

## Example Problem W-4

### Aqueous Flow in Variably Saturated Porous Media with Inactive Regions and Linked-List X-Y-Z Seepage Face and X-Y-Z Hydraulic Gradient Boundary Conditions

**Abstract:** *This test problem illustrates the use of zonation files for specifying both spatially variable material types and inactive nodes, and linked-list x-y-z seepage face and x-y-z hydraulic gradient boundary conditions. When used in combination, these features are useful for representing boundary conditions over irregular surfaces such as undulating surface topography and sloping river shorelines. Furthermore, when large regions of a model domain can be specified as inactive (e.g. the part of the domain representing the river itself and the atmosphere above the ground surface) significant improvements in the computational performance of STOMP can potentially be achieved due to the decreased number of unknowns that are being solved for. Note that the features demonstrated by this test problem also provide an alternative to using curvilinear or boundary-fitted coordinates, or finite element methods, for representing irregular physical boundaries.*

#### Problem Description

Three-dimensional, single-phase (aqueous) flow is simulated for a 120-day period with the Water Mode of the STOMP simulator (STOMP-W), as indicated in the *Solution Control Card*, shown below.

```
#-----  
~Solution Control Card  
#-----  
Normal,  
Water,,  
1,  
0,day,120,day,0.5,hr,12.0,hr,1.25,20,1.E-6,  
500000,  
0,
```

The *Grid Card* indicates that a Cartesian coordinate system is used. The model domain is 100-m-long in the y-direction (North-South) by 100-m-wide in the x-direction (East-West) by 10-m-thick in the z-direction (Bottom to Top), and is

discretized with uniform 10-m-wide grid blocks in the x- and y-directions, and uniform 1-m-high grid blocks in the z-direction.

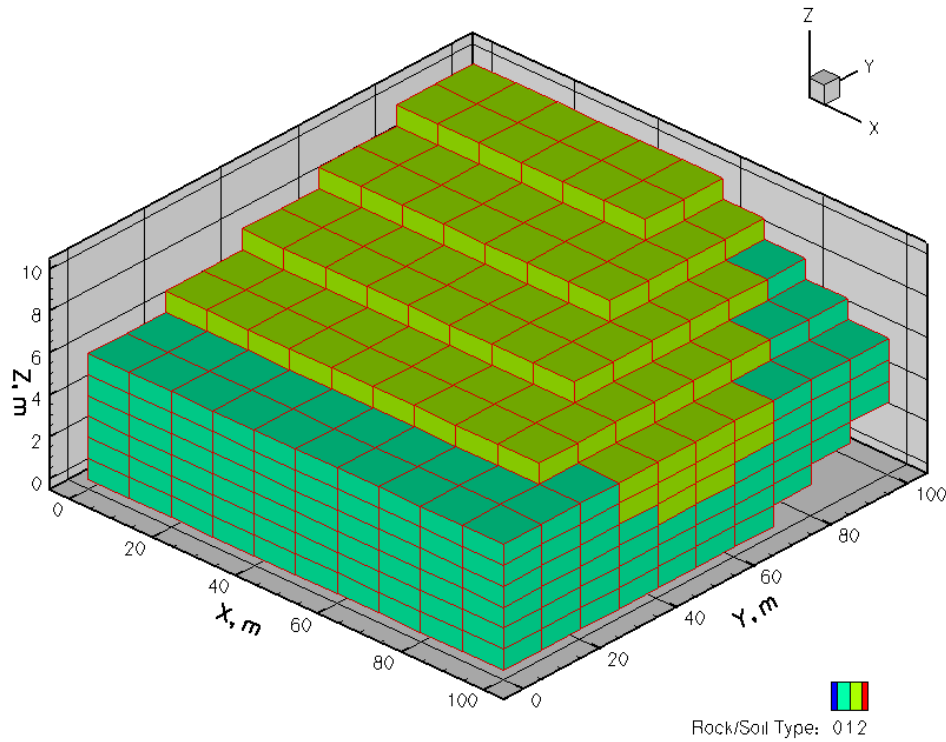
```
#-----  
~Grid Card  
#-----  
Cartesian,  
10,10,10,  
0,m,10@10,m,  
0,m,10@10,m,  
0,m,10@1,m,
```

This example problem focuses on the use of zonation files and linked-list x-y-z seepage face and x-y-z hydraulic gradient boundary conditions. The *Rock/Soil Zonation Card*, shown below, specifies that a zonation file is used to indicate how the rock or soil types are distributed. The name of this zonation file is 'zonation\_10cube.'

```
#-----  
~Rock/Soil Zonation  
#-----  
zonation file formatted,zonation_10cube,  
sand,  
gravel,
```

Two named soil types are specified; sand and gravel. The first soil type, sand, will be assigned to all grid blocks that have index 1 in the zonation file, and the second soil type, gravel, will be assigned to all grid blocks that have index 2. Figure 1 depicts the model domain and spatial distribution of the soil types.

The North end of the bottom of the modeled domain (see Figure 1) contains a region where nodes have been declared inactive to represent, for example, relatively impermeable bedrock at the bottom of the domain. Note that the inactive nodes (denoted by soil type 0) are not depicted in Figure 1. The bedrock is overlain by a zone of relatively high permeability sediments (i.e.. sand), shown in the blue-green color (and denoted as soil type 1) in Figure 1, which is overlain by a zone of even higher permeability sediments (i.e. gravel), shown in the yellowish-green color (and denoted by soil type 2) in Figure 1. The contact between the high permeability zones is irregular (i.e. not horizontal) and could represent, for example, a buried paleochannel in fluvial sediments.



**Figure 1.** Oblique view of gridded model domain depicting rock/soil type zonation. Soil type 1 (sand) is shown in blue-green, and is overlain by soil type 2 (gravel), shown in yellowish-green. (Note: This plot was produced using Tecplot)

The upper and Eastern parts of the model domain also contain inactive regions that could represent, for example, a sloped hillside and an irregular river shoreline, respectively. Time-dependent x-y-z seepage face (or x-y-z hydraulic gradient) boundary conditions are specified, to represent, for example, river stage variations on one side of the model and changes in the water table elevation on the other side of the model.

The *Inactive Domain Card*, shown below, indicates that the locations of the inactive grid blocks are also specified in the file 'zonation\_10cube.' All grid blocks that are assigned index 0 in the zonation file will be given inactive status.

```
#-----
~Inactive Domain Card
#-----
zonation file formatted,zonation_10cube,
```

The contents of the file 'zonation\_10cube' are shown below.

```
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2
```

```

2 2 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
2 2 2 2 2 2 2 2 2 0
2 2 2 2 2 2 2 2 2 0
2 2 2 2 2 2 2 2 2 0
2 2 2 2 2 2 2 2 2 0
2 2 2 2 2 2 2 2 2 0
2 2 2 2 2 2 2 2 2 0
1 1 1 1 1 1 1 1 1 0
1 1 1 1 1 1 1 1 1 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
2 2 2 2 2 2 2 2 0 0
2 2 2 2 2 2 2 2 0 0
2 2 2 2 2 2 2 2 0 0
2 2 2 2 2 2 2 2 0 0
2 2 2 2 2 2 2 2 0 0
1 1 1 1 1 1 1 1 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
2 2 2 2 2 2 2 0 0 0
2 2 2 2 2 2 2 0 0 0
2 2 2 2 2 2 2 0 0 0
2 2 2 2 2 2 2 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
2 2 2 2 2 2 0 0 0 0
2 2 2 2 2 2 0 0 0 0

```

The zonation file contains an integer value for every grid block in the modeled domain, both active and inactive, with index 0 identifying the inactive grid blocks. The zonation file should be written such that the x-direction cycles fastest, followed by the y-direction, followed by the z-direction, using program statements such as those shown below.

```
N = 0
DO 10 K = 1,NZ
  DO 10 J = 1,NY
    DO 10 I = 1,NX
      N = N + 1
      IRK(N) = ...
    10 CONTINUE
```

After the zone indices are generated, they can then be written out to the zonation file using program statements such as

```
WRITE(1,100) (IRK(N),N=1,NXYZ)
100 FORMAT(10(1X,I3))
```

where  $NXYZ = NX * NY * NZ$  and  $NX$ ,  $NY$ , and  $NZ$  are the number of grid blocks or nodes in the  $x$ -,  $y$ -, and  $z$ -directions, respectively, and  $IRK$  is an integer-valued zone index number. For this problem,  $NX=10$ ,  $NY=10$ , and  $NZ=10$ , so  $NXYZ=1000$ .

The *Boundary Conditions Card* for this example problem is given below. Note that the '#' symbol is used to comment out two of the lines in the first part of this *Boundary Conditions Card*, and several lines later in this card. These commented lines are provided simply to show a few of the other boundary condition options that are available. However, only the uncommented lines are actually interpreted and used by the simulator.

