidy, it is often the burden of all the charges together which will influence their choice for or against connection and which thus needs to reflect the addition to system costs caused by their connection. In these circumstances, it is the total of connection charge and the periodic fixed charge which matter rather than the split between them. In other circumstances a property developer may pay a connection charge (or meet the cost of connection and of the local reticulation system himself) while subsequent charges are met by whoever buys or rents the developed property. Yet the difference in circumstances will not usually be significant, since the developer will pass on the cost to the buyer or tenant who can well decide whether or not the service is worth having. It is true that connection is often compulsory, and it may appear that in such cases the question of what the charge is and who pays it is not one of resource allocation effects. But it is possible that compulsion may divert development to areas outside the town. Where the choice lies between a shanty outside the limits without water or sewage, or a dwelling within the limits with higher charges for the services than people are willing to pay, then development is unduly handicapped.

27. In practice, charges not related to metered water consumption or to factors directly related to it, such as tank size or number of taps, probably have little influence upon the amount of water used and sewage generated by existing users. It is true that lower charges will make users richer and that this may lead them to spend more money in various ways, some of which will involve an increase in water use. But such indirect effects upon water use are exerted equally by the charges and prices they pay for anything else. Hence the main point about charges to existing users which are independent of water use and of the volume and type of sewage is that they neither encourage economy nor reflect the system-cost consequences of changes in usage of the services. Whatever their merits in terms of the aims of raising revenue, fairness and simplicity, such charges are no use at all in achieving the aim of influencing consumer behaviour.

28. A metered rate is at the opposite extreme. Whether or not its proceeds are used for sewerage as well as for water supply, if it affects water consumption it will usually affect the amount of waste water to be handled by the sewerage system as well. Hence the costs of both must be brought in, as was suggested earlier. These costs, as a rough order of magnitude, need to be compared with the effective incremental rate paid by users. The sort of thing to look for is:

i) Rates which are the same in dry as in the wet season, even though the risk of shortage or the need for investing in more capacity results exclusively from dry season conditions.

ii) Rates which fail to reflect significant differences in the pumping or capital costs of supplying different areas.

iii) Rate differences reflecting no cost differences, a result which can easily be produced by some consumer-class differentials or by block tariffs.

29. Complicated block tariffs are fairly common. They often result in differences in the effective marginal cost of water as borne by consumers which reflect no corresponding differences in the marginal cost of supply. In such cases it is important to ask, on the lines suggested above, whether the implicit subsidy to those consumers effectively paying less is justified and whether the burden of the cross-subsidization is appropriately distributed. A cheap first block may suffice as a simple way of making minimum water requirement available to all consumers at a low price. If nearly all consumers take more than this first block it needs to be looked at together with the fixed charge.

VII. SUMMARY

30. The main point of this paper is that as the level and structure of charges can affect consumer behaviour and hence system costs they should reflect the way those costs vary with the use of the system. The relevant system may include sewers and sewage disposal whether or not these are financially separate. Revenue-raising, fairness, and administrative

simplicity are the other objectives of a charging system. Compromise between all four objectives will be necessary.

31. The improvement of a charging system normally raises severe political and administrative problems, so that all that is possible initially may be to improve it rather than to move over all at once to a well-conceived system. But the first and subsequent steps of improvement are best chosen in the light of an ideal system. Consequently an attempt should be made to work out such a system, at least in broad outline, to serve as a standard of reference. This involves:

- Analysis of system cost structure in forward-looking terms;
- Considering where metering or flow limitation devices are appropriate;
- Formulating cost-reflecting tariffs;
- Articulating the revenue and fairness objectives;
- Modifying the tentative cost-reflecting tariffs in the light of these objectives;
- Examining necessary institutional and administrative improvements.

32. Armed with this information, the analyst can then judge the main defects of the existing system and work out priorities for action. In particular, he can find out:

- How nearly an appropriate revenue target is met;
- What are the main inequities of the present system;
- How well metering, billing and revenue collection are performed;
- What are the main divergences between the incentives currently presented to users and those in the ideal system;
- What obstacles to improvement have to be overcome.

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(7-73)

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ROUTING SLIP	DATE March 27, 1974

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P.U. Report No. RES 2A

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PAPERS SERIES

VILLAGE WATER SUPPLY AND SANITATION IN LESS DEVELOPED COUNTRIES: SUMMARY AND CONCLUSIONS OF FULL REPORT

March 15, 1974

Central Projects Staff
Public Utilities Department

VILLAGE WATER SUPPLY AND SANITATION
IN
LESS DEVELOPED COUNTRIES

A B S T R A C T

The major difficulties in village water supply and sanitation programs are not technical, but rather administrative and financial. The problems are in large part due to the relative poverty of rural communities; their failure to appreciate and make proper use of potable water; the relatively high cost per consumer of village supplies as compared with urban supplies, the encumbered administration stemming from geographical dispersion; and, undoubtedly most important, the common neglect of operation and maintenance due to the lack of proper allocation of budgetary resources, the lack of ongoing technical assistance, and the lack of administrative attention. This paper, which consists of a review of the current state of knowledge and of the experience of a number of less developed countries in the field of village water supply, concentrates on these areas, highlighting the factors which are significant in determining the likelihood of success or failure of village water supply projects or programs, and their priority in national development planning. There is also a discussion of the problem of identifying and quantifying the benefits of investment in this field.

Since the best means of dealing with many of these issues remains a matter of debate, and in view of the considerable diversity of rural communities in less developed countries, the general approach of the paper is to draw attention to possible courses of action and approaches which Bank staff should consider in appraising such projects. The paper does not pretend to outline actual policies to be followed by the Bank in controversial areas, however, the intention primarily being to make operating staff aware of opposing points of view and of various possible implications of specific actions, so that they would be in a better position to exercise judgment in any particular case. The paper is being widely circulated in order to attract comments to assist the Public Utilities Department in preparing guidelines for the appraisal of village water supply projects.

Prepared by:

Robert J. Saunders (Consultant) and
J. J. Warford

March 15, 1974

SUMMARY AND CONCLUSIONS

This report outlines the major factors which should be considered when planning investments in potable water supply systems in rural areas of less developed countries. Chapter I begins with a brief discussion of a few of the more frequently cited arguments for allocating resources to potable water supply systems in rural areas. The arguments center around the ultimate goals of redistributing real income and slowing population migration. There is little hard evidence, however, that water supply investment is a particularly effective or efficient means of achieving these objectives.

Chapter II discusses the definition of the term "rural" as applied to water supply and sanitation programs. Although frequently the subject of controversy, it is concluded that the distinction between urban and rural systems is essentially unimportant. What is important is that the water supply systems of a particular country should be categorized in a way that is problem-oriented, and in practice, such categorization should normally be influenced by the consideration that the less spatially concentrated the population, the more difficult it is to ensure that a piped water supply system is financially viable and properly operated and maintained.

Many rural communities do not have the ability to pay for the total cost of water supply systems, and in many cases even have difficulty in covering operation and maintenance expenses. In such cases, revenue from water sales clearly cannot be used as the sole indication of project justification, direct qualitative and quantitative analysis of project benefits therefore being desirable. However, this is a tremendously complex task, as subsequent chapters indicate.

Improvement in health is usually the rationale for large investments in village water supply and sanitation. However, the physical and economic impacts of such investments are extremely difficult to quantify. Chapter III discusses the many sources of water-associated diseases, and explains the difficulties involved in estimating the extent of the impact on health if drinking water is improved, or made more convenient to users.

A survey of the findings of twenty-six empirical studies carried out in various parts of the world and directed at the association between water supply and health certainly suggests that a significant relationship exists between an adequate, safe, and convenient source of water and the incidence of waterborne and water-related diseases. The studies provide evidence, particularly for diarrheal diseases, that a more convenient water supply outlet (closer to the user) is generally associated with lower infection rates and that villages with a piped water supply tend to have a lower incidence of a variety of water-associated diseases. However, the studies provide little information that intuition would not, for the magnitude of the relationship between improved water supply and sanitation and health remains uncertain. It is normally so affected by other economic, environmental, social, and cultural factors that specific predictive statements cannot be used to forecast with acceptable accuracy the improvement to health from specific water supply improvements. At the same time, however, it can be concluded that all other measures, such as improved excreta disposal, food and market sanitation, personal hygiene, and village cleanliness, which can be taken to prevent and control the filth-borne diseases are so dependent on the availability of a good water supply that permanent improvements in health will be unlikely if not impossible unless a safe and convenient water supply either precedes or accompanies the other measures.

Accurate prediction of the physical impact of water supply and sanitation projects would in itself provide valuable information for investment planners. Ideally, such information would be supplemented by economic evaluation of the physical impact. This would allow the net economic benefits - or costs - of a program to be made explicit, even though the result of such a calculation would rarely be the sole criterion for decision. However, here too, the analyst runs into considerable problems of evaluation. While discounting changes in the future earnings stream of beneficiaries may be the best single way to value changes in health, such a calculation must be interpreted with great care: the question of whether earnings should be valued net of consumption; the problem of underemployment; and the weighting of benefits accruing to various income groups all require attention.

Economic growth and output is the focus of Chapter IV. The discussion covers general growth and redistributive effects on the national economy, possible short and long run direct effects (gardening, animal husbandry, property values, commerce and village industry, etc.), effects on labor inputs and earnings (death, morbidity, external health effects, additional time for productive work), problems of population growth and income, and the possibility of achieving savings in costs for society at large. It is concluded that, in general, the link between improved economic output and an improved village water supply is not very strong. This is particularly true where unskilled labor is abundant and greatly underemployed. In such cases, a rural water supply program which improves the health of the labor force may increase the extent to which there is an oversupply of labor while having very little impact on economic output and earnings.

Chapter V focuses on some other goals which are sometimes stated to be objectives of rural water supply programs. The most important of these is the general goal of influencing the location of population, by improving the "quality of life" in particular rural areas. The role of the water supply program as a catalyst to establish an organizational infrastructure at the community level is also discussed.

In Chapter VI the focus is on strategies for choosing which villages should be assigned a high priority for water service. It is concluded that if the water supply investment is intended to have a significant impact on economic development, some form of rural growth point or complementary program strategy should be followed. A worst-first strategy, while achieving a relatively large short-run redistribution of income, could run into significant cost and maintenance problems in the longer run. In addition, a worst-first strategy would generally be the least efficient way to allocate resources if one of the goals of the program is economic development.

Chapter VII discusses miscellaneous problem areas of rural water supply programs. These include the role of pricing, quality of service, population acceptance, the role of "self-help" schemes, shadow pricing, level of technology, complementary programs, and the time frame for investment. Common practices in each area are discussed and, when possible, alternative methods and procedures are examined.

Chapter VIII deals with a number of problems of administration. It is particularly important that administration is geared to the crucial problem of operation and maintenance, the inadequacy of which characterizes most rural water supply programs. The advantages of centralized versus decentralized programs are discussed as well as the appropriate form of national agency involvement in the program. Different structures for financing rural water supply programs are also noted together with suggestions for income redistribution possibilities. Finally, the need for water supply-related training programs is discussed and several examples are cited. An existing program in which performance incentives are an important feature is also described.

The report does not offer any conclusion as to the single best means of designing and administering a rural water supply program in all countries. It also does not provide definitive methods for calculating the real and financial costs and benefits of rural water supply systems. Political, geographic, educational, income, and cultural differences among regions of the world, among countries, and even among regions within countries preclude generalization as to "correct" procedures.

What this report does attempt to do is to (1) identify the relevant factors which should be considered when allocating resources to rural water supply investment, (2) analyze these factors in view of the common goals of fostering better health, economic development, redistribution of income and slowing rural to urban population migration, and (3) suggest the effects of geography, political philosophies, income, education, and culture on different methods for achieving the above goals and on methods for measuring the extent of the goal achievement. It is hoped that with a selected set of program goals, together with a crude economic and demographic profile of a country, this report will provide sufficient information so that the problems associated with designing, constructing, and maintaining a rural water supply program can be foreseen and can be minimized.

Following is a summary of the major conclusions reached in the report:

Population to be Served and the Migration Problem

1. There are a number of factors which can be considered in choosing who should benefit from a rural water supply and sanitation program. The program can have many objectives such as improved health, economic development, real income redistribution, influencing migration patterns, and so on. Water supply and sanitation development policies should be determined by these objectives, subject to resource constraints, rather than by an arbitrary dichotomy between so-called urban and rural programs. There is no unique and universal definition of "rural" or "urban" which best fits all less developed countries and all of the possible objectives of water supply investment.

2. The more dispersed the population to be served, the less likely it is that a water supply system can be financially viable, and will be properly maintained, not only because of lower per capita village income but also because average system costs, for a given standard of service, will be higher.

3. It is possible that water supply systems together with improved sanitation and other complementary investment programs could slow rural to urban migration rates. There is little evidence, however, that in the short run a rural water supply program, by itself, will have any effect on migration. In fact, in the long run, if the water supply program results in a healthier, more potentially productive rural population, the lack of rural employment opportunities could result in an increase in the flow of population into urban areas.

4. While the short-run migration effects of a rural water supply and sanitation program are doubtful, it is more likely that potable water supply systems can be used to encourage, over a period of time, the grouping of dispersed populations into more economically viable village units.

Economic Development

5. A potable water supply for residents of an area may be a necessary condition for significant economic development. However, a potable water supply is clearly not sufficient - even as a catalyst - to achieve this objective.

6. Concentrating water supply and sanitation investment in rural growth points will tend to increase the long-run economic development impact of the investment.

7. A strategy of assigning the highest priority for water service to rural villages which are among the smaller, poorer, and least educated is a high cost and extremely risky venture. The smaller and poorer villages generally have higher per capita construction costs, and have difficulty contributing financial resources to construction or levying charges which are adequate to cover even operation and maintenance expenses.

8. Investing in complementary programs (sanitation, health education, feeder roads, marketing information, etc.) will increase the probability that the water supply program will have an economic development impact on an area.

9. If, in semi-arid regions or in areas with a dry season, a village water supply system is designed to include the provision that livestock can be watered and small gardens can be irrigated, the probability that the system will have a significant economic impact is increased substantially.

10. Underemployment is a common characteristic of rural areas in developing countries. Together with the frequently observed overvaluation of local currency this points to the need to shadow price inputs in order that in terms of real resources, the least cost means of construction and operation is selected. However, shadow pricing exercises themselves are costly, and an educational problem exists in persuading the relevant authorities, contractors and consultants to apply economic analysis to investment decisions. One reason for this is that the financial consequences of using shadow pricing may prove unpalatable to the water supply or relevant fiscal authority.

Health-Related Benefits

11. The review of the twenty-six empirical studies, which examine the relationship between the quantity and quality of water consumed and the level of various water-associated diseases, provides some evidence that more and better water and better sanitary facilities are associated with better health.

12. The empirical health studies also suggest that the degree of improvement in health which can be expected in any given population depends on the level of health in the first place, cultural habits, educational level, the general physical environment including adequate means of waste disposal, and income level. These factors are obviously interrelated, but the point is that identical water supply improvements in two different villages can have significantly different results.

13. In many rural areas of developing countries unskilled labor is abundant and is greatly underemployed. Therefore, a rural water supply program which is designed solely to improve the health of the labor force may increase the extent to which there is an over-supply of labor but have very little impact on economic output and earnings.

14. Most studies have shown that water-related health improvements are much greater among children, who are not members of the labor force. Consequently, with respect to those rural localities in which most of those who desire work can find income-generating work, estimates of increased income generation brought about by water supply-induced health improvements must take into account both the age distribution and the distribution of skills among the population.

15. There is some evidence, with regard to waterborne diseases such as typhoid and cholera, that improved sanitation is, in the long run, more effective and less expensive than vaccination. In a more general sense, preventive medicine is usually more cost-effective than curative medicine, and water supply and sanitation are key elements of preventive medicine.

16. There are several different methods by which changes in mortality and morbidity rates can be "valued." The most workable seems to be to discount any changes in expected life-time earnings which result from water supply-induced better health. This method, however, involves the dubious assumption that the economic output of humans reflects the value of life and health.

17. Factors which affect benefits also affect costs of a project. One approach to the cost-health improvement problem would be to formulate it in terms of the question: what amount of improvement in the major disease rates (valued either qualitatively or in income terms) would it take to make a given investment (and the level of service implied by that investment) worthwhile?

18. Studies of the association between health and quality of water supply and sanitation which allow an accurate prediction of health (and economic) improvements under a variety of circumstances have not been carried out. The primary reasons for this are (a) social, economic, and physical conditions vary greatly among target populations, precluding accurate generalizations, (b) sampling problems and problems of uncontrollable exogenous factors greatly increase the probability of significant errors in the results, and (c) the water supply-health relationship is highly collinear with a variety of environmental, social, and cultural factors, the effects of which are difficult, if not impossible, to isolate.

Redistribution of Income

19. Investments in rural water supply systems in developing countries are sometimes claimed to be a useful means of redistributing real income from higher income urban areas to lower income rural areas. This assumes, of course, that most of the real resources which are used in the rural water supply program would have been allocated to, and consumed in, urban areas; that the rural water supply program will not use resources which would otherwise have been consumed by low-income urban-slum dwellers; and that subsidization is a feature of the financing plan.

20. If redistribution of income is one of the goals of the water supply program, a national or regional water board with responsibility for urban and rural supplies may be in the best position to charge higher water rates to middle and upper income urban dwellers in order to subsidize lower income urban-slum and rural dwellers. Such a water board would in effect be using water charges as a tax.

21. Redistribution of real income in a developing country may be accomplished through the water supply sector by serving both rural villages and urban slums. Indeed, it is possible that meeting increasing urban area water supply needs should take precedence over rural programs if a failure to do so results in urban water supplies being furnished on an intermittent basis which, because of wastewater seepage, could turn a water distribution system into a vehicle for the transmission of disease. Eliminating intermittent water service frequently is of a primary benefit to the lower income groups; for only the relatively wealthy have private storage tanks or the money to install pumps to suck water from the main. Intermittent service in a rural village, it should be noted, might not be quite as undesirable from a health point of view since there will normally be no sewerage lines from which seepage can occur.

22. The income distribution case for financing rural water supply systems is not as straightforward as is generally thought. In many countries it is the wealthier villages which receive priority in obtaining water supply because of their political influence, their greater awareness of the benefits of clean water, and the greater chance that their systems will operate efficiently. Furthermore, from a health and income distribution point of view higher income rural villages are probably less in need of assistance than the urban slums, where alternative sources of supply are less available, where greater population density may encourage communicable disease, and where, moreover, subsidies can be generated from higher income users in the larger metropolitan system.

System Design

23. When designing and constructing a rural water supply project, the technology involved should be kept as simple as is possible so that local operators will be able to operate and maintain the system for long periods of time in the absence of a qualified engineer.

24. The design capacity of rural water supply systems should be at least partially dependent upon the presence of economies of scale and the relevant discount rate. In most instances, community needs for a period of not longer than 10 years provide a reasonable design capacity.

25. The quality of service or design criteria for a rural water system should depend primarily on the system's desired goals. Whether or

not residents in a village should have house connections or public standposts is part of the overall quality of service question and should be decided by considering (a) the quantity of water which the villagers should consume to meet minimum health standards, and (b) the expressed demands of water consumers to pay for more convenient house installations.

26. There are economies of scale associated with water supply construction and, for equivalent levels of service, per capita costs of urban systems will usually be lower than for rural. However, per capita costs of rural water supply installations can be less than urban installations, since per capita consumption may be less and the quality of water service lower. Investment programs should be specific in detailing the standards of service that are being aimed at in order that misunderstandings by budgetary and national planning authorities may be avoided.

Administration and Finance

27. The major administrative problems associated with providing water supplies in rural areas of developing countries relate to the operation and maintenance of the systems. In most developing countries it is difficult to find villages where the systems are working precisely as planned (both technically and financially), and it is common to find even relatively new systems which are not functioning at all.

28. Assigning a high priority for water service to villages which can pay a user-fee at least sufficient to cover operation and maintenance expenses, and which are enthusiastic about receiving improved water, increases the probability that the water supply systems will remain operational for a significant period of time.

29. There is some evidence that villages tend to value their water systems more highly, make better use of the systems, and operate and maintain them more efficiently when they have contributed resources (labor and/or money) to help cover construction costs, and are paying user-fees which at least cover operation and maintenance expenses.

30. Encouraging villages to contribute free labor to the construction of their piped water supply systems can lower both the economic and financial costs of the systems and can stimulate the rural population to take pride in their systems. However, numerous instances have been reported where difficulties with the reliability of the free labor force have more than negated any financial savings. In general, a community's contribution of free labor must be encouraged and closely supervised by a capable community water supply promoter, and any work which he does to encourage and supervise the free labor should be counted as one of the costs of the labor.

31. There is some evidence that a community water supply program which requires a contribution (labor or money) from village populations can be used as a catalyst to stimulate a community organizational infrastructure which will continue to function after the water supply project has been completed.

32. The level of education and skills which exist among the rural population is one of the major factors to consider in determining whether or not the operation and maintenance phase of the program should have a national, regional, or local administrative base. When village systems are turned over to low income, relatively uneducated local authorities to operate, the probability of system failure is high. However, many failures have been accompanied by a reluctance on the part of central water authorities to use their best men for the highly important function of training village operating personnel. In cases where it is decided that system operation and maintenance must be handled on a highly centralized basis, it is desirable to at least set up local village advisory committees so that local populations feel the water systems are their own and will take pride in seeing the systems operate properly.

33. To achieve efficient management and avoid duplication of effort, the national rural water supply program should be under the control of, and/or be coordinated by, one national or regional agency. The specific agency which should be in charge (an independent Water Board, Ministry of Public Works, National Planning or Rural Development Authority, Ministry of Agriculture, etc.) depends on the major goals of the program.

34. There are several advantages of combining urban and rural water supply systems under one semi-autonomous water board. In particular, such a board could (a) provide a stable source of revenue to subsidize rural operation and maintenance expenses, and (b) assure a greater availability of experienced engineers to supervise and provide technical assistance for operation and maintenance.

35. To increase the probability that permanent health and economic benefits will occur, the water supply program should provide for the training of pump or system operators, bill collectors and community promoters. An educational program for villagers which focuses on good sanitation and water-use habits and on any village gardening or livestock watering potential of the system should also be provided.

36. An output-oriented bonus incentive system for local and regional employees of the water supply program might be of value in increasing the probability that the continuing goals of the program are met at the local level.

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P.U. Report No. RES 3

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PAPERS SERIES

FRAMEWORK FOR ELECTRICITY TARIFF STUDIES

March 18, 1974

Central Projects Staff
Public Utilities Department

FRAMEWORK FOR

ELECTRICITY TARIFF STUDIES

ABSTRACT

The paper on the Economic Analysis of Electricity Pricing Policies (P.U. Report No.RES 1) examined some of the problems and principles of electricity pricing. The present paper now suggests an approach to applying these principles. It is couched in terms of a series of 13 questions which will need to be answered in most cases, the significance of each being explained in some detail. The first six relate to the structure of costs, and the next three to the market for electricity, relevant distortions in the economy and the existing tariff structure. The tenth question asks what practicable cost-reflecting tariff might be introduced and is followed by questions about modifications necessary to meet financial and social objectives. Finally the ability of the utility to cope with a tariff reform is mentioned. No answers are proposed to any of the questions, the purpose of the paper being to suggest how missions or consultants might usefully undertake a tariff study.

For the readers' convenience, the questions raised in the text are also listed together in Annex 2.

Prepared by: Ralph Turvey (Consultant)

FRAMEWORK FOR ELECTRICITY TARIFF STUDIES

Introduction

1. This paper sets out a series of questions of varying importance which it would often be useful to ask in studying the pricing policy of electricity enterprises from the points of view of economic efficiency and fairness, given a need to meet a certain revenue requirement. This study frequently demands investigation of the structure of marginal costs. The reason is that price is what it costs the consumer to acquire an extra unit of output while marginal cost is a measure of the value of the extra resources required to provide it. While there may be very good reasons for not equating these two things, i.e. strong arguments against pure marginal cost pricing, they should at least be looked at in relation to one another. To set a price below marginal cost is to make the cost to the consumer of buying it less than the cost imposed upon the enterprise (or the economy as a whole), and vice versa. His individual decision for or against purchase is then not related to the use of resources which his purchase will involve or which will be saved by his abstention. This needs justification in terms of its effects.

2. It follows that in many cases it is logical to proceed in two major steps. First the structure of marginal costs should be investigated, and then the pros and cons of setting price higher or lower be studied. But this may not always be the best procedure. In some cases, at least there where only the immediate future is considered, the barrier to expansion of output is not a high marginal cost but a physical or administrative limitation on capacity. In such circumstances, a high price is one way of determining who shall have a share in the limited supply, while waiting lists, priority rules and bribery constitute other ways. The problem is then to determine the best mix in the circumstances of the particular case.

3. One possible reason for setting prices above marginal costs, one which will arise when marginal costs are below unit accounting costs, is the need to provide a certain required revenues. If this, in any particular case, were the only reason, the aim should be to raise the extra revenue with the least possible effect on resource allocation. This would mean concentrating the excess of price over marginal costs on those components of demand least sensitive to price and on those parts of the price (rate) structure which least affect consumers' behaviour.

4. A possible reason for setting prices below marginal cost, on the other hand, is a desire to subsidise consumers. This may rest upon political or social judgements and the responsibility of making such judgements may or may not rest with the analyst. But at the very least it is important to distinguish whether a subsidy is proposed primarily:

- to encourage consumers to consume more;

- or to leave them with more money to spend on other things.

It can be argued, though not in each and every case, that a public enterprise's responsibilities should not include the second of these two. There are many other ways of redistributing income.

5. A third possible reason for setting prices unequal to marginal costs is that other prices may convey a distorted message and that it may seem right to attempt to offset them. Thus marginal cost to the producer may fall below marginal cost from the point of view of the whole economy when extra output requires extra foreign exchange and when foreign exchange is particularly scarce. The prices which consumers are willing to pay for the output may similarly be distorted by, say, heavy taxation of substitutes. The range of such possibilities is large, both with regard to costs and with regard to the demand side. In any particular case, the ones which are significant must be listed and examined. Here, there is only one general point to be made and this is that a distortion can be dealt with either by accepting its existence and offsetting it or by denouncing it and remedying it directly.

6. Yet other reasons may exist for charging prices which neither equal marginal costs nor serve to limit demand to the available supply. But in all cases the particular circumstances of the particular public enterprise will need to be considered. The following pages do not therefore attempt to give general answers to most of the questions which are proposed. Indeed the importance and relevance of these questions will vary from case to case. The only general and positive recommendations relate to the method of enquiry:

- Consider the effects of prices upon resource allocation, i.e. the incentives which they provide to consumers in relation to the structure of costs.

- Look for alternatives and weigh up their advantages and disadvantages as systematically as possible.

- Avoid both "conventional wisdom" and the assumption that the best practices in developed countries are also best in less developed countries.

- Be explicit about political and social judgements involved, whoever makes them.

Cost Analysis of Generation and Transmission

7. Once the plans for the future development of a power system to meet the projected development of the load are given (the shape of the system over the next few years is known in any case), the appropriateness of the present tariff structure can be considered. This, at its most general, is a question of whether existing tariffs adequately discourage loads with characteristics which impose a heavy cost upon the system or conversely, encourage those which involve a low cost. If they do not have such effects, then a change in their structure to introduce incentives of this kind may well be desirable. To charge a little for a load which imposes heavy costs may encourage wasteful use of electricity, while to charge a lot for a load which can easily and cheaply be met is to signal incorrectly to the consumer. Hence it is necessary to relate the incentive effects of the tariff structure to the cost and availability of supply. The relationships of the tariff structure to income distribution and to financial requirements, both very important, are left aside to start with.

8. What concepts of tariffs and costs are relevant? As regards the first, the answer is simple. From the point of view of incentives to consumers, what matters is what they actually pay and not what the electricity supply authority receives. Hence any taxes which consumers pay should be included in the study. As regards costs, in the present context of analysis in terms of the national interest, what matters is cost to the nation as a whole and not what the electricity supply authority pays for its inputs. This means that, where relevant, shadow prices rather than actual prices must be used and that taxes on inputs must be deducted and subsidies added back. If capital is scarce, its opportunity cost rather than the supply authority's borrowing rate should be used in discounting future costs in order to obtain their present worths.

