

Variably Saturated Flow

Introduction

This example uses the Richards' Equation interface to assess how well geophysical irrigation sensors detect the true level of fluid saturation in variably saturated soils. Andrew Hinnell, Alex Furman, and Ty Ferre from the Department of Hydrology and Water Resources at the University of Arizona brought the example to us. They originally worked out the problem in COMSOL Multiphysics' PDE interfaces, but this discussion shares their elegant model reformulated in the Richards' Equation interface.

A major challenge when characterizing fluid movement in variably saturated porous media lies primarily in the need to describe how the capacity to transmit and store fluids changes as fluids enter and fill the pore spaces. Experimental data for these properties are difficult to obtain. Moreover, the properties that change value as the soil saturates happen to be equation coefficients, which makes the mathematics notoriously nonlinear. The Richards' Equation interface provides interfaces that automate the van Genuchten (Ref. 1) as well as the Brooks and Corey (Ref. 2) relationships for fluid retention and material properties that vary with the solution.



Figure 1: A variably saturated porous medium.

This example uses the model of Hinnell, Furman, and Ferre to characterize how the distribution of water changes around three impermeable sensors inserted into two different blocks of uniform soil partially saturated with water. The question for the model to address is this: Does the saturation localized around the sensor give a valid picture of the saturation within the total block?

This example demonstrates how to use the Richards' Equation interface including the van Genuchten (Ref. 1) as well as the Brooks and Corey (Ref. 2) retention models. The step-

by-step instructions assist you in learning how to set up two separate equation systems in one COMSOL Multiphysics model file and then solve them simultaneously.

Model Definition

The problem setup is as follows. Two homogeneous columns of soil, each 2 m-by-2 m on a face, are partially saturated with water. A plot of the hydraulic properties of the first soil (Soil Type 1) fits the van Genuchten retention and permeability formulas. The other soil (Soil Type 2) has material properties that suit the Brooks and Corey formulas. Within each soil column are three impermeable rods, each with a 0.1 m radius. The rods are spaced at 0.5 m increments so they run horizontally down the centerline of each block; see Figure 2. Just after the rods are emplaced, the pressure head is still uniform, but water begins to move vertically downward in steady drainage. Because all vertical slices down a block are identical, you can model a 2D cross section and observe the changes in the flow field for 900 s or 15 minutes.



Figure 2: Soil block with three rods. The shaded plane represents a vertical cross section.

GOVERNING EQUATION

Richards' equation describes the unsaturated-saturated flow of water in the soils. In this problem you can only use Richards' equation for the water since the air in the soil is supposed to be at atmospheric pressure. The governing equation for the model is

$$[C + \text{SeS}]\frac{\partial H_p}{\partial t} + \nabla \cdot [-K\nabla (H_p + D)] = 0$$

Pressure head, H_p (m), is the dependent variable. C denotes specific moisture capacity (m⁻¹), Se is the effective saturation, S is a storage coefficient (m⁻¹), t is time, K denotes the hydraulic conductivity (m/s), and D is the coordinate (for example x, y, or z) for the vertical elevation (m). The equation does not show the volumetric fraction of water, θ , which is a constitutive relation that depends on H_p . Nonlinearities appear because C, Se, and K change with H_p and θ .

The first term in the equation explains that fluid storage can change with time during both unsaturated and saturated conditions. When the soil is unsaturated, the pores fill with (or drain) water. After the pore spaces completely fill, there is slight compression of the fluid and the pore space. The specific moisture capacity $C = \partial \theta / \partial H_p$ describes the change in fluid volume fraction θ with pressure head. The storage coefficient addresses storage changes due to compression and expansion of the pore spaces and the water when the soil is fully wet. To model the storage coefficient, this example uses the specific storage option, which sets $S = \rho_f g(\chi_p + \theta \chi_f)$. Here, ρ_f is the fluid density (kg/m³), g is the acceleration of gravity, while χ_p and χ_f are the compressibilities of the solid particles and fluid, respectively (m·s²/ kg).