On the second line of the *Boundary Conditions Card*, the '4' indicates that four sets of boundary conditions are specified. The first set is applied to grid block surfaces identified in file 'eastside.lnk1st'. The boundary condition type that will be applied to the surfaces specified in this file is the  $x$ - $y$ - $z$  seepage face boundary. The ' $x$ - $y$ - $z$ ' simply indicates that aqueous pressure gradients will be specified in any or all of the  $x$ -,  $y$ -, and  $z$ -directions. The '31' indicates that pressures and pressure gradients will be specified for 31 times. It is important to note that the list of 31 pressures is applied only to the first boundary surface given in the linked list file. The pressures that are applied to the remaining boundary surfaces in each linked list are computed from the distance between each surface and the

first boundary surface, and from the specified gradients. Three gradients are specified after each pressure - one for each of the principal x-, y-, and z- directions. Hydrostatic conditions are assumed for the vertical (z-) direction and changes in aqueous pressure due to elevation are computed such that a gradient of -9793.52 Pa/m (gravitational constant times the aqueous density) is automatically imposed. Therefore the last (z-direction) gradient should generally be specified as zero. For this example, no gradients are applied to the x-direction, a 100 Pa/m gradient is applied to the y-direction, and no additional gradients are applied to the z-direction (although a -9793.52 Pa/m hydrostatic pressure gradient is automatically computed and imposed on the z-direction).

The x-y-z seepage face boundary conditions are also applied to the cell faces identified in the files 'westside.lnk1st' and 'southside.lnk1st'. Note that zero values are specified for the gradients on all cell faces in 'southside.lnk1st', so this boundary condition is equivalent to the standard seepage face boundary condition. The fourth and final set of boundary conditions is applied to surfaces in the file 'topside.lnk1st'. A Neumann or flux boundary condition is specified for all the surfaces in this file. In this case, a flux of zero is specified, but any other reasonable non-zero value could be also be used.

```
#-----
~Boundary Condition Card
#-----
4,
#file,eastside.lnk1st,x-y-z hydraulic gradient,
file,eastside.lnk1st,x-y-z seepage face,
#file,eastside.lnk1st,seepage face,
31,
0.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
1.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
2.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
3.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
4.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
5.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
6.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
7.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
8.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
9.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
10.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
18.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
12.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
13.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
```

14.000000,day, 111118.52,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
15.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
16.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
17.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
18.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
19.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
20.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
21.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
22.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
23.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
24.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
25.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
26.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
27.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
28.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
29.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
120.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
#file,westside.lnk1st,x-y-z hydraulic gradient,  
file,westside.lnk1st,x-y-z seepage face,  
#file,westside.lnk1st,seepage face,  
31,  
0.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
1.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
2.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
3.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
4.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
5.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
6.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
7.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
8.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
9.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
10.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
18.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
12.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
13.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
14.000000,day, 111118.52,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
15.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
16.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
17.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
18.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
19.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
20.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
21.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
22.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
23.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
24.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
25.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
26.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
27.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
28.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
29.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
120.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
#file,southside.lnk1st,x-y-z hydraulic gradient,  
file,southside.lnk1st,x-y-z seepage face,  
#file,southside.lnk1st,hydraulic gradient,  
31,  
0.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,  
1.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,



```

2.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
3.000000,day, 140499.08,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
4.000000,day, 150292.60,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
5.000000,day, 160086.12,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
6.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
7.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
8.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
9.000000,day, 160086.12,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
10.000000,day, 150292.60,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
18.000000,day, 140499.08,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
12.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
13.000000,day, 120912.04,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
14.000000,day, 111118.52,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
15.000000,day, 120912.04,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
16.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
17.000000,day, 140499.08,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
18.000000,day, 150292.60,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
19.000000,day, 160086.12,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
20.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
21.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
22.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
23.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
24.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
25.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
26.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
27.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
28.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
29.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
120.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
file,topside.lnk1st,neumann,
2,
0.000000,day, 0.0000,mm/yr,
120.000000,day, 0.0000,mm/yr,

```

The files containing the linked lists of boundary surfaces should be written in the following format, shown here for file 'eastside.lnk1st'.

```

10 1 1 1
10 2 1 1
10 3 1 1
10 4 1 1
10 5 1 1
10 6 1 1
10 7 1 1
10 1 2 1
10 2 2 1
10 3 2 1
10 4 2 1
10 5 2 1
10 6 2 1
10 7 2 1
10 8 2 1
10 1 3 1
10 2 3 1
10 3 3 1

```

10 4 3 1  
10 5 3 1  
10 6 3 1  
10 7 3 1  
10 8 3 1  
10 9 3 1  
10 1 4 1  
10 2 4 1  
10 3 4 1  
10 4 4 1  
10 5 4 1  
10 6 4 1  
10 7 4 1  
10 8 4 1  
10 9 4 1  
10 10 4 1  
10 1 5 1  
10 2 5 1  
10 3 5 1  
10 4 5 1  
10 5 5 1  
10 6 5 1  
10 7 5 1  
10 8 5 1  
10 9 5 1  
10 10 5 1  
10 1 6 1  
10 2 6 1  
10 3 6 1  
10 4 6 1  
10 5 6 1  
10 6 6 1  
10 7 6 1  
10 8 6 1  
10 9 6 1  
10 10 6 1  
9 3 7 1  
9 4 7 1  
9 5 7 1  
9 6 7 1  
9 7 7 1  
9 8 7 1  
9 9 7 1  
9 10 7 1  
8 5 8 1  
8 6 8 1  
8 7 8 1  
8 8 8 1  
8 9 8 1  
8 10 8 1  
7 7 9 1  
7 8 9 1  
7 9 9 1  
7 10 9 1  
6 9 10 1  
6 10 10 1

The first, second, and third values on each line of the linked list files are the I, J, and K indices of the grid block, respectively. The fourth value on each line is the orientation of the boundary surface. For the boundary surface orientation, the values 1 and -1 correspond to the East and West faces of each specified grid block, respectively. The values 2 and -2 correspond to the North and South faces, respectively, and the values 3 and -3 correspond to the Top and Bottom faces, respectively.

The 'westside.lnk1st' file is shown below. Note that in this file all boundary surfaces have a value of '-1' indicating that the boundary pressures are applied to the West faces of each specified grid block.

```
1 1 1 -1
1 2 1 -1
1 3 1 -1
1 4 1 -1
1 5 1 -1
1 6 1 -1
1 7 1 -1
1 1 2 -1
1 2 2 -1
1 3 2 -1
1 4 2 -1
1 5 2 -1
1 6 2 -1
1 7 2 -1
1 8 2 -1
1 1 3 -1
1 2 3 -1
1 3 3 -1
1 4 3 -1
1 5 3 -1
1 6 3 -1
1 7 3 -1
1 8 3 -1
1 9 3 -1
1 1 4 -1
1 2 4 -1
1 3 4 -1
1 4 4 -1
1 5 4 -1
1 6 4 -1
1 7 4 -1
1 8 4 -1
1 9 4 -1
1 10 4 -1
1 1 5 -1
1 2 5 -1
1 3 5 -1
```

```

1  4  5 -1
1  5  5 -1
1  6  5 -1
1  7  5 -1
1  8  5 -1
1  9  5 -1
1 10  5 -1
1  1  6 -1
1  2  6 -1
1  3  6 -1
1  4  6 -1
1  5  6 -1
1  6  6 -1
1  7  6 -1
1  8  6 -1
1  9  6 -1
1 10  6 -1
1  3  7 -1
1  4  7 -1
1  5  7 -1
1  6  7 -1
1  7  7 -1
1  8  7 -1
1  9  7 -1
1 10  7 -1
1  5  8 -1
1  6  8 -1
1  7  8 -1
1  8  8 -1
1  9  8 -1
1 10  8 -1
1  7  9 -1
1  8  9 -1
1  9  9 -1
1 10  9 -1
1  9 10 -1
1 10 10 -1

```

The 'southside.lnk1st' file is shown below. The boundary surfaces in this file all have a value of '-2' indicating that the boundary pressures are applied to the South faces of each specified grid block.

```

1  1  1 -2
2  1  1 -2
3  1  1 -2
4  1  1 -2
5  1  1 -2
6  1  1 -2
7  1  1 -2
8  1  1 -2
9  1  1 -2
10 1  1 -2
1  1  2 -2
2  1  2 -2

