Chapter 1

Research and Development Policy

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1.1 Introduction

Wastewater is considered a sanitary and health issue dealt with normally by local and health authorities. The degree of treatment is usually dictated by these authorities who lay down the criteria for treatment and discharge of effluents to water bodies, according to quality standards and the diluting effect of the estuaries and other recipient water bodies. Current standards in Israel are for a biological treatment which reduces the *BOD* level to 20 mg l^{-1} and *TSS* to 30 mg l^{-1}. In addition, the local authorities are required to dispose of the effluents in a manner not harmful to the recipient water body. Treating wastewater to this standard is very costly and the Israeli Government has to assist local governments by providing grants and soft loans amounting to more than US$150 million yr^{-1}. In Israel the situation is further complicated because, due to water scarcity, wastewater is highly regarded as potential water that can be treated and recycled, while considering the associated problem of environmental impact and cumulative pollution processes. Thus, the treatment and safe disposal of treated effluents is combined with a policy for reclamation and reuse of effluents as an integral part of the available water resources.

This policy is supported by an R&D programme which is directed toward the following objectives:

- Treatment and storage of wastewater
- Securing a reliable and safe source of water for irrigation
- Safeguard of the environment, soil and groundwater resources
- Cost allocation and economic justification

1.2 Background Data

1.2.1 Water Scarcity and Wastewater Reuse

Israel has a surface area of about 20 000 km^2, a population of about 5.5 million (1995) and an annual water demand of about 2 000 million cubic meters (MCM), compared with a natural potential of about 1 600 MCM. This pressing imbalance has been the focus for the development and conservation of water resources, including wastewater reuse for irrigation (agriculture requires about 1 300 MCM yr^{-1} of water of varying quality; Table 1.1).

The total agricultural consumption has not changed significantly over the last 20 years, although there was a steady increase in the agricultural production output (Gelb and

M. Juanicó et al. (eds.), *Hypertrophic Reservoirs for Wastewater Storage and Reuse*

Table 1.1. Water supply and demand in Israel – 1995 and projection for 2010 (*Source:* Water Commission and authors' estimates)

Water supply and sources	1995	Sector demand	1995	2010
Natural fresh	1600	Urban and industrial	700	900
Natural brackish	180	Agriculture		
Domestic effluents	220	Fresh water	900	650
		Marginal resources	400	600
Total	2000	Total	2000	2150

Table 1.2. Irrigated crops and irrigation water requirements, 1995 (*Source:* Ministry of Agriculture, Central Planning Authority, November 1996)

Crop	Area (× 1000 ha)	Water requirements (MCM yr^{-1})
Citrus and other tree plantations	71.3	576
Field crops	51.7	151
Cotton	24.5	120
Vegetables and flowers	39.0	212
Others	12.8	194
Total	199.3	1253

Kislev 1982). The achievements made in water saving have been accompanied by a gradual change to crops which can be irrigated with low-quality effluents (Table 1.2).

Of the current water demand for irrigation, 70% can be supplied by water of non-potable quality, making the substitution of fresh water with domestic effluents a viable option that attracted farmers, economists and politicians alike. Accordingly, a national wastewater and reuse policy was formulated, assuming that it could be achieved without damaging the environment.

1.2.2 Wastewater Reclamation Plan

The major principles of the adopted policy include the increase of reclaimed wastewater used for irrigation from the current 17% to 34%, and increasing the utilized effluent quantities from the current 220 MCM to 420 MCM by the year 2010 (Table 1.3).

Two major courses have been adopted for the treatment and disposal of urban wastewaters, as shown in Table 1.4. For Greater Tel Aviv the treatment includes advanced tertiary treatment to the level of potable water by Soil Aquifer Treatment, while for other cities and towns, secondary treatment is advocated in a system which combines the treatment of wastewater with controlled irrigation schemes (Waldman and Shevah 1985). A major element in these systems is the large storage bodies which regu-

Table 1.3. Water supply for irrigation in 1995 and projection for 2010

Source	1995 (MCM)	(%)	2010 (MCM)	(%)
Fresh water	900	69	650	52
Brackish water	180	14	180	14
Domestic effluents	220	17	420	34
Total	1300	100	1250	100

Table 1.4. Wastewater Treatment and Reuse Plan (MCM yr^{-1}) 1995–2010 (*Source:* Shevah 1996)

Year	Potential wastewater	Reuse plan		
		Tertiary effluents	Secondary effluents	Total
1995	440	100	120	220
2010	560	160	260	420

late between the relatively constant flow of wastewater during the whole year and the seasonal demand for irrigation (only six to eight months). The storage body is either a surface water body or an underground confined aquifer. Both types of storage provide an additional treatment step.