The van Genuchten and the Brooks and Corey formulas that describe the change in C, Se, K, and θ with H_p require data for the saturated and liquid volume fractions, θ_s and θ_r , as well as for other constants α , n, m, and l, which specify a particular type of medium. With the van Genuchten equations that follow, you consider the soil as being saturated when fluid pressure is atmospheric (that is, $H_p = 0$):

$$\boldsymbol{\theta} = \begin{cases} \boldsymbol{\theta}_{\mathrm{r}} + \operatorname{Se}(\boldsymbol{\theta}_{\mathrm{s}} - \boldsymbol{\theta}_{\mathrm{r}}) & H_p < 0 \\ \boldsymbol{\theta}_{\mathrm{s}} & H_p \ge 0 \end{cases}$$

Se =
$$\begin{cases} \frac{1}{\left[1 + \left|\alpha H_p\right|^n\right]^m} & H_p < 0\\ H_p \ge 0 \end{cases}$$

$$C = \begin{cases} \frac{\alpha m}{1-m} (\theta_{s} - \theta_{r}) \operatorname{Se}^{\frac{1}{m}} \left(1 - \operatorname{Se}^{\frac{1}{m}}\right)^{m} & H_{p} < 0\\ 0 & H_{p} \ge 0 \end{cases}$$
$$k_{r} = \begin{cases} \operatorname{Se}^{l} \left[1 - \left(1 - \operatorname{Se}^{\frac{1}{m}}\right)^{m}\right]^{2} & H_{p} < 0\\ 1 & H_{p} \ge 0 \end{cases}$$

With the Brooks and Corey approach, an air-entry pressure distinguishes saturated $(H_p>-1/\alpha)$ and unsaturated $(H_p<-1/\alpha)$ soil as in

$$\theta = \begin{cases} \theta_{r} + \operatorname{Se}(\theta_{s} - \theta_{r}) & H_{p} < -\frac{1}{\alpha} \\ \theta_{s} & -\frac{1}{\alpha} \leq H_{p} \end{cases}$$

$$\operatorname{Se} = \begin{cases} \frac{1}{|\alpha H_{p}|^{n}} & H_{p} < -\frac{1}{\alpha} \\ 1 & -\frac{1}{\alpha} \leq H_{p} \end{cases}$$

$$C = \begin{cases} \frac{-n}{H_{p}}(\theta_{s} - \theta_{r}) \frac{1}{|\alpha H_{p}|^{n}} & H_{p} < -\frac{1}{\alpha} \\ 0 & -\frac{1}{\alpha} \leq H_{p} \end{cases}$$

$$K = \begin{cases} \frac{-n}{H_{p}}(\theta_{s} - \theta_{r}) \frac{1}{|\alpha H_{p}|^{n}} & H_{p} < -\frac{1}{\alpha} \\ 0 & -\frac{1}{\alpha} \leq H_{p} \end{cases}$$

$$K = \begin{cases} \frac{2}{n} + l + 2 & H_{p} < -\frac{1}{\alpha} \\ K_{s} & -\frac{1}{\alpha} \leq H_{p} \end{cases}$$

To find a unique solution to this problem, you must specify initial and boundary conditions. Initially, the column has uniform pressure head of H_{p0} . The boundary conditions are

$\mathbf{n} \cdot [-\underline{K}\nabla(H_p + D)]$	$\partial \Omega$ Sides	
$\mathbf{n} \cdot [-\underline{K}\nabla(H_p + D)]$	$\partial \Omega$ Rings	
$H_p = H_{p0}$	$\partial \Omega$ Base	
$H_p = H_{p0}$	$\partial \Omega$ Surface	2

where \mathbf{n} is the unit vector normal to the boundary.

MODEL DATA

The following table gives the data needed to complete the two example problems:

VARIABLE	UNIT	DESCRIPTION	VAN GENUCHTEN	BROOKS & COREY
g	m/s ²	Gravity	9.82	9.82
ρ_{f}	kg/m ³	Fluid density	1000	1000
$\chi_{\rm p}$	m∙s²/kg	Compressibility solid particles	10 ⁻⁸	10 ⁻⁸
χf	m∙s²/kg	Compressibility of fluid	4.4·10 ⁻¹⁰	4.4·10 ⁻¹⁰

