CHAPTER 5

VERIFICATIONAL MODELING RESULTS

In Chapter 4, the effects of many parameters, including application rate and frequency, waste permeability characteristics, and daily cover permeability, on the behavior of leachate recirculation systems were studied. The ability to develop predictions and evaluate a variety of different scenarios without the effort and expense of physical experimentation is a great strength of mathematical models. However, it is crucial to remember that mathematical models are idealized representations of physical processes and as such are driven by assumptions and available input data. In order to validate and assess a model's predictive capabilities it is necessary to verify the model results through comparison with field studies.

In order to evaluate the abilities of the modified form of SUTRA, data were collected from four sites operating leachate recirculation systems; the Mill Seat Landfill, New York, the Delaware Solid Waste Authority's Leachate Recirculation Test Cell, the Yolo County Controlled Landfill Demonstration Project, California, and the UCF/EPA Leachate Recirculation Test Cell, Orange County Landfill, Florida. The data were first analyzed for applicability and usefulness. Then, the site recirculation system and operational procedures were modeled in an attempt to verify model estimations. A description of these sites and the accompanying modeling effort follows.

5.1 Mill Seat Landfill, Monroe County, New York.

The goal of the Mill Seat Landfill leachate recirculation project was to design, construct and operate a functional leachate recirculation and gas collection system and demonstrate the feasibility of enhancing methane gas production at an operating landfill. The project is being conducted at the Mill Seat Landfill, Monroe County, New York. Monroe County is located in western New York on the southern shore of Lake Ontario.

System schematics and collected data for this project were provide courtesy of Clark, Patterson, Associates, 1997.

The project consists of three hydraulically separated cells, a 3-hectare (7.6-ac) control cell (gas collection only), a 2.8-ha (6.9-ac) cell recirculating leachate through pressurized loops, and a 2.2-ha (5.4-ac) cell recirculating leachate through deep horizontal trenches. The pressurized loop system consists of six pressurized loops constructed from 10-cm (4-in) perforated pipe installed in trenches filled with highly permeable materials including crushed cullet and tire chips. The loops have been installed at two different elevations, three loops at each elevation, to enhance wetting. The deep trench system consists of three trenches (1.3 m (4 ft) wide by 3 m (10 ft) deep) filled with permeable wastes. These trenches have been topped with prefabricated infiltrators to enhance drainage. The trenches are fed by tanker trucks which discharge into chimneys constructed through the waste layers above the trench.

Leachate routing was to be monitored via gypsum blocks installed at three elevations within the fill. However, the blocks were prematurely wetted during filling and have not yielded any data. Leachate mass balances were collected for all three test cells and will be used to validate fluid budgets generated by the modeling process.

The waste mass permeability used for these simulations was 10^{-2} cm/s with a compressibility of $2\text{x}10^{-6}$ $\text{m}\cdot\text{s}^2/\text{kg}$. This permeability was selected based on analysis of the leachate application and generation data. These data indicated that during the first eleven months of operation (August 1995 through June 1996), leachate was generated at almost exactly the same rate as leachate was applied, virtually no leachate storage occurred. During this time period, leachate injection rates were very low, averaging 1.7 l/m of loop/day and 12 l/m of trench/day for the pressure loop and deep trench systems, respectively. After June 1996, leachate application rates were significantly increased when supplemental liquid was supplied from the control cell and stormwater. Oddly, this increased application did not result in a significant increase in leachate generation which suggests leachate storage. The modeling results presented below cover the June 1996 through August 1996 time period, one month of low leachate application rates followed by two months of higher application rates. Predicted and measured leachate generation rates are presented as well as simulation mass balance results.

5.1.1 Pressurized Leachate Recirculation Loops

The pressurized recirculation loops were modeled using a1-m thick cross section with leachate application occurring at waste heights of 8.0 and 15.5 m. One-half of the loop cross section was modeled based on the results generated from the modeling of the horizontal trench.

Figure 5.1.1 presents the predicted and measured leachate generation results as a function of time for a waste mass with a permeability of 10^{-2} cm/s. The predicted and measured values parallel each other closely until approximately the thirtieth day of simulation. After thirty days, the results begin to diverge, most likely due to increased storage resulting from the higher application rates forcing leachate into areas of the waste mass which had not previously been impacted.

The Mill Seat data indicated that leachate production was fairly constant and essentially independent of leachate application rates. This behavior could be the result of preferential routing effects and flow inhibition by daily cover materials which were not modeled in this simulation. The low initial injection rates may have resulted in little flow out of the channels and into the waste mass. This behavior indicates that leachate recirculation systems will impact the most waste when operated at higher application rates. Daily cover materials may also have had an effect on the leachate arrival behavior. Low permeability materials in particular would decrease vertical flow rates and increase lateral movement resulting in more of the waste being impacted and increasing storage within the waste mass. Information on the location and characteristics of the daily cover materials was not available from the site which makes it impossible to comment definitively on the impact of the daily cover materials.

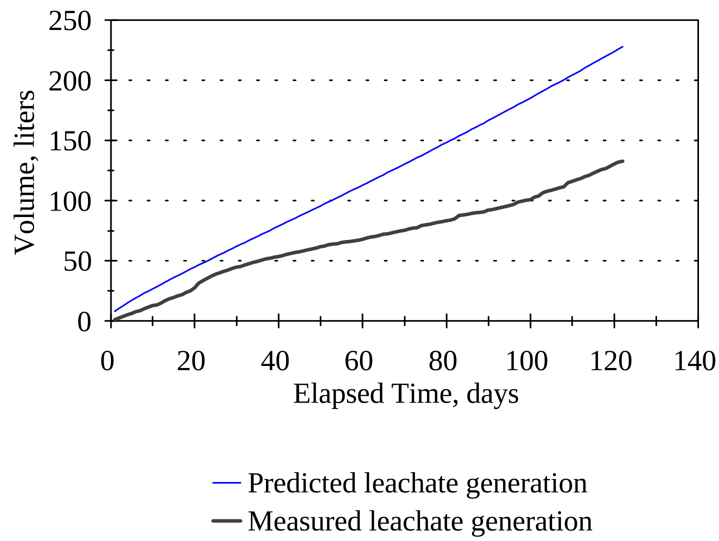


Figure 5.1.1. Predicted and measured leachate generation rates for the Mill Seat pressurized leachate recirculation loop system.

Figures 5.1.2 through 5.1.7 present saturation iso-clines for the Mill Seat Landfill pressure loop recirculation system simulations over the 120-day period modeled at 10-day intervals. It is interesting to observe in these figures the movement of the zones of increased saturation resulting from leachate application. The zones of increased saturation are discrete until the 90th day of simulation, see Figure 5.1.6. At this time, application rates increased to a point where leachate was driven upwards and outwards from the pressure loops. It should also be noted that for the high permeability (10^{-2} cm/s) homogeneous waste mass modeled, the increase in application rates by nearly an order of magnitude significantly increased the area impacted but did not cause saturated condition to develop in the waste mass. Overall, the waste mass saturation increased at most 50 percent (from 0.4 to 0.6).

The buildup of a zone of increased saturation directly above the sand layer of the LCS (permeability = 7.3×10^{-3} cm/s) implies that the filter layer of the LCS should have a permeability greater than or equal to the permeability of the waste mass to prevent the build up of leachate above the LCS and the movement of leachate along the LCS which may ultimately result in seep problems.

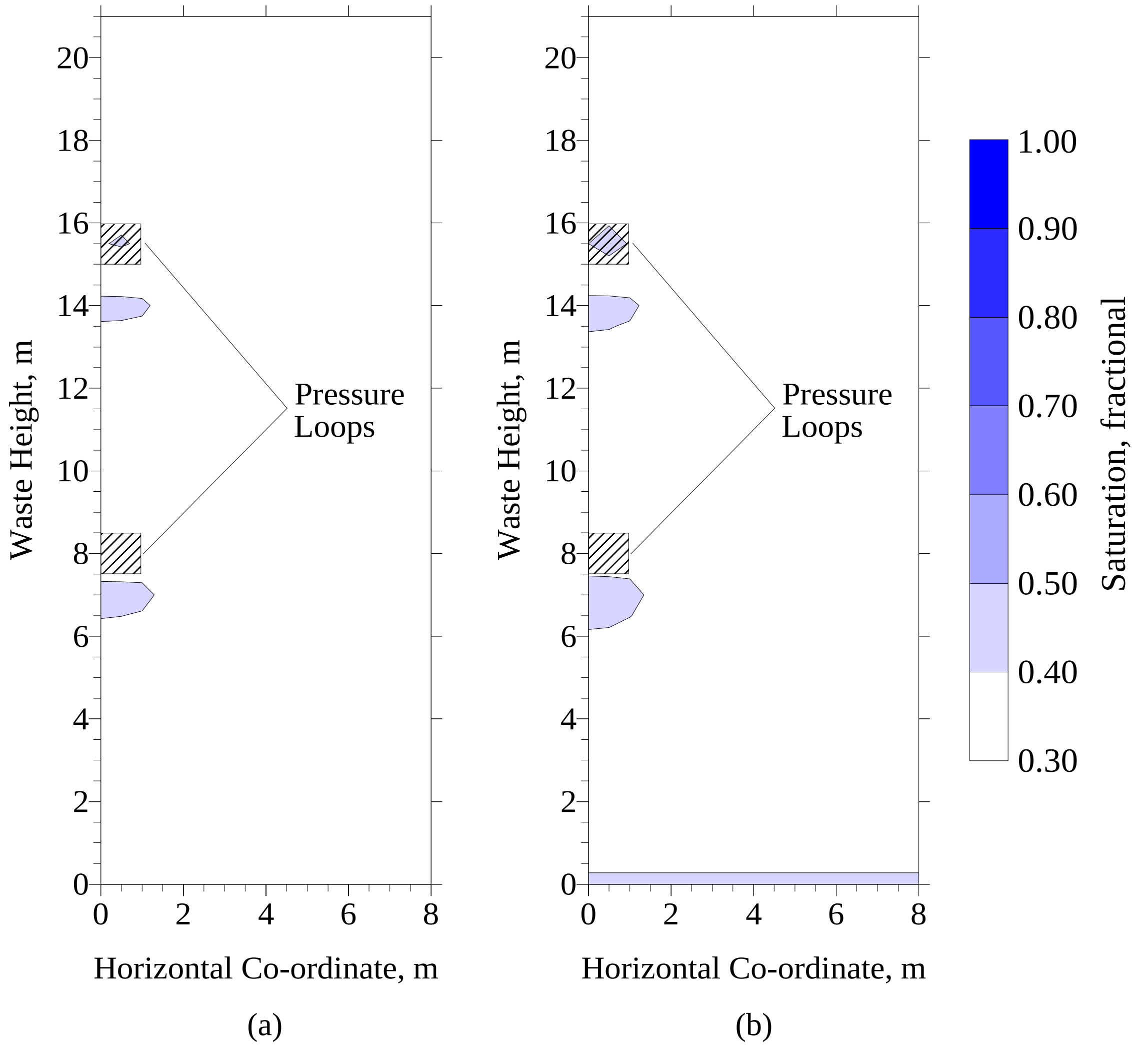


Figure 5.1.2. Saturation iso-clines for the Mill Seat Landfill pressure loop leachate recirculation system at elapsed times of 10 (a) and 20 (b) days.

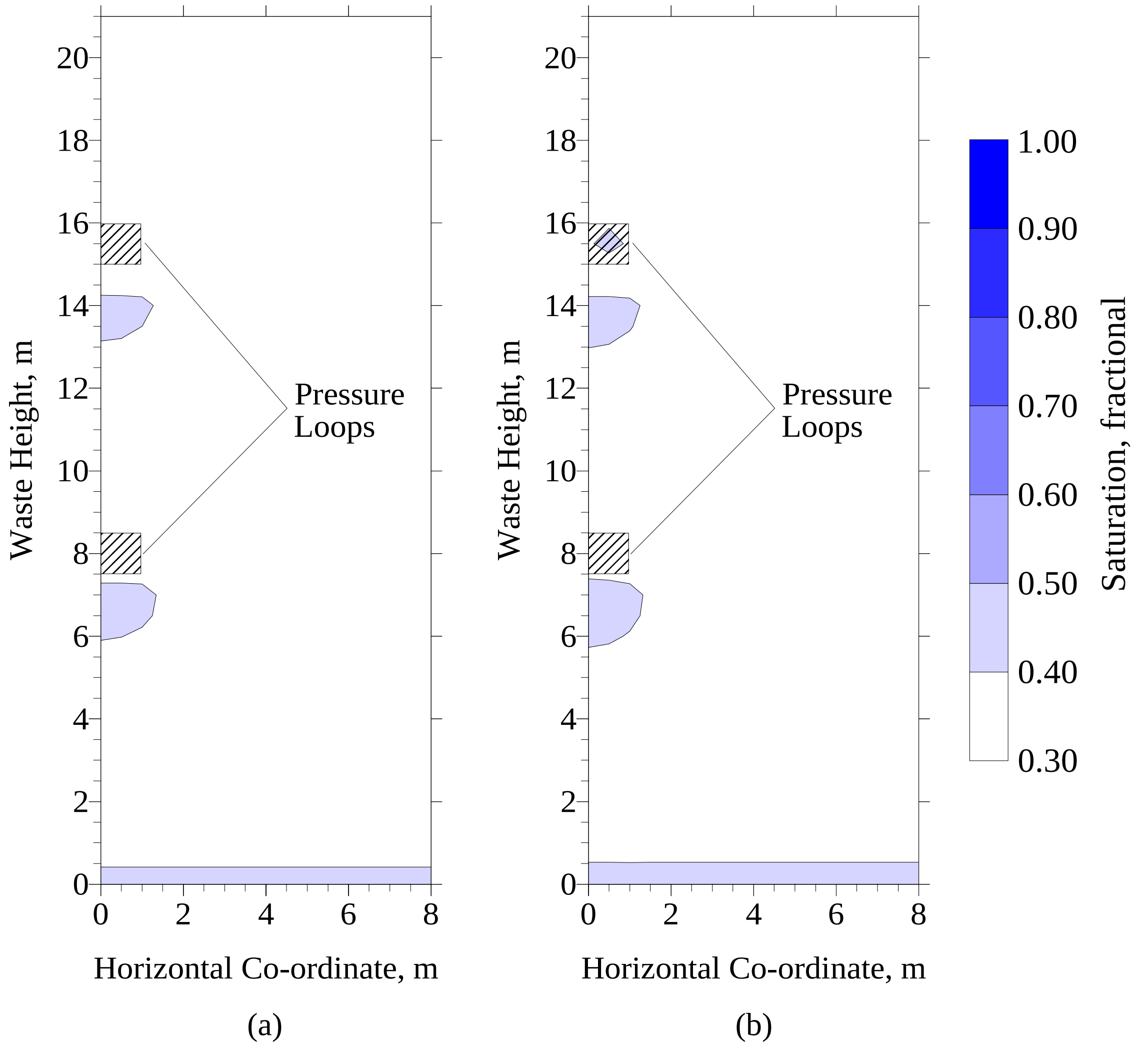


Figure 5.1.3. Saturation iso-clines for the Mill Seat Landfill pressure loop leachate recirculation system at elapsed times of 30 (a) and 40 (b) days.

