ELSEVIER

Agriculture, Ecosystems and Environment 66 (1997) 113–119

Agriculture Ecosystems & Environment

Agricultural reuse of wastewater: nation-wide cost-benefit analysis [1]

Nava Haruvy *

Agricultural Research Organization, The Volcani Center, P.O. Box 12, 50250 Bet Dagan, Israel

Accepted 18 March 1997

Abstract

The increasing agricultural reuse of treated effluent serves goals such as promoting sustainable agriculture, preserving scarce water resources, and maintaining environmental quality. Also, irrigating with wastewater may reduce purification levels and fertilization costs, because soil and crops serve as bio-filters, and wastewater contain nutrients. Policy decisions regarding the level of purification and location of agriculture using wastewater, should consider multifarious aspects including costs, hazards and benefits of agricultural reuse of wastewater. The present paper demonstrates, in a simple way, how to tackle decision-making questions regarding the disposal of wastewater from an economic standpoint. It compares various wastewater reclamation and reuse options such as treatment levels and location of reuse, by computing the net national benefit as applied to a specific case study in central Israel. Several alternatives were compared including river disposal, local agricultural reuse of wastewater, and conveyance to the south. Estimated costs include those of treatment, storage and conveyance, while benefits comprise the value of agricultural output, the decrease in fertilization costs, and aquifer recharge. Hazard costs estimated in this analysis relate to seepage of nitrogen and health risks. According to this analysis, wastewater irrigation in the center of Israel saves US\$0.50–0.60/m^3 compared with river disposal, and US\$0.10–0.20/m^3 compared with conveyance to the south. Conveyance to the south of tertiary-treated effluent (as in the Dan Region Treatment Plant) instead of discard saves US\$0.12/m^3, justifying a subsidy. © 1997 Elsevier Science B.V.

Keywords: Wastewater; Economics; Cost-benefit; Decision-making

1. Introduction

Demands on water resources for household, commercial, industrial, and agricultural purposes are increasing greatly. The world population will have grown 1.5 times over the second half of the 20th century, and the urban population will have grown 3 times, with almost half the total population living in cities by the year 2000 (EPA, 1992). Growing urbanization increases domestic water use while supplying wastewater that can be used for nonpotable purposes, such as agriculture, can be an economically attractive purpose. In Israel, wastewater already plays a dominant role in agriculture.

Israel is characterized by scarcity of water resources which limits agricultural production possibilities. The amount of water currently recycled is 1900 million cubic meters (mcm) annually, or 260 m^3 per

* Corresponding author. Tel.: +972-3-9683823; fax: +972-3-9604017; e-mail: vwnav123@volcani.agri.gov.il

[1] Contribution from Agricultural Research Organization, The Volcani Center, Bet Dagan no. 1823-E, 1996 series. Financed by Chief Scientist, Agricultural Ministry.

PII S0167-8809(97)00046-7

capita. This is allocated for urban, industrial and agricultural uses, leaving 1200 mcm or 63% for current agricultural consumption (Israel Water Commission, 1995). The good-quality water resources available for agricultural use tend to decrease as population growth enhances domestic water use, and, within the next four decades, treated sewage effluent will become the main source of water for irrigation in Israel. Of the 1400 mcm (40% of total water supply) that will be used for irrigation in the year 2040 in Israel and the Palestinian autonomous regions, the amount of treated sewage water will be 1000 mcm. Effluent will satisfy 70% of agricultural water demand and will play a dominant role in sustaining agricultural development. Agricultural use of wastewater should be followed by appropriate management techniques to control long-term effects of its constituents.

Wastewater is a preferred marginal water source, since its supply is reliable and uniform, and is increasing due to population growth and increased awareness of environmental quality. Costs of this water source are low compared with those of other unconventional water sources, since agricultural reuse of urban wastewater serves also to dispose of urban sewage water, and the relevant costs of agricultural reuse are just the additional costs needed for adaptation to the agricultural objective. These are total costs of supplying wastewater for agricultural reuse (treatment, storage and conveyance costs) minus total costs of alternative safe environmental disposal. Wastewater can also serve as a source of macronutrients (nitrogen, phosphorus and potassium), thus further decreasing the cost of wastewater for agricultural reuse.

