Land Based Wastewater Treatment and Reuse– A very short primer

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Land application of wastewater has been recognized as a viable option for the management of both the liquid and process component in domestic, industrial, and agricultural wastewaters. The practice had been utilized historically in Paris France, Berlin, Germany and Edinburgh, Scotland . The **Sewermen of Paris** (Reid, 1991) discusses a history of the sewers in Paris and the associated land application. These large facilities were abandoned in the early part of the 20th century as advances in treatment and disinfection reduced the health risks associated with wastewater management. Historical documentation of land based treatment is focused primarily on health issues. Removal of the discharge reduced health risk.

*Even the most ignorant is aware that rain falling upon the dung heap washes away silver and that it would be more profitable to have on fields what now poisons our village…(*__Natural Law of Husbandry__, Von Liebig, 1863).

In the U.S. Land based treatment was utilized sparingly in the early days of the country. One of the larger systems utilized in the U.S. was in Illinois. This system exhibited a very shallow water-table and the crop selected was rice. The rice that was shipped to Chicago was blamed for disease outbreaks in Chicago. The system closed.

Passage of the Clean Water Act in 1972 required communities eliminate the direct discharge of pollutants to waters of the states. Many communities viewed this as a mandate to reduce the volumes of pollutants discharged. Others took this as a mandate to eliminate the discharge of water and associated pollutants. Several large communities (Muskegon, MI., Jacksonville, NC) developed large land based systems with funding through the USEPA. Many smaller communities, typically generating less than 1 MGD also took advantage of the generous federal grants.

The Muskegon system treats over 40,000,000 GPD. The system consists of a series of ponds covering 1500 acres and a series of spray fields covering over 7,000 acres. The system incorporates a series of drainage ditches and the drainage water is monitored. BOD, TSS, Nutrient (N and P) and bacterial indicator levels are very low. In Jacksonville, NC a 4000 Acre wooded wastewater irrigation system accommodates the 8,000,000 gallons of wastewater generated by the citizens and portions of a large military facility in the area. Groundwater monitoring indicates slight increases in the nitrate level in system monitoring levels over background wells, but the nitrate level measured does not exceed the national drinking water standards. Land based systems perform well. They require large areas for treatment, storage, and irrigation.

Design Issues

Land based system development requires thorough characterization of the liquid to be applied to land. A land treatment system can accommodate any input, but the land area required may be very large depending on the limitations associated with the site. The design process is intended to integrate the issues associated with the pre-application wastewater treatment with the characteristics of the site, the soil, and the cropping system. Included in the design are anciliary issues such as operator training and qualifications, finance, capex and opex, long term management and sustainability.

Liquid: the liquid applied to land contains a variety of resources – Nitrogen, Phosphorus, Sulfur, Calcium, Zinc, Copper, Boron, Organic matter, etc. In addition, the untreated liquid contains potentially pathogenic microorganisms that must be controlled. The intent of the pre-application treatment processes is to condition the liquid to a "fit for purpose" standard. If the treated liquid is to be applied onto a production forest and there is little public exposure to the liquid applied, a very low level of pre-application treatment can be applied. If the liquid will be used to irrigate high value crops or turf where human contact is obvious, high levels of treatment and disinfection are required.

The land can assimilate the resource, but the land area required for assimilation must be based on a limiting constituent assessment. This requires knowledge of the site and soil limitations, the cropping system characteristics (N and P requirements, proposed use), and the management needs of the crop.

