Chapter 4

Economic aspects of irrigation with treated wastewater

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4.1 Introduction

Water is a renewable resource. Precipitations enrich the reservoirs and freshwater can be withdrawn from rivers, lakes, or aquifers. Provision is sustainable only if withdrawals are constrained to safe yields, the supply is finite. Practically unlimited quantities of freshwater can be provided by seawater desalination, but at a cost in energy and damage to the environment. Water is actually consumed in agriculture in the sense that most of it evaporates either directly from the surface of the land or through the plants. Urban water is different; a great part of this water is not consumed but rather it is used as a carrier of dirt and refuse. Once treated, the sewage – now as recycled or reclaimed wastewater – can be reused. Although wastewater may be purified to potable quality, most of the treated effluent is directed to irrigation.

Some of the ingredients in wastewater may be useful for plant growth and replace fertilizers; others may be harmful to human health, the soil, or plants. Sewage treatment, aimed generally at removing harmful components, is expensive. This raises the issue of pricing and cost recovery: who should cover the cost, the producer of the sewage or the final user of the treated wastewater? In this chapter, we review the cost of treatment and discuss pricing.

Water, sewage, treatment plants, reclaimed wastewater and its application are all part of the environment in which we live. Great efforts were invested in recent years in economic assessment of the environmental impact of wastewater treatment and use. Much of the work in this area was motivated by the particular "external" nature of the impact – more often than not wastewater and the ways it is treated or reused affect the health and wellbeing of people not directly involved and markets do not exist to evaluate these health and environmental impacts. Economic studies of the environmental effects are, therefore, a critical part (but never the only part) of a sound policy formation process. Consequently, environmental impact assessment is an important component of the economics of the

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wastewater sector. However, focusing on agriculture, we shall not discuss assessment of environmental impact in this chapter.

The chapter is built as an introduction to be read by economists, agriculturalists, engineers, and others who are interested but not yet experts in the economics of wastewater use in agriculture. Therefore, it focuses on basic information and relatively simple economic analysis. Further reading is found in the other chapters of this volume and in the vast economic literature on pricing and cost allocation.

4.2 Wastewater in agriculture

Urban and industrial wastewater accompanies almost all human settlements and its use in agriculture and other outlets is prevalent around the world. Farmers in poor countries often use untreated sewage, whereas developed countries carefully regulate the treatment and application of reused wastewater. Orderly statistics on the reuse of wastewater are not available, but by one count (Bixio and Wingens, 2006) there were, in 2003, more than 3300 reclamation plants around the world and the numbers are growing rapidly.

4.3 Wastewater and the regulation of its reuse

The composition of raw sewage varies greatly between communities depending on local attributes and the sectors using the water and producing the sewage. Households add salts and organic refuse; industrial enterprises contribute chemicals of diversified nature and composition. The following are broad groupings of sewage constituents (Hussain et al., 2002):

- organic matter;
- nutrients (nitrogen, phosphorus, potassium);
- inorganic matter (dissolved minerals);
- toxic chemicals;
- pathogens.

The regulation of reused wastewater mostly aims at preventing health hazards, both to irrigators and food consumers. Accordingly, different standards are set for restricted irrigation (of crops that are not intended for direct human consumption) and unrestricted irrigation. As a rule, rich countries set higher standards than developing countries and these differences are also reflected in the U.S. requirements as against the recommendations of the WHO (the UN World Health Organization). The American regulations have been criticized as being too high and less stringent requirement for poorer countries are justified on grounds that poor municipalities and farmers cannot and actually will not obey tough regulations.

Although microbial aspects have always predominated wastewater regulations, chemical guidelines are also found. Mostly their aim is to protect plants, the soil, and water reservoirs to which wastewater and their residues leak. In some places irrigation with reused wastewater is confined to areas from which leakage cannot reach aquifers or surface water reservoirs.

In addition to its application in agriculture, reclaimed wastewater is used for watering golf courses, gardens, and forests. Sometimes it may be found as coolant in industries. When not utilized in these ways, effluent, treated or untreated, may be disposed, or find its way, into rivers and oceans. Quite often, national and international regulations and conventions require higher standards for wastewater disposed in nature than for the effluent applied in agricultural irrigation.