VARIABLE	UNIT	DESCRIPTION	VAN GENUCHTEN	BROOKS & COREY
$K_{ m s}$	m/s	Saturated hydraulic conductivity	8.25·10 ⁻⁵	5.83·10 ⁻⁵
$\theta_{\rm s}$		Porosity/void fraction	0.43	0.417
$\theta_{\mathbf{r}}$		Residual saturation	0.045	0.02
α	m ⁻¹	alpha parameter	14.5	13.8
n		n parameter	2.68	0.592
m		m parameter	I-1/n	n/a
l		Pore connectivity parameter	0.5	I
H_{p0}	m	Specified pressure	-0.06	-0.2
H_{p0}	m	Initial pressure	-0.06	-0.2

Results and Discussion

Figure 3 and Figure 4 are solutions to the Richards' equation problem of Prof. Ty Ferre, Andrew Hinnell, and Alex Furman from the University of Arizona's Department of Hydrology and Water Resources. Each figure gives results for similar variably saturated flow problem posed for different soil types. Each snapshot shows effective fluid saturation (surface plot), pressure head (contours), and fluid velocities (arrows). The flow field varies around the rods but remains largely uniform over the remainder of each block.



Figure 3: Solution for effective saturation (surface plot), pressure head (contours), and velocity (arrows) at 15 minutes for Soil Type 1 (van Genuchten).



Figure 4: Solution for effective saturation (surface plot), pressure head (contours), and velocity (arrows) at 15 minutes for Soil Type 2 (Brooks and Corey).

Figure 5 shows the effective saturation evolving over time at the rod-soil boundary. The intervals $(-180^\circ, 0^\circ)$ and $(0^\circ, 180^\circ)$ for the angular coordinate along the horizontal axis correspond to the boundary's lower and upper halves, respectively. In the figure, the solid

lines denote the solution for Soil Type 1, and the dashed lines correspond to Soil Type 2. The soil is wetter just above the rods than below them.



Figure 5: Effective saturation around the center rod in Soil Type 1 (solid lines) and Soil Type 2 (dashed lines).

Figure 6 compares the average fluid saturations at the rod boundary with the average within the two blocks of soil. The range of effective saturation estimates at the rod boundary appears as a scatter plot for different time steps. The solid line is the average of the effective saturation at the rod boundary. The dashed line is the average of effective saturation for the soil. Clearly the average effective saturation at the rods increases with time, but the average for the soil does not change. While the effects shown here are more pronounced in Soil Type 1 than Soil Type 2, the results call to question whether the sensors can accurately assess soil moisture if kept in situ for long times.



Figure 6: Average effective saturation at sensor circumference and overall soil block for Soil Type 1 (blue) and Soil Type 2 (green). Also shown is the range of effective saturation at the rod circumference for Soil Type 1 (circles) and Soil Type 2 (squares).

References

1. M.Th. van Genuchten, "A Closed-form Equation for Predicting the Hydraulic of Conductivity of Unsaturated Soils," *Soil Sci. Soc. Am. J.*, vol. 44, pp. 892–898, 1980.

2. R.H. Brooks and A.T. Corey, "Properties of Porous Media Affecting Fluid Flow," J. Irrig. Drainage Div., ASCE Proc, vol. 72 (IR2), pp. 61–88, 1966.

Application Library path: Subsurface_Flow_Module/Fluid_Flow/ variably_saturated_flow

Modeling Instructions

From the File menu, choose New.

NEW

In the New window, click <u>Model Wizard</u>.

MODEL WIZARD

- I In the Model Wizard window, click 🧐 2D.
- 2 In the Select Physics tree, select Fluid Flow>Porous Media and Subsurface Flow> Richards' Equation (dl).
- 3 Click Add.
- 4 In the Select Physics tree, select Fluid Flow>Porous Media and Subsurface Flow> Richards' Equation (dl).
- 5 Click Add.
- 6 Click 🔿 Study.
- 7 In the Select Study tree, select General Studies>Time Dependent.
- 8 Click **M** Done.

GEOMETRY I

Square 1 (sq1)

- I In the **Geometry** toolbar, click **Square**.
- 2 In the Settings window for Square, locate the Size section.
- **3** In the **Side length** text field, type **2**.
- 4 Locate the **Position** section. From the **Base** list, choose **Center**.

Circle I (c1)

- I In the **Geometry** toolbar, click \bigcirc **Circle**.
- 2 In the Settings window for Circle, locate the Size and Shape section.
- 3 In the Radius text field, type 0.1.
- 4 Locate the **Position** section. In the **x** text field, type -0.5.