9. Starting with costs, consider generation and transmission leaving distribution on one side for the moment. Information is required about:

- the incremental cost of energy delivered to the distribution system at times when an increase in generation will not run up against the security constraints;

- the times at which an increase in generation would bring the system up against the security constraints, (by lowering the generation reserve below its target level, by involving an unacceptably large loss of load should a transmission outage occur or by drawing down all water storage below the rule curves);

- the addition to all system costs resulting from adding to generation, transmission or storage in order to make possible increased generation at such times without infringing the security constraints.

More briefly, these three things are incremental energy costs; bottlenecks, i.e. capacity limitations; and the cost of removing bottlenecks by increasing capacity. In a partly or wholly hydro system, capacity may have a KWh as well as KW dimension.

10. Consider first the incremental costs of delivering more or fewer KWh at times when a small increase in output will not infringe the security constraints. These costs obviously vary with the level of the load and, in a mixed hydro-thermal system, may also vary, with the season. The aim should be to group together times within a seson when the load will be approximately at the same level (e.g. winter nights, weekdays 12:00-14:00 etc). Each set of such times in effect constitutes a "step" on a daily, weekly, seasonal or annual load duration curve. Each will have an average incremental generating cost and it is this which needs to be estimated.

11. At times when an increase in demand would be met by increased thermal generation, incremental generating cost simply depends upon the incremental cost of the plant or plants which would provide the extra power and upon incremental transmission losses. The times in question will occur when thermal plant is on load:

- generating more than the minimum necessitated by a decision to avoid shut-down or to provide spinning reserve;

- but leaving more than sufficient to provide the desired reserve margin.

The incremental cost is then what is termed "system lambda" in discussions of economic dispatching (system operation) i.e. incremental generating cost per unit sent out, divided by one minus incremental transmission losses.

12. Normally, information about future incremental thermal generating costs should be available from the work of the engineering consultants in costing the operation of the system over a period of years in order to choose the least-cost alternative for its future development. But whether or not the programme is an optimal one, once it is known which plant will be operating at what levels of system load and at what times of the year, then the incremental costs can be estimated. Note that where there are several load centres and long transmission lines, these costs may differ between load centres.

13. When thermal plant is not in use, except at some minimum level, or when it is running at capacity, extra generation requires extra use of water. Incremental cost is then the incremental value of water, where water is measured in terms of the KWh it will generate. Here too, the right figures emerge from the sort of simulation of future system operation which is a necessary part of any sophisticated system planning study designed to select the best development programme. Where cruder methods have been used, a more direct approach must be taken. Since the information available and the system configuration vary so much from case to case, generalisation is difficult. Two examples relating to a mixed hydro/thermal system will show what is involved, still confining the analysis to times when there is spare generating capacity:

- Extra hydro generating during a period when reservoirs are not spilling will require either extra thermal generation at some other time during that period or less spillage once the reservoirs are full. In the first case the incremental cost is that of the extra thermal generation; in the second case it is zero. The first case is typical of the "dry" or "discharge" season; the second of the "wet" or "filling" season.

- It is also zero at times when water is being spilled.

Note that the right answer in principle is an average of all the conditions that could occur, each weighted by its probability.

14. Turn now to the second lot of information which was said to be necessary, that relating to bottlenecks. This is a matter of the times and/or load centres when it is anticipated that, under typical or average circumstances, a future increase in some customer's load would necessitate at least one of three things:

- a corresponding reduction of other customer's loads;

- a reduction in security below the chosen threshold;

- more generating, transmission or storage capacity.

In an all-thermal system with a seasonal swing large enough to accomodate all planned maintenance in the slack season, the only such time will be that of system peak. But where planned maintenance is spread throughout the year, many daily weekday peaks may be such times. In mixed systems energy (KWh) as well as capacity (KW) may be involved too, over periods when it is planned to use all the water that is available under normal conditions without drawing down the reservoirs below the levels chosen to give the selected degree of security. Thus just as in the case of incremental energy costs, the information required will reflect both the operating characteristics of the system and the time pattern of the load. In practice the information may relate only to anticipated normal conditions but, in principle, it is again a probability calculation of mean expectations which is the ideal.

15. The third lot of information required is the cost of adding to generating, storage or transmission capacity in order to meet extra load during the times just specified without either reducing other customer's loads or infringing the security constraints. Such an addition to capacity will often involve bringing forward projects which are planned anyway to meet a growing load, but it could, for example, simply involve plant specially designed for peaking. The point is to ascertain the extra costs of removing what were referred to as the "bottlenecks." This may be difficult in cases where the engineering consultants who chose and/or designed the scheme have not used a proper system-planning model. The reason is that the net cost of such additional capacity is

(i) the cost of adding to, or bringing forward plans for new capacity;

(ii) corrected for its effects on the subsequent costs of running the system over the next few decades .

(i) involves only construction cost estimates and a little discounting, but (ii) involves a simulation or optimisation model. Since many consultants do not, or cannot provide such a model, it has at present to be accepted that the third lot of information, an adequate systems analysis of the net cost of capacity additions, will not always be available. Hence the evaluation of a tariff structure may have to proceed using the first two lots of information plus only rough estimates of net incremental system capacity costs.

16. The need for the three lots of information can now be summed up in the following questions:

(a) In the light of the anticipated future mode of operation of the system under normal conditions as a function of the shape of the load curve and where relevant, of hydrology, how can the year be divided into periods and points of time ?

(b) What are the incremental costs (measured from a national point of view) of additional KWh delivered to the distribution system at periods and places when supplying extra power under normal conditions will not infringe the security constraints ?

(c) What are the periods or points of time and places where extra power cannot be supplied without infringing the security constraints and what would be the net addition to discounted system costs of expanding capacity to avoid such infringement ?

17. These questions, and indeed all the following ones suggested in this paper, may appear to demand an impossible precision in their answers. But this would be a false deduction. Precise questions are intended to avoid ambiguity, and a rough and ready answer to them is all that can reasonably be expected from a brief investigation. Even lengthy investigation may do no better in many cases, because of an irremediable lack of basic data. The point is that an analysis which is logically clear but quantitatively crude can suggest tariff improvements which are important and well justified, even though they depart to an unknown extent from the unascertainable optimum optimorum.

<u>Bulk Tariffs</u>

18. Given the answers to these questions, it is possible to inquire:

(d) What bulk tariff structure would accurately reflect the cost and availability structure revealed by the answers to the last three questions ?

This question implicitly asserts that a bulk tariff ought to reflect the cost and availability structure of generation and transmission in some detail. In contrast with the use of retail tariffs, the necessary metering involves too small a cost in relation to the size of the supply to constitute an obstacle. The positive reasons for a detailed cost-reflecting bulk supply tariff are as follows:

- an incentive is provided to the distribution management both to consider some reflection of the bulk tariff in retail tariffs and to concentrate load-building efforts in suitable directions.

- information is communicated pithily.

19. This last point is important in many ways. For example it enables distribution management to cost transformer losses, to examine the case for reactive power compensators, to estimate one of the main cost elements in rural electrification schemes and so on. Even for a generating authority with no bulk sales, calculation of a notional bulk tariff is essential for any examination of retail tariff level and structure.

20. In constructing such a bulk tariff one can start with the answer to question (b) i.e. KWh rates equal to incremental KWh costs for the various periods when, under normal conditions there is spare capacity so that extra energy can be supplied without infringing the security constraints. Periods which turn out to have fairly similar incremental energy costs can be lumped together. At other periods and points of time KWh rates will have to exceed incremental energy costs and/or KW rates will have to exist such that:

- they jointly make the tariff as high as is necessary to keep the load at these times down to a level which will just not infringe the security constraints, and/or

- they jointly measure the net addition to discounted system costs of supplying more power in such periods without infringing security constraints.

21. The first of these, the tariff which rations energy and capacity demands to match the bottlenecks, is more relevant, both as information and incentive, for the next few years. The second of these, the incremental KWh and KW costs of removing bottlenecks is more relevant for subsequent years. If the two differ, then the more tariffs are difficult to alter, the more should the second form the basis of tariff determination though non-price means of encouraging or discouraging demand in the next year or two may then have to be used. What any particular level of rates will do to limit demand is naturally difficult to measure. However it must be recalled that the load forecasts for the next year or two usually continue recent experience. If, to make up an example, the load has recently been pushing against some security constraint on winter weekday evenings, then it should be possible to predict whether the rise in capacity already under way for the next few years is going to outpace the growth in load at these times.

22. If it is, then a reduced tariff component in respect of such loads may be indicated. Conversely, if the bottleneck in question is likely to become tighter, then a tariff high enough to keep these loads within the security constraints will become higher than the existing one. Thus even without any definite knowledge about the responsiveness of sales to tariffs at least a little can be deduced.

23. What has just been said about existing tariffs really applies to any mix of KWh and KW rates in force during the relevant period which adds up to the same total charge for loads during it. Given this total, the problem is to get them right separately as well, remembering that while a KWh charge measures incremental cost or signals scarcity of energy during a period, a peak KW charge measures incremental system cost or signals scarcity of capacity at a point of time when system demand matches capacity less required reserves. While the period can be dated in advance, for example winter weekdays 17:00 to 19:00 from December 15 through Feb 28 excluding public holidays, the actual peak point of time cannot. Such a point can only be ascertained retrospectively. This makes unacceptable a system-peak KW charge when there is more than one bulk customer, as no customer would know (until afterwards) when he was paying for system peak KW. This difficulty will not arise if each such customer is charged on his own peak, but only in the rare event of complete lack of diversity will this provide exactly the desired incentive. Since what is needed is a message conveying information and incentive to the bulk customers in advance, resort could alternatively be had to spreading out the KW charge over all the potential peak hours. The charge on any one of these hours should then be proportional to the probability of its turning out to be the actual peak hour. This would amount to an extra high KWh charge during potential peak hours and the case for it is stronger the larger is the number of such hours in the year.

24. When a bulk tariff has to serve not only as a means of conveying information and incentive but also (for distributional or financial reasons which have yet to be discussed) as a source of funds for the generating authority a conflict may exist between the two sets of purposes. Suppose that a bulk tariff constructed along the above lines has to be supplemented by a certain total amount in order to provide the requisite cash flow or rate of return. Then the aim should be to achieve this with the least possible disturbance to its signalling and incentive functions. Three devices suggest themselves, of which the first necessarily exerts the smallest such disturbance:

- sharing out the excess charge between bulk customers on non-electrical variables, such as population or book value of net assets if they are distributing authorities;

- concentrating the excess on those components of the bulk tariff whose signalling and incentive effects are least, i.e. spreading the excess in such a way that all outputs are reduced by the same percentage;

- spreading the excess uniformly over all components of the bulk tariff, increasing them all in the same proportion, so that its relativities are undisturbed.

No general solution is possible, but it should be noted that providing an adequate answer to question (d) demands the exercise of ingenuity on these matters.

Distribution Cost Analysis

25. In order to proceed from the bulk to the retail level, it is necessary to examine distribution costs. Here too our concern is with engineering estimates of future costs and not with the accounting records of past expenditures.

(e) What is the structure of distribution costs ?

26. A first step is to estimate incremental losses at different supply voltages and at different load levels in order to convert the bulk tariff rates into their retail equivalents. The second step is to estimate customer costs, a topic about which no more is said here. The third step is to examine the annuitised capital costs, plus associated future operations and maintenance costs, of:

- reinforcing the distribution system per KW of load growth in areas currently served;

- extending the system to new areas per KW of new load.

27. While the latter may have to be done ad hoc, there are several approaches to the former. In order of decreasing crudeness they are:

- relating past capital expenditure on distribution corrected for changing price levels and minus guesses of the cost of major system renovations and extensions, to the growth in retail demand at the time of distribution peak in areas currently served;

- relating growth in total length of each type of feeder, number of terminations and transformer capacity at each voltage levels to the growth in maximum demand at that voltage level, leaving out system extensions; the average growth in equipment per KW of demand is then costed at current price levels;

- finding the average cost per KW of reinforcement of each voltage level by costing a weighted sample of reinforcement schemes and then multiplying by the ratio of demand to capacity implicit in the chosen provisioning period to get the average incremental cost per KW of demand of distribution peak.

In all three cases, the annuitised capital costs plus the associated annual operations and maintenance costs can be set out per KW of the relevant maximum demand, without specifying exactly when it is going to occur. Alternatively, they may be spread over KWh in all the hours when it is likely to occur. In this case, as with the similar bulk tariff analysis, the result is to be interpreted probabilistically. Thus if a KW cost of $10 is equally likely to relate to any one of 100 specified hours, the resulting figure of 10¢ applicable to each of them signifies that there is a 99% chance of the cost being zero and a 1% change of it being $10 in any one of them.

Schedule of Rates for Costing

28. Combining the notional bulk tariff with the information on distribution losses and costs makes possible a reply to the question:

(f) What is the schedule of rates which can be used for costing retail loads i.e. which measures:

(i) the extra cost of delivering extra power to consumers at times when this neither infringes the security constraints nor requires extra capital expenditure ?

(ii) the charges which would have to be levied at other times to keep the load within the security constraints ?

(iii) the extra cost to the nation as a whole of expanding production transmission and distribution capacity to meet an increased load at such other times ?

Note that if (ii) exceeds (iii) there is a strong case for expanding capacity. But it is more useful to look at (ii) as having different time dimensions. (ii) is a matter of restraining the load to match the capacity over the next few years while (iii) is a matter of the cost of subsequent system expansion. As argued earlier, which of them is relevant when they differ is a question of tariff flexibility and of the importance of signalling a short-term or a long-term message to consumers. If load-shedding commonly occurs at certain times, then (ii) is in excess of the incremental charge for extra electricity which the existing retail rate structure would involve. It is worth repeating too that in the cost studies used to answer (i) and (iii) rough but relevant information about the future is more relevant than precise data from the past. Great care must be taken in using accounting records to ascertain which pro-rated overheads are included in particular items of costs, since such allocations may (not surprisingly) be inappropriate for the present analysis for which they were not designed.

29. Let it be clear that the schedule of rates used for the casting of retail loads is no more than a collection of information necessary for examining tariffs. Metering and billing problem alone would prevent its implementation as an actual rate structure for all consumers. But is does provide necessary information for constructing feasible retail tariffs and for costing new loads. Before we get on to tariff construction it is worth pausing to note that a distribution undertaking can influence its customers not only via retail tariffs but also by its encouragement or discouragement of particular loads. An "active marketing" posture of this latter sort may be uncommon among electricity authorities, but is to be commended for all that.

Load Analysis

30. The next step is to find out as much as possible about the composition of the load i.e. who uses how much electricity, for what purposes, when:

(g) What information can be assembled about the separate load curves of the different groups of customers, the split of their consumption between different uses and the time pattern of these uses ?

When quantitative information is lacking, merely qualitative information must suffice. Knowledge of factory hours, people's eating habits and the time it gets dark are of some use. Suggestions that quantitative techniques ought to be applied in the future may not come amiss.

Price Distortions

31. Using this information it is then necessary to ask which of the various uses are affected by the availability and price of:

- other fuels,

- electrical appliances

Thus one can find out whether gas competes with electricity for cooking, whether some industrialists generate their own electricity, the importance of other sources of motive power, the tax on air-conditioners and so on. The aim is first to understand these matters as factors helping to determine the pattern of electricity usage and, secondly, to see whether correction of these prices to allow for taxes, shadow exchange rates and the like would make them substantially different. If so, then they constitute misleading incentives. If nothing can be done to change them, then it may be worth considering ways in which the incentives provided by electricity tariffs could be slanted so as to produce an offsetting effect. Two imaginary examples will show what is meant:

- if gas competes with electricity for certain peak-intensive uses, if rates for gas are heavily subsidised and if nothing can be done about it, any case which there might otherwise be for changing high peak rates for these uses of electricity may be weakened;

- if private enterprises obtain generous tax relief on all capital expenditure including auto-generation, then perhaps there is a case for lower electricity tariffs for large industrial users than there otherwise would be.

32. Summing up, the question must be asked:

(h) Are price distortions in other parts of the economy likely to affect electricity sales importantly; if so, can and should these distortions be remedied; if they cannot or should not, should electricity tariffs be slanted in order to offset these distortion ?

Slanting the tariffs in this way may well prove to be too complicated, may conflict with notions of fairness or may interfere with other broad government policy objectives. Nonetheless it is right to consider this problem and include it as one of the factors in a critique of the present tariff structure. The difficulties involved in any such slanting furnish an argument in favour of tackling the distortions directly. The same applies to distortions which make marginal cost to the electricity supply undertaking differ significantly from cost from the national economic view point.

Existing Tariffs

33. Next, the present tariff structure must be described. Such problems of administering it as cost, complexity and fraud must definitely be considered but in the present context the main question is:

(i) What is the present tariff structure and what incentives does it provide to consumers ?

34. Another way of expressing this is to ask what are the partial derivatives of consumers' electricity bills with respect to their electrical behaviour. A few examples will show what is meant by such a description:

- extra KWh cost the same by day and by night;
- a uniform monthly maximum demand charge offers no greater incentive to keep demand lower in the peak months of demand than in the rest of the year;
- penalties for low power factor apply only below 80%;
- a lower domestic rate for "heating" than for "lighting" with separate meters and circuits makes extra KWh dearer for lighting than for other domestic uses;

- a flat rate of 3¢ for users consuming up to 150 KWh per month, and one of 4¢ for users consuming more, strongly encourages small users to keep their monthly consumption below 150 KWh;

- descending block rates make the cost to the small consumers of an extra KWh 5¢ as compared with 3.5¢ for large consumers.

These examples are purely anecdotal, to show what sort of incentive effects can exist, but what is required by way of answer to (i) is naturally a systematic description.

Tentative New Tariffs

35. With all the information collected in answer to the questions it is now time to ask:

(j) How can the tariff structure be changed so that the incentives it gives correspond more closely to the schedule of rates developed for the costing of loads ?

36. This question will not produce a final proposal for a new structure since income distribution and financial problems are still being left on one side, as are the problems of transition to a new structure. But at this stage it is certainly necessary to allow for:

- Any strong arguments for slanting the tariff structure developed under question (h).

- Practicality and cost. If the existing tariff is difficult to administer, conducive to disputes or prone to fraud, ideas for making it better in these respects will be useful and must be allowed to help determine the choice of the new tariff structure.

37. There is, of course, a trade-off between the cost of administering a tariff structure (which depends largely on the cost of metering and billing) and the extent to which it can reflect the structure of the schedule of rates for the costing of retail loads, so providing appropriate incentives. Five rather general but useful propositions about this trade-off can be advanced:

- As the extra cost of more complex metering has to be justified by the effect of the superior incentives it can present, and as this extra cost rises but little with the size of the consumer, while the absolute response to incentives rises quite fast with the size of the consumer, the case for more complex metering is relatively stronger the larger the consumer.

- As the response to incentives is greater for uses which are not time-bound and where there are alternative sources of energy, complex metering is best justified for consumers for whom such uses are important.

- The option between a simple tariff and a more complex more expensive one can often be left to the consumer by allowing him a choice of tariff. With such options, the consumer who could respond strongly to the incentives of the more complex tariff should find it to be the cheaper one, even though he has to bear the extra cost of the more complex metering.

- There is often a choice between a larger number of simple tariffs and smaller number of more complex ones. Thus if night KWh are shown by the schedule of rates for the costing of retail loads to be, on average, much cheaper than day KWh, and if night KWh form a smaller proportion of shop than of domestic consumption, a two-rate night-day tariff will cope with both. The alternative would be to have a separate single-rate tariff for each, with a higher unit charge for shops.

- With monthly meter reading, seasonal KWh tariffs can always be introduced at a negligible extra cost. Such tariffs should, therefore, always be considered when demand and costs display a significant seasonal pattern.

38. An improved tariff structure, once achieved, should be designed to last for a number of years, apart from adjustments to inflation, since the responses to incentives involving the design and the growth in ownership of appropriate appliances are spread out over time. This, it will be seen, is an argument for concentrating on (iii) rather than (ii) in question (f), i.e. for looking at long-run costs - at least when there is no acute shortage of capacity necessitating a lot of load-shedding. A statement that 40% of residential consumers buy less than 100 KWh per month, for example, is less interesting than a forecast that, in five years' time, the figure will be only about 15%. The incentives should be directed at tomorrow's consumers rather than at today's, except when today's problems are particularly acute. When they are not, an attraction of optional tariffs becomes important. Suppose, for example, that a time of day tariff can give much more relevant incentives than a straight energy tariff. However it does cost more, so that its immediate introduction for all consumers would not be worthwhile. In these circumstances it might be introduced as an option to which, initially, only a minority of consumers might subscribe. As individual loads grew, then, with effective marketing, more and more consumers might subscribe and the relationship between the two tariffs could gradually be tilted so as to favour it. But if the course of events showed that its wider adoption was not after all worthwhile, it could be discouraged or even suspended (subject to a right for existing consumers on it to continue) and little would have been lost.

39. Except possibly for large industrial consumers, it is to be expected that the revised or new tariff structure proposed will not reflect most of the details of the schedule of rates for the costing of retail loads by which it is inspired. Thus the new tariffs will contain only a very few of all the possible incentives to economise more in the use of electricity at some times or in some uses than at other times or in other uses. It is, therefore, important to see that those few incentives which can be put in the tariffs are those which matter most. What matters most is proportional to:

- the size of the incentive suggested by the schedule of rate for the costing of retail loads, and

- the magnitude of the response.

Thus a signal that peak KW cost a great deal more than other KW may be less useful than a signal that night KWh are somewhat cheaper than day KWh if the response to contribution-to-system-maximum-demand pricing would be much less than the response to a lower KWh rate at night. If water heating is the most promising subject for domestic tariff incentives, however, telecontrolled water heaters with a special cheap rate and a separate KWh meter may be more appropriate. Similar sort of considerations affect decisions about industrial tariffs. Thus if shift-working is insensitive to electricity charges, it may be better to concentrate on selling interruptible supplies to industry than on cheap night KWh. In most cases, as argued in the previous paragraph, the response which is relevant is not the immediate one but the response over a period of years, so that the relevant schedule of rates for costing retail loads must correspondingly, relate to the average over a future period of years. Only when power shortages are acute and are not going to be remedied for a few years is concentration on short-run load-restraining tariffs to be preferred.

Finance and Income Distribution

40. Any set of new tariffs (and the new consumer classification which they may well involve) tentatively developed along the foregoing lines now has to be modified to allow for:

- financial requirements;

- any desired income redistribution;

- the problems of making the transition

Although these interact, it is expositionally convenient to consider them separately.

41. Taking financial requirements first, these are that the electricity tariffs generate sufficient cash flow, a requirement often translated into rate of return terms. In addition, a government may wish to tax electricity consumers to provide general revenue. This is perfectly reasonable; indeed if other fuels are taxed it may be necessary to tax electricity too in order

avoid a distortion in the relative prices of electricity and other fuels. Circumstances obviously vary between countries too much for generalisation to be possible, but the first step is clearly to inquire:

> (k) If the tariffs tentatively developed so far were applied, how much revenue would they yield and is this sufficient ?

42. It may be thought that tariffs based on the schedules of rates for the costing of retail loads, including connection and/or fixed charges to cover customer costs, will normally fall below accounting costs, so that the revenue produced would be sufficient. But this is in fact far from necessary. For one thing, if inputs are valued at shadow prices, costs looked at from the point of view of an electric utility may be considerably exceeded. But such national economic refinements may be outside the scope of a tariff investigation. The main point which applies to all systems which have existed for any length of time is that accounting costs reflect past capital expenditure and the chosen depreciation rules, whereas any capital costs entering into the analysis relate to expected future expenditure. There is an ongoing race between inflation and technical progress, the one raising and the other lowering future capital costs relative to past capital costs. Furthermore, even when the schedule of rates for the costing of retail loads reflects only generating costs plus losses, these are incremental costs. With plant loaded in "order of merit" these will usually exceed average generating costs, so a tariff based on them will yield an excess of revenue over generating costs which may or may not suffice to cover all other costs. Thus there is no general presumption either way about the answer to (k).

43. If more revenue is required, then the argument follows similar lines to those set out earlier concerning bulk tariffs. Subject to any reservations relating to income distribution, the aim should be to increase the level of tariffs with the least possible disturbance to the incentives which they present to customers to go easy on consumption at times or places when incremental costs of energy are high and/or when extra KW push against the security constraints or necessitate extra capacity. This involves concentrating the increase on those components of the tariffs which will elicit the smallest response by way of change in consumption. Fixed charges are an obvious first target. They do not necessarily have to be uniformly high. For example they could be related to property value as assessed for tax purposes. The same considerations clearly apply if less revenue is needed.

44. Income distribution decisions are difficult for consultants to cope with, since they involve political and social judgements which may be outside their competence. But someone, depending upon the circumstances of the case, must make them, and, once made, they specify:

- who is to benefit;
- who is to pay;

and the problem is to decide how. They can be elicited, and justification of them sought by asking what distributional objectives entered the existing tariffs, if any. Two cases must be distinguished:

- the aim is to stimulate the consumption of a particular group of consumers i.e. to achieve an incentive effect;

- the aim is merely to reduce the bills of a particular group.

45. An example of a subsidy is the provision of rural supplies at tariffs below the cost which can be calculated for rural loads using the schedule of rates for the costing of retail loads (which embodies the capital costs of extending the distribution system). This may be done simply by requiring rural tariffs to be the same as urban tariffs, in which case there is no more to be said. But in other cases, where the nature of the subsidy is an open question, the aim must be to provide any desired incentive without producing other unwanted incentives. Thus a low rate on a first energy block will reduce the bills of the consumers on the tariff. This will have different incentive effects according to whether the consumers on the tariff in question use less or more than this amount of energy. Hence a lower fixed charge might be considered if what is aimed at is merely a financial benefit.

46. The changeover from one tariff structure to another is always difficult, since customers who did well under the old tariff tend to regard themselves as having a vested interest in it. Hence the impact effect of the changeover and possible tactics for making it more acceptable are problems of some importance. The transition may need to be made in several stages and it may be a good idea for the new tariffs to be introduced only as options.

47. All these matters deserve thought and investigation. To sum up, it must be asked:

(l) Given the answer to question (k) and given the amount of any overt subsidies, how can the tentatively-determined customer classifications and tariffs be modified to provide the required revenue and implement the desired subsidies with the least possible distortion of incentives ?

48. The phrasing of the question is not meant to imply that all proposals for income redistribution and subsidisation should be automatically accepted. For example, while nationally uniform tariffs are obviously simple and appear to be fair, it is not at all obvious that the resulting equal incentives to load growth make sense in terms of resource allocation. Perhaps electricity-intensive industries should have an incentive to locate near generation centres. The magnitude of regional differences in the schedule of rates for the costing of retail loads should at least be set out and considered before any decision to ignore tham is made. Another example of conventional wisdom which requires a second look is the notion in some countries that poor electricity consumers should be subsidised. Here it is worth noting that poor people without electricity are worse off than poor people who have it.

Hence the idea of subsidising the poor in some other way than via electricity deserves attention.

Institution Building

49. Whatever professional competence on electricity authority displays, it cannot be taken for granted that it is animated by considerations of the national economic interest. It may judge changes in tariff structures by their immediate public acceptability among the influential, valuing a quiet life more highly than economic effects. It may, alternatively, want to promote peak demand so as to justify more rapid expansion and engage in empire-building. Such attitudes are a luxury which a poor country can ill afford, so it is worth asking:

> (m) Is the client electricity administration both properly motivated to further the economic development of its country and technically capable of examining economic issues ?

Final Remarks

50. The reader of the preceding pages will have noticed the obvious point that the questions proposed will often be rather too general to match the particular circumstances of any particular study. But while the letter of the analysis will need modification from case to case, the spirit of it applies everywhere. Prices can and do affect the attractiveness to consumers of alternative courses of behaviour and so need to be related to their consequences for resource use, consequences measured in terms of a forward-looking concept of costs. This is as much, or more, a matter of the structure of prices and costs as of their levels.

51. Simple and general propositions about pricing cannot be made. But it is usually a good idea to ask whether prices should not be cut at times and places when more could easily be supplied because capacity is under-utilised. Similarly, when capacity limits are strained it is worth considering whether a rise in prices might limit demand more efficiently than interruptions of supply, rationing, etc.

