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Waste water treatment and reuse in irrigation

BY

Engr. Mian Muhammad Amin

Executive Engineer,

Public Health Engineering Department, Punjab

WASTE WATER TREATMENT AND REUSE IN IRRIGATION

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Abstract:

Reuse of sewage effluent has special significance for the developing countries with arid and semi-arid climates and limited water resources. The paper reviews the potential problems in the reutilization of sewage effluent in irrigation. The effluent quality criteria related to health and agronomic aspects are summarized. Attention is drawn to the need for pre-application treatment of sewage and crop selection from the stand point of Public Health considerations as per water quality guidlines of FAO for Agriculture. Comparison of conventional and non-conventional treatment processes with particular reference to Pathogen removal is given. It is suggested that in planning effluent reuse schemes the level of wastewater treatment should be adopted as low as possible. Finally, treatment technologies appropriate for the developing countries viz. wastestabilization ponds, soil Aquifer-treatment system and Root Zone Method are discussed.

1. Introduction

Wastewater irrigation is being practised around the world because of significant economic benefits from reuse of nutrient rich sewage. Effluent reuse has special significance for developing countries with arid and Semi-arid climates and limited water resources. Land application of wastewater provides nutrients for crop growth and organic matter for soil conditioning, and it is often the most economic means of wastewater disposal. However, reuse of sewage effluent for irrigation entails certain risks to health and must be practised under carefully controlled circumstances.

Wastewater reuse through land application is not new, and there have been many successful systems. However, in today's environment, the level of potential contaminants in wastewater is increasing. Salts, fertilizers, toxic materials, Pathogenic bacteria, viruses; and other objectionable microorganizms contribute to the problems associated with treatment and land disposal of wastewater.

Low-cost pretreatment of municipal wastewaters and most industrial effluents is usually necessary. Pretreatment systems employing physical, chemical, biological or combination treatment processes are viable alternative processes. In general, it is not advisable for developing countries to adopt conventional wastewater treatment processes, as more recently new cheap technologies such as waste stabilization ponds, soil-aquifer systems, and Root-Zone method have been developed. These non-conventional treatment technologies are more appropriate and suitable for developing countries because in-addition to being low-cost they are more efficient in the removal of pathogens, which is the primary objective in irrigation reuse schemes. It is imperative that guidance be provided to the reuse planners to select the combination of wastewater treatment, irrigation system and choice of crops which is most appropriate for the local conditions. Provided the downstream effluent reuse system can be properly controlled and managed, the simpler the treatment process the greater the chance the scheme will be successful.

In the absence of the facilities for wastewater treatment, environmental pollution from wastewater can be controlled to a considerable extent by land application-cum-treatment of wastewater with crop/land scape irrigation. In using sewage effluent for agricultural purposes, crop selection should be considered from the stand point of public health considerations. The health hazards due to irrigation with untreated effluent can be reduced by proper planning and management of the

* Executive Engineer, Public Health Engineering Department Punjab.

wastewater-soil-crop system and by restricting the choice of crops for wastewater irrigation, as per water quality guidelines of FAO, 1985[1] for agriculture.

2. Wastewater Irrigation

Land application of wastewater provides an opportunity for exploiting the reuse potential of wastewater for productive purpose. The most attractive feature of irrigation with reclaimed wastewater is the return of plant nutrients to the soil, completing the natural cycle which is very important for preserving soil fertility. Land-applied wastewater also undergoes natural physico-chemical and biological treatment in the soil matrix which provide not only a highly effective low-cost alternative to conventional treatment but also an ecologically balanced and environmentally compatible system of wastewater management.

Land disposal of wastewater predates modern civilization. Controlled wastewater reuse in agriculture has been practised in Europe, North America and Australia. Since the beginning of this century and many sewage farms are still operating today. Selected early land application systems are shown below in table 1.

Table 1.

Selected Early Land Application Systems

Location	Date Started	Type of System	Area (ha)	Flow (cu m/day)
International				
Croydon-Beddington, England.	1860	Sewage Farm	250	20,000
Paris, France.	1869	SR[a]	6,500	300,000
Leamington, England.	1870	Sewage Farm	160	3,000
Berlin, Germany	1874	Sewage Farm	2,800	. . .
Wroclaw, Poland.	1882	Sewage Farm	1,500	170,000
Melbourne, Australia	1893	SR	4,000	180,000
		OF[b]	4,400	260,000
Braunschweig, Germany,	1896	Sewage Farm	4,000	60,000
Mexico City, Mexico.	1900	SR	45,000	2,000,000
United States				
Calument City, Michigean	1888	RI[c]	5	4,500
Woodland, California	1889	SR	1,000	16,000
Fresno, California	1891	SR	1,620	98,000
San Antonio, Texas	1895	SR.	1,620	76,000
Vineland, New Jersey	1901	RI	6	3,000
Ely, Nevada	1908	SR	570	5,700

Note: [a]SR = Slow Rate [b]OF = Overland flow
[c]RI = Rapid infiltration

Source: Gloyna. E. F. Wastewater Reuse through land application.

The value of wastewater for crop irrigation has also been recognised in China, India and latterly, the Middle East. Even in water plentiful areas, reuse of effluent is increasing in importance as a beneficial water conservation measure. The nitrogen and phosphorous contained in municipal and some industrial wastewaters are valuable plant nutrients, which can be of significant economic benefit in irrigation. The results of many studies indicating the beneficial effects of wastewater nutrients on plant growth are reported in the literature over the past few years [2,3,4,5].

In a study carried out at Karachi University with stabilization pond effluent (NPK content: 21.02, 3.49 and 6.66 mg/1) it was found that irrigation of maize plants with liquid fertilizer considerably increased plant growth and yield. The study concluded that for maize crop irrigation liquid fertilizer could effectively replace the standard chemical fertilizer[6]. Another study conducted at Kahna Nau, Lahore by EPCO, Public Health Engineering Department [7] indicated that rapid and miximum growth with excellent yield was achieved by irrigating the crops with raw sewage.

Wastewater irrigation by untreated sewage is being practised in Pakistan since long time. Urban water supplies have been improved considerably in many of the cities and with this advance has come an increasing problem of wastewater disposal. Where water-borne sewerage is installed it is feasible to contemplate reclamation of the collected wastewater and its reutilization. In Lahore 225 mgd of wastewater is generated, out of which 36.4% is utilized for sewage irrigation and the remaining discharged into reiver Ravi[8].