4.4 Treatment

In principle, sewage can be treated and cleansed to high-standard potable water; and this is probably done, albeit indirectly, in several European countries. Treatment for irrigation can also be performed using many and varied technologies. The basic method, and in most cases the first stage if more advanced methods are implemented, is wastewater stabilization land ponds. They are relatively inexpensive, and, if maintained appropriately, very efficient. Other methods include wetland polishing; soil aquifer treatment; disinfection by chlorination, ozone, and UV application; microfiltration and reverse osmosis. The latter are membrane systems, considered expensive and rarely encountered. Supposedly they should be applied only where the recycled wastewater is intended for immediate drinking. Their advantage is, however, wider than this: membrane treatment removes salts and most other contaminants; irrigation with membrane treated wastewater will not damage soils and hurt plants; the treated wastewater can be freely used to recharge aquifers and other reservoirs – saving land, construction cost, water loss in open storage facilities, and separate distribution networks.

Conventionally, wastewater treatment is divided into different levels in accordance with accepted definitions (Halperin, 1999; Fine et al., 2006; Westcot, 1997) as follows:

- Preliminary treatment: removal of solids and other large materials from the row sewage.
- Primary treatment: removal of settleable organic and inorganic solids by sedimentation and removal of floating material by skimming. A half to two-thirds of the organic matter in the sewage is removed at this stage. Effluent from sedimentation plants is referred to as primary effluent.
- Secondary treatment: follows primary treatment and its aim is to remove further biodegradable dissolved and colloidal organic matter. Most of the removal is done at this stage by microorganisms and the process is usually enhanced by aeration and supply of oxygen. Following the treatment, the microorganisms are separated from the fluids by sedimentation and the sludge is removed for further treatment and disposal.
- Tertiary (advanced) treatment: further removes organic and inorganic components from the treated sewage. In most cases it also reduces significantly the nitrogen contents of the wastewater. It is used where specific health or environmental constraints are raised. In most places, edible products cannot be grown on wastewater unless it passed tertiary treatment.
- Quaternary treatment: mostly membrane treatment of effluent suitable for unrestricted household use.

Table 4.1 Investment in treatment plants

	Plant, million US dollars			Per CM, US dollars		
Capacity, CM/D	500	5000	50 000	500	5000	50000
Primary	0.266	1.888	4.888	0.53	0.38	0.09
Secondary	0.555	3.888	15.800	1.11	0.78	0.31
Tertiary	1.000	5.244	21.888	2.00	1.04	0.44
Tertiary + desalination	1.400	6.466	32.185	2.80	1.29	0.67

[a]CM cubic meter; CM/D CM per d.
[b]Calculated from data for 150 treatment plants in Israel in 2006.
[c]Exchange rate NIS 4.5 per US dollar.
Source: David Alkan, private correspondence, 2006.

4.5 Cost

As indicated, primary and secondary treatment is relatively inexpensive; further stages add markedly to the cost of reclaimed wastewater. Still, even the early stages are not free, they are capital-intensive, and may constitute a heavy burden on municipalities or farmers. Tables 4.1 and 4.2 present investment, capital cost, and operating costs for treatment of sewage by capacity of the facility.

The data in Table 4.1 were gathered from information supplied by planners of new plants. The data reveal economies of scale; capital cost per cubic meter (CM) of capacity in a large plant is less than half of the cost in a small plant. Operating costs are reported in Table 4.2. Their level reflects the specific treatment usually employed in the plants. They exhibit only modest economies of scale. Extensive plants are built in relatively small communities.

4.6 Replacement of fertilizers

As indicated above, sewage and recycled water usually contain nutrients of use to plants. Thus, they can replace fertilizers. Table 4.3 reports several examples. As the entries indicate, recycled water, and in some cases sludge, may replace fertilizer application. In several of the cases the replacement is significant, more than 50% of the requirement. In other cases, the replacement is modest. Also reported in the table are some cases in which irrigation with reused wastewater will result in too much of the nutrient being applied to

Table 4.2 Annual capital and operating cost in treatment plants, US dollars per CM

	Capital			Operating			Total		
Capacity, CM/D	500	5000	50 000	500	5000	50 000	500	5000	50 000
Primary	0.12	0.08	0.02	0.11	0.06	0.03	0.23	0.14	0.05
Secondary	0.21	0.17	0.07	0.17	0.13	0.09	0.38	0.30	0.16
Tertiary	0.41	0.23	0.10	0.28	0.22	0.15	0.69	0.45	0.25
Tertiary + desalination	0.86	0.28	0.15	0.54	0.40	0.29	1.40	0.68	0.44

Per unit capital cost was calculated for 25 years life expectancy at 7% interest.
Source: Table 4.1 and its source.

