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STATE OF ART ON HYDROLOGICAL CONSIDERATIONS FOR LANDFILL AND WASTE DISPOSAL SITES

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PREFACE

Historically, land disposal has been the traditional method of getting rid of hazardous waste. Waste disposal techniques include landfills, surface impoundment, underground injection wells, and waste piles. They have been used extensively in the past because they were the most convenient and inexpensive method of disposal. However, remediation at older sites that have leaked toxic into the soil and groundwater has proven to be tremendously costly and the originally perceived economic advantage of land disposal is now seen to have been shortsighted. Other alternatives include recycling, incineration and composting. Mostly these choices are used in conjunction with landfills.

Hydrological considerations play major role in the selection of landfill sites and design and performance of landfills for hazardous waste management. The present report elaborates details of the status of the technology in India and abroad, and also the scientific studies being carried out to support designs for long lasting performance. Further, focussed areas of interest are recommended, which is expected to be of great interest to hydrologists. In India, hydrological evaluation of landfill sites and impact assessment on the environment, especially groundwater, are yet to be initiated in a systematic manner. It is hoped that this report may provide state-of-the-art on the hydrological aspects of landfills in general.

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ABSTRACT

Hydrological considerations play major role in the selection of landfill sites and design and performance of landfills for hazardous waste management. This state of art report goes in to the details of the status of the technology in India and abroad and the scientific studies being carried out to support its design for long lasting performance. In conclusion, pinpoint areas of interests are recommended, which could be of great interest to a hydrologist.

1.0 INTRODUCTION

Status of solid waste management in five metro cities-Delhi, Mumbai, Calcutta, Chennai and Bangalore in India are as follows.

City	Bangalore	Calcutta	Chennai	Delhi	Mumbai
Area(sq km)	226.16	187.33	174.00	1484.46	437.71
Population (projected for 1999, in millions)	5.31	6.00	5.00	12.20	12.50
MSW generation (tonnes/day	2200	3100	3050	6000	6000
MSW per capita (kg/day)	0.414	0.517	0.610	0.492	0.480
Garbage pressure (tonnes/sq km)	9.728	16.548	17.529	4.042	13.708
Pressure on landfill	1400	2500	3050	5000	6000
Safai Karamchari	12600	12030	10130	40483	22128

(Parivesi, 1999)

Historically, land disposal has been the traditional method of getting rid of hazardous waste. Waste disposal techniques include landfills, surface impoundment, underground injection wells, and waste piles. Unfortunately, many of these disposal sites have been properly engineered and monitored and the results have sometimes been tragic, as was the case at Love canal, New York. They have bee used extensively in the past because they were the most convenient and inexpensive method of disposal. However, remediation at older sites that have leaked toxic into the soil and groundwater has proven to be tremendously costly and the originally perceived economic advantage of land disposal is now seen to have been shortsighted. Other alternatives are; recycling, incineration and composting. Mostly these choices are used in conjunction with landfills.

Landfills

A cross section of a completed hazardous waste landfill is shown in (fig.1), which mainly comprised of cover (fig.2), liner (fig.3), and leachate collection system. A hazardous waste landfill is now designed as a modular series of three-dimensional control cells. By incorporating separate cells it becomes possible to segregate wastes so that only compatible wastes are disposed of together. Arriving wastes are placed in an appropriate cell and covered at the end of each working day with a layer of cover soil. Beneath the hazardous wastes there must be a double liner system to stop the flow of liquid, called leachate, from entering the soil and groundwater beneath the site. The upper liner must be a flexible-membrane lining (FML), usually chloride (PVC), high-density polyethylene (HDPE), and chlorinated polythene(CPE).Rubber FMLs include chlorosulfonated polyethene(CSPE) and ethylene propylene diene monomer(EPDM). Depending on the material chosen for the FML, the thickness is typically anywhere from 0.25 mm (10 miles) to over 2.5mm (100miles). The lower liner is usually an FML, but recompacted clay at least 3 ft thick is also considered acceptable.

Leachate that accumulates above each liner is collected in a series of perforated drainage pipes and pumped to the surface for treatment. To help reduce the amount of leachate formed by precipitation seeping into the landfills, a low permeability cap is placed over completed cells. When the landfills is finally closed, a cap that may consist of an FML along with a layer of compacted clay is placed over the entire top, with enough slope to assure drainage away from the wastes. The landfill must also include monitoring facilities. The groundwater flowing beneath the site should be tested with monitoring wells placed up-gradient and down gradient from the site. There may need to be only one up gradient well to test the natural quality of the groundwater before it flows under the site, but there should be at least three or more monitoring wells placed down-gradient to assure detection of any leakage from the site. In addition, the soil under the site, above the water table, should be tested using devices called a suction lysimeters.

Surface impoundments

Surface impoundments are excavated or diked areas used to store liquid hazardous wastes. Usually storage is temporary unless the impoundment has been designed to eventually be closed as a landfill. Impoundments have been popular because they have been cheap and because waste remain accessible, allowing some treatment to take place during storage.. Typical treatment technologies used in surface impoundments include neutralization, precipitation, setting, and biodegradation.

Underground injection

The most popular way to dispose of liquid hazardous wastes has been to force them underground through deep injection wells (Fig.4). To help assure those underground drinking water supplies will not become contaminated, injection wells used to dispose of hazardous industrial wastes are required to extended below the lowest formation containing underground sources of drinking water. Typical injection depths are more than 700 m below for contaminating underground drinking water supplies, the regulation of such systems has come under the safe drinking water Act of 1974.

2.0 STATUS OF USEPA REGULATIONS

Resource Conservation and Recovery Act goes on to provide new restrictions and standards for those land disposal facilities that will be allowed to accept hazardous substances, including (USEPA, 1986B):

- Banning liquids from landfills.
- Banning underground injection of hazardous waste within 1/4-mile of a drinking water well.
- Requiring more stringent structural and design condition for landfills and surface impoundments, including two or more liners, leachate collection system above and between the liners, and groundwater monitoring.
- Requiring cleanup or corrective action if hazardous waste leaks from a facility.
- Requiring information from disposal facilities on pathways of potential human exposure to hazardous substances.
- Requiring location standards that are protective of human health and the environment: for example, allowing disposal facilities to be constructed only in suitable hydrogeological settings.

Unfortunately, a number of hazardous waste injection wells have had leakage problems, so such wells cannot be considered entirely safe. Regulations covering construction, operation, and monitoring of injection wells are becoming more stringent, and, as is the case for all land disposal options, continued reliance on this technology is being discouraged.

Historically, surface impounments have typically been poorly constructed and monitored. In a survey of 180 000 surface impoundments, the EPA estimated the prior to 1980 only about one-fourth were lined and fewer than 10 percent had monitoring programs (USEPA, 1984). The same survey also found that surface impoundments were usually poorly sited. More than half was located over very thin or very permeable soils that would allow easy transport of leachate to groundwater. Over three fourth of the impoundments were located over very thick and permeable aquifers that would allow relatively rapid dispersion of contaminants should they reach the water table. Moreover, about 98 percent of the surface impoundments were located less than one mile from sources of high-quality drinking water.

As a result of these poor siting, construction, and management problems, surface impoundments are the principal sources of contamination in a large number of superfund sites. Recent EPA regulations require new surface impoundments, or expansion to existing impoundments, to have two or more liners, a leachate collection system, and monitoring programs similar to those required for landfills. However, the legacy of past practices will undoubtedly take billions of dollars and decades of time to remediate.

About 5 percent of the hazardous waste in the United States is placed in specially designed landfills. About 35% is disposed of in diked surface impoundments such as pits, pods, lagoons, and basins. About 60% percent are disposed cf deep underground in underground injection well. Waste plies, which are noncontainerized accumulation of solid hazardous waste typically used for temporary storage, account for less than 1 percent of our disposal volume (USEPA, 1986B).

3.0 LANDFILL SITE ASSESSMENT AND SELECTION CRITEIA IN INDIA - A Review

In order to select suitable hazardous waste disposal site for the disposal of hazardous waste in any region, a site evaluation criteria has been developed. The technical evaluation of various key factors involved in this criteria, requires the information on distribution & flow paths of ground water, barriers like aquifers, aquicludes etc. and their hydraulic properties. It also requires information on subsoil, local general geological, and hydrogeological settings. Based on these data, the site has to be evaluated for its suitability as potential secured landfill site.

3.1 MOEF Guidelines

Ministry of Environment and Forest has stipulated methodology for site selection for hazardous waste disposal. These include:

1. Definition of waste management problem
2. Selection of generic technologies
3. Selection of candidate region
4. Selection of candidate area
5. Selection of candidate sites
6. Ranking of site alternatives
7. Confirmation of site acceptibility to public
8. Regulatory approval

All these steps are enumerated in the flow chart shown in (fig.5), and it has been included here in detail from fifth steps onwards.

3.1.1 Selection of candidate sites

This phase is very crucial in the siting process and can be carried out through a multi-level screening process

LEVEL I - Constraint Mapping

Constraint mapping eliminates environmentally unsuitable sites and narrows down the number of sites for further consideration. Certain features termed as " exclusionary factors" are identified and the occurrence of these features in the candidate areas will be mapped (Fig.6) using maps of approximately 1: 250,000 scale. A list of exclusionary factors used for constraint mapping is given in elsewhere (MOEF, 1991). These factors should be imposed alongwith MOEF guidelines for siting of industries (MOEF, 1991), to eliminate environmentally unsuitable sites from further analysis.

Level II - Potential site selection

The level II factors include landuse and infrastructure facilities (major highway access, sites of existing/ former waste disposal facilities and land designated for industrial use) which provide the basis for high lighting promising sites within the candidate areas remaining after level I analysis.

Level III - Community and environmental impacts:

The sites selected in level II are further scrutinized to eliminate areas, which fail to meet additional socio-economic and environmental concerns as well as additional geologic and hydrogeologic factors such as:

- Existing zones of development
- Agricultural land preserves
- Areas of mineral development
- Freshwater wetlands
- Visual corridors of scenic rivers
- Riverine and dam-related flood hazard areas.

3.1.2 Ranking of site Alternatives

The next stage of site selection involves comparison of candidate sites based on evaluation of each site for more detailed environmental, social and community impacts. The methodology for ranking of site alternatives comprises of following steps

- Select attributes for evaluation of site alternatives.
- Apportion a total score of 1000 between the assessment attributes based on their importance through ranked pairwise comparison technique.
- Develop site Sensitivity Index (SSIs) using Delphi Technique.
- Estimate score for each attribute for various candidate site alternatives using SSIs.
- Add the scores for individual site alternatives, to rank the alternatives based on total score.

The alternatives in ranking of the site alternatives, Typical site sensitivity indices and out come of the exercise are illustrated elsewhere in the form of Annexure-III (MOEF,1991).

3.1.3 Confirmation of Site Acceptability to Public

For ensuring site acceptability to public, target audience which include community leaders, municipal authorities, environmental groups, government departments, transporters, educational institutions, local social services, planners and site-specific groups should be addressed.

Two concepts should be emphasized, viz. First that the hazardous waste is only a small part of the overall waste problem: second, showing public their role in waste generation. Given our current lifestyle, and asking them to accept some responsibility. The field staff should also educate the public that the risks associated with well-designed hazardous waste management system are considerably less than its absence and that the risks associated with the facility would be no greater, and probably less, than those associated with any other industry.

3.1.4 Regulatory approval

Within a range of technically feasible sites, Hazardous Waste Treatment and Disposal Facility (HWTDF) siting and facilities require approval from regulatory agencies for all facilities related to storage, treatment and disposal of hazardous waste.

3.2 SITE SELECTION CRITERIA

On the basis of the guidelines issued by MOEF, National Productivity Council has elaborated the methodology for site selection criteria. They found that for the selection of suitable sites for Hazardous waste disposal, the following key factors have to be considered: -

- The type and quantity of waste to be disposed off
- The active life of disposal site.
- The existing traffic linkages and transportation economics.
- What kinds of areas are absolutely "out" for the setting up of the landfills.

A stepwise site selection procedure has been developed as per the international standards (GTZ, 1994) and divided in two phases.

Phase-I: "Rejection or Knock out Criteria"

Phase-II: "Site Identification, Investigation and Evaluation"

3.2.1 REJECTION OR KNOCK OUT CRITERIA

These criteria have been developed to reject the sites based on certain parameters such as characteristics of land, geology, hydrogeology, ground water conditions and ecological considerations etc. These criteria have been adapted from guidelines developed for Management of Domestic Sanitary Landfill sites in Germany (1) and modified to suit Indian conditions.

Under this criteria following areas have to be excluded or rejected:

- Wet lands;
- Historical migration zones;
- Flood prone areas;

- Areas within 500metre from water supply zone and within 200 meter from property line;
- Natural depression and valleys where water contamination is likely;
- Areas with suitable geological features;
- Areas of ground water recharge and extremely high water table zone;
- Unique habitation areas close to national parks with scenic beauty and formerly used landfills.
- Areas with high population, unique archaeological, historical, paleontogical and religious interests;
- Agricultural and forest and existing dump sites.

The identified site should also be excluded (preferably) if the following conditions are existing: -

- An unfavourable local hydrogeological situation, e.g. springs or drinking water wells within very close proximity to the chosen area;
- Extremely bad access, i.e. no existing access roads to the selected area which may involve long distance more than 5km. from main roads;
- Access roads passing densely populated areas;
- Great differences in altitude between the area of waste collection and the selected site;
- Very intense agricultural use;
- Inadequate available area;
- Difficult geological situation, danger of mass movements, too steep slopes, strata-bound groundwater etc.

Criteria have been developed for rejection or knock out of the sites including following observations

1 High flood prone areas
2 Areas with unstable ground
3 Closer than 200 meters to populated areas
4 Closer than 200 meters to river boundaries
5 Closer to National Parks, monuments. Forests with large no, of flora and fauna, historical, religious and 6
6.Other important cultural places
7 Existing use of site (Agricultural Forest Old dump site)

3.2.2 SITE IDENTIFICATION, INVESTIGATION AND EVALUATION

After the sites pass the examination for the above criteria, they are included in the detailed investigation and are further evaluated as per "Site Evaluation Criteria". The sites have to be investigated for geological, hydrogeological, ecological and civil engineering point of view. These criteria have been adated and modified to suit the Indian Environmental conditions, from the Criteria developed by UNEP (2) (UNEP, 1994).

The following key factors have to be considered for investigating the sites.

- General data e.g. volume, traffic links and distance from main waste source;
- Geology and Hydrogeology;
- Meteorological aspects;
- Nature protection and land use;

Following factors are included in the site evaluation criteria

1. General Information

   1.1 Transportation economy
   1.2 Slope percent-1
   1.3 Topography
   1.4 Flood prones
   1.5 Optimum wind direction(down streamvillage in Km.)
   1.6 Infrastructure:
      1.6.1 Accessibility
      1.6.2 Power supply
2. Hydrology/Hydrogeology/Geology/Geotechnology
   2.1 Hydrological features
      2.1.1 Distance from surface water body (m)
      2.1.2 Annual Rainfall (cm/yr)
   2.2 Hydrogeological features
      2.2.1 Ground water depth (m)
      2.2.2 Groundwater flow direction (distance to D/S Village)
      2.2.3 Groundwater quality
      2.2.4 Groundwater gradient (m/km)
   2.3 Geological features
      2.3.1 Subsidence
      2.3.2 Depth to bed rock (m)
      2.3.3 Seismic conditions (Intensity)
   2.4 Geotechnical features:
      2.4.1 Permeability (1*10 cm/s)
      2.4.2 Engineering property (MA. PI.Shear)
3. Socio-Economic/Ecological
   3.1 Demography
   3.2 Land use pattern
      3.2.1 Existing
      3.2.2 Future
   3.3 Transportation impact
   3.4Special ecological features

3.2.3 REASONS FOR SCALING THE CRITERIA AND ASSIGNING THE WEIGHTAGE

The key factors involved for the assessment and selection of site for the disposal of hazardous waste is divided in to three groups. Each group is further subdivided into relevant parameters. The reasons for assigning the due weightage to different factors are given below.

General Information

25% weightage has been given to "General Information" as this pertains to the key features of the sites. The factors like "Transportation economy", "Land Slope", Flood proneness" and " Wind Direction" have been assigned weightages as per their relative importance. The following reasons were considered for assigning the weightage

- Transportation Economy: The transportation of waste from the source of waste generation to the disposal site is one of the important factors in order to decide the economic location of site. So the sites for this evaluation have to be given relative value from 5 to 2 corresponding to excellent to poor as per their distance from the source of generation

Distance(KM.)	Relative (Relative Value)	
0-5.0	Excellent	(5)
5.00-10.00	Ideal	(4)
10.00-20.00	Good	(3)
20.00-40.00	Poor	(2)
>40.00	Bad	(1)

- **Slope Percent:**

Natural slope of a site is important from the drainage consideration. But, more slopy land may pose difficulty in the construction and may need leveling up. To prevent water logging the site should not be concave i.e. there should not be any depression. Therefore, following scales have been developed for evaluating the slope percent of the sites:

First Scale (Slope%)	Second Scale (Slope %)	Evaluation (relative Value)	
1.5	1.5	Excellent	(5)
1.5-1.2	1.5-2.5	Ideal	(4)
1.2-0.75	2.5-7.0	Good	(3)
0.75-0.50	7.0-15	Poor	(2)
<0.5	>15	Bad	(1)

- Topography: In general the site topography should be convex in relation to the surrounding so that the rain water is drained away from the site naturally. So, a site with convex topography can be regarded as excellent and that with concave topography can be regarded as bad.
- Flood Proneness: In general, the flood prone areas have to be rejected. But the site can get flooded in case of very high rainfall and without proper drainage. There is a possibility of water contamination if the site gets flooded. So due weightages have to be given depending upon extent of flood proneness in a scale of 5 to 1 corresponding to excellent to bad.
- Wind Direction: Though, generation of toxic fumes are not expected due to very nature of the waste to be disposed off, handling of waste in the disposal facility may create air pollution in form of dust formation. Prominent wind direct may affect the population on the down stream side of the facility. So any village within a distance of one km. down stream of the sites can be vulnerable to any air pollution due to the operation of the landfill. The sites have to be ranked as per the degree of impact on the down stream. The location of the facility should be selected in such a manner that there is no or minimum effect at the down stream habitation.

Following relative value scale is developed for ranking the sites:

Down stream Distance (KM)	Evaluation (Relative Value)	
>1	Excellent	(5)
1-0.5	Ideal	(4)
0.5-0.2	Good	(3)
0.2-0.1	Poor	(2)
<0.1 (Adjacent to site)	Bad	(1)

- Infrastructure: Out of all the infrastructure required at a landfill site, the approach road and thew power supply are the most important. All the sites have to be evaluated relatively from excellent to bad in a scale of 5 to 1 as per the availability of road and power supply.

