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Drainage and reuse of effluents for agricultural management (DREAM) - a dream project for developing countries

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Abstract

Most of the world=s population live in developing countries where provisions of water and food to the growing population needs to be tackled, before shortage of water and food becomes critical in the near future.

DREAM (Drainage and Reuse of Effluents for Agricultural Management) is a simple and holistic approach to reduce/remove contaminants from effluent to produce Aclean, useable≅ water for agricultural management, particularly in developing countries and areas where water is scarce. This project may solve both food and water shortage.

The DREAM Apackage≅ combines the concepts of land-based effluent irrigation, intensive cropping/ phytoremediation, water harvesting, permeable reactive barriers, and an artificial recharge of groundwater. Although the components are the same in all DREAM projects, the drainage factors, reactive materials, plant varieties used, will all depend on the quantity and quality of effluent, locally available materials, and local soil type. While the operational area of the DREAM project depends on the availability of land and effluent quantity, its success depends purely on the operator=s willingness and commitment. For example, this project may suit farmers, with no access to dependable supplies of groundwater or to perennial streams, who can construct small earth dams. Such dams can be used as irrigation during summer, as support for cut flower marketing, and as an artificial recharge of groundwater.

Although this project has not been tested as a complete package, different components have been tested successfully either at laboratory scale or in field situations worldwide. This is the first time this holistic approach has been offered for discussion in an international conference.

INTRODUCTION

Most of the world=s population live in developing countries, where provisions of water and food to the growing population needs to be tackled, before water and food shortage becomes critical in the near future. Often the available land and freshwater supplies (including groundwater) in these regions are either mismanaged, or are polluted by solid or liquid wastes.

Large quantities of municipal, industrial and agricultural effluents are generated worldwide. In many countries, the treated effluents are discharged into receiving waters such as rivers, lakes and sea (UNEP, 1993). However, these treated effluents may still retain large concentrations of organic matter, nutrients, and other contaminants that can result in depletion of dissolved oxygen and eutrophication if directly discharged into waterways. So land application is becoming popular as an effective management option for the treatment of effluents.

With proper and advance planning, and with improved technology for waste treatment and disposal, it may be possible to tackle the demand for water and food resources in these countries. Since agriculture plays an important role, agricultural water management needed to be coordinated with, and integrated into, the overall water management of these regions (Bouwer, 2000).

Although water reuse has been practised for many centuries, improvements in treatment process, increase in water demands, and public confidence have promoted water reuse in recent years for unrestricted non-potable purposes, such as for landscape and market crop irrigation, and industry (Okun, 2000). The increasing agricultural reuse of treated effluent serves goals such as promoting sustainable agriculture and preserving scarce water resources, and maintaining environmental quality (Haruvy, 1997).

In developing countries, reliable, low-cost, and low-technology methods are needed to acquire new water supplies and to protect existing water sources from pollution. DREAM (Drainage and Reuse of Effluents for Agricultural Management) is a simple, low-cost, and holistic approach to reduce/remove contaminants from effluent to produce Aclean, useable≅ water for agricultural management. It is a Apackage≅ that combines the concepts of land-based effluent irrigation, intensive cropping /phytoremediation, water harvesting, permeable reactive barriers, and an artificial recharge of groundwater. Although this project has not been tested as a complete package, different components have been tested successfully either at laboratory scale or in field situations worldwide. Although the components are the same in all DREAM projects, the drainage factors, reactive materials, and plant varieties used will all depend on the quantity and quality of effluent, locally available materials, and local soil type. This is the first time this holistic approach has been presented /offered for discussion at an international conference.

In this paper, different concepts adopted in the DREAM project for developing countries are introduced. However, for more comprehensive reviews on individual topics readers are directed to excellent reviews on land-based effluent irrigation (Feigin et al., 1991), intensive cropping / phytoremediation (e.g. Meagher, 2000; Salt et al., 1998), water harvesting, permeable reactive barriers (e.g. Scherer et al., 2000), and artificial recharge of groundwater (Bouwer, 1996; 2000).

LAND-BASED EFFLUENT IRRIGATION

The objective of land treatment of effluent is to utilise the physical, chemical and biological properties of the soil/plant system to assimilate the waste components without adversely affecting soil quality or causing contaminants to be released into water or the atmosphere (Feigin et al., 1991).

