II. TREATED WASTEWATER PROPERTIES IN RELATION TO IRRIGATION

Wastewater is classified according to the source: domestic, industrial, and agricultural. Effluents from industrial plants are not uniform in their composition and may contain toxic compounds, as mentioned previously. Such effluents may have to be disposed of. Domestic effluents are more uniform in their composition and the mineral pickup found in such effluents can be estimated. A sample composition is presented in Table I and Fig. 1. The supply water source is from Lake Kinneret, which is a major water reservoir in Israel, and the mineral pickup composition is an average of domestic effluents in Israel (Water Commission, 1963). Accordingly, the resultant wastewater composition is always made up by contributions of both supply water concentrations and mineral pickup during use.

Table I
The Resultant Composition of Wastewater from Kinneret Supply Water and Average Mineral Pickup

Composition	Supply water (Kinneret)	Mineral pickup (Average)	Resultant Waste-Water Composition
Ca (mEq/liter)	2.43	1.41	3.84
Mg (mEq/liter	2.19	2.54	4.73
Na (mEq/liter)	4.72	3.63	8.35
K (mEq/liter)	0.13	0.48	0.61
Cl (mEq/liter)	6.77	2.32	9.09
HCO_3 (mEq/liter)	2.70	3.55	6.25
SO_4	1.61	1.06	2.67
EC (micromhos/cm)	1050	560	1610
SAR	3.1	2.0	5.1

A. The Effect of Wastewater on Soil Properties

1. SOLIDS IN WASTEWATER

Treated effluents usually do not contain settleable solids, although they do contain a certain amount of suspended organic and inorganic solids. The amount of organic matter found in effluents is approximately 150 gm/m^3 which is considered a significant contribution to the soil when applied in irrigation. In light soils, these organic solids may increase the water-holding capacity, silt and clay content, cation exchange capacity (CEC), and organic matter content. See Table II, in which average values from a number of plots are presented (Hershkovitz *et al.*, 1969).

Table II
Soil Properties in Plots Irrigated with Effluents and Nonirrigated Plots

	Irrigated with effluent			Nonirrigated		
Depth (cm):	0–30	30–60	60–90	0–30	30–60	60–90
Sand (%)	88.7	92.9	91.8	97.0	95.5	97.0
Silt (%)	10.2	5.0	5.0	0	0.5	0.5
Clay (%)	11.1	2.1	3.2	3.0	4.0	2.5
CEC (mEq/100 gm)	11.0	9.5	6.6	4.8	2.3	2.4
Organic matter (%)	2.1	0.3	0.14	0.9	0.3	0.07

The effect was measured after 25 years of wastewater irrigation. The effect on the physical and physicochemical properties of the soil is to be related not only to the organic matter contributed directly by the effluent applied in irrigation, but also to the organic matter synthesized by plant and microbiological growth. The decomposition of the organic solids of the effluents proceeds at a fast rate judged by the rate of decrease in BOD levels of the effluent. However, plants irrigated with effluents leave behind organic residues, thus the measured increase is also indirect because of the stimulation of vegetative growth.

In heavy soils, there is a danger of soil-pore clogging. This is not only a mechanical process, but also a biological phenomenon due to the fast rate of algae development on the organic particles that precipitate in the small soil pores. Thus, a crust is formed in the upper soil layer.

The rate of infiltration of a sandy loam was measured in a citrus orchard that has been irrigated with treated effluent for a number of years. The measurements included an irrigated undisturbed surface and an irrigated disturbed surface, which had been tilled prior to the infiltration test. A third measurement was made in a neighboring orchard with the same soil type, except that it received a regular supply of water. The results are presented in Fig. 2 (Noy and Brum, 1973). Therefore, it can be seen that the restricting surface can be rendered more permeable when mechanically disturbed.

Another example is groundwater recharge by spreading basins in Israel, in which the infiltration rate decreases with time due to the clogging of the surface soil layer. Water is then transferred to another basin, so that the soil surface is dried out. It is then tilled and, in turn, receives effluent again.

Some accumulation of organic products, mainly due to anaerobic decomposition, may cause the clogging of soil pores in deeper layers. Decomposition of organic matter, enhanced when aerated, will clear these pores of such clogging.