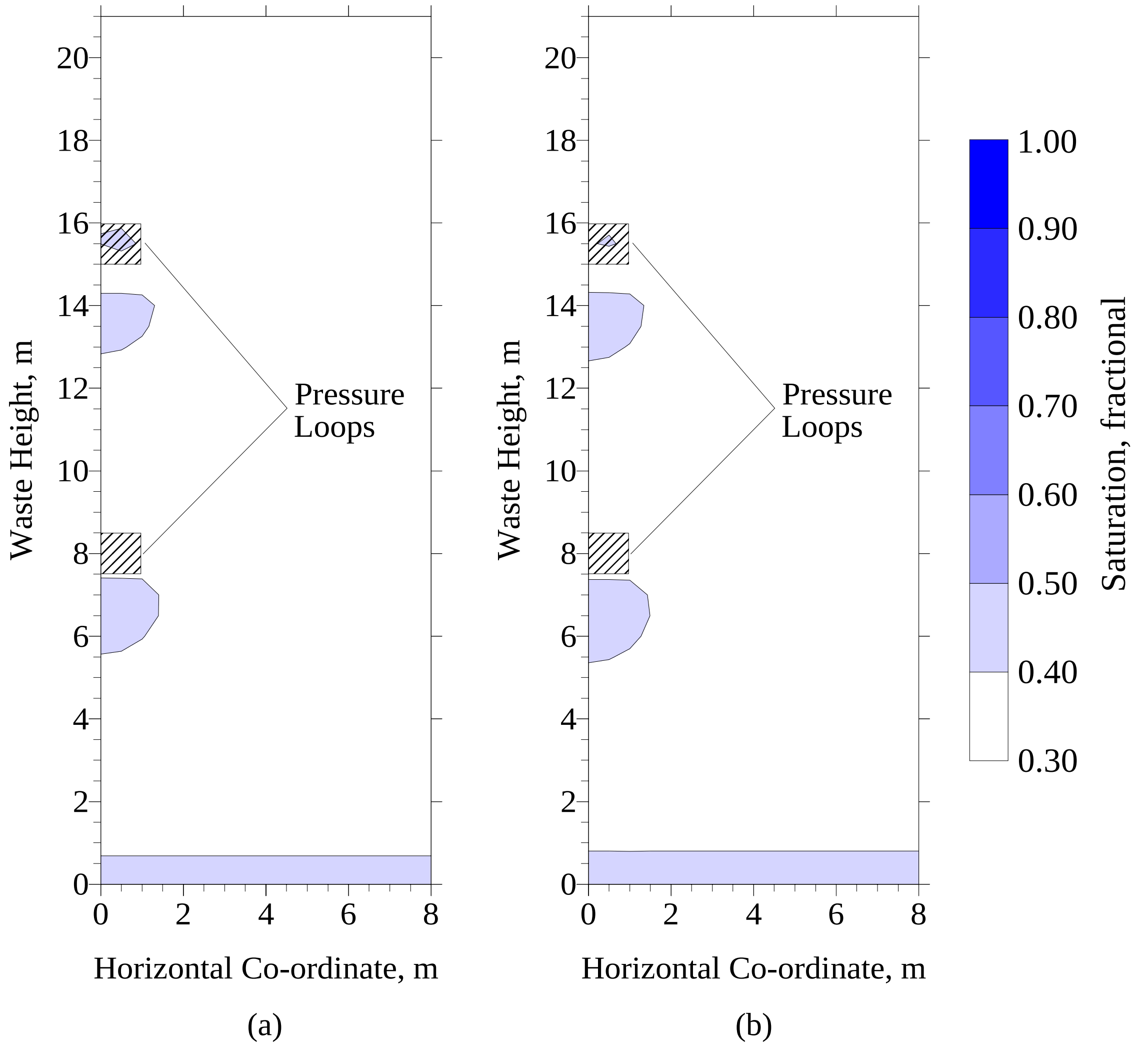


Figure 5.1.4. Saturation iso-clines for the Mill Seat Landfill pressure loop leachate recirculation system at elapsed times of 50 (a) and 60 (b) days.

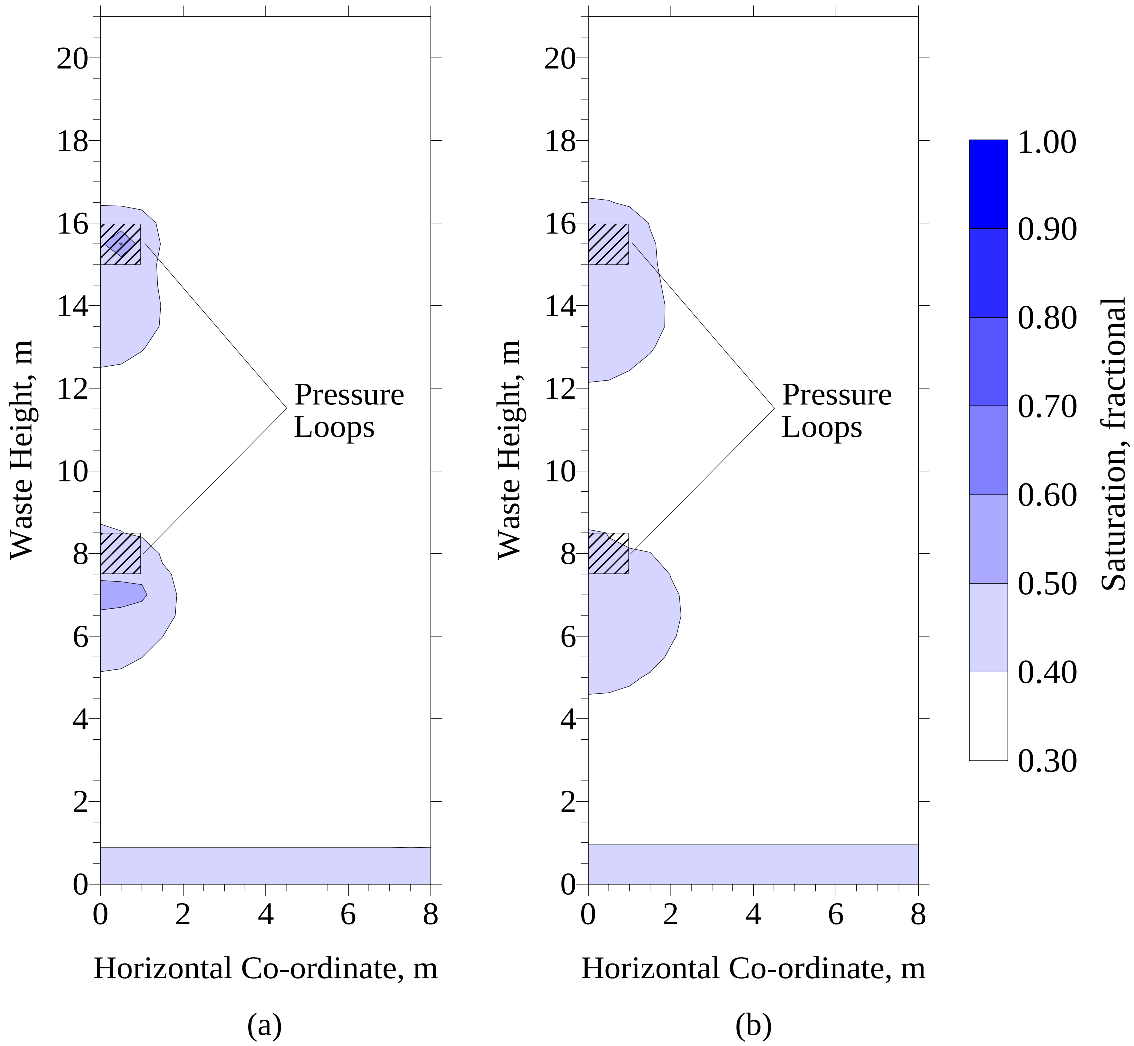


Figure 5.1.5. Saturation iso-clines for the Mill Seat Landfill pressure loop leachate recirculation system at elapsed times of 70 (a) and 80 (b) days.

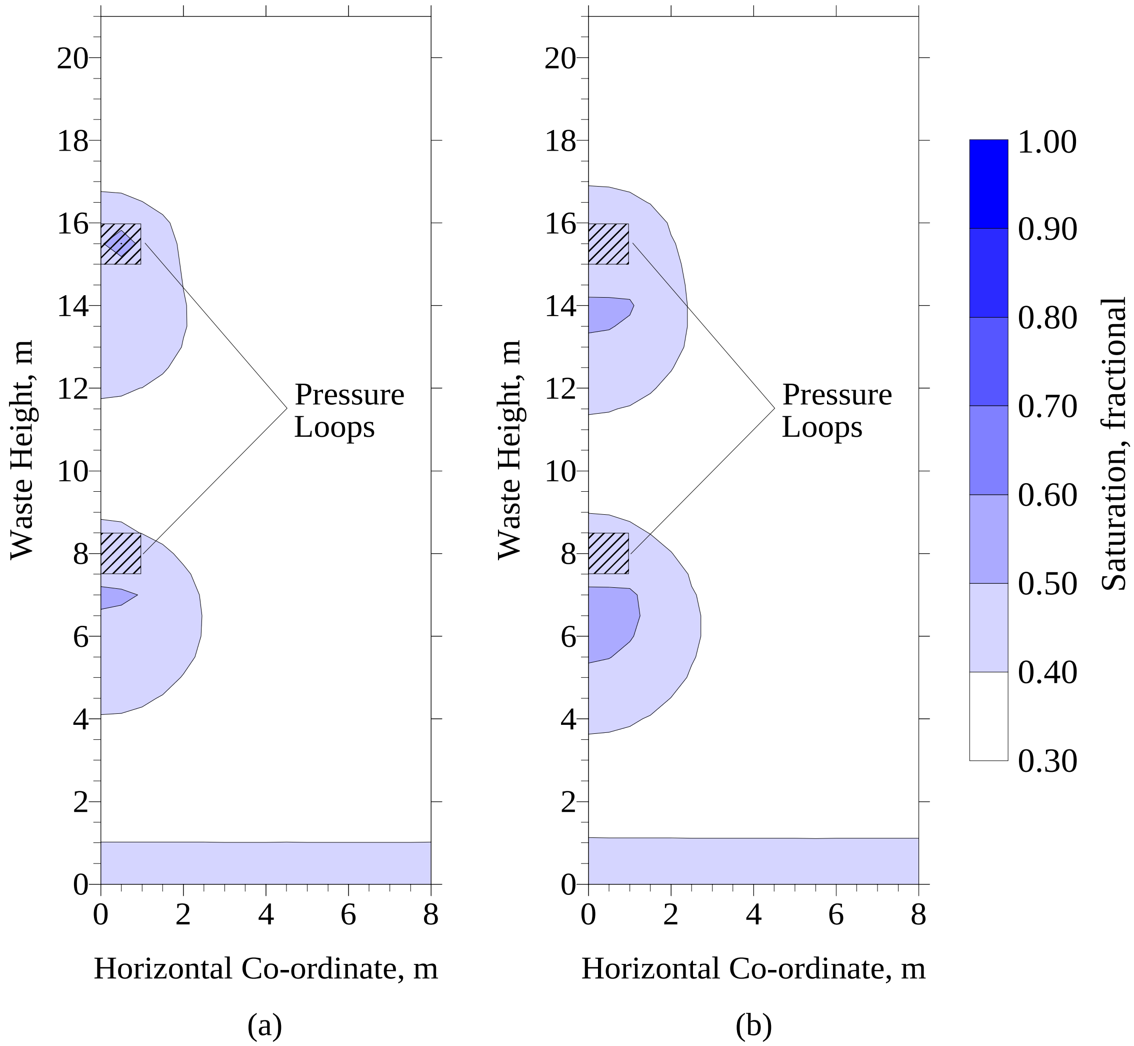


Figure 5.1.6. Saturation iso-clines for the Mill Seat Landfill pressure loop leachate recirculation system at elapsed times of 90 (a) and 100 (b) days.

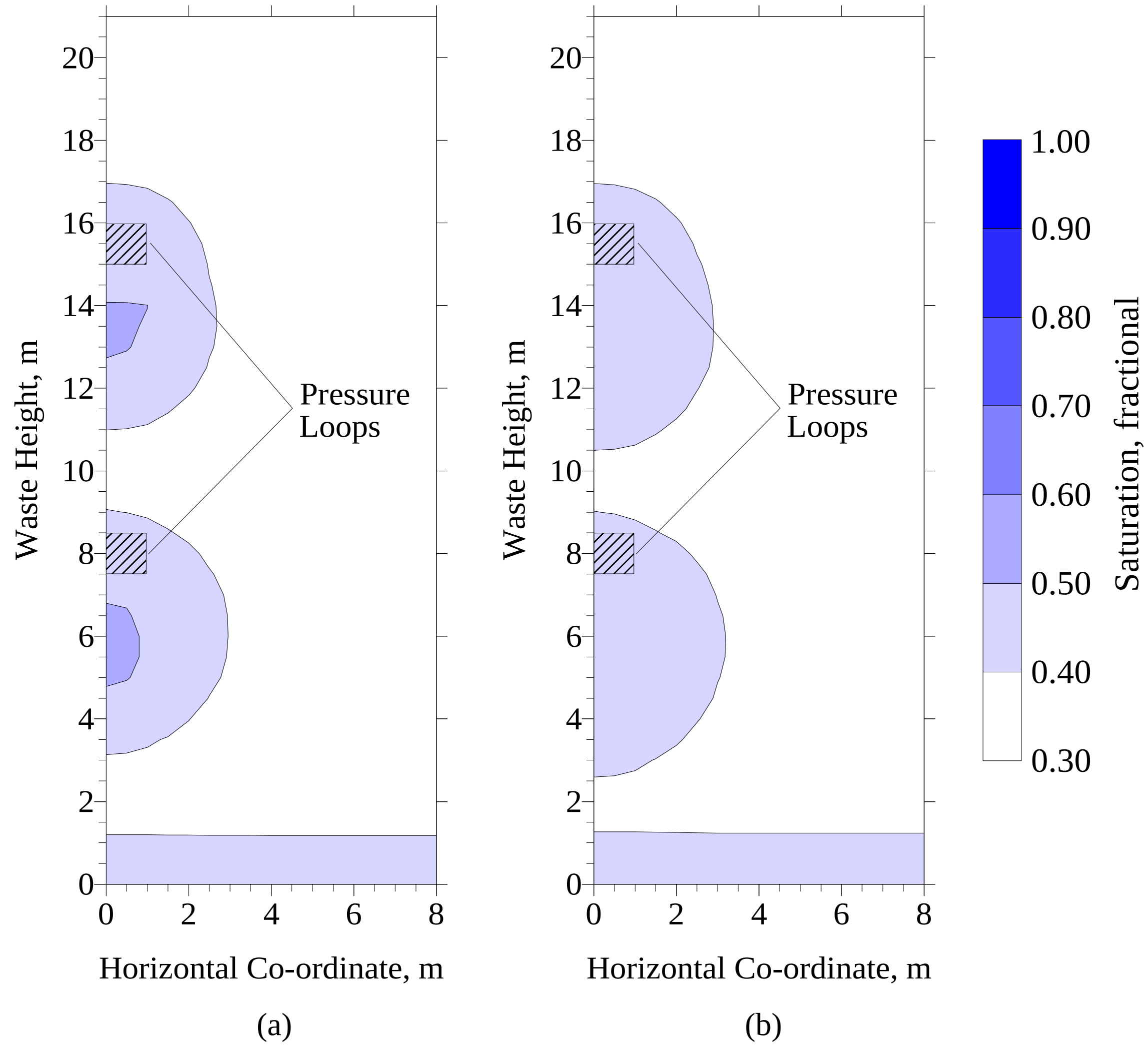


Figure 5.1.7. Saturation iso-clines for the Mill Seat Landfill pressure loop leachate recirculation system at elapsed times of 110 (a) and 120 (b) days.

5.1.2 Deep Trench Recirculation

The deep trenches were also modeled using a 1-m thick cross section with leachate application to 1-m wide by 3-m deep gravel filled trench at a height of 7.5 m within the waste mass. One-half of the deep trench cross section was modeled based on the results generated from the modeling of the horizontal trench.

