ALABAMA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

WATER DIVISION
ADMINISTRATIVE AND ENGINEERING GUIDELINES
INDUSTRIAL WASTE LAND TREATMENT FACILITIES

I. Definition/Applicability of Land Treatment

Land treatment is use of a vegetation-soil system to both renovate and serve as the ultimate receiver of industrial wastes and residues. Typically the wastes are applied to the land surface or surface zone such that chemical and biological reactions breakdown a portion of the waste, adsorption and fixation occur for other portions, and controlled migration is allowed for certain inorganic fractions. These criteria do not necessarily apply to overland flow, rapid infiltration or other similar land treatment techniques.

II. Statement of Intent

The engineering guidelines portion of this document is not intended to be a "cookbook" set of design rules, and it is not the intention of the Department to suppress the state-of-the-art by enacting overly restrictive design requirements in this developing field of waste treatment. In certain instances, some of the criteria may be altered to suit individual project conditions; however, until data from additional systems operating in Alabama is obtained, the basic guidelines should be adhered to. It should be emphasized that since the majority of the material published by EPA and available in the literature to date has been based on land application of municipal wastewaters and sludges, these sources do not necessarily provide adequate design information for industrial wastes due to the great variability of these wastes. Also, geologic and hydrologic differences between sites, even those geographically close, can result in significant variation in site assimilative capacity. Therefore, each specific site and waste will be evaluated individually using all constraints of these guidelines. The Department will require extensive justification and geotechnical investigation prior to considering use of land treatment in limestone terrain. land treatment of wastes containing significant radioactive substances is prohibited.

III. Approval Procedures

The following two phase approach should be followed in obtaining approval of land treatment projects.

A. <u>Phase I</u>

1. The industry or consultant should contact the Alabama Department of Environmental Management – Water Division (WD) staff to informally discuss the proposed land treatment project. The staff may then offer guidance as to the extent of preliminary analytical and engineering data to be collected in accordance with Item III.B. In addition, should any waste and/or geologic/hydrologic conditions necessarily preclude land treatment, the project can be terminated prior to unnecessary expenditures by the industry;

2. The industry or consultant provides the staff with a description of the proposed land treatment project (Phase I report), to include the following information:

    a. A representative quantitative and analytical analysis of the waste should be provided and the waste characterized as hazardous or non-hazardous as defined by the regulations of the Resource Conservation and Recovery Act and/or those promulgated by the Alabama Department of Environmental Management – Land Division. A description of the process and raw materials contributing to the wastes, and treatment or pretreatment provided, should be included. A list of relevant parameters is included in Appendix C. If any of these parameters are applicable to the waste, an analysis should be made. Sampling requirements are included in Appendix C;

    b. The proposed land treatment area should be transposed on a current USGS 7.5 minute series, or similar scale, topographic map extending at least a mile outward from the site. Located on this map should be all active wells, sinkholes or sink features, quarries, sand and gravel pits, dwellings, ponds and other bodies of water, soil borings as noted in Item III.B.v., and proposed location of monitoring wells;

    c. A four inch per mile or similar scale Soil Conservation Service soil map should be provided, if available. The land treatment area should be transposed onto this map. If a soil map is not available, the area should be surveyed and typed by a qualified soil scientist;

    d. For each soil type identified within the land treatment area, a soil sample, composited over the top six inches of soil, should be collected and analyzed for Cation Exchange Capacity (CEC), pH, conductivity of saturation extract, Sodium Adsorption Ration (SAR), and other parameters as identified by the staff during the preliminary meeting. All soil analyses should be conducted in accordance with "Methods of Soil Analysis" published by the American Society of Agronomists. Percolation tests using the falling head technique (see Appendix E), may be required for each major soil type. The double-cylinder infiltrometer, as found in "Process Design manual for Land Treatment of Municipal Wastewater" (EPA 625/1-77-088) may be substituted for the falling head technique. If greater soil depths are considered as part of the assimilation capacity, deeper sampling may be necessary;

