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Land treatment Methods A review on Available Methods and its Ability to Remove Pollutants

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ABSTRACT

One of the most cost effective way of wastewater treatment is land treatment. This process is defined as the application of wastewater to the land at a controlled rate in adesigned and engineered setting. The purpose of the activity isto obtain beneficial use of these materials, to improve environmentalquality, and to achieve treatment and disposal goals in acost-effective manner. Land treatment systems include slow rate (SR), overland flow (OF), and soilaquifer treatment (SAT) or rapid infiltration (RI). These systems require minimal effort for operation and maintenance. This paper first describe each of these methods by: hydraulic pathways, the way of treatment, and there pros and cons. In the next part some standards and ability of each method in removal of pollutions and chemical compounds described. In this part also some successful application of land treatment reviewed and the ability of these method for crop irrigation and its limitations reviewed.

Key words: Land Treatment, slow rate, overland flow,rapid infiltration

INTRODUCTION

The process of land treatment is the controlled application of wastewater to soil to achieve treatment of constituents in the wastewater. All three major processes (include slow rate (SR), overland flow (OF), and rapid infiltration (RI)) use the natural physical, chemical, and biological mechanisms within the soil–plant–water matrix. The SR processes use the soil matrix for treatment after infiltration of the wastewater, the major difference between the processes being the rate at which the wastewater is loaded onto the site. The OF process uses the soil surface and vegetation for treatment, with limited percolation, and the treated effluent is collected as surface runoff at the bottom of the slope[1].

These systems can often be the most cost-effective option in terms of both construction and operation and are therefore, frequently being used in small communities and rural areas[2].

The use of domestic wastewater emanating from these communities on fast growing plant species can be an effective way of wastewater treatment as well as a source of water and nutrients for growing plants. The application of domestic wastewater for irrigation to food crops generally fulfills their nutrient requirement but in other hand make them more vulnerable to the attack of insects and pathogens. Hence, the irrigation of trees with this wastewater is considered as more economical and eco-friendly method of fertilization. The species like Poplar and Salix have longer growing seasons and deeper, longer lasting root systems than annual crops, which enables them to have a better utilization of the nutrients from wastewater. Secondly, these plant species possess high rate of evapotranspiration which further enhances the LTS treatment efficiency[3].

The technical design of the land treatment system mainly depends on the mode of wastewater application, and characteristics of wastewater and on-site soil profile. The parameters that should be given utmost consideration during land application are dissolved salts, suspended solids, nutrients like nitrogen and phosphorus, organic matter, cations like sodium and magnesium, and toxic substances. The important site conditions include the depth of the soil mantle, depth of ground water table, slope and permeability. The land based treatment of wastewater based on how it is applied over land can be classified as:

1. Slow rate (SR) method
2. Rapid infiltration (RI)
3. Overland Flow (OF)

Types of natural treatment systems

There are three basic types of natural treatment systems. Here we describe each type

Slow Rate Process

Slow rate (SR) land treatment is the controlled application of wastewater to vegetated land surface at a rate typically measured in terms of a few centimeters of liquid per week (Fig. 1).The design flow path depends on infiltration, percolation, and usually lateral flow within the boundaries of the treatment site.

Treatment occurs at the soil surface and as the wastewater percolates through the plant root-soil matrix. Depending on the specific system design, some to most of the water may be used by the vegetation, some may reach the groundwater, and some may be recovered for other beneficial uses. Off-site runoff of any of the applied wastewater is specifically avoided by the system design[4].