52. Pricing, as well as being a means of raising revenue, is about future choices in relation to future costs. This means that the relevant figures are only estimates and are subject to uncertainty. There is therefore a temptation to go back to accounting cost figures. But an accurate record of the past is not relevant; rough and uncertain estimates about the future are unavoidable in decision-taking. Accounting costs, on the other hand, are relevant for total revenue requirements.

53. Politics may demand that pricing policy should aim to achieve some measure of income re-distribution. This may have to be accepted but the analyst should at least ask whether other methods are not better.

ANNEX 1

Further Question: The Security of Supply

1. Less developed countries cannot afford the same quality of service as developed countries. An application of this obvious point related to the provisions made to ensure security of electricity supply.

2. Any project for the expansion of power capacity normally constitutes the next step in a whole proposed programme for the development of a power system. This programme is asserted to be the minimum-cost way of meeting the projected load, subject to certain constraints relating to the security of supply. Two simple illustrative examples of such constraints are:

- there must be enough generating capacity to withstand the loss of the largest single generating unit without output falling below the predicted peak demand;

- water storage capacity and thermal capacity must together be sufficient to meet predicted energy requirements in the critical period even if the inflow is as low as in the driest season experienced since records began.

3. The probability of interruptions of supply is often not calculated by the engineering consultants responsible. This would require data about the weather sensitivity of consumption, plant outage risks and the range of forecasting errors, as well as about the variability of water flows (where hydropower is involved). Nevertheless, even without a probability calculation, it is obvious that if the constraints were less stringent:

- there would be a cheaper minimum-cost programme to meet the projected load;

- the probability of interruptions of supply would be greater.

4. Hence the question arises of whether this saving in cost (which can be readily calculated) outweighs the disadvantages of the greater probability of interruptions. Even if the latter is calculated too, this question cannot be answered purely objectively because of the problem of putting money values on interruptions of supply. But this does not justify ignoring the question. It is necessary to gather whatever information can be obtained and use it to form a judgement. Continuing the simple example given above, more relaxed constraints could be considered, such as:

- ability to withstand outage of the second largest unit;

- meeting energy requirements in the second driest season experienced in the past.

5. The resulting cost-saving could then be calculated and estimates made of how much load shedding would be required if

- outage of the largest unit occured;
- a season as dry as the driest experienced in the past occured;

assuming correctness of the load forecasts. This would give a rough idea of the order of magnitude of the possible disadvantages of the reduction in security. It might be expressed in value terms by using a "penalty price" per KWh of supply failure. A judgement could then be made as to which of the two levels of security was the better choice in the circumstances of the country in question. The system's arrangements for load control and load-shedding obviously figure among these circumstances and their adequacy would have to be investigated.

6. Generalising from this example, a question can be formulated as follows:

(n) How do the possible consequences of a lower degree of security compare with the cost savings it would involve, given that load-shedding arrangements are made as good as possible ?

This question should be applied to investment in transmission and distribution as well as to investment in generation. It might, for example, lead to a judgement that suburban distribution networks should be provided with relatively less security than urban networks.

ANNEX 2

List of Questions Raised in the Text

(a) In the light of the anticipated future mode of operations of the system under normal conditions as a function of the shape of the load curve and where relevant, of hydrology, how can the year be divided into periods and points of time ?

(b) What are the incremental costs (measured from a national point of view) of additional KWh delivered to the distribution system at periods and places when supplying extra power under normal conditions will not infringe the security constraints ?

(c) What are the periods or points of time and places where extra power cannot be supplied without infringing the security constraints and what would be the net addition to discounted system costs of expanding capacity to avoid such infringement ?

(d) What bulk tariff structure would accurately reflect the cost and availability structure revealed by the answers to the last three questions ?

(e) What is the structure of distribution costs ?

(f) What is the schedule of rates which can be used for costing retail loads i.e. which measures:

(i) the extra cost of delivering extra power to consumers at times when this neither infringes the security constraints nor requires extra capital expenditure.

(ii) the charges which would have to be levied at other times to keep the load within the security constraints:

(iii) the extra cost to the nation as a whole of expanding production transmission and distribution capacity to meet an increased load at such other times ?

(g) What information can be assembled about the separate load curves of the different groups of customers, the split of their consumption between different uses and the time pattern of these uses ?

(h) Are price distortions in other parts of the economy likely to affect electricity sales importantly; if so, can and should these distortions be remedied; if they cannot or should not, should electricity tariffs be slanted in order to offset these distortions ?

(i) What is the present tariff structure and what incentives does it provide to consumers ?

(j) How can the tariff structure be changed so that the incentives it gives correspond more closely to the schedule of rates developed for the costing of loads ?

(k) If the tariffs tentatively developed so far were applied, how much revenue would they yield and is this sufficient ?

(l) Given the answer to question (k) and given the amount of any overt subsidies, how can the tentatively-determined customer classifications and tariffs be modified to provide the required revenue and implement the desired subsidies with the least possible distortion of incentives ?

(m) Is the client electricity administration both properly motivated to further the economic development of its country and technically capable of examining economic issues ?

(n) How do the possible consequences of a lower degree of security compare with the cost savings it would involve, given that load-shedding arrangements are made as good as possible ?

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NOTES SERIES

STATUS AND OUTLOOK OF GEOTHERMAL ENERGY

March 7, 1974

Central Projects Staff
Public Utilities Department

STATUS AND OUTLOOK OF GEOTHERMAL ENERGY

ABSTRACT

This Note examines the status and prospects of geothermal development: potential reserves, actual and planned installations, available cost data, technological constraints, research needs and programs of national and international agencies, including those of the UN Resources and Transport Division.

It forms part of a series of papers reviewing the principal sources of energy -- nuclear power and coal are next -- designed to serve the needs of energy and power sector work and to be used also as inputs to the work of the Energy Task Force.

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March 7, 1974

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I. INTRODUCTION

The utilization of geothermal energy, or the heat of the earth, as an economic resource has been practiced for over a century, in diverse ways and in many parts of the world. These installations have been relatively small and their economic impact has been only local. However, the number and magnitude of geothermal installations has increased rapidly in recent years and many projects are in various stages of planning or construction.

The most obvious geothermal development is its conversion to electrical energy, with a present worldwide capacity of about 1100 megawatts. Equally important are its wide usage in some countries for space heating and for heating of greenhouses. Minor applications to date include refrigeration, chemical recovery, and process heating.

The industrial potential of geothermal energy is enhanced by two characteristics. First, geothermal brines are amenable to economic multiple-purpose utilization. Thus, potable water production, space heating and cooling, and chemical byproduct recovery can often be combined with electric energy generation at an increased overall utilization of the available energy. Secondly, cost penalties incurred as electric plant size decreases are relatively small. Thus, small local generating stations are feasible. Because geothermal deposits also favor multiple small installations, this aspect is favorable to its application to developing countries.

This paper will discuss the status of geothermal development in the world. Actual and planned installations are presented, as are potential reserves and costs where available. The state of the art is analyzed as are the technological problems that would tend to inhibit rapid growth of the industry. To resolve these problems, some developmental work must be undertaken that would involve both the adaptation of existing technology already developed in other industries, and the initiation of research to perfect new technology. The programs of various national and international agencies are summarized.

As in the case of liquid and gaseous hydrocarbon reserves, it is not possible to estimate the size of geothermal reserves until extensive deep drilling has been undertaken to find the geothermal deposits and to prove their extent. On the other hand, estimates of the potential geothermal resource have been made for several parts of the world. These are reported with the cautionary remark that both time and money devoted to exploration and drilling are required to verify the estimates.

Before entering into these topics, a resume will be made of the nature of the geothermal resource, of the geologic basis for its existence, and of the most probable locations where geothermal energy might be concentrated.

II. NATURE OF THE GEOTHERMAL RESOURCE

A. Background

Geothermal energy is literally the heat of the earth; that is, the energy stored within the earth at temperatures higher than the mean surface temperature. Natural processes occurring within the earth, such as decay of radioactive elements and frictional movements of tectonic plates, generate energy at enormous rates. The escape of this energy to the surface results in a temperature gradient increasing from the surface to the earth's interior. The magnitude of the gradient at any point is determined by the local rate of heat flow and the local resistance to heat flow. Where heat flow occurs by pure conduction through rocks and trapped water, the temperature gradient is relatively high. Where it occurs by vertical convection of water flowing through permeable rock formations, the temperature gradient is relatively small.

On a worldwide basis, the average heat flow is estimated at 1.5×10^{-6} cal/sec-cm^2, which results in an average temperature gradient of about 20° to 30°C per kilometer of depth. At the interface of the earth's crust with its mantle, estimated to occur at about 25 to 50 kilometers below the surface, temperatures up to 1000°C have been estimated. Temperatures at the core of the earth are estimated to be as high as 4500°C (1)*.

On this basis, the total quantity of energy stored within the top 10 kilometers of the earth's crust has been estimated to be about 3×10^{26} calories. By way of comparison, worldwide energy consumption in 1971 was estimated to be about 6×10^{19} calories.

Unfortunately, only a small fraction of this energy is stored in "economic deposits." Economic deposits, however, are believed to be so numerous as to justify the exploration and exploitation costs to find and utilize them. When found, the energy stored in geothermal deposits must be mined, just as fossil fuels and mineral deposits are mined, and they will be eventually depleted in a similar way. This is true because the local rate of natural energy generation is many times smaller than the rate of energy extraction in a commercial operation. Nevertheless, many technical papers mistakenly call for geothermal production at rates equal to the natural energy recharge rate.

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* Numbers in parentheses refer to the Bibliography.

Before a geothermal energy deposit can be classified as being economic, it must satisfy certain general criteria, but specific limiting values for the criteria will depend upon local conditions. First, the geothermal deposit must be accessible, and located at reasonable drilling depths; 3500 meters is sometimes cited as a maximum feasible depth, although some studies of deposits as deep as 6000 meters indicate that they may be economic. Secondly, an economic deposit will be "concentrated;" that is, temperatures must be sufficiently high. In the case of brine deposits, temperatures of over 240°C have been considered necessary, but with advanced processing techniques, as little as 150°C should be acceptable. One installation produces electricity from water at 83°C. Dry steam deposits at produced temperatures of 150°C are being processed commercially. Third, the energy in an economic deposit must be stored in a form that can be easily processed to convert the energy to electricity. Systems where brine or steam occupy the pore space of the hot rocks have been economically developed. This is not yet the case for systems of hot dry rocks, although extensive research is being undertaken with the goal of achieving economic development of the latter systems.

B. Origin of Economic Geothermal Deposits

In the previous section, economic deposits were generally defined as brine or vapor deposits at temperatures exceeding 150°C and at depths of less than 3500 meters. It was also shown, however, that with normal temperature gradients, depths of over 6500 meters are required to achieve these temperatures. Thus, economic deposits of geothermal energy must be considered geologic anomalies.

Local hot spots are created close to the surface by the intrusion of very hot or molten rock from the mantle into the earth's crustal zone. (If they reach the surface, as in volcanos, they are called extrusions.) The surrounding rock and sediments are heated by conduction from the hot intrusive. Water from rainfall, rivers, or lakes may seep into the zone of hot sediments and be heated in turn. As this hot water flows upward by convection, it may find access to the surface through cracks or permeable formations. In this case, the local heat source may be manifested as hot springs, mud pots, fumaroles, or geysers.

Under other circumstances, the hot water may be trapped underground in large deposits. The traps may be due to the obstruction of impermeable rocks, as is true for petroleum deposits, or it may consist of a thick overlying bed of water, itself contained in the pore space of the rocks. Hydrostatic pressure due to the upper water bed inhibits boiling in the hot brines, thus maintaining the heated fluid in the liquid state. Under special conditions of trap characteristics and heat flow, the liquid may vaporize and form a dry steam deposit.

C. Location of Economic Geothermal Deposits

Modern geology relates geothermal deposits to the tectonic plate theory (2). The earth's crust is being spread apart along a network of bands, due to the convective movement of the semi-plastic rock within the mantle. Where this crustal spreading occurs, the crust is weakened and cracked, permitting the very hot rocks to penetrate the crust and move towards the surface. Thus, geothermal deposits can be expected to be found in regions of recent earthquake and volcanic activity which are also associated with tectonic plate movements.

That this is actually the case can be determined by considering the primary areas of geothermal interest. These include the geothermal fields of Iceland, and the Western Coast of Mexico and the United States which are on spreading ridges of the type described above. The fields of New Zealand, Japan, and Central America are located along subduction zones, which are the boundaries at which the crustal plates are pushed together.

Recently active geological sites, however, are not the only criteria for the accumulation of hot brines. A different geologic phenomena accounts for the deposits of "geo-pressured" brines, such as have been found on the Gulf Coast of the United States and are believed to exist in many other parts of the world (3). In these instances, a rapid (in geologic time) settling of sediments leads to a non-equilibrium situation in the deep clays, usually those deeper than 3500 meters. Water that would normally escape upwards, after being squeezed out of the clays under the high pressures at depth, is instead trapped. The low thermal conductivity of the water compared to that of dry rocks results in large temperature gradients, and high localized temperatures within the deep clays. The temperature gradient above the geo-pressured zone will then be lower than average, effectively masking the existence of the deposit from discovery when exploration is based on the measurement of temperature gradients near the earth's surface. The Gulf Coast geo-pressured deposits at depths of greater than 4000 m are at pressures in excess of 800 atmospheres and at temperatures exceeding 150°C. A significant quantity of methane gas is believed to be dissolved in these brines.

D. Chemistry of Geothermal Fluids

The chemistry of brine deposits is as varied as it is complex. They may be almost pure water, containing only a few hundred parts per million of dissolved solids, or they may be almost saturated with up to 30% by weight of dissolved salts. An arbitrary designation is sometimes made whereby geothermal "brines" are hot liquids containing more than 30,000 ppm of dissolved salts, while geothermal "water" contains less than this amount.

Sodium chloride usually predominates as the chemical constituent. Silica dissolved from the rocks will often be present up to the saturated quantity of several hundred parts per million. Carbonates or bicarbonates, depending upon the pH, are usually present in significant amounts, but calcium sulfate will not be because of the elevated temperature. Ferric ions may be present, and lead to potential corrosion problems, while other minor constituents such as lithium, bromine, or iodine may be potentially profitable byproducts.

Dissolved gases are usually present in deposits of both geothermal brines and geothermal steam. These gases are primarily carbon dioxide with significant amounts of hydrogen sulfide and ammonia. Trace quantities of many hydrocarbon gases may also be present, but dissolved oxygen can usually be expected to be totally absent.

E. Exploration Techniques

To the present time, the finding of general areas with the potential for producing geothermal energy has depended on chance and primitive techniques. As discussed, geologically active regions would provide the first criteria to explorers. Surface manifestations of high temperature, such as geysers, fumaroles, hot springs and bubbling mud holes are a clue to higher temperatures underground. The rate of temperature increase with depth may be too small, however, to yield an economic deposit; or the source of the fluid arriving at the surface may be displaced horizontally a considerable distance and difficult to locate. Thus, these surface manifestations are not reliable guides for exploration.

Several hot zones have been encountered by chance, during drilling efforts by explorers for petroleum. This is true for the hot brines in Imperial Valley, California, and the geopressured brines of the Gulf Coast.

More sophisticated methods of general exploration are under development, but none is very reliable at this time. Infra-red imagery and geothermometers are among these. The latter refers to the chemical analysis of surface waters, in an attempt to discern temperature related chemical reaction products that may have been formed when the water was still in contact with higher temperatures underground. Several geophysical techniques are used to locate "anomalies" that may be associated with high temperatures underground. These include magnetic, heat flow, gravity, seismic, and electric surveys.

III. PRESENT UTILIZATION OF GEOTHERMAL ENERGY

The first known commercial utilization of geothermal energy occurred in Larderello, Italy. Boric acid was recovered from hot spring waters as early as 1812, and the first production of electricity occurred at the same location in 1904. Growth of the industry has not been rapid since then, but has been accelerating during the past decade.

Electricity is now being produced from geothermal heat in 8 or 9 countries. Other applications such as space heating, refrigeration, and as supplemental heating for greenhouses occur in many other countries. Planning and exploration studies are underway in much of the world. Many major American oil companies are leasing geothermal lands in the United States, and the United States government has committed a large budget to research and development studies.

These applications are discussed in the following sections, while more details are presented in Tables 1A, 1B, and 2.

A. Generation of Electricity

1. Steam Systems--The simplest power application of geothermal energy is to produce electricity from natural steam. Steam produced from wells is sent directly to low pressure turbines, the only treatment being to remove dust and other solid particles from the steam. Conventional separators are used, wherein a change in flow direction is forced to take place at the expense of a drop in steam pressure.

Condensing turbines are usually used. Cooling water may be available for the condensers, or the condensate itself may be cooled in cooling towers and recycled to the condensers. The rate of evaporation from the cooling towers is 80 to 90% of the rate of steam flow to the turbine. The remaining condensate is disposed of to local surface waters, or by reinjection into the producing formation.

Non-condensable gases are produced with the steam, consisting mostly of carbon dioxide with smaller amounts of ammonia and hydrogen sulfide. Trace amounts of other gases will usually be found, including hydrogen, methane, argon, and nitrogen. Amounts and compositions of these gases vary, but they normally range up to 5% of the steam flow. These gases are removed from the condenser vacuum system by removing a part of the geothermal steam from the turbine feed and using this steam to drive the jet ejectors.

The primary examples of this type system are the steam fields of Larderello, Italy, and the Geysers in northern California in the United States, which have capacities of about 400 megawatts each. Details of these installations are presented in Table 1A (4).

2. Hot Brine Systems--The more common geothermal deposit consists of hot water or brine in the underground reservoir. These can be very hot, such as the fields at Wairakei, New Zealand, and Cerro Prieto, Mexico, where temperatures up to 388°C have been recorded (5, 6). At these locations, the liquid is produced under its own pressure, as it flashes within the well to produce a two-phase mixture of steam and liquid. The hydrostatic head within the well is much reduced when steam is thus formed during production, and the reservoir pressure is therefore sufficient to cause flows of several hundred thousand kilograms per hour.

The two-phase mixture leaving the well is separated in a cyclone type separator at the wellhead, with the steam being directed to low pressure turbines. This part of the system is then similar to the power plants run by natural geothermal steam. The steam temperature at the surface, however, will be much less than the underground brine temperature.

At the Cerro Prieto installation, the brine leaves the wellhead separator at temperatures greater than 150°C, and is discarded to surface evaporation ponds. The Wairakei unit, however, further processes the hot water leaving the wellhead separators. This water is sent to other flash tanks, producing lower pressure steam to drive second and third stage turbines, with the inlet pressure to the final turbine being about 1.35 atmospheres absolute. The geothermal water now cooled to almost 100°C is disposed of to mountain rivers that discharge to the ocean.

Further details of the hot water systems are presented in Table 1B.

3. Moderate Temperature Brine Systems--The most abundant geothermal brine will be moderate temperature brines, defined arbitrarily as having an upper limit of about 150 to 200°C. Economical utilization of these waters for the production of electricity will require a secondary fluid loop. This will contain a low boiling fluid, such as Freon or i-butane, which is heated and vaporized by the geothermal brine. The vapor then drives the turbine, is condensed, and recycled to the heater (7). Only one actual installation is known for this system, but considerable developmental work is underway in the United States.

The known installation, at Paratunka on the east coast of Kamchatka in the Soviet Union, is an extreme example of this technology, for the hot water is at a temperature of only 83°C (8). A Freon (it appears to be Freon 12) is vaporized at 55°C and superheated to 65°C before entering a 750 or 1000 kw turbine (references differ on the size). Condensation takes place at less than 20°C. Thirty-five percent of the gross production is used for in plant requirements. Not much information is available on this unit, but it apparently has been operating successfully since 1970, following tests that began in late 1967.

B. Space Heating

The use of geothermal energy for heating of homes and buildings occurs in many parts of the world, in both organized and unorganized fashions. As an example of the latter, many individual households in rural areas of the Western United States tap shallow hot wells for heating the home and water (9). This is probably also true in other countries.

Iceland probably provides the best example of effective, large scale utilization of geothermal energy. Hot water for heating has been used since the 1930's, and now supplies about one-half of its total population of 200,000 (10, 11). This percentage will continue to increase over the next decade. At Reykjavik, 90% of the homes are geothermally heated, resulting in an estimated fuel oil saving of about 200,000 tons per year. The water is produced from over 100 wells, the deepest being about 2200 m, and ranges in temperature from 98 to 146°C in the earth. Distribution takes place through 35 cm steel lines, contained within a concrete conduit, over distances of up to 18 km. The distribution temperature is about 80°C. The water quality is good, with about 400 ppm of dissolved solids; the only treatment required is the separation of gases that dissolved in the water while under pressure in the reservoir.

Geothermal space heating is employed in several areas of the Soviet Union, the principal one being a 500 km zone along the north slope of the Caucasus. Waters in the reservoirs range from 100 to 150°C, while the distribution temperatures range from 47 to 86°C. The salinity of the water is often low enough to allow its direct use, but closed loop heat exchangers are sometimes required. Geothermal heating systems serve about 15,000 people in Makhach Kala, 18,000 in Cherkessk, as well as districts in Maykop, Grozny, and elsewhere (12).

Other areas of the Soviet Union with heating projects include the Caspian Sea near Iran, the Black Sea coast of Georgia, parts of Siberia and Lake Baikal. More than half of the city buildings of Dagestan, on the Caspian, are heated by an underground sea 2 or 3 km away.

Communities heated by geothermal waters also exist in the United States, New Zealand, Japan, Hungary, and France. At Melun, 50 km southeast of Paris, 3,000 lodgings were equipped for geothermal heating in 1972 by means of waters at 60 to 80°C, taken from depths of 1500 to 1900 meters (13).

C. Miscellaneous Uses of Geothermal Energy

This category covers a wide range of activities, commercial, agricultural and industrial, although most of them are small. Greenhouses use geothermal heat in many countries. Reported surface areas under such cultivation include one million square meters in Hungary, 300,000 in Iceland, 30 million in the Soviet Union, and lesser amounts elsewhere (2). Air conditioning by an absorption refrigeration unit run by geothermal water supplies a 100 room hotel in New Zealand. Here, also, geothermal steam is used for process purposes in a paper mill. Geothermal heat is used in Japan to evaporate sea water for the recovery of salts. A pilot plant to desalt geothermal brines has been successfully operated by the Office of Saline Water in the United States (14).

IV. FUTURE PROSPECTS

As with oil and gas, the actual reserve of geothermal energy in any location cannot be determined until deep drilling has verified its presence. Surface measurements, which can be made relatively quickly and inexpensively, can indicate promising places to drill but cannot guarantee the presence of an economic resource. For instance high temperature gradients measured near the surface may not continue at depth, but may level off at a low temperature value. Even when the temperature is sufficiently high at depth, water or steam may not be present, leaving only the hot, dry rocks to exploit. Finally, when geothermal fluids are present, reservoir conditions, such as low permeability or porosity, may prevent economic production.

Nevertheless, some estimates have been made of the geothermal potential in many parts of the world. These estimates are more or less reliable depending upon the extent of exploratory studies. In some cases, enough exploratory drilling has been accomplished to permit firm power goals to be established. In other areas, surface measurements of geochemical and geophysical parameters justify the next step of exploratory drilling. In little studied areas, general geological considerations indicate the compatibility of the region to the formation of geothermal deposits, and thus justify the undertaking of surface measurements that could lead to exploratory drilling. Table 3 attempts to summarize the conclusions of several references as to the size of the geothermal resource.

In a broad sense, several promising areas for geothermal development have been identified. Indications of the presence of geopressured deposits occur in many places, including the following countries and regions: Africa-Morocco, Algeria, Nigeria, West Coast, Mozambique, Egypt, and offshore Ethiopia; Middle East--Iran, Iraq, Saudi Arabia, and the Red Sea area; South America--Venezuela, Brazil, Argentina, Peru, Colombia, and Trinidad; Oceania--Indonesia, Timor, New Guinea, New Zealand, Australia, and the South China Sea region; Indian Sub-Continent--West Pakistan, Bangladesh, Burma, Gujaret, India (Jammel and Kashmir), and the Bengal Basin (16).

Geological indications of the probable presence of geothermal potential in many arid areas have been listed. Tectonic belts and rift zones, and areas with Quaternary and Recent volcanism have the promise of yielding steam and high temperature water. Countries where such geologic features are present include: Chad, Sudan, Somalia, Ethiopia, Algeria, Libya, Morocco, Tunisia, Yemen, India, Iran, Saudi Arabia, Turkey, Chile Peru, and Bolivia. Wide limits are guessed at for the potential productivity of unexplored areas of these types, with the estimates ranging from 100 megawatts of heat energy for a hot spring area to as much as 10,000 megawatts of electric energy for the Danakil Desert and neighboring hot zones in northeast Ethiopia (16).

A general estimate has been made of the total worldwide geothermal energy available from "first-type" reservoirs, which are discovered on the basis of visible surface manifestations of the heat pool. The estimate states that 2 x 10^{12} calories per second of heat energy could be mined from these sources for several hundreds of years. Ten to 20 percent of this energy could supposedly be converted to electricity (15). This would be of the order of 0.8 to 1.6 million megawatts.

The same reference defines "second-type" reservoirs as those areas with moderately hypernormal geothermal temperature gradients that are usually associated with crustal plate boundaries and other orogenic belts. These areas cover about 10 percent of the total land surface of the earth. The Afar-Danakil depression of Ethiopia is such a region, with an estimated geothermal resource equivalent to satisfy all of Africa's present needs for electricity (15).

The "third-type" resource involves the normal temperature gradient of the earth, thereby requiring great depths to attain usable temperatures. The total estimated energy stored in these regions, between 3.5 and 7.5 kilometers of depth, is 7500 megawatt years per square kilometer of the earth's surface (15).

V. STATUS OF GEOTHERMAL TECHNOLOGY

Worldwide utilization of geothermal energy for many years, in many different applications, proves that it is technically and economically feasible in some instances. However, the deposits that have been exploited have often been the obvious ones, where surface activity indicated the presence of a hot zone below. The larger electrical installations utilize either dry steam or the very hot brines, which present relatively few problems.

With interest in geothermal energy growing rapidly, more attention is being focussed on the problems of large scale exploration for hot deposits that are not obvious on the surface, and to the development and utilization of the marginal prospects, including the moderately hot brines and the hot, dry rocks. The main problem areas are discussed below, separated into technological and environmental groupings.

A. Technological Problems

The usage of dry steam to generate electricity has been straightforward. Dust and rock particles produced with the steam cause problems of more rapid turbine wear, despite the partial removal of the particles in wellhead separators. Non-condensable gases result in system losses due to the need for steam to power the vacuum unit on the condensers.

Both problems could be solved, with perhaps a small net reduction in power output, by using the geothermal steam as the heat source in a boiler. In this case, high quality water, isolated from the geothermal steam, would circulate in a closed loop from the boiler where it is vaporized, to the turbine, the condenser, and back to the boiler. A vent from the boiler would release non-condensable gases from the geothermal steam at high pressure; condensate from the boiler, which would then pass through the preheaters on the closed-loop water system, would contain the dust particles.

When high temperature brines are produced, problems are similar to those just discussed in the steam portion of the system, beginning at the wellhead separator, and continuing through the turbine and condenser. In addition, the wellhead separator must effectively prevent entrainment of liquid droplets by the steam. Where this has not been rigorously achieved in previous tests, especially in the case of the highly saline brines in the Imperial Valley, severe corrosion of turbine blades has been the result. Equipment and process techniques are available to resolve the liquid carry-over problem, however. De-entrainment of brine from the steam can be improved at the expense of a greater pressure loss and reduced power production. Also, the steam leaving the wellhead separator can be scrubbed with fresh water to remove the entrained brine droplets, while replacing them with entrained droplets of fresh water, which are less noxious. The latter approach would result in a lower pressure loss by the steam for a given attained purity.

Brine handling can also pose serious problems when its chemistry is particularly severe. Well bores have been plugged with carbonates that precipitate from the brine when flashing occurs in the well. This problem has been especially pronounced in wells at Tekke Hammen in Turkey. Surface piping also plugs with precipitated solids when highly saline brines are allowed to cool excessively within them.