The conditions in arid or semi-arid regions give rise to a perpetual demand for irrigation water and are congenial for land treatment-cum-utilization of wastewater for irrigation. The importance of conserving water and nutrients and recycling these constitutents of wastewater is being increasingly realised and emphasised in many countries around the globe.

Today the disposal of wastewater on land and the utilization of land treatment processes have developed into a well-defined technology. Added emphasis is placed on pre-treatment, overall planning, and efficient reuse of water. Some selected wastewater reuse and land disposal projects are described below:-

Australia:

Werribbee Farm, Melbourne, Australia, discharges $4.4 x 10^5$ cu m/day to several thousand acres of crop land supporting 30,000 sheep and 22,000 beef cattle [9]. The concentration of heavy metals in the harvested herbagefall within acceptable ranges although N, P and K show increases, the BOD_5 and SS removal rates are around 95%. All of this is remarkable since 30% of the flow and 75% of the organic loading is contributed by industrial wastes.

France:

The municipal wastewater farms of Paris has been in operation since 1880, and these farms have been very successful. These farms are receiving about 100 million cu m/yr of wastewater. Application rates are 4 m per year over a mixture of sand, clay, and gravel[10].

Germany:

At Braunschweig, Germany, cereal crops, potatoes, sugar beets, and asparagus have been irrigated by wastewater application for many decades10.

Poland:

In Poland during dry years, sewage represents 50% of all surface flow. The Wroclaw Farm, 1,500 ha, receives 170,000 cu m/day it has been in operation for 100 years[10].

United States:

The U.S. nearly a decade ago registered about 600 municipalities and 1,300 industrial facilities discharging wastewaters on land. Most of these sites were located in the dryer western states. The 1972 Amendments to the U.S. Federal Water Pollution Control Act indicate that it is a national goal to minimize discharge of waste to surface waters.

The state of California leads the U.S. in reuse with a history of irrigation and reuse that dates back to 1929. The volume of wastewater reused in 1977 was about 227 billion cu m. Of the 200 projects in operation, 150 were classified as nonsensitive crop irrigation and 50 were used to water golf course, recharge groundwater, industrial reuse and other purposes [11].

At the billion dollar Disney World complex in Florida, a secondary treatment plant with teritary holding ponds provides water for tree farms, agricultural usage, aquaculture, and wetlands-land treatment systems.

India:

The first sewage farm in India was established as far back as 1895, today there are over 132 farms covering more than 12,000 hectares and utilizing over 1 million m^3 of sewage per day. There are several more farms that receive industrial effluents, particularly from the sugar distillery, food-processing, fertilizer and other industries [12].

Kuwait:

Tertiary treated sewage effluent from three sewage treatment works is transferred to a central distribution and administration centre, wherefrom effluent is directed to an existing farm (860 ha) and also to a newly created agricultural area (870 ha). Forage (alfafa) for the dairy industry is the main crop, but peppers, onions and other crops are grown on experimental basis. As effluent quantity increases a third agricultural area of around 1400 ha will be established to produce similar crops.

Our 10 million m^3/a of effluent is currently being used which will rise to 125 million m^3/a by the year 2010 constituting one of the most ambitious schemes for agricultural reuse in the Middle East. In addition to the above, an ambitious programme of afforestation to cover an ultimate area of 12,000 ha is planned. The prime purpose of the afforestation is to grow a variety of trees for beautification and wind/dust breaks particularly for marginal strips along major highways and to protect new townships [13]

Qatar:

In 1983 a new sewage works incorporating biological treatment by activated sludge and tertiary treatment by rapid gravity sand filters was commissioned with a capacity of 60,000 m^3/day. Of this some 15,000 m^3/day is used for mainly amenity and afforestation, the surplus being pumped to an evaporation lagoon in a remote desert region where it also provides ground water recharge. The long term policy envisages all effluent being reused and by the year 2000. it is anticipated 72,000 m^3/day will be available for agriculture [13].

Saudi Arabia:

The King Khalid Military City, Saudi Arabia, a city of 70,000 people and one of the World's largest and costliest construction projects, will reuse all water. Sewage effluents will be used for agricultural purposes [14].

Effluent reuse scheme is planned for the Qassim Area, comprising 1000 Sq. K.M. and including the major towns of Buraydah, Unayzah, Al-Rass, Al-Burkayriya and Riyad Al-Khabra. It is planned to develop the irrigation of fodder crops on Government controlled farms, landscaping where human contact is minimal, and tree planting for sand stabilization and environmental protection[13].

Iraq:

Effluent from sewage treatment work is discharged into a tributary of the Tigris and, with ample dilution and further purification in the river, water is abstracted downstream for irrigation of crops [13].

3. Potential Hazrds of Wastewater Irrigation

Wastewater of domestic origin carry pathogenic and parasitic organisms which form souce of contamination of soil and crops and may cause infection to farm labourers and consumers of sewage-irrigated crops[15]. The main objectives, therefore, in treating wastewater in an effluent reuse scheme are to reduce health risks and prevent environmental contamination.

3.1 Health Hazards:

The potential risk of infection to humans, animals and plants from land application of treated wastewater is attributable to the presence of pathogenic organisms in the raw wastewater. A number of studies have indicated that under favourable conditions enteric pathogens can survive for extremely long periods of time on crops, in water or in the soil. Factors that affect survival include the number and type of organisms, soil organic matter content, temperature, humidity, PH, amount of rainfall, amount of sunlight protection provided by foliage, and competitive microbial flora. The variation in survival time is large as indicated in table 2 Organisms such as *Vibro chloera* have relatively short survival times, whereas other pathogns, including some bacterial species, ascaris ova and enteric viruses, appear to be highly resistant to environmental stress. The survival times of pathogenic organisms on wastewater irrigated crops tend to be lower than in soils as shown in table 2.[16]

The mere presence of an infectious agent in an effluent is not sufficient cause to declare the wastewater unsafe. Hutzler and Boyle[17] have indicated that 'Even the most dreaded hazard poses no risk if people are not exposed to it'. It is important, therefore in assessing the health hazards of wastewater reuse to establish the relative importance of various routes of transmission, from direct contact with the wastewater, through food or air, to indirect contact. Important parameters are: the concentration of the infectious agents, the amounts ingested, the duration of exposure and the characteristics of the exposed population. The first three are closely related and are controlled by the survival of pathogenic organisms in the effluent, on crops and in the soil.

The transfer of wastewater irrigated produce from field to market and thence into the home presents the greatest risk to the general public. During this period there may be cross-contamination with other products, contamination from handling the produce and contamination of food preparation environments. Cooking of produce at a temperature in excess of 75^{o}C will kill bacteria, protozoa, helminthic and most viruses. The greatest risk is from health sensitive crops, including fruit and vegetable that are eaten raw.