Table 1: BOD_5 Removal at Typical Land Treatment Systems[21]

Process/ location	Hydraulic loading, m/year	BOD5, mg/L Applied	BOD5, mg/L Effluent	Sample depth, m
Hanover, N.H. San Angelo, Tex.	1–7.53	40–9289	0.9–1.70.7	1.5
Rapid Infiltration				
Lake George, N.Y.	40	38	1.2	3
Phoenix, Ariz.	110	15	1.0	9
Hollister, California.	15	220	8.0	7.5
Overland Flow				
Hanover, N.H.	7	72	9	
Easley, S.C.	8	200	23	
Davis, California.	12.5	112	10	

Table 2: Typical Organic Loading Rates for Land Treatment Systems[21b, 22]

Process	Organic loading, Kg BOD_5/ (ha. Day)
Slow rate (SR)	50-500
Rapid infiltration (RI)	145-1000
Overland flow (OF)	40-110

The hydraulic pathways of the applied water can include:

a) % Vegetation irrigation with incremental percolation for salt leaching
b) %Some vegetative uptake with percolation the major pathway
c) % Percolation to under drains or wells for water recovery and reuse
d) % Percolation to groundwater and/or lateral subsurface flow to adjacent surface waters

Wastewater applications can be via ridge and furrow or border strip flood irrigation or with sprinklers using fixed nozzles or moving sprinkler systems. The selection of the application method is dependent on site conditions. The surface vegetation is an essential component in all SR systems.

Slow rate land treatment can be operated to achieve a number of objectives including:

a) % Treatment of the applied wastewater
b) % Economic return from the use of water and nutrients to produce marketable crops
c) % Exchange of wastewater for potable water for irrigation purposes in arid climates to achieve overall water conservation
d) % Development and preservation of open space and greenbelts

These goals are not mutually exclusive, but it is unlikely that all can be brought to an optimum level within the same system. In general, maximum cost-effectiveness for both municipal and industrial systems will be achieved by applying the maximum possible amount of wastewater to the smallest possible land area. That will in turn limit the choice of suitable vegetation and possibly the market value of the harvested crop. In the more humid optimization of treatment is usually the major objective for land treatment systems[5].

Optimization of a system for wastewater treatment usually results in the selection of perennial grasses because a longer application season, higher hydraulic loadings, and greater nitrogen removals are possible compared to other agricultural crops.

Rapid Infiltration Process

Rapid infiltration (RI) land treatment is the controlled application of wastewater to earthen basins in permeable soils at a rate typically measured in terms of meter of liquid per week. The hydraulic loading rates for RI are usually at least an order of magnitude higher than for SR systems. Any surface vegetation that is present has a marginal role for treatment owing to the high hydraulic loadings. However, vegetation is sometimes critical for stabilization of surface soils and the maintenance of acceptable infiltration rates. In these cases, water-tolerant grasses are typically used[6]. Treatment in the RI process is accomplished by biological, chemical, and physical interactions in the soil matrix, with the near surface layers being the most active zone.The design flow path involves surface infiltration, subsurface percolation, and lateral flow away from the application site (Fig. 2). A cyclic application is thetypical operational mode with a flooding period followed by days or weeks of drying. This allows aerobic restoration of the infiltration surface and drainage of the applied percolate[7].

Table 3: Metals Concentrations in Wastewaters and Suggested Concentrations in Drinking and Irrigation Waters[24]

			Irrigation water, mg/L	
Element	**Raw sewagemg/L**	**Drinking watermg/L**	**20 years***	**Continuous†**
Cadmium	0.004–0.14	0.01	0.05	0.005
Chromium	0.02–0.70	0.05	20	5.0
Lead	0.05–1.27	0.05	20	5.0
Zinc	0.05–1.27	0.05	20	5.0

*For fine-textured soils only. Normalirrigationpracticefor20years.

†For any soil, normal irrigation practice, no time limit.

The geo-hydrological aspects of the RI site are more critical than for the other processes, and a proper definition of subsurface conditions and the local groundwater system is essential for design.

The purpose of a rapid infiltration system is wastewater treatment, so the system design and operating criteria are developed to achieve that goal. However, there are several alternatives with respect to the utilization or final disposal of the treated water:

a) % Groundwater recharge
b) % Recovery of treated water for subsequent reuse or discharge
c) % Recharge of adjacent surface streams
d) % Seasonal storage of treated water beneath the site with seasonal recovery for agriculture

The recovery and reuse of the treated RI effluent is particularly attractive in arid regions, and studies in Arizona and California[9]have demonstrated that the recovery of the treated water is suitable for unrestricted irrigation on any type of crop. Groundwater recharge may also be attractive, but special attention is required for nitrogen if drinking water aquifers are involved. Unless special measures are employed, it is unlikely that drinking water levels for nitrate nitrogen (10 mg/L as N) can be routinely attained immediately beneath the application zone with typical municipal waste-waters[10]. If special measures are not employed, there must then be sufficient mixing and dispersion with the native groundwater prior to the down gradient extraction points. In the more humid regions neither recovery nor reuse is typically considered[11].