The carbonate precipitation problem can be resolved by taking advantage of the chemistry of carbon dioxide: that is, by keeping the gas dissolved by keeping it under pressure. One way of accomplishing this is by pumping the well so as to avoid the flashing that occurs within a self-producing well. However, deep well pumps are not currently available for brines exceeding about 180°C, although higher temperature pumps are under development. A second method of preventing CO_2 release is to inject CO_2 gas into the well in the vicinity of the point where natural flashing occurs. The excess CO_2 changes the system equilibrium and keeps the carbonate in solution. This technique was developed by the Office of Saline Water to prevent similar precipitation problems during the desalting of sea water.

Low and moderate temperature brines present basically the same problems as high temperature brines, except that deep well pumps are available for their temperature range. In addition, severe problems of scaling and corrosion have been encountered in test heat exchangers within which the secondary fluid is heated. Desalting technology may be able to resolve these problems as well. For instance, flash type evaporators can be used in place of conventional shell and tube heat exchangers. Then, only steam is in contact with the heat exchanger tubes, while the troublesome brine remains in a large agitated pool. The geothermal brine desalting pilot plant previously mentioned incorporates this principal.

Turbines will have to be developed in relatively large sizes to handle the various secondary fluids that can be used. This should be a relatively minor developmental problem, since various companies now fabricate such turbines in small sizes of less than a megawatt. Larger compressors are also available for these fluids, in sizes ranging up to about 10 megawatts; the switch from compressor to turbine design will not be excessively difficult.

Brine disposal problems remain to be resolved, and are perhaps the major obstacle to be overcome, when the mineralization is too great to allow simple dumping to surface waters. Reinjection of the residual brine is the obvious solution. However, compatibility of this brine with the underground rocks must be assured. Silica will normally have precipitated as the geothermal brine cools, and it must be removed before reinjection of the brine to avoid plugging of the disposal wells. Silica removal will require various unit operations, including flocculation and settling, filtering, and drying. The colloidal nature of precipitated silica requires that special techniques be developed for these processes. Some of this development work has already been done by the Office of Saline Water.

It is believed that these problems can all be resolved at acceptable costs with modern technology, and much has already been accomplished. What will be required, however, is the application to geothermal units of technology that has been perfected in other industries; such transfer of technology is rarely automatic and a special effort will be required to assure that it occurs.

The status of technology is completely different in the case of hot, dry rocks. There is no assurance at this time that the exploitation of this resource will be either technically or economically feasible. Before specific tests are undertaken, it is not even possible to define with certainty the problems to be resolved. Extensive paper studies have been made and a research and development program has been defined as a result of these studies (20). However, even assuming that the most optimistic projections will be realized as to low cost and early development of technology for energy production from dry hot rock systems, reasonable costs will be incurred only for large developments. Thus, this resource would not appear to be applicable in the near future to the developing countries.

B. Environmental Problems

Almost unending discussions have taken place in the United States regarding the potential environmental problems to be encountered, almost even before the industry has been born. Most of the problems are similar to those involved in any industrial development. These include the irrevocable dedication of land to the industrial usage once development begins; noise and dirt during construction; effects on wildlife displaced by the human activity; and the social and economic effects on the existing, and usually rural, communities.

More specific problems exist as well. Hydrogen sulfide gas is usually present and vented to the atmosphere. Where not allowed, it will either have to be collected under pressure, upstream of the turbine, and reinjected underground; or converted chemically to sulfur or sulfuric acid, thus making disposal easier. This can be accomplished by established techniques, although the presence of ammonia is a complicating factor. Where H_2S recovery is required, however, some of the simplicity of a geothermal installation is lost.

Brines are now disposed of to rivers or surface pools. This is not acceptable in many locations and reinjection techniques will have to be perfected. This requires a knowledge of the rock and brine chemistry in the reinjection formations, and treatment of the residual brine so as to be chemically compatible with them.

Underground problems of subsidence and seismic dangers are often anticipated, as a result of the need to withdraw and reinject large quantities of fluids to the geothermal reservoir. Subsidence will not always be objectionable; indeed, large scale subsidence has often occurred almost without notice, in many areas of extensive water withdrawal by wells for irrigation or for industrial applications. Where it would be a problem, oil field experience indicates that proper reinjection techniques can control subsidence.

Geophysicists also seem to believe that seismic dangers can be controlled by proper monitoring procedures, and by controlling production and reinjection so as to minimize changes to the underground environment. The New Zealand experience of somewhat more than ten years is encouraging in this respect, but certainly not definitive.

The above discussion should make it clear that each situation will be different. The general uniformity of conditions that apply in other industries are not found in geothermal developments. The fuel is as it is found; it must be used in place and cannot be blended as differing crude petroleums can be at the refinery. Temperatures cannot be controlled as at a fossil fuel power station. Environmental considerations will be severe at some sites and almost nonexistent at others. Thus, each geothermal opportunity must be evaluated in itself, both technically and economically, while applying the technology that has been developed at other geothermal sites or in related industries.

VI. COST OF GEOTHERMAL POWER

Costs are difficult to assign because of the limited number of geothermal developments. These developments have occurred in countries of differing economic and political characteristics, and have utilized geothermal deposits of vastly different qualities. Nevertheless, some cost figures can be cited to provide some perspective. They are discussed below and tabulated on Table 4. Reported costs must be used with care, however, for the bases of them are not always known and are rarely consistent.

The dry steam field at the Geysers in California is "developed" in the sense that principal roads into the area have been built and the industrial infrastructure is in place. Capacity is about 400 megawatts, and will increase at the rate of about one hundred megawatts per year for the next several years. The utility company, Pacific Gas and Electric Co. (PG&E), constructs and operates the generating plant, but buys the steam from the operator of the field. Steam costs to PG&E have been 2 mils per produced kilowatt hour until recently; they are now 3.15 mils/kwh, and in 1976 will be 5.53 mils/kwh. These figures include the charges imposed by the field operator for disposal of cooling tower blowdown.

Capital costs for building the generating station, in unit sizes of about 110 megawatts and turbine sizes of 55 megawatts, are currently about $150 per installed kilowatt. It has been estimated that the total investment to date, by all parties, to reach the 400 megawatt level over more than ten years of activity, has been about 100 million dollars. PG&E anticipates total costs in 1976 of 9.11 mils/kwh if that plant operates at a stream factor of 70%, and 8.35 mils/kwh for a 90% load factor. Experience to date has been close to the 80% level (19).*

Estimated costs for well drilling vary, but some order of consistency can be found in them. Cased wells of 1800 to 3000 meters deep, and 23 cm diameter, will cost about $200 per meter. Unit depth costs of twice this amount have been estimated for wells that approach 6000 meters in depth.

* Comparative costs for a 100 MW oil fired steam plant, operated at 80% load factor, would be of the order of 11 mils/kwh (oil prices of January 1973) or 18 mils/kwh at current prices.

Exploration costs, of course, cannot be predicted. An experienced drilling company, however, has provided a general guide. For a large project, it believes that 20 million dollars, of which 8 million is for exploration, must be budgeted for at least five years before a return can be expected (20). The United Nations estimates exploration costs of about 3 million dollars for a 2 year period are required to define a geothermal area (21). As an indication of activity underway, it is estimated that about 25 million dollars per year is being spent for geothermal exploration in the United States. Recent lease sales of United States government owned land in California attracted bids of as much as $1300 per acre, before rent and production royalties (22).

Some other specific costs have been reported, but details are lacking as to exactly what is included in the figures. A projected 25 megawatt plant in Japan is estimated to cost 14 million dollars. The 750 kilowatt plant in the Soviet Union, which uses 83°C water, cost a reported 1600 rubles in 1967. Design costs for the 5 megawatt plant at Pauzhutka in the Soviet Union were 400 rubles per installed kilowatt and 0.65 kopeck/kwh (8). This plant, commissioned in 1967, operates on steam separated from a steam-brine mixture at an average temperature of 170°C.

Projected costs have been developed for a 200 megawatt unit that utilizes the heat from hot, dry rocks. This estimate, however, assumes that the technology will be perfected after a 5- to 10-year research and development program. The estimate was based upon underground atomic explosions to open up the low permeability hot rock formations, but current thinking involves other, and equally unproved, fracturing techniques.

With these restrictions understood, the capital costs for a 30-year power project were estimated to be about 70 million dollars, of which about 40 is for field stimulation and about 30 is for plant construction. The cost of produced energy, including capital and operating allocations, was estimated to be 7 mils/kwh (23).

Design studies of the secondary fluid cycle have been made by several American groups. The costs vary widely, however, depending almost equally on the temperature of the geothermal brine, and on the level of heat exchanger technology that was used. For the former, designs have been based on brines from 100 to 210°C; for the latter, both conventional heat exchanger concepts and desalting technology have been used. Capital cost estimates, exclusive of exploration and well drilling, range from 150 to 350 dollars per installed kilowatt.

An estimate has been made of cost of electric power produced from a "typical" geothermal deposit of very hot brine (10b). This analysis was based on a New Zealand type development. Experience at various geothermal installations were used to develop the costs. Several assumptions had to be made regarding typical elements within the system, such as the downhole brine temperature, production rate per well, and distance between wells and the power plant. A summary of the results of this study is presented in Table 5.

VII. PARTICIPATION BY AGENCIES AND PRIVATE COMPANIES

Several agencies of the United States government are conducting or funding research and development efforts for geothermal energy systems. These projects range from studies of new exploration techniques, through actual drilling, to pilot plant design and construction. The annual expenditure has been as much as 4 or 5 million dollars per year, and increased to over 11 million dollars in fiscal year 1974. Interagency committees recommended that the President request 44 million dollars for geothermal energy development in fiscal year 1975; this recommendation has been accepted by the Office of Management and Budget. In addition, the committee recommended research and development budgets for geothermal energy that total 140 million dollars for the following four years.

The division of this money for the next five years would be broken down as follows, in millions of dollars: 49 for resource exploration and assessment, 11 for environmental and legal research, 46 for advanced research and technology, and 79 for resource utilization. The latter category would include money for five large demonstration plants, of at least 10 megawatts each. These plants would be built for each of the following types of geothermal resource: high temperature and low salinity brine system; high temperature and high salinity brine system; low temperature and low salinity brine system; geopressured sedimentary system; and hot dry rock system.

The agencies involved include the Geological Survey, Bureau of Reclamation, Office of Saline Water, Bureau of Mines, Office of Land Management, Atomic Energy Commission, National Science Foundation, and the National Aeronautical and Space Agency. In addition, the United States A.I.D. program has provided a geothermal loan to the Philippines.

The North Atlantic Treaty Organization, through its Committee on Challenges to Modern Society, is considering a joint geothermal project to be undertaken by its member nations. The most likely project to be approved among those proposed is the organization of a central geothermal information clearing house.

The World Bank funded the geothermal development in El Salvador.

The United Nations, through its Resource and Transport Division, has and is conducting geothermal investigations, in cooperation with many governments. These include Chile, Turkey, El Salvador, Kenya, Ethiopia, Nicaragua, and others.

A typical United Nations program would consist of several phases, leading to a final decision of whether to undertake full production drilling (21). Reconnaissance missions and desk studies are first made to plan the overall program. This would be followed by field studies aimed at determining the most likely areas for geothermal deposits. Geologic, geochemical and geophysical studies are made in the second phase, as well as the drilling of some very shallow test holes. The third phase is the most costly, involving the drilling of 5 or 6 holes to depth to find a geothermal deposit and evaluate its potential if found. Costs for this part of the program can be expected to be between 1 and 2 million dollars, with a successful program probably being at the expensive end of the range. The final phase involves the preparation of a feasibility study covering a full commercial project, from production through disposal. Total costs of the preliminary studies are estimated at about 3 million dollars. This cost appears to be consistent with the experience and expectations of private companies working in the United States.

The United Nations program in El Salvador culminated in the construction now under way of a 30 megawatt plant. The programs in the other countries listed above have gone through exploration drilling or drilling is planned in the near future (2, 8, 24, 25). The Nicaraguan project was interrupted by the earthquake of 1972, but has recently been reinitiated. Four areas are being considered for further testing, including Volcan Momotombo and San Jacinto. Exploratory drilling of up to six wells will begin in the summer of 1974, with well depths of up to 1000 meters. The schedule calls for completion of drilling in 1974, followed by 6 months to one year of testing. If some wells appear especially productive, consideration will be given to the early installation of "portable" non-condensing turbines on individual wells before full project plans are completed.

The program in Chile is progressing slowly, in part due to the remoteness of the geothermal area and its altitude of more than 4000 meters.

Two holes have been drilled to about 2000 meters at El Tatio. Project concepts include the production of desalted water along with the production of electricity, and a desalting pilot plant will be installed. A scheme to produce hydroelectric power from the fresh water as it descends the mountain has also been suggested.

The drilling of six small diameter holes has been undertaken in Kenya and the second production hole is being drilled. The joint exploration program in Ethiopia will be continued into Phase 2 in 1974, with intensive studies planned in three promising areas identified in previous work. The United Nations has also made preliminary geothermal evaluations, in the form of technical assistance missions, with several countries including Greece, India, Peru, and Guatemala. The United Nations has plans to publish a World Geothermal Catalogue and Atlas.

Several American oil companies are involved in geothermal development. These include Union Oil, Phillips, Chevron, Signal Oil, and many more. A number of smaller drilling or land holding companies are also taking part. The potential users of geothermal energy are usually identified as the electric utility companies in the western part of the United States. However, some processing and other industrial companies appear ready to develop their own geothermal energy resource so as to become independent with respect to energy.

The French oil drilling company, Eurafrep, is also known to be interested in geothermal development, and has conducted studies in Algeria (17c), Guadeloupe and Martinique (17b). The New Zealand government is supplying personnel and equipment as part of a recently announced joint geothermal program to be conducted in the Philippines.

VIII. SUMMARY

Geothermal energy has been seen to be an old and proven development and, at the same time, the basis of a new industry that is beginning to emerge. Its usages are varied and its costs appear to be competitive with other fuels. It is particularly applicable to small, isolated applications, for electricity, space heating, or other purposes, and does not lead to large cost penalties in small installations. Many technological problems remain to be resolved, but this is also the case for fossil fuel installations where environmental damage must be avoided. Large government and private budgets are being directed to the resolution of these problems.

TABLE 1A

GENERATION OF ELECTRICITY FROM GEOTHERMAL DRY STEAM FIELDS

Country: Location	Year Began	Capacity (MW)	Reservoir[1] Temp. (°C)	Steam[1] Flow Kg/hr	Well Depth (m)
Italy:					
Larderello	1913	365	245	23,000	1,000
Mount Amiata		25		3,600	
Travale	1952	15			
United States:					
Geysers	1960	412	245	70,000	2,500
Japan:					
Matsukawa [2]	1966	20	230	50,000	1,100
Hatchimantai	1973	10			

NOTES: 1 - Values are average, with wide variations occurring from well to well.
2 - This is a mixed field: 3 wells produce dry steam, 2 produce 80% w steam.

Present Status: Larderello - Mount Amiata: Exploration continues. May convert to condensing turbines where non-condensing now exist, for possible 40 MW capacity increase.
Travale - Plant shutdown in 1962. New discoveries in 1972 appear important.
Geysers - Planned increase by 110 MW per year, through 1980.
Matsukawa - Plan increase to 27 MW in 1970's, 60 MW later.

TABLE 1B

GENERATION OF ELECTRICITY FROM GEOTHERMAL BRINE FIELDS

Country: Location	Year Began	Capacity (MW)	Reservoir[1] Temp. (°C)	Brine[1] Salinity (ppm)	Total[1] Flow (Kg/hr)	Well[1] Depth (M)
New Zealand:						
Wairakei	1960	192	270	12,000		1,000
Kawerau		10				
Mexico:						
Cerro Prieto	1973	75	300+	15,000	230,000	1,500
Soviet Union:						
Pauzhetsk	1967	6	200	3,000	60,000	600
Japan:						
Otake	1967	13	200+	4,000	100,000	500
Iceland:						
Namafjall	1969	3	280	4,000	400,000	900
China:[2]						
Kwantang Province						

NOTES: 1 - Values are average, with wide variations occurring from well to well.
2 - No details available.

Present Status: New Zealand - After several years of reduced interest, activity appears to be increasing, especially at Broadlands area.
Mexico - Plan to double capacity by 1980.
Soviet Union - Uncertain. Plans to increase capacity to 25 MW reported.

TABLE 2

Status of Geothermal Exploration and Development, 1972

Nation	Electric-power generation/ construction	Experimental power stations	Significant direct utilization	Other geothermal-field discoveries	Additional exploration under way[c]
Chile				x	
China		x			
Ethiopia					x
Guadeloupe (Fr. W. Indies)				x	
Hungary			x		
Iceland	x		x	x	
Indonesia					x
Italy	x				x
Japan	x	x[b]	x	x	x
Kenya			x		x
Mexico	x[a]	x	x	x	x
New Zealand	x		x	x	
Nicaragua				x	
Philippines		x		x	
El Salvador	x[a]			x	
Taiwan				x	
Turkey				x	
U.S.S.R.	x	x	x	x	x
United States	x	x[b]	x	x	x
Zaire		x[b]			

[a] Under construction. [b] Inactive.

[c] Other geothermal exploration/interest: Algeria, Argentina, Bulgaria, Burundi, Colombia, Costa Rica, Czechoslovakia, Ecuador, Fiji Islands, Greece, Guatemala, India, Israel, Malawi, Mali, Morocco, New Britain, New Hebrides, Peru, Poland, Portugal (Azores Is.), Rwanda, Spain (Canary Is.), Tanzania, Tunisia, TFAI (French Somaliland), Uganda, Venezuela, Yugoslavia, Zambia.

TABLE 3

GEOTHERMAL RESOURCES

Planned and Potential Developments

NOTE: Many of these figures are based on very preliminary data

Country	Area	MW	Potential or Planned	References; Comments
Japan	Onikohbe	25	1974	8, 18, 26; dry steam
	Katsukonda	50-100	1974-79	8, 18, 26; dry steam
	Hatchobaru	50-100	1974-79	8, 18, 26
	Otake	47	1980	2, 26 ; now 13 MW
	Matsukawa	40	1980	2, 26 ; now 20 MW
El Salvador	Ahuachapan	30	1975	2
		30	1976	2, 22 ; not underway
		20	1978	22 ; bottoming cycle on above
		100	potential	2 ; 50 year reserve
Philippines	Tiwi,Luzon	10	1975	18, 22 ; binary cycle
		50	1979	8 ; not underway
Chili	El Tatio	20-30	potential	2 ; drilling underway
Mexico	Cerro Prieto	75	1976-1980	2, 8 ; now 75 MW, new plant not underway
Guadeloupe	La Bouillante	30	1977	2,17b, 18; underway?
Taiwan	Matsao	10	--	2 ; pilot plant considered
	Tatun	80-100	potential	2, 17f ;
Iceland	Hengil	15-35	1980	2
Turkey	Kizildere	10-20	--	2 ; binary cycle considered
		30	1977	18
Indonesia				
A. Sulawesi	Sulili	50	potential	17e
	Masepe	50	potential	17e
	Malawa	25	potential	17e
	Tondong	25	potential	17e
	Sangala	25	potential	17e
	Parara	25	potential	17e
	Mamasa	25	potential	17e
	Somba	15	potential	17e
	Pambusam	10	potential	17e
B. Java				2 ; promising

TABLE 3 -- Continued

Country	Area	NW	Potential or Planned	References; Comments	
New Hebrides		?	1977	18	
Ethiopia		10	--	16	; being considered
	Panakil Desert	10,000	potential	15, 16	
Nicaragua		50	potential	16	; drilling underway
Greece	Aegeen Islands			22	; drilling planned
Algeria				17c	; promising
Kenya				16, 22	; drilling underway
USSR	Pauzhetsk	19	1980	2	; now 6 MW
	Kunashir	13	1980	2	
	Kurile Islands	10-20	potential	2	; each of several fields
	Kamchatka	10-20	potential	2	; each of several fields
New Zealand	Wairakei	90	potential	2	; now 192 MW
	Broadlands	90-120	potential	2	
World		2,500	1980	2	

TABLE 4

REPORTED GEOTHERMAL COSTS

NOTE: The bases for these costs are not always reported in full.

I. DISTRICT HEATING SYSTEM

Reykjavik, Iceland (Reference 10a)

Capacity: 225×10^9 calories/hour
Serves: 72,000 people in 1969 (87% of homes)
(Supplementary oil heating for very cold weather)
Replacement cost: 17 million dollars.
34% for heat production
66% for distribution system
Charge to consumers: $\$16/m^3$ water at 80°C

II. ELECTRIC POWER PRODUCTION

A. CAPITAL COSTS

Geysers: \$130/kw for Unit 14 (110 MW) power plant, scheduled for 1976 operation (Ref. 19).

\$250/kw total investment over more than 15 years, for 412 MW installed by end of 1973 (Ref. 8).

Japan: \$440/kw for 25 MW plant; no breakdown (Ref. 25).

Mexico: \$427/kw total costs to achieve 75 MW at end of 1973 (Ref. 22).

B. COST OF PRODUCED ELECTRICITY

Wairakei:	192 MW	8% interest	5.1 mil/kwh	(Ref. 10b)
Larderello:	390	6%	2.7[1]	(Ref. 10b)
			2.4-3.0[2]	(Ref. 10b)
Cerro Prieto:	75		8	(Ref. 22)
Namafjall:	3		2.5-3.5	(Ref. 10b)
Geysers:	81	8.5%	4.8	(Ref. 10b)

[1] Non-condensing turbines. [2] Condensing turbines

C. COST OF HEAT ENERGY (Reference 10b)

Wairakei:	8% interest	$2.6¢/10^6$ Btu	Total fluid, wellhead.
		6.9	Steam, wellhead.
		13.3	Steam, delivered.
Rotorua:		3.4	Wellhead.
Larderello:		3.2	Wellhead.
Iceland:		7-14	Thermal area
Geysers:		12.5	Delivered (price, not cost)

TABLE 5

ESTIMATED COSTS FOR A "TYPICAL" GEOTHERMAL POWER INSTALLATION (REFERENCE 10b)

A. ENERGY COSTS, AT POWER PLANT

1. BASIS: 50 successful holes (25 unsuccessful).
   Hole depth: 1170 meters.
   Flow rate/hole: 100,000 LB/hour steam
   250,000 LB/hour water
   Wellhead conditions: 6 atmospheres pressure absolute, saturated.
   Pipeline: 1.6 kilometers average well to plant distance.
   5 atmospheres absolute delivered steam pressure.

2. CAPITAL COSTS (basis is per successful hole)

Exploration:	\$50,000/hole; 3.0 million dollars total
Drilling:	\$90,000/hole; 4.5
Wellhead equipment:	\$35,000/hole; 1.75
Steam lines:	\$150,000/hole; 7.5
Water lines:	\$104,000/hole; 5.7

3. OPERATING COSTS
   Wells: 10 year life; \$15,000 additional charges per new well drilled.
   Other equipment: 25 year life.
   Operating and maintenance costs: 2% of capital cost per year.

4. DELIVERED COST OF ENERGY TO POWERPLANT
   Basis: 90% load factor; 20°C datum temperature; 7½% loss of heat in steam during transmission.

Interest rate (%):	5	6	7	8	10
Energy cost (¢/10^6 Btu):					
Steam only:	4.5	4.8	5.1	5.4	6.1
Total fluid:	3.9	4.2	4.4	4.7	5.3

B. COST OF ELECTRIC ENERGY

1. BASIS: 5 atmospheres absolute steam pressure at turbine
   6.3 cm Hg absolute turbine back pressure
   Power Production: 7.6 Kg steam/Kwh
   108 Kg water/Kwh
   20% extra wells for reserve
   85% plant factor
   25 year plant life

2. CAPITAL COST FOR POWER PLANT

Size (megawatts)	20	50	100	200
Installed Cost (\$/Kw)	465	324	270	233

3. PRODUCED POWER COST

Size (megawatts)	20	50	100	200
Maintenance (\$/year/Kw)	3.7	3.0	2.6	2.25
Power costs* (mil/Kwh)	6.55	4.66	3.93	3.41

* 8% interest rate

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Mr. Willoughby
File Power
Follow-up.

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INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

INTERNATIONAL DEVELOPMENT ASSOCIATION

PUBLIC UTILITIES DEPARTMENT

PUBLIC UTILITIES NOTES

WATER DESALINATION

February 20, 1974

Central Projects Staff
Public Utilities Department

WATER DESALINATION

ABSTRACT

Desalination is increasing in importance in areas of the world where the need for domestic and industrial water approaches or outstrips economically available fresh water supplies. At present there are about 800 desalting plants in operation; they produce an aggregate of 4 million m^3/d, equivalent to the daily consumption of 20 to 30 million people. The paper reviews salinity tolerance levels for various water uses, desalination technology, operation and maintenance problems, and the importance of the cost of energy on overall production costs. Noting that desalination costs are 10 to 15 times greater than the cost of conventional water production processes and that scientific breakthroughs to dramatically reduce costs are unlikely, it discusses the prospects of effecting savings through dual purpose plants, better plant utilization and economies of scale. Criteria for evaluating desalting processes and comparing them with alternative water supply projects are presented along with a guideline suggesting that desalination may be a viable option if alternative fresh water must be piped more than 200 km. Because of high costs and the large quantities required, the paper concludes that desalination for irrigation is unlikely to prove economic except for a very few specialized situations.

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WATER DESALINATION

1. Summary and Conclusions

(i) Desalination has been increasing in importance in various areas of the world and there are today about 800 desalting plants in operation with capacities in the 100 m^3/d to 30,000 m^3/d range. By comparison with conventional water plants, desalination is providing only a modest amount of water, primarily for domestic and industrial uses. Existing output capacities total about 4 million m^3/d, an amount equivalent to the daily consumption of 20 to 30 million people.

(ii) Well organized research activities in various countries are directed to improving the technology and reducing the cost of the product water. Research and development work has advanced sufficiently to ensure that the most important design, construction, and operation risks have been eliminated for distillation plants smaller than 40,000 m^3/d. Further work is required and in progress on larger plants, and on such processes as reverse osmosis, freezing, vapor compression, and electrodyalysis.

(iii) Records of operating costs of existing desalination plants show that reduction of costs can be achieved through economies of scale; by multipurpose application particularly when linked to power generation; and by extended plant life and lower maintenance requirements. Sea water conversion plants of recent design are capable of operating in the US \$0.25 to \$0.60/m^3 cost range while plants converting brackish water usually operate at costs somewhat lower.

(iv) Despite the considerable progress achieved over the past 10 to 15 years through basic and applied research, the costs of product water from the various desalting processes remain high. Costs range from 5 to 10 times higher than those experienced from conventional alternatives. There are no major technological breakthroughs in prospect and further cost reductions through economies of scale, from geothermal and nuclear energy applications, from improved efficiencies, from reduced down times, and from lowered operating costs, will probably appear in the form of a modest and gradual lowering of costs rather than a dramatic drop.

(v) Dual purpose (power and desalination) plants offer cost advantages over separate desalination plants particularly in the savings realized through common management and operations, and maintenance personnel. Comparison of individual water and power costs in dual installations with alternative sources is made difficult because of the need to equitably allocate capital and operating costs between the two operations.

(vi) Desalination as an alternative to fresh water transported by pipelines should be considered when pipelines longer than 200 km are required. For distances in the 100 to 200 km range, pipelines will usually prove more economic unless unusually high pumping or treatment costs are involved or unless the combination of factors involved in desalting operations are particularly favorable. Desalination will rarely be the most economic alternative where pipelines of less than 100 km in length can be employed.

(vii) The use of desalinated water for urban and industrial purposes will increase with time as existing low cost water sources become fully utilized. On the other hand, based on even the most favorable water costs projected for very large scale multipurpose plants not yet built, it appears unlikely that desalination will prove feasible for production of irrigation water in any but a very few specialized situations.

(viii) When deciding on the feasibility of desalination and between alternative desalting processes, all criteria normally applied to evaluation of other water projects should be employed. Emphasis on good management and conservation of existing fresh water resources needs to be stressed, to postpone the more expensive and sophisticated approaches required when desalination is adopted.