Figure 5.1.8 plots the predicted and measured leachate generation as a function of time. It can be clearly seen that the model significantly under predicts leachate generation until the ninetieth day at which time the predicted generation begins to increase exponentially resulting in a significant over prediction of leachate generation. This sudden change in leachate production at the ninetieth day is due at least in part to significant increases in leachate application. On several days during the 90^{th} to 100^{th} day time period, leachate was applied at rates of 200 l/m/day, almost four times higher than the highest previous application rates which were at most 50 l/m/day and 17 times higher than the average injection rates, 12 l/m/day, prior to July 1996. The impact of increased leachate application rate is indicative of the compressibility effects previously noted. As the application rate increases, hydrostatic pressures around the point of application also increase resulting in more liquid storage due to the specific storativity phenomenon.

Figures 5.1.9 through 5.1.14 illustrate the saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at 10-day intervals over the 120-day period simulated. It is interesting to note in these figures that the areas of increased saturation propagate not only from the trench outwards but also, as we have seen before, upwards from the LCS. It is difficult to compare these figures quantitatively with the ones from the pressure loop simulations, leachate application rates and schedules differed, but qualitatively it can be seen that there was more lateral spreading in this case and higher saturation levels were reached, 0.7 for this case versus 0.6 for the pressure loops. Also, a mound of higher saturation iso-clines developed above the LCS which did not happen in the pressure loop case. This mound was most likely due to the higher volume of leachate applied in this case, 5200 l over the 120 days as compared to 1300 l in the pressure loop simulation.

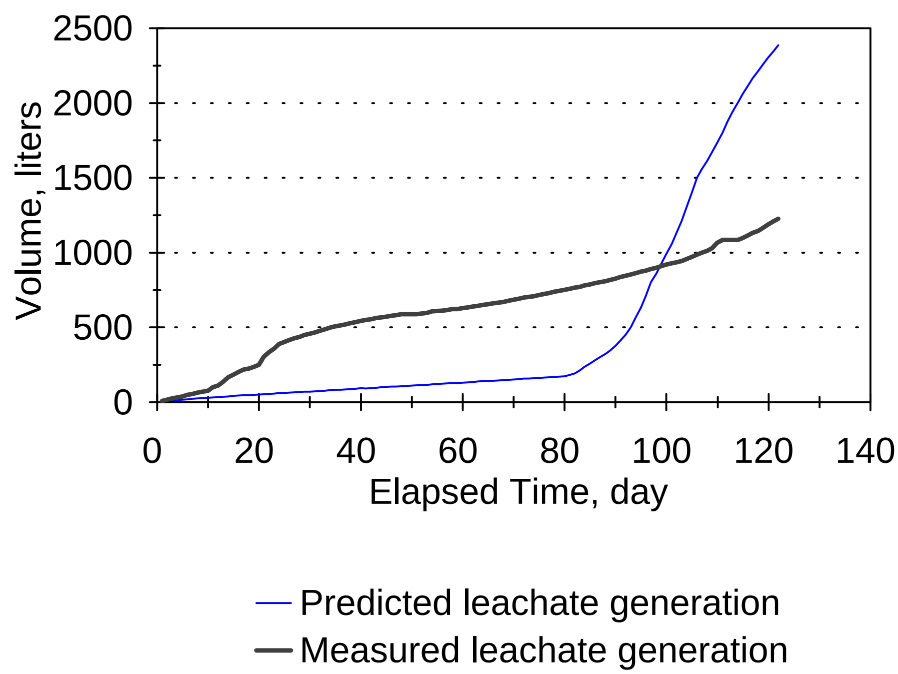


Figure 5.1.8. Predicted and measured leachate generation rates for the Mill Seat deep trench leachate recirculation system.

It is also interesting to qualitatively compare the leachate production results for the deep trench simulation to the results for the pressure loop simulation. The pressure loop simulation consistently under-predicted leachate production whereas the deep trench simulation under-predicted and then suddenly over predicted production greatly. This

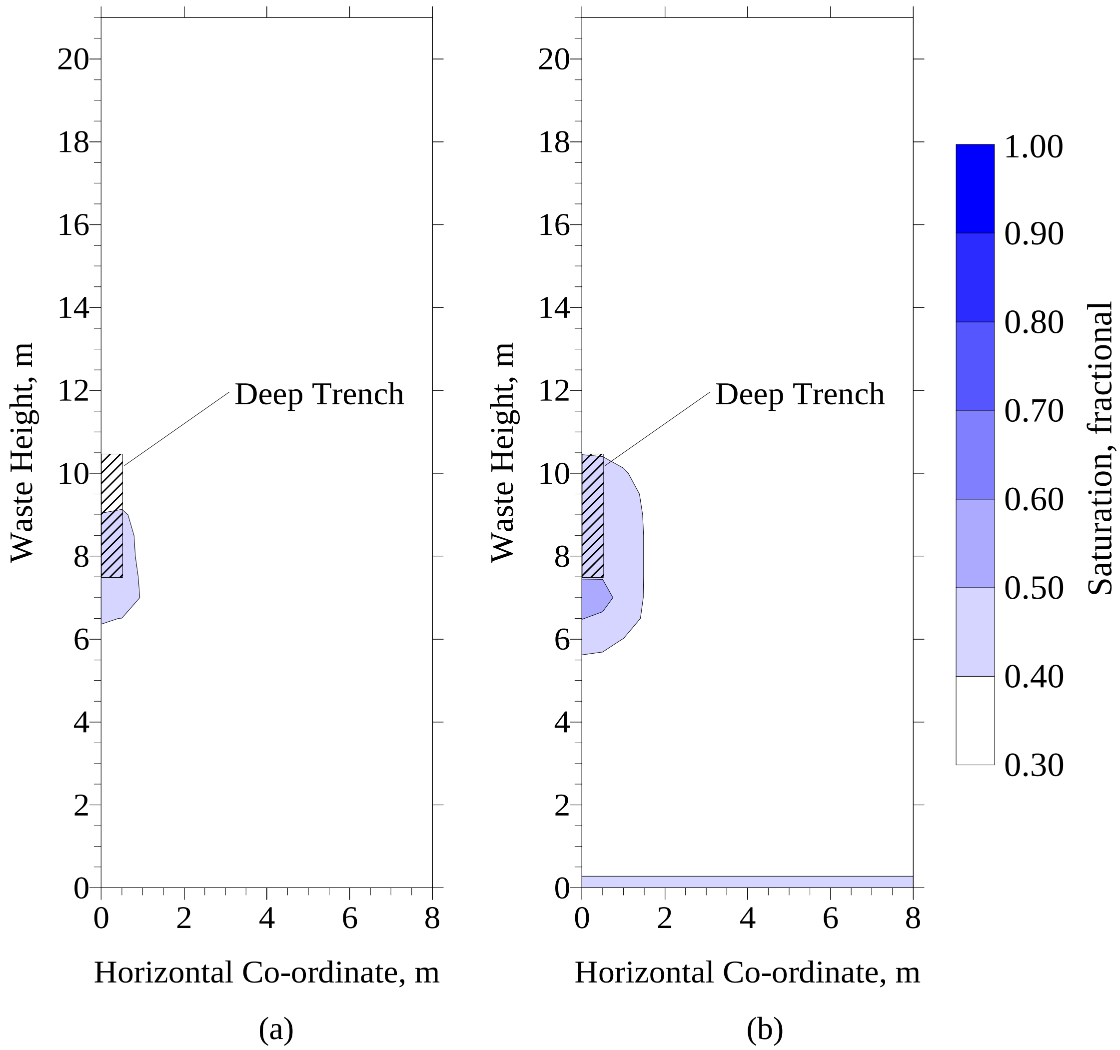


Figure 5.1.9. Saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at elapsed times of 10 (a) and 20 (b) days.

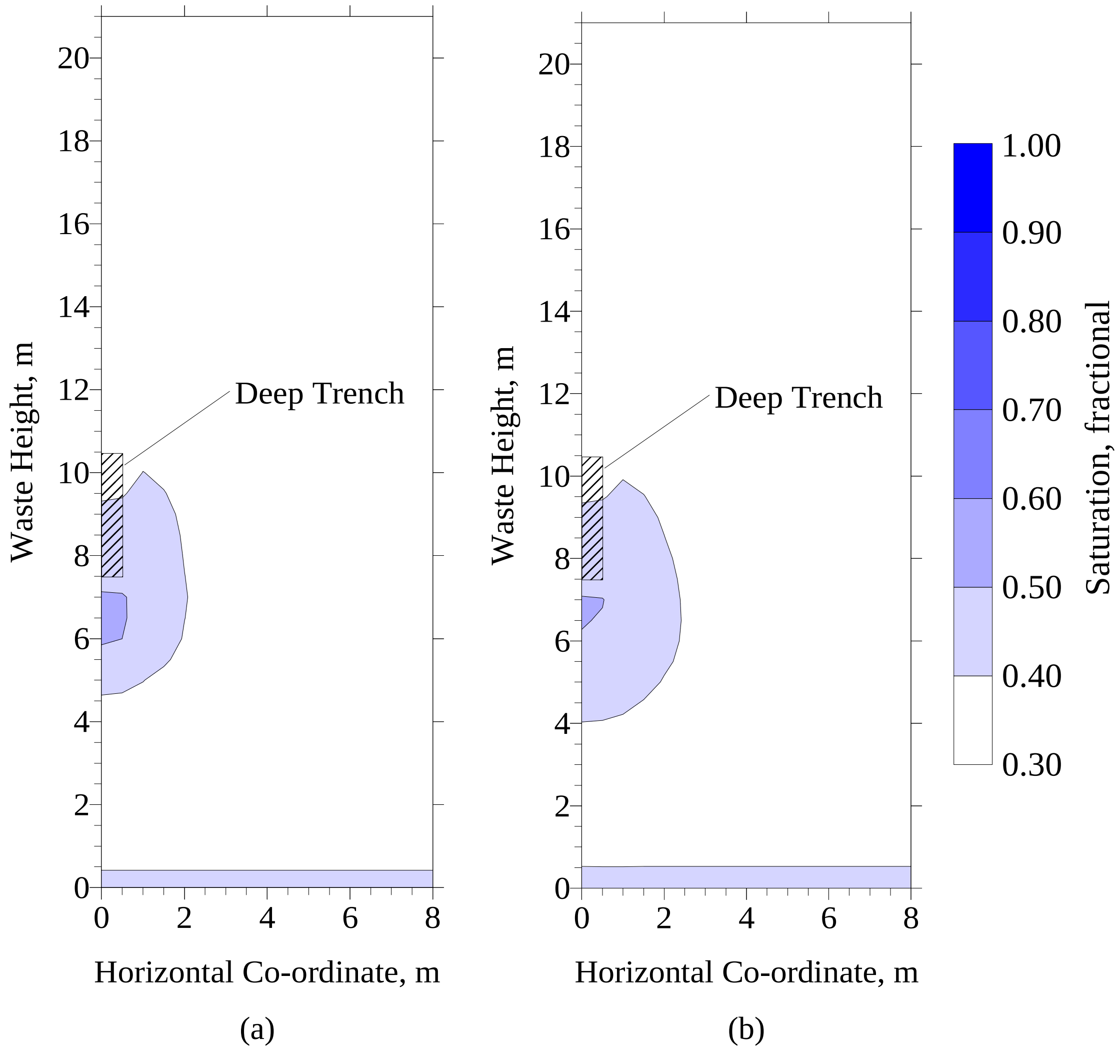


Figure 5.1.10. Saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at elapsed times of 30 (a) and 40 (b) days.

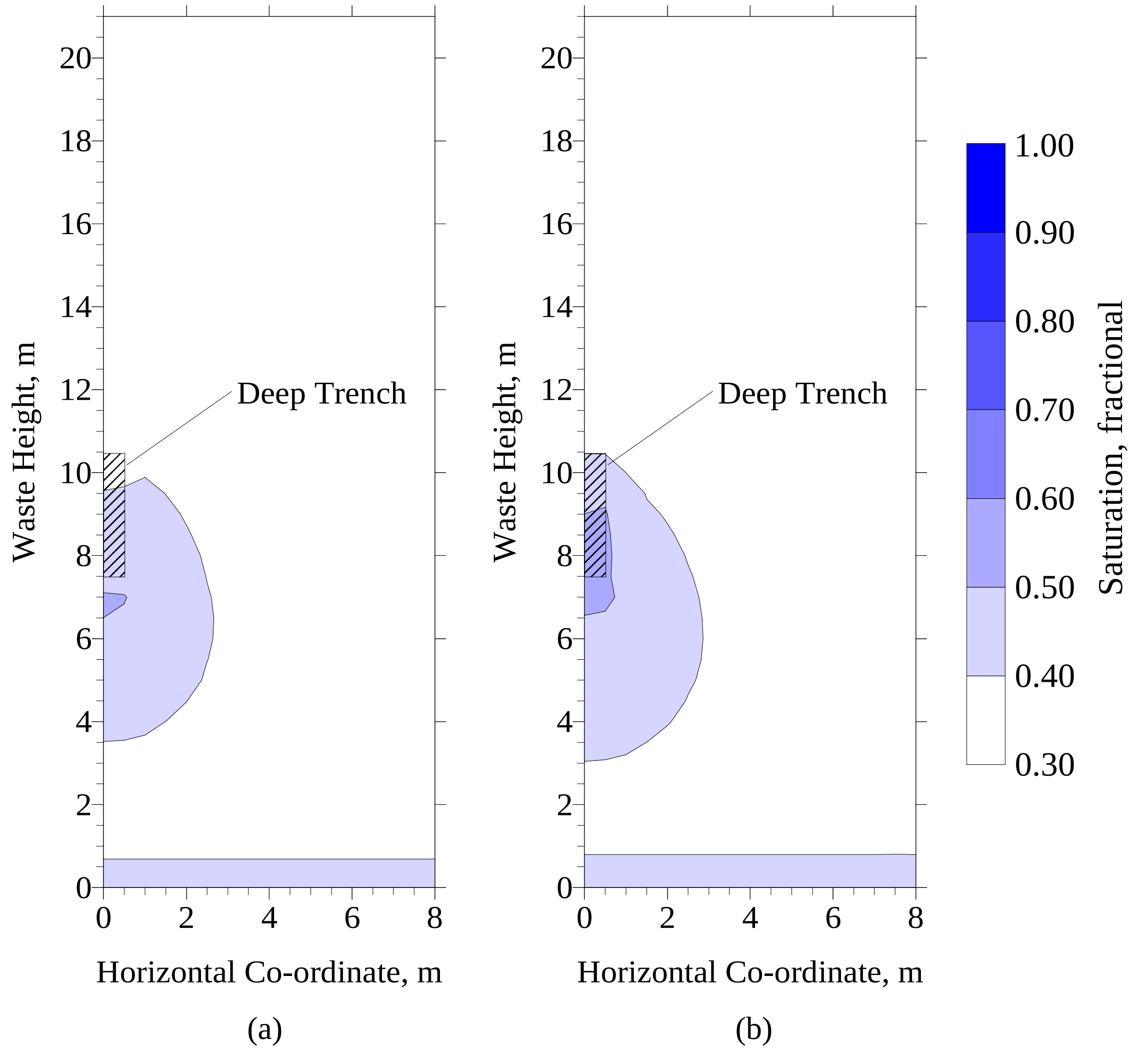


Figure 5.1.11. Saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at elapsed times of 50 (a) and 60 (b) days.