The favorable effect on the physical properties of soil can be found in light soils, while in heavy soils a temporary decrease in permeability of water and air may be anticipated.

2. THE EFFECT OF SODIUM ON SOIL AGGREGATION

Clay particles are generally aggregated in soils and thus coarse pores can be found in between them. The composition of the exchangeable cations, adsorbed to the clay particles, affects aggregation. When the exchangeable sodium percentage ESP (exchange Na/CEC) $\times$ 100 in. mEq/100 gm soils exceeds 15, clay particle, flocculation is avoided, packing of particles becomes denser, coarse porosity decreases, and permeability to water and air is drastically reduced. This hazard is limited to medium and heavy soils. In light soils, which contain little clay, the sodium hazard is much less pronounced. The desirable ESP value should be less than 10. The quantitative relation between exchangeable cations is dependent on the quantitative relation between the cations in the soil solution, which will depend on the composition of applied irrigation water. The sodium adsorption ratio (SAR) which is $Na/(Ca + Mg/2)^{1/2}$ in mEq/liter of solution is related to ESP when soluble and exchangeable cations are at equilibrium, see Fig. 3 (Richards, 1954). Thus, the critical SAR value of the soil solution is about 13 and the desirable value should be less than 9.

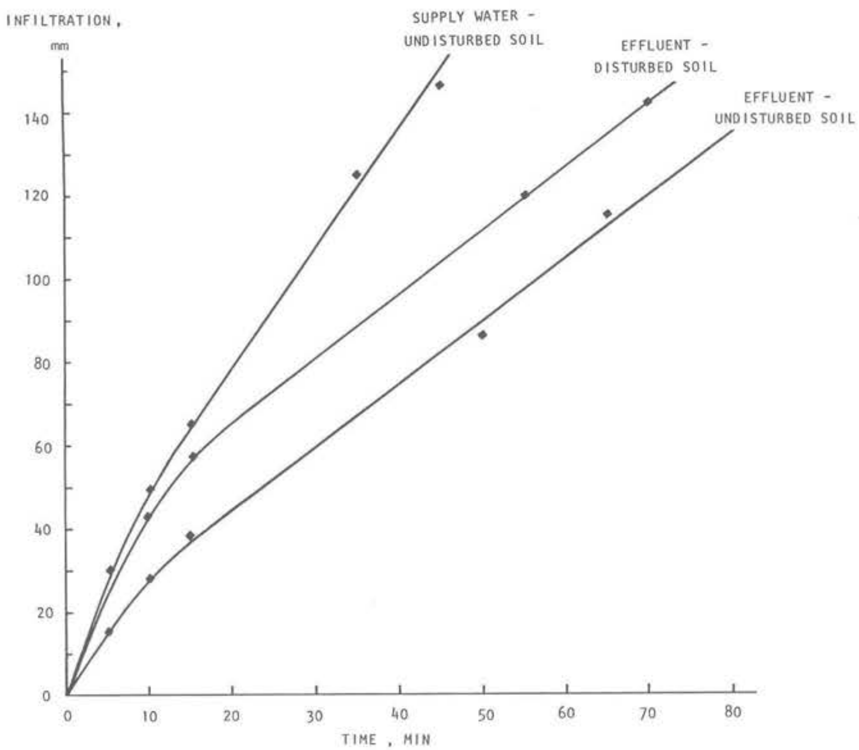

Fig. 2. The infiltration into a sandy loam through soil surfaces irrigated with treated wastewater and supply water.

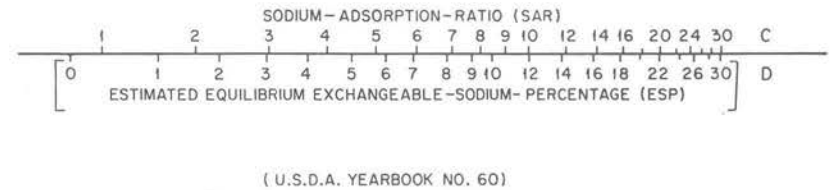

Fig. 3. ESP and SAR values of soil at equilibrium.

Treated wastewater has a high concentration of bicarbonate ions. As the water content of soil decreases, due to plant use and evaporation from the soil surface, the ion concentration increases. The solubility product of calcium and carbonate ions is low and calcium carbonate precipitates out. As a result of the reduction in soluble calcium, SAR values increase and the effected ESP of the soil increases beyond the expected value from the original composition of irrigation water.

