2. Infiltration of Water From Rainfall or Sprinkler Irrigation

Objective:

1. To determine the nature of the dynamic infiltration process for rainfall or sprinkler irrigation.
2. To compare the infiltration rate at different times with the saturated hydraulic conductivity of the soil.
3. To determine the total amount of infiltration, the total amount of runoff, and the time at which runoff occurs

Situation:

A farmer recently irrigated his field so that the soil was relatively wet. Unexpectedly, a rainstorm occurred. The storm lasted for 6 hours. The rainfall rate was 0.75 cm/hr. The field was a silt loam soil.

Simulation:

Simulate water movement into a vertical semi-infinite silt loam soil with an initial matric potential of -100 cm. Apply water to the soil at a rainfall rate of 0.75 cm/hr. Simulate movement for 6 hours. Display the flux of water at the soil surface and the cumulative infiltration of water as functions of time.

Solution:

To better understand the nature of the infiltration process due to the storm rainfall, the CHEMFLO model was generated. The model consists of three main steps: 1) defining the soil system, 2) specifying the initial conditions, and 3) assigning the boundary conditions.

For soil system properties, we set the soil type to Silt Loam, with semi-infinite soil characteristic of maximum distance equal to 50 cm. Figure 1 represents the soil properties in the problem of interest.

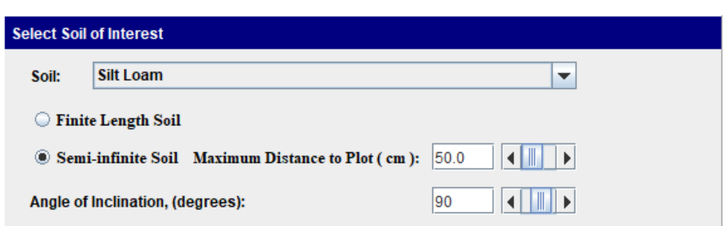

Figure 1- Soil system properties

Then, the Uniform Metric Potential condition was selected to be equal to -100 cm (Figure 2).

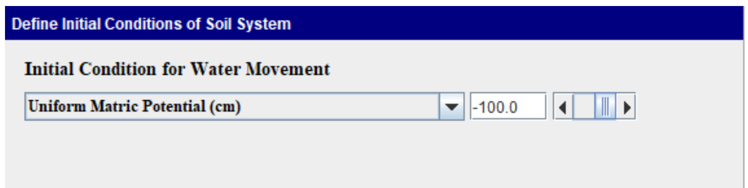

Figure 2- Initial Conditions

Finally, for boundary conditions, the rainfall with the intensity of 0.75 cm/hr was defined at distance x = 0 cm. Figure 3 shows the attributes of the boundary conditions.

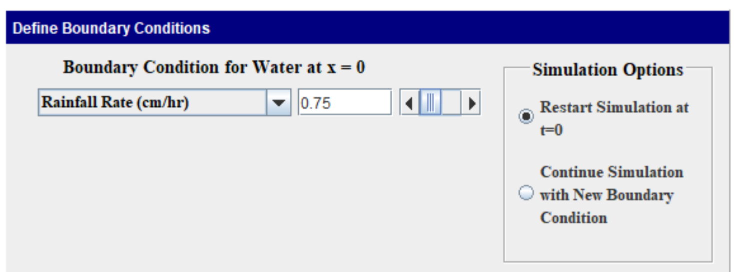

Figure 3- Boundary Conditions

After building the model based on the information provided in this problem, the following answers were driven from the model's results.

Questions:

- How much of the rain water entered the soil?

For answering the question, the table of the Cumulative Flux (cm) vs. Time at position x = 0 cm during the 6 hr rainfall was extracted from the graph output (Table 1).

Table 1- Cumulative flux (cm) over. time at position x = 0 cm

Time (hr)	Position (cm)	Cumulative Flux (cm)
0	0	0
1	0	0.75
2	0	1.343
3	0	1.812
4	0	2.26
5	0	2.706
6	0	3.152

Data shows that the total rainfall infiltrated over the 6 hours of event is equal to 3.152 cm from total rainfall equal to 0.75 (cm/hr) × 6 hrs = 4.5 cm.

- Did any runoff occur? If so, how much?

Yes. The total runoff value is:

$$Runoff = P - F$$
$$Runoff\ (cm) = 4.5\ cm - 3.152\ cm = 1.348\ cm$$

- When did runoff begin?

Figure 4 represents the infiltration rate of the soil during the 6 hours period. Runoff begins when the infiltration rate starts to decrease, which in this problem it is around 1 hour after beginning of the rainfall.

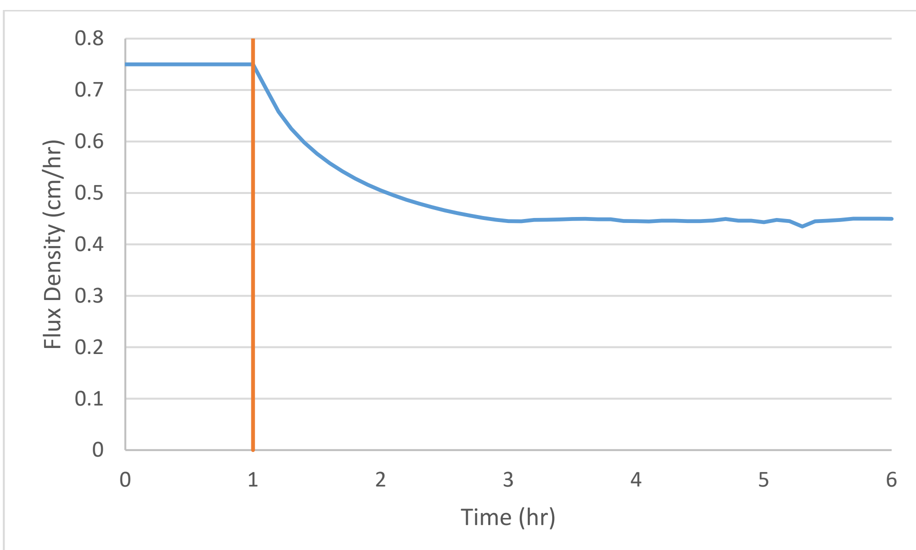

Figure 4- Infiltration Rate vs. Time

- Describe the curve for the infiltration rate as a function of time. It is initially constant. What is the value of the infiltration rate during this constant phase? Compare this rate to the rainfall rate.

The curve for infiltration rate over time represents how much rainfall water interns into the soil from the surface (Figure 4). It is constant and equal to 0.75 cm because the rainfall content is less than the maximum infiltration rate (happens at the begging of the infiltration). Therefore, all the value is penetrated into the soil.

- Eventually the infiltration rate decreases. At this time the soil is no longer able to transport water from its surface as fast as it is applied. This is the beginning of the runoff phase. At what time does runoff begin?

About an hour after rain started. The orang line in figure 4 shows the beginning of the runoff phase.

- How much water entered the soil surface by the end of the 6-hour period? How much water was applied as rainfall during this period? How much runoff occurred? (The amount of runoff is the difference between the amount applied and the amount entering the soil. This calculation assumes that there is no surface storage of water.)

3.152 cm water entered the soil surface during the 6-hour rainfall event. In addition, we got 4.5 cm rainfall in this period. The subtraction of the rainfall and infiltration gives us the total runoff, which is equal to1.348 cm (Table 1).

- Compare the rainfall rate to the saturated hydraulic conductivity for the soil. Compare the final infiltration rate to the saturated conductivity of the soil.

Figure 5 shows the hydraulic conductivity curve over the 6 hours period. From the Figure 5, it can be seen that the maximum value of the hydraulic conductivity happens at time 1 hour, when soil completely saturated. Since its maximum value is less than the rainfall rate (P = 0.75 cm), it is expected that the runoff happens after that time.