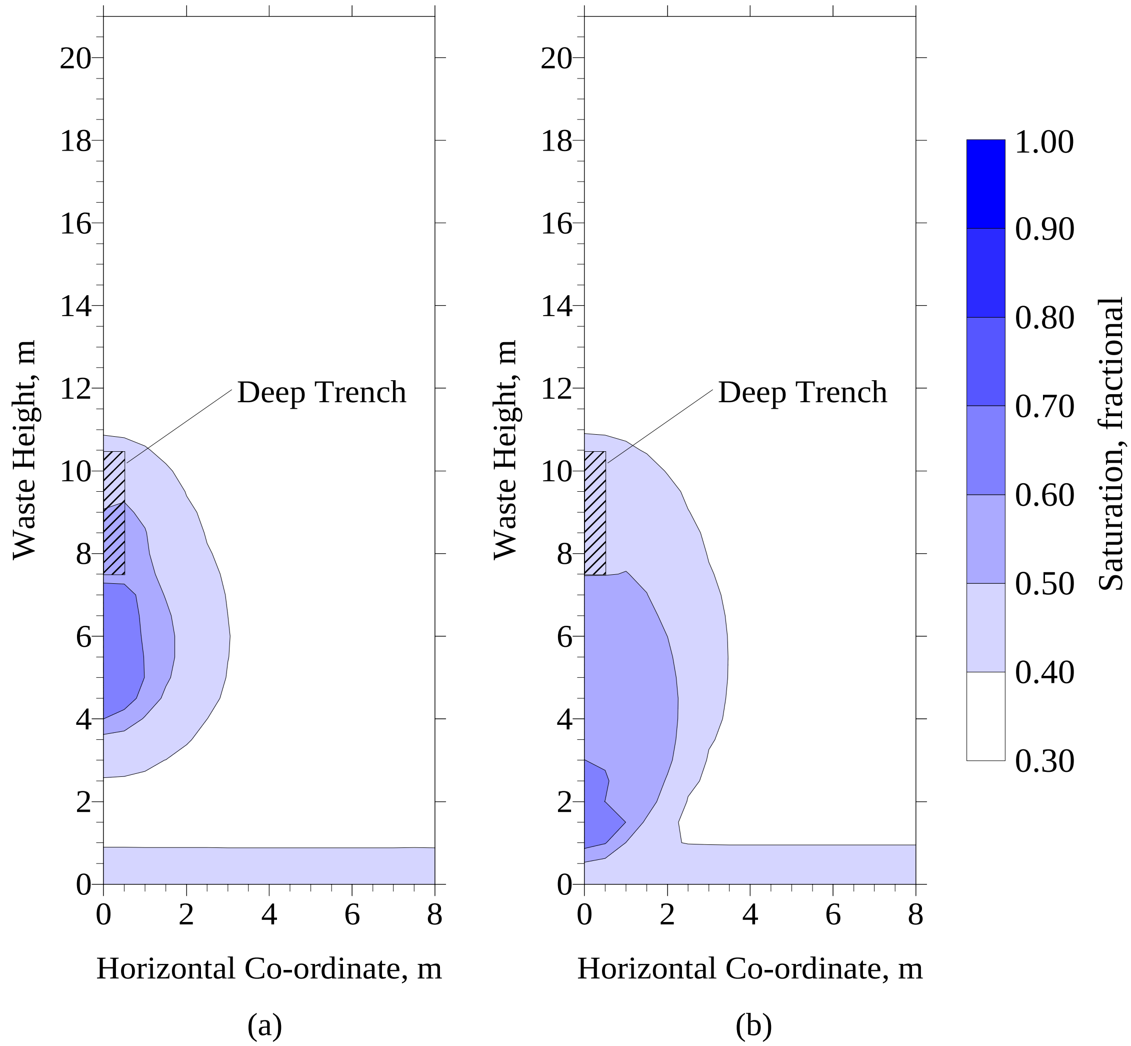


Figure 5.1.12. Saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at elapsed times of 70 (a) and 80 (b) days.

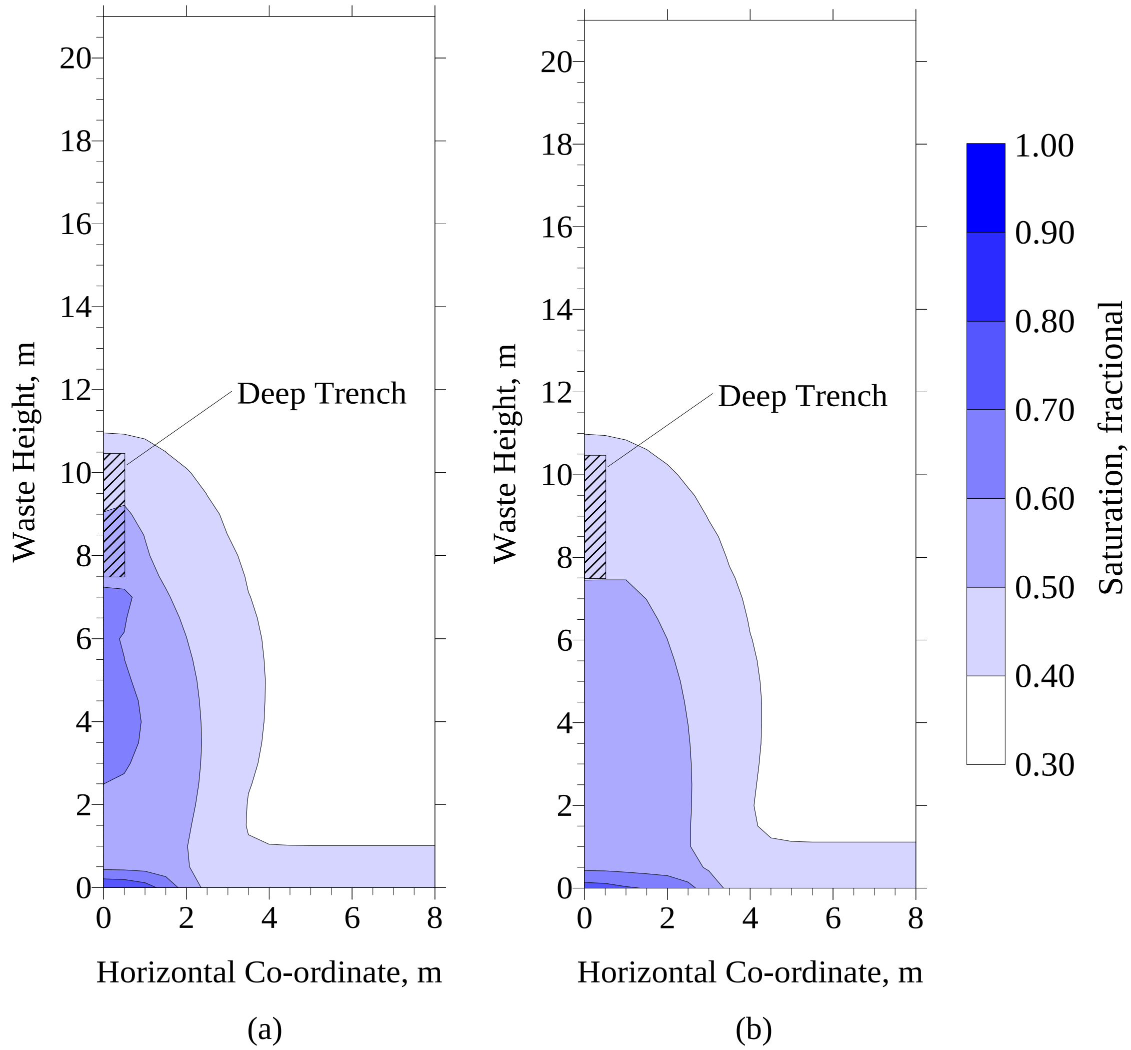


Figure 5.1.13. Saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at elapsed times of 90 (a) and 100 (b) days.

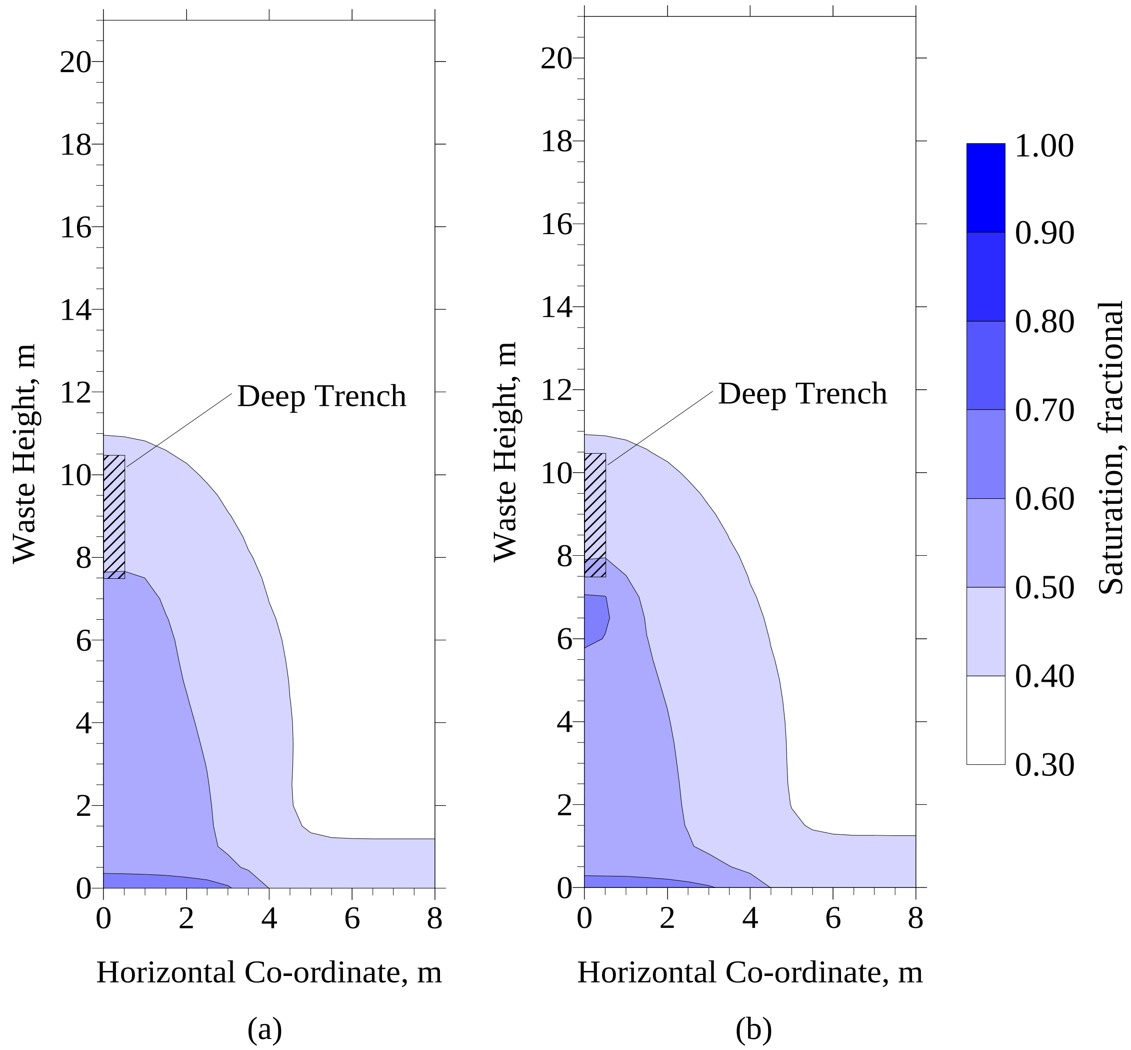


Figure 5.1.14. Saturation iso-clines for the Mill Seat Landfill deep trench leachate recirculation system at elapsed times of 110 (a) and 120 (b) days.

difference in simulation outputs was due in part to the increase in application rates on the 30^{th} day of simulation. The increase was much greater for the deep trench simulation than for the pressure loop simulation which affected the mass balance accuracy of the deep trench. This impact can be seen by comparing the mass balance graphs for the pressure loop and deep trench simulations, Chapter 3. The pressure loop mass balance shows very little error whereas the mass balance plot for the deep trench case begins to diverge around day 60. Inspection of Figures 5.1.11 through 5.1.14 indicates that the divergence coincides with increased application rate, leachate spreading, and leachate storage in the waste mass.

Differences between the measured and predicted leachate generation can again be attributed to the effects of channeling and daily cover materials, however the configuration of the deep trench system may have had an effect as well. Leachate breakouts at the surface were noted in the deep trench cell during high leachate loading rates. The iso-cline figures presented in this section do indicate a slight rise (0.5 m) in leachate above the trench but do not predict anything close to the upward movement that would be required to create a surface breakout. The surface breakouts would be due to channeled flow, the mechanisms of which , as discussed previously, were not directly simulated in this modeling effort. In addition to channeled flow, the construction of the vertical trenches may have led to enhanced upward flow opportunities. The deep trenches were fed via six vertical chimneys, a 1-m diameter pipe casing filled with high permeability materials. These chimneys were constructed one lift at a time during normal landfill operations. It is unlikely that compaction equipment could be operated in close proximity to these chimney without creating stability and structural concerns. If the waste around the chimneys was not compacted, it would have a higher permeabilities than the rest of the waste mass resulting in an increased likelihood of upward leachate movement around the chimney.

5.2 Delaware Solid Waste Authority

As described in Chapter 3, the DSWA's test cells have the shape of a truncated pyramid with approximate dimensions as follows; a base area of 3948 m^2 (42,471 ft^2), an upper area of 921 m^2 (9910 ft^2), and a waste depth of 7.6 m (25 ft). A 9.45-m by 13.4-m (31-ft by 44-ft) leach field with four separate, but identical, quadrants was constructed just beneath the final cover. The leach field had four separate, but identical quadrants. System schematics and collected data were provided courtesy of the Delaware Solid Waste Authority, 1997.

The simulation work modeled one of these quadrants or one-quarter of the test cell. In order to accurately represents this non-symmetrical shape, the quasi-three-dimensional abilities of SUTRA were used which involved specifying lateral thicknesses (essentially a 'z' co-ordinate for each x, y co-ordinate). The difficulty encountered with this techniques was that SUTRA simulates liquid movement as if it is occurring across the entire specified thickness. This simulation technique then results in the implied assumption that the lateral movement in the 'z' direction is equal to the local thickness which is not the case. Lateral spreading in the 'z' direction would be approximately equal to the lateral spreading in the 'x' direction which is simulated by the model. An iterative approach to calibrating the local thicknesses was then employed based on the assumption that spreading in the 'z' direction would be approximately equal to spreading in the 'x' direction. More precise details on this procedure are documented in Chapter 3.

The DSWA test cell was modeled using waste permeabilities of $8.1x10^{-3}$ cm/s and 0.1 cm/s. The former permeability was based on the calculation of an apparent hydraulic conductivity (flow distance/arrival time) as suggested by Zeiss and Uguccioni, 1994. The latter permeability was employed once it became obvious that leachate was not going to reach the LCS as quickly as leachate mass balance measurements indicated. Saturation iso-clines from both simulations are presented in Figures 5.2.1 through 5.2.7 at elapsed time of 5, 10, 15, 20, 25, 30, and 35 days,. The $8.1x10^{-4}$ cm/s waste permeability simulation was not modeled beyond 35 days since leachate had not reached the LCS within this time period. The data collected on leachate generation indicated that it arrived at the LCS within one-day of application. Therefore, no comparative iso-clines are presented after 35 days elapsed time. Comparison of the saturation iso-clines for the two different permeabilitis modeled indicates that the lower permeability case, $8.1x10^{-3}$ cm/s, developed higher saturations within the waste matrix as would be expected. It is also interesting to note the saturation iso-clines generated in the higher permeability (0.1 cm/s) simulations propagated outwards from the bottom. This propagation suggests that lateral spreading may occur due to flow limitations at the LCS/waste interface. The upper layer of the LCS for this simulation was a sand with a permeabiltiy of $7x10^{-3}$ cm/s.