    e. Soil boring logs should be provided. The number and location of borings should be discussed with the Water Division prior to implementation;

f. In some cases, particularly where complex wastes and/or geology are involved, a geologic and hydrologic study will be required. This study, which must be completed by a geologist, groundwater hydrologist, or other qualified consultant, should include a lithologic description of bedrock, depth to consolidated rock, static water level (including seasonal variation of depth), depth to water bearing formation, flow characteristics (horizontal and vertical), and the presence of faults, fractures, joints, solution openings, sinkholes, seeps and springs. As appropriate, these features should be located on the maps referenced in Item III.B.ii.;

g. A description of past and present uses of land should be included;

h. A description of proposed application method.

The above information, which must be prepared, reviewed by and bear the seal of a Professional Engineer (P.E.), registered in Alabama, should be provided as soon as practicable in a project to facilitate an on-site geologic/hydrologic review by the Commission;

3. The staff reviews the above information and concurrently arranges an on-site geologic/hydrologic review. If the waste is classified as hazardous, additional review by the Land Division will be performed simultaneously;

4. If the initial geologic/hydrologic review reveals that the proposed site is acceptable, and the staff determines that waste and geographic considerations allow land treatment, approval is given to complete Phase II. If the waste is classified as hazardous, engineering or administrative requirements other than those in this criteria may be specified at that time. If the site is not acceptable, alternate sites are considered, and if necessary additional on-site geologic/hydrologic reviews are arranged.

B. <u>Phase II</u>

1. A Phase II report is completed and submitted to the staff. The report includes calculations to determine area required for waste assimilation, and addresses, item by item, the proposed methods and associated data necessary to meet the engineering criteria specified in Part IV. Also included should be specifications for storage, pumping, distribution and application equipment. As with the Phase I report, this report must be prepared, reviewed by and bear the seal of a P.E. registered in Alabama;

2. After approval of the acceptable Phase II report, the staff issues approval to construct;

3. Upon completion of construction, but prior to operation of the system, the P.E. provides the staff with a letter of certification stating that the land treatment system was built in accordance with the Phase I and II reports, the engineering requirements specified in Part IV, and any stipulations specified in the approval to construct. The staff will then issue a permit;

IV. Engineering Requirements

A. The criteria for maintenance of groundwater impacted by land treatment shall be that contaminants in the groundwater not to exceed the maximum contaiminant levels (MCLs) specified under P.L. 92-523 (The Safe Drinking Water Act), Interim Primary and Secondary Drinking Water Standards (Title 40, Parts 141 and 143)(see Appendix B). In some instance where existing groundwater exceeds Primary and Secondary MCL Standards, the staff shall set acceptable contaminant levels on a case-by-case basis;

B. The area required for assimilation of the waste shall be determined, on a constituent by constituent basis, in accordance with the assimilation criteria specified in Appendix A. The fate of all waste constituents shall be considered. The largest area determined shall then be the area utilized for land treatment;

C. In all cases, background data shall be obtained on the soil, runoff, surface water, and groundwater affected by the land treatment system. Parameters and number of samples shall be specified by the staff after completion of the Phase I report. For complex wastes whose effects may be unknown, a control plot allowing unaffected groundwater, soil and runoff sampling, may be required. All water analyses shall be performed in accordance with the current regulations of the Environmental Protection Agency;

D. The minimum depth to groundwater, without use of an underdrain collection system, shall be 10 feet;

E. Land treatment sites shall not be located within the 100 year floodplain as determined by the latest USGS floodplain map;

F. Excessive rainwater run-on should be diverted from the land treatment area;

G. The maximum slope within the land treatment area should be 10% for sodded or crop areas, and 20% for forested sites. Soil conservation and erosion control measures such as but not limited to contour tillage, strip cropping and terracing should be practiced to minimize erosion losses;

H. As suitable cover crop shall be provided for the whole of the land treatment area;

I. To prevent odors, inadequate wastewater renovation and possible metals liberation, the soil shall remain predominantly aerobic. Excessive ponding should be avoided;