The SAR pickup of domestic sewage is about 2. In industrial wastes, it may be higher where water softeners are in use. When an additional pickup of 3.5 mEq/liter or more of bicarbonate ions is considered, the possible hazard of sodium is increased.

There are several claims that have not been substantiated: first, that critical SAR values in wastewater can be higher than in supply water because sodium is less effective in avoiding clay particle flocculation in the presence of other flocculants carried by wastewater (Hershkovitz *et al.*, 1969).

When the expected sodium hazard is great, for any of the following parameters—SAR and bicarbonate content of the wastewater, the soil texture, and the amount of water applied in irrigation—a soluble calcium salt, such as gypsum $CaSO_4$, may be applied to reduce the effective SAR value. The amendment is applied directly to the soil or with the irrigation water.

3. EXCHANGEABLE CATIONS

The relationship between the exchangeable and the soluble cations in the soil has been discussed in relation to sodium. Potassium ion concentration increases in the soil solution after treated effluent is applied to the soil (see Table I) and so does the exchangeable potassium percentage EPP. This contributes to the fertilizer value of wastewater.

The magnesium increment during use is usually greater than that of calcium, increasing the magnesium-calcium ratio in wastewater. In heavy soils, magnesium is weaker than calcium in maintaining clay particles flocculated; thus, the deflocculating effect of the increased sodium concentration may be more effective.

Industrial wastes may contain low concentrations of heavy metals such as zinc, chromium, nickel, copper, and cadmium. These cations are strongly adsorbed and will be retained in the upper soil layer when effluent is applied in irrigation. The percolating effluents lose most of these cations and will contain smaller concentrations of the above cations upon reaching groundwater. Some pollution of the root zone must therefore be anticipated, although it is diminished by the precipitation of insoluble salts and the uptake of these ions by plants.

B. The Effect of Effluents on Plants

Wastewater is useful primarily as a source of water for irrigation and other purposes. This is especially felt in arid areas where water is scarce and its cost high.

The concentration of salts in supply water of arid areas approaches the limit tolerated by plants in many cases, so that treated wastewater does not effectively deteriorate the existing supply water. Wastewater contains, as mentioned previously, soluble constituents, of which some serve as plant nutrients and some may have a specific detrimental effect on plants.

1. PLANT NUTRIENTS IN EFFLUENTS

The amount of nutrients contained in treated domestic wastewater in Israel are about 50 gm N, 15 gm P_2O_5, and 30 gm K_2O/m^3 (Hershkovitz and Feinmesser, 1967). These must be assumed to save fertilizers when applied in irrigation. A number of trials have shown an increase in yield due to the fertilizer effect of the effluents used in irrigation. Wachs *et al.* (1971). Weighed *Avena* plants that were grown in pots and were irrigated with supply water and treated effluent, with and without fertilizer application. See Table III.

Table III

Yield, Grams per Pot, of Avena Irrigated with Supply Water, Effluent, And Different Amounts of Fertilizer [N as $(NH_4)_2SO_4$ and P + K Fertilizers]

$(NH_4)_2SO_4$ equivalent to kg/hectare	Supply water: Without P + K	Supply water: With P + K	Effluent: Without P + K	Effluent: With P + K
0	1.54	1.44	3.90	4.10
150	1.70	1.99	3.86	4.14
300	1.77	2.61	3.94	4.06
600	2.21	3.26	4.14	4.19
1200	2.46	4.36	4.19	4.11

Note that the yield of plants irrigated with effluent was about 4 gm per pot, with and without the addition of phosphorus and potassium. When the high level of the nitrogen fertilizer was applied to the plants irrigated with supply water, with the addition of phosphorus and potassium, the yield of 4 gm per pot was also obtained. The addition of fertilizer to the treated, effluent-irrigated pots did not increase their yield. It may be concluded that the effluent contained sufficient nutrients to satisfy the full requirement of the plants.