The lower the treatment costs, the more profitable and attractive is wastewater for agriculture, which is true for any given wastewater quality, but this is a decision variable. In referring to any wastewater treatment level, one should also mention quality level, since improvement augments reclamation costs. The possibility of choosing an inferior wastewater treatment level to decrease costs, should be regarded in parallel with the environmental impacts of wastewater irrigation, as related to health, soil and aquifer. Referring to environmental impacts alone would dictate improved treatment levels and higher treatment costs.

Consideration of optimal treatment level relates to costs and hazards as well as to the beneficial aspects of effluent reuse. The same applies to other reuse decisions such as the location of wastewater irrigation, since conveyance to regions far away from an active aquifer results in high conveyance costs (Sadan and Haruvy, 1994). Moreover, the costs of producing or treating wastewater are not necessarily reflected in the prices to farmers, as affected by recovery costs and allocation factors, and should be considered in political decision making (Haruvy, 1994).

Economic considerations become more significant as the use of reclaimed sewage increases. For any wastewater decision-making issue, one should analyze multifarious aspects of costs, risks and benefits. The analysis will be based on maximization of nation-wide net benefit, evaluated as total benefits minus total costs and value of environmental damage (Haruvy and Sadan, 1994).

The present paper demonstrates, in a simple way, how to tackle decision-making questions regarding the disposal of wastewater from an economic standpoint. It compares various wastewater reclamation and reuse options such as treatment levels and location of reuse, by computing the net national benefit. Concepts of wastewater quality and treatment will be described, followed by estimation of costs, hazards and benefits.

2. Treatment levels and processes

Wastewater quality or treatment level are defined by various constituents, such as: (a) macroorganic matter–biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS), which are reduced by common reclamation processes; (b) microorganic pollutants, i.e., stable organic matter that may affect health through leaching to ground water; (c) trace elements resulting from industrial water use; (d) pathogenic microorganisms, the concentration of which can be reduced significantly through wastewater reclamation and disinfection; (e) nutrients such as nitrogen and phosphorous which serve both as a pollution hazard and a fertilizer; and (f) salinity, increased inorganic soluble salts in wastewater caused by urban and industrial use, which are not removed during the conventional reclamation processes (EPA, 1992).

Treatment processes are divided into primary, secondary and advanced processes. Primary treatment includes basic treatment such as screening of coarse solids and grit removal. Secondary treatment includes low-rate processes such as stabilization ponds with high land and low capital and energy inputs, and high-rate processes such as activated sludge with low land and high capital and energy inputs (Pettygrove and Asano, 1985). Tertiary stages further improve quality by nitrification–denitrification (to reduce the nitrogen level) and soil and aquifer treatment (SAT, infiltration and pumping from a shallow aquifer).

The Dan Region Treatment Plant (DRTP) is the largest wastewater treatment plant in Israel, treating about 100 mcm annually of wastewater from the Tel Aviv vicinity. It is based on the aerated activated sludge process assisted by the nitrification–denitrification and SAT processes and provides water for unrestricted irrigation, which is conveyed to the Negev in the south. Following treatment, pollutant concentration were (Dan Region Association of Towns, 1991; Shelef et al., 1994): TSS and BOD decreased from 372 and 392 to 17 and 20 mg/l, respectively, N-Kjeldahl decreased from 63 to approximately 12 mg/l (ammonium-10.4 mg/l and nitrates-2.9 mg/l). Concentration of salts in DRTP wastewater was: electrical conductivity (EC)-5.9 (1.8 times higher than in origin water), sodium-236 mg/l (2.2 times higher) and chlorides-300 mg/l (1.6 times). Concentration of heavy metals was significantly below US EPA standards (Feigin et al., 1990).

The quality of wastewater should be adapted to the intended uses. While there are regulations and recommendations for treatment levels, there is a degree of freedom in choosing whether to restrain or release some parameters, such as the nitrate content. The legally mandated treatment levels for a municipality of more than 10,000 citizens are BOD and TSS of 20 and 30 mg/l respectively, which can be obtained by secondary treatment processes. Criteria for river disposal are '10/10' mg/l BOD and TSS and restricted levels of ammonium (Fine et al., 1995). Recommended levels for agricultural use are '20/30' for most crops, excluding raw-eaten vegetables (Shelef, 1991), which are attained through secondary treatment processes. Primary treatment can be adapted to crops that are not consumed by humans, while tertiary treatment is required for unrestricted use.

