Principals of Reusing Municipal and Industrial Wastewater Discharges for Irrigated Agriculture

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Many regions around the world are currently facing water shortages which inhibit development and economic growth. Although some of the allocation problems faced by these regions can be partially alleviated by improving agricultural irrigation efficiencies, another means for substantial water savings involves the reuse of municipal and industrial discharges to offset freshwater demands. In many cases, the pollutants associated with these wastewater discharges are actually valuable crop nutrients (i.e., nitrogen, potassium, phosphorus, magnesium, etc.) that can actually improve crop production while reducing input costs. By utilizing industrial and municipal discharges to augment agricultural production, regions around the world can realize multiple economic gains through improved agricultural productivity, reduced wastewater treatment requirements, and the more efficient use and allocation of water resources.

A land-based wastewater management system, often referred to as land application, is a cost-effective, natural way to reuse wastewater and its associated pollutants in a soil/crop system by applying the water in a controlled manner. The area to which the water is applied is managed so that constituent loadings are at or slightly below the agronomic and hydraulic uptake rates of the designated soil/crop system, which could include urban green spaces (e.g., parks), golf courses, agricultural fields, and/or tree/forested areas, depending on the quality and type of wastewater being applied. In such a system, the nutrients contained in the wastewater become fertilizers while the other constituents, such as biological oxygen demand (BOD), pH, and salts, are managed in a manner protective of the soil/crop system as well as the surrounding environment (e.g., groundwater, odors, etc.).

Land application sites are usually managed based on the daily, monthly, or annual "per acre" loading rates as opposed to wastewater constituent concentrations. For example, land application systems can typically absorb a high BOD load in the surface soil where the organic material is consumed by microorganisms. Some systems in the United States are operated with BOD loading rates of more than 200 lb-BOD/ac/day. Salts and pH are typically managed by adding soil amendments and implementing controlled leaching. Controlled leaching is a management tool that allows for extra water to percolate below the root zone to reduce salt concentrations or to minimize the build-up of other wastewater constituents that could be detrimental to the soil/crop system. Once removed, these constituents could undergo additional treatment or reduction in the underlying geologic profile or be precipitated out of the leachate, as in the case of many salts. However, this process must be closely managed because excess leaching can lead to groundwater impacts. As such, it is critical that the land application system have an irrigation system where the water can be fully controlled (e.g., center pivot mechanical irrigation as opposed to flood irrigation). Because of this, land application is not the same as an infiltration or recharge basin. It is a well-managed treatment approach designed to maximize the treatment potential within a soil/crop system. The following diagram summarizes the various treatment mechanisms incorporated with land application.

