74. A particular aspect of this problem, which the legislation or the law should provide means for resolving, is the intergovernmental relationship, whether as between the political subdivisions of a federal State or as between sovereign States at the international level. In respect of the latter, see paragraphs 46 to 48 above. The Colombian Environmental Code referred to in paragraph 42 above (article 10 (a) and (b) and articles 20 to 24) deals with this matter both domestically and internationally and is significant in the latter regard because of the unilateral adoption, through domestic legislation, of standards which are internationally binding on the Government enacting the legislation.

10. Water legislation as a policy instrument in other areas

75. As was stated in paragraphs 11 and 41, neither water legislation nor water policy constitute ends in themselves; rather, they should be regarded simply as integral parts of a broader whole, namely, a country's over-all policy for the achievement of national goals. That being so, water policy, together with water legislation, may be and often is used for purposes unrelated to water as such. For example, its function may be to: influence the location and size of urban or rural human settlements by withholding or providing water supply; promote the integration of different regions of a country by providing for the diversion of water from water-surplus to water-deficit areas by means of water grids or interbasin transfers; influence land-distribution and land-tenure patterns in arid and semi-arid areas where there can be no land reform without water reform; implement a zoning policy by providing or failing to provide water in conformity with the policy objectives; influence food production by granting priority to the agricultural sector over others in the use of water; or implement an environmental policy.

11. Conclusions

76. It was not intended that this paper should contain recommendations, since the participants in the Mar del Plata Conference will no doubt wish to extract and formulate these for themselves.

It should be borne in mind that the Valencia "considerations" and the Caracas recommendations represent the essence of the many working papers presented at those two forums. More than 100 documents, totalling over 1,500 printed pages assembled in 17 volumes, were discussed at Caracas. These figures are given to highlight the fact that the 52 recommendations referred to throughout this paper represent the distilled thinking of many extremely highly qualified water experts from all parts of the world. Both the Caracas and the Valencia Conferences brought together for completely free discussions participants from North and South and from East and West.

This monograph is intended as a methodological aid for those who propose to embark on the task of adopting water legislation or brining it up to date. Its purpose is similar to that of the ECAFE document referred to in foot-note 5, and it does not claim to offer specific recommendations for any particular problem. An attempt has been made (chap. 8) to identify the factors which have caused many existing water laws to be ineffective or to constitute bottle-necks, and an account has been given in some detail (chap. 9) of the prevailing trends in the modernization of water laws. Thus, the reader may, if he so desires, draw his own conclusions and make his own recommendations in the light of the circumstances in his own country. The international organizations, for their part, may wish to consider the recommendations addressed specifically to them by the Caracas Conference. 103/

103/ Caracas 48 to 51

JDK #238

NON-CONVENTIONAL WATER RESOURCES: SOME ADVANCES IN THEIR DEVELOPMENT

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INTRODUCTION

A rapidly growing world population, increasingly scarce natural resources and a rising standard of living have all contributed to an increase in the demand for water. This, in turn, has led to the need to supply more water than existing sources can provide in many already settled areas and, in addition, has produced demands in areas where, formerly, settlements either did not exist or were severely limited. The era of "free" or inexpensive water is rapidly coming to an end in many locations.

The growing scarcity of water has led to the investigation of ways to increase the available supply. These include more efficient utilization of existing resources, selective use of water of varying quality, and the tapping of non-conventional water resources. This paper summarizes some of the advances in the use of non-conventional water resources.

When one considers all possible non-conventional water resources, water can be thought of as an unlimited resource in comparison with other natural resources such as land, energy and raw materials. Given foreseeable technological progress, the location of human settlements and their level of economic activity need no longer be dictated by the availability of conventional water resources. Non-conventional water resources can be defined as water made available for human use by planned intervention in the chemical or physical phenomena of the hydrological cycle using non-conventional techniques. In some cases this intervention accelerates or decelerates the natural processes, e.g., cloud seeding, evaporation suppression, phreatophyte removal and glacier tapping. In other cases, the intervention is an imitation of a natural process in a closed or controlled system, e.g., desalination or waste-water reclamation. Still other non-conventional resources have been considered, such as long-distance hauling of water by supertankers or the even more exotic concept of transportation of icebergs from arctic regions.

Note: This report was prepared at the request of the Conference secretariat as a supporting document for the Conference. The views expressed are those of the author and do not necessarily reflect the position of the United Nations.

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These latter non-conventional resources involve systems which deliver water from one location to meet a demand elsewhere. The long history of the development of non-conventional water resources, i.e., the supply of water by techniques considered revolutionary for their time, has centred on the delivery of water from its natural source to centres of population. Water supply and drainage systems, while conventional to us, must certainly have been non-conventional 5,000 years ago when first introduced in the Indus Valley of India, as must have been the first rockfill dam built about the same time by the Egyptians. Long-distance conveyance of water, conventional even to the Romans, was certainly considered non-conventional before the construction of large water supply adequaducts by King Solomon of Israel in the tenth century B.C. The same is true of the development of ground water in both confined and unconfined aquifers in the Fertile Crescent, the most impressive of which, the Ghanat system of the ancient Persians, is still operational in modern Iran. Various water-pumping devices (whether powered by humans, animals or water in ancient times, by Leonardo da Vinci's pumping inventions, by steam, internal combustion, or electric-powered pumps of the modern era), have all broadened the concept of conventional water resources.

Water resources are exploited for many purposes. It is possible to divide these into three major categories - domestic (life-sustaining), agricultural and industrial (economic inputs), and recreational. The former two are consumptive; the latter is not. Because of the special effort and considerable cost involved in supplying non-conventional water resources, it is crucial to evaluate the ultimate use of this water. The supplying of water for life-sustaining needs requires a different justification from that for the supplying of water for economic or recreational activities. For production inputs, the feasibility of exploitation of these resources depends on economic justification.

In most places and in most instances, the marginal cost of producing water by non-conventional techniques exceeds the marginal product value of the water. Because many of the more promising techniques - desalination, for example - are energy intensive, the end of the era of "cheap energy" will greatly affect their development and exploitation. Yet, just as the scarcity and pricing of energy resources have led to intensive development of non-conventional sources (such as off-shore drilling, gasification of coal, nuclear and solar power), parallel economic forces are acting as catalysts in the water resources sector. What once seemed impossible or unfeasible is slowly becoming merely non-conventional and will later become conventional.

Man's relentless effort to discover and develop the means to overcome natural constraints is producing results in the water resources sector. The following discussion is a brief description of the progress made in developing some of these non-conventional water resources.