Hydrology/hydrogeology/geology/geotechnology:

50% weightage has been given to hydrological, Hydrogeological, Geological geotechnical situation of the site as these are the environmental conditions that will affect the design of the landfill.

- Hydrological conditions:
- Distance from water body

Surface water bodies & drinking water sources should be protected and site should not be close to these sources. Following scale has been developed for ranking the sites:

Distance (km.)	Evaluation (Relative Value)
>5	Excellent (5)
5-3	Ideal (4)
3-2	Good (3)
2-1	Poor (2)
<1	Bad (1)

Rainfall

Higher annual precipitation will not only lead to higher leachable generation and therefore more chances of ground water contamination, but also will create problems in controlling surface contact water at dumpsite. Following scale for annual rainfall has been developed for ranking the sites:

Annual rainfall (cm/yr)	Evaluation (Relative Value)
<25	Excellent (5)
25-80	Ideal (4)
80-150	Good (3)
150-250	Poor (2)
>250	Bad (1)

Hydrogeology

Groundwater table depth:

Groundwater table should be as low as possible because of its possible contamination. The level of ground water should be more than 1metre below the bearing surface of the landfill. More the clearance between the ground level and the post-monsoon groundwater table depth, more depth is available for excavation of the landfill. If the ground water is high the facility has to be designed as a stock-pile. Following scale for groundwater table has been developed for ranking the sites:

Groundwater flow direction:

As the wastes will be disposed in the landfill permanently, they can pose a threat to the groundwater in case of failure of the linear system. So it is necessary to locate the site in such a way that in case of such eventuality, the impact is least. The sites have to be evaluated as per the distance of downstream village.

Following relative value scale is developed for ranking the sites:

Distance in Downstream (Km.)	Evaluation (Relative Value)	
>5	Excellent	(5)
5.0-3.0	Ideal	(4)
3.0-1.0	Good	(3)
1.0-0.5	Poor	(2)
<0.5(Adjacent to site)	Bad	(1)

Groundwater Flow Gradient:

The groundwater gradient gives the idea of the rate of flow of the groundwater. Greater the gradient, the greater is flow rate, For a suitable site, the hydraulic gradient should be as low as possible. If there is any contamination due to the failure of the liner system then the impact at the downstream is minimum.
Following scale has been developed for evaluating the sites from the groundwater gradient consideration.

G.W. Gradient (m/km)	Evaluation (Relative Value)	
<5	Excellent	(5)
5-10	Ideal	(4)
10-20	Good	(3)
20-50	Poor	(2)
>50	Bad	(1)

Groundwater quality

Groundwater quality may not directly influence the selection of the waste disposal site. But if the groundwater is non-potable or can not be used for any useful purpose, then the site has the advantage over the others. If the groundwater quality does not confirm to the drinking water quality standards then the site is to be considered as excellent with a relative value of 5 otherwise can be considered as bad with a value of 1.

Geological features:

Subsidence:

Area with unsuitable soil such as filled up area still under the process of consolidation may not be suitable for construction of the landfill due to chances of uneven settlement, which may rupture the liner system. A fairly settled soil can be considered as an excellent site whereas a site filled up with borrowed soil can be considered as a bad or poor site from the subsidence point of view.

Depth to bedrock:

Higher the depth to bedrock, better will be the site from construction of landfill point of view. Following scale has been developed for ranking the sites from depth to bed rock considerations:

Depth to bed rock (m)	Evaluation (Relative Value)
>15	Excellent (5)
15-10	Ideal (4)
10-5	Good (3)
5-1	Poor (2)
<1	Bad (1)

Seismic Condition:

Seismic conditions, should be considered in the site evaluation to know the seismic intensity at various identified sites. The seismic intensity should be as low as possible so that there is no danger involved due to any earthquake. Following scale has been developed for ranking the sites from seismic intensity considerations:

Seismic Intensity	Evaluation (Relative Value)
V	Excellent (5)
VI	Ideal (4)
VII	Good (3)
VIII	Poor (2)
IX	Bad (1)

Permeability:

The permeability of the subsoil of a landfill site has an important role to play in the development of landfill as it acts like a barrier to leachable. In an ideal condition the permeability of the soil be about 1 X 10-7 cm/sec. Following scale has been developed for ranking the sites from permeability of the subsoil considerations:

Permeability (1X10 cm/sec)	Evaluation (Relative Value)
<0.1	Excellent (5)
0.1-1	Ideal (4)
1-10	Good (3)
10-100	Poor (2)
>100	Bad (1)

Engineering Properties:

The grain size distribution c-1 analysis and the plasticity index of the soil gives the idea about the engineering properties of the soil. Depending upon the soil analysis for these parameters the site have to relatively classified from excellent to bad with relative value of 5 to 1.

Socio-Economic/Ecological Features:

25% weightage has been to "Socio-economic/ecological features" as this pertains to the surrounding features of the sites. The factors like "Demography", "landuse", "Distance from airport" and "Special Ecological Features" have been assigned due weightages as per their relative importance.

Demography:

Demography is important factor in choosing the landfill sites. The population and the distance of the populated areas from the sites should be considered for evaluating the sites. For this reason, the population of village within 5-km radius and their distances from the site have to be considered.

Distance from site (km)	Evaluation (Relative Value)	
<5	Excellent	(5)
5-2.5	Ideal	(4)
1.0-2.5	Good	(3)
0.2-1.0	Poor	(2)
>0.2	Bad	(1)

Land use:

Existing Land use:

The existing land cover depicts the economics importance of the site. Less the economic importance of the site more suitability of the site for landfill developed. Following scale has been developed for ranking the sites from existing landuse considerations:

Existing landuse	Evaluation (Relative Value)	
Waste land/saline	excellent	(5)
Grazing/fallow	Ideal	(4)
Single Crop/non-irrigated	Good	(3)
Double Crop/irrigated	Poor	(2)
Plantation	Bad	(1)

Proposed Landuse:

The proposed landuse around the sites by the local development authority is another major consideration for evaluation of the sites. If any sort of development is envisaged by the development authority nearby the site, then the site should not be preferred. If the area around the site has the potentiality for development then the relative value of 1 i.e. bad has to be given otherwise a relative value of 5 i.e. excellent has to be assigned.

Impact of waste transportation:

The transportation of waste poses threat to the area through it passes. A site which poses minimum threat to the health by virtue of its traffic linkage, should be considered as ideal site. Any site due to which there is possibility of increased exposure of the waste to the population have to be assigned a relative value of 1 otherwise 5.

Special ecological features:

Areas surrounding the site with special ecological features such as habitation endangered species should be avoided for landfill development. The sites were given a relative value of 1 if it close to such areas other wise 5.

4.0 LITERATURE SURVEY

4.1 International Context

Galya, 1987 derived a model through the use of Green's functions to simulate three-dimensional contaminant transport from horizontal plane source (HPS). This analytical model incorporates retardation and decay, and can simulate varying source emission rates. Appropriate uses of the model include simulations of contaminant transport from landfills, waste lagoons, land treatment facilities, and areas of pesticide application. Comparison between HPS and point source solutions indicates that for such simulations, the HPS model will provide more accurate results than the point source solution, particularly near the source. Representative model applications indicate the model's sensitivity to variations in retardation, decay, and temporal period of source emission.

Keely et.al.,1987, examined commonly employed techniques for the installation, purging, and samplings of monitoring wells. The hydrogeology and chemical quality of the shallow ground water regime at a coal fly ash landfill was investigated by Spencer et.al.,1987, near Montpelier, Iowa. Although groundwater pH increased after entering the landfill, bicarbonate alkalinity declined. Results of equilibrium solubility calculations suggest that this condition evolved from calcite supersaturation within the landfill, precipitating calcium carbonate. Dissolution of calcium and magnesium oxides on glassy fly ash spheres sustains the highly alkaline leachate strength. The occurrence of low-level hits of volatile organic priority pollutant compounds are statistically modeled as a Poisson process, by Gibbons 1987

The Lantana landfill located in Palm Beach Country rises 40 to 50 feet above normal ground level and consists of about 250 acres of compound garbage and trash, some below the water table. Analysis of geoelectric, lithologic, and water-quality data carried out by Russell et.al.,1988, indicate that surface geo-physical techniques were successful in determining the areal and vertical extent of leachate migration at this location.

Water movement through a waste-trench cover under natural conditions at a low-level radioactive waste disposal site in north western Illinois was studied by Healy, 1989, from July 1982 to June 1984, using tensiometers, a moisture probe, and meteorological instruments. Four methods were used to estimate seepage: the Darcy, zero-flux lane, surface-based water-budget, and groundwater-based water budget methods. Seepage varied by almost an order of magnitude across the width of the trench. Lowest seepage rates occurred near the center of the cover, where seepage was gradual. Highest rates occurred along the edge of the cover. The existence and importance of macro-pores to the contaminant efficiency of cover clay liners at waste landfills is documented by Mller et.al.,1989.

Miller et.al.,1989 presented an hydraulic description of moisture transport through the compacted clay layers of a landfill cover liner. The variety of modes and mechanisms of flow that are operative in flow through cracked clay liners is discussed and analogies are made to familiar concepts in open channel flow theory. The discussion provides the conceptual framework for the development of a numerical model to simulate both the micro- and macro-pore flow phenomena. The location of a stagnation boundary, separating a flow zone and a stagnation zone, is unknown a priori in a boundary value problem statement.

The determination of the stagnation boundary is a part of the problem solution (just as is the determination of the water table position in an unconfined groundwater flow problem). The principles governing stagnation boundaries are elucidated: a method is described for determining the location of the stagnation boundary for a porous medium with "jump-to-proportionality" threshold gradient behavior by Boast et.al.,1989, and the method is used to solve the "flow at a corner" boundary value problem. The solution is compared to that of the analogous classical problem, in which strict adherence to Darcy's equation is assumed. Demetracopoulos, 1989, presents an overview of several models, describing the flow over and through liners. The hydraulic conductivities of the liner and the drainage layer and the leachate accretion rates are parameters whose magnitudes must be known with relative accuracy for good evaluation of system performance.

Gibbson 1990 developed non-parametric upper prediction limits for groundwater detection monitoring are developed. Sixteen Wenner and Schulumberger array electrical soundings were made in portions of the Mallard North landfill in Country, Illinois, by Carpenter et.al.,1990, to map the gross layered structure of a closed landfill. Such sounding could be used to map internal structure in other layered landfills that lack construction and operational records. Vroblesky et.al.,1990 show that the annual rings of tulip trees (Liriodendron tulipifera L.) appear to preserve a chemical record of groundwater contamination at a landfill in Maryland. Zones of elevated iron and chlorine concentrations in growth rings from trees immediately down gradient from the land fill are closely correlated temporally with activities in the landfill expected to penetrate iron chloride contamination in the groundwater. Successively later iron peaks in trees increasingly distant from the landfill along the general direction of ground-water flow imply movement of iron-contaminated ground water away from the landfill.

The KL Landfill in Kalamazoo Country, Michigan was closed in June 1979 because of groundwater contamination. Study of water analysis is carried out by Kehew et.al.1990 from a monitoring-well network has proved insight into a variety of pH and pe buffering reaction within the contaminant plume. Geochemical modeling using WATEQF indicates that the plume is supersaturated with respect to calcite, dolomite, and siderite.

Roy et.al.,1991 shows that computer models like PHRQPITZ and PHREEQE may be useful tools for estimating mineral equilibria in deep-well scenarios, but there is a need to expand the database used in these kinds of calculations, Caution must be applied in interpreting the predicted equilibria. Fate modeling based on thermodynamics principles can predict simple geochemical interactions, but empirical, laboratory-based investigations may be needed in addition to modeling for a reliable assessment of the fate of injected wastes.

Landfill siting and design guidelines or regulations differ from state to state. Most include hydrogeological criteria, referring to hydraulic conductivities, aquifers, ground water flow patterns, contaminant travel times, and distance between landfill and sensitive targets for contaminants, etc. However, almost all of the existing hydrogeological guidelines are incomplete, inconsistent, or both. The aquitard between landfill and regional aquifer frequently offers less resistance to leachate migration than compliance with regulations may suggest. Residence times of leachate, that makes through landfill liner, is often overestimated. Monitoring wells in the regional aquifer are unreliable detectors of local leaks in a landfill. If a landfill does leak, costly aquifer restoration is called for. For traditional landfill designs, groundwater-monitoring considerations suggest the siting over homogeneous sand and gravel aquifers, rather than over complex till environments. An alternative landfill design criterion is suggested by Haitjema, 1991, which is based on a negative hydraulic gradient underneath the landfill. This design guarantees ground water protection, simplifies landfill monitoring, and generally enhances the landfill economy.

Rugge et.al.,1992 detected heavy metals, polychlorinated biphenyls (PCBs) and various organics in surface and subsurface water around two peninsular landfills. The use of remote sensing provides a tool to relate prior disposal locations to current topography for design of a cost effective geo-exploration effort. Ahmed et.al., 1992, developed a numerical model to compute the time variation of leachate flow in landfills. The model is applied to a landfill section in New York to demonstrate the simulation of runoff, moisture content, recharge, as well as lateral and vertical flows for the field conditions in a landfill.

Kjeldsen, 1993 found that only a few landfill investigations have focussed on both the quantity of leachate as a source of groundwater pollution. The investigation of Vejen Landfill in Denmark included an introductionary historical survey (old maps, aerial photographs, interviews, etc.). leachate quality analysis, potential mapping of the groundwater surface below the landfill and leachate flow to surface waters and groundwater. The historical investigation showed that the original soil surface beneath the waste was a relatively heterogeneous mixture of boggy ground and sand soil areas. This indicated that the leaching from the landfill could be unevenly distributed. The main specific organic compounds observed in the leachate were aromatic hydrocarbons (mainly xylenes), phenols and the pesticide MCPP. Preliminary investigations of the leach from the landfill indicated that both a northerly leach to a drainage ditch and a southerly leach to the secondary aquifer was taking place. To evaluate the proportion of leachate discharging to the drainage ditch, piezometers were installed in the shallow leachate-affected aquifer. On the basis of several soundings, the groundwater surface was mapped and the expected groundwater divides were located. These measurements indicated that approximately 50% of the leachate from the mixed waste discharged to the drainage ditch. This was supported by directly measuring the flux of leachate (as kilogram chloride per year) carried out by continuos gauging of water flow and chloride concentration in the drainage ditch. Wells were driven into the aquifer at the borders of the landfill area. These proved that the leaching from the landfill was very unevenly distributed. By measurement of present, and estimation of the past, leachate quality and quantity, an evaluation of the history of leachate recharge to the groundwater is given, including time of recharge start and recharge quantities in cubic meters and kilograms of chloride per year.

Hanor, 1993 depicts that intercalated sands and zones of pedogenic secondary porosity and fracturing developed during periods subaerial weathering are apparently the dominant controls on vertical permeability, not the matrix properties of the clay. Javandel et.al., 1993, attempt to address the problem of initial detection of improperly plugged or open abandoned wells. A new analytic solution has been derived to calculate the amount of leakage from an abandoned well and the corresponding drawdown at monitoring wells. A method is proposed that can be used to detect such deep abandoned wells in the area of influence of a proposed deep injection well in a multiple-aquifer system. Through a case study application, Hudak et.al., 1993, outline the utility of GIS for detection-based groundwater quality monitoring network design. The results suggest that GIS capabilities for analyzing spatially referenced data can enhance the field-applicability of established methodologies for ground water monitoring network design.

Reddi et al, 1996 report the results of a research project conducted at eleven municipal landfills with modern liner technology throughout the state Florida. Through actual field data and computer modeling, it was found that the liner standards applied in the state of Florida are very effective at preventing any groundwater contamination. Thus, the present monitoring well regulations is too conservative. Reduction of the monitoring wells and/or of the frequency of sampling would result in substantial cost savings. Bendz et.al.,1996, found that the biological heat enhanced the net energy flux and the actual evaporation by 20% and 10% respectively. Reddi et.al.,1996 reports the results of a research project conducted at eleven municipal landfills with modern liner technology through the State of Florida. Through actual field data and computer modeling, it was found that the liner systems standards applied in the State of Florida are very effective at Preventing any ground water contamination. Thus, the present monitoring well regulations is too conservative.

Bendz et al, 1998 modeled the movement of water in a large ($3.5m^3$) undisturbed sample of 22-year-old municipal solid waste using a kinematic wave approximation for unsaturated infiltration and internal drainage. To help demonstrate the ability to operate a hazardous waste landfill with no escape of leachate, permeameter tests of the effects on clay liner material of leachates containing PPM levels of organics such as chloroform, methylene, chloride, toluene, and chlorobenzene were run by Ilgenfritz et.al.,1988. To get an unambiguous future determination of a detection of failure by leachate leakage into the landfill underliner monitoring system, a single compound or agent was sought which could be used as a tracer material. Fluorobenzene was chosen because of its physicochemical properties and its uniqueness in the normal industrial waste stream. Woldt et.al.,1998, develops a geoelectrical and geostatistical-based methodologies that can be used to screen unregulated landfills for the presence of leachate and obtain an approximation of the vertical/ spatial extent of waste. A case study is used to determine the methodology at an unregulated landfill in eastern Nebraska.

Helene et.al.,1999 have examined whether a relationship exists between the accumulation of exopolymeric substances (EPS) in landfill cover soil and the gradual decline in biotic methane oxidation observed in laboratory soil columns sparged with synthetic landfill gas. A mathematical model that combined multi-component gas diffusion along the vertical axis of the columns with biotic methane oxidation suggests that EPS accumulation may regulate methane oxidation rates in landfill covers. Popov and Power, 2000 used a 2D numerical model for convection-diffusion flow of a multispecies mixture through a multi-layer porous medium to analyze the efficiency of landfill venting trenches. The fate of seven aromatic and four chlorinated aliphatic compounds was studied by Bjerg et.al.,1999, using in situ microcosm (ISM) and laboratory batch (LB) experiments performed at six distances along a flow line in the anaerobic leachate plume downgradient of the Grindsted Landfill, Denmark. This suggests that laboratory batch experiments, which are easier to run than ISM experiments, may be useful tool in determining the degradability of mono aromatic hydrocarbons and chlorinated aliphatic hydrocarbons under strongly anaerobic conditions in the investigation of natural attenuation in landfill leachate plumes.

Inchul et.al, 2001 developed a model to describe dynamic leaching of metal contaminants from solidified wastes using data for calibration that are taken only from batch tests. The model describes the three major factors affecting leaching: (1) acid/base reactions that determine the pH within the waste; (2) pH-dependent reactions that determine whether the contaminants are in mobile or immobile forms; and (3) diffusion that transports mobile contaminants from the waste. Model simulations indicate that the assumption of an infinite bath may not apply to dynamic leach tests when contaminants are strongly immobilized.