Levels of nitrate in potable water that exceed 45–90 mg/l are considered hazardous; they can cause methemoglobinemia in infants. Levels of nitrogen in treated effluent should be coordinated with crop needs and such effluent should be applied by irrigation technologies and practices designed to minimize leaching to groundwater. For example, citrus orchards irrigated with 6000 m^3 per ha, can consume nitrogen levels of approximately 45 mg/l without significant leaching if applied by proper methods (Fine et al., 1995).

3. Costs and hazards

Treatment costs (operation, maintenance and capital recovery) are affected by the required level and extent of effluent treatment. Costs of characteristic treatment processes are presented in Table 1. The addition of any treatment stage results in higher treatment costs, for example, (relating to treatment of 14 mcm), the basic stage of activated sludge treatment costs US\$0.12/m^3 (per annum), while the addition of a nitrification–denitrification stage adds US\$0.07/m^3 annually.

Table 1
Wastewater treatment costs (cents/m^3) (1992 prices)

Output Treatment process	4 mcm/yr Costs (cents/m^3)	14 mcm/yr	40 mcm/yr	90 mcm/yr
Trickling filter	16.6	10.1	7.4	6.3
Activated sludge	20.3	12.1	8.6	7.2
Activated sludge + nitrification	23.0	13.7	9.7	8.2
Activated sludge + nitrification–denitrification.	31.6	19.3	14.2	12.3

Source: EPA, 1975.

Average treatment costs decrease with the amount of effluent treated, resembling 'economies of scale'. Hence, larger plants which are more efficient may involve technical and political difficulties. In the Tel Aviv area sewage treatment plant, annual costs are approximately US\$0.60/m^3, about one third for each of the stages: treatment, recharge and conveyance.

Hazards may be caused by each of the wastewater constituents (Feigin et al., 1990). Extra nitrogen may leach below the root zone increasing groundwater pollution. Human health may be affected by methemoglobinemia, eutrophication of surface and groundwater resources, algal bloom and oxygenation which cause fish starvation (Hanely, 1990). In more than half of the Israeli wells, nitrates concentration was already higher than the European drinking water standard of 45 mg/l and in 20% of the wells, it was more than the Israeli standard of 90 mg/l (Kanfi et al., 1983).

Considerable concern relates to the possible presence of trace organic chemicals in wastewater. Ronen and Magaritz (1980) investigated aquifer pollution in the coastal region and found high pollution by organic matter. Today, wastewater quality has been improved considerably and a columns based experiment showed (Fine et al., 1995) that the rate of organic matter decomposition may be high enough, that its movement in soil is insignificant. Field experiments showed enhanced transport of atrazine under irrigation with effluent (Graber et al., 1995). More experiments are needed to evaluate possible risks.

An important parameter determining wastewater suitability for irrigation is salts concentration since they are not reduced by regular reclamation processes, but by much more expensive desalination processes. High levels of total dissolved salts may constrain effluent use for irrigation and decrease yields according to salt tolerance of crops (Maas, 1986; Shalhevet, 1994). High sodium levels increase sodium absorption ratio (SAR) which may deteriorate soil hydraulic conductivity (Levi et al., 1995). Still, potassium salts can replace sodium salts in dishwashers, and fresh water can be delivered from low-salinity sources (Fine et al., 1995).

Pathogenic organisms can be reduced by treatment processes and their level should be monitored regularly, in coordination with other disinfection methods to protect exposed population and crops (Oron, 1991). Hazards from heavy metals do not seem high in Israeli soil conditions, especially if treated at the originating industries. The low concentration of metals in secondary effluent from domestic origin enables long-term irrigation without significant concentration in soil (Page and Chang, 1985). Their mobility will be low in highly oxygenated Israeli soils (Chaney and Giordano, 1977).