1.2.3 Surface Wastewater Reservoirs

These reservoirs are the key element in the sewage treatment system, employing conventional biological treatments in anaerobic sedimentation ponds, followed by a series of aerobic ponds with or without mechanical aeration means, and the reservoir which receives the secondary effluents all the year round, thus regulating between sewage production and irrigation demand (Dor 1986; Juanicó and Shelef 1994). Such treatment and reuse schemes proved to be a feasible technology and more than 200 reservoirs with a capacity ranging between 0.1 MCM and 12 MCM are already available turning in more than 150 MCM of sewage effluents.

1.3 R&D Support

1.3.1 The R&D Policy

The experience gained with the use of these systems required the initiation of a comprehensive R&D system that enabled the expansion of the programme without detrimental effects to the environment. Stabilization ponds which are relatively cheap to construct and operate are clearly more efficient in protecting the environment than the conventional treatment systems designed principally to reduce the content of organic matter and suspended solids. On the other hand, effluents contain many pathogenic microorganisms and toxic compounds of industrial origin which may have direct health hazards (WHO 1979), although no epidemiological evidence indicating a link between sickness and the use of effluents for irrigation was reported (Hillman 1985). However, because of the associated health and environmental risks, the policy that emphasizes reuse of wastewater on an unconventional scale could have enormous implications on public health and as such it had to be accompanied by a well-defined research and monitoring programme, built in as an integral part of the national wastewater reclamation programme (Waldman and Shevah 1985).

Several interdisciplinary research groups were established to study the biological, chemical and engineering aspects of reservoirs impounding sewage effluents. An elaborated research programme was established to standardize sampling procedures, analytical methods and data banks. Over the years, the research programme was expanded to include: a) oxygen balance and the development of odours; b) survival and regrowth of enteric micro-organisms; c) behaviour and characteristics of suspended solids; d) accumulation and release of nitrogen, phosphorous and organic carbon sediments at the bottom of the reservoirs; e) nitrogen balance, isolation of nitrifying organisms and determination of optimal conditions for nitrification; f) epidemiological and population studies; and g) mathematical modelling for the description of the processes which incur in the reservoirs.

1.3.2
Overview of the Ongoing R&D Programme

Despite their heterogeneity, wastewater reservoirs constitute a well defined category of aquatic ecosystem. They represent a unique hypertrophic aquatic ecosystem due to a combination of high organic loading, which makes possible the development of active biomass, and relatively deep water that lends importance to the limnological processes taking place. Being seasonal reservoirs, they function under non steady-state conditions which induce great fluctuations in the quality of effluents as evolved from the ongoing comprehensive research programme reviewed in the following.

1.3.2.1
Limnology

Several research studies have been conducted in order to study the effect of the long detention period on the quality of the effluents as expressed by various indicators, both chemical (Abeliovich 1980; Dor 1982) and biological (Kott 1980). The emphasis is on the concentration of organic matter expressed as *BOD* and *COD* and the removal of heavy metals and detergents (Eren 1987). Similarly, the effects of the low rate reactions which take place during the long retention time on the removal of the hard pollutants not affected by the treatment were studied (Abeliovich 1985), as well as the large populations of phytoplankton and zooplankton which extremely fluctuate and vary over the year (Dor et al. 1987a,b) and the considerable impact of large planktonic algae and metazoan species on the performance of the micro-irrigation systems which are highly susceptible to clogging (Teltch et al. 1991).

1.3.2.2
Health Aspects

The elimination of pathogenic bacteria, coliform, faecal streptococci and enteroviruses after long detention period followed by disinfecting at the end of the storage period was studied by Kott (1980). This study prompted the development of a research programme on viruses in water (Shuval 1984). This programme has been sustained through nearly two decades, and has generated much valuable information regarding the detection of cultivable enteroviruses and the common adenoviruses, and the need to examine their significance in the context of waterborne virus diseases (Marzuk et al. 1980) and exposure to aerosolized viruses from wastewater used for sprinkler irrigation (Fattal and Teltch 1982).