Table 4.3 Nutrients required and potential provision by recycled wastewater (kg per hectare and percent)

Crop	Nitrogen N		Phosphorus $P_2 0_5$		Potassium K_2O		Treatment in calculation
	kg/hectare	% from recycl.	kg/hectare	% from recycl.	kg/hectare	% from recycl.	
Citrus	285.3	55	61.7	21	306.7	90	Mechanical-biological treatment
Fruit trees	183.0	88	38.0	35	250.1	112	Mechanical-biological treatment
Dryland fruit trees	150.0	140	0.0		250.0	64	Sludge A
Open space vegetables	304.2	12	175.9	13	400.5	68	Treatment for all uses
Greenhouse vegetables	1159.0	5	748.3	3	1731.0	24	Treatment for all uses
Open space flowers	1596.4	4	655.6	3	1649.7	33	Mechanical-biological and sludge A
Flowers in a protected structure	208.2	19	140.7	17	224.0	127	Treatment for all uses
Irrigated field crops	185.2	35	73.2	7	161.4	70	Sludge A
Dryland field crops	77.0	351	73.0	85	0.0		Sludge A

Column 8 reports the sewage treatment assumed for each row.
Source: Hadas and Fine (2009).

Table 4.4 Typical cost of fertilizers and total cost of production (US dollars/hectare)

Crop	Nitrogen	Phosphorus	Potassium	Total fertilizers	Total cost
Citrus	304	76	224	604	7055
Fruit trees	162	38	140	340	17 916
Dryland fruit trees	96	0	111	197	3107
Open space vegetables	324	204	300	828	17 741
Greenhouse vegetables	1633	1222	1729	4584	122 542
Open space flowers	422	122	144	688	9731
Flowers in a protected structure	2649	1256	1882	5787	148 534
Irrigated field crops	131	64	78	273	2573
Dryland field crops	18	38	0	56	718

Exchange rate NIS 4.5 per 1 US dollar.
Source: Hadas and Fine (2009).

the plants. As indicated, overdoses may be harmful and their occurrence may require dilution of the water with freshwater or purposive removal of the nutrient from the effluent of the treatment plants.

"To be on the safe side" farmers often apply more than the recommended amounts of fertilizers and do not reduce application even when irrigating with recycled wastewater. This practice, often detrimental to soil and water resources, can be explained by the small share of fertilizers in the cost of production (Table 4.4).

4.7 Cost allocation and prices

The treatment of sewage is expensive; the product, effluent, is used in agriculture. Who should cover the cost, the producers of the sewage or the user of the effluent? The conventional wisdom is often that "the polluter pays". But this is not always so. Cost is allocated by prices, if farmers pay for the reused wastewater they share in covering its cost. We have, therefore, to examine prices. We shall distinguish between two cases: in the first, reclaimed wastewater is allocated by prices; in the second case, allocation is not based on prices.

As explained above, recycled water carries contaminations that are added to the soil and the groundwater. In many cases, the most important contaminations are salts as they are not removed in regular treatment of the sewage, not even in tertiary treatment. (Table salt, sodium chloride, is most abundant. Sodium is harmful to soil structure but, as chloride concentration is easier to measure, salinity is often expressed as ppm (part per million) chlorides. A more comprehensive measure of salinity is the electrical conductivity of the water commonly expressed in deciSiemens/meter.) Therefore, we take salts as representing all forms of contamination. Recycled wastewater is, however, not the only source of salts, freshwater also contains salt and therefore irrigation, whether with fresh or with reused water, adds salts to the soil. The salts added are drained to water sources and may have to be removed when their accumulation reaches harmful concentrations. The cost of removal will eventually become part and parcel of the cost of irrigation in general, and, in particular, the use of wastewater in agriculture. Moreover, the cost of reused water cannot be analyzed in isolation; the costs of freshwater and reused water have to be considered together. We begin with price allocation.