Day and Tucker (1960) compared the effect on three crops (barley, rye, and wheat) in the field, which received different treatments:

a. Well water with no fertilizer (control).

b. Well water with recommended fertilizer (100 lb N, 75 lb P_2O_5, 0 lb K_2O/acre).

c. Well water with synthetic sewage (200 lb N, 150 lb P_2O_5, 100 lb K_2O/acre).

d. Sewage effluent with no additional fertilizer (see Table IV).

The effect of sewage water on yield increase was not the same for the three grains. The yields of cotton in a heavy soil, irrigated for 5 yr with municipal sewage water (1963–1968) did not show an increase in yield compared to neighboring plots irrigated with supply water. All plots received the same amounts of water and fertilizers (Noy and Kalmer, 1970). Since 1968, there has been a lower yield of cotton in the effluent irrigated plots compared to the neighboring plots receiving supply water. The lag in yield may be a result of a more vigorous vegetative growth, observed in the plots irrigated with effluents, which repressed the yield of fiber.

It is evident that the response of plants to nutrients contained in treated effluents applied in irrigation depends on the kind of plant, its nutrient requirements, and the fertility level of the soil. The economical value of the nutrients in wastewater must be related to crop response and not to the nominal contents in the effluent.

In some cases, yields from plots irrigated by effluents were higher than could be expected due to the nutrients contained in them. These increments in yields

Table IV

Hay Yields (Air-dry in Tons/Acre) for Three Small Grains Grown under Different Irrigation and Fertilizer Treatments

Irrigation and fertilizer treatment	Barley	Oats	Wheat
a. Well water with no fertilizer	2.42 a[a]	2.13 a	2.76 a
b. Well water with recommended fertilizer	5.64 b	2.73 b	5.47 b
c. Well water with synthetic sewage	7.15 c	4.27 c	5.93 bc
d. Sewage water with no additonal fertilizer	5.88 b	6.05 d	6.43 c

[a] Yield values followed by the same letter for each crop are "equal."

Table V

Protein Percentage and Digestible Laboratory Nutrient (DLN) Percentage in Barley Forage Grown with Different Irrigation and Fertilizer Treatments

Irrigation and fertilizer treatment[a]	Protein	DLN
a. Well water with no fertilizer	11.1	72.7
b. Well water with recommended fertilizer	15.0	72.9
c. Well water with synthetic sewage	19.9	71.7
d. Sewage water with no additional fertilizer	20.0	71.1

[a]See Table IV.

may be obtained by improved conditions of plant absorption due to chelation of cations, or to specific effects of organic compounds. An example cited from G. Tewes *et al.* (1953) (cited in: Sklute, 1956) is the polyuronic acids formed from carbohydrates in dairy wastewater. Some workers point at changes in the chemical composition of yields from effluent applications. An example is presented in Table V (Day *et al.*, 1961).

Citrus plots were irrigated with effluents and supply water for a period of a number of years. Fertilizers were applied equally to all plots (Noy and Amichai, 1968). See Table VI. There was no significant difference between the plots receiving effluent compared to plots receiving supply water in yield, size of fruit, juice content, sugar to acid ratio, and mineral composition of the leaves; except for a slight increase in sodium and chloride leaf content and a decreased potassium content in the plots irrigated with effluent compared to the plots receiving supply water. Differences may become apparent after more years of the same treatments.

It may be concluded that the nutrients in treated wastewater are valuable. Some fertilizer amounts may be saved by the use of effluents for irrigation. The

Table VI

Yield, Juice Content, Sugar to Acid Ratio, and Mineral Content of Leaves in Citrus Plots on Two Soils Irrigated with Effluents and with Supply Water

					Mineral content of leaves, %					
Soil	Irrig. water	Yield kg per tree	Juice content %	Sugar to acid ratio	N	P	K	Mg	Na	Cl
Sandy clay loam	Supply	90	43.6	6.9	2.3	0.13	0.82	0.40	0.19	0.33
	Effluent	101	43.5	7.0	2.4	0.12	0.71	0.44	0.21	0.36
Sand	Supply	90	44.3	7.1	2.3	0.13	1.01	0.36	0.37	0.56
	Effluent	91	44.6	6.9	2.3	0.11	0.78	0.27	0.32	0.59

increments in yields and in certain plant constituents may be significant in soils of low fertility. However, the benefit from the nutrients in wastewater is not uniform and cannot be expressed in fixed monetary values.