4.2 NATIONAL CONTEXT

National Environmental Engineering Institute, in December 1996, developed design guidelines for lined landfill for the disposal of oily sludges at the Guwahati refinery for M/s Indian Oil Corporation Limited (IOCL). The sludges at the generated during refinery operations include crude tank bottoms, product tank bottoms, distillation column residues, and exchanger tube bundle sludge: and the sludges generated from the effluent treatment plant. These sludges fall under Categories 10 and 12, respectively of the Hazardous Waste Rules promulgated by Ministry of Environmental and Forests (MEF)

The existing stored quality of sludges (since 1962) is estimated as 2720 metric tonnes (MT) of oily sludge and 11900 MT of biosludge. Considering the design period for the landfill as 30 years, additional generation was estimated at 2400 MT of oily sludge and 10500 MT of biosludge, thus making the total quantity of sludge destined for landfill as 27520 MT.

The electrical resistivity survey indicated that the subsurface sediments in the region are non-homogeneous in nature and are composed of fine sand, silt, clay and hard rock. The permeability of the soil is 2.43×10^{-4} cm/sec. Based on the geological and hydrogeological features, and receptor/ pathway and waste characteristics, a site suitability evaluation exercise was undertaken as per the MEF criteria. A score of 496 out 1000 was obtained for the site identified by the refinery-indicating moderate to high hazard potential. An engineered landfill with double liner system has been keeping with the hazard potential

Heavy Metal Concentration in Sludges and TCLP Extracts at Guwahati

	Concentration ranges	
Heavy Metals	**Sludge (mg/g)**	**TCLP(mg/l)**
Fe	1-3	1.4-6.4
Cu	0-0.07	0.02-0.07
Mn	0.3-2.8	0.13-3.19
Pb	0-0.12	0.04-0.08
Zn	0-.76	0.45-1.12
Cd	0-0.02	0.003-0.01
Ni	0-0.41	0.02-0.005

(NEERI, 1997)

Design Parameters for Secure Landfill at Guwahati Refinery

Sr. No.	Description	Details
1.	TOTALS HEIGHT FOR THE LANDFILL	= 4M
2.	LANDFILL SIDE SLOPE	= 3:1 (HORIZONTAL TO VERTICAL)
3.	BERM WIDTH	= 3M
4.	BOTTOM LINERS (CLAY)	
	- PERMEABILITY (CM/SEC)	= NOT MORE THAN $1X10^{-7}$
	- DRY DENSITY	= 1900 KG/CUM
	- THICKNESS	
	- MOISTURE CONTENT	= 2-3 %
5.	LEACHATE COLLECTION SYSTEM (PRIMARY AND SECONDARY)	
	- FLEXIBLE MEMBRANE LINER (FML) THICKNESS	= 50 MILS (MIN) FOR PRIMARY 30 MIL(MIN) FOR SECONDARY
	- ANCHORAGE FOR FML	=TRENCH OF 30 CM*30 CM
	- PROTECTIVE COVER ON FML	= CLAY LAYER OF 15 CM
	- LEACHATE COLLECTION AND REMOVAL SYSTEM (LCRS):	
	PVC PIPES (LATERAL)	= 15 CM DIAMETER
	SPACING	= 2M APART
	SLOPE	=2%
	PVC PIPES (MAIN PIPE)	= 20 CM DIAMETER
	SLOPE	= 2%
	GRANULAR DRAINAGE MATERIAL	= 30 CM THICK GRAVEL
	PERCOLATION RATE	= 0.01 CM/SEC
6.	FILTER MEDIUM/GEOTEXTILE	= 15 CM THICKNESS
7.	INTERMEDIATE COVER (CLAY)	= 7.5 CM
8.	FINAL COVER	
	- VEGETATIVE COVER	= 30 CM THICKNESS
	- VEGETATIVE ROOT GROWTH	= 30 CM
	- FINAL TOP SLOPE	= 3 TO 5 %
	- FML	=20 MIL (MIN)
	- SOIL THICKNESS	= 30 CM (MIN)
	- HYDRAULIC CONDUCTIVITY	= LESS THAN 1X10-7 CM/SEC
	- DRAINAGE LAYER THICKNESS	= 30 CM

(NEERI, 1997)

NEERI has also prepared report on environmental impact assessment of landfill sites in Bangalore (Karnataka) and Delhi Municipal area. For Bangalore, NEERI has developed a set of criteria for selection for sanitary landfill site out of the four proposed sites to suit the environment. Aspects related to receptor, environment, accesseibilty, socio-economics, waste management practices, climatology, and geology were considered for development of the criteria. The validity of the criteria may be adopted for other cities in India after suitable modifications.

National Productivity Council has conducted "Technical Environment Impact Assessment (EIA) studies for identification of sites for disposal of hazardous wastes " for following sites

- Ahemdabad, Bharuch, Valsad districts of Gujarat
- Udaipur district of Rajasthan
- Rourkela region of Orissa
- Faridabad district of Hayrana
- Delhi
- Noida, Ghaziabad, and Meerut of Uttar Pradesh
- Kanpur, Uttar Pradesh

NPC has been conducting a study on the Assessment of impact of existing and completed municipal waste landfill sites at Kanpur in UP. The study intents to assess the impact of landfills on the surrounding environment and to prepare an environment management plan for the landfill sites.

They have also carried out Investigation and Remediation of Hazardous Wastes dump sites at Ahmedabad (for Ahmedabad Municipal Corporation) and Baroda (for GACL) and Tracking of Hazardous Wastes in Gujarat based on Geographical Information system (GIS) (Radian Inc., USA).

Further, EPTRI (Environmental Protection Training and Research Institute) at Hyderabad engages in regular training of personnel as well as conducting studies. Recently, they have carried out a study on the assessment of existing municipal solid waste dumpsites with an aim to establish the impacts related to water and air pollution due to these dumpsites in Hyderabad. The activities include quantification of wastes generated, analysis of surface and ground waters, soil/ solid waste testing, hydrogeological investigations and air quality monitoring. Based on the findings from the study appropriate recommendations were also made to prevent further polluting of the environment and also for selection of alternative sites for secured landfill facilities.

5.0 HYDROLOGICAL ANALYSIS AND MODELLING

5.1 WATER BALANCE METHOD (WBM)
(Fenn et. al., 1975)

Schematic diagram of water movement in landfill is shown in fig.7. On the basis of this scheme equation developed for water balance is given by,

$$PERC = P - AET - RO - \Delta ST$$

PERC= percolation
P= precipitation
AET= actual evapotranspiration (ET)
$\leq$ Potential ET (PET)
RO= runoff
ΔST= change in stoge of soil or refuse

The estimates are, empirical, experimental and on the basis of judgement. Month by month analysis is being carried out considering Precipitation as the only source of water and landfill is at its field capacity (fc) moisture content. - Stages of the analysis are, Open refuses, Daily cover and Final cover.

5.1.2 Sequence of calculations as a part of the WBM procedure
(After kmet (1982))

1. T-Enter the average monthly temperature (^{0}f)
2. I- using the monthly temperature determines the monthly heat index for each month from Annexure-I. For months with T<32F, I=0. Sum the "I" values to obtain I (the yearly heat index).
3. UPET- using the monthly temperature and the yearly heat index find the Unadjusted Potential Evapotranspiration from Annexure-II.
4. R- using the site latitude find monthly correction factor for sunlight duration(r) from Annexure-III.
5. PET- multiplies the monthly UPET by the monthly r to obtain the adjusted potential evaporation for each month.
6. P- enter the average monthly precipitation (inches of water).
7. C r/o-- enter the appropriate runoff coefficient to calculate the runoff for each month from Annexure-IV.
8. R/o- multiply the monthly precipitation by the monthly runoff coefficient to calculate the runoff for each month (inches of water)
9. I- subtract the monthly runoff from the monthly precipitation to obtain the monthly infiltration (inches of water).
10. I-PET- subtract the monthly adusted potential evapotranspiration from the monthly infiltration to obtain the water available for storage (inches ofwater).
11. ACC WL- assumes the negative (I-PET) values on a cumulative basis to obtain the cumulative water loss (ACC WL). Note: start the summation with zero accumulated water loss for the last month having (I-PET)>0 (inches of water).

12. ST- determine the monthly soil moisture storage (ST) as per (inches of water):
   a) determine the initial soil moisture storage for the soil depth and type from Annexure-V.
   b) assign this value to the last month having I-PET>0
   c) determine ST for each subsequent month having I-PET<0 from Annexure-VI
   d) for months having (I-PET)>=0, add the (I-PET) value to the preceding months storage. Do not exceed the field capacity. Enter the field capacity if the summation exceeds this maximum.
13. ΔST-Calculate the change in soil moisture for each month by subtracting the ST for each month from the preceding month (inches of water).
14. AET- calculate actual evapotranspiration as follows (inches of water):
   a) wet months (I-PET)>=0 indicates AET=PET
   b) dry months (I-PET)<0
      AET=PET+((I-PET)- ΔST))

Note that for months when I-PET is negative, the evapotranspired amount is the amount potentially evapotranspired plus that available from "excess" infiltration which would otherwise add to soil moisture storage and that available from previously-stored soil moisture.

15. PERC- calculate the percolation as follows (inches of water):
   a) dry months (I-PET)<0
      PERC=0
   b) wet months (I-PET)>=0
      PERC=(I-PET)- ΔST))

Sum the percolation values for the year to obtain total annual leachate production per unit area.

16. To check calculations for each month (inches of water)
    P=PERC+AET+ΔST+r/o

All these steps are shown in the flowchart in fig.8. A sample output for the water balance method is shown in fig.9.

5.2 The HELP MODEL (Schoeder, 1983)

Hydrologic Evaluation of Landfill Performance (Help) is a versatile model for predicting landfill hydrologic processes and testing the effectiveness of landfill designs, therefore, enabling the prediction of landfill design failure resulting in groundwater contamination. Help has become a requirement for obtaining landfill operation permits in the U.S. HELP is also effective in assessment of groundwater recharge rates.

The quasi-two-dimensional hydrologic model accepts the following input data:

- Weather (precipitation, solar radiation, temperature, evapotranspiration parameters)
- Soil (porosity, field capacity, wilting point, and hydraulic conductivity
- Engineering design data (liners, leachate and runoff collection systems, surfaceslope)

The profile structure can be multi-layered, consisting of a combination of natural (soil) and artificial materials (waste, geomembranes) with an option to install horizontal drainage, and change the slope of profile parts (e.g. landfill cap, leachate collection and removal systems).

HELP uses numerical solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, or leakage through soil, geomembrane, or composite liners.

Built-in Databases and tools are:

- Whether Generator, a tool for synthetic generation for up to 100 years of daily values of recipitation, air temperature and solar radiation.
- Soil, waste and geomembrane database which contains parameters for 42 materials.

A sample problem, list of input data files and output file contents are shown in Annexure-VII.

5.3 CHRONO Model

Chronological leachate quality prediction program (chrono) is used to estimate leachate contaminant concentrations in a landfill.

CHRONO calculates weighted leachate flow and contaminant concentrations

$$C=C_0e^{-kt}$$

Where C= Concentration at time t(mg/l)
Co= initial concentration (mg/l)
K=decay coefficient
T= time (month)

Using the program:

- define landfill, construction method etc
- Obtain infiltration rates (HELP, WBM)
- Make data files
- Run CHRONO

Define Landfill

A spatial delamination of the landfill must be done that reflect the construction history of the landfill and the surface topology of the landfill. This includes the cell construction history. Divide landfill into columns (10000 max) and cells (50 per column max) using filling sequence, .6-12 No. intervals. Enter column and cell numbers, mass of waste/cell, cell start and finish times.

Infiltration Rates

The infiltration rates into each column of the landfill must be obtained using either HELP or WBM or meteorological data.

CONSTRUCTION OF DATA FILES

All the input files are to be ASCII files. They include DCELL. DAT, DFLOW.DAT, CONTAM.DAT

DCELL.DAT file contains the cell construction data. The file may have an unlimited amount of records. Each record has 6 fields separated by one space.

Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
Cell id	Column number	Cell start month	Cell End month	999	Mass (tonnes)

DFLOW.DAT file contains the column construction and leachate flow data. The file may contain an unlimited number of records. Each record consists of a minimum of 1004 numeric fields.

Field 1	Field 2	Field 3	Field 4	Field 5-1004
Column number	Column start month	End Month (Simulation)	Duration (Months)	Infiltration into column (m^3/month)

CONTAM.DAT file contains the contaminant names and the decay curve data. The file can contain up to 10 records. Each record may be 30 characters long. Use Input leaching curves: $C=C_0e^{-kt}$ for each contaminant. A sample curve for chloride production is shown in fig. 10.

Field 1(characters 1-10)	Field 2(character 11-20)	Field 3(characters 21-30)
Contaminant name	C_0 Value (mg/L)	Decay co-eff. k

RUN CHRONO

To run chrono enter q basic and load the CHRONO program. A sample output table is given in Annexure VIII

6.0 SUMMARY

An Enigma with landfills is said to be," Few people want them; most people use them". Concerns of contamination of groundwater, air and surface water are the reasons behind that. However, risk is high only at uncontrolled sites and always low at well designed sites but, care is perpetual. There are few alternatives like incineration, recycling and composting, most of them are used in conjunction with landfills. A landfill is a form of biochemical reactor where the municipal solid waste (MSW) comes into the contact of moisture, a catalyst, to get decomposed in to solid waste, gases, liquid contaminants (leachate) and heat. To design the control and recovery systems it is required to estimate the amount and composition of gas and leachate accurately and also changes in these with time. Lysimeters are used to simulate the landfill performances.

Landfill leachate contaminant concentrations are of prime importance, these may include; organic matter, nitrogen compounds, anions, metals, Volatile Organic Compounds and other organics. Chemical and biological reactions change the compound composition with age of the landfill, which might be of interest to many environmental hydrologists. Permeability and hydraulic conductivity measurements for the liners and natural barriers, supply basic parameters for the landfill design. Various field and laboratory experiment methods are available for estimating these parameters. These, along with the estimation of various soil parameters like; Porosity, Field capacity, Wilting point, saturated hydraulic conductivity and soil retention capacities could be a valuable input from a hydrologist.

More-over, hydrological parameters like; weather, topography, surface storage, snowmelt, runoff, infiltration, evapotranspiration, soil storage, lateral drainage, leakage through liner and geo-membrane could also be monitored in the selected sites. These parameters could also be used in water balance method to estimate the percolation of exact quantity of leachate periodically. Hydro-geological investigations could be carried out, by fixing and monitoring of observation wells. Resistivity surveys could easily supply the necessary lithological information.

Ministry of Environment and Forest has notified the site sensitivity indices for selected social, hydrological and environmental attributes. Pathways to surface water storages could be identified far easily than the groundwater, having known the topography and the geo-morphological characteristics. In case of groundwater, only mathematical modelling of flow and contaminant transport could ensure the degree of risk involved with the selection of a landfill site. Proper use of models like HELP and CHRONO along with numerical flow and transport models like MODFLOW, SWIFT, MT3D, MODPATH may serve the purpose. National Productivity council has tried to justify it by incorporating parameters such as groundwater flow direction and its gradient in the site evaluation criteria. Soil erosion models like WEPP and RUSLE could intimate the degree of soil erosion and runoff. Finally, it may be concluded that Environmental Impact Assessment of a landfill and waste disposal sites requires extensive hydrological investigations to safeguard our natural resources from pollution.

8.0 RECCOMENDATIONS

In an Environmental Impact Assessment programme following hydrological investigations are reccomended.

1. Leachate movement simulation using Lysimeters.
2. Chemical and biological analysis for Landfill leachate contaminant concentrations.
3. Chemical and biological reaction changes with age of the landfill.
4. Field and laboratory testing for estimating Permeability and Hydraulic conductivity of soil and bed rock.
5. Estimation of various saturated and unsaturated soil parameters.
6. Estimation of Infiltration and lateral drainage using infiltrometers.
7. Hydro-geological investigations and Resistivity surveys.
8. Geo-morphological study.
9. Application of water balance method to estimate the percolation of quantity of leachate periodically.
10. Application HELP and CHRONO for assessment of landfill performance.
11. Mathematical modelling of flow and contaminant transport.
12. Application of Soil erosion models.