4.7.1 The role of prices

Prices provide, in the water economy and in general, three different functions:

(i) Prices convey information. Where prices are equal to marginal costs, the cost to the users of water, who pay the prices, is equal to the cost to the national economy. Water is used only if its contribution is economically justified.
(ii) Prices clear the market; in the sense that with appropriate prices all the available quantity of water, fresh and reused, is taken and shortages do not develop.
(iii) Prices cover cost. The revenue collected by the providers of water of any quality cover the cost of provision.

As we shall see, not always are all three functions fulfilled simultaneously.

4.7.2 The model economy

The principles of pricing are simple and well known; their application in the water economy is, however, generally not straightforward and depends on local and technological circumstances. Price determination is, therefore, presented here within the framework of a model economy. The model is based on a highly simplified description of the Coastal region in Israel (for a more detailed treatment, see Goldfarb and Kislev, 2007). In the model, water is supplied to the region from an outside source, Lake Kinneret (Sea of Galilee), and is used in urban communities and in agriculture. A constant share of urban water is collected as sewage, treated, and provided for reuse in agriculture. Irrigation adds salt to groundwater and it is removed by desalination. Prices determined in the model allocate the cost of freshwater and the reclaimed wastewater, including the cost of salt removal, between farmers and urban users.

Again for simplicity, the model envisages a water economy in a steady state: constant quantities of water are provided annually to the urban sector; agriculture receives year in and year out constant quantities of fresh and reclaimed water; and, also, the same quantities of salts as added yearly to the aquifer are removed by desalination. Consequently, the concentration of salt in the coastal groundwater is kept constant; it does not accumulate.

Formally, prices are determined in a cost minimization model. Agriculture is provided with the quantity X_A of freshwater (measured in CM per year) or its wastewater equivalent. Households (the urban sector) are provided annually with X_U. Freshwater from Lake Kinneret, M_{KH}, is supplied to households and agriculture. The ratio of sewage to water in households is r. Agriculture uses M_A CM of freshwater annually and R CM reclaimed wastewater. One CM of wastewater is equivalent, in its contribution to production, to γ CM of freshwater ($0 \leq \gamma \leq 1$). The system of equations describing these requirements is

$$
\begin{aligned}
M_A + M_U &= M_{KH} \\
M_A + \gamma R &= X_A \\
M_U &= X_U \\
R &= r M_U
\end{aligned}
\tag{4.1}
$$

Irrigation water carries salt and it is deposited on the surface of the land and drained to the aquifer. Salt concentration, measured in grams of chlorides per CM (mg/l), is μ_K in Kinneret water, μ_R in wastewater, and μ_S in the water of the coastal aquifer. The quantity of desalinated coastal water is M_D CM/yr. For simplicity, we assume that the desalinated water (to remove salts) is returned to the aquifer and not consumed directly. We also disregard water lost in the concentrate. In the steady state all salts reaching the aquifer are removed by desalination

$$\mu_K M_A + \mu_R R = \mu_S M_D \tag{4.2}$$

The cost items in the model are conveyance from Lake Kinneret to the Coastal region, C_{KH} dollars/CM, sewage treatment, C_A dollars/CM (the index A stands for treatment to the level required for use in agriculture), and desalination C_D dollars/CM. We disregard the cost of intra-urban distribution and sewage removal, and extraction levies that are imposed in Israel on the withdrawal of water from reservoirs. The mathematical model is presented in Appendix 4.1.

4.7.3 Prices

The prices fulfilling the first function mentioned above (information) are equal to marginal cost and they will be, by Appendix 4.1,

$$\begin{aligned} P_A &= C_{KH} + C_D \frac{\mu_K}{\mu_S} \\ P_U &= C_{KH}(1-\gamma r) + rC_A + rC_D \frac{\mu_R - \gamma\mu_K}{\mu_S} \\ P_R &= \gamma P_A \end{aligned} \tag{4.3}$$

In equation 4.3, P_A, P_U, and P_R are, respectively, the price of water in agriculture, urban use, and the price farmers pay for reclaimed wastewater. The last price reflects the contribution of the recycled water in agriculture, relatively to the contribution of freshwater.