4. Case study and method

The case study relates to sewage treatment in Ra'anana, located in central Israel. The treatment plant treats approximately 6 mcm annually, but the analysis includes the Ra'anana region with an expected annual wastewater of 30 mcm by 2020. Assuming an irrigation level of 6000 m^3 per ha, 5000 ha, comprising only 30% of the irrigated area with 60% orchards and 40% citrus (Israel Ministry of Agriculture, 1994) are to be irrigated by effluent. Wastewater quality following treatment is about the same as that after the DRTP plant, with two major exceptions: the level of chlorides is approximately 200 mg/l, as in the National Water Carrier, and we consider a nitrogen level of 45 mg/l (without nitrification–denitrification), which can be consumed by orchards.

Net benefits are compared for the following options: (a) river disposal; (b) irrigation in the region, and (c) conveyance to the south (with no active aquifer) at two treatment levels: (1) tertiary treatment (including nitrification–denitrification, filtration and disinfection) for unrestricted irrigation (this option reflects the present situation whereby DRTP wastewater is conveyed to the south); and, (2) secondary treatment, for restricted irrigation.

Recommended treatment levels are (Fine et al., 1995): tertiary treatment (BOD and TSS both of 10 mg/l, and ammonium-N 5 mg/l) for river disposal in the summer, and secondary treatment is sufficient (BOD 20 mg/l and TSS 30 mg/l, without nitrification–denitrification) for irrigation of orchards and field-crops. Additional disinfection is needed for river disposal and for restricted irrigation (Oron, 1991) but is not necessary for unrestricted irrigation (Fine et al., 1995, p. 64). For each of the relevant options, costs, hazards and benefits were computed and com-

Table 2
Direct costs for various alternatives (cents/m^3), treatment extent (10 mcm/yr); treatment levels are according to Fine et al. (1995)

Alternative	River disposal	Local irrigation	Southern conveyance	Southern conveyance
Treatment level	tertiary	secondary	tertiary	secondary
Treatment process				
Activated sludge	16	16	16	16
Nitrification–denitrification	9	–	9	–
Soil filtration	8	–	8	–
Disinfection	2	–	–	–
Total treatment costs	35	16	33	16
In addition				
Storage	–	6	6	6
Conveyance	5	5	18	18
Total treatment and other	40	27	57	40
Saved fertilization cost	0	−5	0	−5
Total direct costs	40	22	57	35

Source: costs are based on Table 1 and engineering estimates.

pared. Direct costs, including treatment, storage and conveyance costs for each alternative are presented in Table 2, and net value estimates in Table 3.

Direct costs comprise net value of benefits, e.g., direct and indirect benefits minus direct and indirect costs. Direct benefits from irrigated agriculture are expressed as the marginal value of water in agriculture, estimated as US\$0.36/m^3 and US\$0.29/m^3, in the center and south of Israel, respectively (Sadan and Ben Zvi, 1987). Benefits from river disposal are assumed to be zero, and, in fact, are affected by the value of recreation activities. Estimated direct costs are presented in Table 2 and indirect costs for restricted irrigation are expressed as a decrease in farmers' incomes of US\$0.5/m^3, where raw-eaten vegetables are replaced with field-crops.

Indirect benefits are estimated according to the value of the contribution of irrigation to aquifer recharge. In the coastal aquifer, out of 397 mcm of annual replenishment, irrigation recharge accounts for 144 mcm, or 36% (Israel Hydrological Service, Water Commission, 1995). Assuming aquifer

Table 3
Net benefits for various alternatives (cents/m^3)

Estimates of	River disposal	Local irrigation	Southern conveyance	Southern conveyance
Treatment level	Tertiary	Secondary	Tertiary	Secondary
+Direct benefits				
Value of marginal output	0	36	29	29
−Direct costs	−40	−22	−57	−35
−Indirect costs				
Income decrease	0	–	0	−5
= Net value of output	−40	14	−28	−11
+Indirect benefits				
Aquifer recharge	0	7	0	0
−Environmental damage				
Damage to aquifer	0	−10	0	0
Damage to health	0	–	0	−4
= National net benefit	−40	11	−28	−15

Source: Direct costs are based on Table 2; other costs and benefits are computed as described in the text.

recharge of 20% and cost of water production of US$0.35/$m^3$, each irrigated m^3 contributes US$0.7/$m^3$.