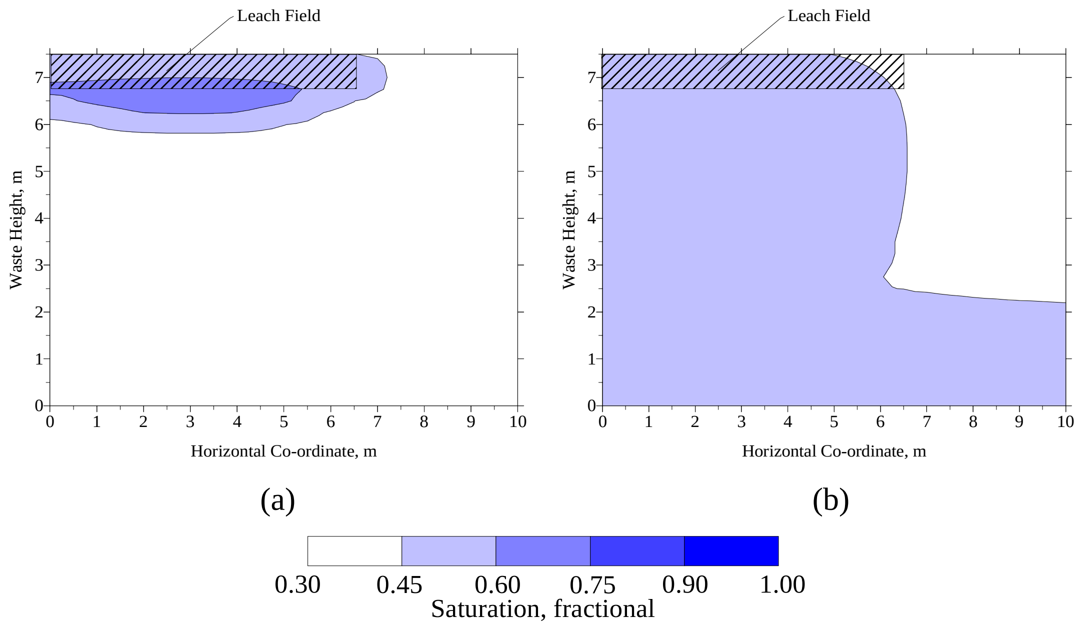


Figure 5.2.1. Saturation iso-clines for waste permeabilities of $8.1\text{x}10^{-3}$ cm/s (a) and 0.1 cm/s (b) after five days of operation.

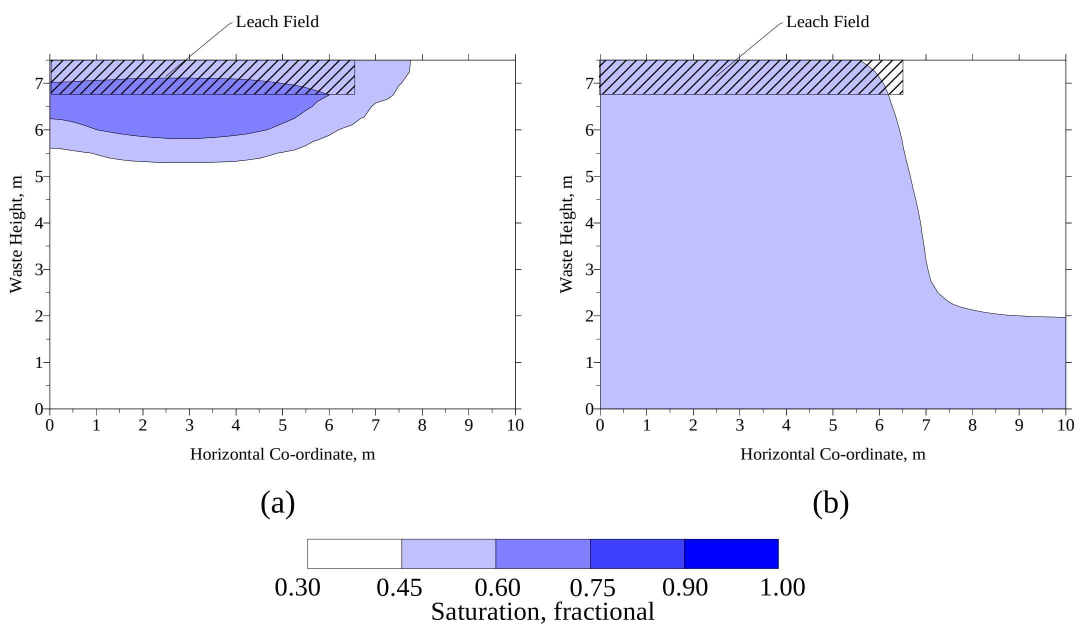


Figure 5.2.2. Saturation iso-clines for waste permeabilities of $8.1\text{x}10^{-3}$ cm/s (a) and 0.1 cm/s (b) after 10 days of operation.

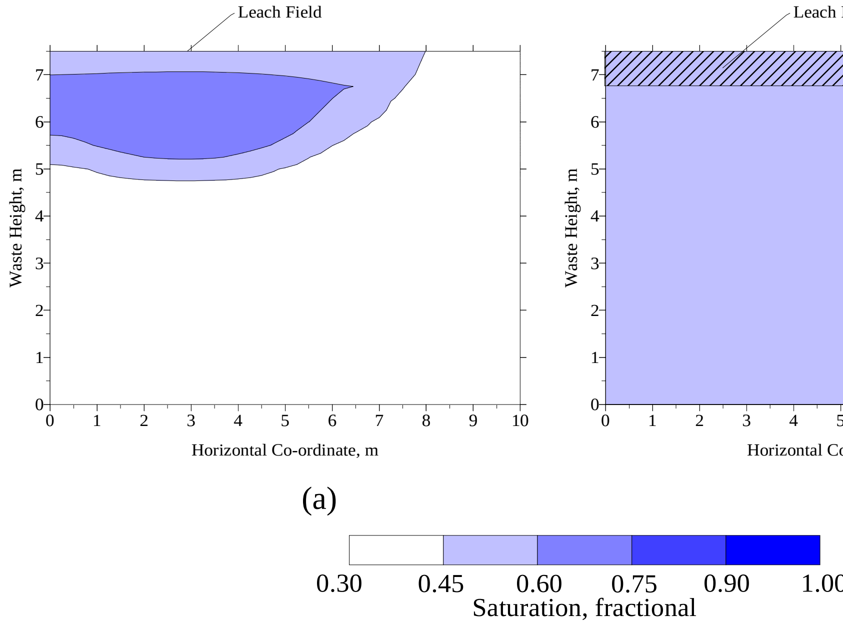


Figure 5.2.3. Saturation iso-clines for waste permeabilities of 8.1×10^{-3} cm/s (a) and 0.1 cm/s (b) after 15 days of operation.

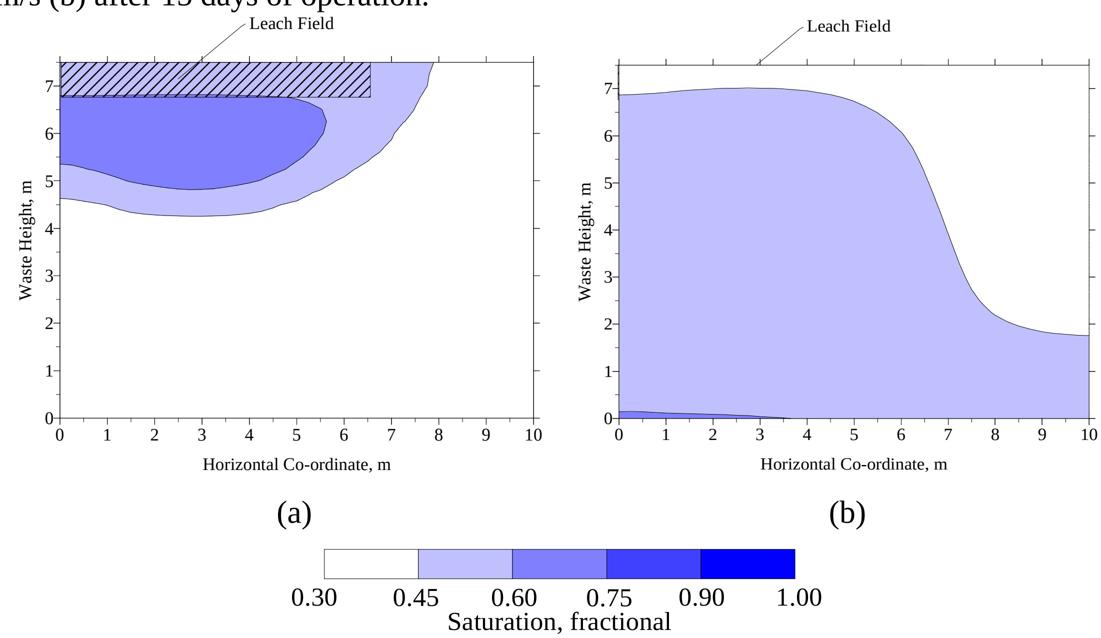


Figure 5.2.4. Saturation iso-clines for waste permeabilities of 8.1×10^{-3} cm/s (a) and 0.1 cm/s (b) after 20 days of operation.

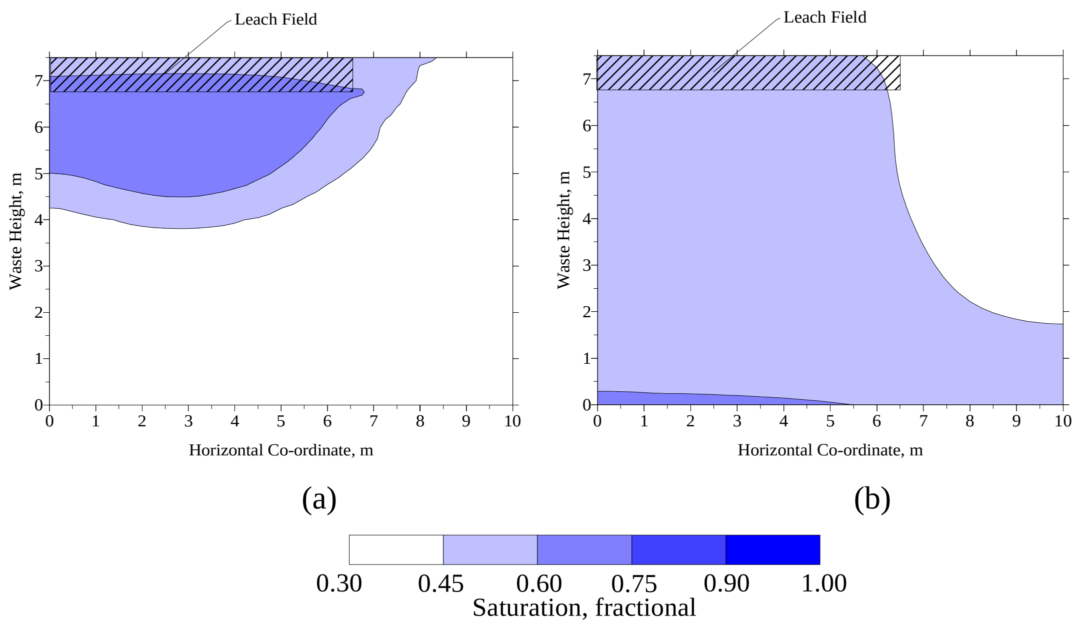


Figure 5.2.5. Saturation iso-clines for waste permeabilities of 8.1×10^{-3} cm/s (a) and 0.1 cm/s (b) after 25 days of operation.

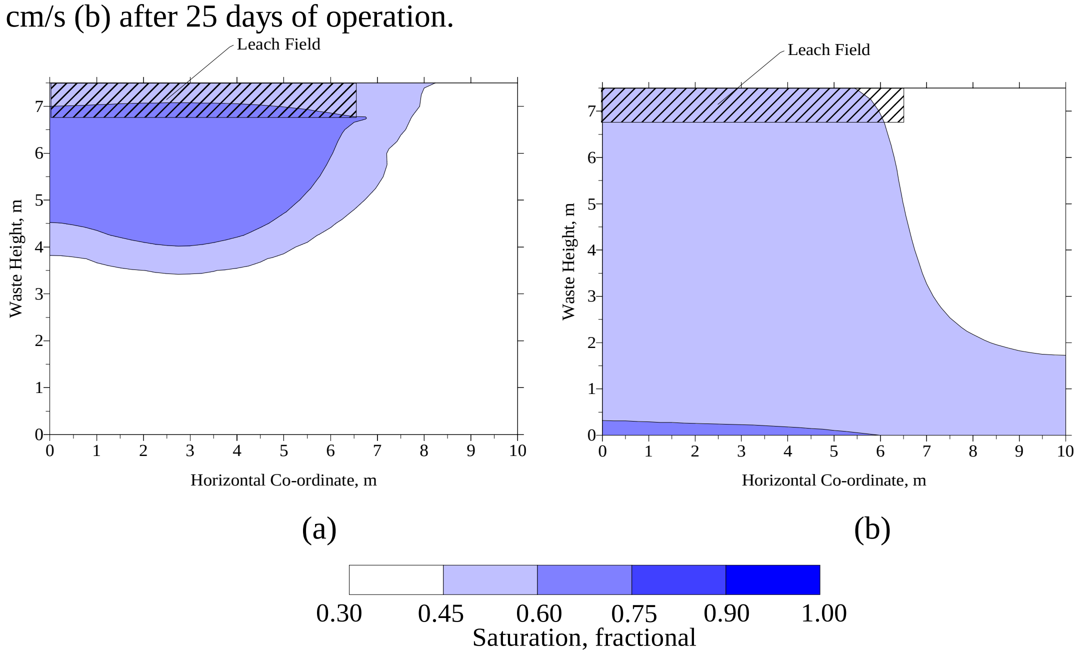


Figure 5.2.6. Saturation iso-clines for waste permeabilities of 8.1×10^{-3} cm/s (a) and 0.1 cm/s (b) after 30 days of operation.

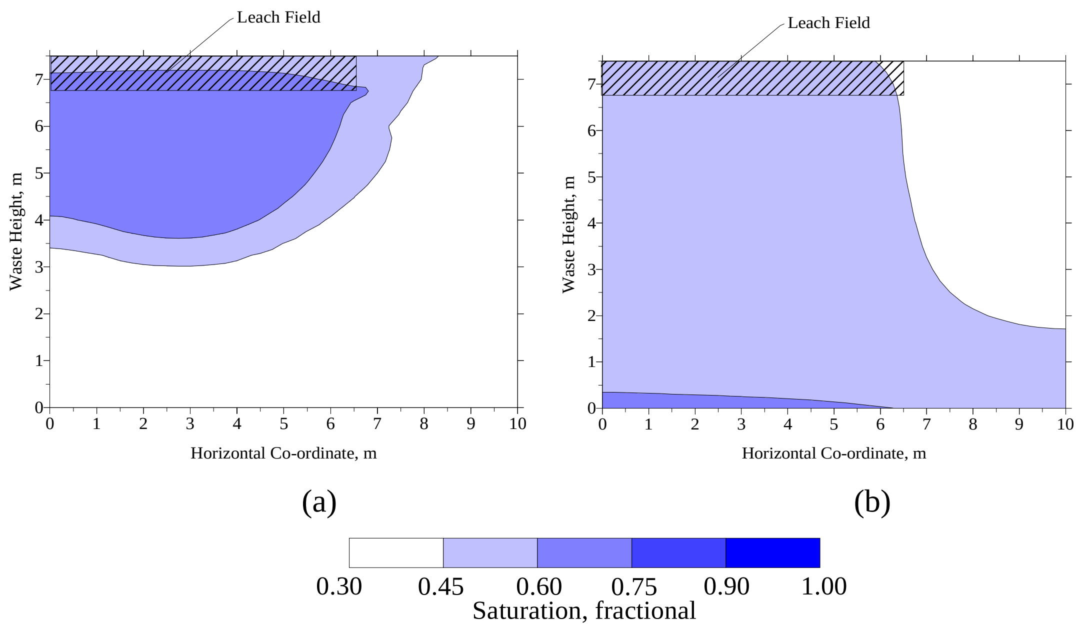


Figure 5.2.7. Saturation iso-clines for waste permeabilities of $8.1x10^{-3}$ cm/s (a) and 0.1 cm/s (b) after 35 days of operation.