```

```
3 1 2 -2
4 1 2 -2
5 1 2 -2
6 1 2 -2
7 1 2 -2
8 1 2 -2
9 1 2 -2
10 1 2 -2
1 1 3 -2
2 1 3 -2
3 1 3 -2
4 1 3 -2
5 1 3 -2
6 1 3 -2
7 1 3 -2
8 1 3 -2
9 1 3 -2
10 1 3 -2
1 1 4 -2
2 1 4 -2
3 1 4 -2
4 1 4 -2
5 1 4 -2
6 1 4 -2
7 1 4 -2
8 1 4 -2
9 1 4 -2
10 1 4 -2
1 1 5 -2
2 1 5 -2
3 1 5 -2
4 1 5 -2
5 1 5 -2
6 1 5 -2
7 1 5 -2
8 1 5 -2
9 1 5 -2
10 1 5 -2
1 1 6 -2
2 1 6 -2
3 1 6 -2
4 1 6 -2
5 1 6 -2
6 1 6 -2
7 1 6 -2
8 1 6 -2
9 1 6 -2
10 1 6 -2
```

Finally, the 'topside.lnk1st' file is shown below. All the boundary surfaces in this file have a value of '3' indicating that the boundary pressures are applied to the Top faces of each specified grid block. Zero fluxes were specified for this example problem, but any other reasonable values could be used. Specifying negative values of flux for the Top faces of the grid blocks in 'topside.lnk1st'

would indicate vertical downward flow into the model domain, which could represent, for example, natural groundwater recharge.

```
1 1 6 3
2 1 6 3
3 1 6 3
4 1 6 3
5 1 6 3
6 1 6 3
7 1 6 3
8 1 6 3
9 1 6 3
10 1 6 3
1 2 6 3
2 2 6 3
3 2 6 3
4 2 6 3
5 2 6 3
6 2 6 3
7 2 6 3
8 2 6 3
9 2 6 3
10 2 6 3
1 3 7 3
2 3 7 3
3 3 7 3
4 3 7 3
5 3 7 3
6 3 7 3
7 3 7 3
8 3 7 3
9 3 7 3
1 4 7 3
2 4 7 3
3 4 7 3
4 4 7 3
5 4 7 3
6 4 7 3
7 4 7 3
8 4 7 3
9 4 7 3
1 5 8 3
2 5 8 3
3 5 8 3
4 5 8 3
5 5 8 3
6 5 8 3
7 5 8 3
8 5 8 3
1 6 8 3
2 6 8 3
3 6 8 3
4 6 8 3
5 6 8 3
6 6 8 3
7 6 8 3
```

```
8 6 8 3
1 7 9 3
2 7 9 3
3 7 9 3
4 7 9 3
5 7 9 3
6 7 9 3
7 7 9 3
1 8 9 3
2 8 9 3
3 8 9 3
4 8 9 3
5 8 9 3
6 8 9 3
7 8 9 3
```

Any combination of cell surface orientations can be included in the linked list files, assuming that the specified grid blocks and cell faces are on outer boundaries of the modeled domain (i.e. not internal to the domain). If the specified grid blocks and cell faces listed in a linked list file are internal to the domain, they must have inactive grid blocks between them and the outer domain boundary. Otherwise an error message will result and code execution will be terminated. Outer grid block cell faces that are left unspecified are automatically assigned Neumann-type zero flux (a.k.a. no-flow) boundary conditions.

## Exercises

1. Run the base STOMP-W problem using an appropriate executable. Verify that one output file and 31 plot files are created. Generate 3D images of the aqueous saturation distributions for times of 0, 15, 17, and 120 days. Verify that the computed aqueous pressures for the reference nodes match the results given in the solution for this exercise for the time of 120 days.
2. Change the y-direction gradients applied to the 'eastbnd.lnkfst' and 'westbnd.lnkfst' files from 100 Pa/m to 500 Pa/m. (Note: In Unix vi editor type /g/ 100./s/ 100./ 500./g ). Rerun the problem. Generate 3D images of the aqueous saturation distributions for times of 0, 15, 17, and 120 days. Verify that the computed aqueous pressures for the reference nodes match the results given in the solution for this exercise for the time of 120 days.
3. Change the number of boundary conditions from '4' to '3' and comment out the line with the file name 'southside.lnkfst' and all associated

boundary specifications. Rerun the problem using the same 500 Pa/m gradient boundary conditions. Generate 3D images of the aqueous saturation distributions for times of 0, 15, 17, and 120 days. Verify that the computed pressures for the reference nodes match the results given in the solution for this exercise for the time of 120 days.

## Input File

```
#-----  
~Simulation Title Card  
#-----  
1,  
STOMP Example Problem W-4,  
Mark Rockhold,  
Pacific Northwest National Laboratory,  
Monday, August 14, 2006,  
10:37:00 AM,  
2,  
Example of X-Y-Z Hydraulic Gradient and X-Y-Z Seepage Face boundary  
conditions applied to linked lists of boundary cell faces,  
  
#-----  
~Solution Control Card  
#-----  
Normal,  
Water,,  
1,  
0,day,120,day,0.5,hr,12.0,hr,1.25,20,1.E-6,  
500000,  
0,  
  
#-----  
~Grid Card  
#-----  
Cartesian,  
10,10,10,  
0,m,10@10,m,  
0,m,10@10,m,  
0,m,10@1,m,
```



```
#-----  
~Rock/Soil Zonation  
#-----  
zonation file formatted,zonation_10cube,  
sand,  
gravel,  
  
#-----  
~Inactive Domain Card  
#-----  
zonation file formatted,zonation_10cube,  
  
#-----  
~Mechanical Properties Card  
#-----  
sand,2760,kg/m^3,0.2,0.2,0.0,1/m,Millington and Quirk,  
gravel,2760,kg/m^3,0.3,0.3,0.0,1/m,Millington and Quirk,  
  
#-----  
~Hydraulic Properties Card  
#-----  
sand,100,hc m/day,100,hc m/day,10,hc m/day,  
gravel,10000,hc m/day,10000,hc m/day,1000,hc m/day,  
  
#-----  
~Aqueous Relative Permeability Card  
#-----  
sand,Burdine,,  
gravel,Burdine,,  
  
#-----  
~Saturation Function Card  
#-----  
sand,Brooks and Corey,25.0,cm,0.5,0.15,,  
gravel,Brooks and Corey,5.0,cm,2.0,0.07,,  
  
#-----  
#~Solute/Fluid Interaction Card  
#-----  
0,  
  
#-----  
#~Solute/Porous Media Interaction Card  
#-----  
0,  
  
#-----  
~Initial Conditions Card  
#-----  
Gas Pressure, Aqueous Pressure,  
2,  
Gas Pressure,101325.0,Pa,,,,,1,10,1,10,1,10,  
Aqueous Pressure,130705.56,Pa,0.0,1/m,100.0,1/m,-9793.5192,1/m,1,10,1,10,1,10,
```

```
#-----  
~Boundary Condition Card  
#-----  
4,  
#file,eastside.lnkfst,x-y-z hydraulic gradient,  
file,eastside.lnkfst,x-y-z seepage face,  
#file,eastside.lnkfst,seepage face,  
31,  
0.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
1.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
2.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
3.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
4.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
5.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
6.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
7.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
8.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
9.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
10.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
18.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
12.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
13.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
14.000000,day, 111118.52,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
15.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
16.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
17.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
18.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
19.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
20.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
21.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
22.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
23.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
24.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
25.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
26.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
27.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
28.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
29.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
120.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
#file,westside.lnkfst,x-y-z hydraulic gradient,  
file,westside.lnkfst,x-y-z seepage face,  
#file,westside.lnkfst,seepage face,  
31,  
0.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
1.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
2.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
3.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
4.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
5.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
6.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
7.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
8.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
9.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
10.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
18.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
12.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
13.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,  
14.000000,day, 111118.52,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
```

```

15.000000,day, 120912.04,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
16.000000,day, 130705.56,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
17.000000,day, 140499.08,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
18.000000,day, 150292.60,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
19.000000,day, 160086.12,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
20.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
21.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
22.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
23.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
24.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
25.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
26.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
27.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
28.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
29.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
120.000000,day, 169879.64,Pa, 0.00,1/m, 100.000,1/m, 0.0000,1/m,
#file,southside.lnk1st,x-y-z hydraulic gradient,
file,southside.lnk1st,x-y-z seepage face,
#file,southside.lnk1st,hydraulic gradient,
31,
0.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
1.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
2.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
3.000000,day, 140499.08,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
4.000000,day, 150292.60,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
5.000000,day, 160086.12,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
6.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
7.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
8.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
9.000000,day, 160086.12,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
10.000000,day, 150292.60,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
18.000000,day, 140499.08,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
12.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
13.000000,day, 120912.04,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
14.000000,day, 111118.52,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
15.000000,day, 120912.04,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
16.000000,day, 130705.56,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
17.000000,day, 140499.08,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
18.000000,day, 150292.60,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
19.000000,day, 160086.12,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
20.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
21.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
22.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
23.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
24.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
25.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
26.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
27.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
28.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
29.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
120.000000,day, 169879.64,Pa, 0.00,1/m, 0.000,1/m, 0.0000,1/m,
file,topside.lnk1st,neumann,
2,
0.000000,day, 0.0000,mm/yr,
120.000000,day, 0.0000,mm/yr,