Estimates of environmental damage caused by nitrate leaching were obtained from a linear optimization model, targeted at maximization of profits and including constraints on cultivated area and water supply, as well as restrictions on nitrogen leaching. The damage was estimated as approximately US$0.10/$m^3$ as reflected by the 'shadow price' of leaching restriction (decrease in farmers' profits in $ due to an additional nitrogen leaching restriction of 1 kg/ha). Analysis of this model is published separately (Haruvy et al., 1997).

Damage estimates of other wastewater pollutants, especially salinity to crops and soil infiltration, are important but are not estimated here. The salinity level is not influenced by regular wastewater treatment processes and salinity was not a critical problem in the case study, since the chlorides level in wastewater from well water was approximately 200 mg/l, similar to that in the Israeli National Water Carrier.

The cost of health damage was estimated as US$0.4/$m^3$. It was based on a population of 40,000 in the western southern region, and an increase in the probability of death by 0.001 (for comparison, for a person drinking 3 l of wastewater a day, the probability to die from micropollutants when wastewater treatment changes from secondary to tertiary, was estimated as 0.006 (Schechter, 1984), and the probability to be injured in a road accident is 0.006). The average value of life was assumed as US$100,000 (Schechter, 1984). The health hazard can be evaluated in many other ways, but it is not the main issue here.

5. Results

The direct cost, (Table 2) including storage and conveyance of river disposal is US$0.40/$m^3$, while the cost of irrigation is US$0.27/$m^3$ or, including the value of nutrients value in wastewater, US$0.22/$m^3$; hence, agricultural reuse directly saves US$0.40 − 0.22 = US$0.18/m^3. Local irrigation, compared with tertiary treatment and conveyance to the south, saves US$0.57 − 0.22 = US$0.35/m^3. Table 3 presents the total net benefit analysis. Direct benefits from irrigated agriculture, i.e., the value of the marginal agricultural output of water, are US$0.36/$m^3$ and US$0.29/$m^3$, in the center and south of Israel, respectively. Hence, net benefits (minus direct costs) amount to US$ − 0.40/m^3 for river disposal, and US$0.14/$m^3$ for local irrigation, bringing the savings due to agricultural wastewater reuse to US$0.14 − (− 0.40) = $0.54/$m^3$. When the value of the irrigation contribution to aquifer recharge US$ − 0.07/m^3 is added and the damage due to nitrogen seepage—estimated as US$0.10/$m^3$—is deducted, local effluent reuse is seen to save US$0.11 − (− 0.40) = US$0.51/m^3.

Local irrigation saves US$0.11 − (− 0.28) = US$0.39/m^3 as compared with conveyance to the south of tertiary treated wastewater. Still, if the water were not reused in the center, southern farmers would save US$ − 0.28 − (− 0.40) = US$0.12/$m^3$ compared with river disposal. Those farmers participating in environmental treatment should be subsidized up to US$0.12/$m^3$ for using wastewater and saving wastewater disposal costs to the nation. Also, if conveyance involved secondary-treated wastewater, irrigation would be restricted, decreasing profits by approximately US$0.05/$m^3$. By deducting also the cost of health damage, estimated as US$0.04/$m^3$, conveyance of secondary-treatment effluent to the south is seen to save US$ − 0.15 − (− 0.28) = US$0.13/$m^3$.

6. Discussion and conclusions

According to current knowledge, wastewater irrigation in the central area could maintain agriculture and reduce costs if were actually demanded by agriculture. Such irrigation should be monitored regularly and applied cautiously, in accordance with optimal irrigation–fertilization policies, to decrease leaching, and in combination with other methods, to decrease salinity and other pollutants.

Economic, agricultural and environmental aspects are important considerations in any decision-making regarding wastewater treatment and reuse options. The application presented here could be practiced for particular plants and regions as assisted by additional experiments and risk assessment.

References

Chaney, R.L., Giordano, P.M., 1977. Microelements as related to plant deficiencies and toxicities. In: Eliot, L.F., Stevenson, J.F. (Eds.), Soils for Management of Organic Wastes and Waste Waters, ASA, Madison, WI pp. 234–279.

Dan Region Association of Towns (Sewerage), Mekorot Water Company, 1991. Dan Region Sewage Treatment and Reclamation Project, Tel Aviv, Israel.