DESALINATION

Introduction and recent history

Many projects have been proposed for solving the sea-water desalination problem. The greatest in scale and detail were the joint American-Israeli project for a nuclear dual-purpose plant designed in 1964 by Kaiser Engineering and the Catalytic Construction Company, and the Bolsa Island project planned for the Los Angeles vicinity, which was also planned as a nuclear plant producing both water and electricity. Neither project materialized owing to financial problems also, shortages in the United States of America did not become as acute as had been predicted. Today, the largest desalination markets in the world are in the Middle East, although many plants exist in Florida, California, Texas and other parts of the world.

The history of modern desalination technology is characterized by the following landmarks:

Multi-effect submerged tube evaporators, used in power plants and ships since the nineteenth century,

The vapour compression (VC) process, used commercially since the early twentieth century;

The invention by Silver of the multistage flash (MSF) evaporator in the early 1940s,

The foundation of the United States Office of Saline Water (OSW) in the late 1950s,

The incorporation by Loeb and Sorirajan of cellulose acetate membranes in the reverse osmosis (RO) process in the early 1960s

The invention of fluted tubes and the incorporation of these tubes and other revolutionary design concepts in commercial-size, multi-effect distillation (MED) plants in the late 1960s;

The invention by the Du Pont Company of hollow fibre nylon membranes in the early 1970s.

Perhaps the greatest single stimulus in the field of desalination so far has been the Unites States Office of Saline Water. This Office of the Department of the Interior has spent hundreds of millions of dollars during its more than 10 years of existence on investigations of every practicable desalination process. Research projects included the operation of several commercial-size pilot plants. Notable successes, which resulted in fully scaled-up commercial desalination plants, were achieved with MSF (San Diego), MED (Freeport), VC (Roswell, New Mexico) and RO (Wrightsville Beach, North Carolina). The OSW also published numerous research and development progress reports and financed many laboratory experiments.

In 1973, OSW was closed and the United States desalination research budget drastically reduced. The functions of OSW were then taken over by the newly formed Office of Water Research and Technology (OWRT) of the Department of the Interior. Its desalination research and development activities today involve primarily the development of RO for large-scale and, possibly, sea-water desalination (operation of Wrightsville Test Station and the design of the Yuma project), combined MED and MSF sea-water desalination and sewage water reclamation (Orange County project), co-operation with the State of Israel in developing low steam pressure distillation using the horizontal aluminium tube multi-effect (ATME) process (Ashdod dual-purpose project), and some research into the freezing process.

Many other companies and governmental aughorities, such as the UKAEC in the United Kingdom, the French Atomic Energy Commission, Israel, Iran, Kuwait and Saudi Arabia are involved today in research on and the design and operation of desalination plants. The cost of water desalted today by thermal processes, which account for most of the current desalting capacity, varies from $3 to $5 per 1,000 U.S. gallons.

Description of desalination processes

A. Multistage flash distillation

In flash evaporators, a large stream of brine is heated in stages as it flows inside copper alloy tubes. In the last stage, the brine is heated by steam supplied from an external source such as a boiler or a power plant exhaust. The brine is then admitted into flash chambers in which, as pressure is reduced from stage to stage, a small proportion of the brine is evaporated. The vapours pass through demisters and condense on the outside of the copper alloy tubes while, at the same time, they heat the brine. The condensate is collected in the product trays and, while accumulating, becomes the desalted water stream. At the cold end, part or all of the brine is blown down. The rest is recycled while being blended with chemically treated and de-aerated make-up brine.

Today, MSF designs vary with respect to the following aspects:

Flow connexions may be once-through or provide for recycling, the former required high pretreatment costs;

The mechanical and structural design may have either long tubes or cross tubes which are more expensive to install and require more pumping power but are more easily cleaned mechanically and allow for the isolation of leaking tubes and easier maintenance in the long run. Other mechanical and structural design variations include one-storey vessels <u>versus</u> two-storey vessels and cylindrical vessels <u>versus</u> rectangular vessels;

The water treatment system may provide for acid addition (H_2SO_4 or HCl) or polyphosphate or poly-electrolyte addition. The non-acidic means prevent serious corrosion problems but are more costly because they require frequent periodic shutdowns for cleaning with mild acid and are limited in use at 160°-200° F. They also sometimes cause foaming problems.

Construction materials include carbon-steel water boxes either coated with epoxy resins, rubber or fibreglass, or clad with stainless steel or copper alloys; tubes may be of aluminium brass or copper nickel; pump casings, shafts and impellers may be of cast iron, stainless steel, copper, nickel or titanium alloys.

Current trends indicate the use of acid treatment with de-aeration and strict pH control, and the cladding in stainless steel of any steel surface which is in contact with hot acidic brine. The trend is to build huge plants, most of which are dual-purpose and automatically controlled.

Plants using the MSF process account for more than two thirds of the world's total installed desalination capacity, making MSF the most widely accepted large-scale sea-water desalination process. Typical plants erected recently are the 48 (6 modules x 8 each) plant in Lok on Pai, Hong Kong and the 13.5 plant (largest module:9) belonging to Societe Italiana Resine in Sardinia, Italy.

The limiting factors in MSF design are the large volume of huge vacuum-tight vessels needed, the flow per unit width of the flash orifices, and the limited permissible range of top brine temperatures, which cannot be too high (over 250° F) or too low (below 170° F). Serious corrosion problems tend to occur in plants operating five years or more. A plant in Key West, Florida, was closed recently due to high energy costs and serious corrosion problems.

B. Multi-effect distillation

In the MED process, the heating steam is condensed on one side of the first effect tube bundle while a comparable amount of steam is evaporated at slightly lower pressure from the brine flowing on the other side of the tubes. This evaporated steam is then used as the heating steam in the next effect. Thus, the condensate flow in the first effect is multiplied by approximately the total number of effects. Research in MED has recently resulted in some revolutionary design concepts. One partitioned vessel is used instead of separate vessels for each effect. Fluted, instead of plain, tubes are used.