In these cases groundwater impacts can often be avoided by locating the RI site adjacent to a surface water body. The quality of the sub flow entering the surface water will generally exceed that which could be produced by an advanced wastewater treatment plant.

Overland Flow Process

Overland flow (OF) is the controlled application of wastewater to relatively impermeable soils on gentle grass covered slopes. The hydraulic loading is typically several inches of liquid per week and is usually higher than for most SR systems.

Since costs tend to be directly related to hydraulic loading, OF systems are usually more cost-effective than SR systems for equivalent water quality requirements.

Vegetation, consisting of perennial grasses, is an essential component in the OF system, for its contribution both to slope stability and erosion protection and to its function as a treatment component[12].

The design flow path is essentially sheet flow down the carefully prepared vegetated surface with runoff collected in ditches or drains at the toe of

Table 4: WHO Recommended Annual and Cumulative Limits for Metals Applied to Agricultural Cropland[2526]

Metal rate,†	Annual loading rate,* kg/ha	Cumulative loadingkg/ha
Arsenic	1.995	41
Cadmium	1.905	39
Chromium	149.066	3000.382
Copper	75.094	1499.63
Lead	14.57	300.374
Mercury	0.852	17.036
Molybdenum	0.897	18.045
Nickel	20.959	420.3
Selenium	5.044	99.751
Zinc	140.1	2799.758

*Loading kg/ha per 365-day period. †Cumulative loading over lifetime of site each slope (see **Figure 3**). Treatment occurs as the applied wastewater interacts with the soil, the vegetation, and the biological surface growths. Many of the treatment responses are similar to those occurring in trickling filters and other attached growth processes. Wastewater is typically applied from gated pipe or nozzles at the top of the slope or from sprinklers located on the slope surface. Industrial wastewaters and those with higher solids content typically use the latter approach[13].

A small portion of the applied water maybe lost to deep percolation and a larger fraction to evapotranspiration, but the major portion is collected in the toe ditches and discharged, typically to an adjacent surface water. The SR and RI concepts may include percolate recovery and discharge but the OF process almost always includes a surface discharge, and the necessary permits are required. The purpose of overland flow is cost-effective wastewater treatment. The harvestand sale of the cover crop may provide some secondary benefit and help offset operational costs, but the primary objective is treatment of the wastewater. One of the largest municipal overland flow systems in the United States was in Davis, California designed for 22 thousand m^3/day flow[14].

System Interactions

Biochemical Oxygen Demand

All land treatment concepts are very efficient at removal of biodegradable organics, typically characterized as biochemical oxygen demand (BOD5). Removal mechanisms include filtration, adsorption, and biological reduction and oxidation. Most of the responses in slow rate (SR) and rapid infiltration (RI) occur at the ground surface or in the near surface soils where microbial activity is most intense. Essentially all of the responses in overland flow (OF) occur at the soil surface or in the mat of plant litter and microbial material[15].

Settling of most particulate matter occurs rapidly in OF systems as the applied wastewater flows in a thin film down the slope. Algae removal is an exception, since the detention time on the slope is not usually sufficient to permit complete removal by physical settling[16]. The biological growths and slimes which develop on the OF slope are primarily responsible for ultimate pollutant removal.