Site and soil:

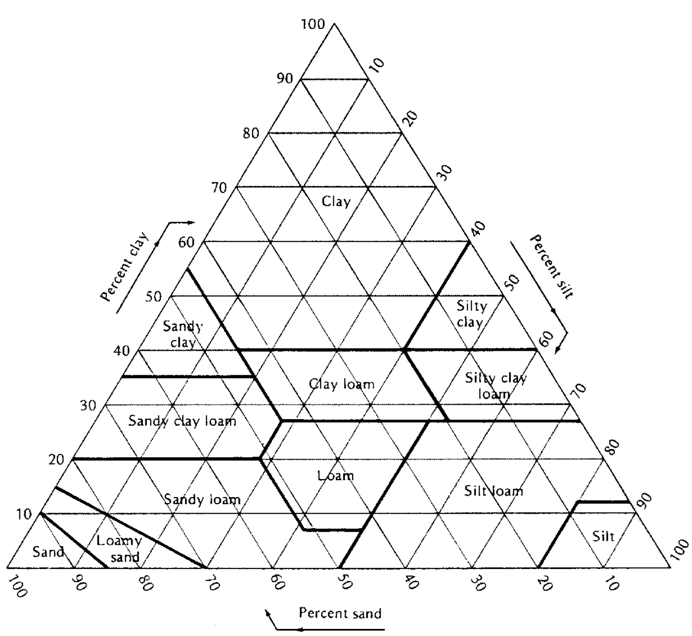
The characteristics of the site (area, slope, drainage potential, location in the watershed). Land area requirements are determined based on the capacity of a site to receive (infiltration) liquid, drain liquid (permeability) and discharge liquid to the receiving environment (transmissivity). The site slope and landscape position are critical in these determinations. Some slope is required to provide the gradient along which liquid will move. If limited gradient exists, drainage can be induced through installation of artificial drainage. Site slopes are defined as flat, gentle, or steep and the elements of slope are defined as concave or convex. The combination of the slope gradient and the shape of the slope define water movement on a site. Concave slopes tend to disperse water while concave slopes tend to concentrate water. Sites located in sensitive watersheds may require extensive buffering to prevent rainfall runoff and advanced levels of treatment may be necessary to reduce potential for nutrients to migrate beyond the plant root zone. These site factors are addressed during the site investigation phases – typically a screening phase, site selection phase and a detailed site assessment phase.

Soil resources are critical in assessing the viability of a site. All sites can receive some water and nutrient. The question is how to optimize site loadings with site area. This allows loading the minimum required land area with liquid treated to the “fit for purpose” level discussed. Typically the site assessment examined selected soil properties important in assessing water movement, nutrient status, crop production potential. These properties include:

Soil depth: the volume of soil above a water table or rock provides the medium for wastewater treatment and assimilation of nutrients. Soil volume is related to the soil depth on a receiver site. Shallow water table reduces the volume of soil available for treatment simply because the treatment of most waste constituents does not occur in the water table.

Soil color: The color of soil within the various layers or horizons indicates the aeration state of the soil. Production of most agriculturally and silviculturally valuable crops requires well to moderately well drained soils where air is present in the plant root zone (yes, rice is an exception). Soil colors indicate the aeration status in natural soil; bright colors indicate presence of air while gray and black soils present below the topsoil layer indicate limited presence or air.

Soil texture: Soil is composed of varying combinations of sand, silt and clay particles. Texture refers to the relative proportion of these soil separates in a layer or horizon. Typically soil texture will vary as depth changes. Topsoil layers often contain sand particles that assist with infiltration of liquid. Deeper layers typically contain clay minerals that hold water and nutrients. Soil texture is probably the most critical component in determining the infiltration and permeability rates on a site. Soil texture is described by the texture triangle.



Soil structure: the aggregation of the soil separates into a unit of soil that you can hold in your hand is described as the soil structure. The structure influences the rates of water movement through a soil profile. Typically soils that exhibit granular, blocky and columnar structure transmit water easily. Soil resources characterized as massive or platy restrict water movement.

Consistence: the consistence of a soil refers to the type of clay material in the various layers or horizons. Some clay materials shrink and swell when dried and wetted. These expansive clay minerals are smectites from montmorllionitic or kaolinitic minerals. Typically soil materials containing these shrink-swell clay minerals are poorly suited to any land based wastewater system. These minerals render the expansive soil very sticky. Soils containing minerals from kaolin are not expansive and are well suited for land treatment.