EPA, 1975. Cost effective wastewater treatment systems: technical report, US Environmental Protection Agency, Washington, DC.

EPA, 1992. Manual, Guidelines for Water Reuse, US Environmental Protection Agency, Washington, DC.

Feigin, A., Ravina, I., Shalhevet, J., 1990. Irrigation with Treated Sewage Effluent, Ecological Series, Springer Verlag, New York.

Fine, P., Haruvy, N., Sheinberg, I. (Eds.), 1995. Ra'anana wastewater-treatment recommendations for criteria for wastewater quality in various alternatives, Institute of Soils and Water, Agricultural Research Organization, The Volcani Center (in Hebrew), Bet Dagan, Israel.

Graber, E.R., Gerstl, Z., Fischer, E., Mingelgrin, U., 1995. Enhanced transport of atrazine under irrigation with effluent. Soil Sci. Soc. Am. J. 59, 1513–1519.

Hanely, N., 1990. The economics of nitrate pollution. Eur. R. Agr. Econ. 17, 29–51.

Haruvy, N., Sadan, E., 1994. Cost benefit analysis of wastewater treatment in the water scarce economy of Israel: a case study. J. Financial Management and Analysis 7 (1), 44–51.

Haruvy, N., 1994. Recycled water utilization in Israel: focus on wastewater pricing versus national and farmers objectives. J. Financial Management and Analysis 7 (2), 39–49.

Haruvy, N., Hadas, A., Hadas, A., 1997, Cost assessment and means of averting environmental damage and ground water contamination by farmland nitrates seepage, Agricultural Water Management (forthcoming).

Israel Hydrological Service, Water Commission, 1995. Development, utilization and status of aquifers in Israel, Israel Hydrological Service, Jerusalem. (in Hebrew).

Israel Ministry of Agriculture, 1994. Agricultural Branches in the Years 1992–1993, Tel Aviv. (in Hebrew).

Israel Water Commission, 1995. Report. (in Hebrew).

Kanfi, Y., Ronen, D., Magaritz, M.G., 1983. Nitrate trends in the coastal plain aquifer of Israel, J. Hydrol., 66.

Levi, G., Feigenbaum, S., Shainberg, I., 1995, Partial transformation of sodium in potassium in wastewater for irrigation: impact on soil quality, Water and Irrigation: 344 (in Hebrew).

Maas, E.V., 1986. Salt tolerance of plants. Appl. Agricultural Res. 1, 12–26.

Oron, G., 1991. The possibilities of effluent reuse for irrigation of raw and processing crops, Survey, Ben Gurion University, Beer Sheva, Israel (in Hebrew).

Page, A.L., Chang, A.C., 1985. Fate of wastewater constituents in soil and groundwater trace elements. In: Pettygrove, G.S., Asano, T. (Eds.), Irrigation with reclaimed municipal wastewater-a guidance manual, Lewis, Chelsea, 1985, pp. 13.1–13.16.

Pettygrove, G.S., Asano, T. (Eds.), 1985. Irrigation with reclaimed municipal wastewater-a guidance manual, Lewis Publishers Inc., Chelsea, Michigan.

Ronen, D., Magaritz, M., 1980. High concentration of solutes at the upper part of the saturated zone (water table) of a deep aquifer under sewage irrigated land. J. Hydrol. 80, 311–323.

Sadan, E., Ben Zvi, R., 1987. The value of institutional change in Israel's water economy, Water Resources Research vol. 23.

Sadan, E., Haruvy, N., 1994. Subsidy by irrigation water - 20 years backwards and 20 years forwards, water and irrigation 335: 7–9.

Schechter, M., 1984. Economic implications of changes in water quality for domestic uses, Haifa University, Haifa. (in Hebrew).

Shalhevet, J., 1994. Using water of marginal quality for crop production: major issues. Agricultural Water Management 25, 233–269.

Shelef, G., Ezov, J., Dagan, M., 1994. Monitoring the third line, annual report, The Technion, Haifa, Israel. (in Hebrew).

Shelef, G., 1991. Using water of marginal quality for crop production: major issues. Agricultural Water Management 25, 233–269.