Despite the extensive world wide practice of nightsoil and sludge fertilization and wastewater irrigation dating back many years there are few epidemiological studies that have established definitive adverse health impacts of the consumption of food grown in this way. Shuval *et al*[18] have reported one of the earliest evidences connecting agricultural wastewater reuse with the occurence of disease. In area of the world where helminthic diseases caused by Ascaris and Trichuris spp. are endemic in the population, and where raw untreated wastewater is used to irrigate salad crops and/or other vegetables which are generally eaten raw, transmission of these infections has been found to occur through the reuse channel. A study in West Germany, reported by Gunnerson *et al*[19] showed that cholera could be transmitted through the same channel. There is also limited epidemiological evidence indicating that beef tapeworm (Taenia saginata) has been transmitted to the population consuming the meat of cattle grazing on wastewater-irrigated fields, or fed crops from such fields. Reports from Melbourne, Australia and Denmark, reviewed by Gunnerson *et al*[19] strongly confirmed this. Although the reported incidence of diseases among workers on sewage farms has been inconclusive, there is always a potential risk associated with direct contact of wastewater with hands, which might then contaminate food. Another potential problem is that of possible inhalation of aerosolised sewage containing pathogens from spray irrigation. Shuval[20] estimated that between 0.1 and 1% of the sewage sprayed into the air form aerosols which are capable of being carried considerable distances by wind.

Table 2.

Survival of Excreted Pathogens (At 20-30^{o}C)[16]

Type of pathogen	Survival times in days: In faeces nightsoil and sludge	In fresh water and sewage	In the soil	On crops
Viruses				
Enteroviruses	< 100 (< 20)	< 120 (< 30)	< 100 (< 20)	< 60 (< 15)
Bacteria				
Faecal coliforms	< 90 (< 50)	< 60 (< 30)	< 70 (< 20)	< 30 (< 15)
Salmonella spp.	< 60 (< 30)	< 60 (< 30)	< 70 (< 20)	< 30 (< 15)
Shigella spp.	< 30 (< 10)	< 30 (< 10)		< 10 (< 5)
Vibrio Cholerae	< 30 (< 5)	< 30 (< 15)	< 20 (< 10)	< 5 (< 2)
Protozoa				
Entamoeba Histolytica cysts	< 30 (< 15)	< 30 (< 15)	< 20 (< 10)	< 10 (< 2)
Helminths				
Ascaris Lumbricoides eggs	Many months	Many months	Many months	< 60 (< 30)

* Figures in brackets show the usual survival time.

Source: Feachem *et al* (1983)

The susceptibility of the population to long-term exposure to low levels of toxic chemicals, through the consumption of groundwater into which these materials have leached, is also of concern. Although studies have indicated that only negligible amount of such toxic chemicals normally move 30 cm beyond the point of application within the soil. Yet it is possible that long-term effluent reuse and eventual accumulation of toxic materials in the soil might lead ultimately to their mobilization and results in an increasing concerntration showing up in groundwater. Numerous studies have indicated that the content of certain toxic metals in plant tissues is directly proportional to the concentration of such metals within the soil root zone. Thus, long-term application of wastewater in irrigation poses the risk of plants having high levels of toxic materials in their tissues and the FAO Irrigation and Dranage Paper No. 29[21] recommended some maximum concentrations for phytotoxic elements in irrigation water.

3.2 Environmental Aspects:

Although irrigation has been practised throughout the world for several millenia, it is only in this century that the importance of the quality of irrigation water has been recognised. Irrigation water quality is of particular importance in arid zones where extremes of temperature and low relative humidity result in high rates of evaporation with consequent salt deposition from the applied water, which tends to accumulate in the soil profile. The physical and mechanical properties of the soil, such as dispersion of particles, stability of aggregates, soil structure and permeability, are very sensitive to the type of exchangeable ions present in irrigation water. Thus, when effluent reuse is being planned, several factors related to soil properties must be taken into consideration.

It has been established that the productivity of irrigated land is fundamentally dependent on its internal drainage, which is a function of the soil profile morphology, pore size distribution and stability of pore structure. The first two factors are of paramount importance in relation to effluent reuse in irrigation. No irrigation scheme can succeed unless the soil profile remains permeable, and this depends both on the proportion of exchangeable cations held by the soil, other than sodium (termed the Exchangeable sodium Percentage - ESP) and on the total concentration of soluble salts in the percolating water. Considerable laboratory evidence exists to indicate that pore structural stability is very important in determining the hydraulic properties of soils. MacNeal and Coleman[22] showed that hydraulic conductivity of a soil is a function of the ESp and is related to a solution parameter termed the Sodium Adsorption Ratio (SAR). Quirk and Schoefield[23] proved that the higher the SAR and the lower the electrolyte concentration of the percolating solution, the larger the hydraulic conductivity reduction. A further factor to consider in respect of wastewater irrigation is the high content of nutrients which might promote microbial growth, with consequent reduction in soil permeability and hydraulic conductivity.

Another aspect of agricultural concern is the effect of dissolved solids in the irrigation water on the growth of plants. Dissolved salts increases the osmotic potential of soil water and an increase in osmotic pressure of the soil solution increases the amount of energy which plants must expend to take up water from the soil. As a result, respiration is increased and the growth and yield of most plants decline progressively as osmotic pressure increases. Although most plants respond to salinity as a function of the total osmotic potential of soil water, some plants are susceptible to specification toxicity. Many of the ions which are harmless or even beneficial at relatively low concentrations may become toxic to plants at high concentration, either through direct interfrence with metabolic processes or through indirect effects on other nutrients, which might be rendered inaccessible.

Morishita[24] has reported that irrigation with nitrogen-enriched polluted water can supply a considerable excess of nutrient nitrogen to growing rice plants and can result in a significant yield loss of rice through lodging, failure to ripen, increased susceptibility to pests and diseases as a result of over luxuriant growth. He further reports that non-polluted soil, having around 0.4 or 0.5 ppm cadmium may produce about 0.08 ppm Cd in brown rice, and only a little increase upto 0.82, 1.25 or 2.1 ppm of soil Cd has the potential to produce heavily polluted brown rice with 1.0 ppm Cd.