J. A water balance should be performed to determine the necessary storage capacity. This balance should include inputs of precipitation and the waste and outputs of percolation and evapotranspiration. Systems should be designed for zero runoff of the applied waste. Where storm water runoff may be significantly contaminated, provisions for treating, reapplication, or other means will be required. It is recommended that the balance be performed on a monthly basis with a precipitation input using a 5-year, 24-hour rainfall event, 30-year minimum base period (where available). Examples of water balances are presented in Appendix D. In addition to the storage dictated by the water balance, storage should be provided for the following contingencies:

1. Mechanical system failure;
2. Harvesting of cover crop, and establishment of succeeding crop;
3. Excessive precipitation exceeding the 5-year return period;
4. Adequate storage to allow non-application periods during regular application, and after rainy periods, to prevent anaerobic conditions developing in the soil;
5. Precipitation interception by the storage pond surface. A minimum of seven days storage should be provided.

K. Consideration shall be given to prevention of odor, with remote sites preferred. Subsurface application is recommended where odor will be a consideration. If spray systems are used, nozzles which produce large drops, and minimuize aerosol formation, should be used to prevent off-site drift. Buffer zones will be determined on a case-by-case basis. The Alabama Department of Environmental Management – Air Division will be contacted by the staff for recommendations on specific potentially odor producing projects;

L. Monitoring Wells

1. General. At least three down-gradient and one up-gradient monitoring well shall be provided and located so as to monitor the effect of the entire land treatment system. More monitoring wells may be required in sinkhole prone areas. The wells should be extended only into the uppermost aquifer, with screen depths varied so as to detect the effect of water/wastes of differing specific gravity. A discussion of the depth(s) selected should be included in the Phase II report. In some cases, more than three wells will be necessary to correctly monitor the vertical and horizontal conditions in the aquifer. Seasonal variation in the groundwater should be considered in placement and depth of the wells. A qualified geologist or groundwater hydrologist should be consulted to assure proper placement and thus representative sampling. Unless no other appropriate sites are available, wells should be located above the 100 year flood elevation. Information regarding well placement and construction may be found in "Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities" (EPA, Number SW-611, Dec. 1980), "Manual of Groundwater Sampling Procedures" published by the EPA and national Water Well Association (National Water Well Association, 500 West Wilson Bridge Road, Worthington, Ohio 43805), and "Manual of Water Well Construction Practices" (EPA, 570/9-75-001);

2. Sampling. A minimum of five well casing volumes should be pumped and the water level allowed to return to its original position before sampling. The well should not be pumped excessively to pull in unrepresentative water. All wells should be securely capped when not being pumped and/or sampled. Sampling procedures noted in "Manual of Groundwater Sampling Procedures" should be followed, and procedures used detailed in the Phase II report. "Bailers" or peristaltic pumps should be used for sample collection;

3. Construction. All monitoring wells should conform to the following:

    a. The well casing shall be constructed of material compatible with the contaminants to be sampled;

    b. An annular space of at least two inches should be provided, and should be pressure cement grouted or otherwise sealed with an impermeable material such as bentonite;

    c. A concrete collar or apron shall be poured, shall extend at least eighteen inches out from the center of the well pipe, be at least four inches thick and extend an additional two inches into the ground. The collar shall bind tightly to the well casing;

    d. The well casing shall extend at least 36 inches above the collar;

    e. The well shall be thoroughly developed immediately after completion so as to remove all cutting fluids, sand, limestone cuttings, and other similar materials;

    f. Consideration should be given to the drilling technique used particularly with respect to possible contamination of the groundwater by drillers mud;

    g. The above ground portion of the monitoring well should be clearly visible to prevent damage from application equipment or vehicles;

    h. After completion of the wells, "as built" drawings of completed monitoring wells should be submitted, and should denote date of drilling, drillers name and associated company, depth of well, static water level, depth to water bearing formation, depth to screen, screen length, screen and casing material, casing diameter, dimensions of concrete collar, and type of sampling apparatus to be used.