The Water Balance: these data are required to determine or calculate a water balance for a site. The water balance is a tool to optimize the liquid application to a site and for sites that are hydraulically limiting this is critical. The water balance is a simple formula balancing water losses with water inputs:

Irrigation = evapotranspiration + soil drainage + rainfall runoff – precipitation

Please note the irrigation includes the wastewater collected and treated to meet the fit for purpose requirement discussed as well as any liquid falling into the storage ponds. This rainfall input can be significant and pond depth is critical to optimize storage while minimizing surface area. The water balance is the most critical element in system design! Professionals familiar with soils and hydrogeology must develop the water balance. The challenge is to get water into, through and off the receiver site.

Typical water balance showing annual liquid load acceptable onto a receiver site:

ɿr Balance for Zone 7

Soils Series Information for Zone 7		Potential site limitations		
Series Name	Drainage class	Water table depth (BLS)	risk of perching	Is bedrock < 60" BLS ?
Norfolk	well	>3.0	low	no
Goldsboro	mod well	2.0-3.0	low	no

BLS = b

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oil Drainage

Step 2	f x Ksat
Drainage factor (f)	Soil Drainage Rate
percent	in/day
0.060	0.22

Copied from Influent & Zones Setup Sheet:		
Daily Flow =	0	gals/day
Zone 7 Area =	0.00	acres

PET	Zone 7 Soil Drainage	Zone 7 Total Loss	Precip	Calculated Maximum Allowable Irrigation	Manual Override Maximum Allowable Irrigation	Actual Used Maximum Allowable Irrigation	Design Irrigation per Month	Monthly Excess	Zone 7 Cummulative Storage Required for Irrigation	Zo Actual Irrigati
inches	inches	inches	inches	inches	inches	inches	inches	inches	inches	inc
0.43	6.70	7.13	4.80	2.32		2.32	0.00	2.32	0.00	0.
0.62	6.05	6.66	3.78	2.89		2.89	0.00	2.89	0.00	0.
1.45	6.70	8.15	4.75	3.40		3.40	0.00	3.40	0.00	0.
2.55	6.48	9.03	3.27	5.75		5.75	0.00	5.75	0.00	0.
4.22	6.70	10.91	4.39	6.53		6.53	0.00	6.53	0.00	0.
5.55	6.48	12.03	5.50	6.53		6.53	0.00	6.53	0.00	0.
6.51	6.70	13.20	7.62	5.58		5.58	0.00	5.58	0.00	0.
5.79	6.70	12.49	7.00	5.49		5.49	0.00	5.49	0.00	0.
4.20	6.48	10.68	6.66	4.03		4.03	0.00	4.03	0.00	0.
2.38	6.70	9.08	3.38	5.70		5.70	0.00	5.70	0.00	0.
1.24	6.48	7.72	3.20	4.52		4.52	0.00	4.52	0.00	0.
0.59	6.70	7.28	3.65	3.63		3.63	0.00	3.63	0.00	0.
	Calcs.	Calcs.		Calc. M.A.I.	Manual M.A.I.	M.A.I. Used		Calcs.		
35.52	78.84	114.36	58.00	56.36		56.36	0.00			0.

Maximum Monthly Storage Required for the Irrigation

inches		acres
0.00	over	0.00

ɿrBudget_DWQ_Ver5-4.xls Z7 Version

Operators must recognize the wastewater load includes the actual wastewater treated and additional liquid falling on the storage facility. The

water balance does not discriminate between wastewater and rainwater; it is all wastewater once commingled in a storage pond.

The measures and determinations inherent in the calculation involve actual measures of soil permeability and the designer then assigns a drainage coefficient as between 4% and 10% of the measured value. Permeability must be measured at a minimum of three locations on a specific soil resource group on a site and the lowest value used in the calculation. This is because of the anisotropic nature of soil material even when within a specific series. On sites with slow permeability, a 4% coefficient is advisable while on rapidly permeable sites a more generous coefficient is allowable. The question of low crop activity is evident in the low evapotranspiration rates during winter months. For New Zealand, the months would be adjusted to accommodate the seasonal variations between seasons in northern hemisphere.