Array I (arr1)

- I In the Geometry toolbar, click 💭 Transforms and choose Array.
- 2 Select the object **cl** only.
- 3 In the Settings window for Array, locate the Size section.
- 4 In the x size text field, type 3.
- 5 Locate the **Displacement** section. In the **x** text field, type 0.5.

Difference I (dif1)

- I In the Geometry toolbar, click i Booleans and Partitions and choose Difference.
- 2 Select the object sql only, to add it to the Objects to add list.
- 3 In the Settings window for Difference, locate the Difference section.
- **4** Find the **Objects to subtract** subsection. Select the **Delta Activate Selection** toggle button.
- 5 Select the objects arr1(1,1), arr1(2,1), and arr1(3,1) only.
- 6 Click 🟢 Build All Objects.

DEFINITIONS

Next, create the selection to simplify the evaluation of the results.

Rod

- I In the Definitions toolbar, click 🐂 Explicit.
- 2 In the Settings window for Explicit, type Rod in the Label text field.
- 3 Locate the Input Entities section. From the Geometric entity level list, choose Boundary.
- 4 Select Boundary 9 only.
- **5** Select the **Group by continuous tangent** check box.

RICHARDS' EQUATION (DL)

Richards' Equation Model 1

First, set up the model for Soil Type 1, which you build with the van Genuchten retention and permeability relationships.

- I In the Model Builder window, under Component I (compl)>Richards' Equation (dl) click Richards' Equation Model I.
- 2 In the Settings window for Richards' Equation Model, locate the Fluid Properties section.
- **3** From the ρ list, choose **User defined**. In the associated text field, type 1000.
- 4 Locate the Matrix Properties section. From the Permeability model list, choose Hydraulic conductivity.
- **5** In the K_s text field, type 8.25e-5.
- 6 Locate the Storage Model section. From the χ_f list, choose User defined. In the associated text field, type 4.4e-10.
- 7 In the χ_p text field, type 1e-8.
- 8 Locate the Matrix Properties section. In the θ_s text field, type 0.43.
- **9** In the θ_r text field, type 0.045.

IO Locate the **Retention Model** section. In the α text field, type 14.5.

II In the *n* text field, type 2.68.

Initial Values 1

- I In the Model Builder window, click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- 3 Click the Pressure head button.
- 4 In the H_p text field, type -0.06.

Pressure Head I

- I In the Physics toolbar, click Boundaries and choose Pressure Head.
- 2 Select Boundaries 2 and 3 only.
- 3 In the Settings window for Pressure Head, locate the Pressure Head section.
- **4** In the H_{p0} text field, type -0.06.

RICHARDS' EQUATION 2 (DL2)

Richards' Equation Model 1

Specify equations and boundary conditions for Soil Type 2 using the Brooks and Corey parameterization approach.

- I In the Model Builder window, under Component I (compl)>Richards' Equation 2 (dl2) click Richards' Equation Model I.
- 2 In the Settings window for Richards' Equation Model, locate the Fluid Properties section.
- **3** From the ρ list, choose **User defined**. In the associated text field, type 1000.
- 4 Locate the Matrix Properties section. From the Permeability model list, choose Hydraulic conductivity.
- **5** In the $K_{\rm s}$ text field, type **5.8333e-5**.
- 6 Locate the Storage Model section. From the χ_f list, choose User defined. In the associated text field, type 4.4e-10.
- 7 In the χ_p text field, type 1e-8.
- 8 Locate the Matrix Properties section. In the $\theta_{\rm s}$ text field, type 0.417.
- **9** In the θ_r text field, type 0.02.
- IO Locate the Retention Model section. From the Retention model list, choose Brooks and Corey.
- II In the α text field, type 13.8.

12 In the *n* text field, type 0.592.

I3 In the l text field, type 1.

Initial Values 1

- I In the Model Builder window, click Initial Values I.
- 2 In the Settings window for Initial Values, locate the Initial Values section.
- **3** Click the **Pressure head** button.
- 4 In the H_p text field, type -0.2.

Pressure Head I

- I In the Physics toolbar, click Boundaries and choose Pressure Head.
- **2** Select Boundaries 2 and 3 only.
- 3 In the Settings window for Pressure Head, locate the Pressure Head section.
- **4** In the H_{p0} text field, type -0.2.

MESH I

Free Triangular 1

In the Mesh toolbar, click Kree Triangular.