2. ADVERSE EFFECTS ON CROP DEVELOPMENTS

The solutes contained in wastewater may restrict crop development either by the increase in osmotic pressure of the soil solution in the root zone, due to the accumulation of soluble salts, or by the specific effect of soluble constituents toxic to plants.

The critical concentrations detrimental to plant development depend on a number of parameters, such as soil permeability, precipitation, quantities of water applied, methods of irrigation, and crop tolerance. There are some indications that the critical levels of the detrimental constituents in treated wastewater are higher than those for the same constituents in supply water because of the moderating effect of organic matter and nutrient elements present (Hershkovitz *et al.*, 1969).

The permissible ranges in wastewater suggested in Israel are presented in Table VII. These are working limits and may be used more liberally when the soil is highly permeable and the climate wet.

The sensitivity of crops to salinity varies. The list of crop tolerance to salinity may be found in publications of the United States Salinity Laboratory at Riverside, California (Richards, 1954). Accordingly, sensitive fruit crops are avocado, citrus, and deciduous trees, while date palms are tolerant to salinity. Sensitive field crops are beans and Ladino clover, while cotton, sugar beet, barley, and Rhodes grass are tolerant.

Boron has a special place among the elements effecting plant growth. It is one of the essential elements; however, at concentrations exceeding 1 ppm boron may be toxic to sensitive crops. Although boron compounds may be highly soluble, it will be partly held by soil particles. Boron reaches waste-

Table VII

Suggested Critical Limits for Domestic Effluents Used for Irrigation

Composition	Sensitive crops	Tolerant crops
Electrical conductivity (micromhos/cm)	2000	3000
Chloride (mg/liter)	200	450
Sulfate (mg/liter)	300	500
Boron (mg/liter)	0.7	2.5
SAR value	8	15

water mainly from soap powders. In Israel, the incorporation of boron into soap powders and other detergent formulations has been restricted to diminish its concentration in wastewater.

The sensitivity of plants to boron varies. A list of tolerance values for plants to boron has been published by the United States Salinity Laboratory at Riverside, California (Richards, 1954). Accordingly, avocado, citrus, and deciduous fruit crops are the most sensitive. Sugar beet, alfalfa, gladiola, onions, and potatoes are among the most tolerant crops.

Industrial wastewater may contain heavy metals in concentrations exceeding the permissible limits for use in irrigation. These can be found in a report of the Committee on Water Quality Criteria of the U.S. Water Pollution Control Administration (1968). Accordingly, limits of chromium, lead, lithium, and zinc are 5 ppm; manganese, 2 ppm; aluminum and arsenic; 1 ppm; nickel, 0.5 ppm; cobalt and copper; 0.2 ppm; and cadmium, 0.005 ppm. When used occasionally, the limiting concentration is higher.

The heavy metals may be diluted by effluents from other sources, so that their concentration does not reach the prohibited values. When industrial wastes contain excessive quantities of heavy metals toxic to plants, they should be separated, usually into special evaporation basins or into the sea, and not used for irrigation.

III. TECHNICAL ASPECTS REGARDING IRRIGATION WITH TREATED WASTEWATER

A. Conveyance of Treated Wastewater from the Treatment Plant to the Irrigation Area

When designing the conveyance system of effluent from the treatment plant to the irrigated area, the topographical conditions have to be considered and, where conditions permit, every effort should be made so that the effluent will be conveyed by gravity flow. Only when topography is unfavorable should a pumping station be erected to pump the effluent to the irrigated fields.

The pipes commonly in use in Israel are asbestos cement pipes or steel pipes, usually with cement lining. Since the raw sewage flow varies during the day, it is necessary to provide a storage reservoir to equalize the flow and to ensure a constant supply of effluent for irrigation. The reservoir is also necessary to store the effluent during night hours and in situations where irrigation is being carried out at intervals of a few days.

The usual arrangement in Israel for conveying treated effluent is to build a

pumping station adjacent to an oxidation pond or another treatment plant, which pumps the effluent (under pressure) to the irrigated area (in case the topography is not suitable for gravity flow) (see Fig. 4).