Land application can have a variety of beneficial or detrimental effects, depending on the characteristics of the effluent and the soil. Some of the benefits include improved effluent quality, a means of disposal of effluent, irrigation to supply moisture and nutrients for plant growth, and the recharging of groundwater. Some detrimental effects include deterioration of the soil, damage to vegetation, the build-up of salts and heavy metals, undesirable odours, pollution of groundwater, and surface runoff of pollutants resulting from high rainfall.

For land treatment systems to be successful, it is important for soil to have high infiltration capacity, sufficient exchange capacity to hold effluent constituents for use by plants and soil organisms, and sufficient soil depth to provide adequate renovation of effluent. For some not so well-drained soils, it may be possible to improve soil drainage characteristics for irrigation treatment by means of subsurface drains (Bowler, 1980).

In DREAM project, effluents are applied to soils, by either sprinklers or flood irrigation. Here, subsurface drains are installed to drain the excess water (Figure 1). Many small, parallel drains run at about 0.5 m depth below the soil surface. A pipe, larger in size than the drains, runs at right angles to them and collect all their water (Bowler, 1980; Magesan et al., 1994; 1995). The backfilling around this larger pipe consists of materials with high hydraulic conductivity and reactive materials to remove contaminates.

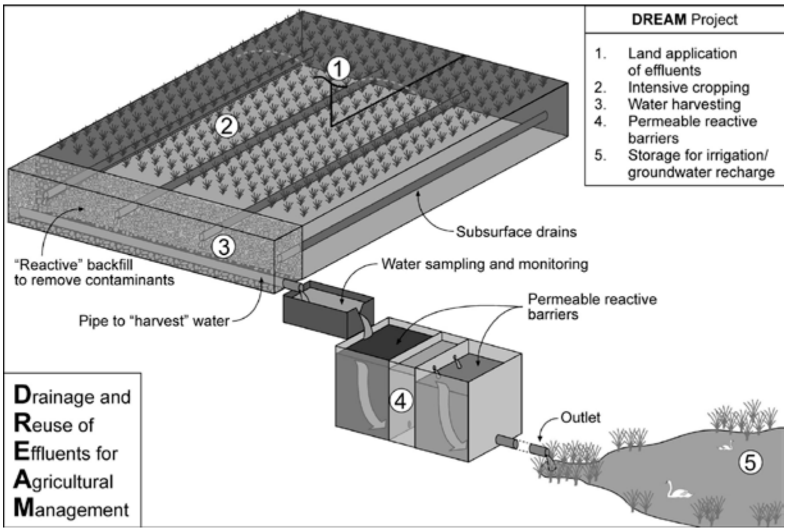

Figure 1. Different components of a DREAM project for developing countries.

INTENSIVE CROPPING/PHYTOREMEDIATION

Soil-plant systems can effectively treat effluents by removing nutrients, organic matter, and other contaminants. The degree of renovation of effluent, however, depends on the type of plant cover, irrigation loading, and management. The plant variety chosen may be determined by local conditions, such as cool temperatures, or effluent type. If the effluent is rich in nutrients, then cropping will take place. If the effluents are from industry and more contaminants are present, then the phytoremediation process will be tried.

Phytoremediation is an environmentally friendly and cost-effective technology where plants are used to remove pollutants from the soil environment. This technology is rapidly developing, and may become commercially viable in near future (Salt et al., 1998). Phytoremediation is viewed as the ecologically responsible alternative to the environmentally destructive physical remediation methods currently practised, because plants have many endogenous genetic, biochemical, and physiological properties that make them ideal agents for soil and water remediation (Meagher, 2000). Significant progress has been made in recent years in developing native or genetically modified plants for the remediation of environmental contaminants. Toxic heavy metals and organic pollutants are the major targets for phytoremediation, and several field trials confirmed the feasibility of using plants for an environmental cleanup (Salt et al., 1998).

In the DREAM project, the plant varieties chosen are cropped and removed, otherwise the nutrients or contaminants taken up by the plants will ultimately be returned to the soil reservoir, thus reducing the treatment efficiency.

CONCEPT OF WATER HARVESTING

Water harvesting is the process of collecting and conveying water from an area that has excess water, or of transferring the surpluses of the wet season into a storage dam and redistributing it by irrigation to selected crops in the dry season (Turner et al., 1976). This practice can be adopted in a situation where water from perennial streams or groundwater wells is either unavailable or too expensive to recover.