Figure 5.2.8 depicts the saturation iso-clines for the 0.1 cm/s permeability waste mass after 65 and 95 days of operation. These figures suggest that the wetted area fluctuates as pumping rates and frequency change. Higher application rates result in more spreading while decreasing application rates causes a recession in the wetted area. Knowledge of this behavior can enable operators to control the impacted area by adjusting application rates.

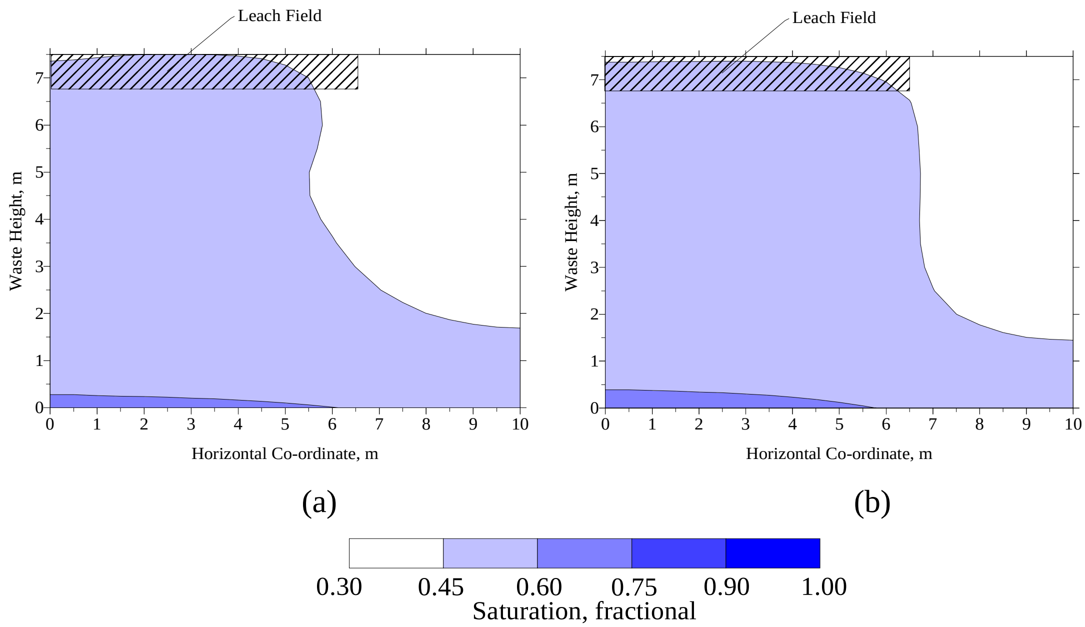


Figure 5.2.8. Saturation iso-clines for a waste permeability of 0.1 cm/s after 65 (a) and 95 (b) days of operation.

In-situ moisture content was not measured in the DSWA study. However, the volume of leachate injected and generated was measured on a daily basis. A comparison was made of the total amount of leachate generated in the field, the amount generated in the simulations, and the amount of leachate recirculated. Figure 5.2.9 depicts these volumes plotted against time for a waste permeability of 0.1 cm/s. The 95-day period shown in Figure 5.2.9 was chosen based on the small amount of rainfall during this period (only 5.56 inches with 80% of this precipitation occurring in five separate rainfall events). Recirculated leachate accounted for only 61% of the total leachate generated during the August 1990 to December 1995 time period (5.5 years). The source of the remaining 39% was not identified, but since the cell is constructed above the groundwater table it is reasonable to assume that it was due to infiltration through the final cap. Since the exact source of this excess leachate was unknown it was not possible to incorporate it into the model.

The results (Figure 5.2.9) indicate that the model predicted leachate arrival and total volume generated fairly accurately. The largest errors, ranging from 27% to 160%, between the measured and predicted leachate generation occurred during the first 23 days simulated when cumulative flows were quite low. During the remaining 72 days simulated, the maximum and average errors were 30% and 15% respectively.

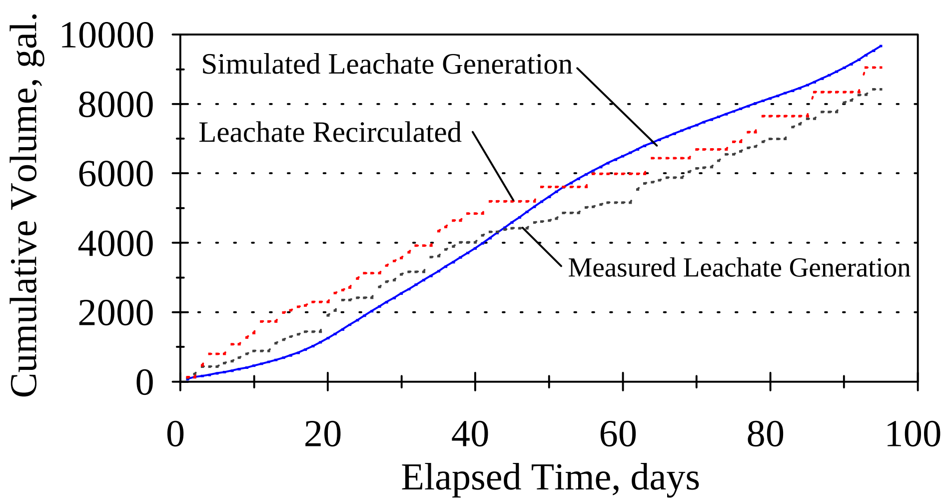


Figure 5.2.9. Cumulative leachate volumes versus time for the DSWA's recirculation test cell.

An important indication of these results is that the incorporation of unsaturated flow characteristics into leachate flow models may necessitate the increase of waste permeability above the values commonly cited in literature and above values estimated from arrival times. Investigation of unsaturated flow relationships on a large scale may also be prudent.

5.3 Yolo County Landfill

The Yolo County LRS Demonstration Project consists of two, 30-m by 30-m (100-ft by 100-ft) cells. Leachate was introduced through a leach field consisting of 14 individual 4-m x 10-m x 1.5-m (width x length x depth) trenches at the top of one of the 14-m (46-ft) deep cells. The second cell serves as a control with a single composite liner, while the recirculation cell has been constructed with a double composite liner. Independent leachate collection and removal systems were constructed. Pressure transducers located within the LCS monitor hydraulic head. Moisture content is being measured with gypsum moisture blocks and custom PVC/gravel sensors, while thermocouples are being used to monitor temperature. Yolo County personnel also plan to measure gas pressure and gas and leachate flow and composition. System schematics and data were compiled from three sources; Yazdani et al., 1997, Moore, 1997, Moore et al., 1997.

Initially, it was envisioned that this system would compare actual versus predicted local saturations. However, the layout of this system made it extremely difficult to isolate a cross-section which could be modeled in this manner. This symmetry issue was discussed in more detail in Chapter 3. Furthermore, the calibration curve required to convert the readings from the gypsum moisture blocks to moisture content was not developed, while the PVC/gravel moisture sensors were only calibrated for three readings, below field capacity, between field capacity and saturation, and saturated. Thus the information produced by these instruments is more qualitative than quantitative. Yolo

County personnel are presently trying to combine leachate mass balance information with the measurements from the gypsum blocks and PVC/gravel sensors to develop calibration curves. Consequently, the system was analyzed by comparing actual and predicted mass balances on leachate arrival and storage rather than for specific local moisture contents.

The initial dry-basis moisture content of the system was assumed by Yolo County operators to be 25% corresponding to a saturation of approximately 12% based on a porosity of 0.55 and a solids density of 0.594 g/cm^3 (Moore et al., 1997). Initially, the simulation was started using a saturation of 10% and a waste permeability of 0.1 cm/s, based on the Delaware simulation results and the nearly instantaneous leachate arrival reported. However, the model was very unstable at this saturation and mass could not be balanced. The first 34 days of operation were then modeled using initial saturations of 20, 30, and 40 percent with all other inputs held constant including the waste permeability of 0.1 cm/s. These simulations yielded the mass balance results shown in Table 5.3.1.

Based on the results shown in Table 5.3.1, it was decided that an initial saturation of 40% provided the best combination of simulation mass balance accuracy and prediction of leachate arrival. Yolo County data show that 17% of the applied leachate reached the LCS during the first 34 days of operation. This 17% was generated almost instantaneously upon leachate application. Table 5.3.1 also supports the theory proposed by Korfiatis et al. (1984) that if a sample is at field capacity, any liquid addition will result in almost immediate leachate generation. The 20 and 30 percent initial saturations simulations (both below field capacity) generated little or no leachate, whereas the 40%

saturation simulation (close to field capacity) generated leachate within the first 24 hours of operation (see Table 5.3.3)

Table 5.3.1. Simulation mass balance results for initial saturations of 20, 30, and 40 percent after 34 days.

Initial Saturation, %	Leachate Generated, l	Leachate Stored, l	Total, l	Ratio of Leachate Generated to Leachate Input, %	Error in Mass Balance, %
20	0	49,541	49,541	0	1.2
30	204	39,875	40,079	0.51	18.1
40	19,349	31,868	51,217	40	4.4

Further simulation results for the 40 percent initial saturation scenario are presented below. The pumping schedule for the 71-day period simulated is shown in Table 5.3.2.

Figure 5.3.1 and 5.3.2 present the measured and simulated volumes of leachate applied and generated. Comparison of these figures shows that while the measured and simulated volumes of leachate applied were fairly similar, there was a significant divergence between the measured and predicted volumes of leachate generation after the 30^{th} day of simulation. The simulated leachate generation indicated a substantial rise in the arrival rate after day 30 while the measured leachate arrival rate increased at a much slower rate.

Table 5.3.2. Leachate pumping schedule for the Yolo County Recirculation System.

Time Period, days	Measured Average Daily Volume of Liquid Input, liters	Simulated Average Daily Volume of Liquid Input, liters[a]
1 to 34	20,257	1,447[b]
35 to 54	27,297	2,275[c]
55 to 71	35,269	2,939[c]

[a]see Chapter 3 for exact calculation details
[b]based on modeling of two adjacent trenches of 14 total
[c] based on modeling of two adjacent trenches of 12 total

Table 5.3.3 compares the data collected by Yolo County to results produced by the simulation effort at 40% initial saturation. The model results over-predicted both average daily leachate generation and the ratio of leachate generated to leachate applied. These results can be explained in part by the fact that over the 71-day time period presented, the measured saturation increased 70 %, from 12.1% to 20.4%, while the simulated saturation increased less than 14% from 40% to 45.4%. This difference can be attributed to the fact

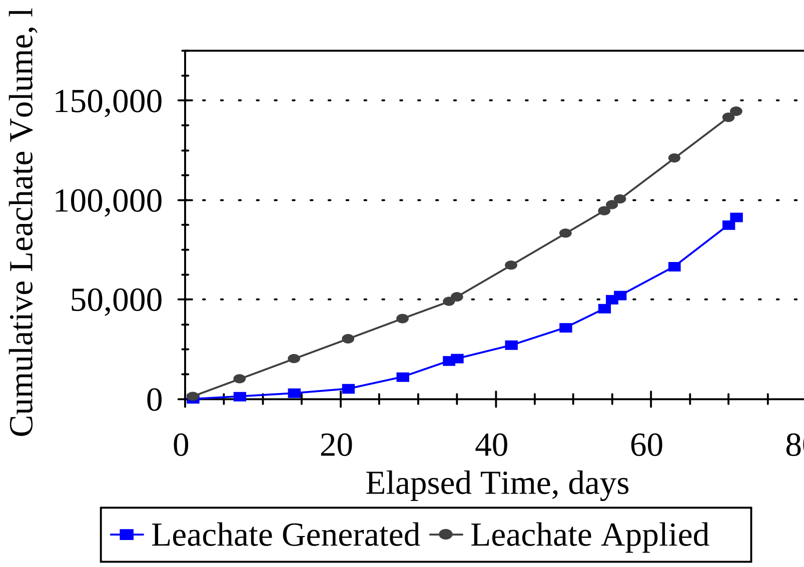


Figure 5.3.1. Cumulative leachate volumes simulated for the Yolo County Project based on an initial saturation of 40%.

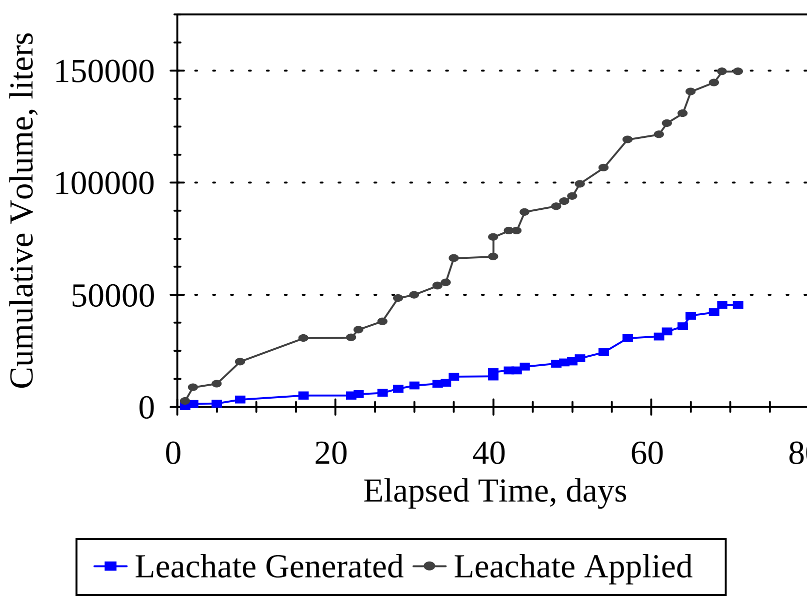


Figure 5.3.2. Cumulative leachate volumes measured at the Yolo County Project.

that the simulated waste mass was near field capacity and could not store much more leachate while the actual waste mass was well below field capacity, providing storage opportunities. Additionally the 17% of the leachate applied which reached the LCS almost immediately in the field was not the result of the displacement of liquid held at field capacity as simulated by the model but rather was most likely the result of channeled flow. The leachate which reached the LCS after 34 days was most likely due to the Darcian movement of liquid through the waste mass. This theory is further confirmed by the fact that the leachate chemistry and appearance changed significantly at this time (Moore et al., 1997).

These results once again indicate that channeled flow is a major leachate movement mechanism which must be accounted for directly. Channeled flow can be mimicked by adjusting the waste permeability and initial saturation as indicated by the results shown in Table 5.3.3 for the first 34 days leachate application. The measured and predicted ratio of generated to applied leachate were close, 17% and 21%, respectively. However, once a model has been adjusted to mimic channeled flow, it will not be able to account for other flow mechanisms such as traditional Darcian flow as indicated by the results for the 35 to 54 and 55 to 71 day time periods shown in Table 5.3.3. The predicted ratio of generated to applied leachate is significantly greater than the measured value. This difference is due to the fact that the measured value is the result of two mechanisms, the quick arrival of leachate due to channeled flow and the slower arrival due to Darcian flow through the waste matrix, whereas the predicted value still accounts for only channeled flow. One approach to solving this problem would be to run two separate simulations, both employing traditional Darcian flow techniques. One simulation would be calibrated to mimic channeled flow while the other would simulate leachate movement through the waste mass. While this technique may produce accurate results once calibrated to fit a particular case, it would require recalibration to fit the next set of circumstances. Therefore, the development of models which can simulate channeled flow, unsaturated Darcian flow, and the interaction between the two is imperative to future large-scale leachate recirculation modeling efforts.

Table 5.3.3. Comparison between collected data and simulated data (40% initial saturation) for the Yolo County Project.