A further factor of environmental concern is the possibility of groundwater contamination due to long-term use of sewage effluents. The potential for groundwater contamination by micro organisms depends upon the rate of removal of pathogens by the soil, the depth to the groundwater, and the survival of pathogens in the soil and in the ground water. It must be appreciated that bacteria and viruses are living things and are subject to death and decay. Prolonged storage, both within the environment and after abstraction, could serve as safeguard against microbial contamination. Because trace inorganic pollutants persist in the environment and do not suffer loss of toxicity, long-term use of wastewater for irrigation may result in their gradual accumulation in and transport through the soil. It is therefore, necessary to assess the build-up and travel times of toxic materials within the soil to ensure the safety of groundwater.

The impact of pollution on groundwater has recently been investigated in a research study at the Institute of Public Health Engg. & Research, Lahore[8]. The study revealed that groundwater quality showed signs of deterioration within a radious of 1 Km from the investigated site. Groundwater examination indicated an increase of total dissolved solids, Electrical conductivity, chlorides, Nitrates, Phosphates, Trace organics, total Coliforms, faecal coliforms and faecal streptococci. The researcher has recommended that a long-term ground and surface water monitoring programme should accompany any land-wastewater-application system in order to detect, as soon as possible, any environmental contamination problems.

4. Effluent Quality for Agricultural Reuse:

4.1 Effluent Quality Criteria Based on Health Requirements:

Developments of standards and water quality criteria for effluent reuse in irrigation have mainly evolved from a consideration of health risks. In the United States, State health departments or agencies responsible for reuse activities formulate policy or decide on specific projects primarily on the basis of concern about infectious agents, accepting that most other constituents in reclaimed water would pose no immediate substantial harm in the rare case of accidental ingestion. For example, the state of California has established standards which require that the reclaimed water for irrigating food crops at all times must be adequately disinfected and filtered, with median coliform .count no more than 2.2/100 ml[25]. In 1973 a World Health Organization (WHO) Committee of Experts on the subject recommended[26] that crops eaten raw should be irrigated only with biologically treated effluent that has been disinfected to achieve a coliform level of not more than 100/100 ml in 80% of the samples.

However, a recent meeting in Engelberg, Switzerland, sponsored by the World Bank and World Health Organization to review the health aspects of wastewater and excreta use in agriculture and aquaculature, concluded[27] that many standards previously recommended were unjustifiably restrictive and not supported by currently available epidemiological evidence. It was recommended that WHO should initiate revision of its 1973 Technical Report No. 517 in collaboration with other interested agencies, such as the World Bank, the U.N. Food and Agriculture Organizaion (FAO) and the U.N. Environment Programme (UNEF). On the basis of a tentative model for the health risks associated with the use of untreated wastewater and exereta. The Engelberg Report[27] included recommendations for the Microbiological quality of treated wastewaters to be used for agricultural irrigation as in table 3. For the first time, a guideline for the helminthic quality of treated wastewater is introduced. The quality guideline for restricted irrigation is intended as protection for the health of agricultural labourers but makes no allowance for future improvements in the design and control of irrigation systems. Guidelines for unrestricted irrigation are related to the need to protect the health of the consumers of crops (Principally vegetables)

Table 3

Tentative Microbiological Quality Guide lines for Treated Wastewater Reuse in Agricultural Irrigation(1)[27]

Reuse Process	Intestinal nematodes (2) (geometric mean no of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml).
Restricted irrigation[3]		
Irrigation of trees, industrial crops, fodder crops, fruit trees[4] and pasture[5]	⩽ 1	not applicable[3]
Unrestricted irrigation		
Irrigation of edible crops sports fields, and public parks[6].	⩽ 1	⩽ 1000[7]

Key:

(1) In specific cases, local epidemiological, socio-cultural, and hydrological factors should be taken into account, and these guidelines modified accordingly.

(2) Ascaris, Trichuris and hookworms.

(3) A minimum degree of treatment equivalent to at least a 1- day anaerobic pond followed by a 5-day facultative pond or its equivalent is required in all cases.

(4) Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.

(5) Irrigation should cease two weeks before animals are allowed to graze.

(6) Local epidemiological factors may require a more stringent standard for public lawns especially hotel lawns in tourist areas.

(7) When edible crops are always consumed well-cooked, this recommendation may be less stringent.

4.2 Effluent Quality Criteria Based on Agronomic Requirements:

Apart from effluent quality criteria related to health there is a need to be concerned about the quality of irrigation water in terms of its effects on the soil and on crops. It must be realised that it is not possible to cover all local situations when preparing water quality criteria and the approach has been to present guidelines that stress the management needed to successfully use water of a certain quality. The exact choice in practice must be made at the planning stage, taking account of the specific local conditions. Guidelines for evaluating irrigation water quality applicable to conditions encountered in California are given in Table 4.

Table 4.
Guidelines For Interpretation of Water Quality for Irrigation (Applicable in California)[28]

Potential Irrigation Problem	Units	Degree of Restriction on Use: None	Slight to Moderate	High
1. Salinity a. EC_w (Affects Crop b. TDS availability)	ds/m or mmho/cm	< 0.7	0.7-3.0	> 3.0
	mg/1	< 450	450-2000	> 2000
2. Permeability	SAR=0.3 ds/m or mmho/cm	> 0.7	0.7-0.2	< 0.2
(Affects infiltration	3-6 (EC_w)	> 1.2	1.2-0.3	< 0.3
rate of water into the soil)	6-12	> 1.9	1.9-0.5	< 0.5
Evaluate using EC_w and SAR	12-20	> 2.9	2.9-1.3	< 1.3
Together)	20-40	> 5.0	5.0-2.9	< 2.9
3. Specific Ion Toxicity:				
Sodium				
a_1 surface irrigation	SAR	< 3	3-9	> 9
a_2 sprinkler irrigation	mg/1	< 70	> 70	–
Chloride				
b_1 surface irrigation	mg/1	<140	140-350	> 350
b_2 sprinkler irrigation	mg/1	<100	> 100	–
Boron	mg/1	< 0.7	0.7-3.0	> 3.0
4. Miscellaneous Effects				
1. Nitrogen(Total-N)	mg/1	< 5	5-30	> 30
2. Bicarbonate (sprinkler only).	mg/1	< 90	90-500	> 500
3. pH	Normal range	6.5-8.4		
4. Residual Chlorine (sprinkler only)	mg/1	<1.0	1.0-5.0	> 5.0

Source: Westcot and Ayers (1984)

4.3 Effluent Monitoring:

Since the use of sewage for irrigation carries the greatest risk from substances with irreversible effects on humans and the environment, monitoring of sewage irrigation must be well regulated. In sewage-irrigated areas, the toxic constituents of the sewage used, and their concentrations in soil, vegetation and groundwater must be monitored and the public health hazard assessed[29]. Monitoring pollutants in soils and crops is useful for estimating hazard level and for determining the effectiveness of control programmes.