2. Introduction and Background

The most common process of removing salt from sea water has been in use for centuries. Ship captains and others faced with the need to obtain fresh drinking water, boiled sea water and collected the condesate on cool surfaces. Examples of stills functioning on solar heat go back to the last century. It has been only recently however, that the need to provide large quantities of fresh water from sea and brackish sources in certain areas has led to improvement of processes which now make it possible to convert water of any saline content and of nearly any volume to fresh water suited to human, animal, agricultural and industrial needs.

While the technology exists to produce nearly any quantity of fresh water, the application of such technology is restrained because of the costs involved.

In the last decade, large sums have been expended on research and development of the desalination processes. The general public, and particularly officials in many of the water scarce areas of the world, have been led to believe that we are entering an era where conversion of sea and brackish water to fresh water for human, agricultural and industrial uses can be accomplished at costs which are lower, or at least only slightly higher, than those from conventional sources. Unfortunately, these expectations cannot be fulfilled if results from existing installations are used as an indicator. There is promise of reduced costs as accomplishments of the research effort are gradually incorporated in new designs. Substantial reductions in costs can be achieved through economies of scale, through improved load and use factors, and through improved efficiencies. However, a breakthrough in the technology which could lead to major cost reductions is unlikely. For example, a prize of US $50,000 offered by a Swiss Foundation (DESARES) in 1960 for a significant contribution to reduction of the cost of desalting water, is still unclaimed.

Objective cost comparisons between desalination processes are made difficult because data are usually inconsistent. Plant and operating costs differ between installations according to the salinity of feed waters and the mineral content in product water; depreciation and interest charges are seldom treated in the same manner; fuel and site costs, brine disposal costs, and the allocation of shared costs in dual purpose installations vary from one plant to another.

These differences are sometimes the result of the costing method employed, and in others the result of differences specific to the installations. Comparisons of conventional and desalted water costs further require that allowance be made for costs of delivery to the customers or to the point of use. Consequently, meaningful analysis can only be done with a reasonable degree of accuracy in relation to a specific need, in a specific location.

A UN survey of desalination plants around the world, made in 1965 and updated by information obtained on certain selected plants in 1973, indicates that there are today in operation around 800 plants with capacities of over 100 cubic meters per day (m^3/d). Of these about 55 have capacities between 4,000 and 125,000 m^3/d. For comparison, large size conventional water treatment plants for urban use have capacities ranging from 0.5 to 1.5 million m^3/d.

Data for desalination plants tabulated in a UN survey show that plants built in the late '50s and early '60s have water costs ranging from US $0.14/m^3 to $10.00/m^3; with the average for all plants about $0.70/m^3. For plants built in the late '60s and early '70s, costs are in the range of $0.25 to $0.50/m^3 with an average of about $0.40/m^3. These costs of water can be compared with those recorded from some of the large conventional municipal treatment plants which show a range of from $0.006/m^3 for large plants to $0.05/m^3 for small plants.

There is some consistency in the percentage breakdown of the unit cost of desalted water for all types of plant and conditions of operation, and it is reasonable to conclude that fixed charges (capital costs) average about 33% of the total cost of water produced, with energy, operation, and maintenance costs averaging around 67%. A more detailed breakdown of these costs is presented in Annex 3.

3. Desalination Technology

3.1 Salinity Limits and Tolerances

Waters may be classified into four broad categories according to salinity as follows (in milligrams of salt per liter):

Sweet water	0 to 1,000 mg/l
Brackish water	1,000 mg/l to 10,000 mg/l
Salty water	10,000 mg/l to 30,000 mg/l
Sea water	30,000 mg/l to 35,000 mg/l +

Humans, animals and crops show varying tolerances for the common salts found in water. Humans show least tolerance, and the permissible upper limit set by WHO is 500 mg/l for public systems. However, it is known that tolerance to salinity varies with climate and that in some arid regions water with salinities of up to 3,000 mg/l is being consumed. WHO has recognized this by setting 1,500 mg/l as the maximum allowable concentration, beyond which potability is seriously impaired.

The range of salinities for animals and fowls extends from 2,800 mg/l for poultry to 12,900 mg/l for certain adult dryland sheep. A general limit of 5,000 mg/l for most animals is used.

Crops vary in tolerance because of interrelations with soil type, drainage characteristics, and the quantities of water applied. In general, 1,500 mg/l appears to be the limit for most crops, but with favorable conditions and proper crop selection, considerably higher levels can be used. Date palms and other tolerant crops have been cultivated with water having up to 10,000 mg/l salinity.

Current and foreseeable future costs of desalination, even where local water requires only limited processing to reduce salinity to acceptable levels, appear unattractive for agricultural use (see Chapter 7). This confines present considerations to application of desalinated water to human, animal and industrial purposes.

3.2 Desalination Processes

Desalination processes can be described as those which use evaporation (distillation), membranes, freezing or chemical means for separation of salt from water. These processes can be classified (a) by type of energy required, (b) by properties, and (c) by levels of salinity to be removed (see Annex 2). Using these classifications about 12 different basic processes can be identified.

Each of the processes and their modifications have advantages and disadvantages. For example, waters of low salinity require less energy for salt removal than those with high salt content. In the case of low salinity waters, selection of a process which has an energy input varying with the salt to be removed has an advantage. It may be, however, that as the volume of water required increases, the advantages of a reduced energy input give way to savings in capital costs for another process even though the latter may require essentially the same energy regardless of salt content.

While there has been much hope for the development of solar stills using raw water from the sea, costs are high at present ($.80 to $1.00 per cubic meter) mainly due to the need for large amounts of capital and a large land area to produce even small amounts of fresh water. This constrains the use of solar stills to small domestic installations.

Dual purpose plants which combine power and desalination are in operation in a number of countries. Since these plants almost always take steam from power generation facilities as the heat source for evaporation, one of the distillation processes is normally employed for desalting in dual purpose installations.

3.3 Operational Aspects

While the technology of desalination is, in itself, not complex, experience with existing plants shows that maintenance and operation are major problems because of corrosion and scaling of equipment, clogging of membranes, and mechanical failures, all leading to excessive periods of "down time" and lowered efficiencies. Equipment life and the operational characteristics of each process also require attention in selection and costing of facilities.

3.4 Corrosion and Scaling

Saline water is extremely corrosive to metals and because of the high solids content of sea water, scaling of heat transfer surfaces also is a cause of major problems for any process which involves brackish solutions. Use of corrosion resistant metals and chemical conditioning of feed waters have been prime subjects for research, and are the means most commonly employed by desalting plants to combat these two problems. Of the 59 plants in a UN survey1/ over two-thirds reported scaling and half reported corrosion as major causes of shutdowns. "Down time" caused by scaling and corrosion in many of the newer pilot and experimental plants proves that these problems are still not completely resolved. Other causes of plant shutdowns include failure of pumps and drives, and blockages or fouling due to inadequate screening of sea water.

3.5 Equipment Life

Desalination processes frequently employ equipment for which a normal operating life is not well established. Even ten years' life may be optimistic without major expenditures on maintenance. On the other hand, those parts of plants which generate steam as the means for effecting vaporization employ equipment which has undergone many years of development for use in thermal power stations. In the distillation processes it is the surfaces and units which convey the heat from the steam to the saline water which cause most problems. Pumps, pipes, valves, surfaces and other appurtenances coming in contact with the saline water are the critical elements. Development of corrosion resistant metals for desalting use is well advanced; the effect of introducing these materials is usually to increase plant costs, while reducing maintenance and prolonging plant life.

3.6 Plant Personnel

While the technology of desalination itself is straight forward, operations are made difficult because of the sensitivity of most of the processes to (a) the proper conditioning of feed water; (b) the maintenance of temperatures, pressures, or vacuums within rather narrow ranges; (c) servicing of membranes and ion exchange beds; (d) close monitoring of performance; and (e) initiation of critical corrective actions when required. These duties require much more highly skilled technicians than those employed in conventional water treatment facilities. This will pose a problem in certain developing countries, and will likely require employment of expatriate staff for a considerable period of time. This means higher costs. Selection of the process best suited to any given circumstances must take account of how the plant is to be operated, and the availability and costs of labor, local and foreign.

1/ United Nations Desalination Plant Survey, 1969.

4. Desalination Cost Considerations

In the UN survey of desalination plants published in 1969[1], it was found that of the cost per cubic meter of fresh water for both distillation and membrane (electrodialysis) processes, about 33% can be assigned each to capital and labor with the remaing 34% broken down into energy (16%), chemicals (10%) and maintenance (8%). These proportions represent the average of 59 desalination plants, 25% dual purpose and 75% single purpose, located in different parts of the world, as noted in the table produced in Annex 1. Thirty per cent of the plants showed a cost of US \$.25 to \$.50/m^3 of water produced and 40% costs of \$.75 to \$1.00/m^3. Very few plants (10%) reported costs of less than \$.25/m^3, and two reported costs of \$7.50 to \$10.00/m^3.

In other technical literature, costs of US \$0.20 to \$0.40/m^3 are shown for plants ranging in size from 1,200 m^3/d to 15,000m^3/d.

Data[2] from plants recently constructed, while difficult to interpret because of research activities frequently incorporated, show that for sea water conversion, costs of well over US \$0.40/m^3 are not uncommon when all costs are taken into consideration.

Capital costs of desalting plants are affected to a great extent by the size of the installations, decreasing in cost per m^3 of water produced as size increases. Rough figures for plants in the USA in 1965-67 show for small plants, investment of around US \$500/m^3 per day of installed capacity. For large plants around US \$400/m^3 and for very large plants an estimated US \$250/m^3. These figures are 6 to 10 times larger than those reported for medium-sized conventional water treatment plants.

The wide variation of unit costs makes it difficult to select a realistic average figure to use when comparing different alternatives, even when comparing plants of about the same size.

While the foregoing figures confirm that present costs are high, there is considerable evidence to indicate that there is a downward trend which will continue, although without dramatic drops. Some of the lines of development which have been explored, and some which give encouragement to lowered costs are noted below.

4.1 Energy Costs

There have been hopes of a breakthrough in reducing energy requirements but physicists and chemists have maintained that the laws of thermodynamics determine the theoretical energy required to remove salts from a solution, given any specified conditions of salinity and temperature. They contend that it is not scientifically possible to reduce energy requirements below these levels. There is no evidence in the extensive research conducted over the past fifteen years that this contention is wrong. This leads to the conclusion that only

1/ First UN Desalination Plant Operation Survey - ST/ECA/112-NY-1969.

2/ Unpublished data collected by correspondence - August 1973.

by finding a lower cost energy source for any given installation and by reducing energy losses through improved efficiencies, can costs be lowered. In the long run, research and development work in nuclear and geothermal energy gives promise of reducing energy costs for certain installations. Efficiencies have been improving and further progress can be anticipated. The outlook for the immediate future suggests only gradual reductions in cost from better efficiencies, and higher costs for operations dependent on fossil fuels for energy.

4.2 Dual Purpose Plants

Dual purpose plants are those built in conjunction with power generation facilities. While the usual practice of taking low pressure exhaust steam to drive the distillation plant in a dual purpose installation undoubtedly offers economies, it demands careful planning of the system to avoid the serious problems arising from a short- or long-term mismatching of power and water demands.

Location of a distillation plant and a power plant on a common site offers considerable advantages even where close coupling of the steam supplies is not practiced. The two functions can share the same management, operation and maintenance facilities; in general, the requirements of the two functions are similar in these three respects. Except for plants of unusually large capacity, it is only on this "shared" basis that the specialized management and maintenance requirements, and the part-time operating labor demands can be met at acceptable costs.

In areas where solid wastes contains a high concentration of combustible matter, combining incineration with steam generation can be considered. Such steam can be used either for desalination, for power generation, or both. In most instances heat recovery from solid waste incineration will not likely be competitive with operations using other fuels. However, where solid waste disposal must be effected at fairly high costs anyway, incineration coupled with steam generation may prove attractive.

Equitable allocation of costs between power and water on dual installations is not easy in practice. Two methods which have been proposed consist of either (a) allocation of annual fixed and variable costs to water and electricity separately, or (b) allocation of total annual costs according to water and electricity production.1/

4.3 Plant Utilization

As with power generation facilities, the plant utilization factor is an important determinant of unit output costs in desalting plants. The plant factor is the annual, monthly or daily production as a percentage of plant capacity. While desalting plants may be designed to provide water for peaking purposes, for example, during summer of dry months when demand exceeds the capacity of the conventional facilities, such cases will be rare because alternate sources for supply of peaking water will usually be cheaper than the desalting source.

1/ Joseph Barnea, "A New Method of Cost Allocation for Combined Power and Water Desalination Plants" - Water Resources Research, Vol. 1, No. 1, Washington DC, March 1965.

Desalination systems can accommodate normal daily and other seasonal variations in consumer demand by changing production rates or through storage facilities, whichever is more suitable or economic.

A more common cause of low plant factors is operational outages - planned and accidental. High "down time" results from the need to replace tubing, remove scale, and maintain pumps and other equipment in a highly corrosive environment.

Annual expenditure for capital charges and labor is determined by installed capacity regardless of utilization. The importance of plant factor in determining water costs can be illustrated by the figures reported in the UN survey of 59 plants. The average annual plant factor of the 59 plants was only 53% while fixed charges and labor amounted to two-thirds of the total water costs (see Annex 3). Thus, if those plants could have been operated at full capacity, the costs attributable to investment and labor would have been halved and total unit water costs reduced by one-third. While it is impractical to operate at full capacity, there is a considerable economic incentive to make the plant factor as high as possible. In many steam power plants, and for some desalination plants, factors of 90% can be obtained.

4.4 Economies of Scale

There is no doubt that as the size of plants is increased, unit costs of product water are reduced. Reports prepared in the late '60s which projected costs of very large schemes where nuclear power and desalination plants were proposed, showed water costs at figures around US $0.09 to $0.12/m^3. Such figures must be viewed with caution since they have been based on assumptions which have not been substantiated by actual operation. Nevertheless, with improved efficiencies, with lower energy costs from developments in nuclear fuels, economies of scale, and the benefits to be realized from dual purpose installations, costs of desalinated water at the plant can be expected to drop.

5. Desalination Plant Investments and Financing

The decision to finance desalination plants should be based on criteria similar to those employed when any other water facilities are considered. It should be demonstrated that desalination is the least costly method of supplying the water required with the same or comparable level of security. In selecting the alternatives to be compared, the possibility of using long pipelines from known fresh water sources should not be forgotten. The desalination process selected for comparison should be the one which promises the least cost water, taking into account such factors as the capacity of the national technicians to operate and maintain, available fuels, and dependability. A few of the points to be noted in reviewing proposals for desalting projects are summarized below:

(a) Comparison of Costs

Costs of desalted water should be compared with costs of water from treatment plants, springs and wells at the point where each source connects to the distribution system or to a common transmission line. Costs between processes should also be compared by using similar levels of salinity in the product water. It is customary to blend salt-free water produced by certain processes (e.g., distillation) with saline water to provide a product water which contains the desired salinity level.

(b) Plant Factors and Storage

Plant factors should be reviewed carefully because of the poor experience to date for installations of all sizes and types.

Unusually large storage capacity for product water is required where dependable service has to be assured by desalination plant output. One week's storage is not uncommon for urban systems (see Annex 1) and this will be inadequate in some instances. Costs of storage in excess of that used for conventional systems must be added for purposes of comparison with other alternatives.

(c) Depreciation Rates

Depreciation should be based on an average life not longer than fifteen years, unless actual experience from plants in operation provides reliable data for the specific process and plant type to support a longer period.

(d) Interest Rates

Interest rates which approximate the opportunity cost of capital for the country in question should be used for comparing alternate sources and alternate processes.

(e) Costing of Power Facilities in Combined Plants

In nuclear and thermal plants where power generation and desalination are combined, it has been common to use the "going" price of power in the area as a base, and where very large power installations are designed which will generate power at costs below the "going" price, to show the savings as a means for reducing the sale price of the desalinated water. This is not an acceptable approach in making investment decisions. Cost estimates of dual purpose plants should be compared to those of equivalent single purpose installations in order to ensure that, under the given conditions, the dual purpose plant is more economic.

(f) Brine Disposal

Concentrated brine is a product of all desalting operations and its final disposal can be a major problem. Siting of plants, and decisions on the economics of various alternatives should take full account of brine disposal, the costs involved, and the ecological implications.

6. Alternatives

Among the alternatives to desalination which should be considered is that of transporting water by pipeline from distant sources of fresh water. While generalizations are difficult for transported water because of variations in treatment and terrain and the consequent effects on pumping costs, guidelines can be established which will suggest the significance of pipeline transportation as an alternative.

Vaillant[1] has prepared a table (see below) showing the approximate costs per cubic meter of transporting by pipeline a range of volumes of water per day over different distances.

Dollars per m^3 of Water Transported

Distance in km	Pipe Capacity in 1,000 m^3/day 20-25	40-50	100	200	250
25	$ 0.03	0.03	0.03	0.03	0.03
50	0.07	0.07	0.06	0.05	0.04
100	0.12	0.11	0.10	0.08	0.08
200	0.20	0.18	0.16	0.13	0.12
400	0.34	0.30	0.28	0.23	0.22
600	-	0.42	0.38	0.33	0.30

From the above table it will be noted, for example, that for a pipeline 200 km long and with a capacity of 100,000m^3/day, the cost of water net of pumping and treatment would be around US $0.16/$m^3$. For volumes of 20,000$m^3$/d the cost would be about US $0.20/$m^3$ for the same distance. Since costs in certain desalination plants where brackish water is converted, are in this range, it would be desirable to analyse the situation further before deciding either in favor of a pipeline or in favor of a desalination plant. For distances of 100 km or less, pipeline transport will almost always be more economic than desalination, and in the volumes of water normally required for expansion of urban water facilities, pipelines will probably be the method of choice for distances up to 200 km, given present technology, and where water of high salinity has to be converted. It will be prudent, however, to examine the feasibility of desalting against pipeline transportation of fresh water, whenever sources of brackish water are immediately available if distances in excess of 100 km are involved.

7. Application of Desalination to Irrigation

Based on the most favorable water costs projected for very large scale multipurpose plants currently under study, it appears unlikely that desalination will prove economic for production of irrigation water in any but a few specialized situations. A recently completed study of agriculture in North America[2] supports this conclusion.

The cost of water onto the land for five irrigation projects financed by the Bank in Malaysia, Colombia, Korea, and Yugoslavia, is estimated to be US $5, $25, $50, $48, and $78 per acre foot. These costs include all dams or weirs, wells and pumps, primary and secondary channels, and miscellaneous costs such as service roads, etc. These figures can be compared with an estimated "water only" cost of US $100-$200 per acre foot[3] from proposed large scale desalina-

1/ Les Problems du Dessalement de L'eau de Mer et des Eaux Saumatres, J. R. Vaillant, Eyrolles, 1970, Paris, France.

2/ Desalting, Victor Koelzer, USA National Water Commission, May 1972.

3/ Eliason, May 22, 1969 - Water Desalting, Present and Future, AWWA Conference, San Diego.

tion plants, to which must be added the cost of conduits, channels, etc., required to bring water onto the land. Even taking account of the lower mineral content of desalinated water it would have cost in the case of those Bank projects from three to forty times water from natural sources. There are, however, a few specialized applications, of limited scope for developing countries, which might be economically attractive. They involve enclosed environmental systems fabricated from plastic, in effect greenhouses, within which evapotranspiration is controlled and moisture is not lost to the atmosphere. Water consumption is reduced to about one-tenth of that in conventional irrigation. In these applications, high yields of high value specialty produce could more than offset the high cost of desalted water.

Public Utilities Department
Central Projects Staff
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PLANT IDENTIFICATION AND GENERAL DATA

Location	Process	Year	Purpose	Unit Capacity m^3 per day	Storage Capacity m^3
USA	a	1965	Dual	532	3,800
Ecuador	a	1960	Dual	228	859
Venezuela	a	1961	-	4,104	-
Bahamas	a	1962	Dual	5,559	-
Bermuda	a	1964	Single	627	3,800
Guantanamo	a	1964	Dual	2,850	15,200
Curacao	a	1963	Single	6,080	-
Curacao	a	1963	-	6,498	-
Virgin Islands	a	1958	Single	114	68
Virgin Islands	a	1961	Dual	1,045	-
Gibraltar	a	1964	Single	494	19
Gibraltar	a	1960	Single	277	-
Italy	a	1964	Single	357	380
Libya	a	1962	Dual	190	1,140
Libya	a	1965	Dual	760	3,040
Arabian Gulf	a	1963	Dual	114	-
Arabian Gulf	a	1962	Single	114	1,140
Kuwait	a	1962	Single	190	1,330
Kuwait	a	1959	Dual	1,368	76,000
Kuwait	a	1962	Dual	2,736	76,000
Kuwait	a	1957	Dual	2,394	129,200
Kuwait	a	1960	Dual	4,560	129,200
USA	b	1961	Single	3,800	-
Kuwait	b	1950	Dual	456	76,000
Kuwait	b	1953	Dual	456	129,000
Kuwait	b	1955	Dual	456	129,000
Polynesia	b	1963	Single	61	-
USA	c	1964	Single	152	1,900
USA	c	1964	Single	53	342
USA	c	1963	Single	3,800	760
Peru	c	1955	Single	76	11
Bahamas	c	1956	Single	137	4,788
Bermuda	c	1955	Single	760	30,400
Antigua	c	1965	Single	53	-
Japan	c	1955	Dual	3,401	50,160
Marshall Islands	c	1951	Single	53	1,239
Ascension Island	c	1957	Single	395	1,341

$1 m^3$ = 264 gallons

1 gallon = 3.78 liters

Location	Process	Year	Purpose	Unit Capacity m^3 per day	Storage Capacity m^3
USA - Arizona	d	1962	Single	2,470	1,140
USA - California	d	1959	Single	106	380
USA - N. Dakota	d	1960	Single	167	475
USA - Illinois	d	1958	Single	266	228
USA - Montana	d	1961	Single	209	380
Finland	d	1964	Single	49	19

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a Multiflash distillation

b Long-tube vertical distillation

c Vapor compression

d Electrodialysis

Source: First UN Desalination Plant Operation Survey
UN - New York - 1969 - ST/ECA/112

CLASSIFICATION OF DESALINATION PROCESSES

Classification by Type of Energy Required1/

A. Processes requiring thermal energy
   Multiple effect distillation
   Multiple stage flash distillation
   Vertical Tube Evaporator (VTE)
   Solar distillation
   Supercritical distillation

B. Processes requiring mechanical energy
   Vapor compression distillation
   Freeze separation
   Hydrate separation
   Hyperfiltration or reverse osmosis

C. Processes requiring electrical energy
   Electrodialysis

D. Processes requiring chemical energy
   Ion exchange
   Solvent extraction

Classification Based on Properties1/

A. Processes dependent on phase changes of water

   1. Evaporation
      Multiple-effect distillation, in which the latent heat comes from a solid surface.
      Multiple stage flash distillation, in which the latent heat comes from cooling of the liquid being evaporated.
      Supercritical distillation, in which all evaporation occurs above the critical temperature of pure water.
      Solar distillation in which the latent heat is derived from direct solar radiation.
      Vapor compression distillation, in which the latent heat is obtained regeneratively.

   2. Crystallization
      Freeze-separation, in which the crystals involved are those of pure water.
      Hydrate-separation, in which the crystals contain molecules of the hydrating agent.

1/ Howe, University of California, Berkeley, 1968.

B. Processes dependent on the surface properties of membranes in contact with water

1. Electrodialysis, in which the unwanted ions are caused to migrate through membranes due to electrical forces.

2. Hyperfiltration or reverse osmosis, in which water is caused to migrate through membranes preferentially to the salt ions, due to pressure.

C. Processes dependent on the surface properties of solids and liquids in contact with water.

1. Ion exchange, in which unwanted ions are exchanged for less offensive ions loosely bonded to certain double salts in solid form.

2. Solvent extraction, in which certain liquids dissolve water more readily than the salt ions contained in the saline water.

Classification based on Variation of Energy Related to Initial Salinity1/

Type of Energy	Conversion Process
Processes in which the energy requirement is essentially independent of initial salinity	Multiple-effect distillation Multi-stage flash distillation Vapor compression distillation Supercritical distillation Vacuum flash distillation Solar distillation Freezing Reverse Osmosis
Processes in which the energy requirement depends on initial salinity	Electrodialysis Ion exchange Chemical precipitation

1/ Howe, University of California, Berkeley, 1968.

DESALINATION COST (Percentage)

	Minimum	Maximum	Average
Fixed Charges	25% a/	45% b/	33%
Labor	18% b/	38% a/	33%
Energy	9% b/	42% c/	16%
Maintenance	2% c/	26% b/	8%
Chemicals	3% c/	16% d/	10%

Resume:

Capital Cost	25%	45%	33%
Operation and Maintenance	55%	75%	67%

a/ Vapor compression distillation

b/ Electrodialysis

c/ Long-tube vertical distillation

d/ Submerged-tube distillation

Source: First UN Desalination Plant Operation Survey
UN - New York - 1969 - ST/ECA/112

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INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

INTERNATIONAL DEVELOPMENT ASSOCIATION

PUBLIC UTILITIES DEPARTMENT

PUBLIC UTILITIES NOTES

FINLAND'S WATER POLLUTION CONTROL PROGRAM: THE ROLE OF ECONOMIC ANALYSIS

February 20, 1974

Central Projects Staff
Public Utilities Department

FINLAND'S WATER POLLUTION
CONTROL PROGRAM:
THE ROLE OF ECONOMIC ANALYSIS

A B S T R A C T

This note is the report of a mission which examined the role that economic analysis should play in the evaluation of a project designed to improve the quality of Finland's lakes and rivers. The project, consisting of the installation of effluent treatment works in industrial plants, is part of the first nationwide environmental improvement program with which the Bank has been involved, and for this reason the report is circulated for the general interest of staff members.

The paper contains some rather controversial recommendations on such issues as the subsidization of polluters, effluent charges versus standards, and the role of benefit-cost analysis in pollution control. As in the case of other notes, the report which was originally prepared for the DFC's Division of EMENA, is not to be interpreted as a policy statement or as a working instruction. In fact, it is to be sent to the Finnish authorities, the final position to be taken by the Bank being the outcome of the ensuing dialogue between us.

Prepared by: J. Warford, T. Pellegrini (IBRD) and
A. Kneese and K Mäler (consultants).

February 20, 1974

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

INTERNATIONAL DEVELOPMENT ASSOCIATION

FINLAND: National Water Pollution Control Program and the Use of Economic Analysis in Determining Alternative Strategies

REPORT OF THE BANK's ECONOMIC METHODOLOGY MISSION WITH TENTATIVE RECOMMENDATIONS AND ISSUES FOR DISCUSSION

This Report was written by Messrs. Warford and Pellegrini of the Bank -- and Messrs. Kneese and Mäler, consultants -- and is based on their mission to Finland from November 19 to 27, 1973.

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I. INTRODUCTION

A. Use of Economic Analysis in Water Pollution Control

1. This report is based on the concept that efficient investment decision-making in water pollution control - as in other areas - requires that the present worth of the benefits of the control program exceeds the present worth of its costs, and that the excess of benefits over costs is maximized. In turn, this requires that the benefits stemming from possible variations in the scale, scope and timing of the program are estimated in monetary terms; that systematic comparison of the costs and benefits of alternative courses of action is used to determine investment priorities; and that program objectives, i.e., the attainment of certain ambient water quality standards, are achieved at the least cost to society. Recognizing that economic efficiency should not necessarily be the sole criterion for decision-making, this report analyzes the extent to which the administrative, financial and technical policies followed by Finnish water pollution control authorities are likely to allow these conditions to be fulfilled, and the role that economic analysis has played, and should play in this process. The emphasis is therefore on applied welfare economics, which incorporates benefit-cost analysis, but is more widely defined to include the role of pricing policies, subsidies, and systems analysis. The report deals almost entirely with the problem of industrial pollution.