```

```

#-----
~Output Card
#-----
5,
10,7,1,
10,7,3,
5,7,1,
1,7,1,
1,7,3,
1,1,day,m,4,6,6,
2,
aqueous saturation,,
aqueous pressure,Pa,,
31,
0,day,
1,day,
2,day,
3,day,
4,day,
5,day,
6,day,
7,day,
8,day,
9,day,
10,day,
11,day,
12,day,
13,day,
14,day,
15,day,
16,day,
17,day,
18,day,
19,day,
20,day,
21,day,
22,day,
23,day,
24,day,
25,day,
26,day,
27,day,
28,day,
29,day,
120,day,
4,
rock / soil type,,
aqueous saturation,,
aqueous pressure,Pa,,
final restart only,,

```

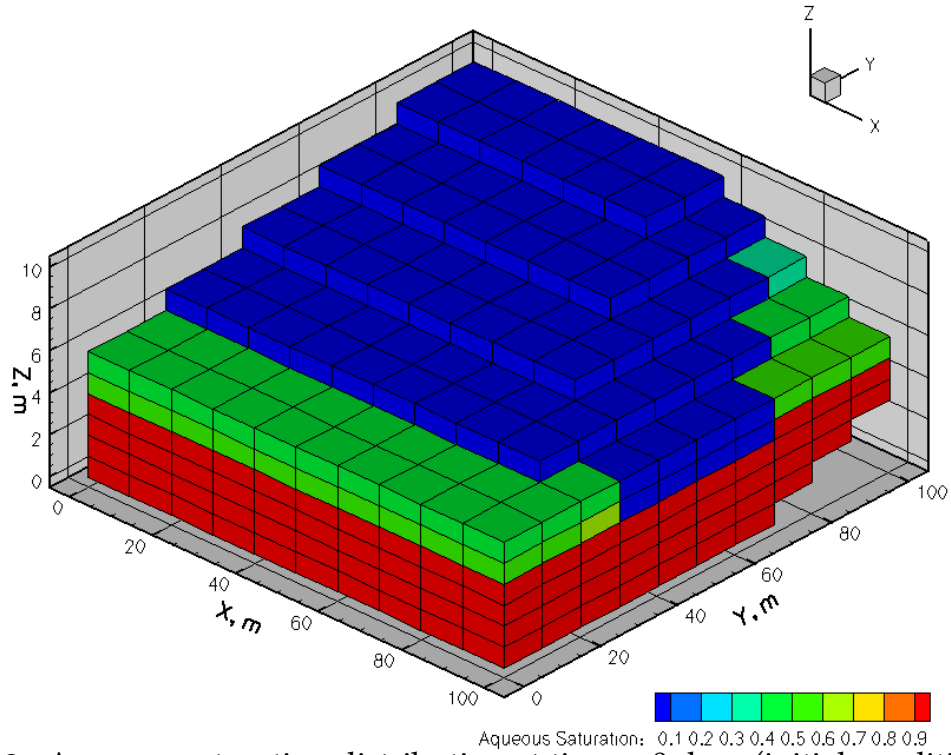
## Solutions to Selected Exercises

### Exercise 1

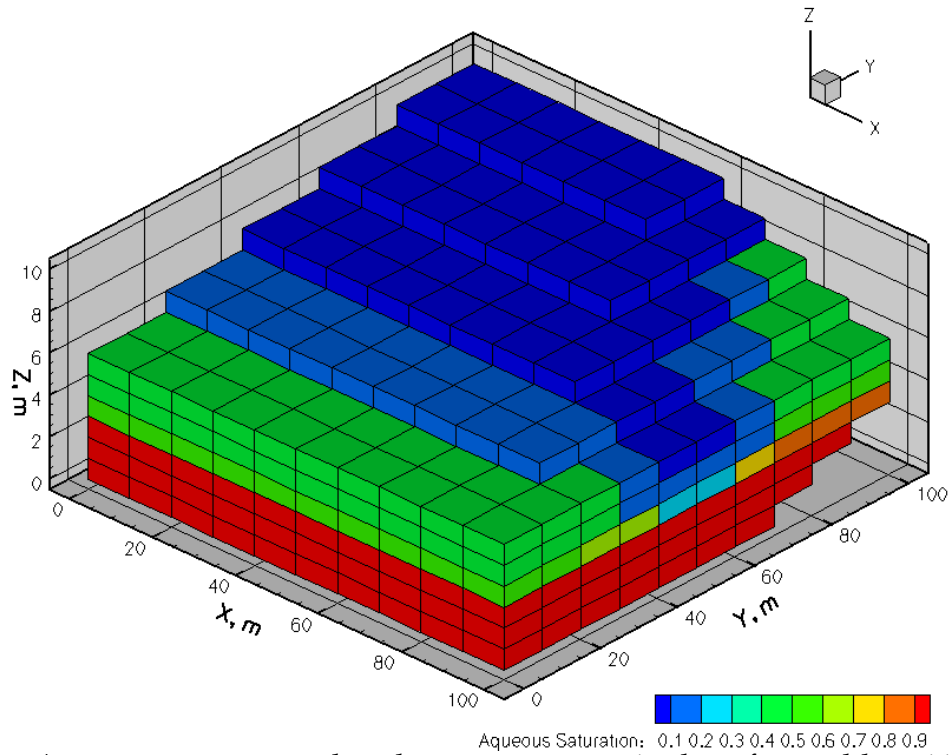
Figures 2 and 3 depict the aqueous saturation distributions for times of 0 and 15 days, respectively. The 100 Pa/m aqueous pressure gradient applied to the y-direction effectively results in the water table sloping downward from North to South. This is evident in Figures 2 and 3 from the regions of aqueous saturations shown in red (Aqueous Saturations > 0.9) that extend higher vertically at the Northern end of the modeled domain than at the Southern end of the domain. Also note that the water table elevation is lower on day 15 than it was on day 0.

Figures 4 and 5 depict the aqueous saturation distributions for times of 17 and 120 days, respectively. In Figure 4 the North-South (y-direction) gradient is again evident, from the increases in aqueous saturations with distance to the North. The water table on day 17 (Figure 4) is also noticeably higher than it was on day 15 (Figure 3) or on day 0 (Figure 2). In Figure 5, the aqueous pressure gradient is not readily apparent from the aqueous saturation distribution, because the water table has risen high up into the gravel unit, which has a very high hydraulic conductivity and very low air-entry pressure.

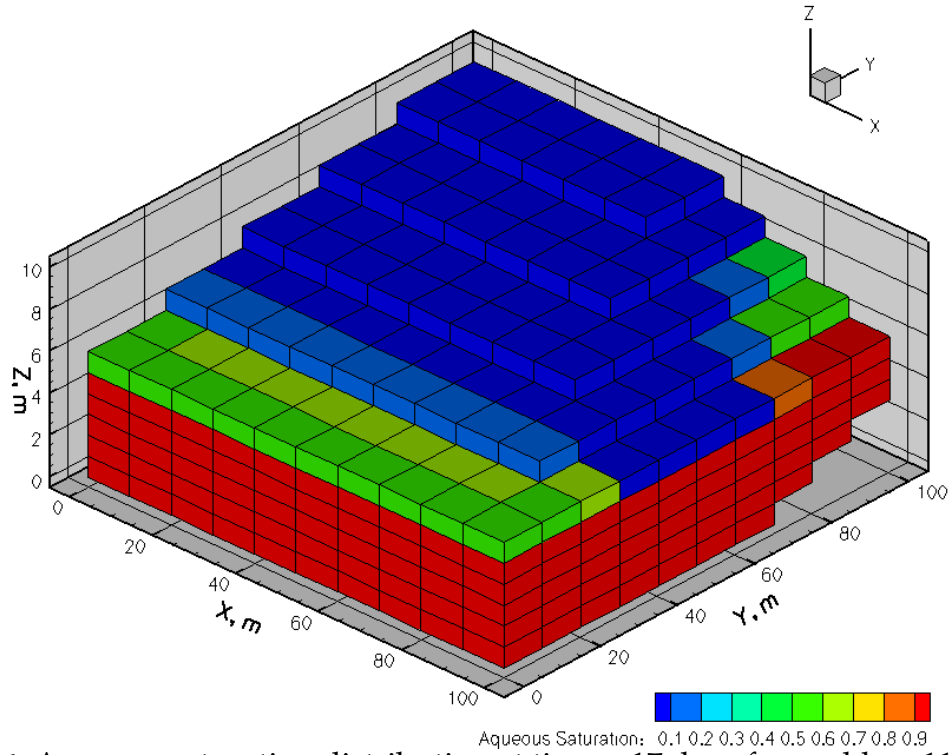
A partial listing of the output file containing selected results for the reference nodes from this exercise is shown in Figure 6. Verify that the results produced by your executable match those shown in Figure 6. Note that the computed pressures for the reference nodes do not match those prescribed at the corresponding cell faces in the linked list files for this problem because the pressure gradients induce flow within the domain. However, if the y-direction gradients applied to the 'eastside.lnk1st' and 'westside.lnk1st' files are set to zero, the pressures at the reference nodes should match those prescribed at the adjacent boundaries.