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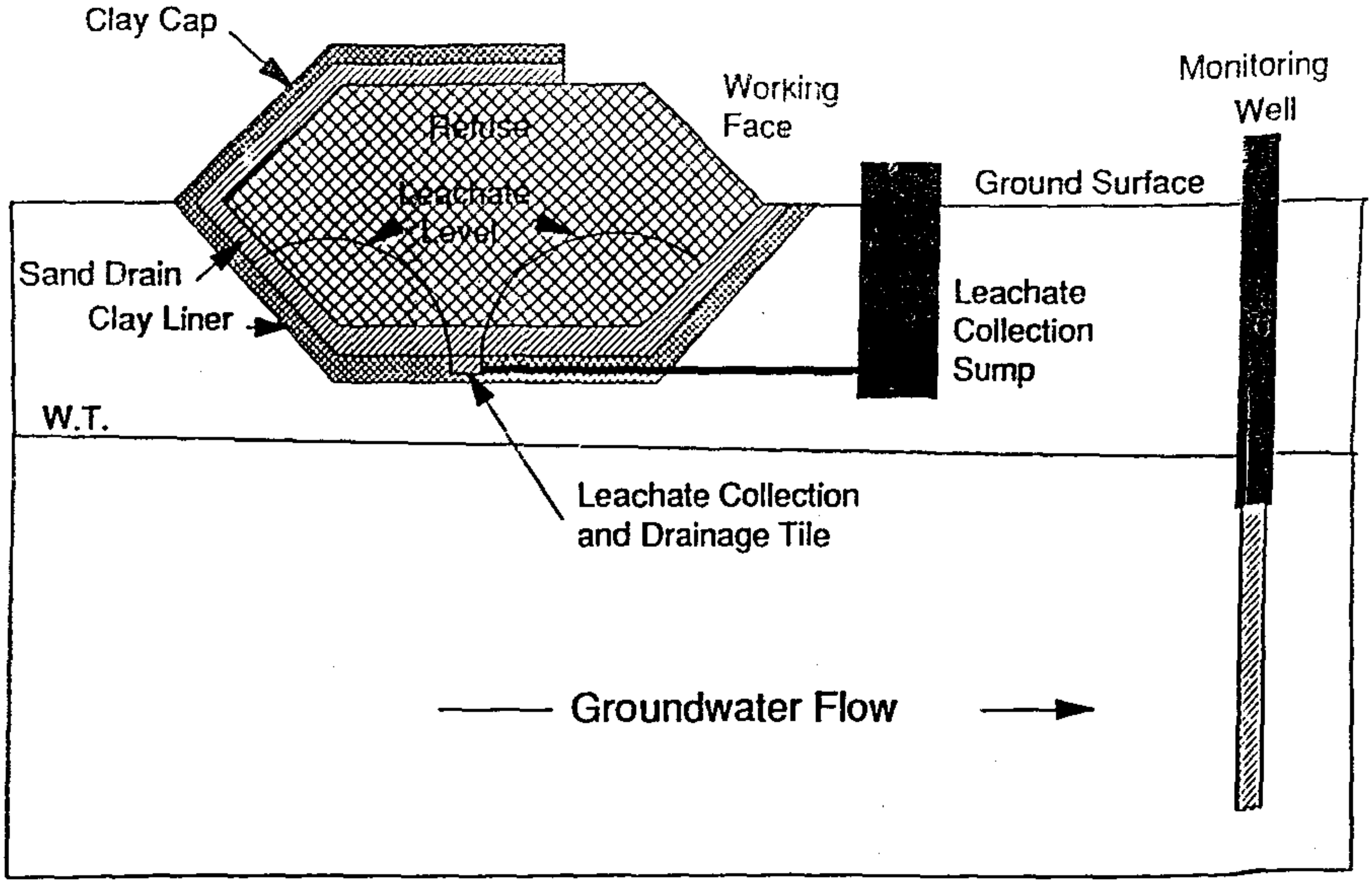


Fig.1 Schematic diagram of landfill

COVER

- trend toward – multicomponent systems
  – entombment and perpetual care

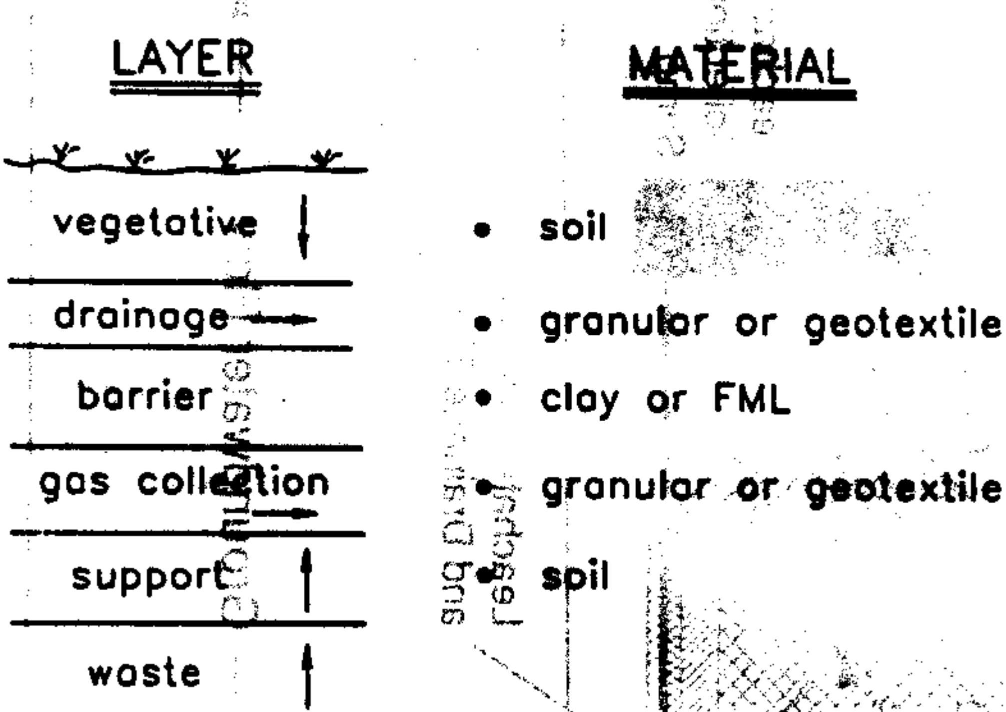


Fig.2 Schematic diagram of landfill cover stratification

LINER

Future Practice: multiple, multicomponent liners

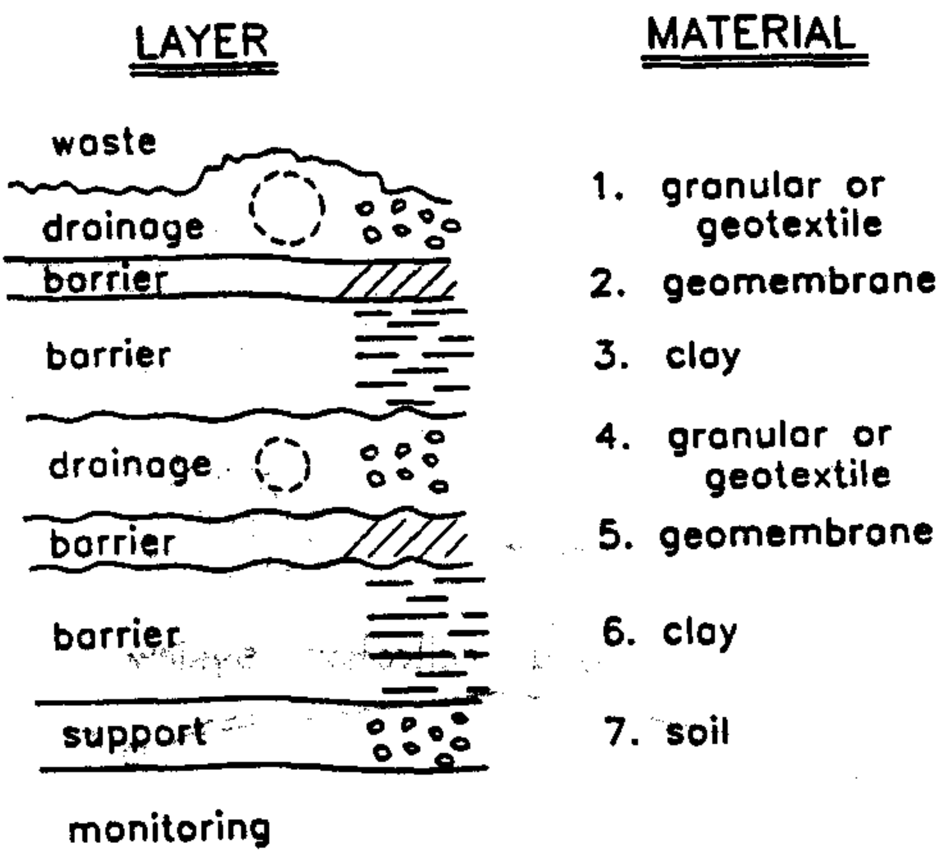
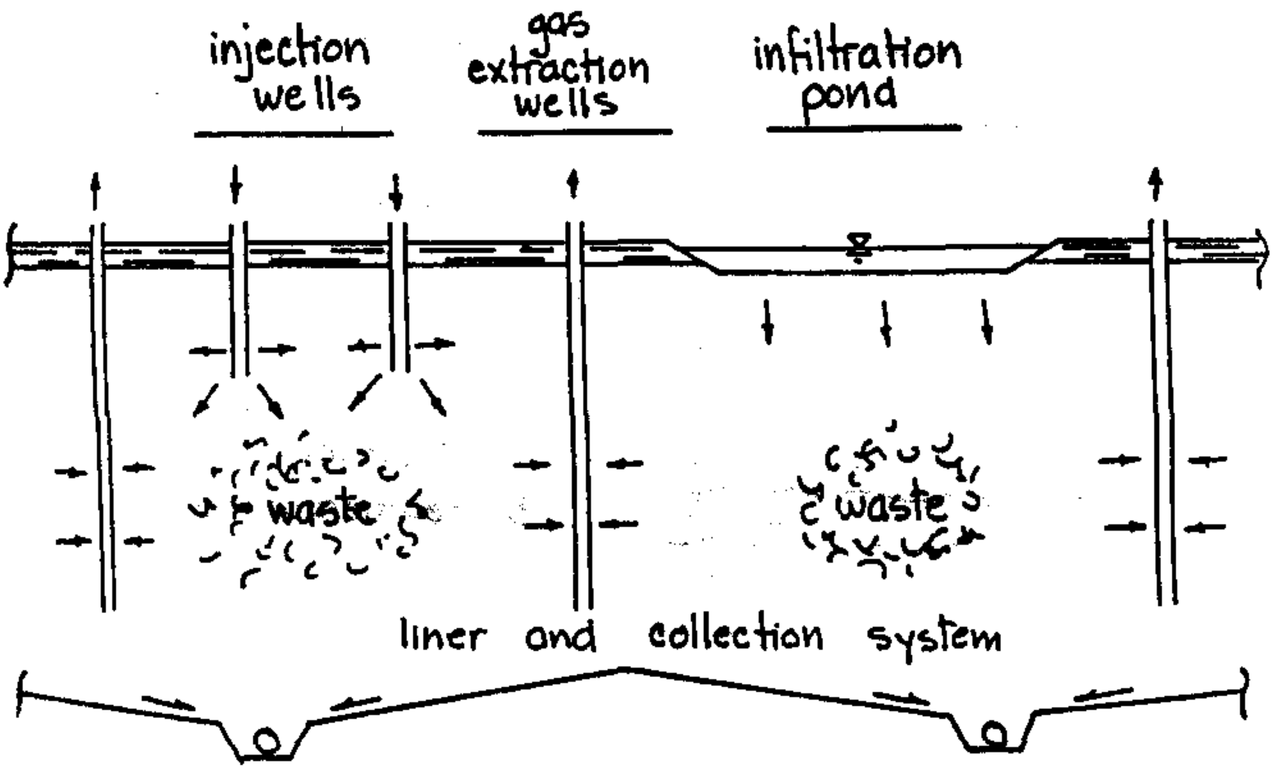


Fig.3 Schematic diagram of landfill liner stratification

Fig.4 Landfill Leachate Recycle and Gas Recovery



(1) Definition of Hazardous Waste Problem

(2) Selection of Generic Technology

(3) Selection of Candidate Region

(4) Selection of Candidate Areas

(5) Selection of Candidate Sites

(6) Comparison of Sites & Selection of Preferred Site

(7) Public & Regulatory Approval

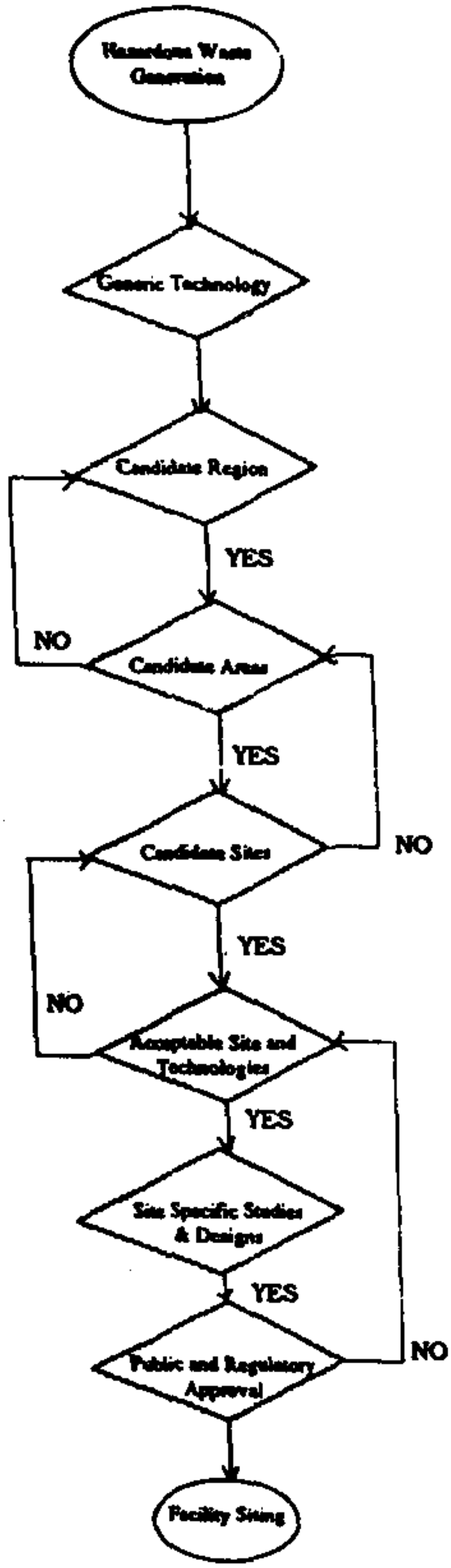


Figure 5 Algorithm for Hazardous Waste Facilities Development (MOEF,1991)

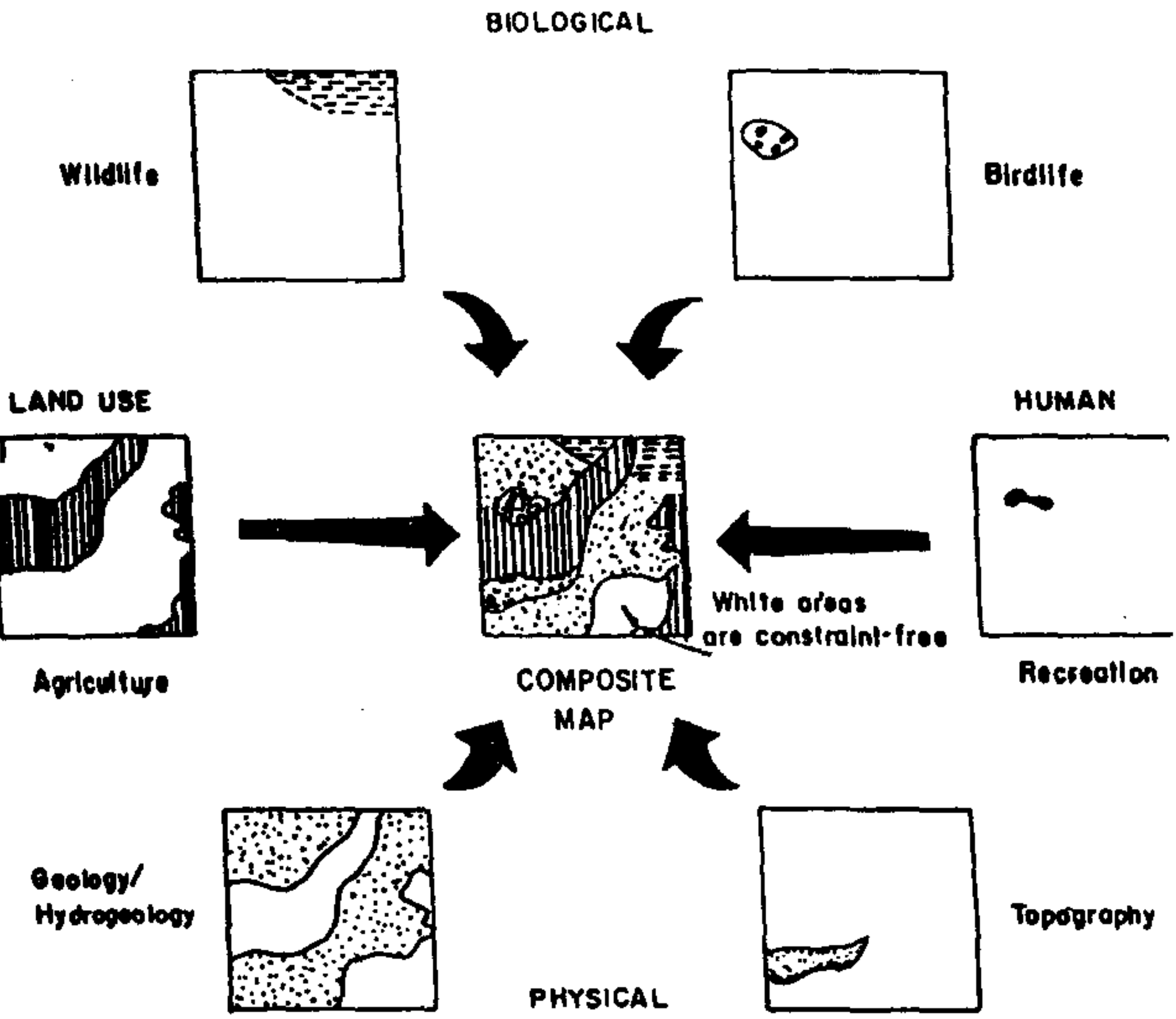


Figure 6 **The Constraint - Mapping Process** (MOEF 1991)

FIGURE 7 WATER MOVEMENT AT A LANDFILL

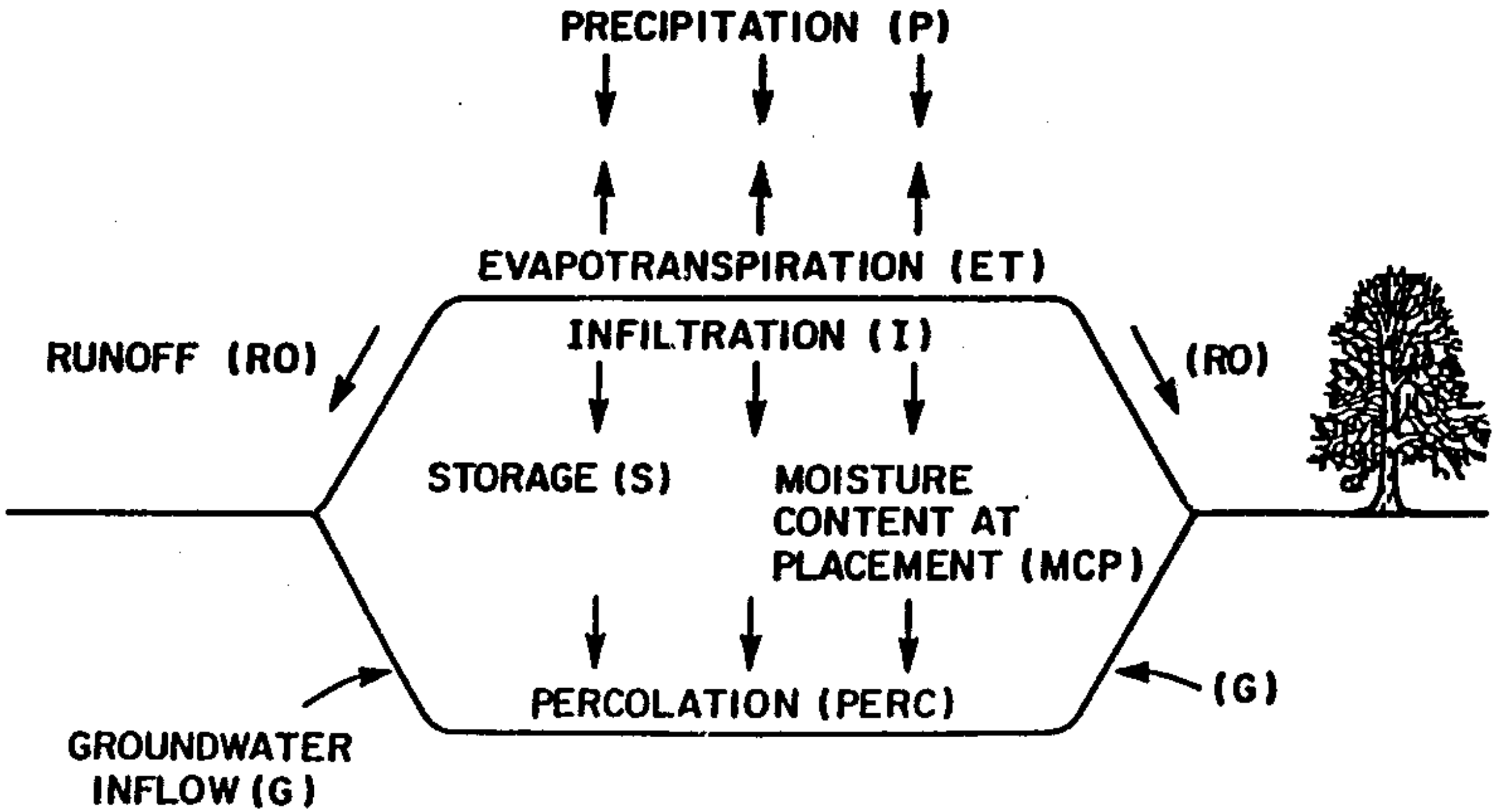


FIGURE 8. FLOWCHART FOR THE WATER BALANCE METHOD (Fenn et al., 1975)