By these prices, farmers are charged for the transfer of water from Lake Kinneret plus the cost of the removal of salt this water adds to the aquifer. Urban dwellers are similarly charged for water transfer and salt removal, and, in addition, for sewage treatment. However, the recycled water, after being treated, is supplied to agriculture and the urban sector is credited in the model for its contribution in agriculture. In other words, the model envisages the urban sector as selling the treated effluent to agriculture at a price equal to its marginal contribution in that sector (not necessarily equal to treatment cost).

In many places, urban dwellers are charged separately for water and for sewage services. But even if these two items appear in different rows on the water bill, or in two different bills altogether, they are a single cost: a household cannot use water without incurring the cost of sewage removal.

The prices of the equation 4.3 can be calculated under the following reasonable assumptions:

$$\begin{aligned} &C_{KH} = 0.30 \quad C_D = 0.44 \quad C_A = 0.67 \\ &r = 0.60 \quad \gamma = 0.80 \\ &\mu_K = 250 \quad \mu_R = 350 \quad \mu_S = 400 \end{aligned} \tag{4.4}$$

The assumptions in equation 4.4 incorporate the estimate that urban use adds 100 g of chlorides/CM of effluent and that, in the steady state, chlorides concentration in the coastal water will be 400 g/CM (at present average concentration is 200 g/CM, but rising). In the calculation of prices we also incorporated the (reasonable) assumption that half the quantity of salts annually reaching the coastal water is removed by means other than desalination – drainage to the sea, fresh and reclaimed water "exported" to other regions. Accordingly, the prices, in dollars/CM, are:

$$P_A = 0.43 \quad P_U = 0.60 \quad P_R = 0.34$$

4.7.4 Cost recovery

We turn now to the third of the functions mentioned above – cost recovery. The first line in the following equation is the total revenue collected for fresh and reclaimed water supplied to urban dwellers and to agriculture; the last line is the total cost of provision, including conveyance, treatment, and desalination. The development of the equation relies on equations 4.1–4.3 above.

$$\begin{aligned} &M_A + R\gamma P_A + M_U \\ &= (M_A + \gamma R)\left(C_{KH} + C_D\frac{\mu_K}{\mu_S}\right) + M_U\left(C_{KH}(1-\gamma r) + rC_A + rC_D\frac{\mu_R - \gamma\mu_K}{\mu_S}\right) \\ &= M_A C_{KH} + \gamma R C_{KH} + M_U C_{KH} - \gamma R C_{KH} + RC_A + \frac{C_D}{\mu_S}(\mu_K M_A \\ &+ \gamma\mu_K R + R\mu_R - \gamma\mu_{KR}) \\ &= C_{KH}M_{KH} + C_A R + C_D M_D \end{aligned} \tag{4.5–4.7}$$

Using equation 4.7, charging marginal cost prices for freshwater and wastewater allows the suppliers to cover all their costs. It should be added that cost is recovered with marginal prices for the particular cost structure assumed in this analysis (linear cost functions). With a different cost structure, charging marginal prices may not lead to cost recovery; this possibility will not be elaborated here.

4.8 Further considerations and alternatives

Up to this point the analysis has been done under the assumption that agriculture uses both fresh and recycled water. The farmers pay for the recycled water according to its (marginal) contribution to production. In such a situation, the price of freshwater in the urban sector may be lower than in agriculture – if γP_A is higher than the cost of treatment and salt removal. As urban dwellers do not consume all the water they get – mostly they use water for the removal of refuse – they can be seen, in analogy to car renting companies, as purchasing water, using it for a while, cleaning the sewage, and selling the treated effluent "second hand". The proceeds from the sale lower the cost of usage.

Although in principle the price of freshwater may be lower in town than on the farm, it will not always be so. If the marginal contribution of water in agriculture is relatively low, the price farmers will pay for recycled water will cover only part of the cost of sewage treatment. Then the cost of water provided to urban dwellers (including sewage treatment) will be higher than the price of freshwater in agriculture.