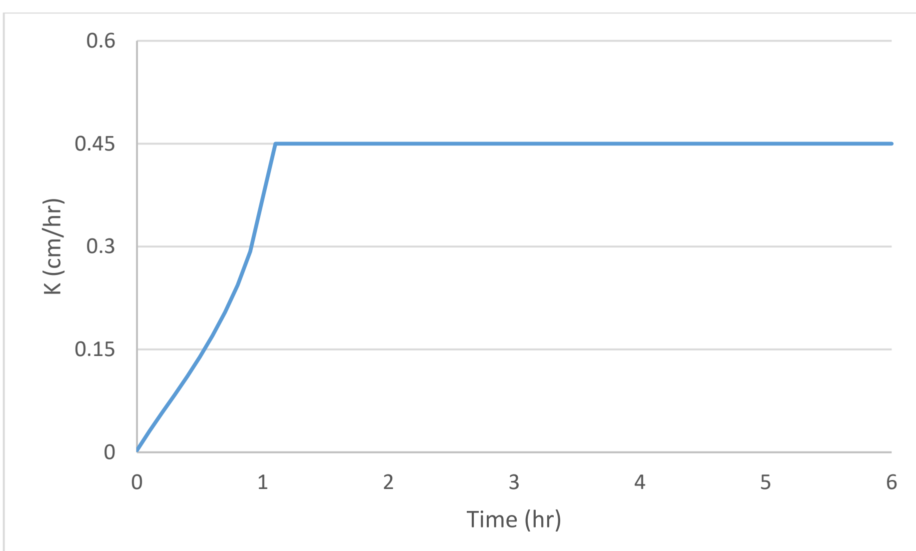

Figure 5- Hydraulic conductivity curve over the 6 hours period

Comparing the final infiltration and the maximum hydraulic conductivity shows that both values are almost the same. However, the time that the minimum infiltration rate happens is far away from the time that hydraulic conductivity gets its maximum value. It is because the unsaturated zone distance from surface is smaller than length of unsaturated influence.

Additional Work:

1. Retain the lines for the graphs used above. Then decrease the saturated conductivity of the soil by 0.1 cm/hr and repeat the simulation. Compare the sets of curves. Did the reduction of saturated conductivity have much impact upon the time at which runoff began or on the total amount entering the soil?

In this part we set the hydraulic conductivity equal to 0.1 cm/hr (Figure 6).

Semi-infinite Soil	Max Dis to Plot (cm)	Conductivity Function	Water Characteristic Function	Organic Carbon (g/g)	Bulk Density (Mg/m3)
	50.0	van Genuchten	van Genuchten	0.014	1.55
		K_s (cm/hr) = 0.1	θ_s (v/v) = 0.45		
		α (1/cm) = 0.02	θ_r (v/v) = 0.067		
		n = 1.41	α (1/cm) = 0.02		
			n = 1.41		

Figure 6- Soil properties

Table 2 represents the comparison of the total runoff infiltrated between two set of soils with deferent hydraulic conductivities. The results show that by decreasing the hydraulic conductivity the cumulative infiltration flux decreases significantly, in contrast, the runoff value increase during the 6 hour rainfall.

Table 2- The comparison of the total runoff infiltrated between two set of soils

Time (hr)	Position (cm)	Cumulative Flux (cm) Ksat = 0.45 (cm/hr)	Cumulative Flux (cm) Ksat = 0.1 (cm/hr)
0	0	0	0
1	0	0.75	0.4503
2	0	1.343	0.6609
3	0	1.812	0.8272
4	0	2.26	0.9718
5	0	2.706	1.103
6	0	3.152	1.225

The effect of the change on timing of the runoff can also be seen in Figure 7 and 8, which the timing change from around an hour for K_{sat} = 0.45 (cm/hr) to about 30 min for K_{sat} = 0.1 (cm/hr).

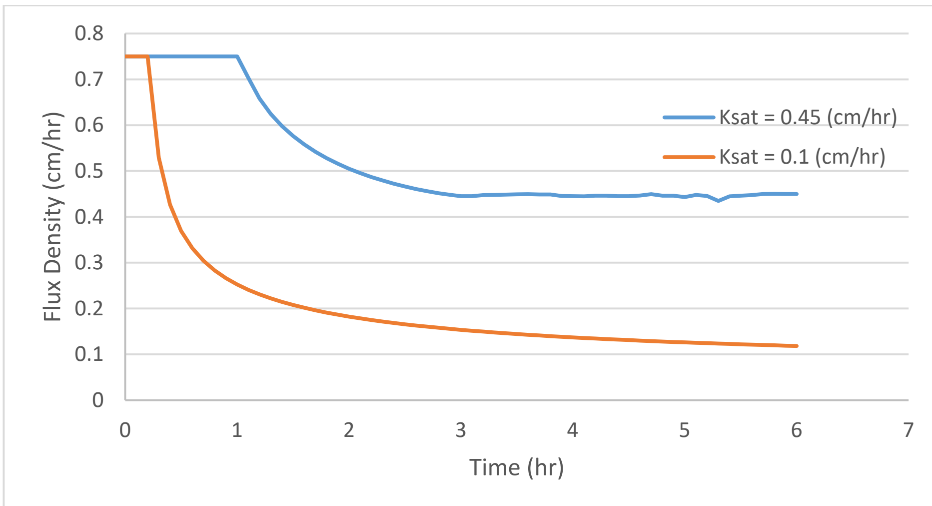

Figure 7- Infiltration Rate vs. Time

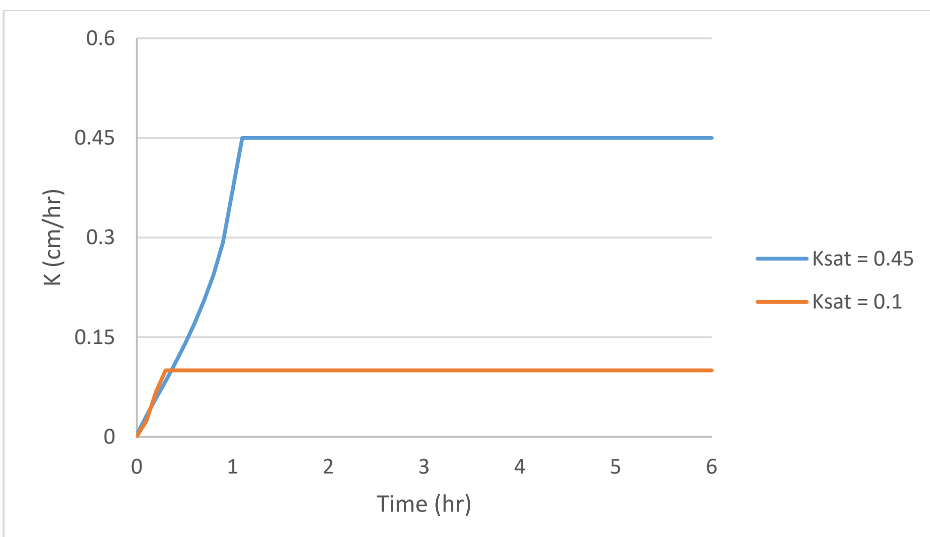

Figure 8- Hydraulic conductivity at soil surface

2. Repeat the exercise with different rainfall rates. How does rainfall rate influence the time at which runoff begins and the total amount entering the soil in the 6 hour period?

From Figure 9, we can see that by reducing the value of the rainfall the timing of the runoff is increases remarkably. The time is increases from about one hour for P = 0.75 cm/hr to almost 3.0 hours for P = 0.5 cm/hr. And there is no runoff in 0.25 cm/hr rainfall, since the infiltration rate is above the rainfall value. Then, all rainfall inters into the soil during the 6 hours period.

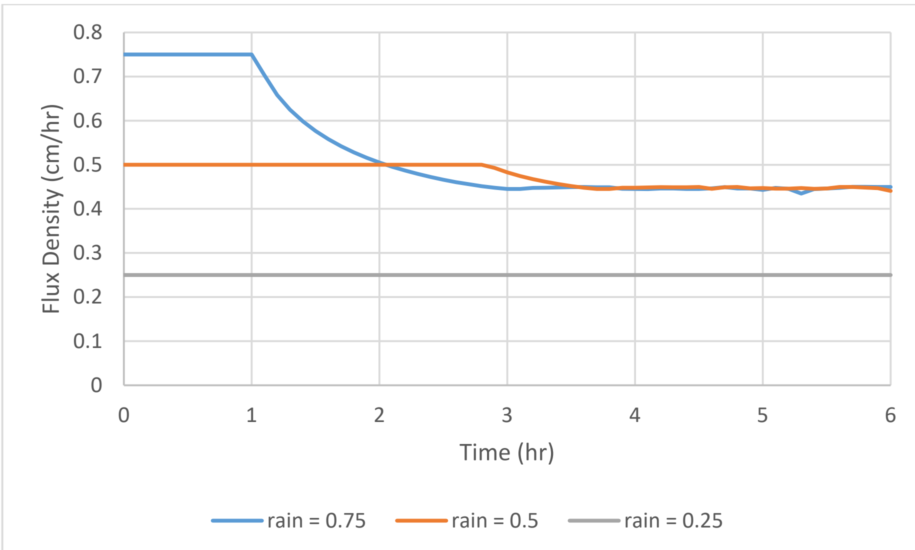

Figure 9- Infiltration rate vs. time for different rain storms

Looking at Hydraulic Conductivity graph, the K have a chance to get its maximum value of 0.45 cm/hr for rainfall 0.75 and 0.5 cm/hr, but K does not reach to saturated hydraulic conductivity in this period due to the small value of the rainfall (0.25 cm/hr) comparing with its K_{sat} (Figure 10).