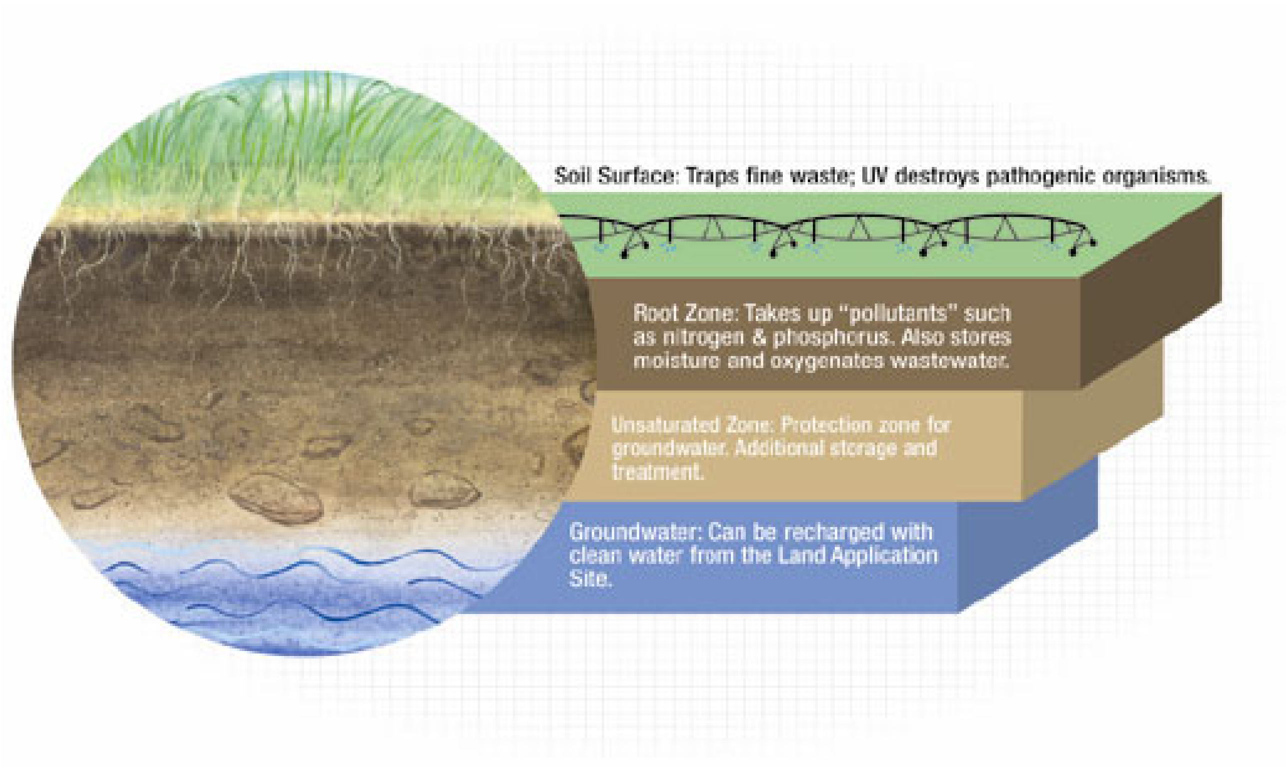

Figure 1. Land Application System Profile (courtesy Cascade Earth Sciences)

Basic Design Concepts

The key components for designing and operating a well managed wastewater land application system include soil characteristics, crop selection, irrigation design, and environmental protection. The following is a brief description of each one of these components.

Soil Characteristics

Soils represent the most important component of the land application system and can dictate the overall approach to the design and operation of a land application system. Besides being the media for growing crops to maximize nutrient removal, the microorganisms located in the soil play a critical role in the reduction of applied organics and nutrients. The type of soil at a proposed land application site will also influence crop selection, leaching requirement, and irrigation system design. Important soil characteristics to consider include texture (e.g., sand, silt, loam, clay), water holding capacities (i.e., the ability of the soil to absorb and retain water), infiltration rates (i.e., the rate at which water will move through the soil profile), and chemistry (e.g., salinity levels, inorganic composition, buffering capacity, etc.). For example, high clay soils typically have excellent water holding capacities but low infiltration rates. While a high clay soil might provide a good growing media for some crops, its texture dictates the use of irrigation systems with low instantaneous application rates operated at frequent intervals. The application of wastewater with excess sodium (e.g., wastewater with an inherently high Sodium Adsorption Ratio or SAR) to high clay soils should be avoided as this would result in surface sealing and the collapse of the soil's structural properties. Since the ability to leach is greatly reduced with high clay soils, the management of wastewater with elevated salinity levels becomes more difficult. Sandy soils, if available, are a much better alternative in these cases.

Crop Selection

Crop selection should be carefully matched to the type of wastewater that is to be applied. The type of crop grown will dictate the nutrient and water loading rates while playing an important role in contributing to the overall health of the soil. For example, alfalfa is an excellent choice for use with municipal wastewater as it has a comparatively high evapotranspiration rate (i.e., uses 40 to 50 inches of water per year), has a long root structure which results in a root zone of 5 to 6 feet for added irrigation flexibility, and has a high nutrient assimilation capacity (i.e., can take up more nitrogen, phosphorus, potassium, etc. than most crops). However, its salinity tolerance (i.e., the ability of a crop to withstand salt concentrations in the soil) is considerably lower than other crops during its initial growing stages. As such, salt tolerant grasses are a better choice when dealing with wastewaters with elevated salinity. Important considerations when selecting a crop include (1) wastewater and freshwater availability, (2) hydraulic loading capacity, (3) nutrient uptake capacity, (4) climate adaptation, (5) management requirements, and (6) commercial value.