Soil fertility: the measure of a soil to produce a crop is reflected in the soil Fertility level. The fertility level is the easiest of the soil parameters to adjust. Additions of supplemental nutrients (N, P, K, S, B) or supplemental lime to adjust soil pH are routine practices in agricultural and silvicultural operations. The addition of these materials to optimize crop production and to minimize potentially adverse environmental impacts is best assessed through annual soil sampling programs on all sites in a land treatment program.

Cropping systems: all crops are suited for use on a land treatment site. The specification of a crop is dependant on the level of liquid to be applied and the requirement for nutrient assimilation and removal. Various crops tolerate liquid addition differently. Grass crops exhibit very large leaf surface per acre and in a warm summer, a warm season grass may evapotranspire up to 0.75 inches of water in a day. Similarly, a warm season grass when properly managed may require up to 300 pounds of PAN, 60 pounds of P, and 150 pounds ok K per acre per year to maximize yield. In contrast, a soybean crop is a legume, veryt little nitrogen is required to optimize the yield of this crop. Liquid containing high levels of essential nutrient should be applied onto crops with high nutrient needs.

The crop nutrient need for a specific crop is best determined based on a comprehensive nutrient management plan (CNMP) based on realistic yield expectations (RYE). The RYE is based on published data for a crop on a soil in a specific area or more appropriately on actual measured yields for a crop from a specific field. The CNMP assesses the nutrient need based on uptake by a crop. Once the yield is assessed, the amount of a specific nutrient, the placement of that nutrient relative to plant root zone, the timing of that application and the various forms of the nutrient are assessed to determine application allowances.

Form – Is the nutrient available in an ionic form readily available to plants. Organic N must be converted to plant available nitrogen before uptake. In what form is the nutrient as discharged from a treatment facility?

Timing – Application of nutrients to most commercial field cropping systems is best accomplished prior to planting or early in the growth stages of the plant. This typically limits application times to a few months during a year. Double cropping allows nutrient applications twice per year. Forest systems have a tremendous ability to utilize and recycle nutrients and timing is less critical on forest systems than agricultural systems.

Yield based nutrient requirements for specific soils are presented in the table below and these data are available for many areas. This example is for crops typical in Alamance County, NC.

Realistic Yields for AbB2: *Appling coarse sandy loam, 2 to 6 percent slopes, eroded* in Alamance County

Crop	Yield	Nitrogen Factor	Realistic Nitrogen Rate (lbs/acre)	Estimated Phosphorus Removal (lbs P_2O_5/acre)
Barley (Grain)	86 Bushels	1.49	128	33
Corn (Grain)	159 Bushels	0.93	148	70
Corn (Silage)	24.5 Tons	10.9	267	83
Cotton	760 Pounds	0.081	62	22
Sorghum (Silage)	20.8 Tons	7.6	158	62
Oats (Grain)	108 Bushels	1.13	122	27
Peanuts	0 Pounds	0	0	0
Rye (Grain)	64 Bushels	2.01	128	21
Small Grain (Silage)	11.3 Tons	11.1	125	61
Sorghum (Grain)	64 CWT	1.72	110	48
Soybeans (Double Cropped)	45 Bushels	0	0	36
Soybeans (Full Season)	54 Bushels	0	0	43
Soybeans (Double Cropped - Manured)	45 Bushels	3.89	175	36
Soybeans (Full Season -	54 Bushels	3.89	210	43

