CHAPTER 8

RECOMMENDATIONS

The results of this modeling and validation effort in combination with literature reviewed and the study of full-scale leachate recirculation experiments led to the following recommendations for the direction of future research.

8.1 Waste Hydraulic Properties

Accurate assessment of the hydraulic properties of waste is crucial to further modeling efforts and LRS design and operation. Several areas in particular require focused research efforts.

Future waste permeability studies should focus on determining the variation in waste permeability as well as mean permeabilities. Multiple samples or measurements should be taken to develop a statistically significant representation of the permeability distribution. Collection of this information should be directed at quantifying waste heterogeneities and assessing anisotropic conditions within the waste mass. It is logical

that landfill operations, placement and compaction of thin waste layers, will result in higher lateral permeabilities which is attractive from the perspective of increasing the impact area of LRSs. Determination of the magnitude of the variation between the vertical and lateral permeability would greatly aid in LRS design and prevention of lateral seeps.

Additionally, other waste characteristics which could be used to estimate permeability should be collected in conjunction with the permeability data. At a minimum, waste density should be recorded for each sample tested. If in-situ tests are used, some effort should be made to estimate local density. Additional information which would be beneficial but may require excessive data collection efforts includes waste composition and particle size distribution. Finally, while it is recognized that compaction increases density and decreases permeability, no quantitative information on this relationship is available for solid waste. Compaction is a major focus of most landfill operations and its effect on waste permeability and thus leachate routing should be determined.

Preferential flow and leachate channeling will have a profound effect on LRS design and operation and the loading of LCS by precipitation events as well as LRS operations. Several research efforts in Canada have developed preliminary information on preferential flow paths in MSW (Zeiss and Major, 1992, Zeiss and Uguccioni, 1994, Zeiss and Uguccioni, 1997). These studies were laboratory studies which developed information on pore size and utilized flow area. Future laboratory studies need to be directed at determining the maximum, minimum, and mean channel diameters, the

characteristic length of the flow channels, and information on the interconnection of flow channels. These studies also need to assess the transport of leachate from the channels into the waste mass. In addition to more accurate hydraulic analysis, this information would be helpful in determining changing leachate characteristics due to leaching of chemical compounds from the waste mass. Attention should also be give to developing factors to scale up this information from the laboratory to full-scale applications. The measurement of changes in the waste mass moisture content would provide important information but, at this time the equipment available is generally designed for soil applications and does not convert well to the landfill environment. Once this information is developed for application to full-scale sites it could be verified in part through accurate monitoring of leachate application and arrival rates and changes in leachate chemistry.

8.2 Modeling Efforts

This research effort conducted a rigorous application of unsaturated groundwater flow modeling techniques to solid waste. This approach may not be the most efficient or conceptually accurate technique for modeling leachate movement in waste. The incorporation of unsaturated flow behavior into future modeling efforts will no doubt be necessary but, the rigorous, numerically intensive treatment conducted for the purposes of this project may be overkill in some respects and insufficient or unrealistic in others.

The specific weaknesses of this model which should be addressed before SUTRA or other saturated/unsaturated flow models are employed in this capacity are:

- reducing the long simulation times due in part to the numerically intensive nature of large-scale unsaturated flow modeling,

- quantifying the variations in hydraulic properties,

- resolving the conflict between the simulation of specific storativity and unsaturated flow characteristics, and

- developing techniques to model the driving forces of channeled flow.

It is this researcher's recommendation that future hydraulic modeling efforts be divided into two categories,

1. numerically intensive simulations directed at assessing the many parameters and their variation over time, and

2. 'desktop' models directed at assessing the effect of design and operational changes on overall leachate routing, LCS impacts, which can be easily and quickly run on desktop computers.

The numerically intensive models, should include as inputs the variation in waste permeability, location and hydraulic properties of cover materials, degree of preferential flow, and the location of hydraulically significant landfill components such as gas

collection devices. Most of these inputs require knowledge of either the site to be

modeled or further research into the hydraulic properties of solid waste. The challenge to

model developers is to link the processes of Darcian flow, unsaturated flow, and flow

channeling. Each of these cases can be handled individually but, bringing them together

into one model will be difficult.

Three methods have been identified which may be used individually or in some

combination to develop more accurate models. A fluid dispersion approach could be

used to model unsaturated flow phenomenon. The fluid dispersion approach treats

unsaturated flow as analogous to solute dispersion. This approach simplifies some of the

numerical complexity and reduces the impact of some of the non-linearities intrinsic to

unsaturated flow. The modeling of preferential flow could be accomplished using a

macro/micro pore technique which has been applied to modeling flow through fractured

media. In this technique, fractured characteristics or macro-pores are assigned to certain

model elements. This technique will require some modifications as it has been developed

for application to impermeable media. In a fractured impermeable media, flow occurs

only through the channels however, in a fractured permeable media some of the liquid

moving through the fractures or flow channels will be absorbed into the media.

Quantification of this effect will be important to modeling efforts. Studies of leakage in

clay barriers due to freeze/ thaw fractures may yield some guidance in this area. The

final modeling technique which should be investigated is a decision tree approach to

assessing liquid movement. This approach would require an accurate accounting of all

the different processes affecting leachate movement, such as those shown in Figure 8.2.1.