The pump, in most cases, is a centrifugal vertical pump to ensure a convenient and simple operation as well as one that can be started easily without priming. Whenever it is feasible, the pumps are driven by means of an electric motor, which is easy to operate and maintain. Only in cases when electric power is not available, or the connection to the electric network is economically unjustified, are the pumps driven by diesel or other internal combustion engines.

B. Irrigation System

In many countries, sprinkler irrigation is commonly used. When irrigating with treated effluent, plugging of sprinkler nozzles should be considered. The raw sewage, after receiving secondary treatment, contains practically no settleable solids and little suspended solids. Therefore, the possibility of plugging of sprinkler nozzles is slight. As a precautionary measure, a gravel filter or a strainer can be installed at the outlet of the oxidation ponds or other treatment plant (see Fig. 5) to prevent the clogging of water meters, irrigation devices, and sprinkler nozzles. In addition, the diameter of the nozzles, preferably, should not be less than 5 mm. These strainers should be cleaned and the lateral pipes flushed out periodically.

Furrow irrigation with treated effluent does not essentially differ from irrigation with water from wells or streams. However, land leveling should be carried out carefully to avoid puddles of a stagnant treated effluent.

Trickle irrigation is now being used more extensively in a number of countries. This irrigation method has proved to be efficient in arid areas, for it saves water consumption and increases yield of crops. Trickle irrigation is based on applying the water to the land continuously by means of tricklers or small diameter pipes having small ports at regular intervals. Tricklers have very small flow of some 2–15 liters hr. The diameter of the passage of the trickle devices is very small, sometimes less than 1 mm. Attempts have been made in Israel to irrigate with treated effluent by this method, and the results have been quite encouraging (Sadovsky *et al.*, 1973). The advantage of trickle irrigation with effluent is that the contact between the treated effluent and the crop is less than with other methods, which reduces the possible contamination by pathogens.

C. Corrosion Problems

Domestic sewage that has received secondary treatment usually does not cause corrosion of the irrigation facilities, such as pumps, pipes (including