Table 5: Mineralization Rates for Organic Matter in Biosolids

Time after biosolids application, years	Mineralization rate, %			
	Unstabilized primary	Aerobically digested	Anaerobically digested	Composted
0–1	40	30	30	10
1–2	20	15	10	5
2–3	10	8	5	
3–4	5	4		

Table 6: Sulfur Uptake by Selected Crops[33]

Crop	Harvested mass	Sulfur removed kg./ha
Corn	12.5 ton/ha	49.32
Wheat	5.2ton/ha	24.66
Barley	6.3ton/ha	28.02
Alfalfa	14.8ton/ha	33.62
Clover	9.8ton/ha	20.17
Coastal Bermuda grass	25ton/ha	50.44
Orchard grass	17.3ton/ha	56.04
Cotton	1.5ton/ha	25.78

Since the basic treatment mechanism is biological, all three systems have a continually renewable capacity for BOD_5 removal as long as the loading rate and cycle allows for preservation and/or restoration of aerobic conditions in the system. Pilot studies[17]in1998 with soil columns indicate that BOD5 removal to low "background" levels was independent of the level of pretreatment , independent of soil type, and essentially independent ofinfiltration rate. These responses confirm the results presented in (Table 1) and also confirm the fact that high levels of pre-application treatment are not necessary for effective BOD5 removal in land treatment systems.

Organic loading

A comparison of the values in (Table 2) indicates that land treatment systems have a very high capacity for treatment of the degradable organics characterized as BOD5. The RI systems produce an effluent close to that of the SR systems with an organic loading which is typically an order of magnitude higher.

A study at five SR systems applying potato processing wastewater in Idaho utilized chemical oxygen demand (COD) loadings ranging from 45 to 310 Kg/(ha . day) with removals up to98 percent after 1.5 m of percolation in the soil. [18] Pilot-scale OF with high-strength snack food processing wastewaters was successful at BOD_5 loading rates ranging from 55 to 110Kg/ (ha. day).[19] Pilot RI studies in Montana with partially treated kraft process paper mill wastes with BOD_5 concentrations up to 600 mg/ L at hydraulic loadings of about 6cm/day were also successful.[20]

Some of the industrial systems discussed above successfully operate with applied BOD_5 concentrations of 1000 mg/L or more.

It can therefore be concluded that neither BOD_5 nor COD is likely to be the limiting factor for design of municipal land treatment systems. Typical organic loadings in current use are summarized in (Table 2).

Pathogenic Organisms

The pathogens of concern in land treatment systems are parasites, bacteria, and virus. The pathways, or vectors, of concern are to groundwater, contamination of crops, translocation

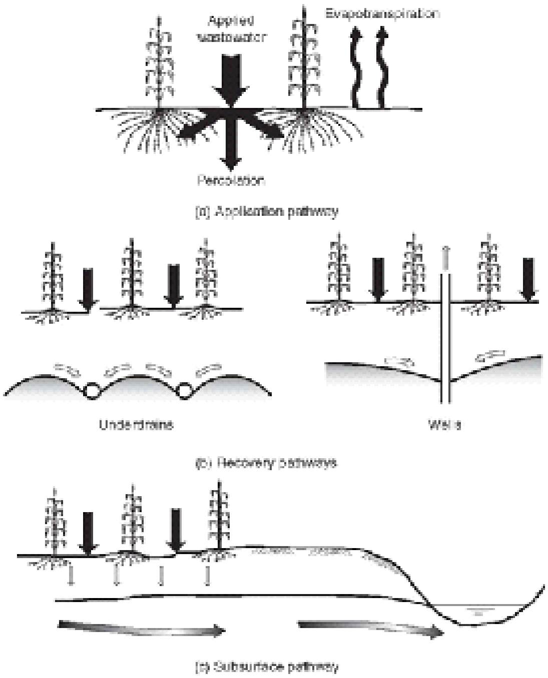

Fig. 1: Hydraulic pathways for slow rate (SR) land treatment[8]