Size 1

- I Right-click Free Triangular I and choose Size.
- 2 In the Settings window for Size, locate the Geometric Entity Selection section.
- 3 From the Geometric entity level list, choose Boundary.
- 4 Select Boundaries 5–16 only.
- 5 Locate the **Element Size** section. Click the **Custom** button.
- 6 Locate the Element Size Parameters section. Select the Maximum element size check box.
- 7 In the associated text field, type 0.025.



STUDY I

- I In the Model Builder window, click Study I.
- 2 In the Settings window for Study, locate the Study Settings section.
- **3** Clear the **Generate default plots** check box.

Step 1: Time Dependent

- I In the Model Builder window, under Study I click Step I: Time Dependent.
- 2 In the Settings window for Time Dependent, locate the Study Settings section.
- 3 From the Time unit list, choose min.
- 4 In the **Output times** text field, type 0 1 5 10 15.
- **5** In the **Home** toolbar, click **= Compute**.

RESULTS

Follow the steps below to reproduce Figure 3 and Figure 4.

Soil Type 1

- I In the Home toolbar, click 🔎 Add Plot Group and choose 2D Plot Group.
- 2 In the Settings window for 2D Plot Group, type Soil Type 1 in the Label text field.

Surface 1

- I Right-click Soil Type I and choose Surface.
- 2 In the Settings window for Surface, locate the Expression section.
- 3 In the **Expression** text field, type dl.Se.

Arrow Surface 1

In the Model Builder window, right-click Soil Type I and choose Arrow Surface.

Contour I

- I Right-click Soil Type I and choose Contour.
- 2 In the Settings window for Contour, locate the Expression section.
- **3** In the **Expression** text field, type dl.Hp.
- 4 Locate the Coloring and Style section. From the Coloring list, choose Uniform.
- 5 From the Color list, choose Black.
- 6 Clear the Color legend check box.
- 7 In the Soil Type I toolbar, click 🗿 Plot.

Soil Type 2

- I Right-click Soil Type I and choose Duplicate.
- 2 In the Settings window for 2D Plot Group, type Soil Type 2 in the Label text field.

Surface 1

- I In the Model Builder window, expand the Soil Type 2 node, then click Surface I.
- 2 In the Settings window for Surface, locate the Expression section.
- 3 In the **Expression** text field, type dl2.Se.

Arrow Surface 1

- I In the Model Builder window, click Arrow Surface I.
- 2 In the Settings window for Arrow Surface, locate the Expression section.
- 3 In the X component text field, type dl2.u.
- 4 In the Y component text field, type dl2.v.

Contour I

- I In the Model Builder window, click Contour I.
- 2 In the Settings window for Contour, locate the Expression section.
- **3** In the **Expression** text field, type dl2.Hp.
- **4** In the **Soil Type 2** toolbar, click **I** Plot.

To generate Figure 5, continue with the steps below.

Effective Saturation

- I In the Home toolbar, click 🚛 Add Plot Group and choose ID Plot Group.
- 2 In the Settings window for ID Plot Group, type Effective Saturation in the Label text field.

Line Graph 1

- I Right-click Effective Saturation and choose Line Graph.
- 2 In the Settings window for Line Graph, locate the Selection section.
- **3** From the **Selection** list, choose **Rod**.
- 4 Locate the y-Axis Data section. In the Expression text field, type dl.Se.
- 5 Locate the x-Axis Data section. From the Parameter list, choose Expression.
- 6 In the **Expression** text field, type atan2(y,x).
- 7 From the **Unit** list, choose °.

The function atan2(y,x) along the circle representing the rod produces unphysical values at one point, because there is 180° =- 180° . To avoid this, the data are filtered.

Filter I

- I Right-click Line Graph I and choose Filter.
- 2 In the Settings window for Filter, locate the Element Selection section.
- 3 In the Logical expression for inclusion text field, type abs(atan2(y,x)) < pi.
- **4** In the **Effective Saturation** toolbar, click **O Plot**.

Line Graph 2

- I In the Model Builder window, under Results>Effective Saturation right-click Line Graph I and choose Duplicate.
- 2 In the Settings window for Line Graph, locate the y-Axis Data section.
- 3 In the **Expression** text field, type dl2.Se.
- 4 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.
- 5 From the Color list, choose Cycle (reset).
- 6 Click to expand the Legends section.