Manured)				
Tobacco (Burley)	0 Pounds	0.074	0	0
Tobacco (Flue Cured)	3234 Pounds	0.029	94	16
Triticale (Grain)	89 Bushels	1.52	136	30
Tropical Corn (Silage)	24.5 Tons	6.5	159	83
Wheat (Grain)	64 Bushels	2.01	128	32
Bahiagrass (Hay)	3.9 Tons	44	172	45
Caucasion/Old World Bluestem (Hay)	4.4 Tons	44	194	52
Common Bermudagrass (Hay)	3.9 Tons	44	172	47
Dallisgrass (Hay)	3.9 Tons	44	172	51
Fescue (Hay)	5.4 Tons	44	237	85
Hybrid Bermudagrass (Hay)	5.4 Tons	44	237	66
Hybrid Bermudagrass overseeded with Rescuegrass (Hay)	0 Tons	44	0	0
Mixed Cool Season Grass (Hay)	3.9 Tons	44	172	56
Orchardgrass (Hay)	4.4 Tons	44	194	64
Pearl Millet (Hay)	4.7 Tons	49	228	62
Rescuegrass (Hay)	0 Tons	44	0	0
Sorghum Sudan (Hay)	5.1 Tons	49	252	72
Timothy Grass (Hay)	0 Tons	44	0	0

To determine the amount of N or P where yield has been measured in a field, simply multiply yield measured by nitrogen factor to obtain nitrogen required.

Site Design:

All the material and information collected in the site and soil investigation phase of a project is incorporated into the system design. The design phase of the project involves the entire project team of soil scientists and agronomists, hydrogeologists, planners, design engineers, and representatives from the outreach community to develop a comprehensive plan that meets local needs. The design of wastewater application systems involves irrigation of liquid at specific rates onto a soil surface or just below the surface as in drip dispersal. Surface spray irrigation is the least costly of the various options. Irrigation systems can be mobile (hose reel or center pivot) or fixed. The irrigation system consists of:

1. Water source with sufficient capacity to supply liquid through an entire scheduled irrigation event,

2. Pump or pumps to assure liquid is supplied at the desired application rate and the desired head pressure to all segments of the system. The goal is uniform coverage of a landmass.

3. Piping and distribution network capable or supplying liquid to a field.

4. Water storage or discharge for periods when liquid cannot be irrigated.

5. Irrigation nozzles or spray-heads capable of supplying liquid to the soil at a rate consistent with the capacity of the soil infiltration rate or a set of drip irrigation tubes delivering liquid at a rate consistent with the surrounding soil

6. Cropping system capable of assimilating the liquid and nutrients applied and suitable for growth in a specific area

7. Harvest system capable of removing a crop in a short timeframe to insure the site is used as a receiver for liquid during the critical times of the year. Long harvest times do not allow irrigation and capacity is lost if harvest requires significant time. This can be addressed simply by allowing more land for irrigation and assuring crop lay-by times are maintained at minimum while having additional land when crop management precludes irrigation

8. crop storage system if necessary, grain bins, ag-bags for forage, etc

9. Staff trained in the farm operations necessary to sustain a system

10. A management team that is familiar with CAPEX and OPEX, asset management strategies, staff management and system management, laws, rules and regulatory requirements necessary to sustain the facility through its design life.

Site Management:

Land treatment operations are developed to optimize liquid and nutrient loadings to land. Trained farm managers are required to insure all required operations are accomplished as necessary. The primary purpose of a land based wastewater system is to accommodate the wastewater applied. Site managers must assure soil testing is accomplished as required by the cropping system and that supplemental nutrients and lime added as required. At minimum, soil testing is required prior to beginning a crop season. Sites should be sampled approximately days prior to seeding or dormancy break for a perennial crop (pasture, hay land, forest system).

Crop harvest is best accomplished when soils are trafficable. This frequently requires some drying between a liquid application operation and the ingress to a field. If these activities are accomplished during peak irrigation times, the irrigation must be curtailed to accomplish the required agricultural or silvicultural activity. Unlike a stream discharge, the land-based system must cope with seasonality of field access and operation. When liquid cannot be applied for weather related or field operation, that liquid must be stored or discharged.

Land based wastewater systems are limited by either a hydraulic load or a process load (N, P or salt typically). Unlike stream discharge systems the capacity of the land base system is evident and when excess liquid accumulates in storage or when excess runoff occurs that capacity is obviously exceeded. A good operations plan includes provisions for expanding a system as the actual flow into a system reaches 75% of the design capacity.