M. For complex systems, or as specified by the staff, an Operations and maintenance manual shall be provided. This manual should cover initial installation and startup, monitoring, equipment maintenance procedures, agronomic information (i.e., harvesting and planting, fertilizing and liming cycles), and recordkeeping procedures;

N. In some cases, particularly where migration of metals is a concern, the use of lysimeters for sampling of soil water in the zone of aeration, and sampling of soil at varying depths, will be required.

V. Appendices

A. Acceptable Assimilative Capacities

1. Anions. These constituents are predominantly mobile (i.e., do not chemically fix to soil particles), and do not undergo decomposition in plant-soil systems. Therefore, the assimilative capacity is based on the use of sufficient land such that, when leached through soil and reaching groundwater, anion concentrations in the groundwater do not cause the groundwater to exceed drinking water standards. Cover crop toxicity must also be considered.

   The method for calculating the required area uses the following equation:

   Area Required (Ha) = $\left[(C_i-C_d)/[D_r(C_d(1-a)-C_r)]\right]$ (QE100)

   Where Q = waste flow, M^3/year

   a = ratio of evaporative losses to rainfall

   C_l = concentration of mobile species in waste, mg/l

   C_d = drinking water (or other) standard applied to groundwater, mg/l

   D_r = rainfall, cm/year

   C_r = concentration of mobile species in rainfall, mg/l

   The literature contains numerous references with respect to toxicity of anions to plants; the area required from consideration of toxicity should be calculated, and compared to the area required for acceptable leaching, with the larger area then governing the design.

   In some instances, adsorption may account for some uptake of anions. Should acceptable data be presented demonstrating this, consideration to reducing the leaching portion accordingly may be given by the staff;

2. Metals. These compounds are predominantly immobile (i.e., chemically fix to soil particles), and do not undergo decomposition. The assimilative capacity for metals is thus generally dictated by the critical upper limit in soils at which vegetation grown would result in permanently reduced crop yields, or irreversibly remove land from agricultural use. The soil uptake capacity is primarily dependent on the soil CEC, i.e., the higher the CEC, the greater potential of the soil for metals uptake. Use of wastes containing significant heavy metals on food chain crops shall not be allowed.

   Three criteria should be evaluated in the design for the major toxic metals – cadmium, copper, nickel, lead, and zinc. First, EPA has determined that to avoid adverse food chain and plant toxicity effects, and thus permanent removal of the site from agricultural use, the following maximum cumulative metals applications are acceptable:

	Soil CEC, meq/100q*		
Metal	0-5	5-15	>15
Maximum metal addition, kg/ha (top 15 cm of soil)			
Cadmium	5	10	20
Copper	125	250	500
Nickel	50	100	200
Lead	500	1000	2000
Zinc	250	500	1000

*Limits apply if background soil pH is $\geq$6.5 s.u.
If background soil pH is <6.5 s.u., maximum addition is 5 kg/ha, regardless of soil CEC.

the second criterion is that when the waste cadmium concentration is >25 ppm, the Cd:Zn ratio should be less than 0.015. Third, the zinc equivalent, which is calculated as follows, should be less than250 ppm in the top 15-30 cm of soil:

Zinc equivalent* = Zn + 2 Cu + 8 Ni
*all in ppm

All three criterion are accumulation limits based on plant toxicity, and include initial soil metals concentration. From these criteria, and knowing the desired lifetime, the yearly waste assimilation can be calculated. It should be noted that these criteria are based on the assumption that other factors such as pH, CEC, soil organic matter content, liming and fertilizing, will be at acceptable values. If this is not the case, phytotoxic effects of metals may increase. Further, factors such as the type and amount of metals in the solution phase, pH of the soil, and environmental factors such as the sunlight, temperature, and rainfall influence the transport and transformation of heavy metals, Due to the complexity of these mechanisms, it is felt that designs where heavy metals are a limiting factor must be necessarily conservative, and monitoring for metals migration more stringent.