5. Appropriate Wastewater Treatment Technologies for Effluence Reuse in Irrigation:

5.1 Need for Pre-application Treatment:

Although irrigation with wastewater is in itself an effective form of wastewater treatment (such as in slow-rate land treatment), some degree of treatment must be provided to untreated municipal wastewater before it can be used for agricultural or landscape irrigation[28]. The degree of pre-application treatment is a key factor in satisfactory operation and performance of a wastewater-soil-plant system.

Pre-application treatment of wastewater is practised for the following reasons:

i) Protect Public Health
ii) Prevent nuisance conditions during storage
iii) Prevent damage to crops and soils.

There are many treatment processes which can be combined to produce an end-product from urban wastewater that would be acceptable for uses ranging from grass irrigation to human consumption. The choice of treatment technology is very important because of the economic consequences of the decision, particularly in developing countries. Unnecessarily costly treatment will divert scarce resources away from other developmental uses. Because wastewater treatment is expensive and because crops differ very much in the level of effluent treatment they require, decisions on the choice of crops and level of treatment is crucial to the economic and environmental success of the system[30].

The level of treatment required for agricultural and landscape irrigation uses depends on the soil characteristics the crop irrigated and the irrigation system. Through crop restriction and selection of irrigation system which minimize health risk, the level of wastewater treatment can be reduced. In the developing countries, it is desireable to adopt as low a level of treatment as possible not only from the stand-point of cost but also due to the difficulty in operating complex systems reliably. In many locations it will be better to design the reuse system to accept a low-grade of effluent rather than rely on advanced treatment processes producing a relaimed effluent which continuously meets a stringent quality standard.

Nevertheless, there will be locations where a higher-grade effluent is necessary and it is essential that information on the performance of a wide range of wastewater treatment technology should be made available. Unfortunately few performance data on wastewater treatment plants in developing countries are available and even then they would not normally include effluent quality parameters of importance in irrigation reuse.

Excreted pathogens and bacteria are present in both the effluent and the sludge in high concentrations and the heavier Protozoal systs and helminth eggs tend to be concentrated in the sludge. The expected efficiency of micro-organism removal in primary treatment is compared with that in biological treatment in table 5. It can be seen that although biological treatment is more efficient than primary treatment in removing certain pathogens, even the secondary treatment does not produce an effluent which is pathogen free.

The principal object of sewage treatment is to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment.

Hence the most appropriate wastewater treatment process to be used for irrigation is that which will produce an effluent which meets the recommended microbiological and chemical quality guidelines both at low-cost and with minimal operational and maintenance requirements.

The design of wastewater treatment plants has usually been based on the need to reduce organic and suspended solids loads to limit pollution of the environment. Pathogen removal was very rarely considered an objective. For reuse of effluents in agriculture this must now be of primary concern and processes should be selected and designed accordingly[31].

5.2 Sewage Treatment and Pathogen Removal:

Conventional sewage treatment is primarily concerned with achieving effluent standards for BOD and suspended solids. However, the conventional treatment processes do not provide for any degree of pathogen removal. Moreover, conventional sewage treatment plants are normally energy intensive with mechanical treatment systems, costly to operate, requiring skilled operator and generally leading to sludge disposal problems.

The WHO committee of experts in 1973[26] gave some guidence on the levels of wastewater treatment required to meet health criteria, as in table 6. Only a limited number of conventional treatment methods were considered whereas recently non conventional low-cost waste treatment processes (e.g. stabilization ponds, soil-aqufer treatment etc) have been developed which are equally effective in the removal of both the organic load and microbial pollution from wastewater.

6. Waste Stabilization Ponds:

It has long been accepted that tropical and sub-tropical climates provide an ideal environment for the natural treatment of sewage in stabilization ponds. By detaining the raw sewage in a multicell Pond System of anaerobic, facultative and maturation Ponds for two to three weeks a significant level of both BOD and pathogen removal can be achieved.

Table 5.

Micro-organism Removal in Wastewater Treatment

Type of Micro-Organism	Percentage Removal	
	Primary	Biological*
Salmonella	15	96-99-999
Mycobacterium	48-57	Slight-99.9
Amoebic Cyst	Limited Removal	0-99.9
Helminth Ova	72-98	0-76
Viruses	3-Extensive	0-84

* Biological includes, trickling filter, activated sludge and waste stabilization ponds.

Table 6.

Suggested Treatment Processes to Meet the Given Health Criteria For Wastewater Reuse in Agriculture[26]

Unit Treatment / Process	Type of Agricultural Reuse: Crops not for Direct Human Consumption	Crops Eaten cooked	Crops Eaten Raw
Primary Treatment	+++	+++	+++
Secondary Treatment		+++	+++
Sand Filtration		+	+
Disinfection		+	+++
Health Criteria	A+F	D+F	

Key:

+++ = Essential
+ = May sometimes be required
A = Freedom from gross solids; significant removal of parasite eggs
D = Not more than 100 coliforms per 100 ml in 80% of samples
F = No chemicals that lead to undesirable residues in crops

Source: WHO (1973)

Table 7.

Removal of Organisms in Stabilization Ponds in India[12]

Organisms	Percent Removal
Coliforms	90-99.9
E.Coli	90-99.9
Salmonella	99-100
Helminths	99-100
Virus	80-95

The natural action of storage and sunlight promotes the rapid growth of micro-organism which remove BOD both aerobically and anerobically. The die-off of pathogens in waste stabilization Pond depends on the environmental and climatological parameters, as well as on the detention time within the Pond System.

Marais[32] proposed a model for the die-off of indicator bacteria in stabilization Pond, based on first-order Kinetics and assuming completely mixed conditions.

$$Ne = \frac{Ni}{(1+K_T\Theta)}$$

Where Ne = effluent faecal coliforms (count/100 ml)

Θ = Detention time (days)

K_T = Faecal coliform removal rate constant, temperature dependent (day^{-1})

The first - order rate constant, K_T is given as:

K_T = 2.6 (1.19) T - 20

Where T = Temperature of Pond in ^{o}C

For a number of Ponds in series the effluent faecal coliform concentration is predicted by

$$Ne = \frac{N_i}{(1+K_T\,\Theta 1)\,(1+K_T\,\Theta 2)\,(1+K_T\,\Theta 3)}$$

For n idential ponds, this becomes:

$$\frac{N_i}{(1+K_T\,\Theta)^n}$$

Polprasert *et al*[33] have proposed a more comprehensive model which takes into account the complex nature of waste stabilization pond. Their model includes the relationship of coliform die-off to other major parameters, such as algal biomass concentration, temperature, organic loading, sunlight intensity, sunlight duration, hydraulic detention time, substrate degradation rate and pond dispersion number.