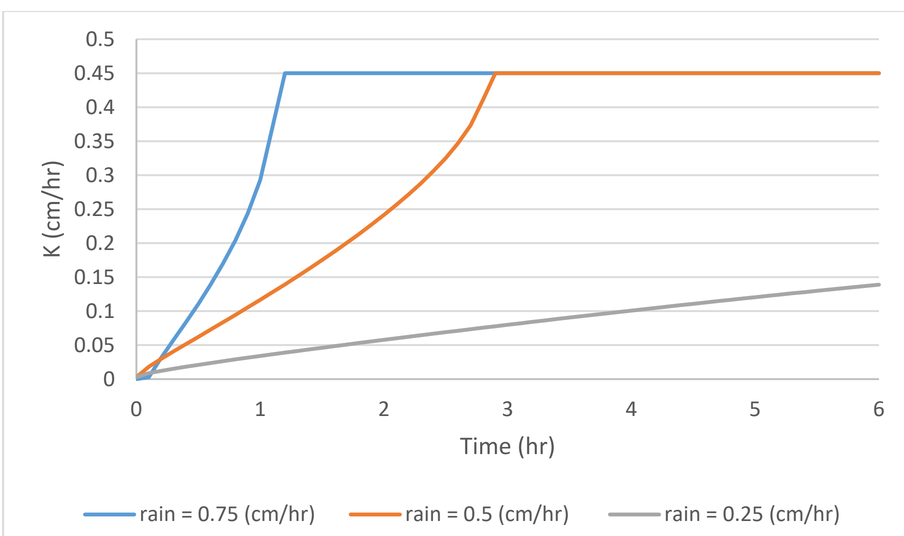

Figure 10- Hydraulic conductivity at surface for different rain storms

Table 3 represents the cumulative infiltration flux for different storm rainfall events. The most vivid difference is associated with the rainfall event P = 0.25 cm/hr which all precipitation is infiltrated over the 6 hours period.

Table 3- cumulative infiltration flux for different storm rainfall events

Time (hr)	Position (cm)	Cumulative Flux (cm)		
		P = 0.75 (cm/hr)	P = 0.5 (cm/hr)	P = 0.25 (cm/hr)
0	0	0	0	0
1	0	0.75	0.5	0.25
2	0	1.343	1	0.5
3	0	1.812	1.499	0.75
4	0	2.26	1.955	1
5	0	2.706	2.403	1.25
6	0	3.152	2.849	1.5

8. Influence of Initial Water Content upon Water Movement

Objective:
To observe the influence of initial soil wetness upon infiltration, runoff, and depth of wetting for a fixed rainfall rate.

Situation:
A person wanting to assess the runoff potential of a certain field, applied water to it by sprinkling at an intensity of 2.5 cm/hr for 6 hours. Runoff began at 5.3 hours. He concluded that runoff would not occur unless storms of 2.5 cm/hr intensity exceeded 5 hr in duration. Another person stated that the time to runoff would depend upon the initial wetness of the soil. You have been asked to simulate infiltration for different initial water contents to inform them of the importance of initial water content upon wetting. Since they are asking for your services, they also want comparisons of the total amount infiltrating the soil in 6 hours and the depth of wetting.

Simulation:
Simulate water movement into 4 vertical semi-infinite columns of the default soil with initial matric potentials of -5000 cm, -1000 cm, -500 cm, and -100 cm. Apply water at a rate of 2.5 cm/hr for 6 hr. Use graphs of water content profiles, infiltration rates, and cumulative infiltration to answer the questions.

Solution:
In this experiment, we set the soil type as a Default Soil along with a semi-infinite soil condition with Maximum Distance equal to 200 cm (Figure 11).

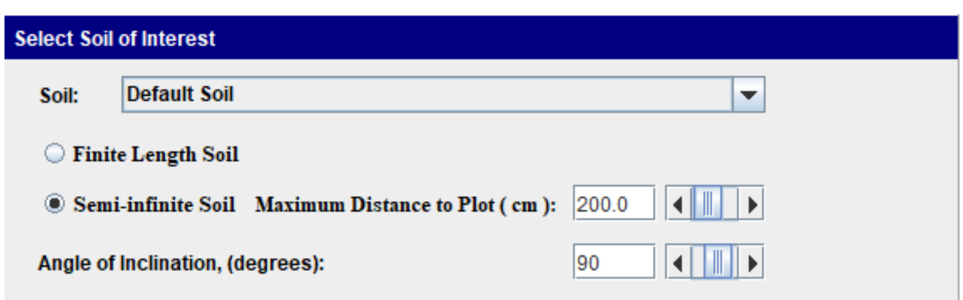

Figure 11 - Soil properties

Then four different soil systems are defined based on the soil wetness. Figure 12 represents the four initial matric potentials of -5000 cm, -1000 cm, -500 cm, and -100 cm assigned into the model in different runs.

Figure 12- Initial matric potentials of -5000 cm, -1000 cm, -500 cm, and -100 cm assigned into the model in different runs

For boundary conditions, rainfall rate is changed to 2.5 cm/hr (Figure 13).

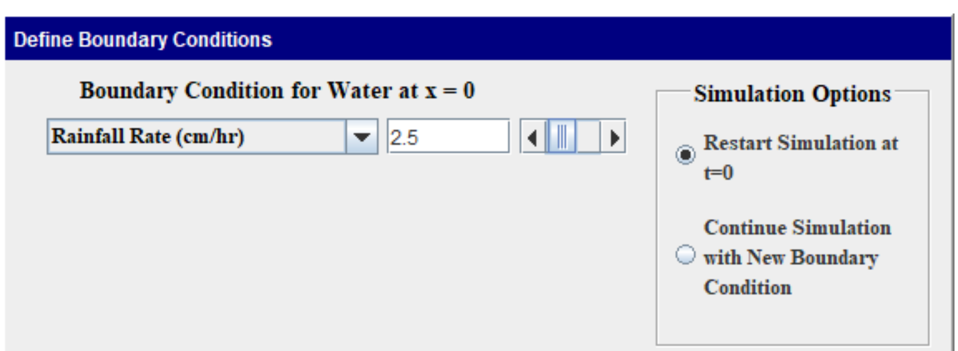

Figure 13- Defining rainfall

Questions:

1. Compare the infiltration rates each hour for the different soil systems. How does the infiltration rate depend upon the initial soil wetness? Explain why this change occurs.

As shown in Figure 14, the infiltration rate has an inverse relation with the wetness of the soil. By increasing the wetness (increase in the potential head), infiltration needs less time to starts lowering its rate with the greater magnitude of decreasing. It is mainly because of the moisture content exists in the soil sample. When we have a high potential head (-100 cm), it takes less time for the soil to reach the saturated zone, as the thickness of the unsaturated zone is small. As the potential head decreases, the pathway will be increased, and as a result, the time of saturation will be increase.

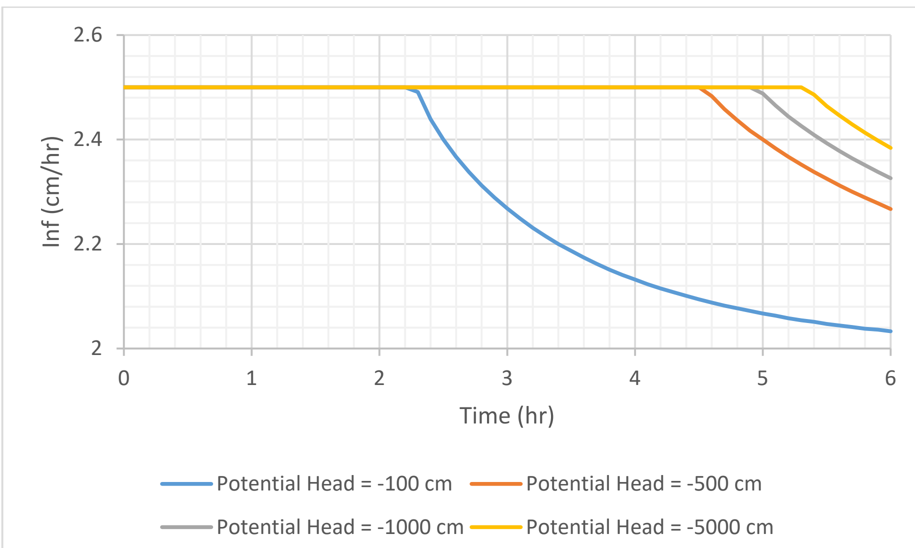

Figure 14- Infiltration rate at the Soil Surface with different potential heads

2. Compare the cumulative infiltration amounts during the entire application.

Table 4 represents the cumulative flux of water at the surface for different wetness conditions during the storm. Results show that the maximum cumulative infiltration is for the potential head -5000cm, which is equal to -14.96 cm, and this value decreases to 13.75 cm for the potential head -100 cm.