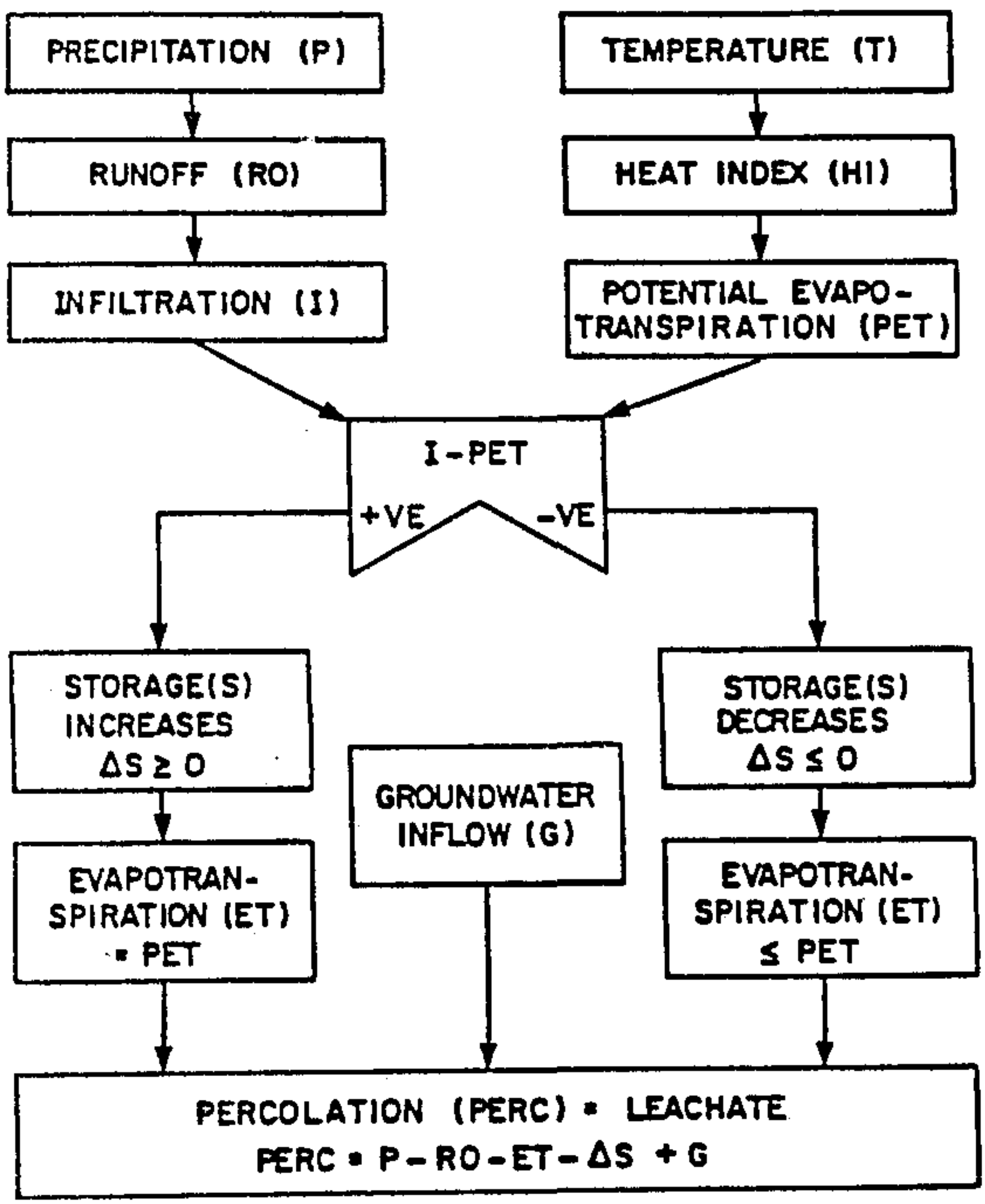


FIGURE 9 SAMPLE OUTPUT FROM THE WATER BALANCE METHOD

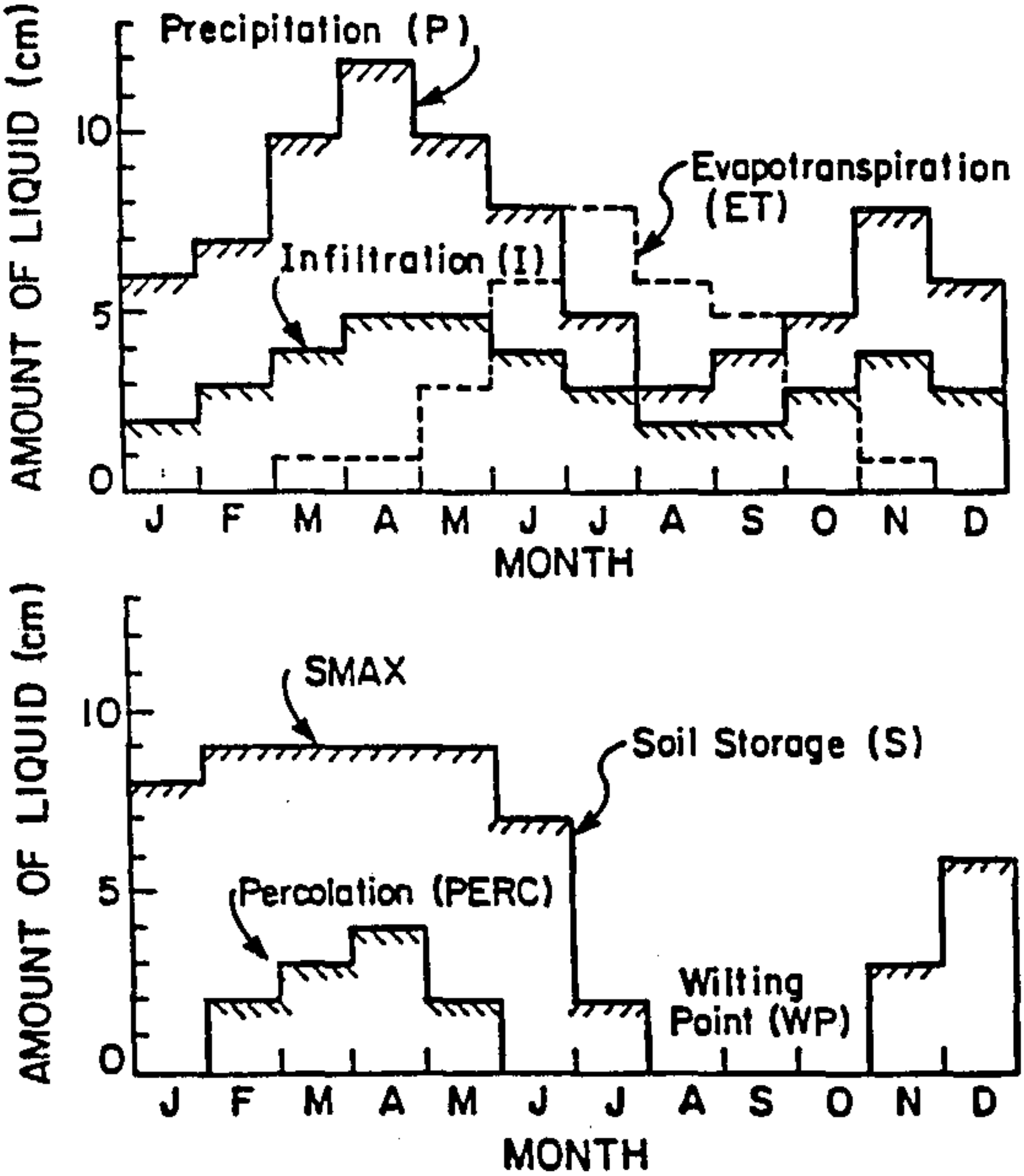


FIGURE 10 LEACHATE CHLORIDE PRODUCTION CURVE
(Adapted from McGinley and Kmet, 1984)

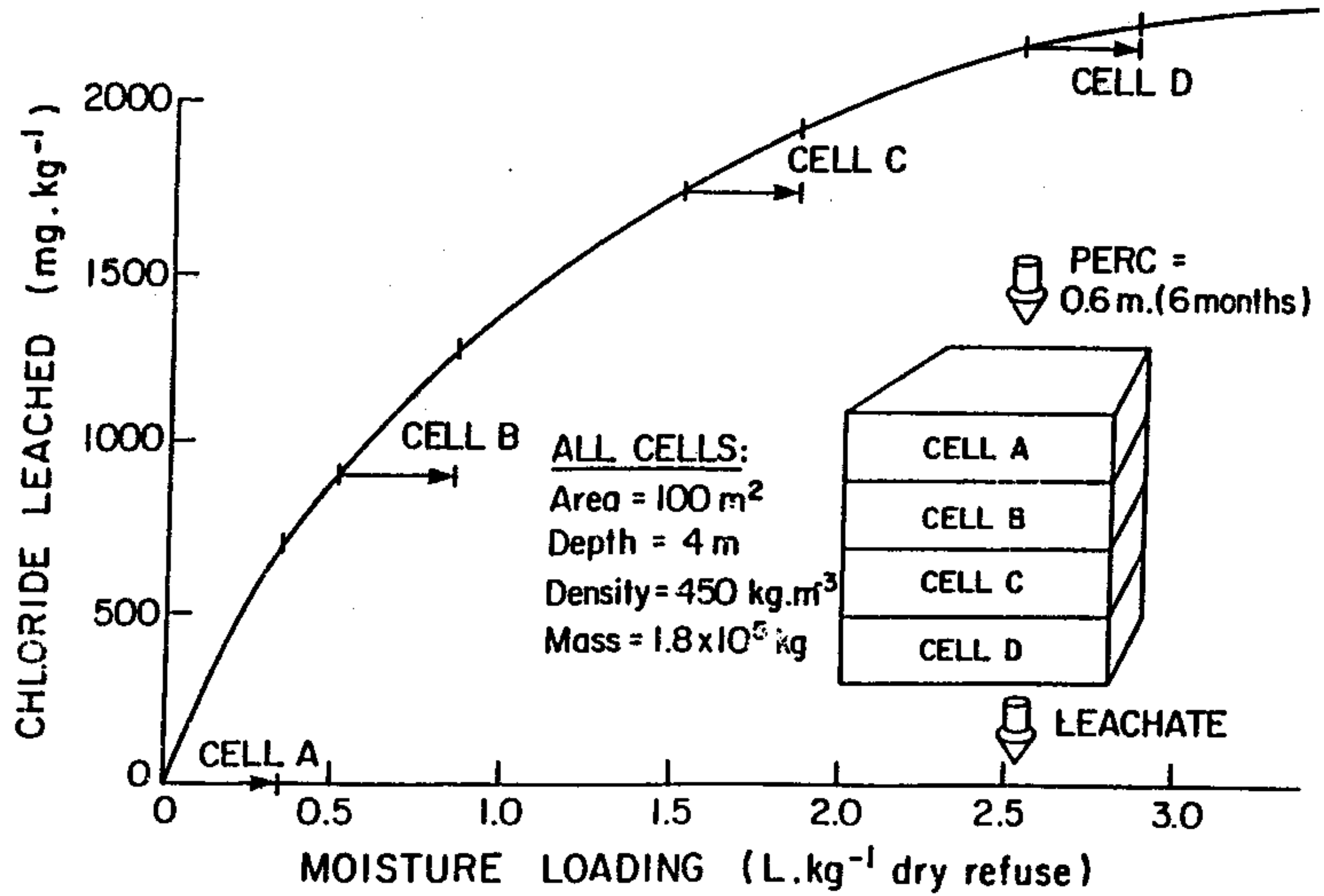


TABLE 7.6

Annexure-I

MONTHLY VALUES OF HEAT INDEX CORRESPONDING TO MONTHLY MEAN TEMPERATURES (°F)

.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
.00	.00	.00	.00	.01	.01	.02	.02	.03	.03
.04	.04	.05	.05	.06	.06	.07	.08	.09	.09
.10	.10	.11	.12	.13	.14	.15	.16	.17	.18
.19	.20	.21	.22	.23	.24	.25	.26	.27	.28
.29	.30	.32	.33	.34	.35	.36	.37	.39	.40
.41	.42	.43	.44	.46	.47	.48	.50	.51	.52
.54	.55	.56	.58	.59	.60	.62	.63	.65	.66
.68	.70	.71	.73	.74	.76	.77	.79	.80	.82
.83	.85	.86	.88	.90	.91	.93	.95	.96	.98
1	1.01	1.03	1.05	1.07	1.08	1.10	1.12	1.14	1.16
1.17	1.19	1.21	1.23	1.24	1.26	1.28	1.30	1.32	1.33
1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.50	1.52
1.54	1.56	1.58	1.60	1.62	1.64	1.66	1.68	1.70	1.72
1.74	1.76	1.78	1.80	1.82	1.85	1.87	1.89	1.91	1.93
1.95	1.97	2.00	2.02	2.04	2.06	2.08	2.10	2.13	2.15
2.17	2.19	2.21	2.23	2.26	2.28	2.30	2.32	2.34	2.37
2.39	2.41	2.43	2.46	2.48	2.50	2.53	2.55	2.57	2.60
2.62	2.64	2.67	2.69	2.71	2.74	2.76	2.79	2.81	2.84
2.86	2.89	2.91	2.93	2.96	2.98	3.01	3.03	3.06	3.08
3.11	3.13	3.16	3.18	3.21	3.23	3.25	3.28	3.30	3.33
3.35	3.38	3.40	3.43	3.45	3.48	3.50	3.53	3.55	3.58
3.6	3.63	3.65	3.68	3.71	3.73	3.76	3.79	3.81	3.84
3.87	3.89	3.92	3.95	3.97	4.00	4.03	4.06	4.08	4.11
4.14	4.16	4.19	4.22	4.25	4.27	4.30	4.33	4.35	4.38
4.41	4.44	4.47	4.50	4.52	4.55	4.57	4.60	4.63	4.66
4.69	4.72	4.75	4.77	4.80	4.83	4.86	4.89	4.92	4.95
4.98	5.01	5.04	5.07	5.10	5.13	5.15	5.19	5.22	5.25
5.28	5.31	5.34	5.37	5.40	5.43	5.46	5.49	5.52	5.55
5.58	5.61	5.64	5.67	5.70	5.73	5.76	5.79	5.82	5.85
5.88	5.91	5.94	5.97	6.00	6.03	6.06	6.10	6.13	6.16
6.19	6.22	6.25	6.28	6.31	6.34	6.38	6.41	6.44	6.47
6.50	6.53	6.56	6.59	6.62	6.66	6.69	6.72	6.75	6.79
6.82	7.85	6.88	6.92	6.95	6.98	7.02	7.05	7.08	7.12
7.15	7.18	7.22	7.25	7.28	7.32	7.35	7.38	7.42	7.45
7.48	7.52	7.55	7.58	7.62	7.65	7.68	7.72	7.75	7.78
7.52	7.85	7.89	7.92	7.95	7.99	8.02	8.05	8.09	8.12
8.16	8.19	8.23	8.26	8.30	8.33	8.37	8.40	8.44	8.47
8.51	8.54	8.57	8.61	8.64	8.68	8.71	8.75	8.78	8.82
8.85	8.89	8.92	8.96	8.99	9.03	9.06	9.10	9.13	9.17
9.2	9.24	9.27	9.31	9.34	9.38	9.42	9.45	9.49	9.53

TABLE 7.6

MONTHLY VALUES OF HEAT INDEX
CORRESPONDING TO MONTHLY MEAN TEMPERATURES (°F)