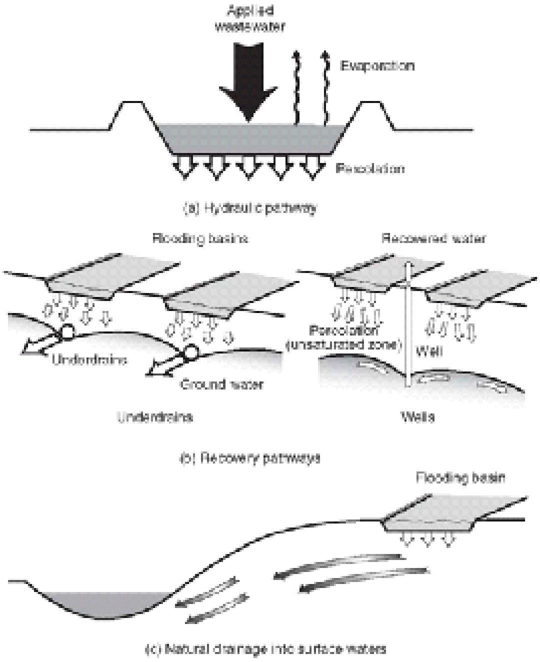

Fig. 2: Hydraulic pathway for rapid infiltration (RI)[8]

or ingestion by grazing animals, and off-site transmission via aerosols or runoff. The removal of pathogens in land treatment systems is accomplished by adsorption, desiccation, radiation, filtration, predation, and exposure to other adverse conditions .The SR process is the most effective, removing about five logs (10^5) of fecal coliforms within a depth of a meter. The RI process typically can remove two to three logs of fecal coliforms within few meter of travel, and the OF process can remove about 90 percent of the applied fecal coliforms.

Metals

The slow rate (SR) land treatment process is the most effective for metals removal because of the finer-textured soils and the greater opportunity for contact and adsorption. Rapid infiltration (RI) can also be quite effective, but a longer travel distance in the soil will be necessary owing to the higher hydraulic loadings and coarser- textured soils. Overland flow (OF) systems allow minimal contact with the soil and typically remove between 60 and 90 percent depending on the hydraulic loading and the particular metal[23].

Adsorption of most trace elements occurs on the surfaces of clay minerals, metal oxides, and organic matter; as a result, fine-textured and organic soils have a greater adsorption capacity for trace elements than sandy soils have.

The major concern with respect to metals is the potential for accumulation in the soil profile and then subsequent translocation, via crops or animals, through the food chain to man .The metals of greatest concern are cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu), and nickel (Ni). The World Health Organization (WHO) has published guidelines for annual and cumulative metal additions to agricultural crop land (Table 3 & 4)

Nitrogen

The removal of nitrogen in land treatment systems is complex and dynamic owing to the many forms of nitrogen (N_2, organic N, NH_3, NH_4, NO_2, and NO3) and the relative ease of changing from one oxidation state to the next.

It is important in the design of all three land treatment concepts to identify the total concentration of nitrogen in the wastewater to be treated as well as the specific forms (i.e., organic, ammonia, nitrate, etc.) expected. Experience with all three land treatment processes demonstrates that the less oxidized the nitrogen is when entering the land treatment system the more effective will be the retention and overall nitrogen removal.

The ammonia fraction can be lost by volatilization, taken up by the crop, or adsorbed by the clay minerals in the soil.[27]

Under favorable conditions (i.e., sufficient alkalinity, suitable temperatures, etc.)Nitrification ranging from 5 to 50 mg/ (L. day) is possible.

Assuming that these reactions are occurring with the adsorbed ammonia ions in the top 10cm of a fine-textured soil means that up to 67 Kg. of ammonia nitrogen per hectare can be converted to nitrate each day.

Nitrification is a conversion process, not a removal process for nitrogen. Denitrification, volatilization, and crop uptake are the only true removal pathways available. Crop uptake is the major pathway considered in the design of most slow rate systems, but the contribution from

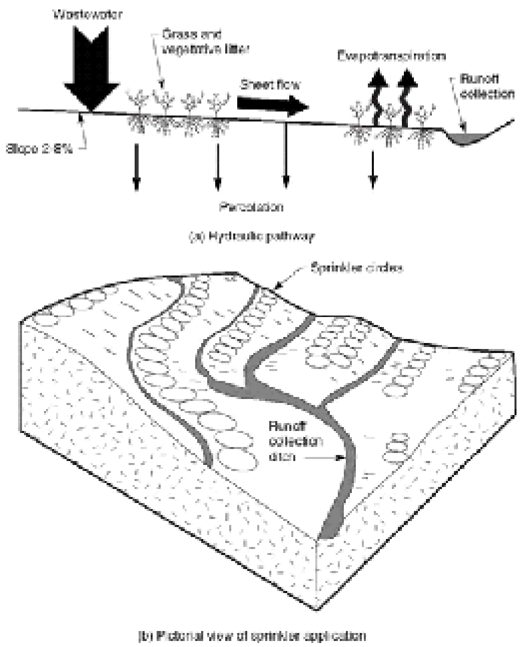

Fig. 3: Hydraulic pathways for overland flow (OF)[8]