Line Graph 1

I In the Model Builder window, click Line Graph I.

- 2 In the Settings window for Line Graph, locate the Legends section.
- 3 Select the Show legends check box.

Effective Saturation

- I In the Model Builder window, click Effective Saturation.
- 2 In the Settings window for ID Plot Group, click to expand the Title section.
- **3** From the **Title type** list, choose **Manual**.
- 4 In the Title text area, type Effective Saturation, S_e (1).
- 5 Locate the Legend section. From the Position list, choose Upper left.
- 6 In the Effective Saturation toolbar, click 🗿 Plot.

To reproduce Figure 6, start by evaluating the average fluid saturation at the rod boundary and the average within the block for two types of soil.

Surface Average 1

- I In the Results toolbar, click 8.85 e-12 More Derived Values and choose Average> Surface Average.
- **2** Select Domain 1 only.
- 3 In the Settings window for Surface Average, locate the Expressions section.
- **4** In the table, enter the following settings:

Expression	Unit	Description
dl.Se	1	Effective saturation
dl2.Se	1	Effective saturation

5 Click **=** Evaluate.

Line Average 2

- I In the Results toolbar, click 8.85 e-12 More Derived Values and choose Average>Line Average.
- 2 In the Settings window for Line Average, locate the Selection section.
- **3** From the **Selection** list, choose **Rod**.
- 4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
dl.Se	1	Effective saturation
dl2.Se	1	Effective saturation

5 Click **•** next to **= Evaluate**, then choose **New Table**.

TABLE

- I Go to the Table window.
- 2 Click **Table Graph** in the window toolbar.

RESULTS

Table Graph 1

- I In the Model Builder window, under Results>ID Plot Group 4 click Table Graph I.
- 2 In the Settings window for Table Graph, click to expand the Legends section.
- 3 Select the Show legends check box.
- 4 From the Legends list, choose Manual.
- 5 In the table, enter the following settings:

Legends

S _e	at	rod,	soil	type	1	
S _e	at	rod,	soil	type	2	

Table Graph 2

- I Right-click Results>ID Plot Group 4>Table Graph I and choose Duplicate.
- 2 In the Settings window for Table Graph, locate the Data section.
- 3 From the Table list, choose Table I.
- 4 Locate the Coloring and Style section. Find the Line style subsection. From the Line list, choose Dashed.
- 5 From the Color list, choose Cycle (reset).
- 6 Locate the Legends section. In the table, enter the following settings:

Legends

Overall S_e, soil type 1 Overall S_e, soil type 2

Continue by adding the distribution of effective saturation estimates at each output time.

ID Plot Group 4

In the Model Builder window, click ID Plot Group 4.

Line Graph 1

I In the ID Plot Group 4 toolbar, click 📐 Line Graph.

- 2 In the Settings window for Line Graph, locate the Data section.
- 3 From the Dataset list, choose Study I/Solution I (soll).
- 4 Locate the Selection section. From the Selection list, choose Rod.
- 5 Locate the y-Axis Data section. In the Expression text field, type dl.Se.
- 6 Locate the x-Axis Data section. From the Parameter list, choose Expression.
- 7 In the **Expression** text field, type t.
- 8 From the Unit list, choose min.
- 9 Locate the Coloring and Style section. From the Color list, choose Blue.
- **IO** In the **Width** text field, type **2**.
- II Find the Line markers subsection. From the Marker list, choose Circle.

Line Graph 2

- I Right-click Line Graph I and choose Duplicate.
- 2 In the Settings window for Line Graph, locate the y-Axis Data section.
- 3 In the **Expression** text field, type dl2.Se.
- 4 Locate the Coloring and Style section. From the Color list, choose Green.
- 5 Find the Line markers subsection. From the Marker list, choose Square.

Average effective saturation

- I In the Model Builder window, under Results click ID Plot Group 4.
- 2 In the Settings window for ID Plot Group, type Average effective saturation in the Label text field.
- 3 Locate the Title section. From the Title type list, choose Manual.
- 4 In the Title text area, type Average effective saturation, S_e.
- 5 Locate the Plot Settings section. Select the y-axis label check box.
- 6 In the associated text field, type S_e(1).
- 7 Locate the Legend section. From the Position list, choose Upper left.

22 | VARIABLY SATURATED FLOW