Table 4- Cumulative flux of water at the surface for different wetness conditions

Time	Position	Cumulative Flux (cm)			
(hr)	(cm)	Hp = -100 cm	Hp = -500 cm	Hp = -1000 cm	Hp = -5000 cm
0	0	0	0	0	0
1	0	2.5	2.5	2.5	2.5
2	0	5	5	5	5
3	0	7.401	7.5	7.5	7.5
4	0	9.592	10	10	10
5	0	11.69	12.47	12.5	12.5
6	0	13.74	14.8	14.9	14.96

3. Does the time to the beginning of runoff depend upon the initial soil wetness? How much does it change for this soil?

Yes. We know that runoff occurs when a curve of infiltration rate starts to decrease. By looking at Figure 14, it can be seen that the runoff happens faster for the higher value of potential head. This time changes from 2.3 hours for PH = -100 cm to 4.5, 5 and 5.3 for PH = -500, -1000 and -5000 cm, respectively.

4. Compare the final infiltration rates for the different initial conditions. How do they compare with the saturated hydraulic conductivity of the soil?

Table 5 shows the final infiltration rates for different soil conditions at the soil surface. Looking at the flux rate, we can see that all values are higher than the saturated hydraulic conductivity 2.0 cm/hr with the smallest value equal to 2.033 cm/hr for PH = -100 cm. It indicates that there is still an unsaturated zone left somewhere below the surface and helps to suck water into the soil.

Table 5- Final infiltration rates for different soil conditions

Time (hr)	Position (cm)	Flux Density (cm/hr)			
		Hp = -100 cm	Hp = -500 cm	Hp = -1000 cm	Hp = -5000 cm
6	0	2.033	2.267	2.326	2.384

5. What is the depth of wetting for each case? Do the water content profiles change?

Table 6 shows the depth of wetting at time 6 hr for each case. Results indicate that water can penetrate into the certain point for each soil system. Figure 15 represents the range of the changes for moisture content over the 120m depth at hour 6. Based on Figure 15 and Table 6, the depth of wetting increases by increasing the initial wetness.

Table 6- Depth of wetting at time 6 hr

Potential Head (cm)	Time (hr)	Wetting Depth (cm)
-100	6	114
-500	6	57
-1000	6	52
-5000	6	48

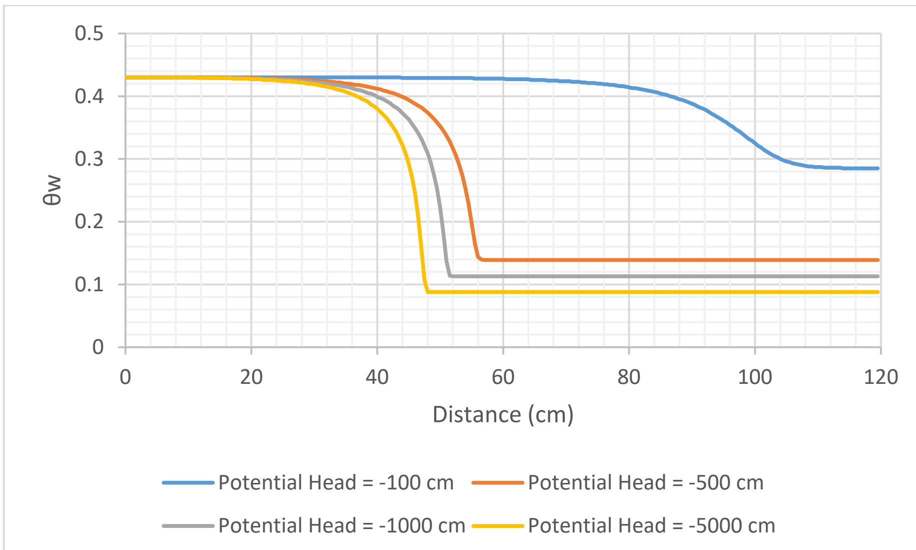

Figure 15- Moisture content vs. depth at hour 6

6. Does the time to runoff depend upon the initial wetness? Does this answer depend upon the soil? Does it depend upon the rainfall rate? Explain your answer.

From the infiltration result in Experiment 2 and 8, we can conclude that the runoff time depends on the initial wetness, soil type, and storm intensity. By increasing the initial moisture or rainfall rate, the time of runoff will decease. And depending on which soil type selected, the hydraulic conductivity and porosity change, and consequently, the runoff time will be change.

Additional Work:

- Reduce the saturated hydraulic conductivity of the soil used by 25% and repeat the experiment. How much does that change the answers you obtained.

For this work, we changed the saturated hydraulic conductivity from 2 cm/hr to 1.5 cm/hr (Figure 16), then six recent questions reviewed for this task.

Semi-infinite Soil	Max Dis to Plot (cm)	Conductivity Function	Water Characteristic Function	Organic Carbon (g/g)	Bulk Density (Mg/m3)
	200.0	van Genuchten	van Genuchten	0.014	1.55
		K_s (cm/hr) = 1.5	θ_s (v/v) = 0.43		
		α (1/cm) = 0.015	θ_r (v/v) = 0.08		
		n = 1.875	α (1/cm) = 0.015		
			n = 1.875		

Figure 16 - Saturated hydraulic conductivity change

1. Compare the infiltration rates each hour for the different soil systems. How does the infiltration rate depend upon the initial soil wetness? Explain why this change occurs.

By decreasing 25 percent of the saturated hydraulic conductivity, the time of water movement will increase. This reduction causes less water to infiltrate over time due to the rise of water moves through the pores. However, the same pattern is observed with this change, compared with previous results (Figure 17).

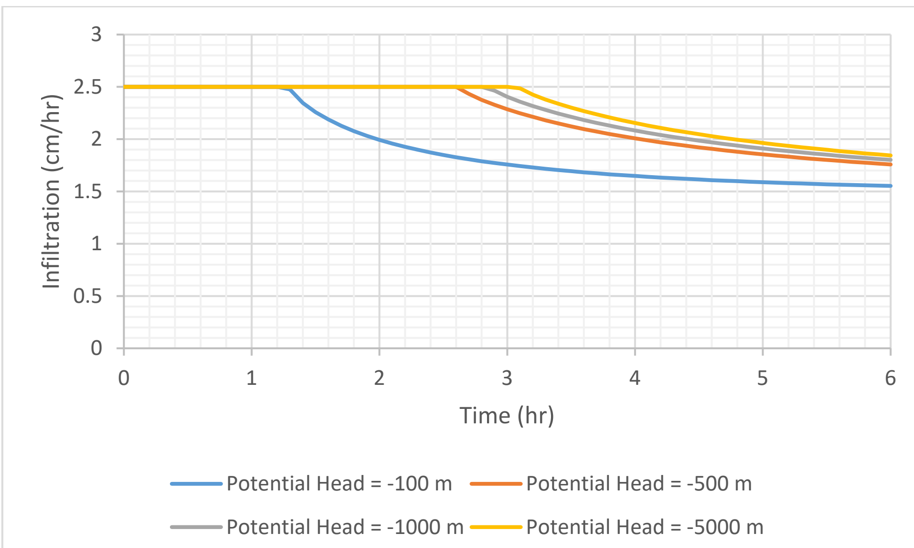

Figure 17- Infiltration rate at the soil surface

2. Compare the cumulative infiltration amounts during the entire application.

Comparing the results in Tables 4 and 7 shows that the cumulative flux reduced by reducing the value of saturated hydraulic conductivity. Overall, there is no change in the pattern observed in the previous study.

Table 7- Cumulative flux of water at the surface for different wetness conditions

Time (hr)	Position (cm)	Cumulative Flux (cm) Hp = -100 cm	Hp = -500 cm	Hp = -1000 cm	Hp = -5000 cm
0	0	0	0	0	0
1	0	2.5	2.5	2.5	2.5
2	0	4.774	5	5	5
3	0	6.631	7.452	7.492	7.5
4	0	8.327	9.582	9.714	9.814
5	0	9.942	11.51	11.7	11.86
6	0	11.51	13.31	13.55	13.76

3. Does the time to the beginning of runoff depend upon the initial soil wetness? How much does it change for this soil?

Yes, results also show that the decrease of saturated hydraulic conductivity accelerates the runoff to happen more quickly. This time changes to 1.3, 2.6, 2.8 and 3.0 hours for PH = -100, -500, -1000 and -5000 cm, respectively.