2. The National Water Board (NWB), which has primary responsibility for water pollution control in Finland, has made a start on the application of benefit-cost and regional systems analysis techniques to water quality problems, but the proposed program for water pollution control over the next ten years is based on past experience and is designed for quick implementation. At the same time, an effort, which so far has been modest, is being made to develop a sounder analytical base for longer term water quality management. The contemplated program is based on the idea that severe pollution problems obviously exist in some areas of Finland and that in both economic and political terms it is urgent and clearly justifiable that water quality be improved to some extent in these areas. Benefit-cost and systems analysis, which the Mission regards as in principle relevant to these problems, and indeed, essential for dealing with the more complex ones to be encountered later, has so far not been explicitly brought to bear in establishing specific effluent reduction requirements under the ten-year program. While the Mission believes that a concerted effort could have resulted in an acceptable socio-economic analysis, in view of the urgency of the problem, the complexities of identifying and quantifying the long-term ecological consequences of pollution, and the limited staff of NWB, it is difficult to quarrel with this general approach.

3. The national water pollution program has been fully supported by the Government and, in January, 1974, was endorsed by the Parliament. However, whether or not the benefits of the program are quantifiable, and

whether or not program objectives are in any sense "correct", it is important to ensure that the program is implemented efficiently. In this respect, the Mission has serious reservations about the policies followed by the Finnish pollution control authorities. Characterized by subsidies on the one hand and the enforcement of standards for individual effluent discharges on the other, the Mission thinks it unlikely that standards of ambient water quality will be achieved at least social cost. This is discussed at length in Part II of this report, and Part III goes on to suggest an alternative implementation strategy. Part IV deals with the need to prepare for the more refined policies of benefit-cost and systems analysis which will clearly be required in later stages. Part V deals with some broader problems associated with the Finnish water quality management effort and Part VI concludes with a summary of the main findings and their implications for Bank appraisal.

B. The Implementation Strategy

4. As background for the later discussion, we here present a brief and highly simplified overview of the present strategy for achieving pollution control over the next ten years. More detail on some of these matters is found in the background paper attached as Annex I.

5. The importance of industrial waste discharge in contributing to the Finnish water pollution problem is clear. While municipalities produce about half of the phosphorous load discharged into Finnish waters, they are responsible for only about 7% of the BOD load. The forest products industry alone produces about 83% of the BOD load and about 20% of the phosphorous load. In addition, the pulp and paper industry produces a most serious form of pollution in the form of suspended solids, e.g., wood fibre sludge, which has the most lasting affect on the environment. Chemicals and food stuffs are also significant, but the industrial pollution problem is overwhelmingly associated with pulp and paper production. A table showing loads from municipalities and industries is appended as Annex II.

6. The general physical objectives of the plan are that, by the end of the ten-year period, the total BOD load discharged to the nation's lakes and rivers should be reduced by 50%. In order to achieve this, with respect to municipalities the plan calls for primary plus secondary treatment, and, in some cases chemical precipitation of phosphorous by the end of the decade. With respect to industry, certain guidelines relating to rather basic process changes, to meet target loadings per pound of product output, have been prepared by the NWB for different types of production processes. The emphasis is on internal rather than external, or "end of the pipe" treatment. Industry is required to conform to these guidelines, but this requirement is considerably tempered by considerations of the plant's apparent ability to pay and various appeal processes, to be described below. For new plants, of which there will be relatively few in the ten-year priod ahead, the "best available technology economically achievable" is to be applied. The device for implementing these requirements is a licensing system, and subsidies are also supplied for certain

investments. We briefly discuss each in turn.

The Licensing System 1/

7. Prior to the 1960's, water law in Finland had little bearing on water pollution. A number of pertinent acts and statutes were passed between 1961 and 1970. The legislation set up a number of water courts (each of which consisting of a judge and two engineers) to interpret and enforce regulations, and established the NWB (1970) which provides technical inputs and assists the court in the administration of the legislation.

8. The current procedure requires each waste discharger to have a license, application for which has to be made to the water court. The NWB then gives its views on the application. If the views of the waste discharger and the NWB coincide, or negotiations lead to consensus, the license is granted. The license establishes, among other things, a maximum effluent load requirement and a schedule for implementation of improvements. The strictness of the requirement and the schedule reflect the court's view of (a) the company's ability to pay (although neither the court nor its adviser, the NWB, has a genuine independent capacity to assess this) - and (b) the severity of the pollution problem associated with the discharge. Within each category of industry, the effluent standard is uniform regardless of the characteristics of the particular plant; however, there can be variation in the time period for compliance from plant to plant if circumstances warrant. Accelerated compliance is required where the problems are particularly severe. The term of licenses runs from two to five years. If the applicant is dissatisfied with the court's ruling he may appeal to the Supreme Administrative Court. A still further appeal is possible if the discharger claims he cannot meet the schedule for compliance. This appeal is directly to the Minister of Agriculture (the NWB being part of this Ministry), who may grant a delay.

9. Licenses may be revoked by the water court upon non-compliance. At the end of 1971, 101 applications for waste water discharge had been conclusively acted upon and 267 were pending. The process can have numerous steps and has often been quite lengthy, even up to the license stage. Compliance delays can of course also occur, but not much experience has accumulated on this. Time delays are said to have been reduced more recently. The process is discussed further in Part II B, with special reference to the shortcomings of requiring firms to maintain effluent standards in order to achieve global water quality goals.

Subsidies

10. A second element of the water pollution control strategy is the subsidization of water pollution control investments. This takes a number

1/ For details on the licensing system, see Annex I, Pages 1 - 4.

of forms. Grants from the Government's budget are available to cities to support up to 30% of the cost of pollution control projects. The actual amount depends on the treatment level achieved and 30% would presuppose an extremely high level. The total amount involved however is small (Fmk five million proposed for 1974) and it is not intended that this program should be a large part of the investment costs of municipal sewage works. It is seen more as a reward for special effort. Low interest term loans from the central government, channeled via the Post Bank, are also made to the municipalities for water pollution control measures (Fmk 45 million proposed for 1974).

11. Another type of subsidy is in the form of pollution control loans to industry. In 1958 the government passed a law permitting the granting of low interest term loans from funds accrued as export levies. In principle the loans could amount to 50% of project costs, but since the total applications for these loans amounted to over five times the funds available, the loans actually made covered from 10% to 15% of project costs (a total of Fmk 41 million from 1969 to 1973). Among the borowers have been 34 out of the 35 pulp and paper companies.

12. Loans are made only to existing industries and are supposed to be unrelated to increases in production. Under the national pollution control program, separate loans from the export levy fund (which is rapidly diminishing since export levies have been abolished) will cease and general government funds will be used to continue the program. Probably as important as the low interest loans are the tax write-offs available for industrial pollution control facilities. The tax authorities have so far decided upon the eligibility for such write-offs without use of the technical expertise of the NWB.

13. Theory suggests and experience confirms that it is very difficult if not impossible to design subsidies of this type which do not have serious deficiencies in terms of their efficiency and equity. These aspects are explained in Part II A.

Preparing for More Refined Analysis and Regional Management

14. A national plan for water pollution control, made available to the Mission in draft form, is to be completed by the NWB in the next few months. This will be a general document which provides broad perspective on pollution problems and general information on costs, financing and administration of the program. Its relation to specific water quality management decisions is, however, only indirect.

15. Regional plans for the 19 regions of Finland are to be completed within the next two years. Some of these contain elements of benefit-cost and systems analysis. This aspect of planning is not highly developed, although it displays some familiarity with the salient methodologies. As noted at the outset, these plans and techniques seem to bear little relation

to the program to be carried out over the next ten years. The NWB realizes the importance of regional systems planning and benefit-cost analysis in later water quality management and hopes to continue their development as part of the plan. Resources for this purpose are however severely limited. There is a danger that benefit measurement, in particular, may be neglected.

II. SHORTCOMINGS OF THE PRESENT APPROACH

16. Although economic benefits have not been quantified, the objectives of the program appear reasonable, since the aim at least during the first phase of the program is to deal with the grossest forms of pollution. Benefit evaluation will become increasingly important as water quality standards improve, when marginal benefits of pollution control may be expected to fall, while costs of control increase exponentially (see Annex V). However, while the objectives themselves seem reasonable, the Mission has a number of reasons for doubting that the administrative and financing procedures selected by the Finnish government are likely to achieve those objectives in the most efficient way. In particular, the establishment of effluent standards, combined with a system of subsidies to industries which install pollution control equipment, is unlikely to result in the achievement of improved ambient water quality conditions at the least social cost. We first consider the subsidy issue.

A. Subsidy Problems

Forms of Subsidy

17. The Finnish government has indicated that it intends to continue the subsidization of investment in water pollution control equipment by industry. Across-the-board subsidies will continue to take two forms: (a) the granting of term loans at favorable rates of interest and (b) accelerated depreciation rates for approved pollution control investments. The government intends to allocate a sum from the national budget that will permit the Post Office Bank to make pollution control loans for a maximum of 15 years, a maximum 5 years grace included, at a rate to be negotiated and to be considerably below that of commerical long-term loans; the maximum amount for a Post Office Bank/Government loan would be 38.5% of the total cost of the pollution control project and this total cost must be a minimum of Fmk 300,000. The remaining funds for the project would come 38.5% from the Bank of Finland and Mortgage Bank of Finland at commerical rates, and 23% from the Company. 1/

18. Tax laws currently in force allow all pollution control equipment, whatever its form, to be written off on a straight line basis over four years. The additional subsidy resulting from this procedure can be calculated by estimating the present worth of the tax liability it implies with the present worth of the tax liability if the equipment were classed as normal production equipment. For investment other than pollution control, machinery may be

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1/ The actual division between Post Bank/Government budget (38.5%), Bank of Finland/Mortgage Bank of Finland (38.5%) and the Company (23%) would vary accordingly to the size of the project.

depreciated at an annual rate of 30% on a declining balance basis, while industrial buildings may, depending on type of use and construction, be written off at 9% or 20%, also on a declining balance basis.

19. Annex III, which *inter alia* provides an estimate of the magnitude of the two types of subsidy, suggests that the subsidies are relatively small when compared with the total cost of the national water pollution control program. However, certain critical assumptions upon which these estimates are based (in particular those relating to the tax write-off provision) have yet to be tested in practice, so the true extent of the subsidy remains somewhat conjectural. The principle is however an important one: industry has insisted upon the need to subsidize pollution control investments and can be expected to maintain and possibly harden this attitude as water quality standards required by government, and therefore control costs, increase. It is therefore necessary to analyze the concept of subsidization and to discuss its inherent problems.

Rationale for Subsidies

20. International Competitiveness. An argument that has in the past been used to justify subsidization of pollution control investment in Finland is that firms would not be able to maintain their international competitive position if called upon to finance the total cost themselves. This applied in particular to the pulp and paper industry, at once the country's major polluter and exporter. However, the argument is rarely used now on the macroeconomic level. Prospects for Finnish exports in the wood processing industries appear to be excellent. Faced with rapidly increasing demand and slowly responding supply, the wood processing industries are expected to become increasingly profitable in the foreseeable future. Finland's suppliers are expected to fare particularly well in view of their relatively low production costs and the fact that Canada, a major competitor for the European market, is likely to suffer from increasing freight costs. Moreover, plastics, a major substitute for wood products, will be damaged considerably by the increasing cost of oil. From opinions expressed by Finnish consultants to the pulp and paper industry and from information obtained in discussions with pulp and paper industry representatives themselves, it appears that the Finns have a competitive advantage for the following reasons: lower unit installation costs for capital equipment, lower labor costs, favorable geographical position with respect to North American competitors, a secure fuel supply (from the USSR), and the fact that Finnish pulp and paper plants are newer, larger and therefore more efficient than those of competitors.

21. Marginal Firms. Arguments in favor of subsidization normally emphasize the plight of older pulp and paper mills, with outdated processing techniques and equipment which was installed well before the current preoccupation with environmental protection. Adherence to the government's effluent quality standards, it is claimed, may force some of these mills out of business, and subsidy is necessary to prevent this.

22. Since most mills depend to a considerable extent upon export trade this of course relates to the international competitiveness argument, but the more serious impact of closure is the creation of large pockets of unemployment that would result. It can however be argued that not only is the subsidization of pollution control investment by a marginal firm a particularly inefficient way of maintaining its solvency (for reasons described in the next section), but also that a blanket policy of subsidizing water pollution control investments, whatever the economic status of the firm concerned, is not the way to achieve this objective.

23. Although it is already the case that water pollution control subsidies by means of accelerated depreciation are generally applicable, it may or may not be the case that interest subsidies will be. It may be decided that such subsidies should be awarded in part on the basis of demonstrated need. However, it seems unlikely that decisions on subsidies for general economic reasons are best made by the Post Office Bank, the Mortgage Bank, or the National Water Board. An agency concerned more specifically with regional development, such as that to be found within the Department of Commerce and Industry, might be in a better position to exercise judgment in these cases.

24. The general principle should be that the burden of proving the necessity for subsidy should be put on the firm. In-depth analysis by the appropriate government department would be more feasible if the general across-the-board subsidy is eliminated (see below for difficulties encountered under present policy). Subsidy should then be determined on an ad hoc basis, much as those for municipal treatment works are.

25. Finally, it should be noted that the types of subsidy that will be employed are unlikely to achieve the objective of assisting the less profitable industries. First, the tax write-off advantages are, by definition, of no benefit to industries that are not making profits. Second, the creditworthiness test that the Post Office and Mortgage Bank are probably going to apply may not permit the poorer firms to borrow at all - let alone at subsidized rates. In turn, this may well mean that some of the less profitable firms are simply not required to carry out pollution control investment - or that the need to do so is indefinitely delayed. Others may be forced out of production entirely. The advantages of interest subsidies might then accrue solely to the more profitable firms.

Efficiency Implications of Subsidies

26. We now discuss the distorting effect that subsidies are likely to have on the technical efficiency of a firm's operations. In general, the presence of subsidies means that the least social cost method of meeting a given ambient water quality standard is unlikely to be achieved. In particular, since the subsidies under consideration apply only to capital investment, they will tend to bias firms' investment decisions in favor of capital intensive pollution control processes as opposed to those

with relatively high operating costs. An example of this is construction of treatment plants to handle spent sulphite liquor (very capital intensive), rather than higher rate evaporation and burning of the liquor with recovery of energy (operating cost intensive).

27. A particularly difficult problem, a natural consequence of the subsidy system, is that firms are given the incentive to claim that investments are necessitated by pollution control legislation when in fact they are not. To the extent that a firm is successful in its claim, an unwarranted income transfer to that firm results. Moreover, as a consequence of the subsidy to "productive" investment, a firm may follow an investment program that it would not have chosen had it been faced with the true cost of capital.

28. Unfortunately, the task of disentangling pollution control investments from "productive" investments will frequently be too complex for a regulatory authority to handle, since firms' responses to regulatory requirements will often involve some increase in usable or marketable outputs and, hence, a rise in profits. It has been suggested that the cost of designing an optimal system for one pulp mill could be as much as $100,000 and it is conceivable that it might cost an equal amount in order to determine with any accuracy the net cost to a plant of meeting effluent standards, i.e., to separate the net cost of pollution control per se from the benefits to the firm which would result from the overall investment program for altering production processes. As a consequence, in negotiations with regulatory authorities such as the NWB and the water courts (regarding the interest subsidy) and the tax authorities (regarding the write-off subsidy) the firms have all the advantages, because only the firms have all the facts. In short, the availability of subsidies will tend to bias investment decisions in favor of those expenditures that can be most easily claimed to be for pollution control purposes.

29. Some example of the type of difficulties that arise in determining the cost to a firm of pollution control are as follows. First, suppose that in the normal process of plant modernization the quality of effluent discharged by a firm improves. One can imagine the difficulty a regulatory authority might have in evaluating the firm's claim that process change was a result of pollution control requirements and therefore merits subsidy. Similarly, finding that it has to improve its effluent quality, a firm may estimate that since it has to invest in a particular type of equipment, it is now profitable - or at least will reduce the net cost of adhering to the regulation - to carry out a further process change. Probably the best example of this in Finland would be a practice frequently employed by calcium based sulphite mills. Being required to curtain their discharge of waste liquor to a watercourse, the alternative of burning may be chosen. With some additional investment, this becomes of value as a source of energy.

30. The problem in such cases is to decide how much of the investment should be subject to subsidy. The government has emphasized that it will not subsidize the "profitable" portion of investment, and consequently should not be prepared to estimate, as the net cost of pollution treatment, the present worth of the firm's net profits with and without that investment. However, it would be difficult for a regulatory authority to obtain the facts and very time consuming and expensive to carry out the necessary calculation. Thus, while we would recommend that, if the subsidy system is retained, firms should provide flow diagrams and "with and without" cost estimates, we have some doubts about the NWB's chances of dealing adequately with this problem.

31. It has been stated by the Finnish authorities that the primary emphasis of the pollution control program will be on the establishment of internal treatment processes. However, in view of the administrative difficulties indicated above, there is a danger that they might be forced to adopt the procedure followed in the United States, which uses a tax write-off subsidy, and where in practice it has only proved possible to apply the subsidy to "end of the pipe" or external pollution control investments, namely those which involve no process change. It is clear that this is likely to involve considerable inefficiencies, since, for a given effluent standard, it will tend to bias investment decisions in favor of processes which create relatively large amounts of pollution and high initial investment in treatment works, and which are relatively wasteful of materials and energy.

B. Effluent Limitations Problems

32. In addition to the inefficiencies and inequities likely to be induced by the subsidy system, difficulties may also arise from the system of effluent standards required by Finnish water pollution control authorities. While the standard setting and enforcement procedures are not worse than those used in a number of other countries, and are clearly superior to some, they can be anticipated to present prblems both of an efficiency and an equity nature. The Finnish system of licenses and enforcement, as in other such systems, lends itself to delays and associated arbitrariness of impact and is difficult to relate systematically to regional water quality management programs. Since the license system gives a discharger so little choice, removing the scope for flexibility in responding to water pollution control requirements, a complex system of appeals is necessary in order to avoid extreme inequities and inefficiencies (for example where the cost to a firm of control is likely to exceed the benefits of control as perceived by society).

33. In the past, delays in getting permits issued by Finnish water pollution authorities have sometimes been quite long (up to eight years) but this process has now been streamlined and usually permits are issued within two years. Even so, if a company wished to exploit all the possibilities for delaying the process until full compliance is reached, it could take many years. Unless Finnish industry is quite different from that of other countries it will take evasive action if the costs of compliance are substantial. Unfortunately, license systems and their associated processes of appeal and litigation have inherent in them incentives to hire lawyers rather than to get on with the job of waste water control.

34. One result is that the process is rather arbitrary in its impact on different companies depending upon their willingness or unwillingness to engage in delaying tactics. The possibilities for the government to engage in coherent and efficient programs of regional water quality management, with discharge reductions concentrated where problems are most serious and costs of control least, are therefore limited.

35. Furthermore, in an effort to simplify administration and to make the procedure more equitable, an effort is made to standardize requirements among the different dischargers. The Finnish program is no exception to this. The result of such an approach is that plants with greatly differing costs of control are required to reduce their discharge to a similar level, with the only variation between firms being in the timetable for implementation. However, this not only turns out to be inequitable, but is also likely to be inefficient, for marginal costs of control will differ greatly from firm to firm.

36. Ambient standards can be met at least cost only if each source with a similar effect on the standard has the same marginal control cost (the nature of this concept is explained in Annex V). As Part III and Annex IV indicate, this condition can, at least in some major cases, be approximated by a relatively simple system of effluent charges. Permit systems are not very suitable for this purpose because to implement programs at minimum cost requires detailed information on costs at each source. This is unlikely to be available to a regulatory authority, the problem being compounded by the wide range of control requirements and associated costs at the various sources.

37. Another difficulty with licenses is that they are usually - and again this is the case in Finland - stated in terms of a permitted weight of discharge per unit of final product. This means that large sources are accorded a far greater right of discharge than small ones even though their total discharge is much more harmful. In effect large sources are given much larger property-type rights in the water resource than small ones, free of charge. As pointed out in Part III, with a charges system each user pays for what he gets and large discharges are appropriately costly to the discharger whether they come from large plants, municipalities or smaller polluters.

38. Any effective water pollution policy, whether based primarily on permits or incentives, requires a certain amount of monitoring and measuring. In Finland this matter takes on a special importance because of a particular condition in the pulp and paper industry. One of the conditions for obtaining a permit from the water court is that the company must make regular measurements of the quality of the receiving waters and also check its own discharge. Besides this basic monitoring system, the NWB makes random inspections of the plants, covering the equipment, the condition of the receiving waters, and the actual waste loads. For municipal waste treatment plants, there is a development towards automatic metering devices for the discharges, although this is not so for industrial wastes.

39. As a substantial part of the water pollution problem in Finland is generated by the pulp and paper industry, it is necessary that the measuring and monitoring system be developed further. It is known from other studies that about one-third of the total discharge of wastes into water-courses from the pulp and paper industry is of an occasional nature,

i.e., due to malfunctioning of equipment, mistakes on the part of management or workers,etc. It is therefore necessary to create conditions that ensure that these occasional discharges are reduced: the problem then is to create incentives to management to reduce the probability of occasional discharges. This would require of course a method of monitoring actual discharges in such a way that authorities can quickly intervene, putting economic or other pressures on the management each time an unexpected increase in their waste discharge occurs.

40. Whether or not the permit system is retained, the NWB must try to devise methods of measuring and monitoring that will take care of this important problem. However, experience with a license system in Sweden (very similar to that employed in Finland) suggests that it is not well suited to cope with occasional discharges. Since equipment can and does malfunction, some flexibility must be allowed. But under a permit system this tends to relieve the plant of any penalty when occasional discharges occur, and therefore does not provide much incentive to good maintenance or operation of equipment; it may even open the door to deliberate discharges in excess of permit terms. It is possible to sue plant managers but this is a cumbersome and costly process, which in fact has never been used in Sweden. A system which sets a price on the actual discharges which occur should produce better results.

C. <u>Conclusions on the Merits of the Subsidy/License System</u>

41. The general conclusions regarding the merits of subsidies are therefore as follows:

- They are probably not necessary in order to retain the general international competitiveness of Finnish industry;

- The methods used are unlikely to achieve the objective of assisting marginal firms;

- If it is deemed necessary to subsidize marginal firms there are better ad hoc ways of doing so, and pollution control authorities are unlikely to be in the best position to make this kind of decision;

- Subsidies will bias investment decisions in favor of capital intensive methods of pollution control;

- Subsidies might also be granted to productive investments if they can successfully be claimed to be necessitated by pollution control and therefore qualify for subsidy;

-Regulatory authorities are unlikely to be able to challenge firms' claims regarding the net cost of pollution control because of the complex relationship between pollution control and general process change.

As to the license system:

-It normally requires a complex time consuming administrative process;

-It is arbitrary in impact;

-The system is unlikely to permit the achievement of ambient standards at least cost;

-It does not deal satisfactorily with the important occasional discharge problem.

42. The shortcomings of the subsidy/license system, in terms of technological efficiency, equity, and achievement of the least social cost method of attaining effluent quality standards appear to be clear. The next section will demonstrate that there is an alternative way of achieving these standards - namely, by means of effluent charges - that should facilitate achievement of the least cost solution. If so, industry as a whole would be the primary beneficiary, although some firms would fare better and others worse than under a system of standards. The reduction in industries' costs by improving the technological solution to pollution control is clearly a more desirable approach than a system of subsidies that creates distortions and disincentives to efficient behavior.

III. AN ALTERNATIVE STRATEGY FOR THE NEXT TEN YEARS

43. An alternative strategy to the subsidy/license approach would be to levy a fee on polluting plants for the discharge of pollutants into the waterways. The amount of the fee would be based upon the total load of pollutant discharged. There is some precedent for this approach: several major European countries, among them, France, Holland, Czechoslovakia, Germany, and Britain that have used license systems in the past have replaced or supplemented them or are seriously considering doing so, with effluent charges.

44. In principle, the fee rate per unit of discharge should be set equal to an estimate of the cost to society of an additional unit of pollutant discharged. (Such an estimate of social cost would have to be made to rationalize any form of regulation.) A practical method for accomplishing this might involve first, an estimate of the total amount of harm in a region being caused by a particular effluent, e.g. BOD, and

second an estimate of the total quantity in kilograms of the effluent currently being discharged by all sources into the region's waterways. Dividing the damage estimate by the quantity would give an average cost that could be used as the effluent charge.

45. A somewhat less desirable method which does not require an estimate of social damages to be made can also be devised. For example, one of the goals of the national plan is a fifty per cent reduction in BOD discharge over the ten-year period. One could roughly estimate an average per unit marginal cost for achieving this specific goal across industries and municipalities in Finland (as indeed has already been done) then on the implicit assumption that the social benefits of control exceed the social costs of so doing, to levy a charge equal to this cost on every unit of waste discharge from all sources. Dischargers would then find it worthwhile to reduce their discharge until the marginal cost of a further unit of waste reduction would just equal the charge avoided on that unit. Whatever the details of the charge system, this economic incentive would come into play to achieve the desired result with minimum of administrative effort, the complex permit issuance and appeals process being avoided. While this approach would not precisely achieve the 50% BOD reduction goal (it could be somewhat more or less) it would probably come as close as the direct regulation strategy.

46. In addition to greatly simplifying administration, such a charging scheme would have a number of desirable efficiency and equity aspects. First, in contrast to the subsidy/regulation approach, a charge is technologically neutral, and does not force the use of specific and possibly inefficient technologies. In particular, it does not favor capital intensive or end-of-the-pipe processes over other techniques, and it leaves the specific timing of response to the discharger. The latter is important because strict enforcement of externally imposed timetables often encourages tinkering with existing processes rather than more effective and efficient longer term changes. (in another context, the proposed use of catalytic converters in U.S. automobiles is a prime example of this.) Although the NWB tries to cooperate with industry in trying to ensure that pollution control investments are not required immediately if they can be more efficiently incorporated in subsequent plant expansion or modernization schemes, there is clearly an incentive to firms to take advantage of this attitude, thereby deferring the need to improve effluent quality.

47. A crucially important aspect of the type of charges system indicated is that it concentrates waste discharge reductions where it is least costly to undertake them. In contrast to the license system, which de facto allocates most of the available assimilative capacity to the large sources, the likely result of a charges system is that the smaller (and in case of industry usually the older) sources could find it advantageous to pay for the discharge of a higher proportion of wastes generated than would the

larger sources where unit costs of control are lower. The effect of concentrating controls where costs are lowest can be very large, and must be seen as an important determinant of whether or not the least social cost of achieving global water quality objectives is likely to be met. Several careful studies of particular regions suggest that overall costs of achieving ambient standards might be only <u>half</u> as great with such a system as compared with a policy of requiring uniform rates of cutback at all sources. One of the most important of these studies, that of the Delaware Estuary in the U.S., is discussed briefly in Annex IV.

48. The charges system would also most likely have highly favorable effects upon the very important occasional discharge problem, if proper monitoring equipment were installed. The discharger would have to pay for every unit of discharge whether accidental or not. Accordingly there will be an incentive to conduct high quality maintenance and to run "a tight ship." Also the incentive to try to "beat the system" will disappear. We are informed that the latter exists on some considerable scale in Sweden, where there is more experience with the license system, and it would be surprising if the same were not true in Finland.

49. As already noted, in achieving the desired ambient standard, a system of effluent charges is likely to cause some firms to discharge more, and others less polluting matter than under a system of standards for individual discharges. One particular manifestation of the greater freedom of choice resulting from the introduction of charges might be the stimulation of private research and development in methods of pollution control.

50. However, it is unlikely that charges alone would be sufficient to create incentives for adequate levels of research and development. The main reason for this is of course that the benefits of research may not accrue entirely to the firm taking the risk; market forces cannot be relied upon to result in an optimal amount of research and development. In consequence, it is suggested that the government should consider the subsidization of specific pollution control experiments and demonstration projects, since it is about to embark upon a program of pollution control that has no precedent in the country. The benefits of a subsidy of this kind are solidly supported by economic theory while the subsidies now in existence in Finland are not.