1.3.2.3
Nutrients Balance

Stored effluents contain a high concentration of ammonia which triggers the nitrification-denitrification process. The effects of a variety of environmental, physical, and chemical factors on the nitrogen cycle, and the transformation of ammonia to nitrite, nitrate, and free nitrogen was studied by Abeliovich (1993). Nitrogen and other elements' concentrations are also affected by the sedimentation process and the storage capacity of the particles comprising the bottom sediment. The nutrient fluxes to and from the sediment, and nutrients' balance was studied by Avnimelech and Wodka (1988) and Avnimelech (1989).

1.3.2.4
Heavy Metals

The pathways of metals found in municipal wastewater through the treatment and reuse process was studied by Kaplan et al. (1986), who assessed the heavy metal pollution hazard by measuring the concentration of dissolved and bound fractions, and the chelation process of zinc, cadmium, lead and copper. Similarly, the presence of micro pollutants, which cannot be totally removed and can therefore accumulate in the food chain were intensively investigated, using advanced instruments that facilitate their measurement in water (Rebhun et al. 1987).

1.3.2.5
Organic Micropollutants

The positive effect of solar photocatalytic mineralization of pesticides such as alkyl benzene and alkyl phenolic constituents, phathalates alkyl phosphates and di- and triethoxylates was assessed in eight reservoirs receiving domestic effluents (Muskat et al. 1995; see chapter in this book).

1.3.2.6
Monitoring Programme

For effective management of wastewater reservoirs, an effective monitoring programme is essential in order to control water quality, identify problematic areas from the pollution perspective, and to build a database which could be used at a later stage to measure the success or failure of the system. Data normally collected include *BOD*, *COD*, suspended solids, total solids, and chemical elements, namely: sodium, chloride, potassium and boron. Current monitoring programmes are however compounded by the large number and the complexity of the measured parameters and the related cost. Various attempts are made to achieve the maximum value from the available sampling and analytical facilities, while new monitoring techniques are being developed.

Standard analytical methods rely on sampling and laboratory analysis using specialized and highly expensive equipment. These cumbersome field sampling and laboratory testing methods can be replaced by rapid tests using accelerated immunofluorescence assays (Nasser et al. 1993; Bustyak et al. 1995). Automatic sampling is being introduced in order to overcome the deficiencies of grab samples which represent the quality of water at the time of sampling. To monitor the influx of solutes into the water body, a Multi-Level Sampler (MLS) device was developed to monitor water quality and to study the process of solutes transport (Ronen et al. 1987). A selective and highly sensitive chemical sensor system that will continuously monitor pollutants in water bodies is also being investigated using fiberoptic evanescent wave spectroscopy technique for continuous monitoring in real time and *in situ* (Schnitzer et al. 1990). An inexpensive portable system based on a spectrometer comprising a tunable diode laser and a sensitive infrared detector will be developed in the near future.

Remote sensing techniques are also investigated using reflected light measurements by satellite multispectral imaging (Dor and Ben-Yosef 1995; see chapter in this book), while mathematical modelling was developed for the description of the processes which incur in the reservoirs (Friedler 1993; see chapter in this book).

1.3.2.7
Socio-Economic Research

Early studies of the economic aspects of treatment and reuse systems were conducted by Horowitz and Shevah (1985) who analysed the economic benefits accruing to each of the three sectors involved in the treatment and utilization of domestic effluents for irrigation, namely: the local authorities, the government, and the agricultural sector. Reuse of effluents as an ultimate disposal system, results in significant savings to the local authorities, the party primarily responsible for sewage treatment and disposal, who can do without the energy-intensive treatment processes needed to eliminate the organic content of sewage. Similarly, the central government benefits from the generation of additional water sources, protection of the environment, and the postponement of large-scale desalination of sea water, which is the ultimate solution for water scarcity.

A high treatment level is generally favored by local authorities, but the additional costs should be considered as an input in the decision-making process, taking into consideration that reuse for irrigation results in adequate treatment while reducing both treatment and fertilizer cost. In addition to the quantity of effluents allocated to the farmer, further benefits derive from the nutrient content of wastewater which has an economic value (Haruvi and Sadan 1994).