Irrigation Design

The next important design concept is the selection of the irrigation system. Irrigation schemes typically fall into three categories: (1) sprinkler/spray including mechanical move systems (e.g., center pivots), wheel lines, solid sets, and traveling guns, (2) drip including micro-emitters, subsurface and tape, and (3) surface including flood, furrow, or gated pipe irrigation. The selected irrigation system should correspond to site soil conditions and be capable of meeting crop growing requirements. In addition, it is important from a management standpoint that the systems provide uniform application across the entire land application site as well as be suitable for use with the wastewater being handled. Sprinkler systems are advantageous over drip and surface irrigation approaches because they provide for the most uniform application (refer to Figure 2) and are much less susceptible to clogging and fouling. Sprinkler systems can also be easily adapted to handle corrosive types of wastewater such as those found in the food processing industry. Flood irrigation is the least controllable with the added challenge of having to manage tail water runoff. Hence, this irrigation approach should be avoided in most cases.

Environmental Protection

The design of the land application system must take into account the potential impacts the operation of such a system could have on the surrounding environment. Some key environmental concerns include groundwater, surface water impacts from runoff, wind drift, and soil health. Groundwater impacts can result from excess leaching if the field is hydraulically overloaded while potential surface water impacts could occur if the irrigation application rate exceeds the soil infiltration rate of the soil resulting in runoff. Wind drift (i.e., wastewater spray being blown off site) can result from operating a high pressure sprinkler system during windy conditions. Finally, soil impacts can readily result from the misapplication of wastewater with crop sensitive constituents, elevated salnity or high SAR.

Municipal wastewater has the potential for containing a number of waste-borne pathogens. As shown in Figure 1, many of these pathogens are destroyed on the surface soil from direct exposure to sunlight and an extreme change in living environment (e.g., from being in water to being placed on the soil surface). There are a number of long-term studies that have documented the efficiency of this treatment methodology. However, unless public access to the land application site can be fully controlled, the United States Environmental Protection Agency (USEPA) recommends that all wastewater be disinfected prior to irrigation (e.g., chlorination, ozone, etc.). Please note, however, that pathogens are usually not present in many types of industrial wastewater and there are usually no restrictions placed on these types of discharges (e.g., food processing, cooling tower blowdown, etc.).

Odors depend on the characteristics of the wastewater and are typically associated with high-strength wastewater or situations where the organic load in the wastewater has been allowed to turn septic. There are several approaches that can be used to combat odors within the land application system itself, including adjustments in the sprinkler types, the irrigation approach, cropping, etc., while changes to the pre-treatment and collection system can also improve odor management. The best way to control odor, however, is is to fully characterize the wastewater prior to the design of the system.