51. While recognizing its efficiency attributes much of the recent support for the charges approach has come from those who emphasize its effectiveness and equity. There is a folklore in many governments that holds a regulatory system to be certain and direct while incentive-based schemes such as effluent charges are regarded as being quite uncertain in effect. Experience with enforcement, and limited experience with

charges, has convinced many observers that almost exactly the opposite is the case. Reduction in industrial waste loads where even modest sewer surcharges have been imposed by municipalities has often been rapid and spectacularly large;dramatic responses to the imposition of sewer surcharges have recently been documented in the United States and Canada. On the other hand, regulatory processes are frequently not only time consuming but also quite uncertain in result.

52. The equity aspect of charges has two dimensions. First, the charges affect all waste dischargers at the same time, rather than having the somewhat capricious distribution of effects in the permit issuing-enforcement - appeals process. Secondly, all waste dischargers are confronted with a price for their discharges. The combination of charges paid and internal costs incurred for controls tends to be more evenly distributed among dischargers than either the costs associated with a uniform cutback strategy or a minimum cost strategy imposed through direct regulation.

53. A further advantage of the charges system is that it yields revenue. The revenue could be put to various uses, but one attractive possibility is to create a fund to be used to support planning and implementation of regional water quality management measures such as low flow augmentation, aeration and collective treatment. The importance of such technological alternatives are discussed in the next section. Loans for large scale experiments in innovative processes or treatment devices might also be made with such funds.

54. At present the NWB's budget for direct construction work is very limited and it could not carry out large scale river basin improvements other than by requiring firms to improve the quality of their discharges individually. It has no power to require individual firms to contribute to the cost of direct construction works, even though such works may be the cheapest means of achieving the desired ambient water quality standard. Clearly, the introduction of effluent charges, the revenues from which could be used to finance collective works in appropriate situations, would be an important step in ensuring that waste quality objectives are attained at least cost.

55. While efficient water quality management would best be served by replacing the subsidies/licensing system with a system of charges that reflect society's perception of the costs of pollution, such an immediate and thorough reorientation might not be politically acceptable, since the regulatory machinery is already in place. Furthermore, a minimum regulation system could provide protection against irrational or otherwise unpredictable behavior on the part of some plants. Accordingly minimum effluent standards could be set for industries and municipalities.

56. Subject to the foregoing, there should over time, be a determined effort to change the emphasis from reliance upon regulation to reliance upon charges. In practice it would probably be necessary to introduce charges gradually, increasing over a period of five years, until the establishment of individual effluent standards is phased out altogether. It might be politically feasible and also particularly desirable to accelerate the introduction of charges in the worst regions.

57. While having desirable near term effects the charges scheme would perhaps show itself to best advantage as target levels of water quality are advanced, for then complex and subtle process changes and treatment technologies can be very important. Moreover, the efficiency aspects of the charges system will become increasingly important as unit costs of pollution control become larger. As noted earlier, the revenues accruing from the effluent charges will begin to become available at the time when it may be desirable for the government to undertake more ambitious schemes of lake or river basin management.

IV. SYSTEMS AND BENEFIT-COST ANALYSIS IN LONG-TERM PLANNING

58. While one can understand the rationale for the lack of emphasis on benefit cost and systems analysis during the first phase of the water pollution control program, given the manpower constraints of the NWB, in the longer run these techniques will become increasingly important and even essential. As the incremental costs of water pollution control begin to rise rapidly, the consequences of inefficient programs will become more severe. Furthermore, large scale regional measures for water quality management such as those briefly mentioned in Part III will become increasingly attractive. Accordingly the planning and execution of programs making efficient use of a wide array of technological alternatives and spanning the various interdependencies of the problem takes on a high importance. Equally important is the fact that as ambient water quality in Finland improves, the effects of marginal improvements will increasingly accrue in the form of recreational benefits. Since pressure for the water pollution control program is largely from users of lakeside recreational properties, benefit measurement will become an increasingly feasible and important decision-making tool.

A. Basic Principles

59. In formulating an efficient program for the use of a watershed there are at least four basic principles that should be taken into account.

60. First, the discharge of wastes into a water course is related to the discharge of wastes into the atmosphere and disposal of solid wastes. It is therefore desirable to coordinate water and air pollution

policies in Finland. In particular, an integration of the institutions responsible for carrying out these policies would be likely to facilitate the optimal treatment of water-borne, solid, and gaseous emissions.

61. Second, it is frequently possible to reduce the discharge of waste water either by "end of the pipe" treatment or by internal process changes. As we have seen, the pollution control measures in the Finnish pulp and paper industry are mainly of the latter type.

62. Third, ambient water quality depends on the integration of all uses in a particular watershed. It is therefore necessary to simultaneously take into account all the sources of pollution within the watershed.

63. Fourth, it may sometimes be possible to improve the quality of the watershed by collective action such as sludge dredging, flow augmentation, collective effluent treatment plants, transport of effluent to receiving waters with greater assimilative capacity, in-stream water quality modification, lake aeration, etc.

64. In view of these four principles it is necessary, when formulating an efficient program for the use of the watershed, to simultaneously take into account:

- -The impact on all receiving environmental media.

- -All possibilities of reducing the waste load at each source by in-plant process changes and end of the pipe waste treatment, and the cost of the carrying out these different possibilities.

- -The interaction of the different wastes discharges within the watershed.

- -The cost and effectiveness of collective facilities.

65. In order to take all these considerations into account, it is necessary to use a systems analysis approach to planning, and to have, at least, a conceptual model of the watershed and the activities that are conducted therein. The main components of such a conceptual model are: a water quality model for the watershed; an economic activity model; and an objective function.

The Water Quality Model

66. Water quality must be defined in some way by a set of variables, related to the planning objectives. The quality, so defined, in one

section of the watershed will depend in a complex way on what happens in other sections of the watershed. These interrelationships are particularly complex when lakes dominate the watershed, as is typical in Finland. But, in spite of these complexities, it is necessary to have at least some broad ideas about the interdependencies between different sections of the watershed and between the different quality variables and waste discharges. Otherwise, it is impossible to identify the costs and benefits associated with any plan for the use of the watershed.

67. It is important to bear in mind, however, that a perfect understanding of the basic biological and chemical processes that take place in the watershed and of transport of biomass and nutrients from one section to another is not necessary as long as it is possible to predict the main effects on the system of, say, a change in the discharge pattern. Thus, while in view of the interrelationships involved, it is desirable to have a formal structure of the system instead of a more intuitive one, it may be acceptable (especially in the earlier years) to employ relatively simple models.

68. The attempts already made by the NWB to develop lake models are considered as important first steps in the direction outlined above. The ultimate aim of these attempts should be the calculation of a set of transfer functions for each of the watersheds, relating the water quality of the different sections of the watershed to the different uses.

The Economic Activity Model

69. An economically efficient use of the watershed implies that whatever the objectives of water quality are, they must be achieved at least social cost. It is thus necessary to have information on the costs of reducing the waste discharge at various sources. In view of the relation between the different water-borne waste discharges and gaseous emission and solid waste production, it is necessary to have information on the relation between the cost of reducing the discharge of a certain substance, the amount of that substance discharged, and the amounts of other waste generated.

70. A formalized structure describing the foregoing cost relationship can be achieved by several methods, including for example the use of activity analysis models. Here one tries to model each individual plant by representing technical options by certain activity or process vectors. By combining this representation of production processes with prices of inputs and products it is possible to estimate the cost to the plant from different reductions in waste loads. Besides being useful for planning purposes, in particular in determining whether or not a particular type of collective action is justified, such models have the further advantage that they can be used when dealing with the information supplied by a firm when it is applying for a permit. Moreover, if an effluent charges scheme is accepted, initial estimates of the total cost to industry of achieving certain ambient standards will assist the implementation of such an approach.

The Objective Function

71. The objectives of a water resource plan will contain the benefits of using a particular watershed for waste disposal, which has been dealt with above in connection with the water quality/economic activity model. There are, however, in general other kinds of benefits that must be traded off against the former kind. These benefits include ecological, aesthetic and recreational benefits as well as the supply of water for different uses.

72. Once the first basic steps toward water quality improvement are taken, recreational benefits will typically dominate over the other amenities water quality improvements would provide. The Finnish authorities have carried out a number of studies intended to make a monetary evaluation of recreational benefits. A variety of methods have been used, including property value studies, questionnaires and information on transportation costs. It is the mission's view that these studies could have a better conceptual basis to include, for example, precise definitions of cost and benefit categories. Also the studies do not deal adequately with elementary considerations such as the choice of discount rate and avoidance of double counting of benefits.

73. In view of the dominance of recreational considerations in water quality benefit evaluation in Finland, a concerted effort to apply existing methodology and to develop improved ones is clearly merited. Even though there will undoubtedly remain some unquantifiable relationships and variables a conceptual model is indispensable to the planning process and can be used, for example, to compute the implicit value that net benefits must have in order for a sub-program to be justified, or to compute the value that a variable must have if certain effects are to be realized.

74. It seems that the possibilities of carrying out this program are good in Finland. Some evidence of this is the benefit-cost studies already undertaken. But of greater importance is the fact that it will in the future probably be sufficient to limit the analysis to recreational benefits. These should be easier to evaluate than aesthetic, health and other benefits, since, in the Finnish context, it should to a large extent be possible to base these estimates on property values.

75. The foregoing of course raises the question of income distribution. Increases in the value of lakeside recreational properties will frequently benefit the wealthier segments of society, although it should be recognized that even the relatively low income classes in Finland own summer cottages and would also benefit from the appreciation of recreation property values. Explicitly or implicitly, any benefit-cost analysis would have to weigh benefits according to the economic status of beneficiaries: this seems to be a particularly relevant consideration in the present context. Finally, estimates of the impact of water quality improvement on property values might have useful financial and fiscal consequences. Consideration might be given to the introduction of betterment levies which allow, at least in part, the costs of pollution control to be recovered from beneficiaries.

B. Development of a Regional Evaluation Model

76. Given (a) a lake model which relates the effects of a quality change in one section of a stream to a change in quality in other sections; (b) a model which relates a change in quality in one section of a region to a change in economic and social benefits; and (c) adequate cost information, it is possible to make a determination about the most appropriate investment program. That is, an overall decision model can be used to determine the optimal levels of target stream quality in each section of a region. Where a more refined system of effluent charges is used, such a model could be employed to test the effect of different levels of charges on the resulting stream conditions. Either a simulation model or an optimizing model could be developed.

77. The goal of the methodological development should be to have a model or medeling framework which can be easily adapted from one region to another. Because the wood processing industry together with households are the dominant source of water quality degradation in Finland and because similar conditions of shallow lakes and streams prevail throughout the country, this should be relatively more easily accomplished for Finland than for most other countries.

78. An important feature of the modeling framework is that it should permit the investigation of waterway modification techniques that could become important in advanced stages of the environmental program. In some cases, the configuration of the waterways in certain sections of a region may be such as to permit achievement of incremental quality gains at lowest cost by means of public works affecting the entire section rather than by means of point discharge reduction. Regional benefit-cost studies and the benefit models and evaluation models that support these studies should explicitly allow for such possibilities since the cost differentials between the approaches could be substantial.

79. The development of a model implies the need for parallel efforts in the area of data collection and social surveys. Since manpower and financial resources are limited these efforts should be carefully related to the regional model or decision methodology in which the data will be subsequently employed. Even the early years of the ten year program will result in certain quality changes in waterways (though some regenerative effects will occur only after a time lag). It is important, therefore, that before-and-after surveys of water use and public attitudes and perceptions of water quality changes be made so that benefit measurement in later phases of the plan can be accomplished.

80. The improvement of systems analysis and the collection of data required to support decision making will primarily be the responsibility of the NWB: it is unlikely that much reliance can be placed upon industry to assist in this way. While the studies and research already done by the NWB itself, and those undertaken for the NWB by the State Center for Technical Research indicate promise, the limitations of trained manpower have meant

that relatively few of such studies have been undertaken, and, as noted, even these have shortcomings. Current plans that suggest the same or even a lower level of effort along these lines in the near future should be reconsidered. The magnitude of expenditures anticipated during the ten year plan warrants the expenditure of correspondingly appropriate resources to assure that all policy alternatives are carefully and systematically explored. As the plan proceeds, and marginal costs of quality improvements increase, it will be necessary to more carefully consider incremental benefits before resources are committed.

81. In addition, as point sources are controlled to a higher degree, non-point sources (runoff from agricultural and forest land particularly) will become relatively more important. Planning and systems analysis must be designed to understand the nature and effects of these sources and to develop management programs for them.

82. If the NWB is to be in a position to refine its methodological approach and to have necessary data available to it during the second phase of the plan, an early augmentation of staff and the initiation of a training program in systems analysis and benefit-cost methodology is clearly necessary.

V. BROADER ISSUES

A. Integration of Planning Efforts

83. Increasing governmental pressure for higher environmental standards will require on government's side improved integration of plans and planning studies. Two different levels of coordination should receive attention. At one level, the regional water plans and the policies deriving from them should be integrated into the national water plan. At another level, planning and benefit-cost analysis done in all government departments should explicitly include environmental considerations.

Regional Water Plans and the National Water Plan

84. As higher environmental goals are sought, the target ambient water quality in regions and sub-regions must be refined. These targets and the means of achieving them would be different for different locations, and this should be reflected in the national plan. It would be unreasonable to expect complete integration to begin immediately. The first phase, which in the light of manpower constraints and the sophistication of the studies that would be required might last three years, would consist of the development of benefit-cost methodology and the collection of data in order to facilitate measurement of economic benefits and of the system-wide effects of various pollution control measures. After about three years it might then become feasible to use benefit-cost studies to support regional decision making, which would then form the heart of the national plan. Existing regional studies would then be updated and refined one by one, and the more uniform minimum standards which might apply in the first phase could then be replaced by separate ambient water standards and separate levels of effluent charges for industrial regions or sub-regions.

Need for Interdepartmental Coordination of Plans and Studies

85. Clearly, all human activities involving the use of physical resources have an effect on the environment to a greater or lesser degree. Plans involving transportation, agricultural, energy projects, or the specification of land use and industrial location, for example, can have significant impacts on water quality. It is important that plans and studies by the governmental agencies involved should explicitly recognize possible environmental impact. A recent Finnish transportation study of a causeway which if built would have prevented the natural flushing action of a major waterway is an example of a case in which environmental considerations were ignored in the early stages of project formulation. Coordination of course implies reciprocity: the NWB at present has no routine method of dealing with environment protection projects which might have an impact on other spheres of activity such as transportation and industrial location.

B. The Baltic

86. The most serious problem of the Baltic seems to be the oxygen deficiency in the deep waters of the Central Basin (of which the Gulf of Finland is a part). This problem arises primarily because of the stable stratification of the water at the permanent halocline. This halocline effectively prevents circulation of oxygenised surface water into the bottom layer. The additions of oxygenised water comes through the eratic influx of ocean waters through the Danish Sounds and Oresand. It is presently believed that the recent growth of areas in the Baltic where oxygen is completely depleted and hydrogen sulphide appears is due to excessive loads of phosphorous, which causes growth of algae. The biodegradation of algae then consumes the scarce supply of molecular oxygen in the deep waters. Other serious problems are the eutrophication of coastal zones, due also to the discharge of nutrients; the high concentrations of toxic materials such as PCB and DDT, and oil pollution.

87. At least the first two problems, i.e. the oxygen deficiency in the central basin and the eutrophication of coastal zones seem to be pertinent to the national water pollution control policies in Finland. Even the third problem, toxic materials and oil pollution, is related and should be considered when formulating the objectives of the national policy. When making benefit-cost analysis - or any other decision - relating to a particular pollution control project, it therefore seems necessary to consider the international impact of such decisions in their effort on the load of nutrients and toxic substances on the Baltic. Clearly, it will be very difficult, and may be impossible to assess precisely the monetary value of such benefits, but there may be some crude ways of doing this. If, for example, other countries adjacent to the Baltic are reducing their discharge of phosphorous, the marginal cost for those reductions may be taken as a very crude estimate of what other countries are willing to pay for an overall reduction of the waste load. Even if it is impossible to make a monetary evaluation it is necessary to give at least a qualitative indication of the international effects.

88. The pollution problem in the Baltic is an international problem, and the solution must be found in international cooperation and agreements among the countries concerned. A Draft Convention on the Protection of the Marine Environment of the Baltic Sea Area will be discussed in March 1974, at a ministerial conference of the countries touching the Baltic and is an important step in the development of international responsibility for the quality of sea waters. This Draft Convention will apparently oblige signatory countries to take explicit account of the Baltic when formulating the objectives of national water pollution policy. In Finland, the implementation of those objectives will be largely the responsibility of the NWB.

VI. CONCLUSION: IMPLICATIONS FOR BANK APPRAISAL

89. The objectives of this report were to evaluate and make recommendations concerning the actual and potential role of economic analysis in the Finnish water pollution control program. Major emphasis has been on determining whether current policies are likely to result in (a) the achievement of least cost solutions and (b) measurement of the benefits of pollution control programs, in order that optimal investment decision-making in the sector may be realized.

90. A major conclusion is that the least cost solution to achieving targeted ambient water quality standards is not likely to be achieved, due to the presence of subsidies on the one hand, and the system of uniform effluent standards on the other. It is therefore recommended, not only on grounds of technical - or economic - efficiency, but also on equity grounds, that:

- the system of subsidies presently in force and expected to be retained during the ten-year program should be abolished and

- consideration be given to replacing the establishment of effluent standards with one of effluent charges - or at least a combination of the two which over time would become increasingly reliant upon charges.

91. As to the question of benefit measurement, it would not at the present time be realistic to expect the Finnish authorities to be able to compute with any accuracy a benefit-cost ratio of the whole ten-year program. The early phase of the program, designed as it is to clean up the worst parts of the Finnish inland water system, will have a long-term ecological impact - not only inland but also in the Baltic - which while probably substantial, is certainly unquantifiable in the absence of a major research undertaking. As the program proceeds, however, the benefits of maintaining a given water quality standard will accrue mainly in the form of recreational benefits. Since unit costs of control will rise as pollution decreases, the need for benefit-cost analysis will then become increasingly important, and also feasible as there is a market for recreational benefits - namely for properties adjoining the lakes - which can be used to quantify benefits. It is therefore urged that the Finnish authorities begin now to develop the methodology for applying benefit-cost analysis as a routine part of their water

pollution control activity; in addition, more attention should be paid to systems analysis, particularly to identify the nature of transfer functions - i.e., the relationship between changes in an effluent discharge at any one source and the impact on the rest of the system. Specific attention should be paid to income distributional aspects of pollution control projects; in particular, consideration should be given to weighing project benefits to reflect the fact that they will increasingly accrue to owners and users of recreational properties. Since it would be unrealistic to rely upon the assistance of industry in the monitoring and measurement of the impact of pollution control measures, the responsibility must be in the hands of a public authority, and units within the NWB should therefore be built up now to do that work. Annex VI outlines the recommended time phasing of elements in the ten-year national plan.

WATER LEGISLATION AND ENFORCEMENT1/

Finland's Water Legislation

1. Water legislation in Finland is based upon the principles of Scandinavian law according to which water areas are in general privately owned and considered to be real estate. The rights of the owner of the water area are subject to certain restrictions concerning the utilization of water courses. Even individuals other than the owner have certain rights of general usage.

2. The first legislation passed in Finland was the Water Act of 1902, which was in effect for almost 60 years. It was, however, not until 1934 that the Act was completed and covered all forms of water course usage, except for ground water. The need for revising the 1902 Act subsequently became apparent, but this was actually not done until the 1960's. A number of acts and statutes were passed between 1961 and 1970. This legislation provided regulations extending to all functions relating to water, excepting the ownership of water areas. The legislation set up the system of water courts which are to interpret regulations and established the National Water Board which assists the courts in the administration.

3. During 1972 a committee was appointed by the Government to review the water legislation, particularly with regard to the functioning of the Water Court system. To date, none of the alternative solutions recommended by the Committee have been adopted. It is now understood that, instead, the Court system will be given more staff in order to expedite its operations, rather than changing legislation or the role of the Courts themselves.

Enforcement by the Water Courts

4. Under the Water Act of 1902 permits were first granted by the provincial governments, but in 1934 a Water Course Committee was founded to handle legal administration. In the Water Act of 1962, administration was centralized by the founding of the Water Courts which are also competent to try related criminal cases and law suits. There are three district Water Courts in Finland covering the three regions of the country; the courts are located in Helsinki, Kuopio and Oulu. Each court has two judges, four engineers, four secretaries and five other staff members. There is a Water Court of Appeals composed of one chief justice, one chairman, two engineers and two jurists. Finally, there is the Supreme Administrative Court which is made up of five judges and two engineers. In the government's 1974 budget there are requests for one new engineer and one new staff member for each of the district Water Courts.

5. The procedure for obtaining a license for water usage can be simple or complicated, relatively quick or time-consuming, depending upon the size

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1/ Excerpted from "Finland Water Pollution Control Project - Background Information Paper" R. Storch and F. Batzella; October 31, 1973.

and nature of the applicant's business and the water course to be affected. A company prepares its application for a license and submits it to the National Water Board (NWB) which recommends whether or not a license is needed. It can happen that the NWB decides that a license is not required if the applicant undertakes certain protective measures. If a license is needed, then a lengthy application must be filled covering a minimum of 12 different points set forth in the legislation. The company submits the application to the appropriate district Water Court which checks to see that the application is complete and conforms to requirements in the law; if not, the application is returned for revision or completion. If the application is in order, then the Water Court follows one of two procedures: public notification or general survey. Public notification involves posting and publishing of the application in the local community for access to all interested parties three months in advance of project works. The general survey[1/] is a more involved process since the Water Court asks the NWB to nominate an engineer to conduct ad hoc committee hearings in the local community, accompanied by two members of the general public. This ad hoc committee makes a report to the Water Court within 30 days after which either the NWB itself or the applicant can give to the Water Court their responses to the report (under the public notification procedure, the same holds true, i.e. comments received from the public can be responded to by the NWB or the applicant).

6. The Water Court reviews all the evidence gathered under the notification or general survey procedures, and even makes a visit to the site if necessary. On rare occasions the Water Court may ask interested parties to come in for an oral hearing with the court. Usually the court reaches its decision about the license in camera. Some cases to obtain a license have taken from 6 to 8 years. Cases in which a general survey is involved are the ones which usually take over one year. In general, about 60 percent of the applications are granted within 12 months. Companies already in operation needing a license and involved in lengthy hearings are granted temporary licenses intermittently. If the costs of pollution control are considered too high, the company can ask the Government for financial assistance on concessional terms.

7. The validity of licenses runs from two to five years, averaging about four years. Intermediate licenses may be valid for up to two years, but it is usually for a period of less than one year. It is the responsibility of the companies in Finland to have a valid license or to have confirmed that the license is not necessary. In paragraph 10.25 of the Water Act the Water Courts are given the power to suspend, revoke, or require a new application of any license--thus giving the Water Courts authority for constant review. There is an appeal mechanism which, if involving damages (a law suit or a criminal case), goes to the Water Court of Appeals. Compensation can be from 100 to 150 percent of the damages. If the appeal of the license granted by the District Water Court involves the licensing itself, then the case goes to the Supreme Administrative Court. It it theoretically possible for a company to delay licensing procedures against its interests by two to three years through usage of the appeals mechanism, although the company must prove in the meantime that no serious damage to the water body is being caused by its continued operations. The total number of cases

1/ The applicant is liable to pay the expenses incurred in the general survey, though this is not necessarily always the case.

before the Water Courts during 1971 are shown below (no complete breakdown for 1972 and 1973 is yet available):

Applications	Transferred	Initiated	To be dealt with	Concluded	Pending Dec. 31
Construction, power stations, lowering of watercourses, regulation, etc.	436	370	806	368	438
Water supply, protection zones	153	92	245	94	151
Discharging of waste water	267	101	368	101	267
Damages	61	17	78	23	55
Lawsuits	16	8	24	9	15
Criminal cases	3	4	7	4	3
Cases of Appeal	61	86	147	68	79
Cases of official rectification	21	24	45	23	22
Total	1018	702	1720	690 1/	1030 2/

8. In conclusion, it should be pointed out that the granting of a license involves consideration by the Water Courts not only of the standards set for the particular water body by the NWB, but also the circumstances of the applicant. It is the opinion of some people in Finland that the Water Courts are sometimes too lenient with industries and, for this reason, these critics have suggested that the Water Courts be eliminated and the NWB exercise the authority of controlling licenses.

Terms of Water Use Licenses

9. The license terms include regulations binding on the licensee, which enter into force when the project is undertaken. The regulations are not, however, ordinary license terms in the sense that failure to comply with some of the regulations would lead to postponement or cancellation of the license. The license terms are regulations binding on the licensee and defining the licensee's relations with the parties with whose interests the project may interfere in one form or other. They stipulate the principles to be observed for the protection of public interests. If the license terms are not obeyed in the implementation of the project, they may be enforced by coercive measures as prescribed by the Water Act.

1/ In 1972 this figure was 696 and in 1973, 689.
2/ In 1973 this figure was 1071 and in 1973, 1138.

10. The general principle is that obligations other than those based on the law cannot be imposed on the licensee. In certain cases the law lays down in great detail the prerequisites for including some obligation in the license terms, or provides for the factual contents of a regulation to be imposed. In some other cases the law gives far-reaching discretionary powers to the authorities granting licenses. Depending on the nature of the case, the license terms contain varying regulations. The Water Act provides for a list of details to be included in the license terms. On the basis of this list the regulations to be imposed under license terms can be grouped as follows:

a. Regulations on structures and equipment.

b. Obligations involving apparatus and measures.

c. Regulations on the operation of the project.

d. Imposition of obligations for control of water conditions.

e. Regulations imposing a liability to pay compensations or corresponding charges.

f. Imposition of a maintenance obligation.

g. Regulation on construction-period conditions.

h. Imposition of a deadline for the realization of the project and a compulsory final inspection.

i. Clarification of the level of comparison and imposition of other regulations based on the law.

Organization of the National Water Board[1/]

11. The NWB which has six divisions (each with its various offices) and 13 water district offices, was created in 1970 when its budget was fixed at Fmk 21 million. By 1973 the budget had mounted to Fmk 80 million and is very conservatively projected to rise to Fmk 116 million by 1979. It should be pointed out that twice a year the NWB can submit supplementary budget requests, and they generally add 10 to 15 percent to the amounts mentioned above; also, the NWB receives the services of other government's employees seconded to it. The total number of employees in 1973 is 1,259 (458 in the head office and 801 in the district offices). The tasks of the various divisions are described below in a somewhat simplified manner.

12. General Planning Division. This division has 112 employees, which makes it the largest division in the head office. The planning functions are comprehensive and include pollution control, water supply, regulation, drainage

1/ The Statute and Act of Water Administration, 1970, set forth the legal framework of the NWB's responsibilities.

and river planning. The most important office within the division at the present time is the Office for Water Pollution Control and Recreational Use of the Waters which is responsible for planning Finland's national water pollution control program. Including those seconded from elsewhere within the NWB and the government, there are 30 people involved in planning the national program. The Office is headed by a chemical engineer who has a number of very able assistants, most of them also engineers.

13. Technical Division. The Technical Division has 36 employees divided into three offices. Its responsibilities are entirely directed toward water systems in the municipalities and communities of the country. Its main task involves giving technical advice and applying NWB criteria to the large projects which exceed the local budget of the communities and municipalities (these projects receive budgetary help from the central government). About 40 percent of the cost of this division's operations are covered by other Government sources outside the NWB budget. This division examines the technical construction and engineering aspects of existing and planned water systems and gives advice on contracts. The scope of the work includes water supply, sewerage, flood control, dams, and timber floating; in short, everything which involves the fresh water needs of communities and municipalities (harbors, ports, and the sea coast are not within the scope of NWB's activities).

14. Legal Division. Out of a staff of 45, 11 are lawyers--five employed in actual legal affairs and six in NWB administration. The primary responsibility of the Legal Division is to look after the legal responsibilities of the NWB regarding the preparation and interpretation of legislation and the gathering of documentation needed in the operations of the Water Courts. The Legal Division represents the NWB in notifying the Water Courts when there is a water violation, presenting evidence of the NWB to the Water Courts, and bringing to the attention of the Government prosecutor those cases of water violation deserving legal action. In all these tasks the Legal Division provides information, advice and counsel, but it does not have executive powers. The greatest part of this division's work, from the point of view of volume, concerns the internal business of the NWB such as personnel and social welfare matters.