Stabilization Pond effluents are nutrient-rich because of the high algal content, but are generally low in excreted pathogens and other faecal organisms. This is particularly relevant in hot climates where the spread of gestro-enteric and other diseases by excreted pathogens presents very serious problem, expecially in densely populated urban areas and whereever reuse is considered.

The work of Shuval *et al*[33] suggests that Stabilization Pond treatment produces a better effluent than conventional treatment processes, in terms of helminth removal and the reduction of bacterial and viral pathogens. Arceival reported[12] that studies on Stabilization Ponds in India have shown that treatment in wastestabilization ponds has given practically complete removal of salmonella and helminths as indicated in table 7.

Sewage treatment using wastestabilization ponds if well designed and operated can eliminate protozoal cysts and helminth eggs and reduce the concentration of excreted bacteria and viruses to low levels. Hence this type of treatment will be able to produce an effluent which meets the recommended quality guidelines for unrestricted irrigation, both at low cost and with minimal operational and maintenance requirements. However, it requires extensive land, which is not a serious handicap in arid and semi-arid areas where land is normally available and cheap. Table 8 gives a comparison of the effectiveness of wastestabilization.

Table 8.

Advantages and Disadvantages of Various Sewage Treatment System[35]

Criteria:	Package Plant	Activated sludge plant	Extended Aeration Activated sludge	Trickling Filter	Oxidation Ditch	Aerated Lagoons	Wastestabilization pond system
BOD_5 Removal	F	F	F	F	G	G	G
FC Removal	P	P	F	P	F	G	G
SS Removal	F	G	G	G	G	F	F
Helminth Removal	P	F	P	P	F	F	G
Virus Removal	P	F	F	P	F	G	G
Simple and cheap Construction	P	P	P	P	F	F	G
Simple Operation	P	P	P	F	F	P	G
Land Requirement	G	G	G	G	G	F	P
Maintenance Costs	P	P	P	F	P	P	G
Energy Demand	P	P	P	F	P	P	G
Sludge Removal Costs	P	F	F	F	P	F	G

Key:
FC = Faecal coliforms
SS = Suspended Solids
G = Good
F = Fair
P = Poor

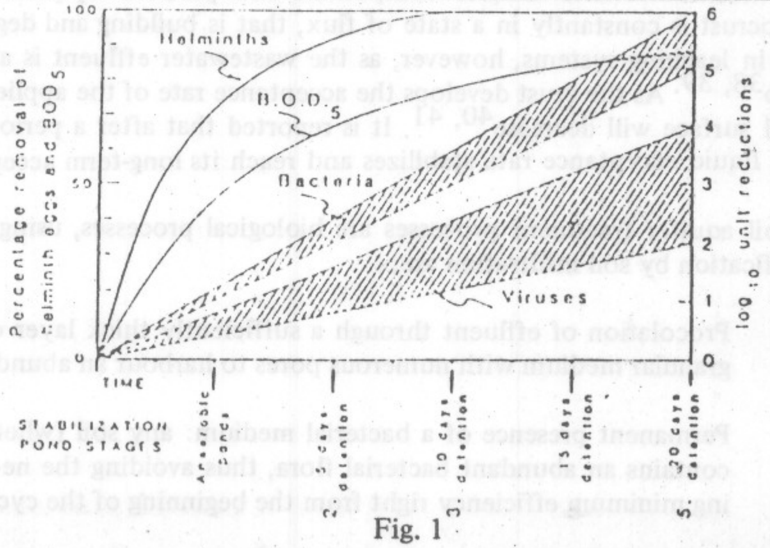

Fig. 1

Generalized Removal Curves for BOD, Helminth Eggs, Excreted Bacteria and Viruses in Waste Stabilization Ponds at Temperatures Above 20°C (after Shuval *et al* 1985)

Ponds with that of conventional treatment process in terms of health criteria and economy[35].

The recent World Bank Report [27] comes out strongly in favour of stabilization ponds as the most suitable treatment for effluent reuse in irrigation. Generalised removal curves were given in this report, as shown in Fig. 1, but it was admitted in the Engleberg Report that there was still a need for further evaluation of existing low-cost wastewater treatment technologies in the light of pathogen removal priorities identified by the meeting.

The Engelberg meeting[27] reaffirmed that, in tropical and subtropical countries, the most appropriate wastewater treatment technology is generally waste stabilization ponds. Nevertheless, because of the extensive land requirements of ponds the meeting recommended that priority be given to the development of alternative low-cost treatment processes which require less land but are still capable of producing effluents which meet the recommended microbiological quality guidelines of table[3].

7. Soil-Aquifer Treatment System:

Bize *et al*36 has recently demonstrated that soil-aquifer treatment offers the advantages of low-cost purification and requires much less land (approx: 0.5 to $1m^2$ per inhabitant) than stabilization ponds ($5m^2$ per inhabitant for final oxidation ponds or $10m^2$ per inhabitant total surface pond receiving raw sewage). The technique (incorporating infiltration basins the unsaturated zone and the aquifer) is adapted to permeable and aquifer soils. The three major considerations involved in soils treatment are: (i) the system must be hydraulically sound: (ii) the average application rate, called the clogging consideration: (iii) adequate treatment must be provided before the water reaches wells, surface waters of users[37]

Continuous of frequent application of biologically treated wastewater (domestic sewage) on fixed or moving surfaces results in the growth of a bacterial and/or zooglocal layer (biocrust).

The microorganisms (bacteria, protozoa and nematodes) convert complex organic compounds in the wastewater into simpler compounds and produce by-products as well as end-products. The biocrust is constantly in a state of flux, that is building and degrading. Initially the biocrust is absent in leaching systems, however, as the wastewater effluent is applied the crust will gradually develop[38, 39]. As the crust develops the acceptance rate of the applied wastewater effluent through the soil surface will decrease[40, 41]. It is reported that after a period of a 3-6 months, the crust's average liquid acceptance rate stabilizes and reach its long-term acceptance rate (LTAR)[38, 39, 42].