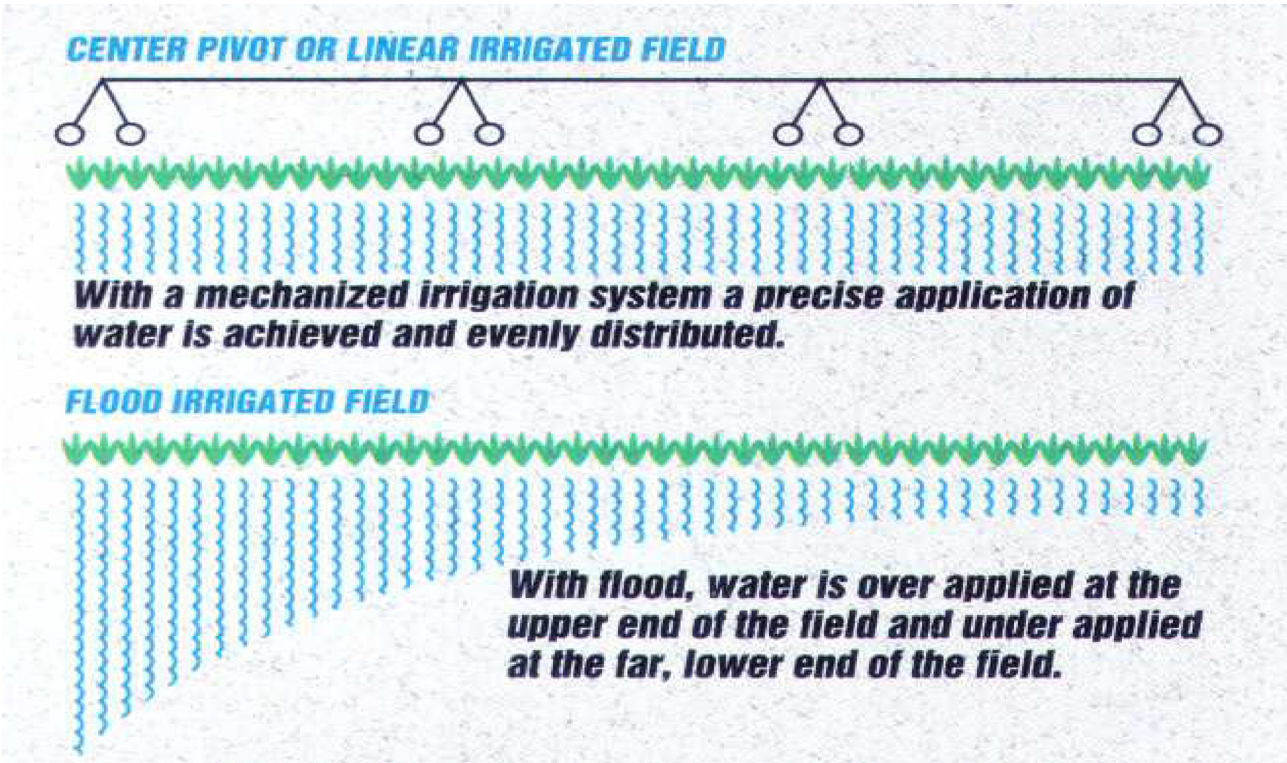

Figure 2. Irrigation Application Comparison (courtesy Valmont Industries, Inc.)

Regulatory Considerations

United States

In the United Stated, the USEPA is the federal agency with primary responsibility for regulating environmental concerns. The USEPA does not have specific water quality discharge standards for the land application of industrial wastewater but does provide guidelines for the operation of land application systems associated with municipal wastewater based on the degree of public access or the type and end use of the crop grown. These guidelines include the following:

- Effluent with primary treatment only - acceptable for isolated location with restricted public access and when limited to crops not for direct human consumption.
- Effluent with biological treatment by lagoon or in-plant processes plus control of fecal coliform count to less than 1,000 MPN/100 ml - acceptable for controlled agricultural irrigation except for human food crops to be eaten raw.
- Effluent with biological treatment by lagoons or in-plant processes with additional biological oxygen demand and total suspended solids removal as needed for aesthetics plus disinfection of fecal coliform to less than log mean of 200 MPN/100 ml - acceptable for application in public access areas such as parks and golf courses.

In other words, the USEPA requires at least primary treatment for all municipal wastewater land application systems where public access is limited (e.g., private farms where the workers have been trained in managing the risks associated with wastewater contact, etc.) and where the crop raised is not sold for direct human consumption (e.g., forage crops). If the land application system is to be established where crops are grown for human consumption, additional treatment measures are needed to reduce the potential coliform concentration. The only time that the wastewater needs to be fully treated is when the water is going to be used in areas open to the public (e.g., golf courses, city parks, etc.) or if, in an agricultural setting, the crop is being raised for direct human consumption (e.g., fresh vegetables for market). Aside from the pathogen treatment requirements, there are no other requirements for municipal wastewater treatment systems and no minimum treatment requirements for industrial effluent.

This being said, the USEPA and state environmental protection agencies have a considerable number of rules and regulations for the protection of surface water and groundwater resources. These rules typically become the overriding factor in the design of both industrial and municipal land application systems. For example, the system has to be design so that there will be no run-off or contact with surface water. If surface water contact occurs, it is considered a direct discharge and the wastewater must have been treated to meet the surface water discharge requirements or else this is considered a violation.