Data is available for metals in addition to those addressed above, and from this data loading criteria is established based on soil uptake and phytotoxicity;

3. Acids and bases. Due to the somewhat limited buffering capacity of soil systems, the inability to establish adequate cover crops on highly acidic or basic soils, and the sometime deleterious affect on the assimilation capacity of certain constituents, the pH of the applied waste should be in the range of 6.5 – 8.5 standard units;

4. Phosphorus. This compound is predominantly immobile and does not undergo decomposition. Basically, mineralization – immobilization, crop up-take and adsorption/precipitation account for phosphorus assimilation mechanisms, with adsorption/precipitation accounting for the greatest fraction. For most applications, particularly where phosphorus concentrations are similar or less than those found in sanitary wastewaters and hydraulic application rates are not excessive, the soil phosphorus adsorption/precipitation capacity will adequately assimilate phosphorus. However, where phosphorus concentrations are significantly greater than those found in sanitary waste, the soil adsorption/precipitation capacity should be calculated, divided by the site lifetime, and added to the yearly crop up-take values to determine a yearly assimilative capacity. The adsorption/precipitation data may be described by use of a Langmuir isothern; organic or inorganic (NH_3, NO_3 and NO_2) forms. Inorganic nitrogen will be immediately available to the cover crop, while microbial breakdown will convert much of the organic N to inorganic forms. The greatest concern involved with land treatment of nitrogen is leaching of the nitrate ion, which is very soluble in water, stable, and quite mobile in a soil system. Substantial losses of nitrogen occur as a result of volatilization, immobilization, and denitrification. 1.5 times the crop up-take rate has been demonstrated as the soil assimilation capacity for nitrogen assuming the crops are harvested and removed from the land treatment site. Thus, total yearly allowable nitrogen application rates can be derived from crop up-take using this criterion. Nitrogen up-take rates for various crops are as follows:

Expected Nutrient Removal by Forage and Field Crops, and Forest Trees 1/

Vegetative Cover (yield goals)	Nitrogen Up-take (kg/ha/yr)
Forage and Field Crops	
Coastal Bermudagrass with rye overseed	570 + 205 = 775
Coastal Bermudagrass	480 – 600
Reed canary grass	226 – 359
Ryegrass	235
Fescue	275

1/ Overcash, M.R. and Dhiraj Pal – Design of Land Treatment Systems for Industrial Wastes – Theory and Practice, Ann Arbor Science, 1979, and Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal, Reuse, McGraw Hill, 1979.

Vegetative Cover (yield goals)	Nitrogen Up-take (kg/ha/yr)
Alfalfa	155 – 220
Sweet clover	158
Red clover	77 – 126
Lespedeza hay	130
Johnson Grass, 27 metric ton/ha	890
Peanuts, 7.5 metric ton/ha	140
Corn, 7.6 – 12.9 m^3/ha	155
Soybeans, 5.2 m^3/ha	94 – 113
Irish potatoes	108
Cotton	66 – 100
Milo maize	81
Wheat	50 – 76
Sweet potatoes	75
Sugar beets	73
Barley	63
Oats	53
Tobacco, flue cured, 3,300 kg/ha	85
Forest Trees	
Mixed Coniferous & Deciduous	40 – 80
Pines	30 – 70
Deciduous	50 – 100

Other nitrogen up-take data is available from the Alabama Agriculture Extension Service.

5. Salts. The basic concerns resulting from land treatment of salts are (1) leaching to groundwater, (2) excess sodium with respect to calcium and magnesium, resulting in reduced soil permeability, and (3) maintenance of acceptable soil-water salt concentrations for adequate cover crop growth. All three criteria should be evaluated in determining the necessary assimilation area.