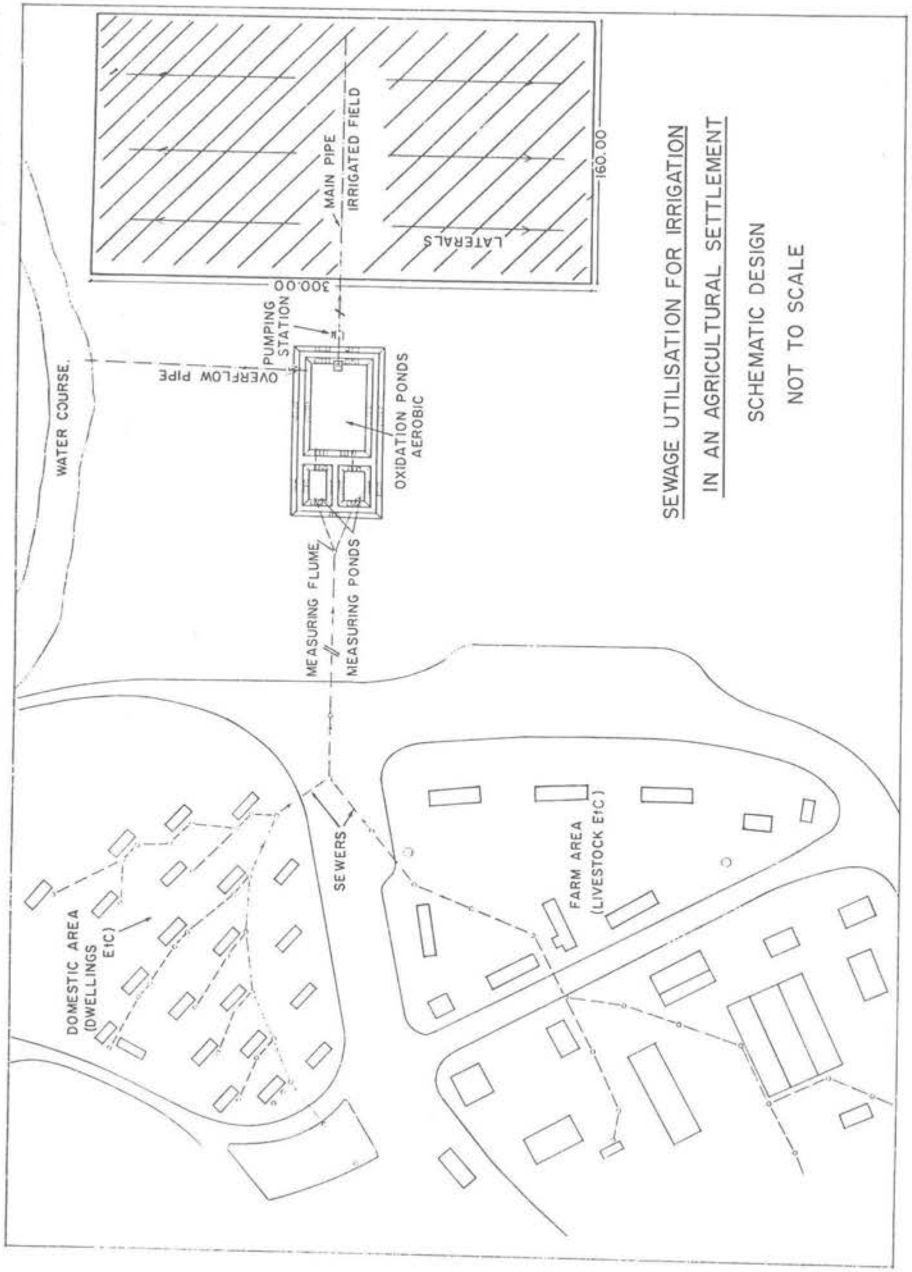

Fig. 4. Sewage utilization for irrigation in an agricultural settlement.