Since groundwater quality is also protected under these rules, the system must be designed to prevent the degradation of groundwater beneath the land application site. As such, the system has to be designed to control leaching to groundwater. Given the variety of site conditions that could be encountered, each system has to be individually designed. A land application system in an area with sandy soil and hundreds of feet to groundwater would be designed and managed differently from one that has clay soils and a shallow groundwater table. In either case, the goal is to design a system that takes full advantage of the soil/plant treatment potential while maintaining environmental protection.

World Health Organization

The World Health Organization (WHO) has a number of suggested water quality guidelines for wastewater land application. These guidelines include the following:

- Effluent with primary treatment only - localized irrigation of crops such as cereal crops, industrial crops, fodder crops, pasture and trees where exposure to workers and the public does not occur.

- Effluent with biological treatment by lagoon or in-plant processes to control intestinal nematodes to less than or equal to 1 AMN/L. No standard recommendation for fecal coliform.

Acceptable for localized irrigation of crops such as cereal crops, industrial crops, fodder crops, pasture and trees where exposure to workers and the public is a concern.

- Effluent with biological treatment by lagoon or in-plant processes to control intestinal nematodes to less than 1 AMN/L and fecal coliform to less than 1,000 GMN/100 ml. Acceptable for localized irrigation of crops that are likely to be eaten uncooked and irrigation on public areas such as sports fields and parks.

As shown, these guidelines are similar to those observed by the USEPA and wastewater constituents are managed to prevent environmental impacts. It should also be noted that both the USEPA and WHO have guidelines for annual and cumulative limits for metals applied to agricultural cropland. Below are the guidelines from WHO for reference, as the USEPA's are very similar.

Metal	Annual Loading Limit lb/acre	Lifetime Loading Limit lb/acre
Arsenic	1.78	36.58
Cadmium	1.70	34.80
Chromium	133.0	2,677.0
Copper	67.0	1,338.0
Lead	13.0	268.0
Mercury	0.76	15.2
Molybdenum	0.80	16.1
Nickel	18.7	375.0
Selenium	4.5	89.0
Zinc	125.0	2,498.0

Benefits of Land Application

There are many economic and environmental benefits of land applying wastewater. The benefits of using land application versus other treatment and discharge methods include:

- Lower maintenance – Land application systems using primary treated wastewater are much easier to operate and maintain compared to the maintenance requirements of a wastewater treatment facility with secondary treatment capability.

- Lower energy costs – The highest energy use component of a land application system is typically associated with the pumping of wastewater from the collection point to the land application site. A typical activated sludge system requires 5 to 10 times more energy.

- Reduced system upsets - Land application systems have the resiliency to recover from short-term overloads and upsets within the treatment train. An upset at a traditional wastewater treatment system usually allows non-treated or under-treated wastewater to enter the environment at the discharge point.

- Potential opportunities for local revenue improvement - By reusing wastewater as an irrigation and nutrient source, landowners have the opportunity to save on fertilizers and pumping costs while maximizing crop productivity.

- Net water savings - Reusing wastewater for irrigation reduces the net demand on freshwater resources. This is especially important in areas facing water scarcity problems.

- Net capital savings - Land applications systems are typically 30 to 60% less expensive than conventional wastewater treatment/discharge systems. Land application systems can also be associated with a number of indirect savings. For example, reusing partially treated water in an agricultural setting will reduce the pollution on the receiving stream whereby lowering the pretreatment requirements for downstream users.

Potential Risks and Drawbacks of Land Application

While the benefits of land application might appear numerous, there are a number of risks associated with this process that should be considered.

- Excess Hydraulic Loading - One potential risk is excess hydraulic loading (i.e., over-irrigation). Over irrigation will cause deep percolation, which has the potential of carrying constituents to an underlying aquifer or surface runoff. While, it is extremely important for the irrigation to be conducted in a controlled manner (e.g., sprinkler irrigation using center pivots or linear move systems) and the site routinely monitored (e.g., soil conditions, soil moisture, crop productivity, shallow groundwater, etc.), environmental factors beyond operator control can contribute to the occurrence of adverse conditions (e.g., a heavy thunderstorm could cause leaching to exceed prescribed limits or runoff to occur).