Today, MED evaporators vary in the following respects:

The process flow sheet may have either backward feed with brine preheating or forward feed, the latter being simpler but making for less efficient use of energy;

The mechanical design may have either vertical or horizontal tubes, the latter design being limited in heat fluxes and condensate drain but having a simpler steam flow pattern. The design may also call for separate vessels or one partitioned vessel, fluted tubes or plain tubes which have a much lower heat transfer co-efficient but less severe scaling problems and downflow or upflow, which requires fewer pumps;

The construction materials may provide for either CuNi, AlBr, titanium, or aluminium tubes, the last being the cheapest but limited to temperatures up to 160° F. Other construction material problems are the same as for MSF and vary according to temperatures and water treatment methods;

The water treatment methods are similar to those for MSF, except that this process allows for lower maximum brine or steam temperatures and, thus, for the use of non-acidizing water treatment system with less serious corrosion problems. A seeding process for scale prevention is also being studied.

The MED process ranks second to the MSF process with respect to installed capacity and technological acceptance. Modern plants use backward feed with a flash-like preheating system and aluminium brass double fluted tubes. Other advanced concepts are being developed now in France, Israel and the United Kingdom which utilize low-cost horizontal aluminium tubes and perhaps low-temperature steam. Typical MED plants are the Gibralter 0.4 plant with AlBr fluted tubes, the St. Croix 2.2 plant with AlBr fluted tubes, the Eilat 1 plant with aluminium horizontal tubes, and the Shevchenko 13.5 plant.

The most serious limiting factors in MED are the need to preserve the high heat transfer coefficients of new fluted tubes which tend to deteriorate due to scaling. In horizontal aluminium plants, the problem is to obtain sufficiently high coefficients. Other problems are similar to those of MSF.

C. Vapour compression

In this process, feed water is introduced into a vessel under vacuum conditions. The water vapour is compressed by a mechanical compressor to one side of the tube bundle, where it condenses and gives up its latent heat to the vapour extracted from the brine feed. The latent heat of evaporation is consequently supplied by the condensing vapour. This process does not require a cooling water supply.

Vapour compression plants vary in the following respects:

Process conditions: There are moderate vacuum plants and extreme vacuum plants which require less feed water pretreatment and preheating and have fewer corrosion problems. However, extreme vacuum requires higher volumetric capacities of the compressor, tighter vacuum vessels, and leak-proof shaft seals. The source of energy may be an electrical or diesel motor. The latter requires more maintenance but also allows for the use of its cooling water for feed preheating and is, therefore, practical for remote sites with no electricity supply.

The mechanical design may call for either centrifugal compressors or roots-type compressors, the former being more difficult to design and less efficient but also requiring fewer shaft bearings and seals; they are, thus, more reliable. Other design variations include horizontal *versus* vertical tubes, natural circulation *versus* forced circulation which has higher heat transfer coefficients but requires additional pumps, vapours in the tube side *versus* vapours in the shell side, and preheaters of plate type *versus* preheaters of shell and tube type.

The construction materials may provide for vapour compressor blades of titanium or inconel and for tubes made of aluminium *versus* AlBr or CuNi.

The water treatment methods may require no treatment at all, polyphosphate addition or acid addition, depending on the temperatures (vacuum levels).

The VC process still requires verification of its reliability. Some modern plants proved to be very reliable in the initial years of operation and needed a minimum of maintenance and fuel. Modern plants use extreme vacuum conditions, forced circulation, minimum water treatment, and employ centrifugal compressors. One modern plant with a capacity of 0.16, built by Israel Desalination Engineers, is located in the Canary Islands. The maximum capacity of VC per unit is 0.2-0.3. Many such plants operate in Israel, the Persian Gulf area and the Canary Islands.

The most serious limiting factors of this process are found in the volumetric capacity, the efficiency, the compression ratio, and the reliability of the compressors which restrict the capacity per unit.

D. Reverse osmosis

In the reverse osmosis process, the treated feed water is compressed and passes under high pressure (400-800 psi) through a semi-permeable plastic membrane which rejects 90-95 per cent of the salts.

Reverse osmosis plants differ in the following respects:

The process parameters of maximum concentration ratio or extraction ratio vary depending on the salinity of the feed water,

The pressure level may range from 400 psi to 1,500 psi for sea-water RO plants;

There may be one stage or two stages for sea water,

The mechanical design may call for one of the three types of membrane configuration commercially available today:

(a) Tubular modules which require minimum pretreatment and are easily cleaned but are not efficiently packed give large module volumes per unit area of membrane,

(b) Spirally wound membranes which are better packed need more pretreatment than tubular modules

(c) Hollow fibre nylon membranes produced by Du Pont or those made of cellulose triacetate by Dow are packed best but have the lowest fluxes and are most sensitive to feed-water turbidity and other types of contamination

Pretreatment, the extent of which depends on the quality of the feed water. Pretreatment usually requires at least two stages of filtering and softening, one stage of ion exchange or other means to remove iron and manganese traces, pH control by addition of acid, and chlorination to prevent biological attacks on the membranes.

Present commercial RO plants desalt brackish water containing 2,500-6,000 ppm TDS. Full-scale field testing with various feed waters is now in progress. Hundreds of plants have been installed in the past five years. Some modules are used to treat tap water in hospitals and electronics plants. This process is considered to be the most promising because of its extremely low energy requirements and its simplicity. The OWRT is involved in the feasibility study of a large RO plant at Yuma. Mekoroth, the Israel Water Company, after several years of testing RO modules in Eilat, decided to build a 0.5 plant for desalting brackish water in the Israeli desert. Du Pont is developing its PERMASEP module for sea-water desalination, while other manufacturers are doing so for their own modules. A large, typical plant is the Ocean Reef, Florida 0.6 plant. One limiting factor in the RO process is the rejection ratio which today is close to 95 per cent of the salts per stage. Another restricting factor is the fluxes which are low. Manufacturers of RO modules today (including Du Pont, Dow, UOP and Ajax) guarantee not more than 20-30 per cent of flux deterioration at the end of the three-year lifetime of their membranes. Membranes, especially those of cellulose acetate, are also sensitive to biological attack and to traces of metal which may be found in the feed water. The short expected lifetime of membranes, the low fluxes and the poor salt rejection ratio are the most detrimental factors which research must aim at improving.

E. Solar distillation

In this process, the water is fed into a pool which is covered with plastic or glass. Due to solar radiation, part of the brine evaporates and condenses on the inner side of the cover while the heat is removed by the surrounding air.

This process is employed to a very limited extent in remote locations. It requires a minimum of moving parts and almost no energy. The Governments of Mexico and Chile plan to use this process in some locations.

The most serious limiting factors here are the water production per unit area of the pool, which is 2-4 litres/m^2/day of the pool area, and the high investment per unit of water production ($60/$m^3$/year).