4. Compare the final infiltration rates for the different initial conditions. How do they compare with the saturated hydraulic conductivity of the soil?

From Table 8, we can see that all values are still higher than the saturated hydraulic conductivity 1.5 cm/hr with the smallest value close to 1.5 cm/hr for PH = -100 cm.

Table 8 - Flux density for different initial potential head

Time (hr)	Position (cm)	Flux Density (cm/hr)			
		Hp = -100 cm	Hp = -500 cm	Hp = -1000 cm	Hp = -5000 cm
6	0	1.553	1.758	1.802	1.844

5. What is the depth of wetting for each case? Do the water content profiles change?

Comparing the results in Table 9 with previous ones in Table 6, water content profile are almost the same in each case with different hydraulic conductivity. The big difference is associated with the potential head -100 m which 20 cm decreased by this change.

Table 9- Wetting Depth for different potential head at time 6 hr

Potential Head (cm)	Time (hr)	Wetting Depth (cm)
-100	6	98.5
-500	6	51.5
-1000	6	47.5
-5000	6	44.5

6. Does the time to runoff depend upon the initial wetness? Does this answer depend upon the soil? Does it depend upon the rainfall rate? Explain your answer.

Yes. The same reason as the previous one.

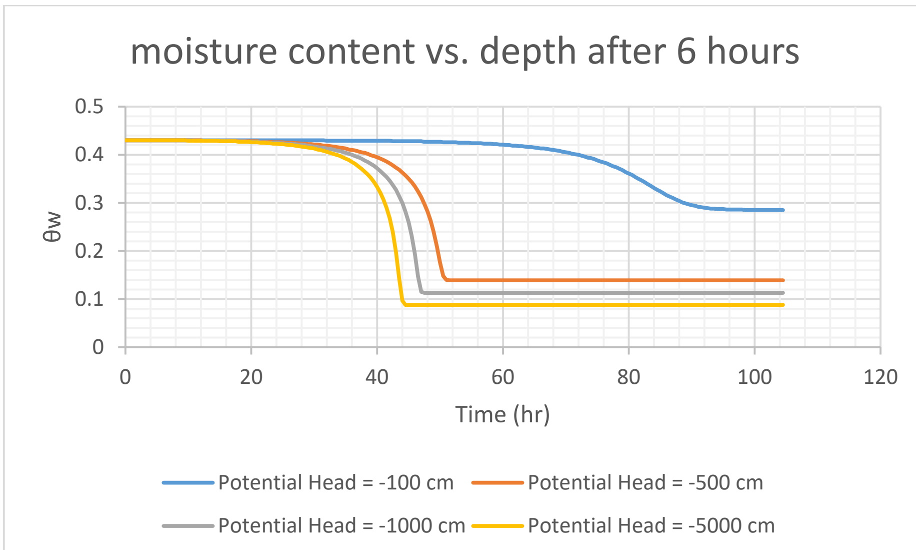

Figure 18- Moisture content vs. depth at hour 6

1. **Chemical Movement during Infiltration Due to Rainfall**
   Objective:
   To observe the movement of a chemical applied with irrigation water.

Situation:

A farmer decided to apply nitrate nitrogen to his field with his irrigation water. He irrigated for 6 hours at 1 cm/hr with a solution of 20 g m^{-3} nitrate. The soil contained no nitrate nitrogen before irrigation. What will be the distribution of the chemical immediately after irrigation?

Simulation:

Simulate movement into a loam soil with an initial matric potential of -500 cm and a length of 100 cm. The lower boundary condition for water is a constant potential of -500 cm. The upper boundary condition is a constant rainfall rate of 1 cm/hr. The upper boundary condition for chemical is that the inflowing solution has a concentration of 20 g m^{-3}. The chemical leaves the bottom by mass flow only. The loam has a bulk density of 1.55 Mg m^{-3}. The partition coefficient, degradation rate constants, and zero-order rate constants are all zero. Simulate movement for 6 hours.

Solution:

To track the chemical movement and its distribution in the vadose zone beneath the farmer field, the 1-D numerical model, CHEMFLO, is set up. In the soil property part, soil type is defined as a loam soil with a finite length of 100 cm at 90 degrees angle (Figure 19).

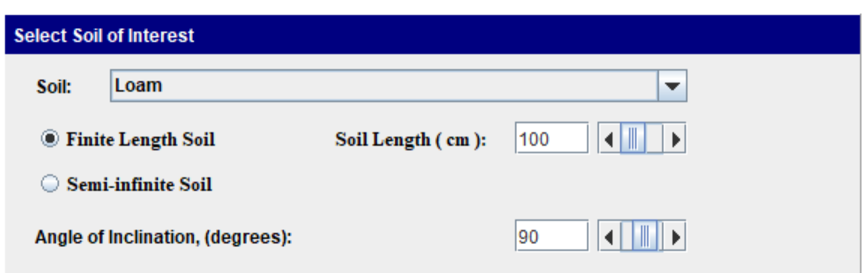

Figure 19- Soil properties

The vadose zone has an initial matric potential of -500 cm at the beginning, and there is no initial chemical concentration through the soil cylinder. Figure 20 represents the introduced initial values into the model.

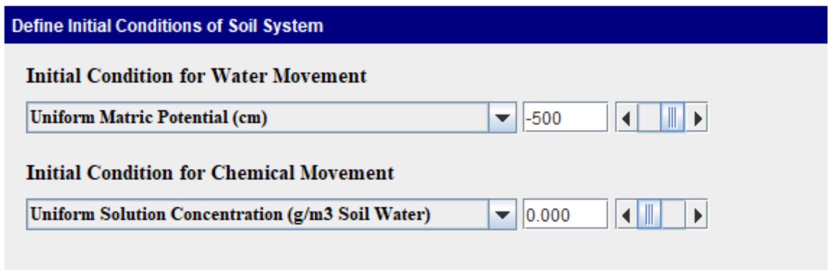

Figure 20- Introduced initial values

For boundary conditions at the surface area, the rainfall with the intensity of 1.0 cm per hour is defined to represent the Sprinkler Irrigation. Chemical concentration entering with this irrigation is about 20 gr/m3 (Figure 21). We also have a matric potential of -500 cm at the bottom boundary, and let the particles pass it freely to the deeper side (convective flow only for chemical movement in Figure 21).

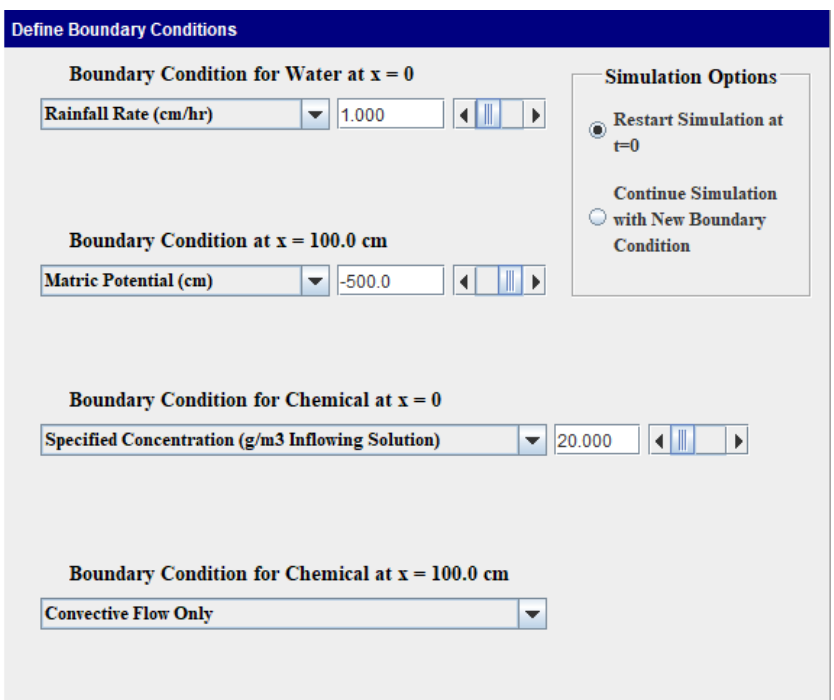

Figure 21- Boundary conditions

In the Transport Properties part, we left the information as default (Figure 22).