On intensively used fine-textured soils the need for drainage in wet seasons is usually more important than irrigation in dry seasons. So the most efficient subsurface drainage, consistent with economic consideration, will be justified. Areas of low relief, consisting of fine textured soils, can be drained and the water discharged into a dam constructed in a convenient site. In the DREAM project, however, water harvesting is achieved by an appropriate subsurface drainage system that underlies the treatment plot. Residual waters from effluent applied to land treatment areas percolate through unsaturated strata to enter the subsurface drainage system in the treatment plot. The drainage system removes surplus water from the soil and ultimately discharges it into suitably placed storage dams (after passing through reactive barriers). It is expected that parallel drainage systems will be spaced 5 m apart and drawn 0.5 m deep, although the spacing and depth depend on soil type. The pipeline that runs at right angles to the parallel drainage system is placed at about 1 m depth and has backfill mixed with gravel or reactive materials.

PERMEABLE REACTIVE BARRIERS

A permeable reactive barrier (PRB) is an innovative and low-cost remediation technology for *in situ* clean up of groundwater contamination (Scherer et al., 2000). Table 1 shows some semipermeable reactive media that are placed in the flow path of contaminants to remove organic and inorganic contaminants either by transforming the contaminant to a less harmful compound (by chemical or biochemical reactions) or to immobilize the contaminant within the barrier (by sorption or precipitation).

The success of reactive materials used in PRBs will depend on the capacity of the material to sorb a particular contaminant. Proposed materials for use in reactive barriers include modified clays and zeolite, humic materials, oxides, and precipitation agents (Scherer et al., 2000). Natural materials, such as clays and zeolite have large surface area and so have a high capacity for ion exchange. Surfactant-modified clays and zeolite can substantially change the affinity for anions and other compounds. While modified clays have been proposed for use in landfill liners, and containment barriers (Sheng et al., 1996), modified zeolite can be used in PRBs to remove non-polar organic compounds, inorganic cations, and inorganic oxy anions (Bowman et al., 1995).

Table 1. Reactive materials tested for treatment of organic and inorganic contaminants.

	Contaminant	Reactive material	Removal mechanism	Reference
1	Nitrate	Organic material Sawdust	Microbial denitrification Microbial denitrification	Robertson & Cherry, 1995 Schipper & Vojvodic-Vukovic, 1998
2	Phosphate	Limestone	Precipitation	Baker et al. 1998
3	Metals (e.g. chromium)	Peat moss Modified zeolite	Sorption Sorption	Crist et al. 1996; McLennon & Rock, 1988 Haggerty & Bowman, 1994
4	Acid mine drainage	Limestone Organic material	Precipitation Microbial sulfate reduction & precipitation	Hedin et al. 1994 Benner et al. 1997
5	Organics	Coal, powdered activated carbon, peat & saw dust Modified clays	Sorption Sorption	Rael et al. 1995 Smith & Galan, 1995

As humic materials (e.g., peat and activated carbon) are inexpensive and widely available, and have large specific surface area and high porosity (McLellan and Rock, 1988), these materials have been used as effective sorbent in wastewater treatment for many years (e.g. Couillard, 1994). Peat moss is an effective ion-exchange material for the removal of heavy metals, non-polar organics, and some anions (e.g., Crist et al., 1996; Morrison and Spangler, 1993).

Naturally occurring oxides also provide sites for the sorption and exchange of anions and cations, and have been used for the treatment of industrial wastewater and may provide a promising alternative for containment of metals (Morrison and Spangler, 1993).

Immobilization of contaminants via precipitation is a significantly different mechanism than adsorption to a solid medium. Precipitation is enhanced either by increasing the solubility limit or through the addition of an excess ion. The addition of lime, or limestone, is a common method for raising the pH, and has been used as a passive treatment technology for acid mine drainage (Hedin et al., 1994). A mixture of crushed limestone and sand has been found to reduce the concentration of phosphate (Baker et al., 1998). Phosphate minerals, such as apatite, can be used for in situ treatment technology for precipitation of low solubility metal phosphates (Ma et al., 1995).

Transformation of the contaminant to a less harmful compound can be achieved by either a chemical reaction barrier or by a biological barrier. The goal of a chemical barrier is to produce chemicals less toxic or less mobile than the original compound (Scherer et al., 2000). Transformation within a chemical reaction barrier most often involves a redox reaction in which the contaminant is reduced (gains electrons) and the reaction medium is oxidised (loses electrons). Some viable media that have been proposed for PRBs include zero-valent metals and reduced minerals. Zero-valent metals such as iron, tin, and zinc are moderately strong reducing agents capable of reducing many common environmental contaminants such as metals (Blowes et al., 1997), nitrate (Huang et al., 1998), and pesticides (Singh et al., 1998). A biological barrier may be constructed by adding organic matter to a subsurface barrier, and is a novel approach to create *in situ* reactive zones where anaerobic bio-transformations are simulated. These barriers are successful in treating acid mine drainage (Benner et al., 1997), and in removing nitrate by denitrification under field conditions (Robertson and Cherry, 1995; Schipper and Vojvodic-Vukovic, 1998).