Choice of a desalination process

The selection of a deslination process depends upon factors such as operating experience and technological acceptance, capacity required, salinity of feed water, reliability required and access to skilled maintenance personnel, specific fuel demand and type of energy supply available and specific investment per unit capacity. Tables 1, 2 and 3 summarize these considerations.

Dual-purpose plants

Thermal distillation processes are scaled-up, in contrast with vapour compression, and can desalt sea water, as contrasted to reverse osmosis and electrodialysis, but they need two to 10 times as much energy per unit of water production. On the other hand, these processes use "low-grade" thermal energy. Indeed, they cannot use steam at higher than 260° F saturation temperature due to sulfate scaling limits. The energy required to produce steam varies only slightly with its pressure. Therefore, it is possible to produce high-pressure steam, to let it produce electricity while it expands (from 2,000 psi in a fossil plant and ~1,000 psi in a nuclear plant), and to use it as 20-30 psi or even 5 psi for desalination. A normal condensing power plant condenses its steam by cooling water at 1.5"-3.5" HgAbs (0.7-1.7 psi). When coupled to a desalination plant, it has to condense the steam at a higher pressure and a portion of its power is lost.

The cost of energy contained in one ton of steam increases from zero at 1.5"-3.5" HgAbs to a maximum cost of $2x10^6 BTU ≈$4.4/tons of steam at maximum pressures (1,000-2,000 psi). This corresponds to a primary fuel cost of $80/ton. Since the energy requirements of thermal desalting processes today are twice as high as those of sea-water RO plants, they will compete with the latter only when the relative energy cost becomes one half of the primary energy. This can be achieved at a temperature of about 250°-260° F.

Summary and future prospects

Progress in desalination technology in the past decade was less than hoped for but more than had been expected. The developments of MED with double fluted vertical tubes or horizontal aluminium tubes and the breakthrough in RO were big steps forward. The cost (C_W) of product water, excluding site development, overhead and pretreatment, is comprised of energy expenses and expenses proportional to the specific investment, which usually decreases with specific energy demand. Thermal processes may be optimized so as to make these expenses approximately equal by optimizing the temperature drop per effect in MED and the vacuum level (pressure) in VC.

The over-all result is that the product water cost is a geometric mean of the energy cost (C_E) and the investment cost (C_C) (construction material and annual fixed charges), multiplied by some factor which depends on the specific process and units: $C_W = 2\sqrt{C_E \cdot C_C}$. Otherwise stated: the water cost is approximately proportional to the optimal specific energy cost per unit water production. In a thermal process which produces 10 lb of product water per 1 lb of steam, this is ≈ 10 lb/1,000 BTU ≈ 10 tons of water/ton of steam. The limit to the cost of 1 lb of water is thus 20 per cent of the cost of 1,000 BTU, or the cost of 1 m3 of water is 20 per cent of the cost of 1 ton of steam. Adding some allowance for operation and maintenance, it is concluded that the limit to the cost of 1 m^3 of water cannot be lower than 20-30 per cent of the cost of 1 ton of steam. The cost of steam in a dual-purpose plant at the exhaust of a back pressure turbine may be 30-50 per cent of the cost of primary steam. Thus, the cost of 1 m^3 of desalted water in a dual-purpose plant may be as low as 15 per cent of the cost of the fuel required to produce 1 ton of steam.

In the RO process, the greater part of the water cost is due to the high price, low productivity, and short life of the membrane. Therefore, developments in this process might be expected to be along the lines of reducing investment costs by increasing pressures and related fluxes. There will also be research into cheap membranes with high fluxes and high salt rejection.

Table 1. Present-day desalination installations

	Flash evaporator	Multi-effect evaporator	Vapour compression	Reverse osmosis	Electro-dialysis	Solar distillation
Operating experience	Has been used for decades; capacity increased largely in the past 10 years.	Has been used for decades in the form of a submerged tube evaporator; present concepts evolved in the past 5-10 years.	Has been used for decades; modern compressors improve performance.	Number of plants increased largely in the past 3 years.	Used wherever feed water quality permits.	Used in very remote locations (Australia, Mexico, Chile).
Capacity per unit	Largest single unit: 9 mgd	Largest single unit: 2.2 mgd	0.2 mgd	1.4 mgd 0.015 mgd/module	5 mgd	
Salinity	Sea water	Sea water	Sea water	Brackish water up to 2 500-6 000 TDS	Brackish water up to 2 000 TDS	Sea and brackish water
Reliability	Reliable due to its simplicity. However, production deteriorates with time as a result of scale deposits and corrosion problems. Plants that use acid need water box cladding and pH control.	High-temperature plants: the same as MSF. Low-temperature plants: may use cheaper materials (aluminium tubes) and a cheaper pretreatment method.	Plants recently installed are very reliable.	Process may be very reliable due to its simplicity. Its reliability is subject to field tests with respect to membrane lifetime, salt rejection properties, flux, and response to feed water quality.		

Table 2: Specific energy demand and investment a/

	Unit	Multistage flash	Multi-effect distillation	Vapour compression	Reverse osmosis b/	Solar distillation
Specific output	(lb product water/ 1 000 BTU)	8-12	8-12	20	110	
Specific energy demand:						
Low-grade heat	(Kcal/m^3)	55 000	55 000			
Heat equivalent of electric power c/	(Kcal/m^3)	5 200	3 900	31 000	5 200	
Total heat requirement	(Kcal/1 000 U.S. gal.)	227 500	222 600	117 200	19 700	
Fuel consumption d/	(kg fuel/m^3	6	5.8	3-4	0.5	
	(kg fuel/1 000 U.S. gal.)	22.8	22.1	11.3	1.8	
Specific investment:						
including site development and energy source	(\$/m^3/year)	2-3	2-3	3-5	0.8-1.2	30-60
	(\$/1 000 U.S. gal. day)	3-4.5	3-4.5	4-7	1.1-1.7	40-80

Note: 1 m^3 of water = 265 U.S. gallons.

a/ For the largest module existing in 1975.

b/ For brackish water only.

c/ Assuming a power generation thermal efficiency of 33 per cent.

d/ Based upon bunker fuel oil.