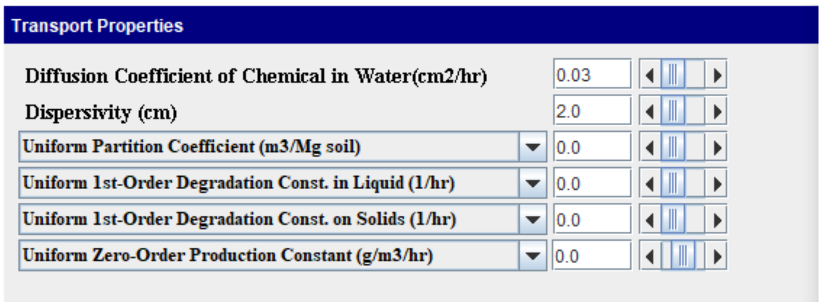

Figure 22- Transport properties

Questions:

1. Compare the shape of the water content vs. distance graph with the concentration vs. depth. What similarities do you observe? What are the differences? Does one seem to be ahead of the other?

Figures 23 and 24 represent the water content and contaminant variations through the depth for different periods. As can be seen, by increasing the time, both variables percolate deeper through the soil with the same penetration speed at the front. However, the rate of change is significantly sharper for the water content curve than the concentration one.

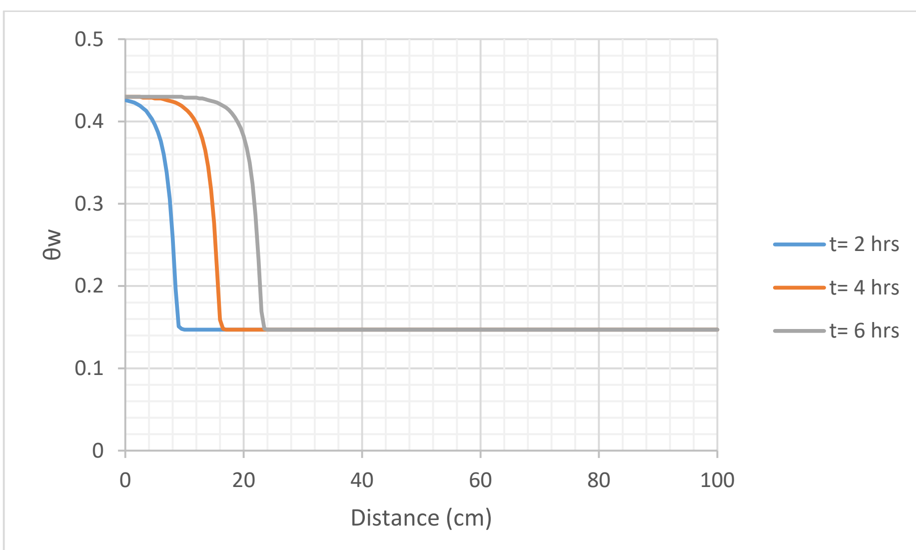

Figure 23- Water content vs. distance at different times

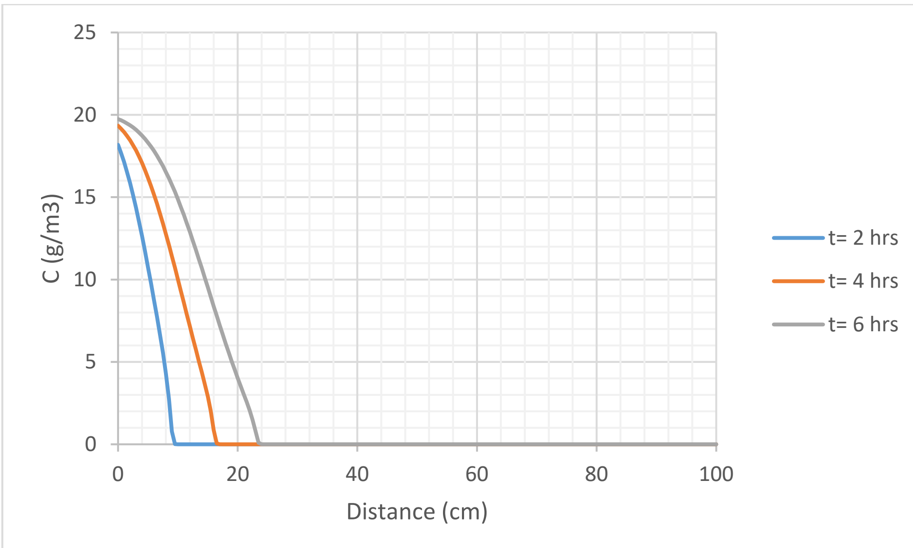

Figure 24- Concentration vs. depth at different times

2. Compare graphs of the flux of chemical at selected depths with the flux of water at those depths.

Figures 25 and 26 are brought down of the flux of water and chemical during the irrigation time at different places, respectively. Comparing both graphs shows that the compound reaches specific points when the flux of water starts to rise. For instance, the chemical reaches its maximum value immediately after starting the simulation at the x =0 cm. In contrast, the chemical is not seen at x = 30 cm, due to zero flux in 6 hours period of irrigation. However, the rate of the changes over time is remarkably grater for the curve of flux of water than the flux of chemical.

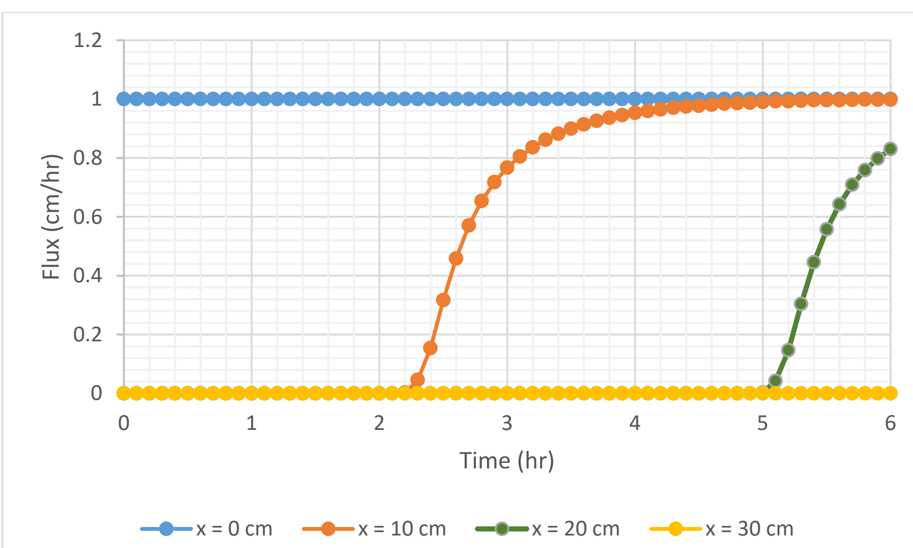

Figure 25- Flux of water vs. time at selected points

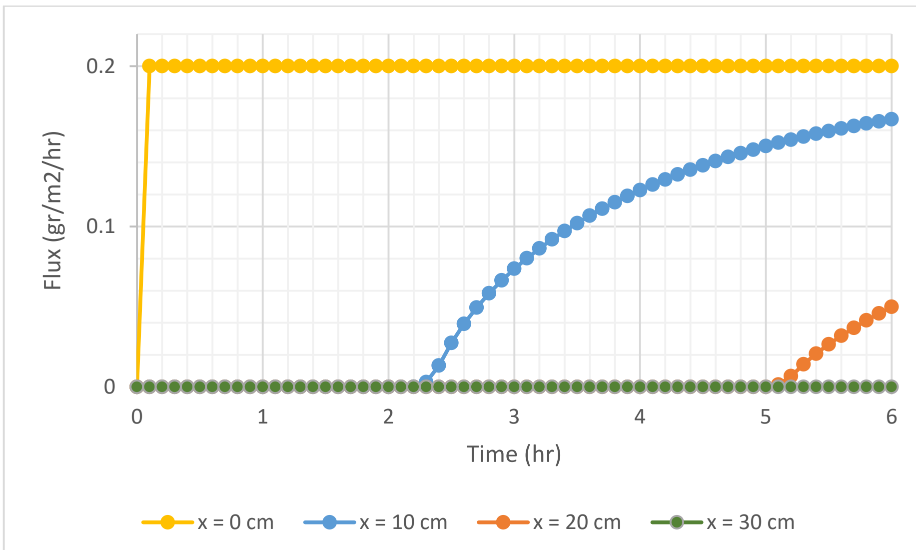

Figure 26- Flux of chemical vs. time at selected points

Additional Work:
Imagine that an unexpected storm came up after the irrigation. During the 12-hour storm, rain fell at a rate of .5 cm/hr. The concentration of the chemical in the rainfall was zero.

Solution:
To assess how much 12 hours storm affects the concentration of the chemical in the soil, we added the 0.5 cm/hr rainfall after 6 hours imposing the compound. Figure 27 represents the changes that have been down for this purpose.