The operation and management of land-based systems requires a strong knowledge of agriculture or silviculture. The operation of the pre-application system requires knowledge of the wastewater unit processes necessary to condition liquid for application onto land.

In addition to these traditional ag operations, high quality treated water can be recycled and reused in a community for a variety of non-potable demands. Dual use plumbing where non-potable water is plumbed into buildings for toilet flush, irrigated parks and recreation areas, irrigated turf fields and golf courses, cooling tower make up water and other activities can all benefit from recycle and reuse water – water fit for purpose. This can be accomplished through of satellite or distributed onsite wastewater systems located at points in the community where wastewater could be diverted for advanced treatment from the wastewater collection system or where wastewater from a building. Once treated this liquid could be used in a dual distribution system for non potable end uses in a building or at a park, golf course, turf field or other application where non-potable use is allowed.

Ancillary issues:

Biosolids from wastewater treatment facility must be accommodated. Biosolids may compete with irrigation system for suitable land. Options for generating high quality biosolid material may benefit community.

Regional cooperation may be an option. Several of the facilities operating in the U.S. provide wastewater service to neighboring communities where the wastewater generation is small and watershed classifications or site limitations render land treatment challenging to a small community

Other options:

The discussion has addressed traditional land based systems. Other land based system approaches may involve the development of constructed wetland systems or aquifer storage and recovery systems. The design and management of these land-based systems require skills in wetland management of groundwater hydrology. They are considered as land based systems by the USEPA.

Wetland: The constructed wetland does discharge typically to a surface water. Constructed wetlands have been developed and utilized throughout North America and they do provide excellent treatment of wastewater. Perhaps the most significant example of a large constructed wetland system is the Clayton County system in Georgia. This system was initially designed and developed as a forested spray irrigation system. The system was designed to accommodate 10 MGD flow. As the area grew and developed, portions of the forested system were modified to allow development of wetland plants and the irrigation was modified to promote creation of wetlands. The liquid in these wetlands now serves as a back-up water supply for Clayton County Georgia.

Aquifer storage and recovery: Discharge of high quality treated wastewater into an aquifer system with subsequent removal of that water at some tiome in the future is the ASR concept. This is accomplished at Water Factory 21 in Orange County, Ca, at several facilities in Florida and in Israel. High quality water is discharged into an aquifer and the travel time in the aquifer system is determined. Once liquid has been in aquifer system for a specified period of time – typically 6 month to a year, it is withdrawn and used as source water for a water supply or as irrigation water.

Distributed system: A distributed, decentralized or satellite facility can be developed anywhere in the service area where there is both a source of wastewater and a need for reclaimed water. In Lexington, NC the city built a reclaimed water plant at the golf course. This facility diverts wastewater from the municipal collection system, treats and stores that reclaimed water on site and diverts the treated liquid to a municipal golf course. In the peak summer irrigation season, the golf course utilizes over one million gallons of water per week for irrigation. That irrigation water was never delivered to the central wastewater plant. That satellite facility removes over 1000 pounds of nitrogen from the permitted stream discharge.

Conclusions:

We have learned a bit about the development of land based systems since those early efforts in Europe and Illinois. The focus today is on sustainability, protection of public health and improvement of environmental quality. These goals can be realized with land-based systems that are properly developed and operated. Those activities require careful assessment of the water quality to be applied, extensive site assessment to include site, soil, and hydrogeologic properties of receiver sites, development of farm management plans addressing nutrient and water requirements of receiver sites, and competent operators and managers. Yes, it has been done successfully with large flows in cool, humid climes.

Some References:

USEPA Land Treatment Manual, 2011, EPA 625/R-06/016

USEPA Water Reuse Guidelines, 2012

15 A NCAC 02T and 02U, Non Discharge Rules for NC

9 VAC 25-740, Virginia Water Reuse Regulation

Guidelines for On-Site Non-Potable Water Reuse, sfwater.org