Table 3. Water cost

	Unit	Multistage flash	Multi-effect distillation	Vapour compression	Reverse osmosis a/	Solar distillation
Energy at \$80/ton of fuel	\$/m^3	0.48	0.46	0.26	0.04	
	\$/1 000 U.S. gal.	1.81	1.74	1.06	0.15	
Fixed charges at 10 per cent/ year and capacity factor 0.8	\$/m^3	0.32	0.32	0.50	0.12	5.0
	\$/1 000 U.S. gal.	1.20	1.20	1.90	0.45	
Operation and maintenance staff	\$/m^3	0.05	0.05	0.12	0.10	
	\$/1 000 U.S. gal.	0.19	0.19	0.45	0.38	
Membrane replacement or chemical pretreatment	\$/m^3	0.15	0.15	0.15	0.18	
	\$/1 000 U.S. gal.	0.57	0.57	0.57	0.68	
Total	\$/m^3	1.00	0.98	1.05	0.44	5.0
		3.78	3.70	3.98	1.66	

Note: 1 m^3 of water = 265 U.S. gallons.

a/ Brackish water.

Another desirable breakthrough would be some kind of ion exchanger that could be regenerated by cheap chemicals. Future advances in desalination technology will probably also be seen in the use of dual-purpose plants to reduce energy costs. Larger plants will reduce site development costs, overhead, and operation costs per unit of water. There will also be research into cheap corrosion resistant materials and high heat transfer coefficients for distillation plants.

RENOVATION OF WASTE WATER

Introduction

Water is used as a means of transporting pollutants. In water-short areas, however, it is uneconomical to throw away 999 tons of water to dispose of 1 ton of pollutants. This is the basic motivation for waste-water reclamation - the preservation and recycling of the water used to transport pollutants.

Water has always been used and reused by man. Cities draw water from surface streams and lakes and discharge wastes into the same streams and lakes, which in turn become the water supply for downstream users. In the past, dilution and natural purification were usually sufficient to allow such a system to be satisfactory. In recent years, however, population and industrial growth have made it evident that waste water must be treated before its discharge into bodies of fresh water in order to maintain their quality.

To ensure the exploitation of waste-water potential, it is necessary to develop an integrated approach to the disposal of waste water to prevent ecological pollution while allowing for the possibility of reuse. This requires the adaptation of techniques and methodology which will integrate treatment, disposal and reuse processes.

In Israel where all the known fresh-water resources have been developed, the new decade will be a transition period in which large-scale waste-water reclamation projects will be initiated and will increase in proportion to domestic consumption. The reclaimed water will then become the main additional source of water, providing a substitute for water drawn from agricultural consumption in order to meet domestic demand. The water management will have to be adjusted for the absorption of water of varying quality within the consumption balance.

Historical background

The use of sewage effluents began long before today's complex technology of treatment systems was developed. Waste-water application to the land was recorded by the ancient Greeks in Athens. The use of effluents for farmland irrigation was first reported in sixteenth century Germany. From there the concept of the application of sewage effluents to farmland spread throughout continental Europe and England, and then to South Africa, Australia and Mexico, as those areas were colonized by Europeans.

The use of sewage effluents for irrigation in the United States began in the late nineteenth century. Ground-water recharge projects started in the early twentieth century in the semi-arid regions of California and Utah. With the passing of time, the crude sewage farms of the early 1900s have been replaced for the most part by managed farms on which treated waste water is used for growing crops, for landscape irrigation, and for ground-water recharge.

In Israel waste-water renovation is relatively new. In 1956 a plan was drawn up for the reuse of effluents as an additional water resource. This policy has been reflected in the increasing utilization of this resource.

Table 4 summarizes the results of a survey carried out in 1967 on waste-water reuse in Israel. It will be noted that the utilization rate of waste water produced in rural communities is higher than that produced in urban centres. This situation will be substantially changed during the next decade when plans for the reuse of waste water originating in urban areas, especially the Dan (Tel Aviv) region and the Kishon (Haifa) area, are expected to be implemented.

Table 4. Reuse of waste water in Israel

Source of waste water	Amount produced (m^3/day)	Amount reused (m^3/day)	Percentage reused on daily basis	Amount reused (millions of m^3/yr)
Urban areas	343,000	79,000	23	20.6
Rural settlements	64,000	42,000	65	8.5
Total	407,000	121,000	30	29.1

Technology

The challenge of reclamation projects is not so much to develop advanced treatment technologies, since many already exist; it is rather to choose and adapt these existing techniques to ensure that suitable effluents are provided to meet specific demands for the required quality and at minimum cost. Sewage treatment must be more advanced for reclamation than for disposal purposes. In recent years, new technologies have been introduced and found to improve the quality of biologically treated effluent. These include chemical oxidation, coagulation, floatation, absorption, ion exchange, ultra-filtration. While these processes are efficient, they present problems of monitoring, control and reliability. These difficulties stem from the fact that the techniques were developed to overcome specific problems and not to reach target qualities.

The selection of the proper sequence of treatment processes requires:

A characterization of the quality of the waste water;

A definition of the target quality required;

The formulation of alternative treatment processes;

An economic evaluation.

The possible types of use for reclaimed waste water are:

Restricted irrigation (for field crops);

Unrestricted irrigation and recreation;

Industrial use;

Artificial recharge of aquifer (for indirect supply);

Direct water supply.

To reach the quality requirements for the above uses, the following sequences of treatment are usually practised:

(a) For restricted agricultural irrigation use, the basic methods of secondary treatment, biological flocculation and oxidation are employed. Under Israeli conditions, the activated sludge process and biological filtration (trickling filter) are not extensively used. More common are the stabilization ponds in which the waste water, which may or may not have received some preliminary treatment, is retained in a pond or lagoon for a period of up to several weeks. These ponds have the advantage of providing a fairly high degree of treatment at low cost with little need for equipment or skilled operators. As a consequence, these ponds are more suitable for small communities where land is not costly and odour nuisances are more manageable.

In large communities in Israel, the use of aerated lagoons followed by polishing ponds (secondary sedimentation) is becoming an established practice. The effluent leaving the aerated lagoons has a relatively high concentration of suspended solids (200 mg/l) which is reduced to about 30 mg/l in the polishing ponds. This process is not widely used in other parts of the world. However, the results obtained to date from the first plants in Israel are promising;

(b) For unrestricted agricultural use it is essential to remove nitrogen from the effluent or to nitrificate it by continuing the process beyond the biological treatment. For this use disinfection is also required. A high BOD removal is necessary. In this context, the incorporation of nitrification-denitrification within the biological treatment has been proposed and is now being tested;

(c) For industrial cooling use, in addition to the biological treatment, chemical - usually lime - treatment is required to reduce phosphate, alkali, ammonia and detergent;

(d) For ground-water recharge, nitrogen removal and chemical coagulation are compulsory beyond the biological treatment. The effluent quality should approach that of potable water. Additional quality improvement is achieved during passage through the soil profile. The renovated water should be chlorinated before distribution;

(e) For direct use, the specified drinking water quality is required. Furthermore, in the treatment process, potential polluting elements not specifically detailed in the standards are also removed. This could be achieved by the use of a chemical coagulation treatment with active carbon filtration and disinfection.