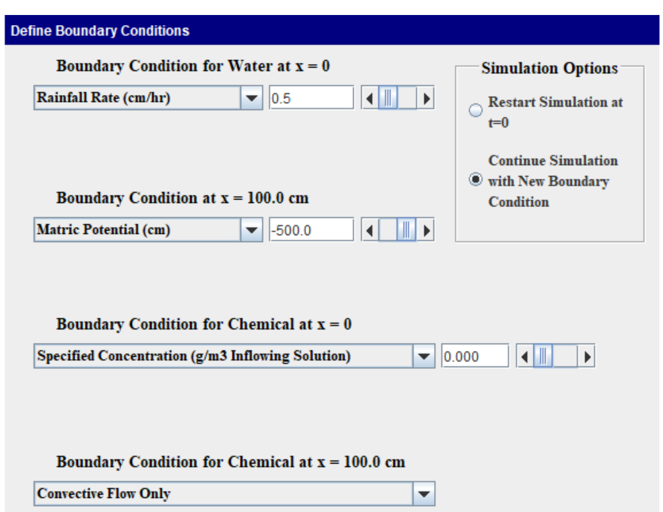

Figure 27- Changes that have been down for this purpose

1. What was the distribution of chemical after the rainstorm? Compare the water content and concentration distributions.

Figure 28 represents the chemical distribution through depth. The concentration, as can be seen, starts to rise from almost zero at the surface and reaches its maximum value of about 12 gr/m3 at x = 20 cm. After that, it dips to zero value at the point of 47 cm. Comparing the graph with water content vs. distance (Figure 29) shows that although the water content has its maximum value at the locations near the surface, the chemical is observed with the lower amount. It is because the value of the compound at the surface boundary for 12 hours storm even is equal to zero.

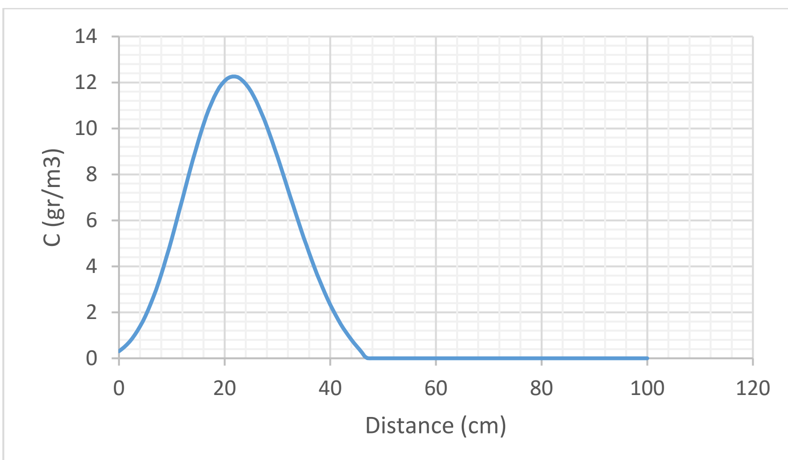

Figure 28- Chemical concentration vs. depth at 18 hr

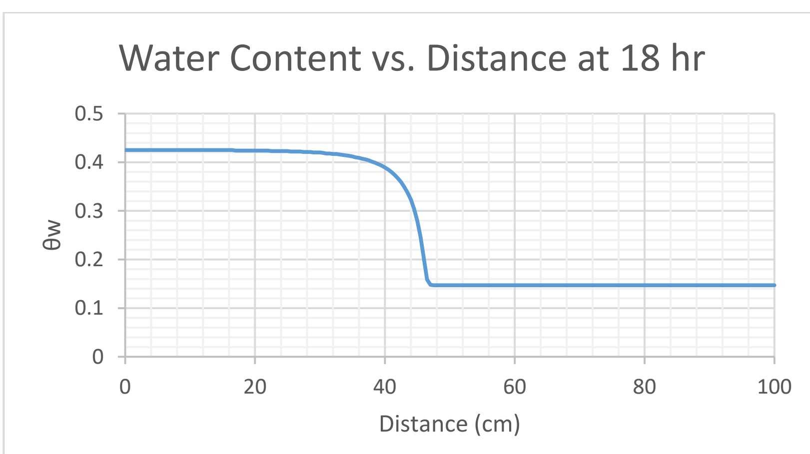

Figure 29- Water content vs. distance at 18 hr

2. How far has the chemical moved into the soil?

47 cm

3. Influence of Adsorption on Chemical Movement

Objective:
To determine the impact of adsorption of chemicals upon the chemical movement during infiltration.

Situation:
The farmer described in exercise 1 is considering applying other chemicals to his soil. These soils are adsorbed on the soil solids. How will this affect the movement of the chemicals?

Simulation:
Define the flow problem as in the case of exercise 1 with one exception. In this case, specify a partition coefficient of 0.5 m^3 Mg^{-1} for one experiment and 5 m^3 Mg^{-1} for a second experiment.

Solution:
In this experiment, two sets of the components with the partition coefficient equal to the 0.5 m3/Mg and 5.0 m3/Mg were defined to evaluate the absorption impact on chemical movement. Figure 30 and 31 are the screen capture of the values defined in the model.

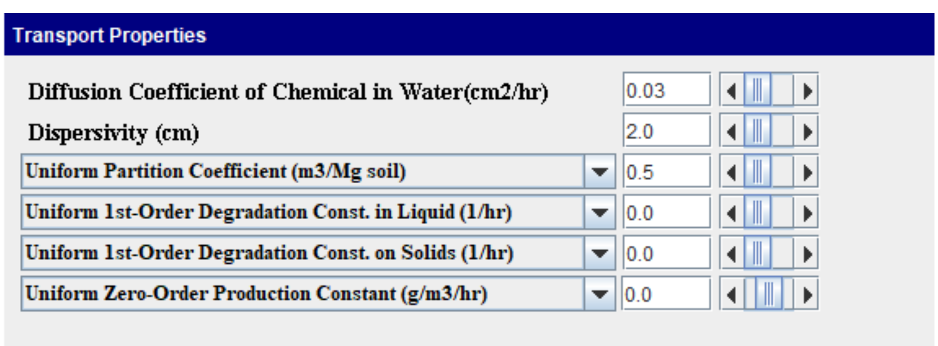

Figure 30- Transport properties for chemical with the partition coefficient 0.5 m3/Mg

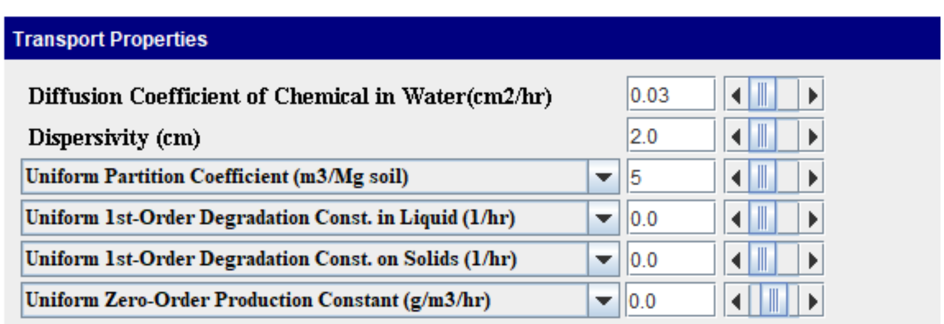

Figure 31- Transport properties for chemical with the partition coefficient 5 m3/Mg

1. Compare the shape of the water content vs. distance graph with the concentration vs. depth. What similarities do you observe? What are the differences? Does one seem to be ahead of the other?

Figures 32 and 34 represent the water content vs. depth over different time steps (t = 2, 4, and 6 hours) for two rates of absorptions. Results show that the water content is not changing by altering the partition coefficient, since fading the tracers does not affect the water balance as expected. However, the wetting zone expanded through depth by time increasing. Figures 33 and 35 represent the chemical concentration through the 100 cm soil depth for three different times of 2, 4, and 6 hours. Looking at the graphs represents that by increasing the partition coefficient, a more considerable amount of the components absorbs into the soil. As a result, the active zone imposed on the chemical is reduced significantly from about 18 cm for the partition coefficient of 0.5 m3/Mg to 8 cm for the partition coefficient equal to 5 m3/Mg.

Comparing the water content with the concentration solution reveals that the curves for both have the prompt falling trends into the ground. But the length of penetration for solution concentration is remarkably smaller than the water content due to the sorption factor.