A situation may even arise when farmers will be paid for taking the recycled water. In a place with ample supply of freshwater, its cost and price to farmers will be low, and they will not be interested in taking a lower productivity effluent. The town may then "bribe" agriculture to help it get rid of the pollution it created.

Where urban communities are located close to oceans or rivers, they may dispose of the treated effluent in the nature. This option may not be open to inland communities. Where reclaimed water can be delivered to nature at a relatively low cost (although it is seldom the case), it will not be economically justified to allocate it to agriculture unless the contribution of the recycled water in agriculture is higher than the cost of provision. The existence of a non-agricultural option is sometimes termed "the zero alternative": the proceeds from turning the recycled water to agriculture must be comparatively high for the urban communities not to prefer the zero solution.

4.8.1 Will the polluter pay?

As we have seen, the recycled water may be "sold" to farmers, and, in this way, free the cities from the cost of sewage treatment. At the same time, it should not be forgotten that the fundamental approach of the preceding analysis is that the responsibility for the treatment of the sewage and its disposal lies with the users of the water: the urban dwellers and industry. If the treated effluent cannot be transferred for a price, the urban sector must cover all the cost of its disposal. The polluter pays in the sense of being responsible.

4.8.2 Scarcity rents and extraction levies

Water in most places is a scarce resource; its use is limited. Being scarce, it has economic value – seawater is not scarce and does not have, in general, economic value. Economic analysis justifies payment of a scarcity rent by water users. For example, in Israel, water providers pay an extraction levy for water withdrawn from aquifers or from surface sources, including Lake Kinneret (trying not to burden the argument, we disregarded the levy in the foregoing analysis). As water belongs to the public, the levy is paid as a tax to the treasury to be used for social benefit.

Where farmers take all the available recycled water, it is also scarce – they are willing to pay for additional quantities. This scarcity does not, however, justify the imposition of a scarcity levy on recycled water. The basic scarcity is that of freshwater at the source, and it is there that the levy should be charged. Once paid, the water "belongs" to the urban sector and any payment for it should go to whomever does the treatment and recycling. Imposing a tax on the recycled water will introduce a wedge between the value of the treated effluent in agriculture and the cost of its collection and treatment in the city and lower the incentive of the urban sector to recycle its water.

4.9 Agreements

The provision of recycled water for a price is appropriate where the number of users is large. But sewage treatment and reuse is often a local affair: a town disposes of the reclaimed water and an agricultural cooperative accepts it to be distributed to its members. In such a case, the town and the cooperative may enter negotiations on the conditions of the transfer. The agreement the parties reach will be bounded: the town will not transfer the treated wastewater to the farmers if the associated cost is higher than that of the (zero) alternative. Likewise, the farmers will not take the wastewater unless its contribution to their fields is higher than its cost to them. But between these two limits, there is room for negotiations. Where will they settle? One possibility is that they will follow, even if unknowingly, the bargaining solution proposed by Nash (1950). The solution is a framework for the analysis of cost allocation under simplifying and reasonable assumptions (not detailed here).

4.9.1 Nash bargaining solution

The town operates a sewage treatment plant and it disposes of its effluent into the ocean at a cost of C_S dollars/CM. A suggestion is raised to redirect the effluent to neighboring agriculture. The cost of treating and provision of the recycled water to agriculture is C_A dollars/CM and it is lower than the cost of ocean disposal, $C_S > C_A$. The recycled water will be given to the farmers at a price P_R lower than the price they pay for freshwater (disregarding, for simplicity, quality differences) $P_A > P_R$. The utility the town draws from the shift of the treated effluent from ocean disposal to agriculture is

$$U = R(C_S - C_A + P_R) \tag{4.8}$$

The utility of the farmers

$$A = R(P_A - P_R) \tag{4.9}$$

Using the Nash Solution, the transfer price to be set in the bargaining process will maximize the product of the utilities of the bargaining parties. The maximization problem is: choose a transfer price P_R to maximize N in the following equation

$$N = UA \tag{4.10}$$

By the first order condition, the price is

$$P_R = \frac{P_A - (C_S - C_A)}{2} \tag{4.11}$$

With this transfer price, the parties to the agreement – agriculture and the urban sector – will derive equal utilities

$$U = A = R\left(\frac{P_A + (C_S - C_A)}{2}\right) \tag{4.12}$$

The nominator in equation 4.12 is the utility, measured in dollars CM of recycled water: the saving of freshwater in agriculture, P_A, plus the saving in cost of treatment in town, $C_S - C_A$, and this sum is divided equally between the parties. Notice that according to equation 4.12, the agreed price, P_R, may be negative: the agreement reached will determine that the town pays the farmer for taking the effluent of its treatment plant. As indicated above, such a solution can be expected if the contribution of water in agriculture is comparatively low and the cost of disposing of the treated effluent in the ocean or river is high.