°F	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
72	9.57	9.60	9.64	9.67	9.71	9.75	9.78	9.82	9.85	9.89
73	9.93	9.97	10.01	10.04	10.08	10.12	10.15	10.19	10.22	10.26
74	10.30	10.34	10.37	10.41	10.45	10.48	10.52	10.56	10.60	10.64
75	10.67	10.71	10.75	10.78	10.82	10.86	10.89	10.93	10.97	11.01
76	11.05	11.09	11.13	11.17	11.20	11.24	11.28	11.31	11.35	11.39
77	11.43	11.47	11.51	11.54	11.58	11.62	11.66	11.70	11.74	11.76
78	11.82	11.85	11.89	11.93	11.97	12.01	12.05	12.09	12.13	12.17
79	12.21	12.25	12.29	12.33	12.37	12.41	12.45	12.49	12.53	12.57
80	12.61	12.65	12.69	12.73	12.77	12.81	12.85	12.89	12.93	12.97
81	13.01	13.05	13.09	13.13	13.17	13.21	13.25	13.29	13.33	13.37
82	13.41	13.45	13.49	13.53	13.57	13.61	13.65	13.69	13.73	13.77
83	13.81	13.85	13.89	13.94	13.98	14.02	14.06	14.10	14.14	14.18
84	14.22	14.26	14.31	14.35	14.39	14.43	14.47	14.52	14.56	14.60
85	14.64	14.69	14.73	14.77	14.81	14.85	14.90	14.94	14.98	15.02
86	15.07	15.11	15.15	15.19	15.23	15.28	15.32	15.36	15.40	15.45
87	15.49	15.53	15.58	15.62	15.66	15.71	15.75	15.79	15.84	15.88
88	15.92	15.97	16.01	16.05	16.10	16.14	16.18	16.23	16.27	16.31
89	16.36	16.40	16.44	16.49	16.53	16.57	16.62	16.66	16.70	16.75
90	16.79	16.83	16.88	16.92	16.96	17.01	17.05	17.09	17.14	17.18
91	17.23	17.27	17.32	17.36	17.41	17.45	17.49	17.54	17.58	17.63
92	17.67	17.72	17.76	17.81	17.85	17.89	17.94	17.98	18.03	18.07
93	18.12	18.16	18.21	18.25	18.30	18.34	18.39	18.43	18.48	18.52
94	18.57	18.62	18.66	18.71	18.75	18.80	18.84	18.89	18.93	18.98
95	19.03	19.07	19.12	19.16	19.21	19.25	19.30	19.34	19.39	19.44
96	19.48	19.53	19.58	19.62	19.67	19.71	19.76	19.81	19.86	19.90
97	19.95	20.00	20.04	20.09	20.14	20.18	20.23	20.28	20.32	20.37
98	20.42	20.46	20.51	20.56	20.60	20.65	20.70	20.74	20.79	20.84
99	20.88	20.93	20.98	21.03	21.08	21.13	21.17	21.22	21.27	21.32
100	21.36	21.41	21.46	21.51	21.56	21.60	21.65	21.70	21.75	21.79
101	21.84	21.89	21.94	21.99	22.03	22.08	22.13	22.18	22.23	22.29
102	22.33	22.38	22.42	22.47	22.52	22.57	22.62	22.67	22.71	22.76
103	22.81	22.86	22.91	22.96	23.00	23.05	23.10	23.15	23.20	23.25
104	23.30									

ample - for a temperature of 77.5°F, I = 11.62

Annexure-II

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

	I Value											
°F	*25.0*	*27.5*	*30.0*	*32.5*	*35.0*	*37.5*	*40.0*	*42.5*	*45.0*	*47.5*	*50.0*	*52.5*
32.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.0	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.5	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.0	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00
34.5	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00
35.0	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
35.5	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
36.0	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01
36.5	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01
37.0	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01
37.5	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01
38.0	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01
38.5	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
39.0	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02
39.5	.04	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
40.0	.04	.04	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02
40.5	.04	.04	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
41.0	.04	.04	.04	.03	.03	.03	.03	.03	.02	.02	.02	.02
41.5	.04	.04	.04	.04	.03	.03	.03	.03	.03	.02	.02	.02
42.0	.04	.04	.04	.04	.04	.03	.03	.03	.03	.02	.02	.02
42.5	.05	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.02
43.0	.05	.05	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
43.5	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03
44.0	.05	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03	.03
44.5	.06	.05	.05	.04	.04	.04	.04	.04	.04	.04	.03	.03
45.0	.06	.06	.05	.05	.04	.04	.04	.04	.04	.04	.04	.03
45.5	.06	.06	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04
46.0	.06	.06	.06	.05	.05	.05	.04	.04	.04	.04	.04	.04
46.5	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04	.04	.04
47.0	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04	.04
47.5	.06	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

T°F	*I Value* 25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5	50.0	52.5
48.0	.07	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05	.04
48.5	.07	.07	.06	.06	.06	.06	.06	.05	.05	.05	.05	.04
49.0	.07	.07	.06	.06	.06	.06	.06	.06	.05	.05	.05	.04
49.5	.07	.07	.07	.06	.06	.06	.06	.06	.06	.05	.05	.05
50.0	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06	.05	.05
50.5	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06	.05
51.0	.08	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
51.5	.08	.08	.07	.07	.07	.07	.06	.06	.05	.06	.06	.06
52.0	.08	.08	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
52.5	.08	.08	.08	.07	.07	.07	.07	.07	.06	.06	.06	.06
53.0	.09	.08	.08	.07	.07	.07	.07	.07	.07	.06	.06	.06
53.5	.09	.09	.08	.08	.07	.07	.07	.07	.07	.07	.07	.06
54.0	.09	.09	.08	.08	.08	.07	.07	.07	.07	.07	.07	.06
54.5	.09	.09	.09	.08	.08	.08	.07	.07	.07	.07	.07	.07
55.0	.09	.09	.09	.08	.08	.08	.08	.07	.07	.07	.07	.07
55.5	.09	.09	.09	.09	.08	.08	.08	.08	.07	.07	.07	.07
56.0	.09	.09	.09	.09	.09	.08	.08	.08	.08	.07	.07	.07
56.5	.10	.09	.09	.09	.09	.09	.08	.08	.08	.08	.08	.07
57.0	.10	.10	.09	.09	.09	.09	.09	.08	.08	.08	.08	.07
57.5	.10	.10	.09	.09	.09	.09	.09	.09	.07	.08	.08	.08
58.0	.10	.10	.10	.09	.09	.09	.09	.09	.09	.08	.08	.08
58.5	.11	.10	.10	.10	.09	.09	.09	.09	.09	.09	.09	.08
59.0	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09	.08
59.5	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09
60.0	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09
60.5	.11	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09
61.0	.11	.11	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09
61.5	.12	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10	.09
62.0	.12	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10
62.5	.12	.12	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10
63.0	.12	.12	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10
63.5	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11	.11	.10

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL
EVAPOTRANSPIRATION (in.)
FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

T.	*I Value* 25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5	50.0	52.5
64.0	.13	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11	.11
64.5	.13	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11
65.0	.13	.13	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11
65.5	.13	.13	.13	.12	.12	.12	.12	.12	.12	.11	.11	.11
66.0	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12	.12	.11
66.5	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12	.12
67.0	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12
67.5	.14	.13	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12
68.0	.14	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13	.12
68.5	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13
69.0	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13
69.5	.15	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13	.13
70.0	.15	.14	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13
70.5	.15	.15	.14	.14	.14	.14	.14	.14	14	.14	.14	.13
71.0	.15	.15	.15	.15	.14	.14	.14	.14	.14	.14	.14	.14
71.5	[illegible]	.15	.15	.15	.15	.15	.14	.14	.14	.14	.14	.14
72.0	.15	.15	.16	.16	.16	.15	.15	.15	.14	.14	.14	.14
72.5	.15	.15	.16	.16	.16	.15	.15	.15	.15	.15	.15	.14
73.0	.16	.15	.15	.15	.16	.15	.15	.15	.15	.15	.15	.15
73.5	.16	.15	.15	.15	.16	.15	.15	.15	.15	.15	.15	.15
74.0	.16	.16	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15
74.5	.16	.16	.16	.16	.16	.16	.15	.15	.15	.15	.15	.15
75.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.15
75.5	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
76.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
76.5	.17	.17	.17	.17	.17	.17	.17	.16	.16	.16	.16	.16
77.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
77.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
78.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
78.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.0	.18	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.5	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18
80.0	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL
EVAPOTRANSPIRATION (in.)
FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

	I Value											
T°F	*55.0*	*57.5*	*60.0*	*62.5*	*65.0*	*67.5*	*70.0*	*72.5*	*75.0*	*77.5*	*80.0*	*82.5*
32.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
36.0	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
36.5	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
37.0	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
37.5	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00
38.0	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00
38.5	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
39.0	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00
39.5	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
40.0	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
40.5	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01
41.0	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01
41.5	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01
42.0	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01
42.5	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01
43.0	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01
43.5	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01
44.0	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
44.5	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02
45.0	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
45.5	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02
46.0	.04	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02
46.5	.04	.04	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
47.0	.04	.04	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02
47.5	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02	.02

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL
EVAPOTRANSPIRATION (in.)
FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

		I Value									
55.0	*57.5*	*60.0*	*62.5*	*65.0*	*67.5*	*70.0*	*72.5*	*75.0*	*77.5*	*80.0*	*82.5*
.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.02	.02
.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.02
.04	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
.05	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
.05	.05	.04	.04	.04	.04	.04	.04	.04	.03	.03	.03
.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.03	.03
.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04	.03
.06	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04
.06	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04
.06	.06	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04
.06	.06	.06	.05	.05	.05	.05	.04	.04	.04	.04	.04
.06	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04
.06	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05	.04
.06	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05
.07	.06	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05
.07	.07	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05
.07	.07	.07	.06	.06	.06	.06	.06	.06	.06	.05	.05
.07	.07	.07	.07	.06	.06	.06	.06	.06	.06	.06	.05
.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
.07	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
.08	.07	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06
.08	.08	.07	.07	.07	.07	.07	.07	.07	.06	.06	.06
.08	.08	.08	.07	.07	.07	.07	.07	.07	.07	.06	.06
.09	.08	.08	.08	.07	.07	.07	.07	.07	.07	.07	.06
.09	.08	.08	.08	.08	.07	.07	.07	.07	.07	.07	.07
.09	.09	.09	.08	.08	.08	.08	.07	.07	.07	.07	.07
.09	.09	.09	.08	.08	.08	.08	.08	.08	.07	.07	.07
.09	.09	.09	.09	.08	.08	.08	.08	.08	.07	.07	.07
.09	.09	.09	.09	.09	.08	.08	.08	.08	.08	.08	.08
.10	.09	.09	.09	.09	.09	.09	.08	.08	.08	.08	.08
.10	.10	.09	.09	.09	.09	.09	.09	.09	.08	.08	.08
.10	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09	.08

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

T°F	*I Value* 55.0	57.5	60.0	62.5	65.0	67.5	70.0	72.5	75.0	77.5	80.0	82.5
64.0	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09
64.5	.11	.10	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09
65.0	.11	.11	.10	.10	.10	.10	.10	.09	.09	.09	.09	.09
65.5	.11	.11	.11	.11	.10	.10	.10	.10	.10	.10	.10	.10
66.0	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10	.10	.10
66.5	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10
67.0	.12	.11	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10
67.5	.12	.12	.11	.11	.11	.11	.11	.11	.11	.11	.11	.11
68.0	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11	.11	.11
68.5	.13	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11	.11
69.0	.13	.13	.13	.12	.12	.12	.12	.12	.11	.11	.11	.11
69.5	.13	.13	.13	.12	.12	.12	.12	.12	.12	.12	.12	.12
70.0	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12	.12	.12
70.5	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12
71.0	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
71.5	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13
72.0	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13
72.5	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
73.0	.15	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
73.5	.15	.15	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14
74.0	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
74.5	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
75.0	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
75.5	.16	.16	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15
76.0	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
76.5	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
77.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
77.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
78.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
78.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.0	.18	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.5	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18
80.0	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

I Value											
85.0	*87.5*	*90.0*	*92.5*	*95.0*	*97.5*	*100.0*	*102.5*	*105.0*	*107.5*	*110.0*	*112.5*
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00
.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
.01	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00
.01	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00
.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00
.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01
.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01
.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01
.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01
.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

I Value											
85.0	*87.5*	*90.0*	*92.5*	*95.0*	*97.5*	*100.0*	*102.5*	*105.0*	*107.5*	*110.0*	*112.5*
.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01
.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01
.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01
.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02
.03	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
.03	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
.03	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
.04	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02
.04	.04	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02
.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02	.02
.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02
.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03
.04	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
.05	.04	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03
.05	.05	.04	.04	.04	.04	.04	.04	.04	.04	.03	.03
.05	.05	.05	.04	.04	.04	.04	.04	.04	.04	.04	.03
.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04	.04
.06	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04
.06	.05	.05	.05	.05	.05	.05	.04	.04	.04	.04	.04
.06	.06	.06	.05	.05	.05	.05	.05	.04	.04	.04	.04
.06	.06	.06	.05	.05	.05	.05	.05	.04	.04	.04	.04
.06	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04	.04
.06	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05	.05
.07	.06	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05
.07	.07	.07	.06	.06	.06	.06	.06	.05	.05	.05	.05
.07	.07	.07	.07	.06	.06	.06	.06	.06	.06	.06	.05
.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
.07	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
.08	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
.08	.08	.08	.07	.07	.07	.07	.07	.07	.06	.06	.06
.08	.08	.08	.08	.07	.07	.07	.07	.07	.07	.07	.06

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

T°F	*I Value*											
	85.0	*87.5*	*90.0*	*92.5*	*95.0*	*97.5*	*100.0*	*102.5*	*105.0*	*107.5*	*110.0*	*112.5*
64.0	.09	.08	.08	.08	.08	.07	.07	.07	.07	.07	.07	.07
64.5	.09	.08	.08	.08	.08	.08	.08	.07	.07	.07	.07	.07
65.0	.09	.09	.09	.09	.09	.08	.08	.08	.07	.07	.07	.07
65.5	.09	.09	.09	.09	.09	.09	.09	.08	.08	.07	.07	.07
66.0	.09	.09	.09	.09	.09	.09	.09	.08	.08	.08	.08	.08
66.5	.10	.09	.09	.09	.09	.09	.09	.08	.08	.08	.08	.08
67.0	.10	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09	.08
67.5	.10	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09	.09
68.0	.11	.10	.10	.10	.10	.10	.09	.09	.09	.09	.09	.09
68.5	.11	.11	.11	.10	.10	.10	.10	.09	.09	.09	.09	.09
69.0	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10	.10
69.5	.12	.11	.11	.11	.11	.11	.11	.10	.10	.10	.10	.10
70.0	.12	.11	.11	.11	.11	.11	.11	.11	.11	.11	.11	.10
70.5	.12	.12	.12	.11	.11	.11	.11	.11	.11	.11	.11	.11
71.0	.13	.12	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11
71.5	.13	.12	.12	.12	.12	.12	.12	.11	.11	.11	.11	.11
72.0	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12
72.5	.13	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12
73.0	.14	.13	.13	.13	.13	.13	.13	.12	.12	.12	.12	.12
73.5	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13	.13	.13
74.0	.14	.14	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13
74.5	.15	.14	.14	.14	.14	.14	.14	.13	.13	.13	.13	.13
75.0	.15	.15	.15	.15	.15	.15	.14	.14	.14	.14	.14	.14
75.5	.15	.15	.15	.15	.15	.15	.15	.14	.14	.14	.14	.14
76.0	.16	.16	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15
76.5	.16	.16	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15
77.0	.16	.16	.16	.16	.16	.16	.16	.15	.15	.15	.15	.15
77.5	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
78.0	.17	.17	.17	.17	.17	.17	.17	.16	.16	.16	.16	.16
78.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.16	.16
79.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.18
79.5	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18
80.0	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

T °F	*I Value* 115.0	117.5	120.0	122.5	125.0	127.5	130.0	132.5	135.0	137.5	140.0
32.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
33.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
34.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
36.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
36.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
37.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
37.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
38.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
38.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
39.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
39.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
40.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
40.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
41.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
41.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
43.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
43.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
44.0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
44.5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.0	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.5	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
46.0	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00
46.5	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00	.00
47.0	.01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00
47.5	01	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

°F	*I Value* 115.0	117.5	120.0	122.5	125.0	127.5	130.0	132.5	135.0	137.5	140.0
48.0	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00
48.5	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00	.00
49.0	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.00
49.5	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
50.0	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
50.5	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01
51.0	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01
51.5	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01	.01
52.0	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01	.01
52.5	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01	.01
53.0	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.01
53.5	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01
54.0	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01
54.5	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
55.0	.03	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
55.5	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
56.0	.03	.03	.03	.02	.02	.02	.02	.02	.02	.02	.02
56.5	.03	.03	.03	.03	.03	.02	.02	.02	.02	.02	.02
57.0	.03	.03	.03	.03	.03	.03	.03	.02	.02	.02	.02
57.5	.03	.03	.03	.03	.03	.03	.03	.03	.02	.02	.02
58.0	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02	.02
58.5	.04	.04	.04	.04	.03	.03	.03	.03	.03	.03	.02
59.0	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
59.5	.04	.04	.04	.04	.04	.04	.04	.03	.03	.03	.03
60.0	.05	.04	.04	.04	.04	.04	.04	.04	.04	.03	.03
60.5	.05	.04	.04	.04	.04	.04	.04	.04	.04	.04	.03
61.0	.05	.05	.05	.04	.04	.04	.04	.04	.04	.04	.04
61.5	.06	.05	.05	.05	.05	.04	.04	.04	.04	.04	.04
62.0	.06	.05	.05	.05	.05	.05	.05	.04	.04	.04	.04
62.5	.06	.06	.05	.05	.05	.05	.05	.05	.04	.04	.04
63.0	.06	.06	.06	.05	.05	.05	.05	.05	.05	.05	.04
63.5	.06	.06	.06	.06	.06	.06	.05	.05	.05	.05	.05

TABLE 7.7

VALUES OF UNADJUSTED DAILY POTENTIAL EVAPOTRANSPIRATION (in.) FOR DIFFERENT MEAN TEMPERATURES (°F) AND I VALUES

	I Value										
°F	*115.0*	*117.5*	*120.0*	*122.5*	*125.0*	*127.5*	*130.0*	*132.5*	*135.0*	*137.5*	*140.0*
64.0	.07	.06	.06	.06	.06	.06	.06	.06	.05	.05	.05
64.5	.07	.06	.06	.06	.06	.06	.06	.06	.06	.06	.05
65.0	.07	.07	.06	.06	.06	.06	.06	.06	.06	.06	.06
65.5	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06	.06
66.0	.07	.07	.07	.07	.07	.07	.06	.06	.06	.06	.06
66.5	.08	.07	.07	.07	.07	.07	.07	.07	.07	.07	.06
67.0	.08	.08	.07	.07	.07	.07	.07	.07	.07	07	.06
67.5	.09	.08	.08	.08	.08	.08	.07	.07	.07	.07	.07
68.0	.09	.08	.08	.08	.08	.08	.08	.07	.07	.07	.07
68.5	.09	.09	.08	.08	.08	.08	.08	.08	.08	.08	.07
69.0	.09	.09	.09	.09	.09	.09	.09	.08	.08	.08	.08
69.5	.10	.09	.09	.09	.09	.09	.09	.09	.09	.09	.09
70.0	.10	.10	.09	.09	.09	.09	.09	.09	.09	.09	.09
70.5	.11	.10	.10	.10	.10	.10	.10	.10	.09	.09	.09
71.0	.11	.10	.10	.10	.10	.10	.10	.10	.10	.09	.09
71.5	.11	.11	.11	.11	.11	.11	.11	.11	.10	.10	.10
72.0	.12	.11	.11	.11	.11	.11	.11	.11	.11	.10	.10
72.5	.12	.11	.11	.11	.11	.11	.11	.11	.11	.11	.11
73.0	.13	.12	.12	.12	.12	.12	.12	.12	.11	.11	.11
73.5	.13	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12
74.0	.13	.12	.12	.12	.12	.12	.12	.12	.12	.12	.12
74.5	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
75.0	.14	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
75.5	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
76.0	.15	.14	.14	.14	.14	.14	.14	.14	.14	.14	.14
76.5	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
77.0	.16	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
77.5	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
78.0	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
78.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.0	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
79.5	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17	.17
80.0	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18	.18