Future directions

Some new treatment approaches are currently being considered.

Among the treatment processes discussed, the nitrification-denitrification process is essential if the effluent is directed to type-b use above. New developments have shown that this process can be incorporated into the existing biological treatment at relatively low additional cost. It is, therefore, worth while to encourage its further development.

The possibility of advancing the chemical treatment to the biological treatment stage is being investigated. If proven successful this will lower the cost of effluent purification for high-quality use (type-c) by about 25 per cent.

One of the key issues in waste-water treatment is the problem of sludge treatment and disposal, since this influences the economics of waste water reclamation. As the reclamation processes become more widespread, the problem of sludge handling becomes more acute, because of the larger quantities involved.

Economics

The total cost estimates of treatment are usually based on the following indicators: biological load as BOD, surface detention time and sludge handling. A cost estimate for a plant in Israel with a capacity of 20,000 m^3/day is presented in table 5.

Table 5. Summary of costs for a 20,000 m^3/day treatment plant a/

(January 1976 prices)

	Type of use	Investments b/ (millions of Israeli pounds)	Annual costs (investment plus O and M) (Israeli pounds per cubic metre)
a.	Restricted agricultural use	5.2-6.1	0.29-0.35
b.	Unrestricted agricultural use	19.7-24.1	0.89-1.07
c.	Industrial use	26.6-36.3	1.19-1.65
d.	Ground-water recharge	20.0-29.8	0.98-1.39
e.	Direct use	44.9-56.3	1.83-2.37

a/ Israeli pounds are converted to dollars at a rate of approximately £I 10 = $1.

b/ Excluding land cost.

It is worth while to note that the cost of basic treatment (usually exceeding the level of type-a use) cannot be justifiably charged directly to a user of reclaimed water. Thus, the water charges should, in this case, include any additional treatment plus the regular conveyance and storage charges. Furthermore, the conventional sludge removal methods are of environmental concern. Also, the introduction of chemical treatment produces chemical sludges that are difficult to dispose of. Consideration should be given to the possibilities of sludge reuse and regeneration.

The reuse of reclaimed waste water for irrigation requires some seasonal storage facilities. Storage of reclaimed waste water, unlike that of conventional water, may be a source of environmental deterioration.

Before reclamation can be widely practised, there are a few questions to be resolved. These include the problems of salt and organic accumulation and the effect of bacteria and viruses on the environment - soil, ground water, vegetation and animal life. Also, the subjects of conveyance and storage of effluents are not well documented and further research is needed before large-scale reclamation projects can be carried out.

Dan region reclamation project

Undoubtedly the most ambitious project for waste-water reuse in Israel is that concerning the Dan region, the metropolitan area of Tel Aviv. The Dan region has the highest concentration of the nation's population. In 1985 the population of the region is projected to reach 1.3 million people, who will consume 144 million m^3/yr of water and produce 115 million m^3/yr of waste water. This waste water was considered a viable national water resource as far back as the 1950s and methods for its reclamation which combine both environmental enhancement and augmentation of water supply have been sought.

The combined project for purification and reclamation, as formulated in the 1960s, foresaw a gradual development of a project for the collection and conveyance of the sewage to the Sorek dunes. After purification in lagoons, the effluent was to be recharged by spreading basins into the local aquifer; the renovated water, after being blended with fresh water, would then be pumped and delivered for general use, including drinking. The original waste-water reclamation project for the Dan region was formulated in 1962. Since then some conceptual changes and design modifications have been made. One such change resulted from the increased alternative value of land in the region, thus substantially increasing the cost of the original project. Another resulted from the stricter standards which were formulated for the quality of renovated water, making the originally proposed treatment unsatisfactory.

At present the somewhat modified original project is operational, treating some 15 million m^3/yr. Under consideration for the second stage of the Dan region project are two alternative designs. They differ in the uses planned for the water.

The first is a modified (lower rate) biological treatment plant (MBT) with combined BOD and nitrogen removal, to produce effluents for unrestricted use in agriculture (type-b use). The MBT comprises treatment of the screened, degritted sewage in a single-stage, internally recirculated reactor, wherein removal of carbonaceous BOD could take place concurrently with successive oxidation of nitrogenous compounds to nitrates and reduction of the nitrogent gas discharged to the atmosphere.

The second is a conventional (activated sludge) biological treatment plant with BOD removal without full nitrification to produce effluents for restricted agricultural use (type-a).

Either effluent has to be stored during the rainy season, when agricultural consumption is at its lowest level. As in the original plan, underground seasonal storage in the local aquifer under hydraulic and hydrologic control is considered for type-b quality. This method, however, is not practicable for type-a quality effluents, mainly because of the presence of ammonia and nitrates.

The investment, at 1976 prices, for the first alternative is estimated to be as follows:

	Millions of Israeli pounds
Treatment plant and additional treatment for 120 million m^3/yr	464
Recharge facilities	37
Pumping system	78
Regional network for drinking supply	45
Network within the settlements	39
Total	663

Construction time is estimated to be 4.5 years.

The total annual cost is estimated as £I 1.34/m^3 of which £I 0.84 is for treatment, £I 0.38 for recharge and pumping and £I 0.12 for distribution.

For the second alternative it is assumed that the total output of the Dan regional effluents can be utilized in the arid south of Israel as part of the existing agricultural quotas for restricted use only. This plan, because of the lower quality of the effluents, also requires a new separate conveyance network consisting of a pipeline 50 kilometres long and 70 inches in diameter, one pumping station, above-ground storage facilities and a distribution system to the irrigation fields. Separate regional and individual supply networks will also be needed to bring drinking water to 40 settlements. Some engineering and environmental problems concerning storage and conveyance of such effluents are still to be resolved.

The estimated investment, at 1976 prices, in this project are:

	Millions of Israeli pounds
Treatment and additional treatment for 110 million m^3/year	426
Conveyance network	246
Above-ground storage	40
Regional networks for drinking supply	45
Networks within the settlements	39
Total	796

Construction time is estimated to be 5.5 years.

The annual cost is estimated to be £I 1.67/m^3 of which £I 0.85 is for treatment and £I 0.82 for water conveyance and distribution.