4.9.2 Remarks

Game theory is the discipline dealing with mutual relations, economic or otherwise. Substantial efforts were devoted in game theory to the question of cost allocation. The Nash Solution presented here is probably the simplest of those problems and solutions. In reality, allocation problems may be more complex and difficult; for example, the sewage may be treated to several quality levels, or the agreement may have more than two bargaining parties. In such cases the solutions that game theory offers may be more complex but the fundamental principle is the same: a cost allocation that all parties can accept (for an application, see Dinar et al., 1986).

The Nash Solution can be viewed from two different angles. Accepting the solution as the finding of a positive analysis, the solution points to the agreement the parties are expected to reach once they realize that it will be for the benefit of both if they cooperate in directing the reclaimed wastewater to agriculture and in sharing the cost. From a normative point of view, the solution can serve the government or a mediator to suggest or force a transfer price – where the parties do not reach an agreement on their own.

The difficulty is that an outside agent, trying to set a transfer price, has to know the utility of the parties sharing the effluent.

Also, notice that the transfer price reached or dictated by the Nash Solution need not be a "market clearing" price. The Nash Solution price applies where an agency or a cooperative allocates the recycled water to its users. Where farmers are free to take as much of the effluent as they see fit at the price P_R of equation 4.12, the quantity demanded may exceed or fall short of the available supply.

A problem that often haunts parties to agreements is of potential opportunistic behavior. Once the agreement has been reached and the appropriate infrastructure installed, the farmers can threaten the town that they will not take the reclaimed water unless the transfer price is lowered. Similarly, the town – if it has an alternative – may threaten the farmers that the treated effluent will not be provided unless the price is increased. These potential threats are often real obstacles to reaching and implementing an agreement.

4.10 The role of the government

Governments provide public goods. In our case, first and foremost are regulations pertaining to treatment and reuse of wastewater. The regulations and their enforcement are public goods – as we have seen, wastewater and its disposal may have severe negative external effects. The health of farmers, their families, food consumers, and water using households cannot be left "to the market". There does not exist a market to regulate these external effects.

Further government involvement may also be justified sometimes. Enforcement is not costless, a city may dispose of its raw sewage into a nearby river at no cost and farmers may use slightly treated wastewater to irrigate sensitive crops. The government may find that it is more efficient and cost-effective to subsidized treatment and recycling than to engage endlessly in futile monitoring and enforcement. Economists who generally oppose subsidies and government economic intervention should be careful when criticizing efforts to achieve environmental public goals.

4.11 Concluding comments

As world population grows and standards of living increase, more water is used and more food is consumed. Irrigated agriculture will have to give up, in many places, freshwater to be diverted to human utilization. Replacement, at least partly, will come in the form of recycled wastewater. The treatment of wastewater is expensive and choice of technique and degree of purification will have to be made carefully. With cost comes the question of its recovery, hence the prices and levies charged in the urban sector and agriculture. These issues can be solved once it is recognized that treated wastewater is both a burden and an input – in agriculture and possibly in nature. Water is often carried over long distances, sewage is in general more local in nature. In this chapter, we demonstrated the basic approach to pricing and cost allocation, both where treated wastewater is provided to a large number of farmers and where a relatively small community comes to an agreement with surrendering agriculturalists. Needless to say, the economic models formulated were founded on a simplifying assumption; reality is more complex and application always requires careful analysis and planning. It is not superfluous, however, to re-emphasize the role of the government as regulator and arbitrator. Because of its strong external effects and complex economic issues, wastewater cannot be left to free market rule. Efficient and health preserving management of the sector can be expected only where the government is responsible and is able to convince the various stakeholders of the need to follow its guidelines.