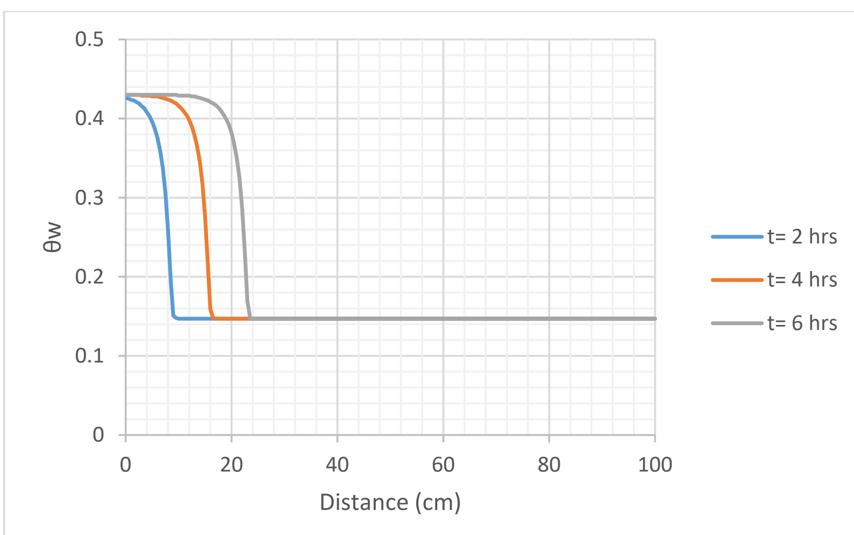

Figure 32- Water Content vs. Distance for Adsorption = 0.5

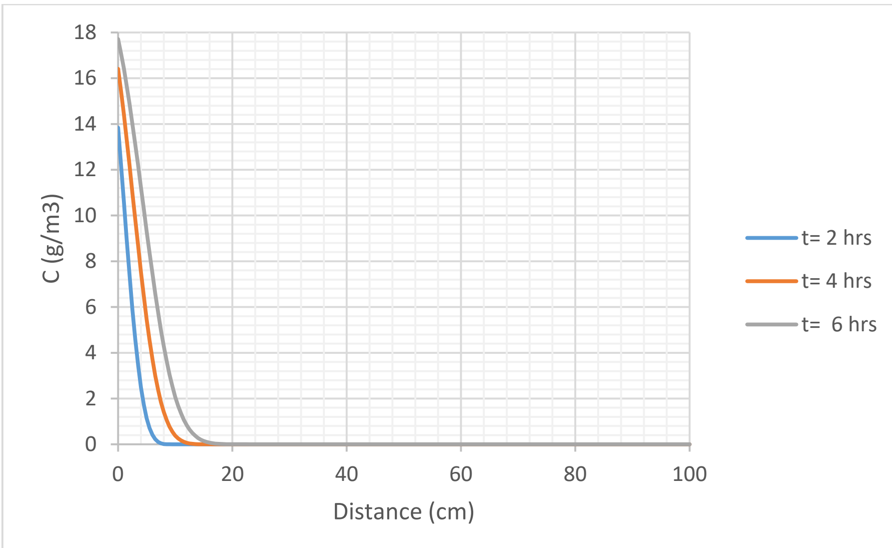

Figure 33- Concentration Solution vs. Depth for Adsorption = 0.5

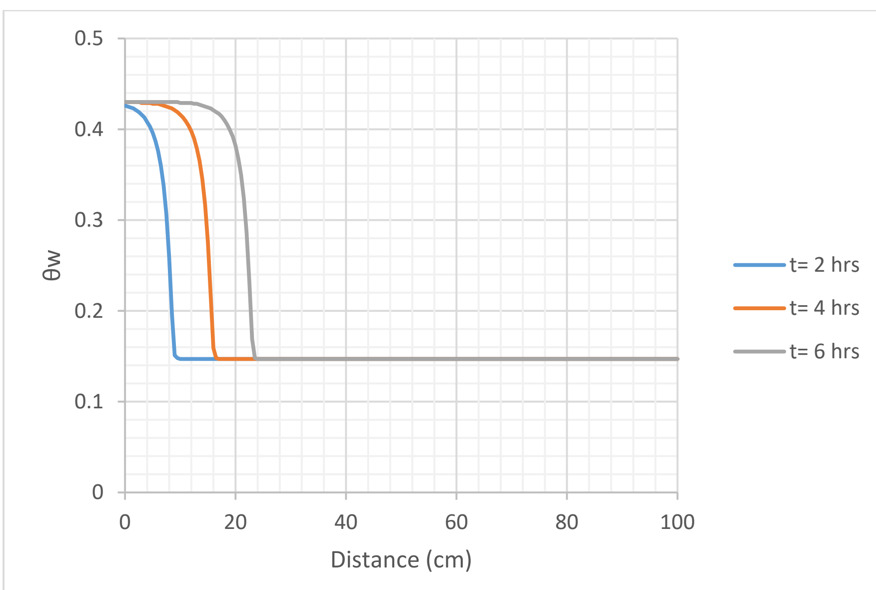

Figure 34- Water Content vs. Distance for Adsorption = 5

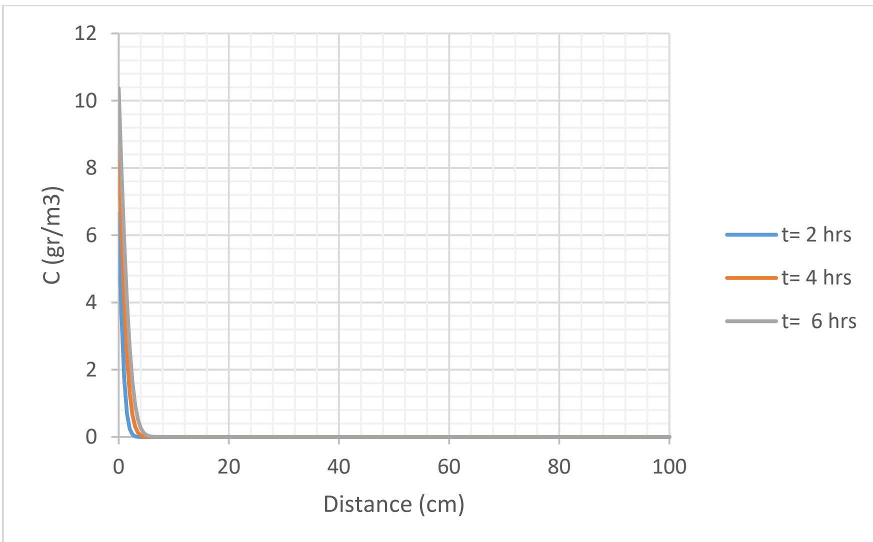

Figure 35- Concentration Solution vs. Depth for Adsorption = 5

2. Compare the graphs of concentration vs. time at the soil surface for the different partition coefficients with those for a partition coefficient of zero. Explain the differences.

By looking at the curves corresponding to the concentration solution with the different adsorption values, it can be seen that the rate of the increase in concentration is alleviated by increasing the sorption parameter with the moderate slope for the partition coefficient equal to 5 m3/Mg and the steeper one for no adsorption (Figure36).

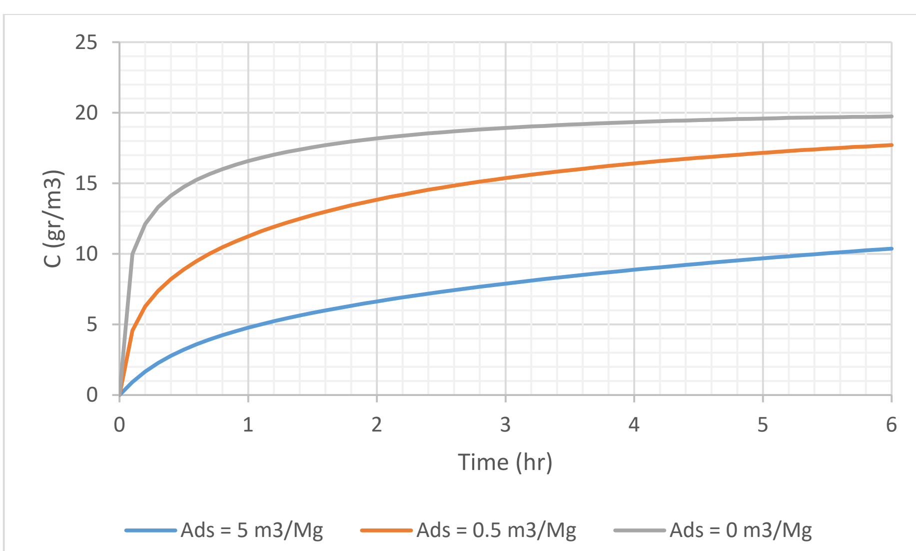

Figure 36- Concentration solution vs. time for different adsorption values