The Dan region reclamation project is recognized as an ambitious and costly undertaking, but its implementation is vital to Israeli development. To ensure successful operation of this complex project, an extensive programme of research, including jar tests, berch-scales and pilot plants, is being carried out. A monitoring system for the quality of the reclaimed water is envisaged during operation of the plant.

Concluding remarks

Water reclamation and reuse are at present the most economical solution to water shortages. Adequate precautions, however, should be taken in the design and operation of these systems to protect the well-being of the community. This presents no insurmountable technical problems, although more knowledge will lead to more efficient and more reliable solutions.

Water supply, waste disposal and water reuse are inextricably interrelated activities, usually affecting more than one population group and several geographical areas. Where applicable, the establishment of regional multipurpose authorities having control of both water resources and water treatment may be the best solution to the management of these activities.

In principle, water uses should be graded according to the degree of purity required, and the available water sources should be allocated in such a way that water of high quality is not used for a purpose that can tolerate a lesser degree of purity.

ARTIFICIAL RAINFALL STIMULATION

Background

Man's attempts at rain-making have progressed from a long history of strange rituals through pseudo-scientific experiments to the present stage of concentrated scientific effort. This effort has led to a comprehensive understanding of the phenomena of cloud physics and the processes leading to precipitation. The progress made supports the thesis that artificial rain stimulation is a feasible method of augmenting rainfall. Research has yielded techniques to determine how and when to intervene in the natural atmospheric phenomena to increase precipitation. Progress has been hampered, however, by the overwhelming complexity of atmospheric phenomena and their variability in time and space. The assessment of the effects of any intervention is currently possible only by the use of statistical methods. One need only consider the reliability of weather forecasts to appreciate the difficulty of analysing weather modification experiments.

The first step in the scientific effort at rainfall augmentation has been to understand the physics of precipitation formation. The degree to which the effects of artificial intervention in natural processes can be controlled so that they act with or against those natural processes depends on our precise knowledge of those natural mechanisms which we wish to modify and an appreciation of the extent to which conditions for such intervention exist.

Rain formation processes

The process which creates rain is the growth or conversion of very small cloud droplets to much larger precipitation elements. A typical cloud element is about 10μ in diameter and a typical raindrop about one millimetre. About one million cloud droplets constitute one raindrop. The embryo of a precipitation particle is a cloud particle of about 100μ in diameter. The existence of such elements in sufficient concentrations in the cloud is a necessary condition for an efficient rain-forming mechanism. The two processes which can operate to cause this growth are the "all water" process and the "cold" process. The all water, or condensation-collision-coalescence, mechanism is a rapid process of condensation of cloud drops that subsequently collide and coalesce to form larger drops. The cold process results from the initial formation of ice crystals followed by a combined growth process from the vapour and riming. Temperature, humidity, aerosol content, cloud droplet size distribution and atmospheric and geographical conditions are the major factors that determine which precipitation-forming process will dominate. Irrespective of which process dominates, the clouds must attain a minimum vertical thickness to provide proper conditions for the time-dependent process of rain formation to become fully operative. The recognition of an opportunity for precipitation augmentation, on the one hand, and the decision to apply a given technique, on the other, depend on a comprehensive understanding of the nature of the clouds in question and of the degree of efficiency of the precipitation mechanisms to be applied.

Techniques

The rationale for the various techniques of seeding clouds to stimulate additional rain rests on the recognition that conditions may exist in the clouds in which a measured degree of artificial intervention can bring about known beneficial changes, and that ways and means are in existence for such artificial intervention. While these assertions are generally agreed upon, there are questions whether these specific conditions are properly defined and whether modification techniques have been applied in such a way as to produce the expected results. Nearly all the experiments conducted to date to augment precipitation involved the seeding of clouds with particles. The seeding was done to affect the clouds in one of the following ways:

(a) By enhancing the condensation-collision-coalescence (all-water) process;

(b) By initiating or increasing the growth of ice precipitation particles (cold process);

(c) By changing the dynamic properties of the clouds.

The first technique is very limited in its applicability because of the large material need and the severe requirements for the existence of suitable specific conditions. It can be effected either by water spray or by the use of hydroscopic materials. Both materials create a severe logistics problem due to the need for large quantities for a large-scale effect. Furthermore, this technique requires conditions in a cloud which themselves render natural precipitation mechanisms quite efficient.

The second technique involves adding the correct amount of seed agent (usually AgI) at the right time to suitable clouds. This can be expected to produce additional precipitation either by initiating precipitation in clouds that otherwise would not have precipitated due to a lack of ice crystals, or by increasing the precipitation efficiency in already precipitating clouds, mainly by the introduction of ice nuclei in warmer parts of the cloud where they would not naturally form. The magnitude of the effect depends mainly on the microstructure and external dimensions of the clouds. It should be noted that if applied incorrectly this technique can decrease precipitation.

The third technique is rainfall augmentation by massive seeding aimed at affecting the dynamic properties of cumulus clouds. Cloud dynamics - the strength, size and duration of vertical air currents - have a major effect on cumulus precipitation. Generally, the larger the cloud the greater the chance that one of the mechanisms will progress to the stage at which the cloud precipitates. Techniques aimed at the "explosion" and merger of clouds have successfully augmentated precipitation.

Two questions arise, especially concerning the third technique, but in fact connected with the whole topic of rainfall augmentation.

Can multiple cloud dynamic seeding lead to rainfall increases over sizable areas without adverse side effects?

Can such effects be produced in a wider variety of climatic regions?

A partial answer to the first question is that rainfall is often redistributed, especially by the third technique, but that redistribution can be planned to be beneficial. The answer to the second question is that the suitability of any technique is dependent on the specific cloud type and surrounding atmospheric conditions. Further research may possibly define how to augment rainfall in a wider variety of circumstances.

A review of progress: assessment of results obtained in selected large-scale experiments

Most of the progress in augmentation has been based on large-scale, well designed experiments which either can provide physical and meteorological data which support the statistical analyses and show that observed effects can be related to a cause-and-effect relationship between seeding and precipitation, or are based on underlying physical concepts which are widely accepted but which require further testing to become fully instructive and of practical value.

These well designed experiments unfortunately constitute only a minority of the experiments undertaken. They include Project Whitetop, conducted in the central United States during 1960-1964; the Climax experiments in the Rocky Mountains of the United States during 1960-1965; the Australian cloud-seeding experiment during 1964-1967; the Florida single and multiple dynamic cloud-seeding experiments of 1965, 1968, 1970; and the Israeli rain stimulation experiments of 1961-1967 and 1969-1975.