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Appendix 4.1 The mathematical model of pricing in the steady state

The model is formulated under the assumption that all the requirements in equations 4.1 and 4.2 in the text are realized and all the variables are positive (no zeroes). The Lagrange function is

$$\begin{aligned} L = {} & C_{KH}M_{KH} + C_A R + C_D M_D + \lambda_A(X_A - M_A - \gamma R) + \lambda_U(X_U - M_U) \\ & + \lambda_M(M_A + M_U - M_{KH}) + \lambda_D(\mu_K M_A + \mu_R R - \mu_S M_D) + \lambda_R(rM_U - R) \end{aligned} \tag{A.1}$$

First order conditions

$$(i) \quad \frac{\partial L}{\partial M_{KH}} = C_{KH} - \lambda_M = 0$$

$$(ii) \quad \frac{\partial L}{\partial M_D} = C_D - \lambda_D \mu_S = 0$$

$$(iii) \quad \frac{\partial L}{\partial M_U} = -\lambda_U + \lambda_M + \lambda_R r = 0$$

$$(iv) \quad \frac{\partial L}{\partial M_A} = -\lambda_A + \lambda_M + \lambda_D \mu_K = 0$$

$$(v) \quad \frac{\partial L}{\partial R} = C_A - \gamma\lambda_A + \lambda_D \mu_R - \lambda_R = 0$$

$$(vi) \quad \frac{\partial L}{\partial \lambda_A} = X_A - M_A - R = 0$$

$$(vii) \quad \frac{\partial L}{\partial \lambda_U} = X_U - M_U = 0$$

$$(viii) \quad \frac{\partial L}{\partial \lambda_M} = M_A + M_U - M_{KH} = 0$$

$$(ix) \quad \frac{\partial L}{\partial \lambda_D} = \mu_K M_A + \mu_R R - \mu_S M_D = 0$$

$$(x) \quad \frac{\partial L}{\partial \lambda_R} = rM_U - R = 0 \qquad \text{(A.2)}$$

Using conditions *(i)*, *(ii)*, *(iv)*

$$\begin{aligned} \lambda_M &= C_{KH} \\ \lambda_D &= C_D \frac{1}{\mu_S} \\ \lambda_A &= C_{KH} + C_D \frac{\mu_K}{\mu_S} \end{aligned} \qquad \text{(A.3)}$$

And incorporating conditions (iv), (v)

$$\begin{aligned} \lambda_R &= C_A - \gamma C_{KH} + C_D \frac{\mu_R - \gamma \mu_K}{\mu_S} \\ \lambda_U &= C_{KH}(1-\gamma r) + rC_A + rC_D \frac{\mu_R - \gamma \mu_K}{\mu_S} \end{aligned} \qquad \text{(A.4)}$$

The shadow prices reflect marginal cost of provision to the sectors. Prices of urban water, freshwater in agriculture, and effluent are therefore

$$\begin{aligned} P_A &= \lambda_A = C_{KH} + C_D \frac{\mu_K}{\mu_S} \\ P_U &= \lambda_U = C_{KH}(1-\gamma r) + rC_A + rC_D \frac{\mu_R - \gamma \mu_K}{\mu_S} \\ P_R &= \gamma P_A \end{aligned} \qquad \text{(A.5)}$$

The last price, $P_R = \gamma P_A$, is not derived from the first order conditions; it reflects the quality ratio of effluent to freshwater. The prices of equation A.5 are presented in equation 4.3 in the text of the chapter.

The shadow price of effluent, λ_R, reports their cost to the national economy: by how much would the cost of the national product increase with an additional MC of effluent – when freshwater supply was not expanded?

$$\lambda_R = C_A - \gamma C_{KH} + C_D \frac{\mu_R - \gamma \mu_K}{\mu_S} = C_A + C_D \frac{\mu_R}{\mu_S} - \gamma P_A \qquad \text{(A.6)}$$

The components of the shadow price are the cost of sewage treatment plus removal of salt in the effluent minus the contribution of the effluent to production in agriculture. In the prices suggested in equation A.5, the cost of effluent is allocated to the sectors, households and agriculture.