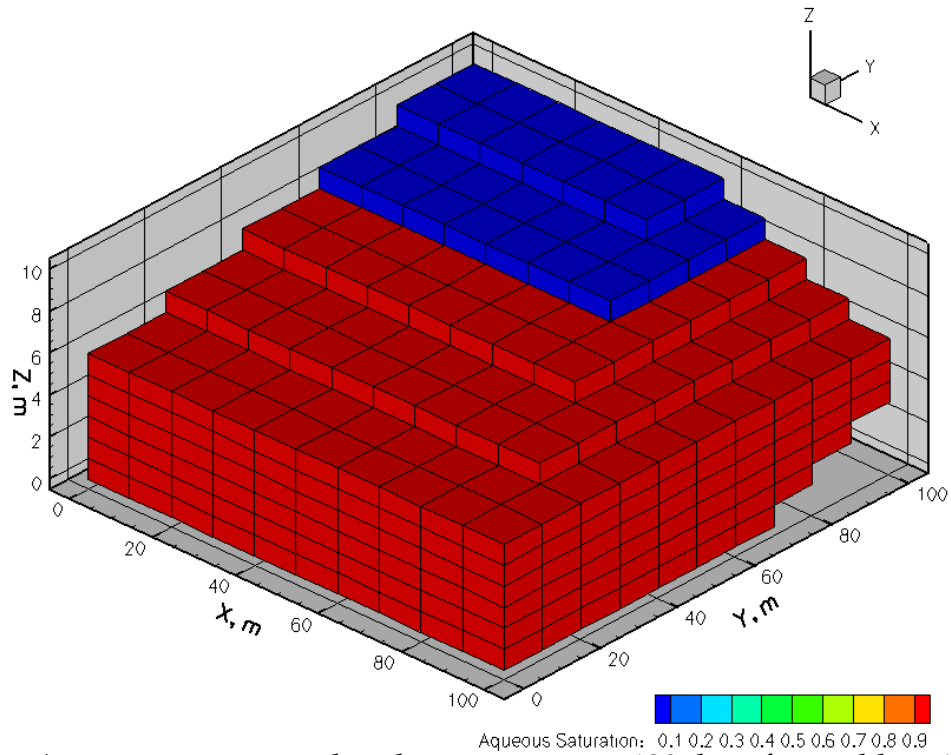
**Figure 2.** Aqueous saturation distribution at time = 0 days (initial condition) for problem 11, exercise 1.



**Figure 3.** Aqueous saturation distribution at time = 15 days for problem 11, exercise 1



**Figure 4.** Aqueous saturation distribution at time = 17 days for problem 11, exercise 1



**Figure 5.** Aqueous saturation distribution at time = 120 days for problem 11, exercise 1.

```

Reference Node(s) ( 10, 7, 1: 70) ( 10, 7, 3: 270) ( 5, 7, 1:
65) ( 1, 7, 1: 61) ( 1, 7, 3: 261)
Step Node Time Timestep Itr SL PL
[day ] [day ] [pa ]
300 70 1.15500E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
300 270 1.15500E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
300 65 1.15500E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
300 61 1.15500E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
300 261 1.15500E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
301 70 1.16000E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
301 270 1.16000E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
301 65 1.16000E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
301 61 1.16000E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
301 261 1.16000E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
302 70 1.16500E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
302 270 1.16500E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
302 65 1.16500E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
302 61 1.16500E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
302 261 1.16500E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
303 70 1.17000E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
303 270 1.17000E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
303 65 1.17000E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
303 61 1.17000E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
303 261 1.17000E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
304 70 1.17500E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
304 270 1.17500E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
304 65 1.17500E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
304 61 1.17500E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
304 261 1.17500E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
305 70 1.18000E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
305 270 1.18000E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
305 65 1.18000E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
305 61 1.18000E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
305 261 1.18000E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
306 70 1.18500E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
306 270 1.18500E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
306 65 1.18500E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
306 61 1.18500E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
306 261 1.18500E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
307 70 1.19000E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
307 270 1.19000E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
307 65 1.19000E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
307 61 1.19000E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
307 261 1.19000E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
308 70 1.19500E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
308 270 1.19500E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
308 65 1.19500E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
308 61 1.19500E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
308 261 1.19500E+02 5.00000E-01 2 1.00000E+00 1.55957E+05
309 70 1.20000E+02 5.00000E-01 2 1.00000E+00 1.75537E+05
309 270 1.20000E+02 5.00000E-01 2 1.00000E+00 1.55970E+05
309 65 1.20000E+02 5.00000E-01 2 1.00000E+00 1.74942E+05
309 61 1.20000E+02 5.00000E-01 2 1.00000E+00 1.75517E+05
309 261 1.20000E+02 5.00000E-01 2 1.00000E+00 1.55957E+05

```

NOTE: Simulation Stopped:

--- End of STOMP Simulation ---

**Figure 6.** Partial listing of reference node output for Problem 11, Exercise 1



## Exercise 2

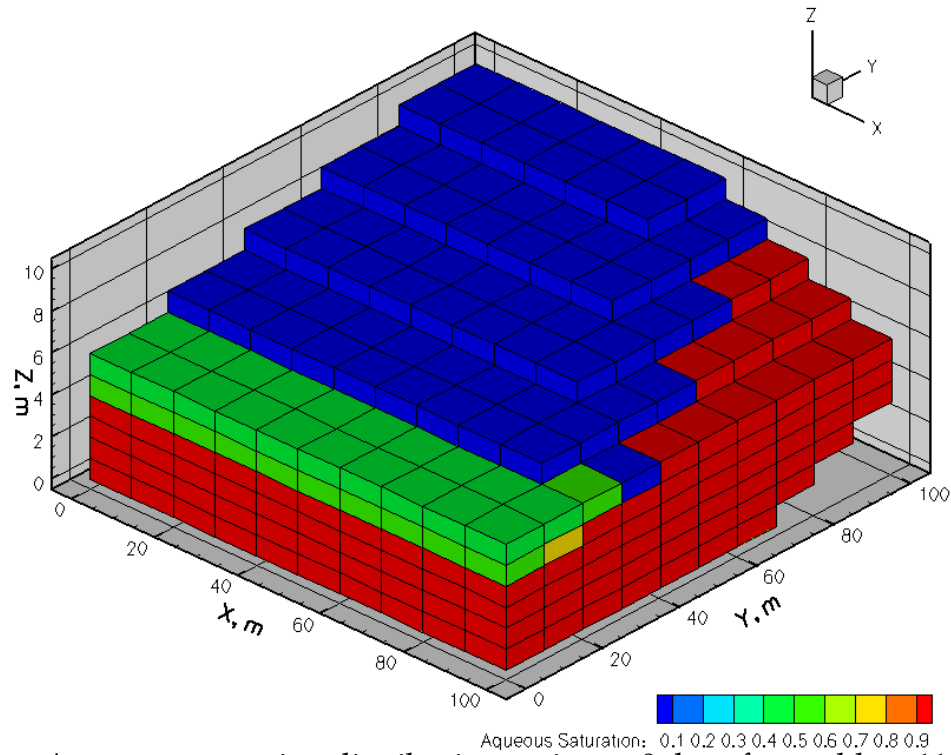
In this exercise, the y-direction aqueous pressure gradients that are applied to the cell faces given in the 'eastside.lnk1st' and 'westside.lnk1st' files should be increased from 100 Pa/m to 500 Pa/m, and problem rerun.

Figures 7 and 8 depict the aqueous saturation distributions for times of 0 and 15 days, respectively. The 500 Pa/m aqueous pressure gradient applied to the y-direction effectively results in the water table sloping downward from North to South. This is evident in Figures 7 and 8 from the regions of aqueous saturations shown in red (Aqueous Saturations > 0.9) that extend higher vertically at the Northern end of the modeled domain than at the Southern end of the domain. Also note that the water table elevation is lower on day 15 than it was on day 0.