Time Period, days	Yolo County Data			Computer Simulation Results		
	Average Daily Leachate Generation, l	Ratio of Generated to Applied Leachate, %	Time Averaged Saturation, %	Average Daily Leachate Generation, l	Ratio of Generated to Applied Leachate, %	Time Averaged Saturation, %
1 to 34	375	17	14.1	569	21	42.3
35 to 54	747	25	18.0	1,314	46	44.5
55 to 71	1,840	47	20.4	2,693	61	45.4

Figure 5.3.3 through 5.3.7 show the model prediction of saturation iso-clines for the ten-week period simulated. It can be seen in these figures that the saturation profile

gradually moves downward and does not begin to spread significantly or propagate upwards until it reaches the filter layer of the LCS, a sand with a permeability of 7.3x10^{-3} cm/s, significantly lower than the waste's permeability (0.1 cm/s). At weeks nine and ten a mound shaped zone of higher saturation has started to develop above the LCS. Although the build up of leachate in this simulation is by no means extreme or excessive, the waste matrix never becomes saturated. It does indicate that the LCS must be able to efficiently convey the leachate received out of the landfill in order to prevent the lateral movement of leachate along the LCS.

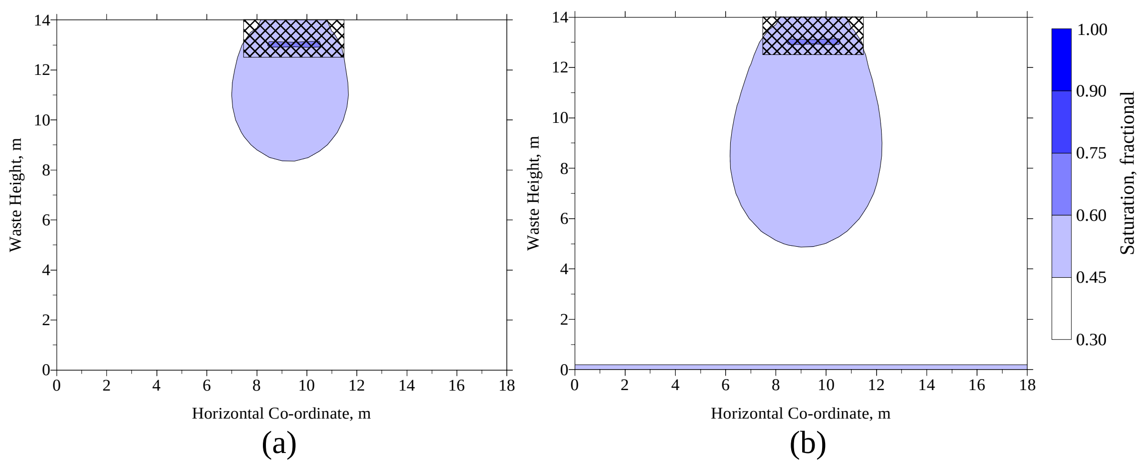
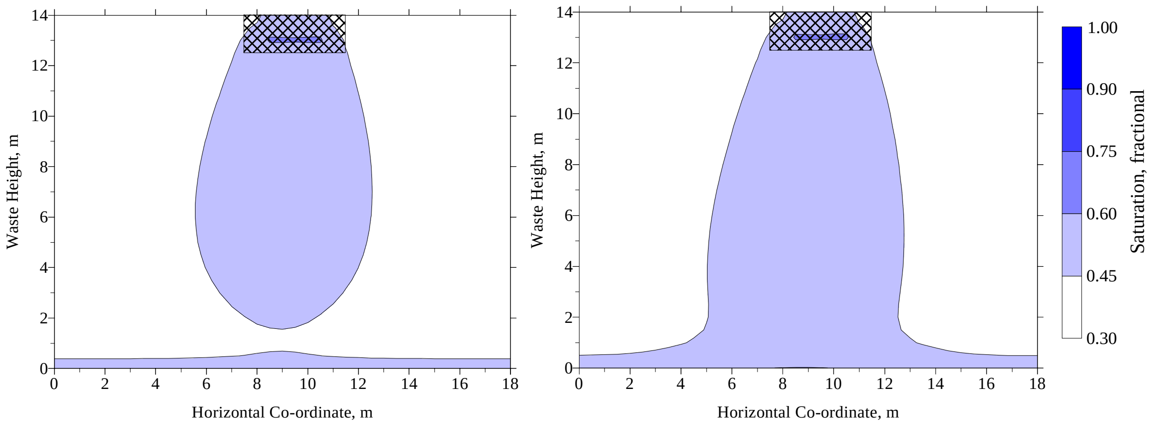
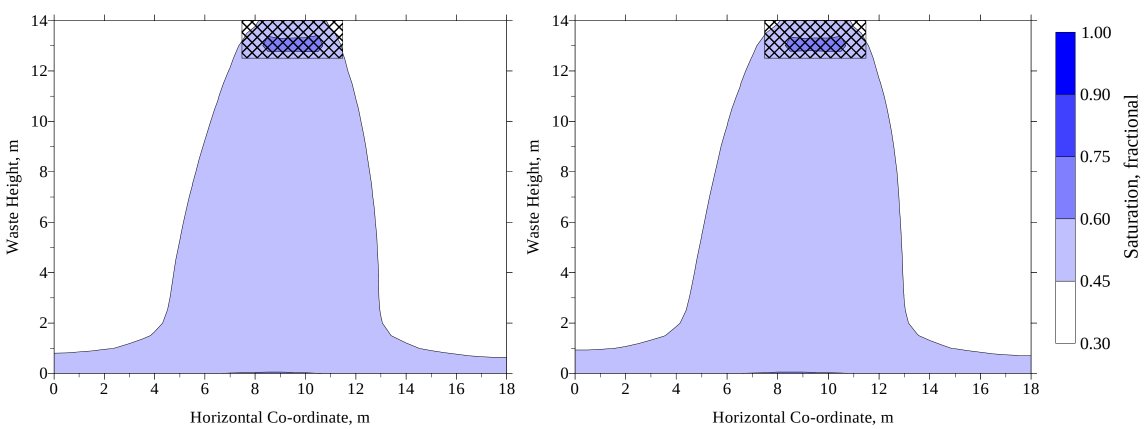


Figure 5.3.3. Predicted saturation iso-clines for a Yolo County Demonstration Project trench after one (a) and two (b) weeks of operation. Daily application rates are shown in Table 5.3.2.



(a) (b)

Figure 5.3.4. Predicted saturation iso-clines for a Yolo County Demonstration Project trench after three (a) and four (b) weeks of operation. Daily application rates are shown in Table 5.3.2.



(a) (b)

Figure 5.3.5. Predicted saturation iso-clines for a Yolo County Demonstration Project trench after five (a) and six (b) weeks of operation. Daily application rates are shown in Table 5.3.2.

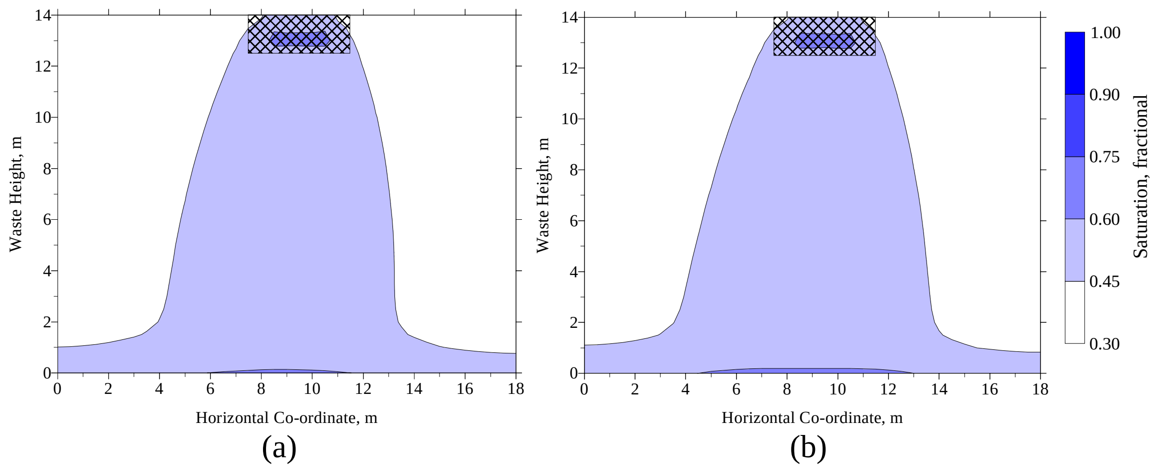


Figure 5.3.6. Predicted saturation iso-clines for a Yolo County Demonstration Project trench after seven (a) and eight (b) weeks of operation. Daily application rates are shown in Table 5.3.2.

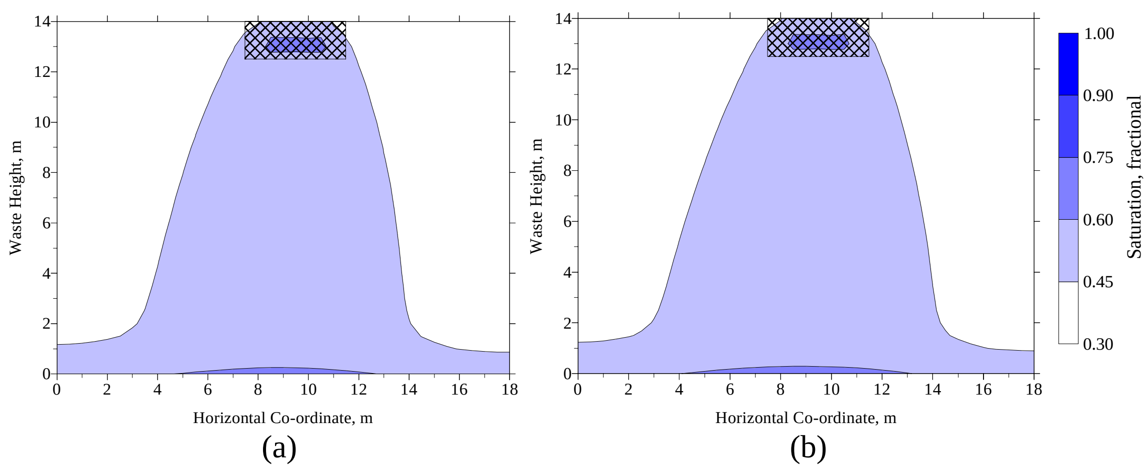


Figure 5.3.7. Predicted saturation iso-clines for a Yolo County Demonstration Project trench after nine (a) and ten (b) weeks of operation. Daily application rates are shown in Table 5.3.2.

5.4 UCF/EPA Test Cell

A test cell was constructed at the Orange County, FL Landfill with the specific goal of monitoring leachate flow characteristics. The test cell was constructed during the period of July 1995 to January 1996 in the southwest corner of the Orange County Landfill. The cell had a 4,047-m^2 (1-acre) footprint, a maximum depth of 7.3 m (24 ft), and a LCS consisting of an HDPE geo-membrane, geonet, perforated pipe, gravel, and sand. Leachate recirculation was accomplished via a 2-m (6-ft) wide by 9.1-m (30-ft) long by 0.6-m (2-ft) deep trench at the top of the cell. The trench was filled with whole waste tires, gravel, and a perforated PVC pipe which was fed via a multiple-stage centrifugal pump located at the landfill leachate sump. Leachate routing was monitored with 48 gypsum blocks installed at various heights within the cell and flow meters on the leachate application pipe and the LCS leachate removal pipe. Soil tensiometers were also installed at the surface of the landfill but yielded little valuable data.

During the 13-week period from March third to June second, 3,434 l (13,000 gal) of leachate were recirculated. Data on the exact times and volumes of leachate application are included in Chapter 3.

The daily cover (silty-sand) applied to the cell eroded into the trench on several occasions and severely impeded leachate flow. The trench was drained and the sides were reinforced with sandbags. Pumping was resumed once the repairs were completed and the trench began to drain again. Nine of the 47 operational moisture blocks (one was damaged during filling operations) generated moisture data during this time period however, no leachate emanated from the LCS.

The simulated application rates were based on modeling one-half of a 1 m section of the 9.1-m long trench. When leachate was recirculated, it was applied over a 2-hr period which is similar to the pumping periods used in the simulation. The results presented below are for a waste mass with a permeability of 10^{-2} cm/s.

Figures 5.4.1 through 5.4.9 depict the saturation iso-clines generated by the model along with data produced by the gypsum moisture blocks. Since it was assumed in the simulations that the waste mass was homogeneous, the absolute value of the x-co-ordinate was used when plotting the gypsum sensor data on the saturation iso-clines generated by the simulation and shown in the results section.

Prior to discussing the figures, it is interesting and important to recall that over the time period studied, only nine of the 47 active sensors indicated an increase in saturation. The lateral spacing of these sensors was approximately 1.5 m in the central 12 m of the test cell and no more than 3 m apart in other areas. Despite this dense sensor placement most of them were not impacted. The most logical reason for this path is preferential flow effects. It is also known from inspection of materials removed during the installation of soil moisture tensiometers that there were several areas with large amounts of plastic sheeting. This sheeting may have caused excessive lateral movement of leachate effectively blinding many of the sensors. The small size and placement requirements of the sensors may have also contributed to these results. They are very small cylinders, approximately 2.5 cm in diameter and 2.5 cm long, and must be placed in intimate contact with the media being measured in order to generate accurate results. In landfills, this media also serves to pad and protect the sensor. The media used in this study was cured compost. The hydraulic characteristics of this compost are unknown. If the compost had lower permeability than the waste mass, it may also have interfered with sensor readings. Future studies which plan to measure in-situ moisture contents should consider these problems prior to selecting and installing devices. Discrete point measurements, which could be missed, may not be as valuable as knowing that leachate is reaching a general area.

Inspection of Figures 5.4.1 through 5.4.9 does not lead to any definitive assessment of model prediction or leachate routing. All of the sensors showed a decrease in saturation after one week of operation, Figure 5.4.1. The sensor located on the ordinate at a height of 3.75 m was the only sensor to show a regular variation in moisture content. At various times, the three inner sensors at a height of 3.75 m agreed fairly well with the predicted iso-clines. The irregular and pointed shape of the predicted iso-clines, despite the homogeneous waste mass, implies that application rate and frequency will significantly impact the shape of the impact area. These effects are indicated most prominently by the fact that foremost point of the saturation front is not located along the ordinate as would be expected in a homogeneous waste mass but rather it is at a horizontal co-ordinate between 0.75 m and 2.25 m.

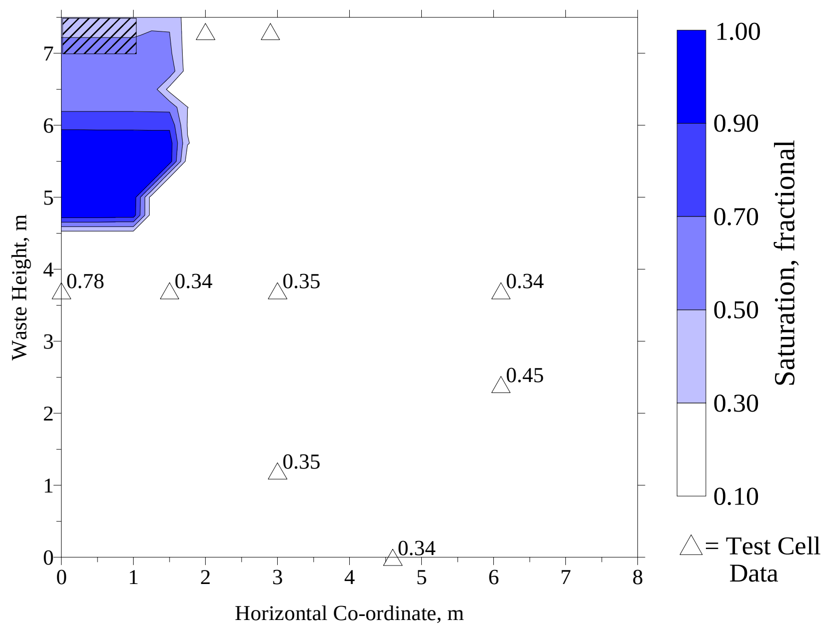


Figure 5.4.1. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after one week of operation.