- Constituent Loading - Excess constituent loadings can result in a number of challenges including crop production reduction, soil sealing, salinity increases, and, when combined with improper hydraulic loading, impacts to groundwater and surface water. Again, proper assessment, design, monitoring, and management of a land application system is required to reduce potential risks associated with constituent loadings.

- Site Selection/Location - It must be stated that land application is not suitable for all situations. Some site specific soil conditions (high clay content) and water qualities (extreme sodium concentrations, heavy metals, certain organic constituents, etc.) prohibit the use of land application as the primary treatment mechanism or do not allow for land application to be the most cost effective water management solution. Pumping and piping costs can become prohibitive if the production water must be transported over long distances to deliver the water to a location with favorable soil characteristics. Local climate or operational considerations could also hinder the efficiency of land application. For example, although year-round irrigation is feasible in some cases, regions with harsh winter climates may require the wastewater to be stored for later use during the growing season only. Finally, care should be taken to assess groundwater resources in the area. Sites with shallow aquifers should be avoided since the goal is to precipitate the salts in the geological zone below the crop root zone but above the nearest aquifer (refer to Figure 3).

Example Cases

The following is a sampling of where land application has been successfully used as part of a wastewater management strategy.

- <u>Fresh Pack Vegetable Processor</u>
  - Problem:
    - High BOD and Nitrogen load in wastewater prevented direct discharge
    - Land was limited
    - Purchasing land for irrigation of full waste stream was cost prohibitive
  - Solution:
    - Separated high strength wastewater from other sources.
    - Sent blanching water for Land Application on a small area
    - Conventional treatment on remaining water for direct discharge
    - Wastewater influent (to conventional treatment system) BOD reduced by 40% and TKN by 20%

- <u>Potato Processor</u>
  - Problem:
    - Nitrogen discharge regulations tightened
    - Conventional mechanical treatment would have required a 90% reduction of nitrogen load for direct discharge
  - Solution:
    - Maximize land application to minimize treatment costs
    - Sizing a constructed wetland for winter storage and land application capacity eliminated need for nitrogen removal
    - Maximizing the land application option 45% less expensive than cost of conventional mechanical treatment

- <u>Power Plant Generator</u>
  - Problem:
    - NPDES discharge approval uncertain
    - High salinity cooling tower water

- Solution:
  - Designed and implemented land application system to be used in conjunction with fresh water irrigation to allow for plant start-up.
  - Specific cropping and irrigation strategy used for high salinity water
  - Plant allowed to operate for 10 months using land application while NPDES permit was processed and issued.

- Coal Bed Natural Gas (CBNG) Producer
  - Problem:
    - CBNG produced water with elevated salinity and SAR
    - Direct discharge to surrounding waterways disallowed
    - Desalination of CBNG produced water cost prohibitive
    - Deep well injection unfeasible
  - Solution:
    - Designed and implemented land application system to receive and irrigate wastewater from numerous production wells
    - Specific cropping and irrigation strategy used for high salinity and SAR water
    - Allowed gas wells to continue operation and production

- Municipalities
  - Problem:
    - Conventional wastewater treatment process expensive:
    - City of Ontario, Oregon – estimated at US$7.9 Million
    - City of Nyssa, Oregon – estimated at US$4.6 Million
    - City fo Akron, Colorado – estimated at US$5.6 Million
  - Solution:
    - Designed and implemented land application systems:
    - City of Ontario, Oregon – US$4.22 Million, 47% savings
    - City of Nyssa, Oregon – US$2.25 Million, 52% savings
    - City of Akron, Colorado – US$3.0 Million (estimate), 46% savings

Conclusions

Land application is a cost-effective approach to managing various municipal and industrial wastewater discharges. While the benefits associated with land application are great (e.g., lower energy costs, reduced system upsets, lower operating and capital costs, and regional water savings), a land application system must be well designed and operated so as to avoid the inherent risks associated with this water management approach (e.g., soil sealing, salinity impacts, groundwater pollution, runoff). Given favorable site conditions, a properly designed and operated land application represents one of the least expensive methods for treating and managing wastewater discharges.