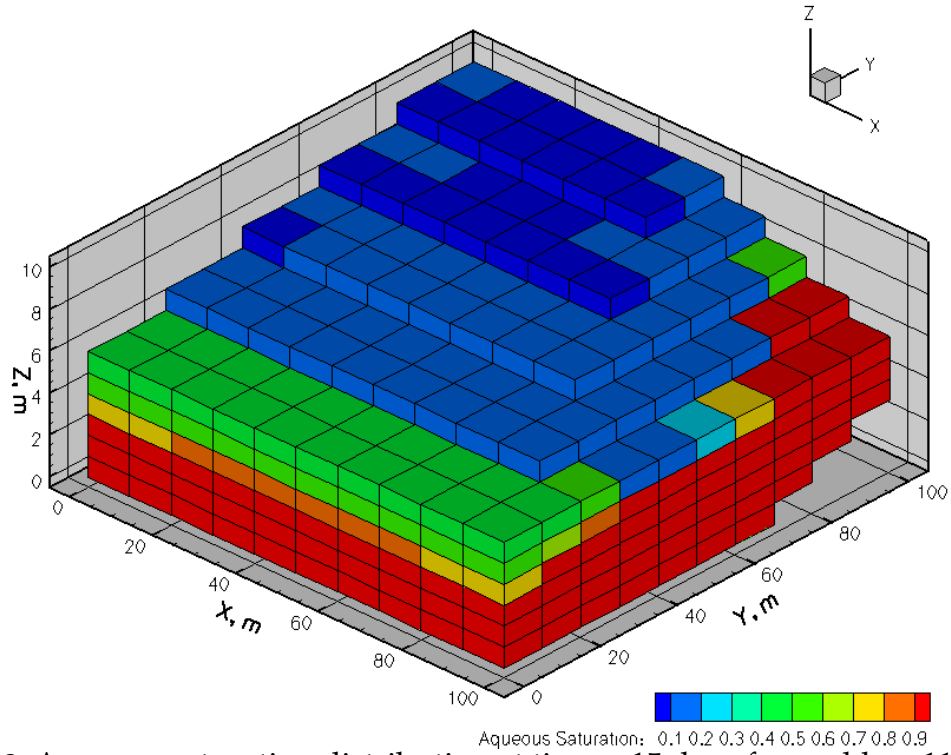
Figures 9 and 10 depict the aqueous saturation distributions for times of 17 and 120 days, respectively. In Figure 9 the North-South (y-direction) gradient is again evident, from the increases in aqueous saturations with distance to the North. The water table on day 17 (Figure 9) is also noticeably higher than it was on day 15 (Figure 8) or on day 0 (Figure 7). In Figure 10, the aqueous pressure gradient is not readily apparent from the aqueous saturation distribution, because the water table has risen high up into the gravel unit, which has a very high hydraulic conductivity and very low air-entry pressure. Also note that in Figure 10 the entire model domain has aqueous saturations > 0.9, in contrast to Figure 5 in which the upper part of the model domain has aqueous saturations < 0.1. This difference is due to the larger y-direction aqueous pressure gradients used in this exercise, relative to those used in Exercise 1.

A partial listing of the output file containing selected results for the reference nodes from this exercise is shown in Figure 11. Verify that the results produced by your executable match those shown in Figure 11. Again, note that the computed pressures for the reference nodes do not match those prescribed at the corresponding cell faces in the linked list files for this problem because the pressure gradients induce flow within the domain. However, if the y-direction

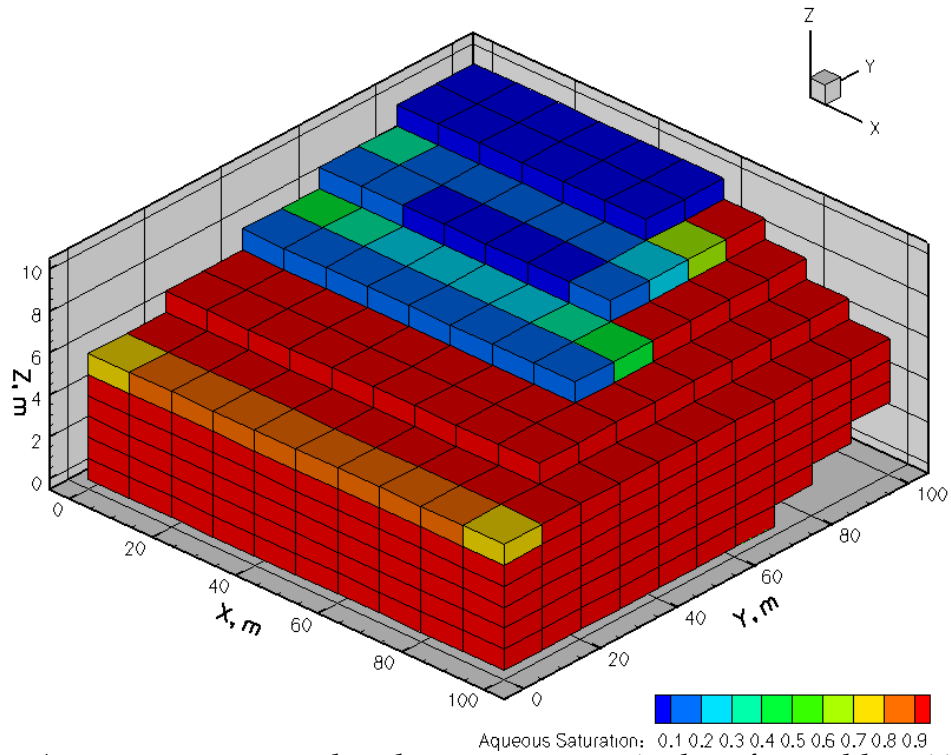
gradients applied to the 'eastside.lnk1st' and 'westside.lnk1st' files are set to zero, the pressures at the reference nodes should match those prescribed at the adjacent boundaries.



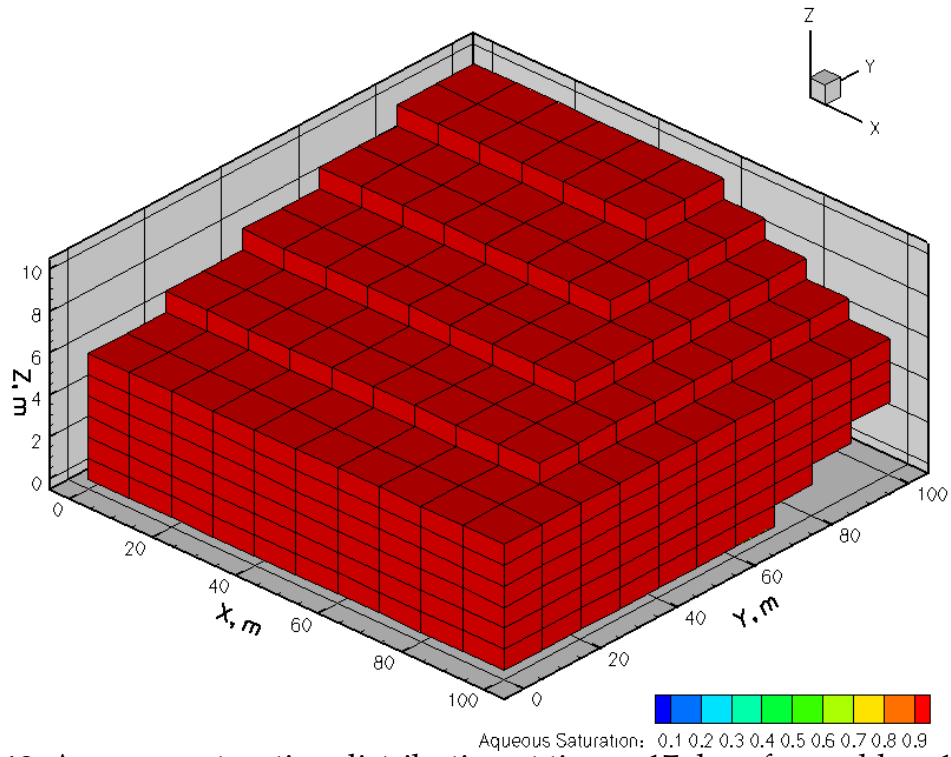
**Figure 7.** Aqueous saturation distribution at time = 0 days for problem 11, exercise 2