The composite benefits of treatment and reuse of effluents for irrigation are obvious. However, the allocation of costs between the sectors involved presents certain difficulties (Selbst 1980). The determination of fair sharing of investment costs and equitable water pricing policies requires estimation of the direct benefits to each of the beneficiaries. Horowitz and Shevah (1985) proposed suitable cost allocation and pricing mechanisms, while also discussing the need for water rate adjustments, so that agriculture is subjected to realistic competition with other users.

1.4 Results Dissemination

The use of wastewater reservoirs as a central element in wastewater treatment and reuse has become a major feature of environmental importance, attracting a wide interest from researchers, engineers and administration personnel. The necessity and the importance of these reservoirs is reflected by their number, which increased from almost nil in 1970 to about 200 units in 1996. The reservoirs, initially a controversial environmental and public health issue, are today the subject of extensive investigations and routine monitoring programmes by scientists and environmental protection agencies.

The results of these activities are disseminated through international journals and reports submitted to the financing agencies. Workshops and seminars dedicated to wastewater reservoirs are frequently organized and attract a large audience. Furthermore, a management information system has been developed for the collection, data analysis, evaluation and dissemination of data on the biological, chemical, microbial and public health aspects of the wastewater reservoirs. Periodical reports, in the form of annual reports and up-to-date data when available, are produced by the Water Commission (Eitan 1995), providing a vital link between the supervisory bodies and the users.

1.5 Discussion

In Israel, the national policy proclaims reuse of effluents for irrigation as an inevitable outcome of the acute shortage of water and the need to conserve existing water resources. Further utilization of domestic effluents is recognized as the most economic course for developing the additional 200 MCM of water required by the turn of the next century (Shevah 1996). These needs are compounded by economic benefits associated with the use of effluents for irrigation, including release of freshwater for domestic use, increase of the irrigated area, recycling of nutrients and trace elements in the effluent, and reduction in the cost of water for irrigation (Haruvi and Sadan 1994).

Secondary effluents from sewage works have, normally, low concentrations of suspended solids and *BOD*. On the other hand, these effluents contain many pathogenic microorganisms and toxic compounds of industrial origin and as such they may have direct health hazards for field workers and the local population, and indirectly hazards for the general public (Hillman 1985). Health hazards derive from viruses, bacteria, and various protozoa (particularly those that are cyst-like), worms, and *Ascaris* larva which can withstand treatment processes and reach the soil to continue their life cycle (WHO 1973, 1979; Shuval 1984).

Therefore, the dilemma remains as to whether we should opt for the costly tertiary treatment and disinfection process, which reduces the health hazard to zero, while at the same time eliminating those very factors that make the use of treated effluents for irrigation economically attractive. It is to be noted that despite the potential health hazards, there is not yet sufficient epidemiological evidence indicating a link between sickness and the use of effluents for irrigation (Hillman 1985). Moreover, the positive effects of long detention periods in stabilization ponds was demonstrated indicating the high efficiency of stabilization ponds in producing safe effluents to be used for irrigation, especially with regard to the removal of pathogenic worms, intestinal nematodes, bacteria, and viruses (Feachem 1984).

Under these circumstances, the introduction of wastewater reservoirs – as extensively discussed in this volume – provides a public health safety measure and a low cost method for preventing environmental pollution. In addition, the utilization of secondary effluents results in energy saving because there is no need to eliminate the organic content of the effluent as discussed by Horowitz and Shevah (1985). Suitable cropping systems and organizational structures of the agricultural sector could have added advantages which effectively permit the integration of effluents in the supply of water for agriculture.

The inclusion of long detention reservoirs and the associated processes as an intermediate step between treatment and reuse is of vital importance in breaking the direct link between the unsafe raw wastewater and the treated effluents suitable for irrigation use. The large volume of the reservoirs compensates the short and long-term differences between water supply and demand, while providing a simple, robust and cost effective method.

Despite the many advantages of wastewater reservoirs and the extensive supporting research which was conducted, it is concluded that further supporting research and stringent monitoring are still a basic requirement, whereby the epidemiological and environmental research and monitoring are essential.

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