TABLE 7.8

MEAN POSSIBLE MONTHLY DURATION OF SUNLIGHT IN THE NORTHERN HEMSPHERE EXPRESSED IN UNITS OF 12 HOURS

Northern Latitudes	January	February	March	April	May	June	July	August	September	October	November	December
0	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	33.3	31.2
1	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	33.3	31.2
2	31.2	28.2	31.2	30.3	31.5	30.5	31.2	31.2	30.3	31.2	33.3	30.9
3	30.9	28.2	30.9	30.3	31.5	30.5	31.5	31.2	30.3	31.2	30.9	30.9
4	30.9	27.9	30.9	30.6	31.8	30.9	31.5	31.5	30.3	30.9	30.9	30.6
5	30.6	27.9	30.9	30.6	31.8	30.9	31.8	31.5	30.3	30.9	29.7	30.6
6	30.6	27.9	30.9	30.6	31.8	31.2	31.8	31.5	30.3	30.9	29.7	30.3
7	30.3	27.6	30.9	30.6	32.1	31.2	32.1	31.8	30.3	30.9	29.7	30.3
8	30.3	27.6	30.9	30.9	32.1	31.5	32.1	31.8	30.6	30.9	29.4	30.0
9	30.0	27.6	30.9	30.9	32.4	31.5	32.4	31.8	30.6	30.9	29.4	30.0
10	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.8	29.4	29.7
11	29.7	27.3	30.9	30.9	32.7	31.8	32.7	32.1	30.6	30.8	29.1	27.9
12	29.7	27.3	30.9	31.2	32.7	32.1	33.0	32.1	30.6	30.8	29.1	27.4
13	29.4	27.3	30.9	31.2	33.0	32.1	33.0	32.4	30.6	30.8	28.8	27.4
14	29.4	27.3	30.9	31.2	33.0	32.4	33.3	32.4	30.6	30.8	28.8	[illegible]
15	29.1	27.3	30.9	31.2	33.3	32.4	33.6	32.4	30.6	30.8	28.5	[illegible]
16	29.1	27.3	30.9	31.2	33.3	32.7	33.6	32.7	30.6	30.8	28.5	[illegible]
17	28.8	27.3	30.9	31.5	33.9	32.7	33.9	32.7	30.6	30.0	28.2	[illegible]
18	28.8	27.0	30.9	31.5	33.9	33.0	33.9	33.0	30.6	30.0	28.2	28.5
19	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	[illegible]

MEAN POSSIBLE MONTHLY DURATION OF SUNLIGHT IN THE NORTHERN HEMISPHERE EXPRESSED IN UNITS OF 12 HOURS

Northern Latitudes	January	February	March	April	May	June	July	August	September	October	November	December
20	28.5	27.0	30.9	31.5	33.0	33.3	34.2	33.3	30.6	30.0	27.9	28.2
21	28.2	27.0	30.9	31.5	33.0	33.3	34.5	33.3	30.6	29.9	27.9	28.2
22	28.2	26.7	30.9	31.8	34.2	33.9	34.5	33.3	30.6	29.7	27.9	27.9
23	27.9	26.7	30.9	31.8	34.2	33.9	34.8	33.6	30.6	29.7	27.9	27.9
24	27.9	26.7	30.9	31.8	34.5	34.2	34.8	33.6	30.6	29.7	27.3	27.9
25	27.9	26.7	30.9	31.8	34.5	34.2	35.1	33.6	30.6	29.7	27.3	27.3
26	27.6	26.4	30.9	32.1	34.8	34.5	35.1	33.6	30.6	29.7	27.3	27.3
27	27.6	26.4	30.9	32.1	34.8	34.5	35.4	33.9	30.9	29.7	27.0	27.3
28	27.3	26.4	30.9	32.1	35.1	34.8	35.4	33.9	30.9	29.4	27.0	27.3
29	27.3	26.1	30.9	32.1	35.1	34.8	35.7	33.9	30.9	29.4	26.7	26.7
30	27.0	26.1	30.9	32.4	35.4	35.1	36.0	34.2	30.9	29.4	26.7	26.4
31	27.0	26.1	30.9	32.4	35.4	35.1	36.0	34.2	30.9	29.4	26.4	26.4
32	26.7	25.8	30.9	32.4	35.7	35.4	36.3	34.5	30.9	29.4	26.4	26.1
33	26.4	25.8	30.9	32.7	35.7	35.7	36.3	34.5	30.9	29.1	26.1	25.9
34	26.4	25.8	30.9	32.7	36.0	36.0	36.6	34.8	30.9	29.1	26.1	25.8
35	26.1	25.5	30.9	32.7	36.3	36.3	36.9	34.8	30.9	29.1	25.8	25.5
36	26.1	25.5	30.9	33.0	36.3	36.6	37.5	34.8	30.9	29.1	25.8	25.2
37	25.8	25.5	30.9	33.0	36.9	36.9	37.5	35.1	30.9	29.1	25.5	24.9
38	25.5	25.2	30.9	33.0	36.9	37.2	37.8	35.1	31.2	28.8	25.2	24.9
39	25.5	25.2	30.9	33.3	36.9	37.2	37.8	35.4	31.2	28.8	25.2	24.6

TABLE 7.8

MEAN POSSIBLE MONTHLY DURATION OF SUNLIGHT IN THE NORTHERN HEMSPHERE EXPRESSED IN UNITS OF 12 HOURS

Northern Latitudes	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
40	25.2	24.9	30.9	33.3	37.5	37.5	38.1	35.4	31.2	28.8	24.9	24.2
41	24.9	24.9	30.9	33.3	37.5	37.8	38.1	35.7	31.2	28.8	24.9	24.0
42	24.6	24.6	30.9	33.6	37.8	38.1	38.4	35.7	31.2	28.5	24.9	23.7
43	24.3	24.6	30.6	33.6	37.9	38.4	38.7	36.0	31.2	28.5	24.3	23.1
44	24.3	24.3	30.6	33.6	38.1	38.7	38.7	36.3	31.2	28.5	24.3	23.0
45	24.0	24.3	30.6	33.9	38.4	38.7	39.3	36.3	31.2	28.2	23.7	22.5
46	23.7	24.0	30.6	33.9	38.7	39.0	39.6	36.3	31.2	28.2	23.7	22.2
47	23.1	24.0	30.6	34.2	39.0	39.0	39.9	37.0	31.5	27.9	23.4	21.9
48	22.0	23.7	30.6	34.2	39.3	39.6	40.2	37.0	31.5	27.9	23.1	21.9
49	22.9	23.7	30.6	34.5	39.3	41.2	40.8	37.2	31.5	27.9	22.8	21.3
50	22.2	23.4	30.6	34.5	39.9	40.8	41.1	37.5	31.8	27.9	22.8	21.0

TABLE 7.9

RUNOFF COEFFICIENTS

Surface Conditions	***Runoff Coefficient***
Grass Cover (slope):	
Sandy soil, flat 2%	0.05 - 0.10
Sand soil, average 2-7%	0.10 - 0.15
Sandy soil, steep, 7%	0.15 - 0.20
Heavy soil, flat 2%	0.13 - 0.17
Heavy soil, average 2-7%	0.18 - 0.22
Heavy soil, steep, 7%	0.25 - 0.35

Ref. Fenn et al. (1975)

TABLE 7.10

PROVISIONAL WATER HOLDING CAPACITIES WITH DIFFERENT COMBINATIONS OF SOIL AND VEGETATION

Soil Type	*Available Water*		*Root Zone*		*Applicable Soil Moisture Retention Table*	
	mm/m	*in/ft*	*m*	*ft*	*mm*	*in*
Shallow-Rooted Crops (spinach, peas, beans, beets, carrots, etc.)						
Fine Sand	100	1.2	.50	1 67	50	2.0
Fine Sandy Loam	150	1.8	.50	1.67	75	3.0
Silt Loam	200	2.4	.62	2.08	125	5.0
Clay Loam	250	3.0	.40	1.33	100	4.0
Clay	300	3.6	.25	.83	75	3.0
Moderately Deep-Rooted Crops (corn, cotton, tobacco, cereal grains)						
Fine Sand	100	1.2	.75	2.50	75	3.0
Fine Sandy Loam	150	1.8	1.00	3.33	150	6.0
Silt Loam	200	2.4	1.00	3.33	200	8.0
Clay Loam	250	3.0	.80	2.67	200	8.0
Clay	300	3.6	.50	1.67	50	6.0
Deep-Rooted Crops (alfalfa, pastures, shrubs)						
Fine Sand	100	1.2	1.00	3.33	100	4.0
Fine Sandy Loam	150	1.8	1.00	3.33	150	6.0
Silt Loam	200	2.4	1.25	4.17	250	10.0
Clay Loam	250	3.0	1.00	3.33	250	10.0
Clay	300	3.6	.67	2.22	200	8.0
Orchards						
Fine Sand	100	1.2	1.50	5.00	150	6.0
Fine Sandy Loam	150	1.8	1.67	5.55	250	10.0
Silt Loam	200	2.4	1.50	5.00	300	12.0
Clay Loam	250	3.0	1.00	3.33	250	10.0
Clay	300	3.6	.67	2.22	200	8.0
Closed Mature Forest						
Fine Sand	100	1.2	2.50	8.33	250	10.0
Fine Sandy Loam	150	1.8	2.00	6.66	300	12.0
Silt Loam	200	2.4	2.00	6.66	400	16.0
Clay Loam	250	3.0	1.60	5.33	400	16.0
Clay	300	3.6	1.17	3.90	350	14.0

These figures are for mature vegetation. Young cultivated crops, seedlings, and other immature vegetation will have shallower root zones and, hence, have less water available for the use of the vegetation. As the plant develops from a seed or a young sprout to the mature form, the root zone will increase progressively from only a few inches to the values listed above. Use of a series of soil moisture retention tables with successfully increasing values of available moisture permits the soil moisture to be determined throughout the growing season.

Annexure-VI

TABLE 7.11

SOIL MOISTURE RETENTION TABLE - 4 INCHES
SOIL MOISTURE RETAINED AFTER DIFFERENT AMOUNTS OF POTENTIAL EVAPOTRANSPIRATION HAVE OCCURED
WATER HOLDING CAPACITY OF ROOT ZONE OF SOIL IS 4 INCHES

PET	*Water Retained in Soil*									
	0.00	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*
0.0	4.00	3.99	3.98	3.97	3.96	3.95	3.94	3.93	3.92	3.91
0.1	3.90	3.89	3.88	3.87	3.86	3.85	3.84	3.83	3.82	3.81
0.2	3.80	3.79	3.78	3.77	3.76	3.75	3.74	3.73	3.72	3.71
0.3	3.70	3.69	3.68	3.67	3.66	3.65	3.64	3.63	3.62	3.62
0.4	3.61	3.60	3.59	3.58	3.57	3.56	3.55	3.54	3.54	3.53
0.5	3.52	3.51	3.50	3.49	3.48	3.47	3.46	3.46	3.45	3.44
0.6	3.43	3.42	3.41	3.40	3.39	3.38	3.38	3.37	3.36	3.35
0.7	3.34	3.33	3.32	3.31	3.30	3.30	3.29	3.28	3.27	3.26
0.9	3.26	3.25	3.24	3.23	3.23	3.22	3.21	3.20	3.19	3.19
0.9	3.18	3.17	3.16	3.16	3.15	3.14	3.13	3.12	3.12	3.11
1.0	3.10	3.09	3.09	3.08	3.07	3.06	3.05	3.05	3.04	3.03
1.1	3.02	3.02	3.01	3.00	2.99	2.98	2.98	2.97	2.96	2.95
1.2	2.94	2.94	2.93	2.92	2.91	2.90	2.90	2.89	2.88	2.87
1.3	2.86	2.86	2.85	2.84	2.83	2.82	2.82	2.81	2.80	2.79
1.4	2.79	2.78	2.77	2.76	2.75	2.75	2.74	2.73	2.73	2.72
1.5	2.72	2.71	2.70	2.70	2.69	2.68	2.68	2.67	2.66	2.66
1.6	2.65	2.64	2.64	2.63	2.62	2.62	2.61	2.60	2.60	2.59
1.7	2.58	2.58	2.57	2.57	2.56	2.55	2.54	2.54	2.53	2.52
1.8	2.51	2.51	2.50	2.49	2.49	2.48	2.48	2.47	2.47	2.46
1.9	2.45	2.45	2.44	2.43	2.43	2.42	2.41	2.40	2.40	2.39
2.0	2.39	2.38	2.38	2.37	2.36	2.36	2.35	2.35	2.34	2.34
2.1	2.33	2.33	2.32	2.32	2.31	2.30	2.29	2.29	2.28	2.28
2.2	2.27	2.27	2.26	2.25	2.25	2.24	2.24	2.23	2.22	2.22
2.3	2.21	2.21	2.20	2.19	2.19	2.18	2.18	2.17	2.16	2.16
2.4	2.15	2.15	2.14	2.14	2.13	2.13	2.12	2.12	2.11	2.11
2.5	2.10	2.10	2.09	2.09	2.08	2.08	2.07	2.07	2.06	2.06
2.6	2.05	2.05	2.04	2.04	2.03	2.03	2.02	2.02	2.01	2.01
2.7	2.00	2.00	1.99	1.99	1.98	1.98	1.97	1.97	1.96	1.96
2.8	1.95	1.95	1.94	1.94	1.93	1.93	1.92	1.89	1.91	1.91
2.9	1.90	1.90	1.89	1.89	1.88	1.88	1.87	1.87	1.86	1.86
3.0	1.85	1.85	1.84	1.84	1.83	1.83	1.82	1.82	1.81	1.81
3.1	1.80	1.80	1.79	1.79	1.78	1.78	1.78	1.77	1.77	1.76
3.2	1.76	1.75	1.75	1.74	1.73	1.73	1.72	1.72	1.71	1.71
3.3	1.71	1.70	1.70	1.69	1.69	1.69	1.68	1.68	1.67	1.67
3.4	1.67	1.66	1.66	1.65	1.65	1.65	1.64	1.64	1.63	1.63

TABLE 7.11

SOIL MOISTURE RETENTION TABLE - 4 INCHES
SOIL MOISTURE RETAINED AFTER DIFFERENT AMOUNTS OF
POTENTIAL EVAPOTRANSPIRATION HAVE OCCURED
WATER HOLDING CAPACITY OF ROOT ZONE OF SOIL IS 4 INCHES

	Water Retained in Soil									
PET	*0.00*	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*
3.5	1.63	1.62	1.62	1.61	1.61	1.61	1.60	1.60	1.59	1.59
3.6	1.59	1.58	1.58	1.57	1.57	1.57	1.56	1.56	1.55	1.55
3.7	1.55	1.54	1.54	1.53	1.53	1.53	1.52	1.52	1.51	1.51
3.8	1.51	1.50	1.50	1.49	1.49	1.49	1.48	1.48	1.47	1.47
3.9	1.47	1.46	1.46	1.45	1.45	1.45	1.44	1.44	1.43	1.43
4.0	1.43	1.42	1.42	1.41	1.41	1.41	1.40	1.40	1.40	1.39
4.1	1.39	1.39	1.38	1.38	1.38	1.37	1.37	1.37	1.36	1.36
4.2	1.36	1.35	1.35	1.35	1.34	1.34	1.34	1.33	1.33	1.33
4.3	1.32	1.32	1.32	1.31	1.31	1.31	1.30	1.30	1.30	1.29
4.4	1.29	1.29	1.28	1.28	1.28	1.28	1.27	1.27	1.27	1.26
4.5	1.26	1.26	1.25	1.25	1.25	1.25	1.24	1.24	1.24	1.23
4.6	1.23	1.23	1.22	1.22	1.22	1.22	1.21	1.21	1.21	1.20
4.7	1.20	1.20	1.19	1.19	1.19	1.19	1.18	1.18	1.18	1.17
4.8	1.17	1.17	1.16	1.16	1.16	1.16	1.15	1.15	1.15	1.14
4.9	1.14	1.14	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.11
5.0	1.11	1.11	1.10	1.10	1.10	1.10	1.09	1.09	1.09	1.09
5.1	1.08	1.08	1.08	1.07	1.07	1.07	1.07	1.06	1.06	1.06
5.2	1.05	1.05	1.05	1.04	1.04	1.04	1.04	1.03	1.03	1.03
5.3	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00	1.00	1.00
5.4	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
5.5	0.98	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.96
5.6	0.95	0.95	0.95	0.94	0.94	0.94	0.94	0.93	0.93	0.93
5.7	0.92	0.92	0.92	0.92	0.91	0.91	0.91	0.91	0.90	0.90
5.8	0.90	0.90	0.90	0.89	0.89	0.89	0.89	0.89	0.88	0.88
5.9	0.88	0.88	0.88	0.87	0.87	0.87	0.87	0.87	0.86	0.86
6.0	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.85	0.84	0.84
6.1	0.84	0.84	0.84	0.83	0.83	0.83	0.83	0.83	0.82	0.82
6.2	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.80	0.80	0.80
6.3	0.80	0.79	0.79	0.79	0.79	0.79	0.78	0.78	0.78	9.78
6.4	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.76	0.76

TABLE 7.11

SOIL MOISTURE RETENTION TABLE - 4 INCHES
SOIL MOISTURE RETAINED AFTER DIFFERENT AMOUNTS OF POTENTIAL EVAPOTRANSPIRATION HAVE OCCURED
WATER HOLDING CAPACITY OF ROOT ZONE OF SOIL IS 4 INCHES

Water Retained in Soil

0.00	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.06*	*0.07*	*0.08*	*0.09*
0.76	0.76	0.76	0.76	0.75	0.75	0.75	0.75	0.74	0.74
0.74	0.74	0.74	0.73	0.73	0.73	0.73	0.73	0.72	0.72
0.72	0.72	0.72	0.72	0.71	0.71	0.71	0.71	0.71	0.70
0.70	0.70	0.70	0.70	0.70	0.69	0.69	0.69	0.68	0.68
0.68	0.68	0.68	0.68	0.67	0.67	0.67	0.67	0.67	0.67
0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.65	0.65
0.65	0.65	0.65	0.64	0.64	0.64	0.64	0.64	0.54	0.63
0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.61
0.61	0.61	0.61	0.61	0.61	0.61	0.60	0.60	0.60	0.60
0.60	0.60	0.60	0.59	0.59	0.59	0.59	0.59	0.58	0.58
0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.57	0.57	0.57
0.57	0.57	0.57	0.57	0.57	0.56	0.56	0.56	0.56	0.56
0.56	0.56	0.56	0.55	0.55	0.55	0.55	0.55	0.55	0.55
0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.53	0.53
0.54	0.53	0.53	0.53	0.53	0.52	0.52	0.52	0.52	0.52

0.05	0.05		0.00	0.05		0.00	0.05
0.52	0.51	9.0	0.40	0.40	10.0	0.31	0.31
0.50	0.50	9.1	0.39	0.39	10.1	0.30	0.30
0.49	0.48	9.2	0.38	0.38	10.2	0.30	0.29
0.48	0.47	9.3	0.37	0.37	10.3	0.29	0.28
0.47	0.46	9.4	0.36	0.36	10.4	0.28	0.28
0.45	0.45	9.5	0.35	0.35	10.5	0.27	0.27
0.44	0.44	9.6	0.34	0.34	10.6	0.27	0.26
0.43	0.43	9.7	0.34	0.33	10.7	0.26	0.26
0.42	0.42	9.8	0.33	0.32	10.8	0.25	0.25
0.41	0.41	9.9	0.32	0.32	10.9	0.25	0.24

ANNEXURE VII

HELP MODEL SIMULATION PROFILE

SYRACUSE LANDFILL SEPTEMBER 6,1995

Layer Type	Thickness (inches)	Medium Type	Comment	
VPL	5	8 topsoil	VEGETATION	
LDL	10	2 sand	pipe	slope=2% Spacing 1000ft
BL	20	14 silty clay		
VPL	400	18 MSW		
LDL	10	2 sand	pipe	slope=2% spacing 100ft
BL	30	16 clay		

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**                                                                          **
**                                                                          **
**          HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                   **
**          HELP MODEL VERSION 3.01   (14 OCTOBER 1994)                     **
**             DEVELOPED BY ENVIRONMENTAL LABORATORY                        **
**               USAE WATERWAYS EXPERIMENT STATION                          **
**          FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                 **
**                                                                          **
**                                                                          **
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```

PRECIPITATION DATA FILE: D:\HELP3\data4.D4
TEMPERATURE DATA FILE: D:\HELP3\data7.D7
SOLAR RADIATION DATA FILE: D:\HELP3\data13.D13
EVAPOTRANSPIRATION DATA: D:\HELP3\DATA11.D11
SOIL AND DESIGN DATA FILE: D:\HELP3\data10.D10
OUTPUT DATA FILE: D:\HELP3\test.OUT

TIME: 14: 9 DATE: 9/ 6/1995

****

TITLE: syracuse landfill

****

NOTE: INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER ARE
COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.