**Figure 8.** Aqueous saturation distribution at time = 15 days for problem 11, exercise 2



**Figure 9.** Aqueous saturation distribution at time = 17 days for problem 11, exercise 2



**Figure 10.** Aqueous saturation distribution at time = 17 days for problem 11, exercise 2

Reference 7, 1: Step	Node(s) ( 10, 7, 1: 65) ( 1, 7, 1: Node	Time [day ]	Timestep [day ]	Itr	SL	PL [pa ]
250	70	1.18000E+02	5.00000E-01	1	1.00000E+00	1.98417E+05
250	270	1.18000E+02	5.00000E-01	1	1.00000E+00	1.78934E+05
250	65	1.18000E+02	5.00000E-01	1	1.00000E+00	1.98094E+05
250	61	1.18000E+02	5.00000E-01	1	1.00000E+00	1.98641E+05
250	261	1.18000E+02	5.00000E-01	1	1.00000E+00	1.79264E+05
251	70	1.18500E+02	5.00000E-01	1	1.00000E+00	1.98417E+05
251	270	1.18500E+02	5.00000E-01	1	1.00000E+00	1.78934E+05
251	65	1.18500E+02	5.00000E-01	1	1.00000E+00	1.98094E+05
251	61	1.18500E+02	5.00000E-01	1	1.00000E+00	1.98641E+05
251	261	1.18500E+02	5.00000E-01	1	1.00000E+00	1.79264E+05
252	70	1.19000E+02	5.00000E-01	1	1.00000E+00	1.98417E+05
252	270	1.19000E+02	5.00000E-01	1	1.00000E+00	1.78934E+05
252	65	1.19000E+02	5.00000E-01	1	1.00000E+00	1.98094E+05
252	61	1.19000E+02	5.00000E-01	1	1.00000E+00	1.98641E+05
252	261	1.19000E+02	5.00000E-01	1	1.00000E+00	1.79264E+05
253	70	1.19500E+02	5.00000E-01	1	1.00000E+00	1.98417E+05
253	270	1.19500E+02	5.00000E-01	1	1.00000E+00	1.78934E+05
253	65	1.19500E+02	5.00000E-01	1	1.00000E+00	1.98094E+05
253	61	1.19500E+02	5.00000E-01	1	1.00000E+00	1.98641E+05
253	261	1.19500E+02	5.00000E-01	1	1.00000E+00	1.79264E+05
254	70	1.20000E+02	5.00000E-01	1	1.00000E+00	1.98417E+05
254	270	1.20000E+02	5.00000E-01	1	1.00000E+00	1.78934E+05
254	65	1.20000E+02	5.00000E-01	1	1.00000E+00	1.98094E+05
254	61	1.20000E+02	5.00000E-01	1	1.00000E+00	1.98641E+05
254	261	1.20000E+02	5.00000E-01	1	1.00000E+00	1.79264E+05

NOTE: Simulation Stopped:

--- End of STOMP Simulation ---

**Figure 11.** Partial listing of reference node output for problem 11, exercise 2

### Exercise 3

In this exercise, the input file used for Exercise 2 should be modified to change the number of boundary conditions specified on the *Boundary Conditions Card* from '4' to '3'. All boundary condition input associated with the file 'southside.lnk1st' should also be commented out, and then the problem should be rerun.

Figures 12 and 13 depict the aqueous saturation distributions for times of 0 and 15 days, respectively. The 500 Pa/m aqueous pressure gradient applied to the y-direction again results in the water table sloping downward from North to South. This is evident in Figures 12 and 13 from the regions of aqueous

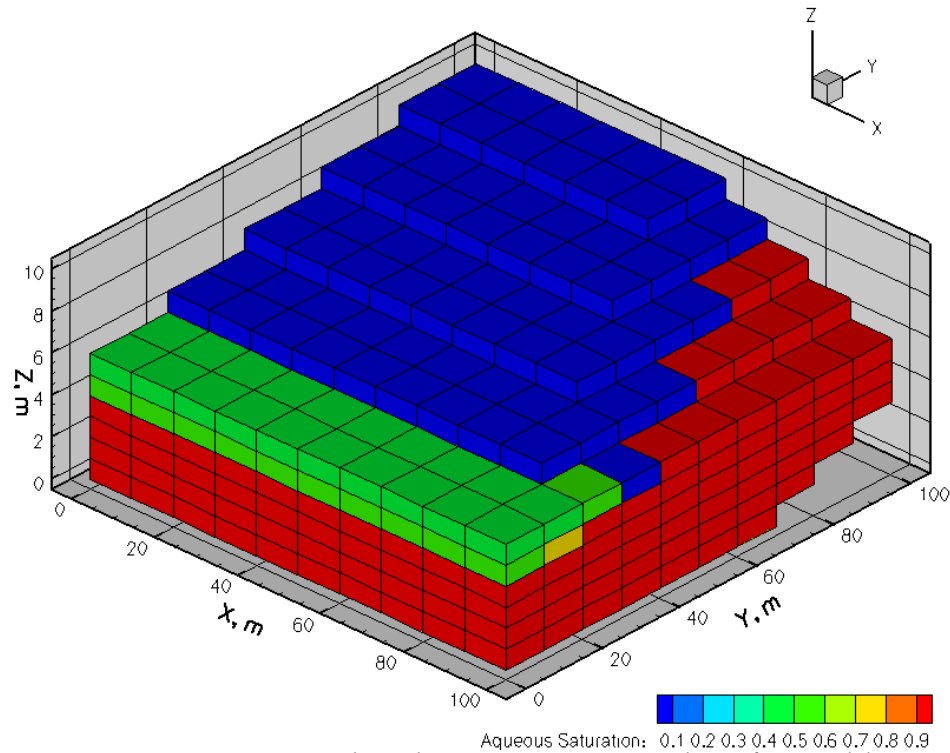
saturations shown in red (Aqueous Saturations  $> 0.9$ ) that extend higher vertically at the Northern end of the modeled domain than at the Southern end of the domain. Also note that the water table elevation is lower on day 15 than it was on day 0.

The influence of the zero-flux boundary applied to the southern boundary of the modeled domain is evident from the differences between the plotted saturations in Figures 13 and 8. Higher liquid saturations occur along the southern boundary in Figure 13 because water accumulates at this boundary due to the no-flow condition. In contrast, the seepage face boundary conditions applied to cell faces along this boundary in Exercise 2 (Figure 8) allow water to flow out of this side of the domain.

Figures 14 and 15 depict the aqueous saturation distributions for times of 17 and 120 days, respectively. In Figure 14 the North-South (y-direction) gradient is again evident, from the increases in aqueous saturations with distance to the North. The water table on day 17 (Figure 14) is also noticeably higher than it was on day 15 (Figure 13) or on day 0 (Figure 12). In Figure 15, the aqueous pressure gradient is not readily apparent from the aqueous saturation distribution, because the water table has risen high up into the gravel unit, which has a very high hydraulic conductivity and very low air-entry pressure. Also note that in Figure 10 the entire model domain has aqueous saturations  $> 0.9$ , in contrast to Figure 5 in which a portion of the upper part of the model domain has aqueous saturations  $< 0.1$ . This difference is due to the larger y-direction aqueous pressure gradients used in this exercise, relative to those used in Exercise 1.

A partial listing of the output file containing selected results for the reference nodes from this exercise is shown in Figure 16. Verify that the results produced by your executable match those shown in Figure 16. Again, note that the computed pressures for the reference nodes do not match those prescribed at the corresponding cell faces in the linked list files for this problem because the pressure gradients induce flow within the domain. However, as noted

previously, if the y-direction gradients applied to the 'eastside.lnk1st' and 'westside.lnk1st' files are set to zero, the pressures at the reference nodes should match those prescribed at the adjacent boundaries for this problem.



**Figure 12.** Aqueous saturation distribution at time = 0 days for problem 11, exercise 3

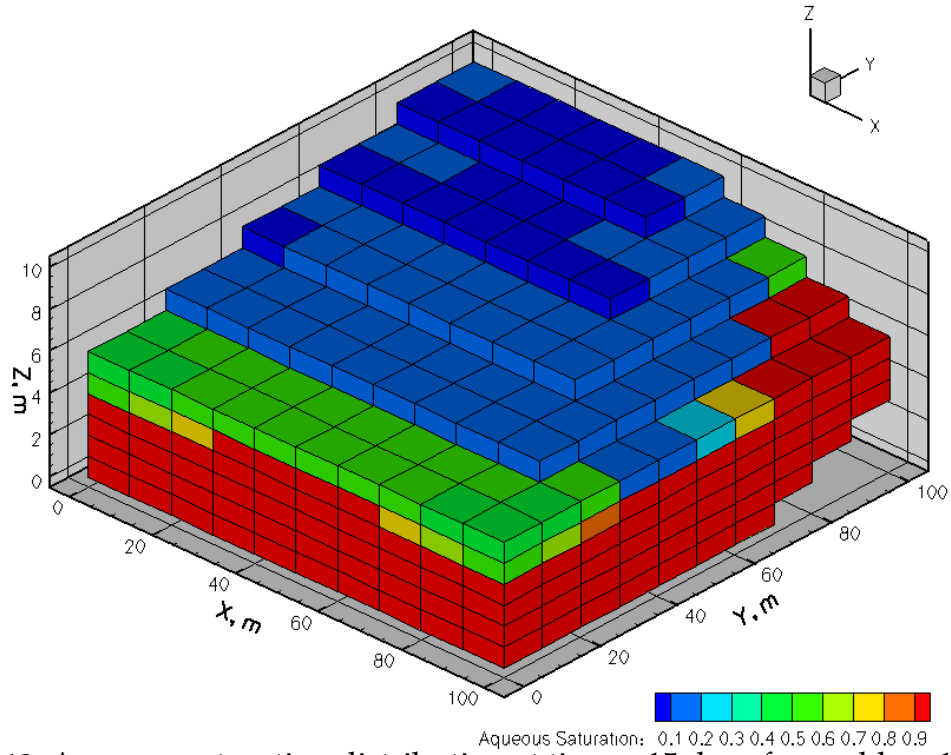


Figure 13. Aqueous saturation distribution at time = 15 days for problem 11, exercise 3