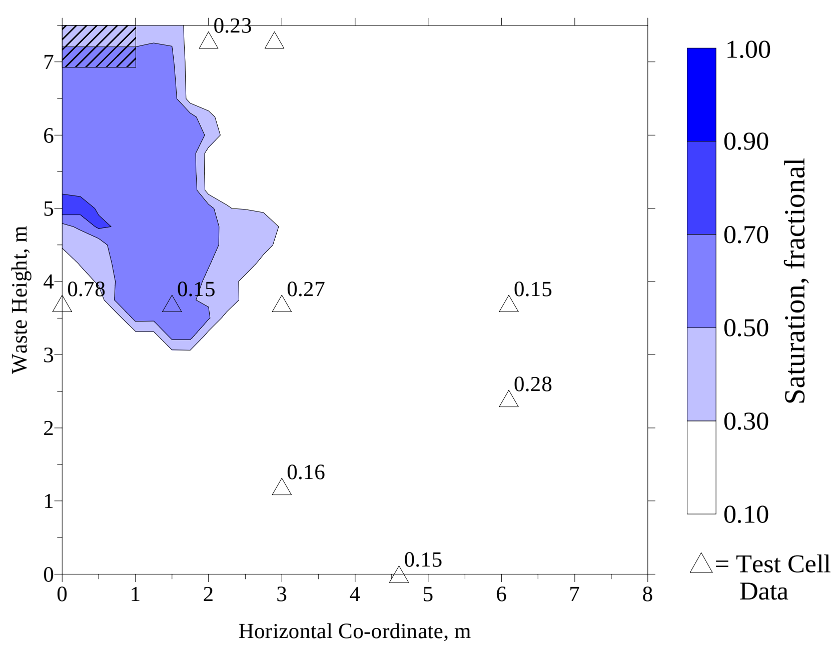


Figure 5.4.2. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after two weeks of operation.

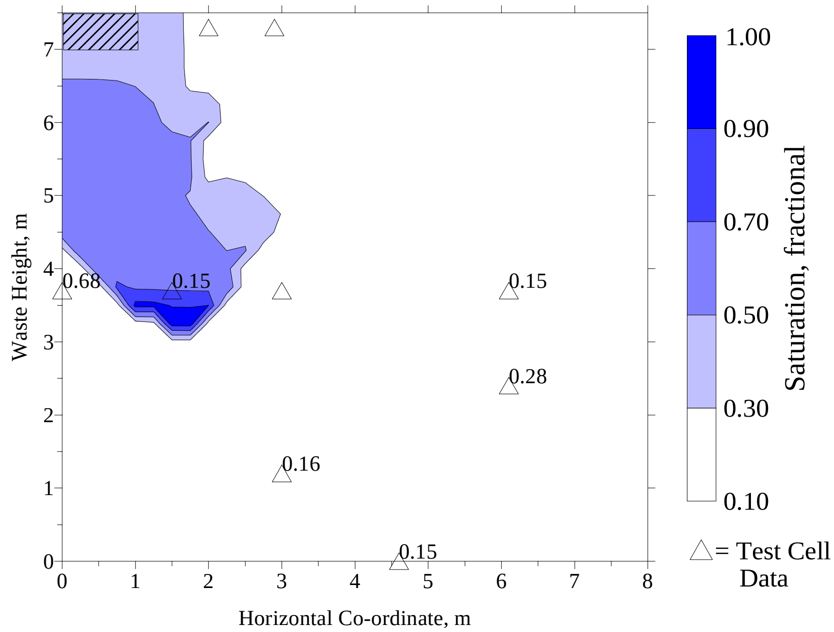


Figure 5.4.3. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after three weeks of operation.

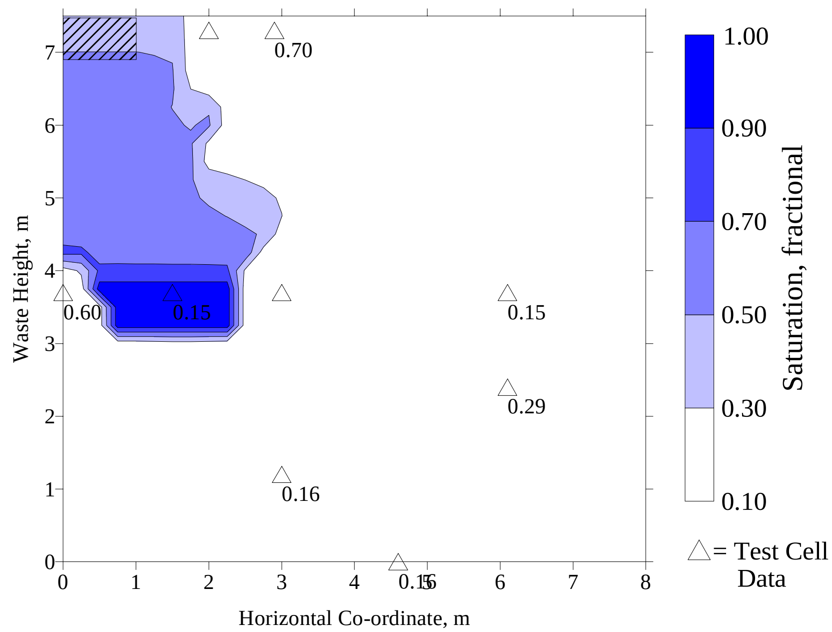


Figure 5.4.4. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after four weeks of operation.

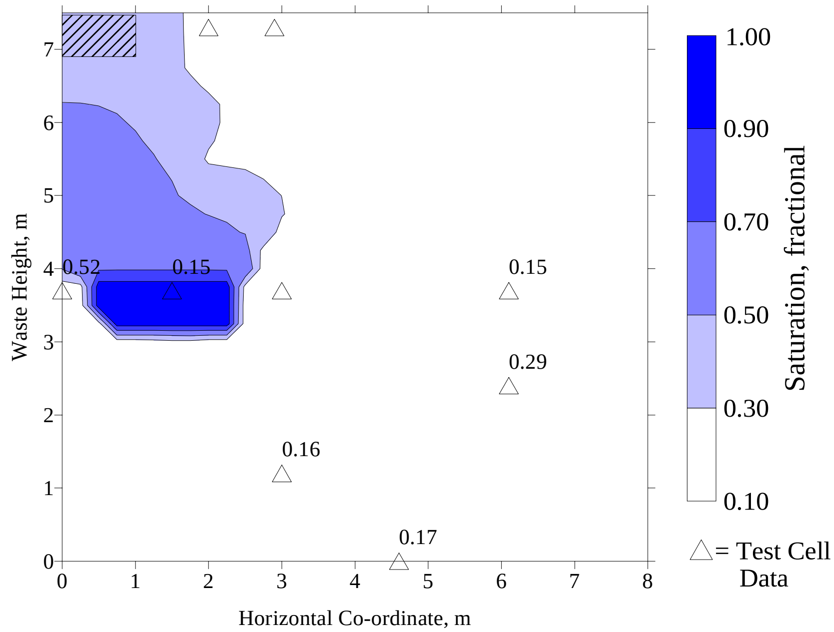


Figure 5.4.5. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after five weeks of operation.

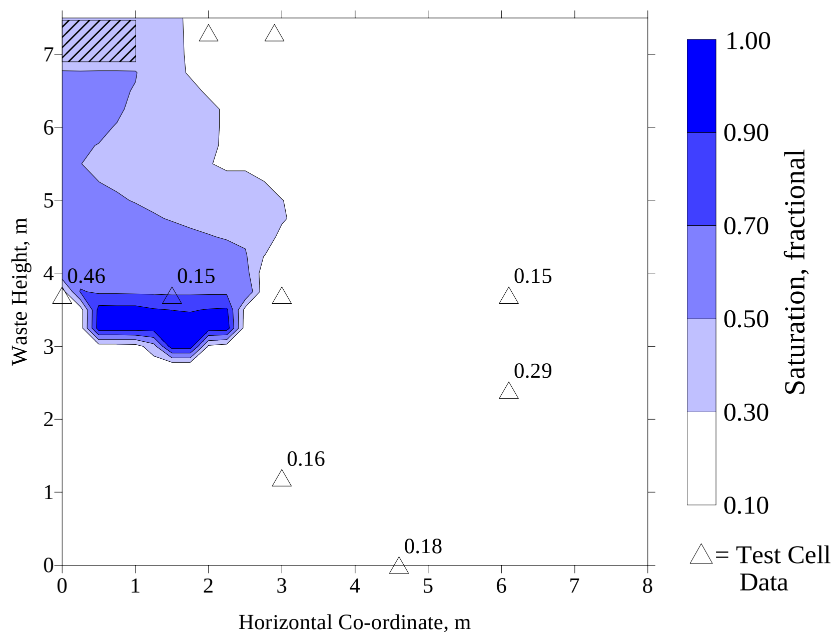


Figure 5.4.6. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after six weeks of operation.

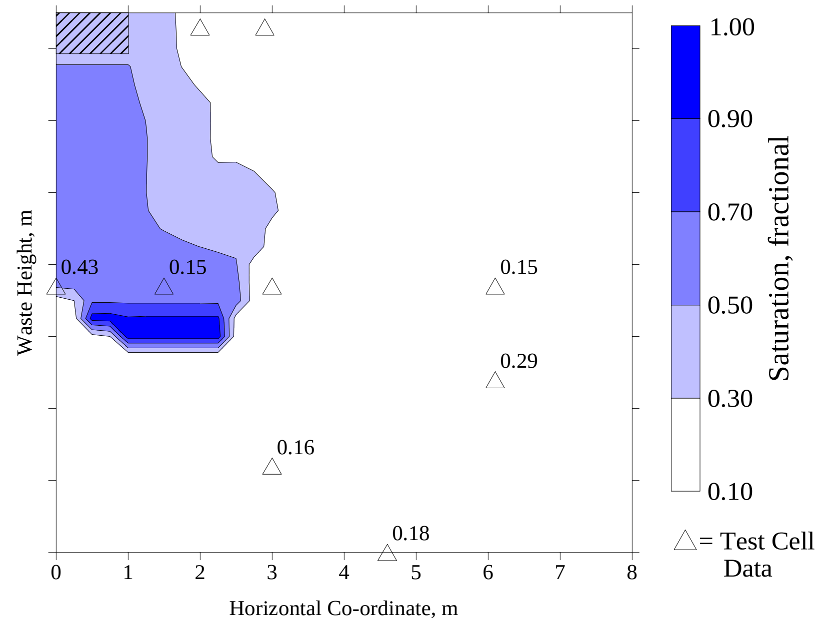


Figure 5.4.7. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after seven weeks of operation.

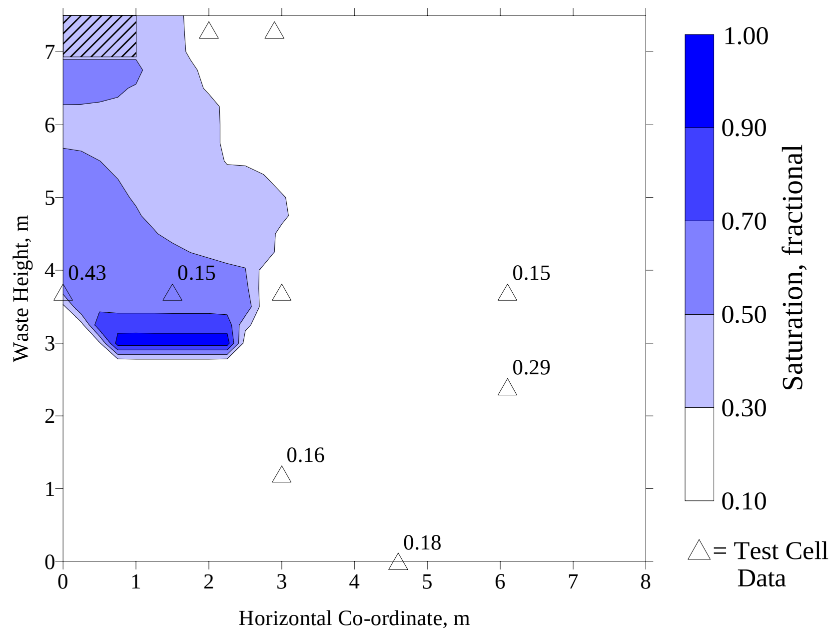


Figure 5.4.8. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after eight weeks of operation.

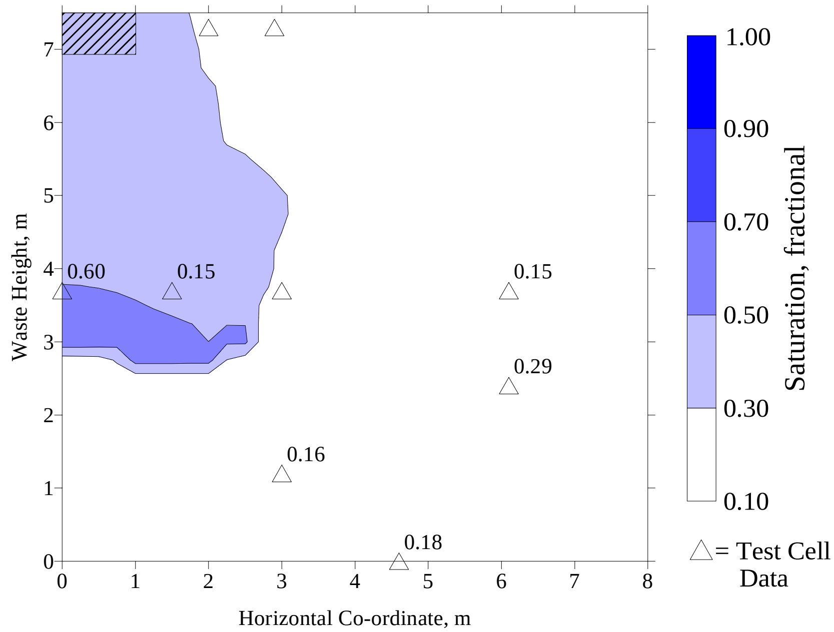


Figure 5.4.9. Simulated saturation iso-clines and measured saturations for the UCF/EPA test cell after thirteen weeks of operation.

5.5 Discussion

While the model did not predict accurately in all cases, the verification modeling effort provided a wealth of information regarding the direction future modeling efforts should, and should not take as well as data requirements for future modeling programs.

Every field study modeled showed that channeled flow must be accounted for in future modeling efforts. Unsaturated Darcian flow will also have to be included in future modeling efforts. While including channeled and unsaturated flow in future models will be difficult, simulating the exchange of liquid between Darcian and channeled flow regimes will be the real challenge.

In order to facilitate these multi-phase modeling efforts, laboratory scale research into these areas will be required. This research should focus on developing relationships between Darcian and channeled flow but must also develop scale-up information so that the laboratory findings can be applied to full-scale studies.

Accurate, complete, and organized data collection from the site to be modeled will be crucial as models become more realistic, and hopefully more accurate. In the verificational modeling effort documented above, little hydraulic information on the waste masses was available. It was necessary to assume permeabilities and moisture contents and adjust them until acceptable results were produced. While this effort was useful in that it showed the model could be calibrated based on bulk site data, most modeling efforts are directed at simulating the future. In order to do this, modelers must have access to data on the waste characteristics (permeability, moisture contents, etc.) as well as the location and characteristics of daily and intermediate cover materials. Once this material is provided, modelers will be able to use it as a starting point for model calibration resulting in better predictive capabilities.