   The first criterion can be evaluated by use of the leaching equation found in Item V.A.i. The second criterion can be evaluated by considering the sodium adsorption ratio (SAR) of the waste with respect to the acceptable values for the soil. SAR is defined as follows:

$$SAR = \frac{NA}{\sqrt{(Ca + Mg)/2}}$$

where Na, Ca, and Mg are in meq/l

As the SAR of the soil approaches a critical number specific to the soil type, the permeability of the soil will decrease, increasing runoff and reducing the water available to the plant. The Na, Ca, and Mg contributed by a land applied waste will add to the pool of these compounds already in the soil, altering the value of the soil SAR. Should the SAR of the waste be greater than the critical soil SAR, the soil SAR will, over time, increase to the critical SAR, producing the undesirable impermeability characteristics. For this reason, the SAR of the applied waste should be less than the critical soil SAR. Where the SAR exceeds or approaches this value, the addition of Ca or Mg (generally in the form of lime or gypsum) to the waste and/or soil will be necessary, or waste NA reduced and the soil SAR monitored extensively. Also, it is obvious that use of a greater area will lengthen the period of time before the SAR reaches the critical value. Calculative techniques are available to determine the necessary lime additions and useful site lifetime.

Critical SAR values for various soils are as follows:

Soil Type	Critical SAR
Swelling clay (bentonite)	8 – 10
Non-swelling clay	20
Pure sand	750

The third criteria is evaluated by analyzing the waste electrical conductivity. To prevent long term salinity and cover crop effects, the waste conductivity should be less than or equal to 3 mmhos/cm. Wastewaters with higher salinity should be applied only on good structured soils with high organic matter and high Ca, Mg, and K concentrations, have a salt tolerant crop, and be monitored closely.

6. Organics. The assimilative mechanisms for organic compounds and wastes containing organic materials when land applied can be volatilization, plant up-take, leaching to groundwater, and decomposition by the soil microbial population. The criteria for evaluating and applying the mechanisms, however, is not yet well-defined, and, therefore, no assimilative criteria can be reasonable determined. It is known, however, that maintenance of predominantly aerobic conditions is necessary for decomposition, so this is required for wastes high in organic materials. Periods of non-application of 5 to 10 days, to allow for dryout, should be used. Otherwise, the performance of operating systems using similar wastes and soils should be compared, and best engineering judgement applied;

7. Others. In that the field of industrial waste land treatment is relatively new, and assimilative mechanisms for some elements and compounds is not yet fully understood, the staff will apply the best available knowledge to individual projects, or may reject the project if insufficient data is available to allow environmentally safe application. Use of bench or field plot testing is encouraged where unusual wastes are being considered.

B. Groundwater Maximum Contaminant Levels Applicable to Groundwater Affected by Land Treatment Sites 1/

Primary Standards

Contaminant	Maximum Level, mg/l or as noted
(Inorganic Chemicals)	
Arsenic, Total	0.05
Barium, Total	1
Cadmium, Total	0.010
Chromium, Total	0.05
Lead, Total	0.05
Mercury, Total	0.002
Nitrate (as N)	10
Selenium, total	0.01
Silver, Total	0.05
Fluoride 2/	1.4 – 2.4
(Organic Chemicals)	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01
Coliform Bacteria	<1/100 ml

Secondary Standards

Contaminant	Maximum Level, mg/l or as noted
Chlorides	250
Color	15 color units
Copper	1
Corrosivity	non-corrosive
Foaming agents	0.5

Contaminant	Maximum Level, mg/l or as noted
Iron	0.3
Manganese	0.05
Odor	3 t.o.n.
pH	6.5 – 8.5
Sulfate	250
TDS	500
Zinc	5

1/ Based on regulations developed after P.L. 92-523 (The Safe Drinking Water Act), Title 40, Parts 141 and 143.

2/ Maximum fluoride concentrations are based on the annual average of the maximum daily air temperature for the location of the land treatment site, as follows:

Temperature, °F	Maximum Fluoride Level, mg/l
53.7 and below	2.4
53.8 – 58.3	2.2
58.4 – 63.8	2.0
63.9 – 70.6	1.8
70.7 – 79.2	1.6
79.3 – 90.5	1.4