denitrification and volatilization can be significant depending on site conditions and wastewater type.

In RI, ammonia adsorption on the soil particles followed by nitrification typically occurs, but denitrification is the only important actual removal mechanism. For OF, crop uptake, volatilization, and denitrification can all contribute to nitrogen removal.

Mineralization rates developed for wastewater bio-solids are given in (Table 5). The values are the percent of the organic nitrogen present that is mineralized (i.e., converted to inorganic forms such as ammonia and nitrate) in a given year.

Phosphorus

Phosphorus is present in municipal wastewater as orthophosphate, polyphosphate, and organic phosphates. The orthophosphates are immediately available for biological reactions in soil ecosystems. The necessary hydrolysis of the polyphosphates proceeds very slowly in typical soils, so these forms are not as readily available[28]. Phosphorus removal in land treatment systems can occur through plant uptake, biological, chemical, and/or physical processes. Phosphorus removal in the soil depends to a significant degree on chemical reactions which are not necessarily renewable. As a result, the retention capacity for phosphorus will be gradually reduced over time, but not exhausted[29].

There is no crop uptake in RI systems, and the soil characteristics and high hydraulic loading rates typically used require greater travel distances in the soil for effective phosphorus removal.

The opportunities for contact between the applied wastewater and the soil are limited to surface reactions in OF systems, and as a result phosphorus removals typically range from 40 to 60percent. Phosphorus removal in overland flow can be improved by chemical addition and then precipitation on the treatment slope[30].

Arsenic

Arsenic is nonessential for all life forms. In significant concentrations it can be moderately toxic to plants and very toxic to animals. The food chain is protected at land treatment sites, since the crops should show adverse effects from arsenic before hazardous levels were reached in the edible portions of the plants. Arsenic is removed in the soil system by adsorption by the soil colloids with clay and the iron and aluminum oxides performing essentially the same function as described previously for phosphorus removal[31].

Poultry manure with 15 to 20 ppm arsenic has been applied for up to 20 years [225 to 450g. As/ (ha. year)] without any adverse effects on either alfalfa or clover. Field tests are recommended for industrial effluents with high arsenic concentrations to develop criteria for loading rates and vegetation to be used at a specific location.[32]

Sulfur

Sulfur is usually present in most wastewaters in either the sulfate or the sulfite form.Crop uptake can account for some sulfur removal table 6. Summarizes typical values for several crops. It is prudent to assume that all of the sulfur compounds applied to the land will be mineralized to sulfate. The 250 mg/L standard for drinking water sulfate would then apply at the project boundary when drinking water aquifers are involved. It should be assumed in sizing the system that the major permanent removal pathway is to the harvested crop, and the values in table 6 can be used for estimating purposes.

CONCLUSION

The selection of a natural wastewater treatment system requires the consideration of a number of factors, including wastewater volume and pollutant characteristics, site soils and geology, and climate. Land application systems also require a large land area. Not all sites will be candidates for land application, but for those sites that do qualify, natural treatment will offer the owner and operator many benefits over systems that employ mechanical and chemical treatment.

Land treatment is the most cost effective way of wastewater treatment however there are some difficulty in its application. Land treatment can’t be used for large cities due to its hydraulic load limitations. But it can be used in villages and small countries and wherever it's difficult to use huge water treatment facilities. It's also possible to use wastewater as a source of nutrition for crops but in this case it need restrict supervision.

To overcome this restriction it's possible to use land treatment of wastewater for non-food crop which needs much less supervisions and restrictions.

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