It was found that, if properly executed, the seeding by AgI of cooler stratiform and cumulus clouds can increase rainfall. The actual increases varied between 10 and 25 per cent. Improper seeding, or over-seeding, however, can cause a decrease in rainfall. Seeding during either too cold or too warm conditions are among the reasons for negative results. The seeding can be effected either by aircraft or by ground-based burners. It was found that both the condensation-collision-coalescence and the cold process cause precipitation; whichever dominates depends on a variety of local conditions. The major reason that some cooler clouds respond so well to seeding is that, although they have a high water content, they lack an ice crystal multiplication process, a deficiency which the addition of solid precipitation particles effectively overcomes. Seeding can be effective for quite a number of days a year. It can either cause precipitation in clouds which otherwise would not have precipitated or make the already existing precipitation process more efficient.

Dynamic cloud seeding can produce much more drastic effects; increases by factors of 3 and 10 were recorded. The effects can be achieved, however, under more limited conditions and also can reduce precipitation in areas where the clouds would normally precipitate.

Concluding remarks

Most cloud seeding experiments designed to stimulate rainfall are outside the category of experiments in a controlled environment. Their evaluation has relied on statistical techniques and has often been inconclusive. It is, therefore, still impossible to evaluate the costs and benefits of the precipitation produced. A critical question remains unanswered: is the added rainfall beneficial, i.e., does it add to the water yield and, therefore, the water potential?

It is possible to say that the progress made and the prospects of economic advantage justify intensified activities for furthering understanding of cloud physics and developing the methods of intervening in the rain-producing processes. There have been highly significant positive results under a variety of cloud conditions. They have laid a firm basis for the application of some of these experimental techniques within the framework of water-producing, cloud-seeding projects. One such carefully monitored operational programme is the use of the combination of ground-based and airborne generators to stimulate rainfall in the Lake Tiberias (Israel) catchment basin.

EVAPORATION REDUCTION

Introduction

Various methods and techniques for reducing evaporation have been considered since the beginning of this century. The spreading of oils in reservoirs to form a multimolecular layer for reducing evaporation was first reported in 1941. Extensive research on this subject, however, began only two or three decades ago.

In principle, the various evaporation reduction methods fall into two main groups:

(a) Formation of a monomolecular layer on the water surface which reduces evaporation by forming a physical barrier to the flow of vapour from the water surface to the air;

(b) Covering the water with insulating materials which reflect or filter some of the radiation reaching the water, thus forming an energy barrier which reduces the evaporation.

Use of monomolecular layers

For these methods to give good results, the monomolecular layer on the water surface must be maintained under various wind and wave conditions. Different means for spreading the monomolecular materials have been tried, including boats, aircraft and pipelines with portable or fixed sprayers along the shore. Irrespective of the spreading technique, the material used may be in crystal or powder form, in suspension in a suitable liquid, or in melted form. Spreading from the air is particularly suited to large areas where advantage may be taken of wind velocity.

Two recent series of large-scale experiments of this method of spreading layers were conducted in 1965/66 at Lake Hefner in Oklahoma and in 1969/70 at the Kishon reservoir in Israel. The experiment in Lake Hefner was conducted over an area of 10 km^2. The spraying was effected by fixed sprayers in the lake, not far from the shore. The experiment resulted in an average of only about 20 per cent coverage of the lake surface by the monomolecular layer. In the second experiment in the Kishon reservoir, the suspension was spread by floating sprayers which allowed a smaller discharge and a finer spray from each sprayer, resulting in an average of 80 per cent coverage of the target area (about 64 per cent of the entire lake).

Inverse relationships between area coverage and wind velocity and between wind velocity and the quantity of the material required per running metre were observed.

In the Kishon reservoir experiment a 22 per cent reduction in evaporation was observed at the beginning of the season. This was decreased and stabilized at about 10 per cent during the course of the season. This recorded decrease in the evaporation reduction has other causes which are coincidental and unrelated to the nature of the experiment. It is clear, however, that the accumulation of heat in the water reduces the real efficiency of the method significantly.

Cost estimates for each cubic metre saved by this method range from as low as $2.6 (reported in 1962) to as high as $25 (reported in 1967). The cost estimate for the Kishon experiment (1970) is at the higher end of this range. This cost estimate indicates that even with further technical improvements, this method will not become economically justifiable.

Use of radiation-reflecting materials

The use of radiation-reflecting materials has the advantage of reducing the net quantity of energy reaching the water body, although with insulated radiation-reflecting materials, a relative increase in water temperature was observed during the morning.

In the first experiments with floating microspheres, it was found that the materials used could promote evaporation because of their rotation and could, therefore, be drifted; winds and waves caused the particles to pile up. Recent experiments have shown that the resistance of the floating particles to dispersion depends upon their size and shape. In Italy it was found that increasing the diameter of the particles increased the rate of evaporation reduction; in Chile it was found that expanded polystyrene spheres reduced the evaporation by 40 per cent. It was also found that several types of floating plastic rafts could be very effective in controlling evaporation losses. Experiments with floating solid and granular materials (e.g., perlite ore) showed that these can provide practical means of reducing evaporation from open water surfaces. In one experiment a reduction of 35 per cent of the evaporation rate was achieved by covering about 50 per cent of the water surface with styrofoam panels.

The use of radiation-reflecting layers to reduce evaporation can interfere with the passage of oxygen into the water body. This has been observed in previous studies and additional research is required. Because of stability problems this method is not yet applicable to medium- and large-size reservoirs. Broad use of this technique will be possible only after a significant technical breakthrough makes it possible to spread particles in reservoirs to form a continuous cover which is stable under various wind and wave conditions.

Concluding remarks

At the current stage, none of the various methods for reducing evaporation has reached the point of practical application, except in some marginal cases. Additional technical research is needed to produce a technique which is feasible from an engineering point of view and at the same time economically justifiable.

CONCLUSION

This paper has surveyed some of the major advances in the development of non-conventional water resources. The development of most of these depends on techniques which are either not yet economically justifiable in most areas (desalination and sewage reclamation, for example) or not yet feasible in terms of engineering (cloud seeding and evaporation reduction, for example).

Still, the increase in demand for water beyond the supply capacity of conventional water resources will, by necessity, impel the development of projects that will be feasible from an engineering point of view. At the same time, technological progress and breakthroughs will make certain developmental techniques economically justifiable. These techniques will, in turn, become conventional, and still other, more exotic sources of supply will then come to be termed "non-conventional water resources".