LAYER 1

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 8
THICKNESS = 5.00 INCHES
POROSITY = 0.4630 VOL/VOL
FIELD CAPACITY = 0.2320 VOL/VOL
WILTING POINT = 0.1160 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.3861 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.369999994000E-03 CM/SEC
NOTE: SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY

FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

LAYER 2

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 2
THICKNESS = 10.00 INCHES
POROSITY = 0.4370 VOL/VOL
FIELD CAPACITY = 0.0620 VOL/VOL
WILTING POINT = 0.0240 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.1242 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.579999993000E-02 CM/SEC
SLOPE = 2.00 PERCENT
DRAINAGE LENGTH = 100.0 FEET

LAYER 3

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 14
THICKNESS = 20.00 INCHES
POROSITY = 0.0000 VOL/VOL

FIELD CAPACITY = 0.0000 VOL/VOL
WILTING POINT = 0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.249999994000E-04 CM/SEC
FML PINHOLE DENSITY = 0.00 HOLES/ACRE
FML INSTALLATION DEFECTS = 0.00 HOLES/ACRE
FML PLACEMENT QUALITY = 4 - POOR

LAYER 4

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 18
THICKNESS = 400.00 INCHES
POROSITY = 0.6710 VOL/VOL
FIELD CAPACITY = 0.2920 VOL/VOL
WILTING POINT = 0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.3028 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000005000E-02 CM/SEC

LAYER 5

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 2
THICKNESS = 10.00 INCHES
POROSITY = 0.4370 VOL/VOL
FIELD CAPACITY = 0.0620 VOL/VOL
WILTING POINT = 0.0240 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.3088 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.579999993000E-02 CM/SEC
SLOPE = 2.00 PERCENT
DRAINAGE LENGTH = 100.0 FEET

LAYER 6

TYPE 4 - FLEXIBLE MEMBRANE LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS = 30.00 INCHES
POROSITY = 0.0000 VOL/VOL
FIELD CAPACITY = 0.0000 VOL/VOL
WILTING POINT = 0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT = 0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND. = 0.100000001000E-06 CM/SEC
FML PINHOLE DENSITY = 0.00 HOLES/ACRE
FML INSTALLATION DEFECTS = 0.00 HOLES/ACRE
FML PLACEMENT QUALITY = 4 - POOR

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM
-AULT
SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
FAIR STAND OF GRASS, A SURFACE SLOPE OF 2.%
AND A SLOPE LENGTH OF 100. FEET.

SCS RUNOFF CURVE NUMBER = 80.40
FRACTION OF AREA ALLOWING RUNOFF = 100.0 PERCENT
AREA PROJECTED ON HORIZONTAL PLANE = 25.000 ACRES
EVAPORATIVE ZONE DEPTH = 15.0 INCHES
INITIAL WATER IN EVAPORATIVE ZONE = 3.173 INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE = 6.685 INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE = 0.820 INCHES
INITIAL SNOW WATER = 0.000 INCHES
INITIAL WATER IN LAYER MATERIALS = 127.380 INCHES
TOTAL INITIAL WATER = 127.380 INCHES
TOTAL SUBSURFACE INFLOW = 0.00 INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM

SYRACUSE NEW YORK

MAXIMUM LEAF AREA INDEX = 3.00
START OF GROWING SEASON (JULIAN DATE) = 124
END OF GROWING SEASON (JULIAN DATE) = 284
AVERAGE ANNUAL WIND SPEED = 9.70 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY = 72.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY = 68.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY = 75.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY = 76.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING

COEFFICIENTS FOR SYRACUSE NEW YORK

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.61	2.65	3.11	3.34	3.16	3.63
3.76	3.77	3.29	3.14	3.45	3.20

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING

COEFFICIENTS FOR SYRACUSE NEW YORK

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
22.80	24.00	33.30	46.10	57.00	66.30
70.90	69.30	62.10	51.30	40.60	28.30

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING

COEFFICIENTS FOR SYRACUSE NEW YORK

STATION LATITUDE = 43.07 DEGREES

HEAD #1: AVERAGE HEAD ON TOP OF LAYER 3
DRAIN #1: LATERAL DRAINAGE FROM LAYER 2 (RECIRCULATION AND COLLECTION)
LEAK #1: PERCOLATION OR LEAKAGE THROUGH LAYER 3
HEAD #2: AVERAGE HEAD ON TOP OF LAYER 6
DRAIN #2: LATERAL DRAINAGE FROM LAYER 5 (RECIRCULATION AND COLLECTION)
LEAK #2: PERCOLATION OR LEAKAGE THROUGH LAYER 6

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                    DAILY OUTPUT FOR YEAR   1
------------------------------------------------------------------------------
      S
 DAY A O RAIN RUNOFF  ET  E. ZONE  HEAD    DRAIN    LEAK
HEAD    DRAIN   LEAK
     I I               WATER    #1      #1      #1      #2      #2      #2
     R L  IN.   IN.   IN.  IN./IN.   IN.     IN.     IN.     IN.     IN.     IN.
 --- - - ----- ------ ------ ------- --------- --------- --------- --------- --------- ---------

   1 * *  0.00 0.000 0.021 0.2102   0.0000 .0000E+00 .0000E+00   6.6855
.2303E-01 .3402E-02
   2 * *  0.00 0.000 0.000 0.2101   0.0000 .0000E+00 .0000E+00   6.9587
.2422E-01 .3402E-02
   3 * *  0.00 0.000 0.000 0.2101   0.0000 .0000E+00 .0000E+00   7.2272
.2542E-01 .3402E-02
   4 * *  0.00 0.000 0.000 0.2101   0.0000 .0000E+00 .0000E+00   7.4905
.2662E-01 .3402E-02
   5 * *  0.00 0.000 0.000 0.2101   0.0000 .0000E+00 .0000E+00   7.7481
.2781E-01 .3402E-02
   6 * *  0.05 0.000 0.032 0.2101   0.0000 .0000E+00 .0000E+00   7.9999
.2900E-01 .3402E-02
   7 * *  0.03 0.000 0.026 0.2101   0.0000 .0000E+00 .0000E+00   8.2457
.3018E-01 .3402E-02
   8 * *  0.06 0.000 0.026 0.2101   0.0000 .0000E+00 .0000E+00   8.4856
.3136E-01 .3402E-02
```

364   0.02 0.000 0.022 0.1600   0.0003 .3728E-07 .3290E-02   8.7682
.3276E-01 .3402E-02
365   0.00 0.000 0.031 0.1581   0.0004 .4259E-07 .2037E-02   8.8835
.3335E-01 .3402E-02
366   0.19 0.000 0.038 0.1672   0.0007 .1870E-06 .8366E-02   9.0182
.3403E-01 .3402E-02

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MONTHLY TOTALS (IN INCHES) FOR YEAR 20

JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV
JUN/DEC

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PRECIPITATION 4.08 1.42 4.20 2.88 5.20 3.91
2.47 5.78 6.65 2.14 2.53 2.58

RUNOFF 1.979 1.891 3.863 0.940 0.000 0.002
0.000 0.286 0.237 0.000 0.000 0.000

EVAPOTRANSPIRATION 0.511 0.459 1.133 2.469 4.441 4.349
1.855 3.877 4.107 2.004 0.880 0.799

LATERAL DRAINAGE COLLECTED 0.0000 0.0000 0.0000 0.0007
0.0003 0.0000
FROM LAYER 2 0.0000 0.0017 0.0006 0.0001 0.0004 0.0005

PERCOLATION THROUGH 0.0000 0.0000 0.0000 0.7239 1.3529
0.1513
LAYER 3 0.0000 1.1458 1.6934 0.5029 1.5404 1.7630

LATERAL-DRAINAGE COLLECTED 0.[illegible] 0.3303 0.2606 0.1768
0.2831 0.5077
FROM LAYER 5 0.3990 0.2801 0.4306 0.7485 0.8077 0.9840

PERCOLATION THROUGH 0.1089 0.0952 0.1054 0.1020 0.1054
0.1020

LAYER 6 0.1054 0.1054 0.1020 0.1054 0.1020 0.1054

MONTHLY SUMMARIES FOR DAILY HEADS (INCHES)

AVERAGE DAILY HEAD ON 0.000 0.000 0.000 0.005 0.005
0.001
LAYER 3 0.000 0.013 0.008 0.002 0.006 0.007

STD. DEVIATION OF DAILY 0.000 0.000 0.000 0.022 0.008 0.001
HEAD ON LAYER 3 0.000 0.064 0.011 0.003 0.007 0.009

AVERAGE DAILY HEAD ON 5.171 3.758 2.705 1.851 2.912
5.173
LAYER 6 4.070 2.909 4.460 6.911 7.550 8.562

STD. DEVIATION OF DAILY 0.000 0.333 0.286 0.218 0.846 0.447
HEAD ON LAYER 6 0.395 0.281 0.878 0.843 0.427 0.251

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ANNUAL TOTALS FOR YEAR 20

	INCHES	CU. FEET	PERCENT
PRECIPITATION	43.84	3978480.000	100.00
RUNOFF	9.196	834557.375	20.98
EVAPOTRANSPIRATION	26.884	2439706.750	61.32
DRAINAGE COLLECTED FROM LAYER 2	0.0043	388.947	0.01
PERC./LEAKAGE THROUGH LAYER 3	8.873645	805283.250	20.24
AVG. HEAD ON TOP OF LAYER 3	0.0038		

DRAINAGE COLLECTED FROM LAYER 5 5.7501 521823.719
13.12

PERC./LEAKAGE THROUGH LAYER 6 1.244986 112982.461
2.84

VG. HEAD ON TOP OF LAYER 6 4.6693

CHANGE IN WATER STORAGE 0.761 69020.898 1.73

SOIL WATER AT START OF YEAR 126.662 11494588.000

SOIL WATER AT END OF YEAR 128.216 11635629.000

SNOW WATER AT START OF YEAR 0.794 72019.914 1.81

SNOW WATER AT END OF YEAR 0.000 0.000 0.00

ANNUAL WATER BUDGET BALANCE 0.0000 0.022 0.00

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH
20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.78	2.52	2.97	3.04	3.14	3.31
	3.50	4.09	3.50	3.04	3.33	3.25
STD DEVIATIONS	0.74	0.83	1.22	1.08	1.24	1.29
	1.30	2.25	1.46	1.01	0.90	0.71

RUNOFF

TOTALS	1.662	1.482	2.706	0.712	0.056	0.008
	0.004	0.036	0.044	0.007	0.027	0.429
STD. DEVIATIONS	1.174	1.010	1.750	0.655	0.206	0.019
	0.009	0.078	0.101	0.018	0.093	0.525

EVAPOTRANSPIRATION

TOTALS	0.599	0.601	1.670	2.367	3.032	3.421
	3.284	2.753	2.856	1.649	0.984	0.594
STD. DEVIATIONS	0.101	0.189	0.296	0.516	0.954	0.892
	1.275	1.144	0.774	0.272	0.149	0.102

LATERAL DRAINAGE COLLECTED FROM LAYER 2

TOTALS	0.0000	0.0000	0.0001	0.0006	0.0004	0.0002
	0.0000	0.0008	0.0007	0.0006	0.0014	0.0005
STD. DEVIATIONS	0.0000	0.0000	0.0002	0.0014	0.0012	0.0006
	0.0001	0.0012	0.0019	0.0012	0.0025	0.0007

PERCOLATION/LEAKAGE THROUGH LAYER 3

TOTALS	0.0000	0.0000	0.0516	0.8319	0.6668	0.3282
	0.0707	0.8344	0.7621	0.7481	1.9097	1.3148
STD. DEVIATIONS	0.0000	0.0000	0.1739	0.9314	0.7287	0.4930
	0.1631	1.0981	0.7881	0.6991	0.8031	1.0145

LATERAL DRAINAGE COLLECTED FROM LAYER 5

TOTALS	0.9221	0.6930	0.5497	0.3964	0.4609	0.4916
	0.4151	0.3411	0.3674	0.4744	0.5605	0.7350
STD. DEVIATIONS	0.3339	0.3560	0.3075	0.2014	0.1624	0.2193
	0.1889	0.1481	0.1638	0.3216	0.3569	0.3015

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.1063	0.0952	0.1054	0.1020	0.1054	0.1020
	0.1054	0.1054	0.1020	0.1054	0.1020	0.1054
STD. DEVIATIONS	0.0015	0.0001	0.0000	0.0000	0.0000	0.0000

0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ACROSS LAYER 3

AVERAGES 0.0000 0.0000 0.0004 0.0060 0.0041 0.0018
0.0004 0.0061 0.0071 0.0054 0.0147 0.0058

STD. DEVIATIONS 0.0000 0.0000 0.0014 0.0115 0.0092 0.0042
0.0010 0.0087 0.0174 0.0093 0.0246 0.0050

DAILY AVERAGE HEAD ACROSS LAYER 6

AVERAGES 8.1986 7.0694 5.1681 4.0214 4.5303 4.9140
4.0977 3.4283 3.7735 4.5066 5.3829 6.6897

STD. DEVIATIONS 2.5807 3.3301 2.4814 1.8559 1.4183 1.7893
1.6307 1.3794 1.5580 2.6934 3.0258 2.2918

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 20

	INCHES	CU. FEET	PERCENT
PRECIPITATION	38.47 (4.560)	3491243.2	100.00
RUNOFF	7.172 (1.9185)	650815.75	18.641
EVAPOTRANSPIRATION	23.809 (2.5220)	2160657.75	61.888
LATERAL DRAINAGE COLLECTED FROM LAYER 2	0.00525 (0.00406)	476.308	0.01364

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 20

	(INCHES)	(CU. FT.)
PITATION	2.61	236857.484
FF	3.973	360545.6870
AGE COLLECTED FROM LAYER 2	0.00647	586.76221
OLATION/LEAKAGE THROUGH LAYER 3	0.850400	
0		
GE HEAD ACROSS LAYER 3	2.050	
AGE COLLECTED FROM LAYER 5	0.05011	4547.19238
OLATION/LEAKAGE THROUGH LAYER 6	0.003402	
GE HEAD ACROSS LAYER 6	14.513	
WATER	4.85	440525.1250
UM VEG. SOIL WATER (VOL/VOL)	0.2733	
UM VEG. SOIL WATER (VOL/VOL)	0.0326	

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PERCOLATION/LEAKAGE THROUGH 7.51827 (2.37563) 682283.000
19.54269
FROM LAYER 3

AVERAGE HEAD ACROSS TOP 0.004 (0.003)
OF LAYER 3

LATERAL DRAINAGE COLLECTED 6.40729 (2.00746) 581461.937
16.65487
FROM LAYER 5

PERCOLATION/LEAKAGE THROUGH 1.24243 (0.00143) 112750.945
3.22954
FROM LAYER 6

AVERAGE HEAD ACROSS TOP 5.148 (1.443)
OF LAYER 6

CHANGE IN WATER STORAGE -0.164 (2.0102) -14919.14 -0.427

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FINAL WATER STORAGE AT END OF YEAR 20

LAYER	(INCHES)	(VOL/VOL)
1	1.3463	0.2693
2	1.1677	0.1168
3	0.0000	0.0000
4	117.5419	0.2939
5	4.0364	0.4036
6	0.0000	0.0000

SNOW WATER 0.000

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CALCULATING LEACHATE CONTAMINANT CONCENTRATION

Averaged over 6 month leachate production period
Total percolation = 60cm

Cell	Total Moisture Loading (l/kg) Before	After	Amount Chloride Leached (mg/kg) Δ	Total	Chloride Concentration in Leachate(mg/l)
A	0.0	0.33	700	700	2,120
B	0.5	0.83	360	1,250	3,210
C	1.5	1.83	70	1,060	3,790
D	2.5	2.83	190	1,320	4,000

Annexure VIII

CALCULATING LEACHATE CONTAMINANT CONCENTRATION

Averaged over 6 month leachate production period
Total percolation = 60cm

Cell	Total Moisture Loading (l/kg) Before	After	Amount Chloride Leached (mg/kg) Δ	Total	Chloride Concentration in Leachate(mg/l)
A	0.0	0.33	700	700	2,120
B	0.5	0.83	360	1,250	3,210
C	1.5	1.83	70	1,060	3,790
D	2.5	2.83	190	1,320	4,000

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