Each process could then be analyzed separately and ultimately, these processes would be super-imposed to develop bulk leachate flow data.
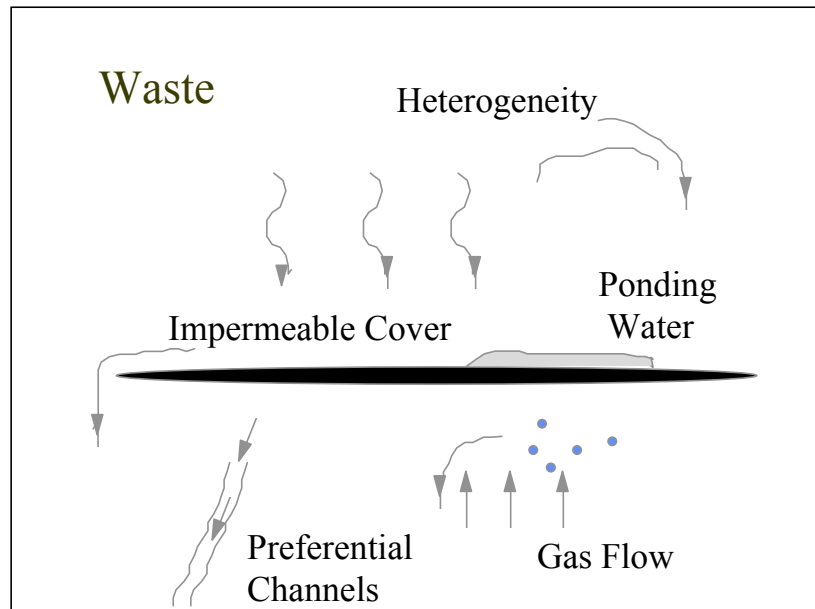

Figure 8.2.1. Theoretical leachate movement and storage processes.

The 'desktop' models should be based on results from both the numerically intensive modeling efforts and field studies but should be aimed at simplicity of use and minimal complexity. These models would produce information such as device spacing, impact areas, and maximum application rates. Designers and operators should be able to use these models to produce quick, rough-cut information on how design and operational

changes will impact system behavior. These models may incorporate a complexity

hierarchy where basic systems can be analyzed first and then additional complexities can

be slowly incorporated. The steps which may be included in the complexity hierarchy

are:

1. analysis of device spacing, application rate, and homogeneous, isotropic waste

    properties,

2. analysis of the effect of daily cover material and gas collection devices on

    step one results, and

3. analysis of the effect of complex waste properties such as anisotropies,

    heterogeneities, and preferential flow on step two results.

These models could be based on either the decision tree technique discussed above or a

simplified finite-element or finite difference model.

8.3 Field Studies

Field studies are imperative to promoting leachate recirculation. Field studies

provide invaluable operational information and site data which can be used to calibrate

and develop leachate routing models. Unfortunately, the funding for solid waste research

has dropped significantly over the last several years and the equipment and monitoring

costs associated with conducting a rigorous field-study can be high and are seldom within the budget of a solid waste facility.

Accurate assessment of the initial waste conditions including moisture content and composition should be included in future studies. Knowledge of these two conditions will enable calculation of the moisture storage capacity of the waste which will be useful when calculating leachate mass balances. Operators should be instructed to remove, breach, or evenly distribute materials such as plastic sheeting and roofing materials which may impede or re-route leachate flows. The goal of this effort should be to normalize the hydraulic characteristics of the waste mass to some degree and ensure that measurement equipment is not blinded by impermeable materials.

Monitoring of the waste moisture content is of invaluable use but requires that data be gathered frequently and a fairly high sensor density (perhaps a spacing of no more than 3 m (10 ft)), employed to accurately characterize leachate movement. Additionally, the sensors currently available for monitoring moisture content were designed for use in soil systems with the sensor in intimate contact with the soil matrix. A calibration curve must be develop prior to sensor installation which relates sensor output to soil moisture content. Solid waste systems will have difficulty guaranteeing intimate contact and developing calibration curves which are characteristic of the entire waste mass. The development of sensors more applicable to solid waste systems from the perspective of data generation and durability would significantly benefit future studies. The moisture sensors fabricated by the Yolo County project, consisting of perforated PVC packed with gravel, are a positive effort in this direction.

The application of leachate should be closely monitored. Daily application rates reported should include the rate and duration of leachate application. The use of a consistent application routine will also aid in the analysis of the data generated. Infrequent, irregular leachate application makes it difficult to analyze the data generated and to develop correlations with other parameters such as leachate generation. The measurement of leachate injection pressure at the pump or distribution manifold and in the recirculation device may provide useful information on device clogging and gas pressure effects. Pressures should be measured before, during, and for a period of time after pumping.

One of the most frequent concerns associated with leachate recirculation is that it will result in an excessive threat to groundwater due to increased heads on the liner. Future leachate recirculation studies should give particular attention to monitoring the LCS in order to put these suspicions to rest. Monitoring of the LCS should include measurement or estimation of head on the liner and leachate production rates, durations, and volumes on a per pipe basis. Collection of this information will provide quantitative information on the effect of leachate recirculation on the LCS, leachate arrival rates, and bulk leachate routing.

The final item future field studies should address is measurement frequency. Manual data collection, usually conducted hourly or daily, may miss important system changes. Automated data collection has been hampered in the past by the large amount of data generated and the subsequent storage, processing, and analysis requirements. Fortunately, recent years have seen significant advances in data storage with the

evolution of file compression technology and high-density removable media drives. Also, processor speed is continuously increasing and most data analysis programs support automated operation at some level. The combination of these technological advances enables the collection and processing of large volumes of data with minimal human labor. Data interpretation will still require human input but the time consuming processes of data analysis can be automated. The exact time scale of data collection will vary from project to project but, it should be cautioned that once a data collection opportunity is missed it cannot be recovered.