15. Supervision and Inspection Division--and Water District Offices. The Supervision and Inspection Division has 44 employees of whom 16 are engineers while the 13 Water District Offices have 801 employees of whom 119 are engineers and 278 'builders'. From the point of view of NWB's overall day-to-day responsibilities, this division and the district offices are the most important elements in the NWB. The purpose of supervision and inspection is to ensure that the possibilities of future water use are preserved, that existing rights to use water resources are not violated, and that the consequences of licensed activities do not exceed the anticipated levels. Supervision is carried out in three basic ways. First, the division examines the applications of water users; there were 507 such inspections in 1971 and 692 in 1972. Secondly, the division and district offices represent the NWB in supervising the public interest in the various phases of the

application procedure such as initial hearings, general surveys, and statements prepared in response to comments made by other parties on applications. Thirdly, the division and district offices supervise the implementation of water regulations as well as over 8,000 court decisions made with regard to particular water users. All companies in Finland licensed for water use must submit monthly reports, and these are spot-checked by the district offices. The NWB has 670 observation stations to take water readings and 300 checkpoints for monitoring discharges. Annually about 300,000 different readings are taken each year. The NWB now has over one million water analyses on record, 23,000 station-years of water level measurements, and 9,000 station-years of discharge readings. The NWB uses the government Data Processing Center and is setting up its own data Bank, for operation hopefully by 1975.

16. Whenever supervision and inspection reveal that the law or regulations have been violated, the consequences of water use more harmful than anticipated, or the future use of water threatened, the NWB makes proposals and initial statements to the proper authorities and to the water users concerned. If there is an immediate and serious health hazard, the NWB goes to the police for urgent action. If it is determined that the water license is not strict enough, the division proposes that it be revoked or amended. In 1972 there were about 10 cases in which water users actually had to close down operations as a result of action taken by the NWB. Altogether, the division and district offices handled about 1,500 cases in 1971 and close to 2,000 cases in 1972.

17. Other Divisions. The Economics Division is actually misnamed since its primary functions are preparation of the NWB budget, handling all accounting matters, and processing data. The work of the Water Research Institute (also a division) involves hydrological research and observation, research into water quality measurement, and equipment research and development.

Pollution Control Loans to Industry made from the Export Levy Fund

18. In 1958 the government passed a law permitting the granting of loans from funds accrued as export levies. These levies were imposed as a result of the excess profits coming to Finnish exporters following the devaluation of the Finnish mark in 1957. The loans permitted under the law could be made for a number of purposes, including investments for water pollution control. A special committee appointed by the Council of State was designed to control these loans and fix their terms. Although figures on such loans made up to 1968 are not available, from 1969 through 1973 the amount of such loans made from the export levy fund will amount to Fmk 41 million. During 1969 and 1970 these loans were made independently by the Ministry of Agriculture and Forestry while in 1972 and 1973 they were made through the Ministry with the recommendation of the NWB, although the final decision on loans was always made by the Council of State. These loans in 1972 bore a 5 percent interest rate and were for 10 years, two years of grace included. In principle the loans could amount to 50% of the project costs but, since the total applications for

these loans amounted to over five times the funds available, the loans actually made covered from 10 to 15% of project costs. Among the borrowers were 34 out of the 35 pulp and paper companies.[1/]

19. The principles and criteria for granting of the loans made out of the export levy fund, as applied by the NWB, are as follows:

a. Only existing industries are eligible.

b. Loans are only granted for pollution control unrelated to increases in production.

c. The project must be in harmony with the provisions of water laws.

d. The project must be urgent from the point of view of the conditions in use of the water body.

e. The project must be urgent from the point of view of the validity of the applicant's license.

f. The measures for water protection executed during previous years and their costs must be known.

g. The economy and efficiency of the project must be superior to that of alternative solutions.

h. Loans for water protection which have been granted earlier and their share of the total investment with the corresponding period must also be taken into account.

20. Under the national pollution control program, separate loans from the export levy fund will cease and the funds will become part of the Government's contribution to the costs of the national program.

Preparation and Status of National Water Program

21. The planning of water resources and water pollution control was done, prior to the creation of the NWB, by the Board of Agriculture and the Board of Roads and Waterways. This earlier work was completed between 1968 and 1970 and is being used by the NWB in its current planning activities

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1/ These loans for water pollution control made from Government funds are not to be confused with low interest term loans granted from the state-owned Post Office Bank which have been and are made to water supply and sewage treatment projects of communities and municipalities. Such loans amount to a maximum 60% of project costs at a 3% rate of interest over 10 to 24 years. The Post Office Bank was and is reimbursed for the difference between the 3% rate and its normal commercial rate for loans.

for the country. There are three levels of planning being done by the NWB's Office for Water Pollution Control and Recreational Use of the Waters. The national plan for water usage in Finland should be completed by February, 1974 and it will be one volume of about 200 pages. The total cost of industrial water pollution control is estimated at Fmk 1,300 million (1972 prices) over 10 years, of which Fmk 500 million are expected to be financed by the Mortgage Bank and the Bank of Finland (central bank), an equivalent amount by the Post Office Bank and the Government budget, with the remaining Fmk 300 million from industry itself. The integrated regional plan for 19 areas compose the second level of planning, and these are in varying stages of completion and preparation: the one for Kymi River is completed, the neighboring Keski-ja Itavusimaa region will be completed in December, four more regions will be completed by June of 1974, and the remaining 13 regional plans should be completed by the end of 1975. The third level of planning concerns particular sections in each region and specifically involves individual companies and the bodies of water directly affected by their operations. For the pulp and paper industry specifically these section plans have been completed on eight regions; a ninth region will be completed in November, another in February of 1974, three in June of 1974, one in September, with no pulp and paper industry present in the remaining six regions of the country. As for other industry, aside from pulp and paper, the section plans have been completed in eight regions, with two more to be completed in 1974, and the remaining nine in 1975.

ESTIMATED WASTE LOAD FROM POPULATION AND INDUSTRY, 1972

ANNEX II

Load or Industry	Sewage quantity m^3/day Total water	Process or waste water	Cooling water	BOD_7 tons/day	Phosphorus kg/day	Nitrogen kg/day	Suspended solids tons/day	Other Continuous load 4/	4/ Risk factor
Population centres	850,000	850,000		116	5,440	26,000		1	1
Forest products industry	5,600,000	5,600,000		1,328	2,000	15,000	820	2	1
Chemical									
Oil refining	680,000	12,500	660,000	0.7	10	1 500	1-2	3	3
Fertilizer	509,000	3,000	497,000	1.2	760	3 450	4	1	1
Other chemical	560,000	36,500	523,000	5.2	60	710	16 2/	1-3	1-3
Mineral	83,200	68,300			1/		1-2	2	1-2
Basic metals industry									
Iron and steel	490,500	20,000	402,500	-	1/		20	2	2
Other (non-ferrous)	605,000	55,000	524,000	-	1/		2	3	3
Metal products and machines								1-3	1-3
Foodstuffs 3/	59,000	59,000		83	835	3,540	10-80	0-1	0-1
Leather	5,700	5,700		4	30	1,040	5	1	1
Textile	26,000	26,000		3	60	150		1	2
Total	9,468,400	6,766,000	2,606,000	1,540	9,195	51,990	879-951		

1/ Data are not available from all plants
2/ Only cooling waters; not comparable
3/ Cooling waters not included; data not available
4/ Other continuous load/risk factor
0 = zero
1 = small quantity and/or slight harmful effect
2 = fairly large quantity and/or considerable harmful effects
3 = large quantity and/or extensive harmful effects

Source: Draft National Plan for Water Usage (amended)

ESTIMATED EXPENDITURES ON WATER POLLUTION CONTROL BY INDUSTRY

1974-1978

	Pollution Control Expenditures (PCE)					Government Subsidies for PCE		
	(A) Investment FMk mill	(B) Operating Costs FMk mill	(C)7/ A + B as % of 5 Year GNP Growth	(D) A as % of Total Net Invest-ment by Affected Industry	(E) A + B as% of Export Value by Affected Industry	(F) Interest Subsidy FMk mill	(G)1/ Accelerated Depreciation FMk mill	(H)9/ F + G as % of National Budget
INDUSTRY								
Sulphite pulp4/	242	65						
Sulphate pulp5/	220	56						
Mechanical pulp, paper & board	50	40						
Semi-chemical pulp6/	2	3						
Fibreboard	6	3						
Water consuming woodworking industry total	520 3/	167	0.054	10.5	2.5 8/	48	46	1.0
Other industry total	180	100 2/	0.022			16	29 2/	0.5
TOTAL	700	267	0.075			64	75	1.5

ESTIMATED EXPENDITURES ON WATER POLLUTION CONTROL BY INDUSTRY
1979-1983

	Pollution Control Expenditures (PCE)					Government Subsidies for PCE		
	(A) Investment FMk mill	(B) 5 Year Operating Costs FMk mill	(C) 7/ A+B as % of GNP Growth	(D) A as % of Total Net Investment by Affected Industry	(E) A+B as % of Export Value by Affected Industry	(F) Interest Subsidy FMk mill	(G) 1/ Accelerated Depreciation FMk Mill	(H) 9/ F+G as % of National Budget
INDUSTRY								
Sulphite pulp 4/	130	35						
Sulphate pulp 5/	170	44						
Mechanical pulp, paper & Board	24	20						
Semi-chemical pulp 6/	2	3						
Fibreboard	4	2						
Water Consuming woodworking industry total	330 3/	104	0.030	6.5	1.0 8/	30	32	0.6
Other industry total	270	150 2/	0.029			25	43 2/	0.6
TOTAL	600	254	0.059			55	75	1.2

Footnotes to Tables 1 and 2

1/ Based on (A), not including investments made prior to period of projection

2/ Very broad estimate

3/ Includes a few investments begun before 1974

4/ Also includes six mech. pulp plants, some paper mills and two small semi-chemical pulp plants

5/ Also includes five sulphite mills, two small semi-chemical pulp plants and some integrated paper and board mills

6/ Only two large semi-chemical pulp and fluting board mills

7/ Annual growth rate assumed to be 4.75%

8/ Annual growth rate assumed to be 6.50%

9/ Growth taken from the National Budget Proposal for 1974

THE DELAWARE STUDY: COST MINIMIZATION, TRANSFER FUNCTIONS, AND EFFLUENT CHARGES

1. One of the most important landmarks in the short history of economic studies of water quality management was performed by the United States government in the Delaware Estuary region during the early and middle 1960s.[1] Among other things, the study permitted cost comparisons to be made among strategies which impose uniform waste reduction requirements at all outfalls and more flexible strategies aimed at achieving the same ambient standards.

2. The concept of ambient standards needs some explanation. Effluent standards pertain to requirements (either by weight of materials or concentrations) set on quality characteristics of the actual wastewater discharges. Ambient standards refer to quality requirements in the watercourse (usually by concentrations). As long as the focus in cost estimation is upon achieving standardized effluent specifications at all outfalls, no connection between the waste discharge reductions achieved and the quality of the water in the stream is provided or needed. But a more logical procedure (on the assumption that the objective is to achieve or maintain quality characteristics in watercourses) is to start with a water quality objective, or objectives, and then reason back to a desirable (based on a specified criterion) strategy for obtaining them.

3. But doing this requires that a quantitative connection be established between what occurs at individual points of residuals discharge and the quality of water in the watercourse at various point of interest. The mathematical functions making this connection are known as transfer functions. They are an essential tool for analyzing the cost effectiveness of water quality management strategies that have as their objective obtaining specified sets, or alternative sets, of water quality goals in the watercourse (ambient standards). Engineers and economists have incorporated such transfer functions into mathematical programing models to provide a powerful device for analyzing the cost implications of alternative implementation strategies.

4. Table 1 shows cost comparisons derived from such a model for the Delaware Estuary area for different objective sets (ambient standards) and two different implementation strategies. One strategy specifies uniform reduction at all outfalls, the other uses a mathematical programing procedure to minimize costs of achieving the objective sets. The latter implies substantially different levels of discharge reduction at different

[1] Delaware Estuary Comprehensive Study, (Philadelphia: Federal Water Pollution Control Administration, 1966). A more detailed discussions of this study can be found in Allen V. Kneese and Blair T. Bower Managing Water Quality, Economics, Technology, Institutions, Johns Hopkins University Press 1968.

outfalls depending upon the cost of achieving reductions at these particular outfalls and the effect (calculated via transfer functions) of reductions at a particular outfall on the ambient quality. For most objective sets, the cost differences are large. Several other studies have obtained analogous results. In some of these other cases the results were even more striking.

Table 1. Summary of Total Costs of Achieving Objective Sets 1, 2, 3, and 4
(Costs reflect waste-load conditions projected for 1975-80)
(million 1968 dollars present value)

Objective Set[1]	Uniform Treatment Total Costs	Cost Minimization Total Costs
1	460	460
2	315	215
3	155	85
4	130	65

5. Additional studies with the Delaware model indicated that a quite simple effluent charges system, imposing a uniform charge on each discharger, could approach the least cost solution solely via its economic incentive effect. Results of the analysis are shown in Table 2. Note that in this table figures are annual, rather than present values, and therefore not directly comparable with the previous table. The reason why the effluent charge induces a solution close to the least cost one is basically simple.

Table 2. Cost of Treatment under Alternative Programs

Do Objective (ppm)	Program		
	Least Cost	Uniform Treatment	Single Effluent Charge
	(million dollars per year)		
2	1.6	5.0	2.4
3-4	7.0	20.0	12.0

If waste dischargers desire to minimize cost, they will reduce discharge until the cost of a unit of further reduction is just equal to the effluent charge they would have to pay on that unit if they did discharge it. If they push discharge reduction further, the incremental costs of reducing discharge for the next units will exceed the charge they would have to pay if they discharged them and their overall cost (effluent charge plus reduction cost) would rise.

1/ Different levels of water quality goals that included as parameters: dissolved oxygen, chlorides, coliforms, turbidity, pH, hardness, temperature, phenols, oil & grease, and toxic substances.

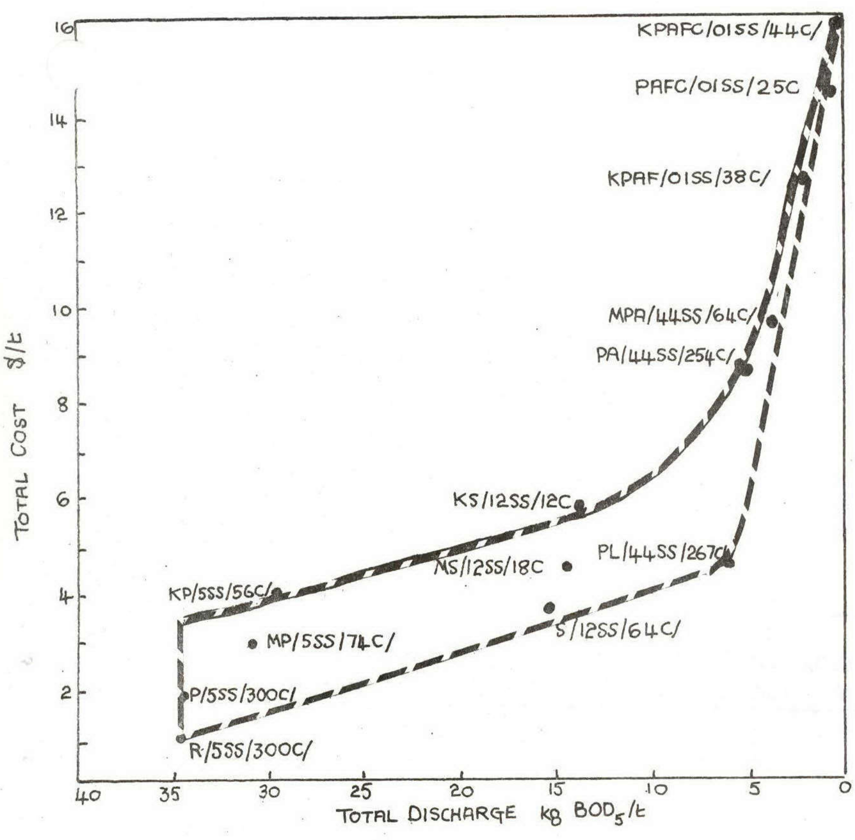
6. As a result of individual cost-minimizing behavior, the highest level of discharge reduction will tend to occur at those outfalls where the costs of making reductions are lowest. The reason why these individual responses to the charge do not produce quite so low a cost as the actual programed solution has to do with the nature of the particular transfer functions used. The contribution of a reduction in discharge to meeting the ambient standards is a function of where the discharge is relative to the point for which the ambient standard is specified, due to the fact that some types of waste degrade naturally in watercourses. It would only be under very specific conditions that the location of the discharger does not matter in achieving the cost-minimizing solution. But this study shows that a very simple effluent charges system can get quite close to a least cost solution in a large and complex case.

THE EXPONENTIAL NATURE OF CONTROL COSTS

1. There is a tendency for costs to rise rapidly as high levels of waste control are approached. This makes benefit-cost or cost-effectiveness considerations increasingly important as higher levels of control are planned. A number of industry studies can be cited to show this.

Figure 1 is from a Finnish study 1/ and shows this phenomenon for the pulp and paper industry using external measures to achieve higher control levels.

FIGURE 1



Legend

Cost of BOD removal by external treatment measures, with reduction in suspended solids and color as further parameters. Case study 300 ton/day sulphate pulp mill

Treatment Processes:

- R primary clarification with solids disposal by landfill
- P primary clarification with solids disposal by incineration
- M massive lime treatment for caustic extraction effluent
- K massive lime treatment for caustic extraction and chlorination stage effluent
- S primary clarification with chemical addition
- L aerated lagoon
- A activated sludge
- F mixed media filtration
- C carbon absorption

Example: PA/4.4 SS/252 C/
Means - primary clarification and activated sludge yielding suspended solids of 4.4 kg/ton of final output, and color coefficient of 252 platinum units/t

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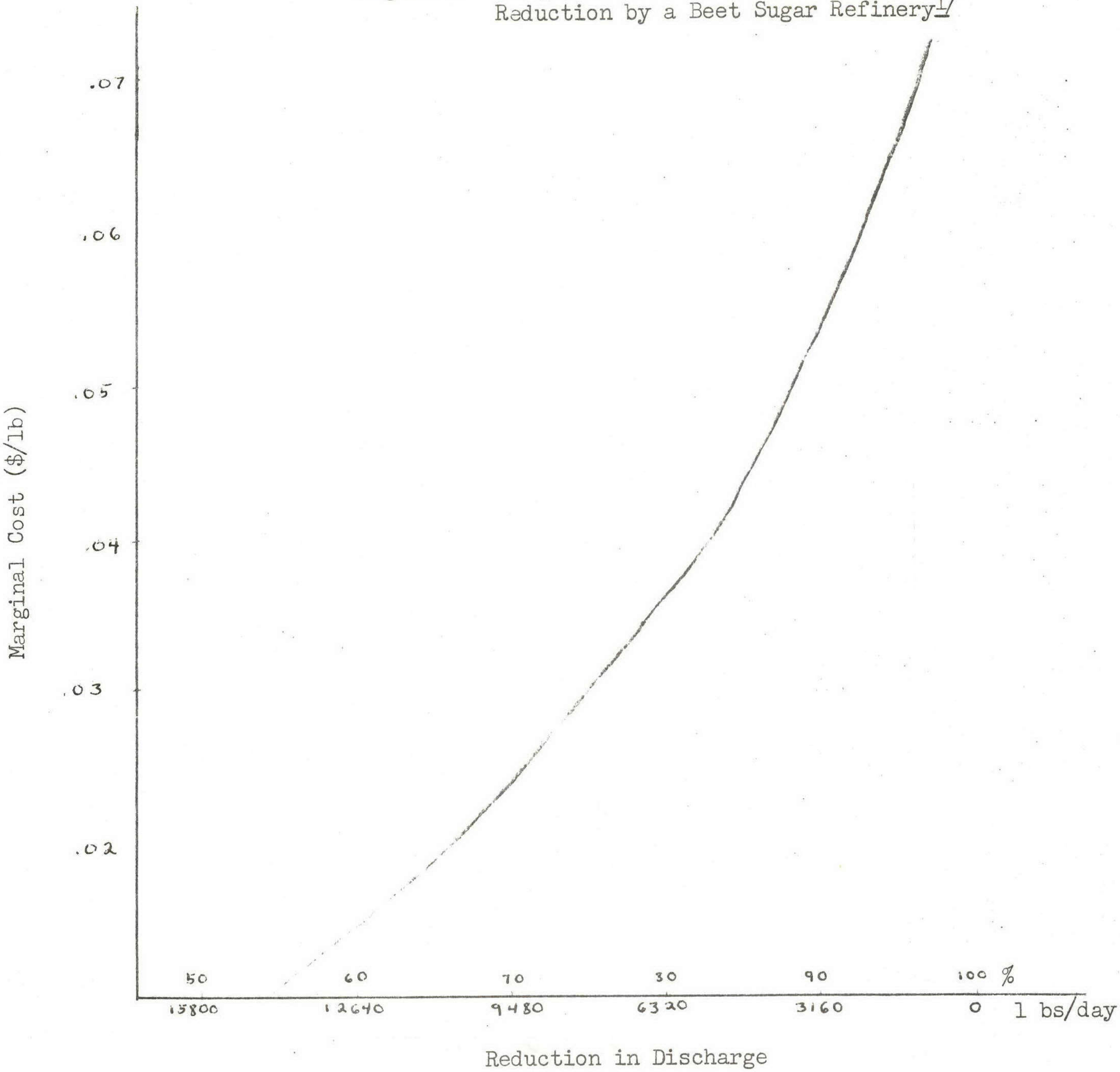
1/ From Westerberg, E.N. "The Use of Process Models in the Evaluation of Environmental Control Systems" Kemian Teollisuus 29 (1972)

2. A beet sugar industry in the United States can be used to illustrate the same point. Figure 2 displays a curve somewhat different in concept from the one in Figure 1, but it shows the exponential nature of the cost rise even more clearly. This curve shows the increase in total costs associated with each successive unit of reduction. In the language of economists this is referred to as a marginal cost curve. For each level of reduction the least cost combination of measures for achieving that level is used in deriving the curve.

3. An analogous result is shown for a petroleum refinery in Figure 3. Again, rapidly rising marginal cost as high levels of removal are approached is evident. In this case, however, marginal costs lie at a higher level. Thus, for a marginal cost of $0.07 the beet sugar plant can achieve more than 96 per cent BOD removal. The same marginal cost permits less than 70 per cent removal in the petroleum removal in the petroleum refinery, and a marginal cost of about $0.22 is required to go over 90 per cent removal. These results suggest the inefficiencies inherent in uniform discharge reduction strategies. 1/

1/ The information on petroleum refining is from Clifford S. Russell, Residuals Management in Industry: A Case Study of Petroleum Refining (The Johns Hopkins University Press, 1973)

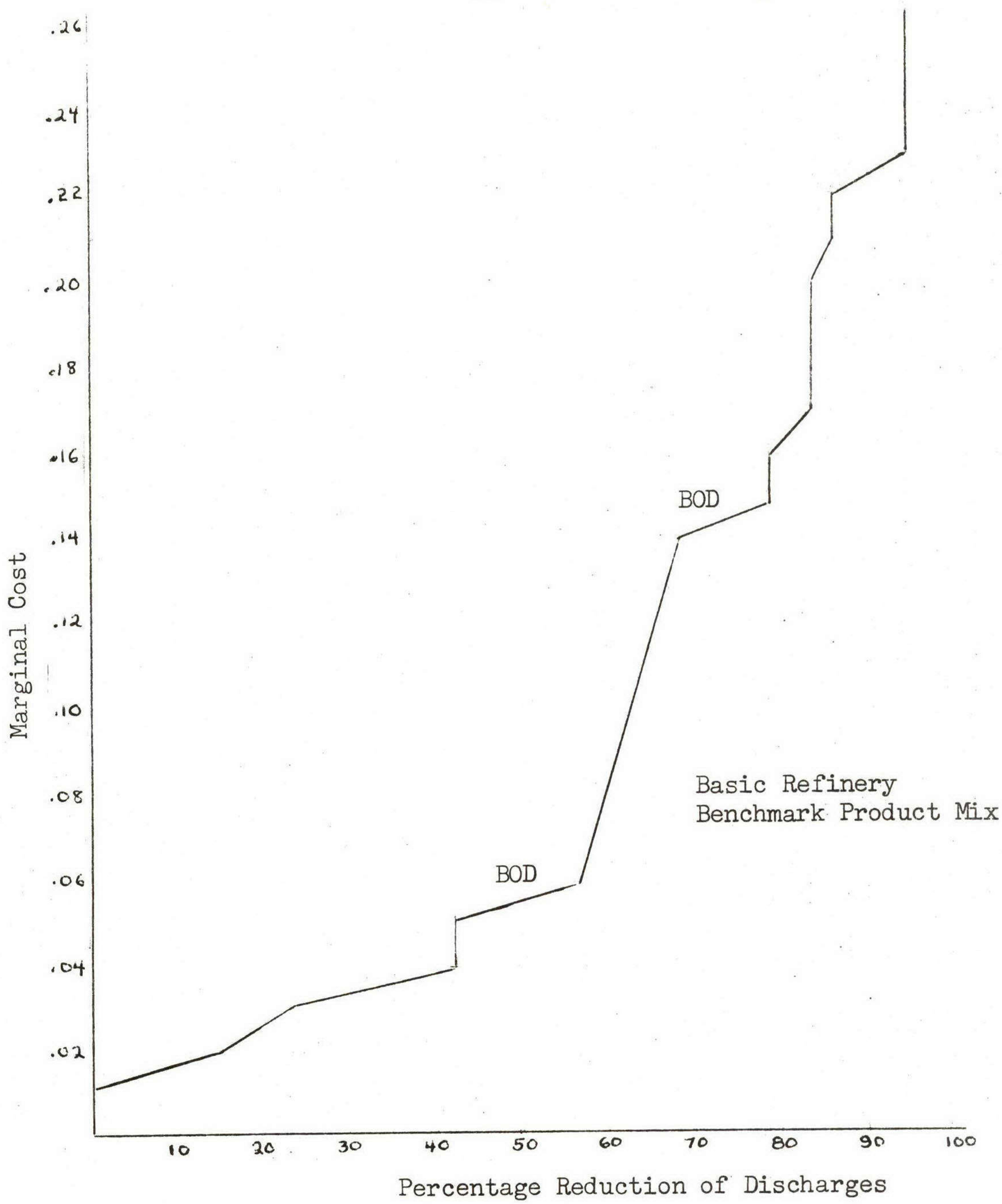
Figure 2 Marginal Cost of BOD Discharge Reduction by a Beet Sugar Refinery1/



1/ 2700 tons of beets processed per day.

Source: Prepared by Clifford Russell on the basis of data presented in G.O.G. Löf and A. V. Kneese, The Economics of Water Utilization in the Beet Sugar Industry (Baltimore: The Johns Hopkins University Press, 1968). Found in "Restraining Demand by Pricing of Water Withdrawals and Wastewater Disposal" Prepared for presentation at the Seminar on the Management of Water Supplies, University of East Anglia, Norwich, England, March 1973.

Figure 3 Marginal Cost of BOD Reduction on Petroleum Refining



SUMMARY OF ALTERNATIVE TEN YEAR PLAN STRATEGY

The recommended strategy for the ten year plan involves two phases that contain the following major elements:

FIRST PHASE - Years 1-3

- Effluent charges possibly combined with minimum effluent standards
- Proceeds of charges included in a fund to support further stages of public water quality management and to support research and development of innovative technology
- Transitional subsidies targeted on the basis of need
- Training of staff in benefit cost methodology and systems analysis
- Development of regional modeling and planning methodology
- Refinement of social surveys and data collection

SECOND PHASE - Years 4-10

- Increasing reliance on effluent charges but more refined systems instituted as salient analyses become available
- Regional studies employ regional model and benefit-cost analysis. These studies are employed to arrive at the effluent charge needed to achieve an ambient standard, to test policy alternatives, and to evaluate lake modification and management possiblities
- Institutions are created to implement regional management plans for waterborne and other waste including large scale regional measures
- Special problems of effluent resulting from non-point sources such as forest development areas are considered