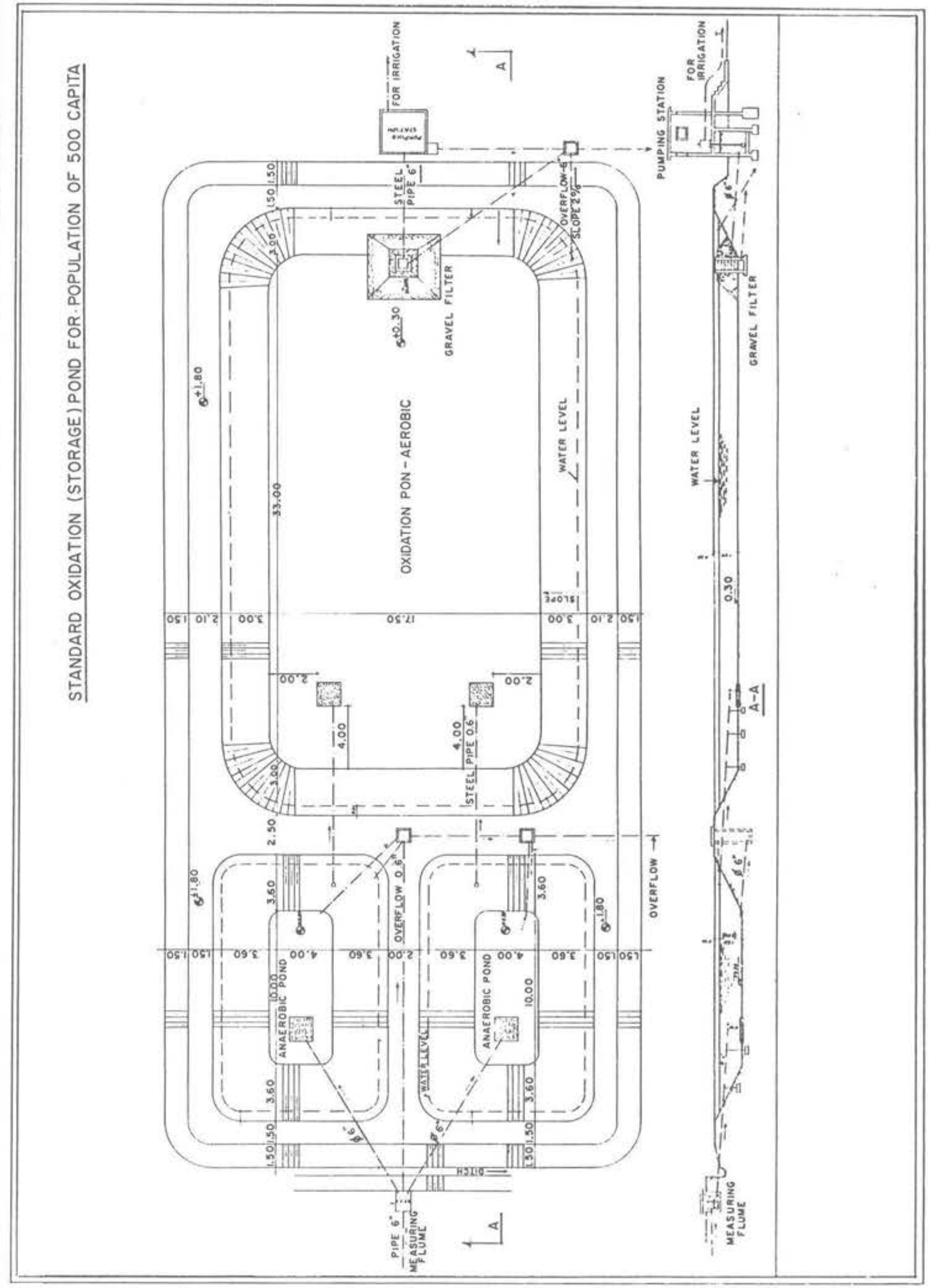

Fig. 5. Standard oxidation (storage) pond for population of 500 capita.

aluminum pipes), etc. This was reported in literature "Corrosion Problems Connected with Sewage Effluent May be Minimum" (Cantrell *et al.*, 1968). In Israel, corrosion problems are minimal. However, based on experience, the life expectancy of aluminum pipes used for irrigation with treated effluent is 10–20% less than when such pipes are used for irrigation with supply water.

On the other hand, industrial wastes are liable to be very corrosive. In certain cases, as was mentioned previously, these kinds of wastes should be segregated to prevent their detrimental effect on the sewer pipe, on the irrigation system, and on the irrigated crop.

D. Storage Reservoirs

As was mentioned previously, to make efficient use of treated effluent for irrigation, storage reservoirs are needed. Actually, such ponds act as polishing ponds and further reduce the BOD and pathogenic organisms (Cantrell *et al.*, 1968). Oxidation ponds can also serve as a dual purpose facility. In semiarid and arid climate, a seasonal storage of effluent is necessary to store effluent during the rainy season so it will be available for use during the dry season. Storing the effluent during the wet season will also prevent it from flowing into water courses, which would create sanitary and pollution problems (Finemesser, 1971).

The relatively inexpensive earthen reservoirs are 3 to 5 m deep and have sufficient capacity to store unutilized treated effluent during the wet period. There is a possibility that during such a long time of storage, anaerobic conditions might develop that will cause sanitary nuisances, such as odor dissipation. To prevent such undesirable anaerobic conditions from developing in the reservoir, artificial aeration is required.

E. Oxidation Ponds

Oxidation ponds to treat sewage are in wide use. This means of treatment has justified itself in Israel, especially in agricultural settlements and small- or medium-sized towns. The long hot summers enhance the development of algae on which this treatment method is based. The building, operation, and maintenance of these ponds are relatively inexpensive when compared with conventional treatment plants. The arrangement generally adopted is to convey raw sewage through two parallel anaerobic ponds where alternate cleaning occurs and then through an aerobic pond for final treatment (see Fig. 2). The design criteria, which are recommended today are as follows: anaerobic ponds: depth, about 2.5 m; detention time, about 1 day; load, 150–200 gm BOD/m^2/day. These values have recently been adopted to assure anaerobic conditions throughout the whole depth of the pond.

Aerobic ponds: depth 1.2–1.5 m for good light penetration; detention time, 7–10 days; load, about 15 gm BOD/m^2/day. This value has been adopted to assure aerobic conditions even during the winter, when the solar radiation is comparatively low. Oxidation ponds have, however, a disadvantage that cannot be disregarded in comparison with conventional treatment plants because they require considerable areas of land. When land value is low, this disadvantage is not particularly significant, but as towns develop and the price of land around them increases, the land value then becomes a factor that has to be taken into consideration. In cases where land values are a factor, aerated ponds are being introduced in Israel, which allow higher rates of organic loading and, consequently, require less land.

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Water Reuse in Industry

Lawrence K. Cecil