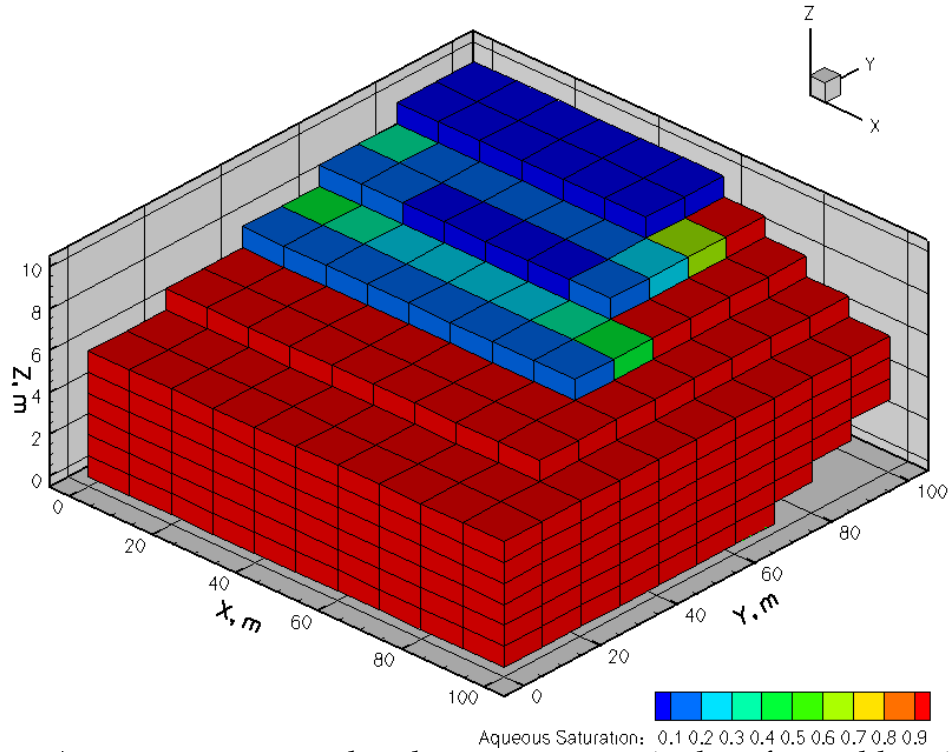
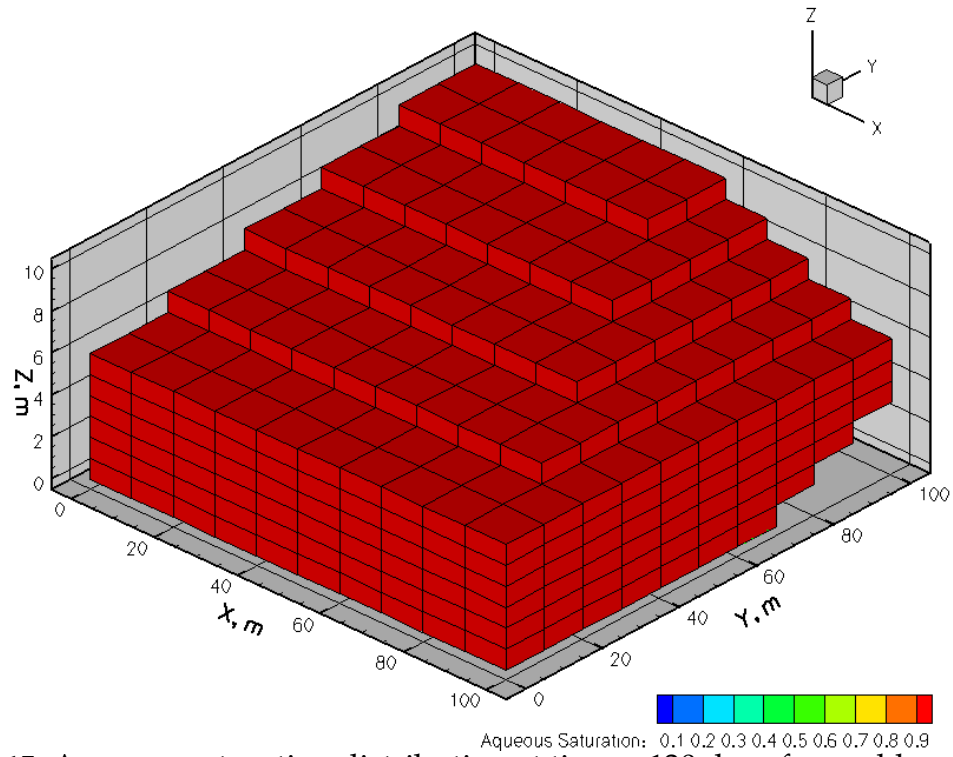


Figure 14. Aqueous saturation distribution at time = 17 days for problem 11, exercise 3





**Figure 15.** Aqueous saturation distribution at time = 120 days for problem 11, exercise 3

Reference 7, 1:	Node(s) 65)	( 10, 7, 1: ( 1, 7, 1:	70) 61)	( 10, 7, 3: ( 1, 7, 3:	270) 261)	( 5, 261)				
Step	Node	Time [day ]	Timestep [day ]	Itr	SL	PL [pa ]				
250	70	1.18000E+02	5.00000E-01	1	1.00000E+00	1.98429E+05				
250	270	1.18000E+02	5.00000E-01	1	1.00000E+00	1.78944E+05				
250	65	1.18000E+02	5.00000E-01	1	1.00000E+00	1.98193E+05				
250	61	1.18000E+02	5.00000E-01	1	1.00000E+00	1.98658E+05				
250	261	1.18000E+02	5.00000E-01	1	1.00000E+00	1.79279E+05				
251	70	1.18500E+02	5.00000E-01	1	1.00000E+00	1.98429E+05				
251	270	1.18500E+02	5.00000E-01	1	1.00000E+00	1.78944E+05				
251	65	1.18500E+02	5.00000E-01	1	1.00000E+00	1.98193E+05				
251	61	1.18500E+02	5.00000E-01	1	1.00000E+00	1.98658E+05				
251	261	1.18500E+02	5.00000E-01	1	1.00000E+00	1.79279E+05				
252	70	1.19000E+02	5.00000E-01	1	1.00000E+00	1.98429E+05				
252	270	1.19000E+02	5.00000E-01	1	1.00000E+00	1.78944E+05				
252	65	1.19000E+02	5.00000E-01	1	1.00000E+00	1.98193E+05				
252	61	1.19000E+02	5.00000E-01	1	1.00000E+00	1.98658E+05				
252	261	1.19000E+02	5.00000E-01	1	1.00000E+00	1.79279E+05				
253	70	1.19500E+02	5.00000E-01	1	1.00000E+00	1.98429E+05				
253	270	1.19500E+02	5.00000E-01	1	1.00000E+00	1.78944E+05				
253	65	1.19500E+02	5.00000E-01	1	1.00000E+00	1.98193E+05				
253	61	1.19500E+02	5.00000E-01	1	1.00000E+00	1.98658E+05				
253	261	1.19500E+02	5.00000E-01	1	1.00000E+00	1.79279E+05				
254	70	1.20000E+02	5.00000E-01	1	1.00000E+00	1.98429E+05				
254	270	1.20000E+02	5.00000E-01	1	1.00000E+00	1.78944E+05				
254	65	1.20000E+02	5.00000E-01	1	1.00000E+00	1.98193E+05				
254	61	1.20000E+02	5.00000E-01	1	1.00000E+00	1.98658E+05				
254	261	1.20000E+02	5.00000E-01	1	1.00000E+00	1.79279E+05				

NOTE: Simulation Stopped:

--- End of STOMP Simulation ---

**Figure 16.** Partial listing of reference node output for Problem 11, Exercise 3