Soil aquifer treatment processes are biological processes, using fixed bacteria. The principles of purification by soil infiltration are:-

– Procolation of effluent through a sufficiently thick layer of soil which acts as a mineral granular medium with numerous pores to harbour an abundant microflora.

– Permanent presence of a bacterial medium: any soil (whether already in place or added) contains an abundant bacterial flora, thus avoiding the necessity of seeding and permitting minimum efficiency right from the beginning of the cycle.

– Aeration of the system requires neither equipment nor any energy consumption. It is carried out naturally by vertical and lateral air penetration during the drying phases.

Bize *et al*[36] reported that high quality of purification (especially in disinfection) was obtained in two pilot developments in France, one in the dunes around Port Leucate on the Mediterranean Coast, and the other in Chalky Parisian Basin at Flesselles. The study indicated a reduction of 2 long units per 50 cm of sand in faecal coliforms and faecal streptococci. The researchers concluded that the disinfecting power of sand is definitely greater than any other disinfecting technique and that in order to achieve a very high level of purification and final disinfection of the effluent the thickness of sand layer in the infiltration basin would have to be approximately increased to 1.50 m (and purification plant could be omitted from the design, leaving just the decentation basins).

Lumbers[43] has also suggested that where a high quality effluent is required the use of percolation basins and the subsequent recovery of the recharged groundwater offers advantages. Percolation basins can follow most treatment processes that achieve a fairly low solids content, so that the frequency of scarifying or sand bed skimming due to clogging is reduced.

Most successful soil treatment systems utilize long distances and long times between application and withdrawal. The long time effectively destroys pathogenic microorganisms since none of them are adapted to life underground. Also fine pores and biological slimes effectively filter out most microorganisms, as reported by Dean and Lund[44].

The soil-aquifer-treatment system, in addition to its remarkable disinfecting power, enables the aquifer to be used to store treated water - thus protecting it from evaporation and loss as in case of stabilization ponds, and permits natural transfer of this valuable resources to agricultural wells. The development of this low-cost technology can lead to safe reuse of wastewater for agricultural purposes in the developing countries. Wastewater treatment-soil aquifer system and utilization of wastewater for irrigation should be integrated and an optimum solution determined for the level of sewage treatment required, depending on maximum efficiency of pretreatment and recommended quality standard.

8. The Root Zone Method for Sewage Treatment:

The Root Zone Method (RZM) is a wetland method of sewage treatment developed over the past twenty years by Prof. Dr. Kickuth at Kassel, University, West Germany[45]. It depends upon the flow of sewage through soil in which common reeds *(Phragmites Australis)* are growing. The perspective and typical root zone installation is shown in Fig. 2. The first full scale trial of the method was undertaken at Othfresen in 1974 and proved to be so successful that the works have been extended in stages from the original design population of 2700 to 10,000.

The key features of the RZM process are:-

- Rhizomes of the reeds grow vertically and horizontally opening up the soil to provide a "hydraulic pathway".

- Wastewater is treated by bacterial activity. Aerobic treatment takes place in the rhizosphere with anoxic and anaerobic treatment taking place in the sorrounding soil .

- Oxygen is passed from the atmosphere to the rhizosphere via the leaves and stems of the reeds through the hollow rhizomes and roots.

- Suspended solids in the sewage are aerobically composted in the above ground layer of straw formed dead leaves and stems.

The following advantages have been claimed for RZM.

- Simple construction, no mechanical or electrical equipment.
- Low maintenance cost
- Robust process able to withstand wide range of operating conditions.
- Consistent effluent quality.
- Environmentally acceptable with potential for wild life conservation.

The land area needed for treatment of acreened, degritted sewage is about 2 to 4 m^2/person to achieve an effluent with less than 20 mg BOD/1 on a 95 percentile basis. The method can also be effectively used for tertiary treatment and improving poor quality effluent.

The capital cost of installing a RZM - type system will vary with (i) the ease or difficulty or working with the soil on the site, (ii) size and (iii) the degree of sophistication that is used. On the basis of the plants built so far in U. K. the cost is reported to be of the order of £ 100/person[45].

Capital costs are likely to be from 25 to 75% of conventional treatment works, particular for population below 10,000. Operating costs will depend on the need to remove accumulated composted sludges from the surface of RZM beds (it may be every 25 to 35 years) but they are likely to be about 10 to 25% of conventional processes.

A number of RZM systems for sewage treatment have been constructed in W. Germany and are in operation. Analyses of effluent from Othfresen Works is given in table 9.

Table 9.

Sewage Composition to the RZM works and effluent quality in 1979 (all values in Mg/1)[45]

	Sewage	Effluent
BOD	500-700	5-15
COD	600-700	20-50
Phosphorous	25-30	< 0.1
Nitrogen	17-110	5-6

The concentration of BOD of the outlet of RZM works (C_T) is related to the BOD of the inlet sewage (C_o) and the retention period in the reed bed (T) by the following equation:

$$C_T = C_o - KT$$

Where K is a function of temperature and treatability of sewage. At 8^oC the value of K for domestic sewage is equal to 0.032 if the perosity of the soil were 42%.

In soil with a hydraulic conductivity of 10^{-3} m/s the total volume of the voids (due to the rhizosphere) is about 6 to 7% of the total bed volume.

The area (A_h) of the RZM bed (assumed to be 0.6 m deep) can be calculated from the equation.

$$A_h = 5.2\, Qd\, (\ln C_o - \ln C_t)$$

Where A_h is the area (m^2) and

Qd is the average flow-rate of sewage (m^3/d). The cross-section area (Ac) can be calculated from the following equation:

$$Ac = \frac{QS}{K_f \quad dH/ds}$$

Where Ac is the cross-sectional area (m^2)
Qs is the average flow-rate of sewage (m^3/S)
Kf is the hydraulic conductivity of a fully developed RZM bed, (about 3×10^{-3} m^3/m^2 S)

and dH/ds is the slope of the bed (m/m)

Thus the steeper the slope the narrower the RZM bed, provided the slope does not exceed about 6%. As reported in the literature the subsoil (below the RZM bed) should have a hydraulic conductivity of 10^{-8} to 10^{-9} m^3/m^2 S[45]

The process is currently being evaluated in the United Kingdom[46] where two RZM systems were constructed in 1985 and three more were in construction in the spring of 1986. The author in September, 1986 visited one of the RZM system at Holtby sewage treatment works, constructed by Oceans International service Limited (UK Licences) under the supervision of Professor Kickuth and Commissioned in June, 1986. The project was designed to serve a population of 130 persons and costed £ 45,000. The R.Z. Bed has a total land area of 880 m^2 (21 x 42m) and net area of 651 m^2 (5.0m^2/ persons) The reed plants for the works were brought from West Germany and planted with a Conveyor belt system to avoid walking on the soil bed and its compaction. It was informed during the visit that the plant was guaranteed with a final effluent quality of 20:30 (BOD and suspended solids), after 3 years from commissioning of the system.