In the DREAM project, the reactive materials used in the barriers will depend on quantity and quality of effluent, and the availability of low-cost materials.

WATER STORAGE FOR IRRIGATION

After passing through the PRB, the excess water collected from the drainage system is collected in the storage ponds. Water storage ponds are constructed, depending on the purpose, and the stored water is used either for irrigation during summer or for an artificial recharge of groundwater. Since harvested water is usually a scarce water, it is important to monitor withdrawals and losses. If the storage pond is used for irrigation, allowance should be made for wastage arising from evaporation, seepage and non-recoverable water when calculating the volume to be stored. The duration of the irrigation schedule and the kind of crop to be irrigated will finally determine the volume of water to be used/stored.

The level of purification and location of agriculture using wastewater, should consider aspects including costs, hazards and benefits of agricultural reuse of wastewater. Estimated costs include those of treatment, storage and conveyance, while benefits comprise the value of agricultural output, the decrease in fertilization costs, and aquifer recharges (Haruvy, 1997). The reclaimed water used for agricultural irrigation purposes has to meet public health and agronomic quality requirements.

High value crops such as fruit and vegetables, amenity horticultural uses such as the irrigation of golf greens, as well as the strategic watering of crops like maize for dairy cows, are examples of attractive uses of harvested water. A commercial hydroponic system is being adapted for studying the potential recycling of nutrients from settled primary domestic wastewater to produce value-added crops such as lettuce, capsicum, corn and tomato (Boyden and Rababah, 1996). The crops grown in these systems have shown a remarkable ability to remove nitrogen and phosphorous. This system not only provides a low-cost water source to increase crop yields, but also decreases reliance on chemical fertilizers (Asano and Levine, 1996).

ARTIFICIAL RECHARGE OF GROUNDWATER

In many dry regions, groundwater is the only water that feeds plants, animals and humankind. It is usually more stable and reliable than any other source of water, but it is increasingly coming under threat because of greater demand. Thus, the option of an artificial recharge of groundwater as an underground storage is increasing and becoming a major alternative for overcoming short-term, seasonal, or long-term differences between water supply and demand (Bouwer, 1996). Use of treated wastewater for a groundwater recharge is also increasing as a way to protect surface water quality by keeping wastewater out of streams and lakes.

Groundwater aquifers provide natural mechanisms for treatment, storage, and subsurface transmission of reclaimed water. Soil aquifer treatment, or geo purification, provides purification during flow of effluent through the soil of the unsaturated zone and in the aquifer. When the effluent is used for an artificial recharge of groundwater by surface infiltration, it will move downward through the unsaturated or vadoze zone to the underlying groundwater table.

If the system is designed and managed as a complete recharge and recovery system, post-treatment is a viable option that can reduce pretreatment and maximise soil-aquifer treatment benefits. To date, the major emphasis on wastewater reclamation and reuse has been for non-portable applications such as agricultural and landscape irrigation. Stormwater and treated sewerage effluent, previously regarded as waste, are now being reused in South Australia through the innovative aquifer storage and recharge technique. After pretreatment in wetlands, this water is stored in otherwise unused brackish aquifers for summer irrigation of parklands. There are many case studies where the aquifer storage and recharge technique has been successful, with savings in water and infrastructure costs, as well as the provision of environmental benefits (Barnett et al., 2000).

CONCLUSION

As explained, DREAM is a simple, low-cost, and holistic approach to reduce/remove contaminants from effluent to produce Aclean, useable≅ water for agricultural management. It is suitable for and can be applied in developing countries, and areas of water scarcity. It is not a single idea but a package that combines the concepts of land-based effluent irrigation, intensive cropping /phytoremediation, water harvesting, permeable reactive barriers, and an artificial recharge of groundwater. Different components of the DREAM project have been tested successfully either at laboratory scale or in field situations worldwide. Although the components are the same in all DREAM projects, the drainage factors, reactive materials, and plant varieties used, will all depend on the quantity and quality of effluent, locally available material, and local soil type.

While the operational area of the DREAM project depends on the availability of land and effluent quantity, the *success* of the project depends purely on the operator=s willingness and commitment.

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