C. Relevant Parameters to be Considered in Characterizing Wastes for Potential land Treatment 1/ 2/

Volume	Ammonia-Nitrogen
pH	Nitrate
Electrical Conductivity	Ammonium
Total Dissolved Solids	Specific Organic Chemicals, particularly priority pollutants
Total Suspended Solids	Phosphorus, Total
% Solids	Sulfur, Total
Oil and Grease	Boron, Total
Calcium, Total	Arsenic, Total
Magnesium, Total	Arsenate, Total
Sodium, Total	Barium, Total
Chloride	Cadmium, Total
Sulfate	Copper, Total
Fluoride	
Total Nitrogen	

Chromium, Total	Chemical Oxygen Demand
Lead, Total	Biochemical Oxygen Demand
Nickel, Total	Fecal Coliform
Selenium, Total	color
Zinc, Total	Radioactive Substances
Other Relevant Metals	Corrosive Substances

1/ All analyses should be conducted in conformance with the most recent EPA approved procedures.

2/ The collection of sample(s) analyzed for this characterization should be collected over sufficient time that hourly, daily or weekly variations in waste composition shall be included. The sampling method, date of sampling(s), and consideration of process variation in how representative the sampling should be documented with submittal of the waste characterization.

D. Water Balance and Storage Requirements

It is recommended that the water balance be performed on a monthly basis using a 5-year, 24-hour rainfall event with a minimum thirty (30) year base period. The water balance is described by the equation:

Design + Effluent = Evapotranspiration + Percolation + Runoff precipitation applied

Land treatment systems should be designed such that all waste infiltrates, therefore, runoff should be assumed to be zero.

Table 1 is an example of a water balance for a land treatment project. Basically, water losses are balanced against water applied on a month-by-month basis. The largest figure in column (5) is then used in conjunction with the Part V assimilation criteria in evaluating land requirements. Where the computations indicate that a water applied surplus would occur, i.e., column (6) figures minimum column (3) figures result in a positive number, the largest positive figure should be used, in conjunction with the contingencies referenced in Item V.J. in determining storage requirements.

E. Sample Collection

The soil samples must be collected from the weathered soil profile at representative depths by a non-destructive method such as employed by UD tubes or soil samplers. The samples must be packaged to prevent excessive drying and settling during transportation and storage.

F. Sample Preparation

All hydraulic conductivity determinations must be conducted on undisturbed soil samples, preferably on soil samples contained in the field sampling tube or retainer. The faces of the soil sample must be carefully scraped smooth to avoid pore clogging, particularly in wet, clayey soils.

The sample must be thoroughly saturated before the measurement of hydraulic conductivity. the removal of all air within the soil pores is extremely important to experimental reproducibility. A soil pore with entrapped air will not pass water and thus the effective porosity is reduced. It is suggested that water de-aired by boiling or vacuum be used in both the saturation procedure and the measurement of hydraulic conductivity.

Several methods can be used to saturate the sample. Soaking may be used to saturate coarse and medium textured soils, but vacuum saturation may be necessary to evacuate all the pore air in fine textured, small pore soils. To saturate a soil by soaking, fasten a fine-weave cloth over the end of the sample with a rubber band, place in a pan and raise the water level to near the soil surface. Twenty-four to forty-eight hours soaking is usually sufficient to attain complete saturation in coarse textured soils. Following saturation, immediately transfer the sample to the falling head apparatus. If vacuum saturation is necessary, a simple method is described in ASTM method D2434. A falling head apparatus may be constructed to permit saturating the sample from the bottom under low heads. In all cases, saturation at low head is necessary to avoid movement or reorientation of the soil particles.

If swelling soils or soils removed from depths with considerable overburden are encountered, the end-caps described in the following section should be clamped in position before saturating the sample. Employing this procedure assures a pore configuration similar to that occurring under field conditions.

G. Falling-Head Apparatus

The actual form of the falling head apparatus may vary over a number of configurations. Basically, the soil sample is held between two porous plates and a standing head of water is applied. One such apparatus is shown in Figure 1 from Klute (1965) (See reference 1.) Another apparatus is presented by Lambe (1951) (See reference 2.).