RZM technique might be more effective and appropriate for developing contries in an irrigation reuse context. Research and development of this low-cost process should be undertaken in this country to evaluate its performance and suitability under our climatic conditions.

9. Summary and Conclusions:

Land application of municipal Wastewater is well-established practice in many countries of the world. Wastewater Irrigation has special significance for the developing countries with arid and semi-arid climates and limited water resources. Land application of wastewater provides nutrients for crop growth and organic matter for soil conditioning and it is often the most economical means of wastewater disposal. Wastewater reuse through land application is not new, and there have been many successful systems. However, reuse of sewage effluent for irrigation entails certain risk to health and must be practised under carefully controlled circumstances. In todays environments, the level of potential contaminants in wastewater is increasing. Therefore, when considering the use of effluents for irrigation their microbical and biochemical properties will have to be evaluated. Water quality criteria for agricultural and landscape irrigation are well-established. These guidlines and criteria can be used to evaluate reclaimed wastewater.

In developing countries, raw sewage is rarely treated before reuse in irrigation and this direct reuse without any restrictions on the types of crops poses potential health hazards and adverse environmental impacts. The health hazards due to irrigation with untreated effluent can be reduced by proper planning and management of the wastewater - soil-crops system and by restricting the choice of crops for wastewater irrigation. If appropriate low-cost technology for wastewater treatment and effluent distribution in irrigation can be developed to suit conditions in developing countries and also provide the necessary safeguards to health, effluent reuse will conserve valuable water resources and produce useful crops.

The conventional treatment processes are too expensive for the developing countries and pollution problems are not satisfactorily solved with these techniques. In tropical and sub-tropical countries the most appropriate wastewater treatment technology is generally wastestabilization ponds. Also, the recently developed new technologies of soil-aquifer treatment system and Root Zone Method seems to be cost-effective and appropriate for developing countries. However, these methods need to be fully evaluated to assess their performance and suitability under our climatic conditions. These non-conventional treatment technologies are more suitable because in-addition to being low-cost they are more efficient in the removal of pathogens, which is the primary objective in irrigation reuse schemes.

In the absence of the facilities for wastewater treatment, environmental pollution from wastewater can be controlled to a considerable extent by land application-cum-treatment of wastewater with crop/landscape irrigation. In using sewage effluent for agricultural purposes, crop selection should be considered from the stand point of Public Health consideration, according to guidelines given in the Engelberg Report[27].

Integrated planning of wastewater treatment, effluent irrigation system design and crop selection should be applied in reuse scheme. Institutional arrangments should be provided for control of irrigation reuse so that effluent is used in a rational manner, and crop selection based on national plans rather than local preferences. A coordinated programme of research on effluent reuse should be undertaken and guidance be provided to allow reuse planners to select the combination of wastewater treatment, irrigation system and choice of crops which is most appropriate for the local conditions.

The integration of sewage effluent into national plan for reuse schemes may give rise to increasing health risks unless a coordinated approach to planning and regulation is adopted. Legislative provisions and enforcement is essential for regulating wastewater discharges, levels of treatment and method of application of effluent to ensure that reuse projects can be introduced and operated safely within the community. It is equally important that introduction of reuse concepts is accompained by wide spread public education as to the health risks and necessary precautions.

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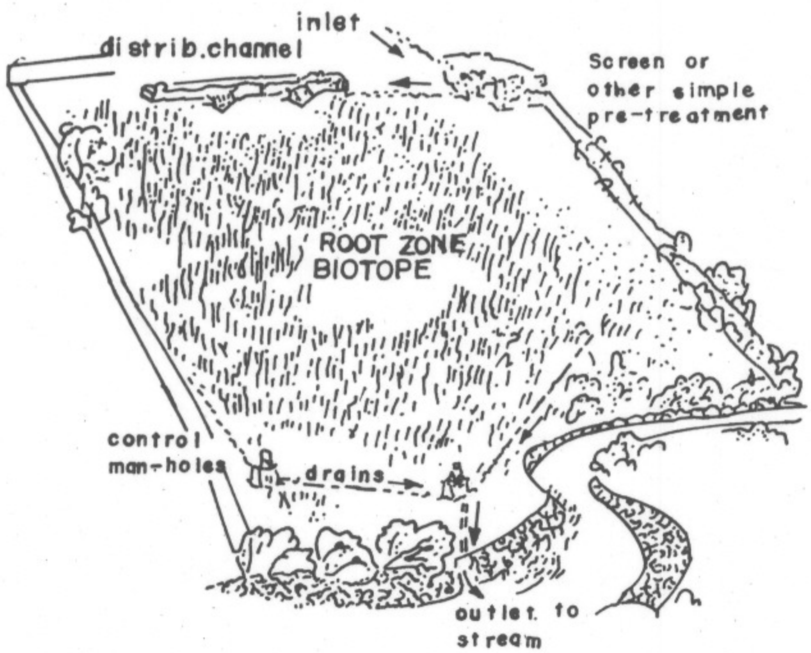
ROOT ZONE BIOTECHNOLOGY

Paper No. 501

BY

KICKUTH METHOD

PERSPECTIVE:



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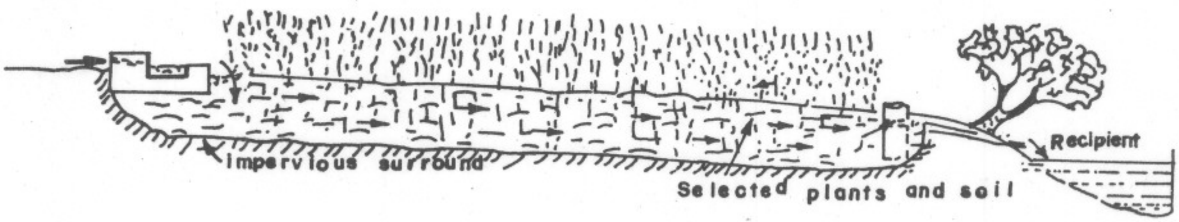

FIG.2. PERSPECTIVE AND SECTION OF TYPICAL ROOT ZONE INSTALLATION

SOURCE:- Oceans International Services Ltd. Bradford, England