Parts from which a falling head apparatus may be constructed are available from geotechnical supply houses or may be constructed from locally available materials. The diameter of the standpipe should be chosen such that a change in head is accurately and easily measured. Care must be taken not to make the standpipe too small in diameter or too short as excessive heads and the need to add water during a run are desirable. The hydraulic gradient (W/L) should not exceed 0.5 to 1 for very coarse to coarse sands for Darcy's Law to apply. The sample end-caps can be constructed of either plastic or aluminum and are held on the sample by bolts passing through both end-caps. The connections from the standpipe to the end-cap should be rigid to eliminate expansion and contraction. The end-caps are sealed to the sample retainer by O-rings to form a leak-proof seal. The porous plates on either end of the sample must have a hydraulic conductivity greater than the sample tested to eliminate as much as possible introduced resistance to water flow. The plates may be of the porous stone-type used in consolidation tests or a very coarse-grade ceramic plat used in filtering.

Table 1: Example Water Balance

Month	Water Losses, cm Evapotranspiration (1)	Percolation (2)	Total Losses (1)+(2)=(3)	Precipitation (4)	Water Applied, cm Wastewater Applied (3)-(4)=(5)	Total Water Applied (4)+(5)=(6)
January	1.8	20.4	22.2	5.8	16.4	22.2
February	3.8	20.4	24.2	5.8	18.4	24.2
March	7.9	20.4	28.3	5.3	23.0	28.3
April	9.9	20.4	30.3	4.1	26.2	30.3
May	13.2	20.4	33.6	1.0	32.6	33.6
June	16.5	20.4	36.9	0.5	36.4	36.9
July	17.8	20.4	38.2	0.3	37.9	38.2
August	16.5	20.4	36.9	trace	36.9	36.9
September	11.2	20.4	31.6	0.5	31.1	31.6
October	9.9	20.4	30.3	1.5	28.8	30.3
November	3.8	20.4	24.2	2.6	21.6	24.2
December	2.0	20.4	22.4	5.6	16.8	22.4
Total Annual	114.3	244.8	359.1	33.0	326.1	359.1

H. Procedure

Saturate the sample as previously described and connect the end-caps. Fill the standpipe and let water flow through the sample for a sufficient time to assure resaturation of any pores drained during the set-up procedure. Refill the standpipe to a height in excess of H_1 to H_2. Also, measure the cross-sectional area of the standpipe, the temperature of the water, and the sample cross-sectional area and length. The hydraulic conductivity is calculated from:

$K = (aL/At)\ 1n\ (H_1 / H_2)$

where a = cross-sectional area of standpipe, cm^2

A = cross-sectional area of the soil sample, cm^2
L = length of the soil sample, cm
t = time for the head to fall from H_1 to H_2, seconds

All results must be corrected to a standard water temperature of 20 by use of the relation:

$K_{20\ C} = K_E\ (n_E/n_{20C})$

where $K_{20\ C}$ = permeability at temperature 20 C, cm/sec

K_E = permeability at temperature T, cm/sec

n_E = viscosity of water at temperature T

$n_{20\ C}$ = viscosity of water at temperature 20 C

I. Determination of percolation for Solution of the Water Budget

To solve the water budget, the amount of water that can safely pass through the soil system without damage to the soil or vegetation must be estimated. The results from the hydraulic conductivity tests aid in the determination of the "percolation" quantity.

The percolation rate, whether in inches/week or inches/month, is a function of the frequency of wastewater application, precipitation regime, hydraulic conductivity and its variably by depth, soil water storage characteristics, mean slope length and angle and the vegetation's root aeration needs and general water tolerance. As such, the determination of the percolation quantity is somewhat judgmental based on careful study of all the site specific factors.

As a rule, the monthly percolation quantity should not exceed 10 to 15 percent of the mean saturated hydraulic conductivity for the most limiting horizon if that horizon is within the surface two feet of soil and not more than 20 to 25 percent of the mean saturated hydraulic conductivity if the most limiting horizon occurs below two feet. For level sites with little free lateral drainage, the values should be reduced by approximately one-half. The depth, extent and water tolerance of the roots for each species grown on the site must be evaluated in light of the percolation quantity derived.

References:

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