Modflow User Tools (MUT) Version 1.22 User's Guide

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Chapter 1

Introduction

This document describes a new MODFLOW-USG[1] development environment which has the following features:

- We refer to it as Modflow User Tools, or MUT for short.
- MUT is designed to work with a modified version of MODFLOW-USG, where a new surface water flow package, called SWF, has been added. Like the Connected Linear Network (CLN) package, the SWF package represents a new domain type that is fully-coupled to the 3D groundwater flow (GWF) domain. There cab also be cell-to-cell flows between the SWF and CLN domains. The SWF domain uses the diffusion-wave approach so simulate 2D surface-water flow.
- We currently develop and run it on a MICROSOFT WINDOWS 10-based computing platform, writing software using the INTEL FORTRAN[2] compiler running inside the MICROSOFT VISUAL STUDIO[3] interactive development environment, which includes software version control tools through GITHUB.
- A text-based approach is used for the MUT interface, in which we first develop an input file of instructions that define our MODFLOW-USG-SWF project, then run MUT to read it and write a complete MODFLOW-USG-SWF data set. MUT also writes output files for TECPLOT[4], a third-party visualization software package, which provides a 3D graphical visualization tool to review the model numerical mesh and material properties in the data set. In future, MUT could be extended to support other third-party visualization packages, for example the open source program Paraview.
- MUT can post-process a MODFLOW-USG-SWF simulation to provide a TECPLOT visualization of temporal model results, including hydraulic heads, saturations, water depths and flow budget data. *If applied to output files which were produced by an earlier version of Modflow, results may be mixed. It is not our intent here to support all existing Modflow packages, many of which have been superceded.*

This document is subivided into the following sections:

Chapter 2 Installation and Setup: How to install MUT, MODFLOW-USG-SWF and TECPLOT and define MICROSOFT WINDOWS environment variables.

[1] https://www.gsienv.com/software/modflow-usg/modflow-usg/
[2] https://www.intel.com/content/www/us/en/developer/tools/oneapi/hpc-toolkit.html
[3] https://visualstudio.microsoft.com/vs/community/
[4] https://tecplot.com/products/tecplot-360/

Chapter 3 Model Build: How to build a MUT input file, run MUT to produce a MODFLOW-USG-SWF-compatible data set and TECPLOT-compatible output files, and run TECPLOT to review the results of the model build.

Chapter 4 Model Execution and Post-Processing How to run MODFLOW-USG-SWF run MUT to convert the output to TECPLOT-compatible output files, and run and run TECPLOT to visualize the results of the model run.

Chapter 5 Examples Examples of MODFLOW-USG-SWF models built using MUT for both the verification and illustration of MUT and MODFLOW-USG-SWF useage.

Chapter 6 Tutorial In the tutorial, we build a 3D fully-coupled GWF-SWF model, check the build using TECPLOT, run MODFLOW-USG-SWF to generate output, then examine the results using TECPLOT.

Chapter 2

Software Installation and Useage

The first step in the software installation process is to obtain the MUT examples, executables and database files from https://github.com/Grdbldr/MUT_Source.git.

GITHUB[1].

For the end user, who is **not interested in fortran programming or working with source code** you can skip to Section 2.2.

2.1 Software Developer

Source code and compiled executables for MUT and MODFLOW-USG are available through Through the GITHUB website, you will need to e footnote at the bottom of this page For the developer who **would like to modify and compile source code** we recommend that you obtain the following software development tools:

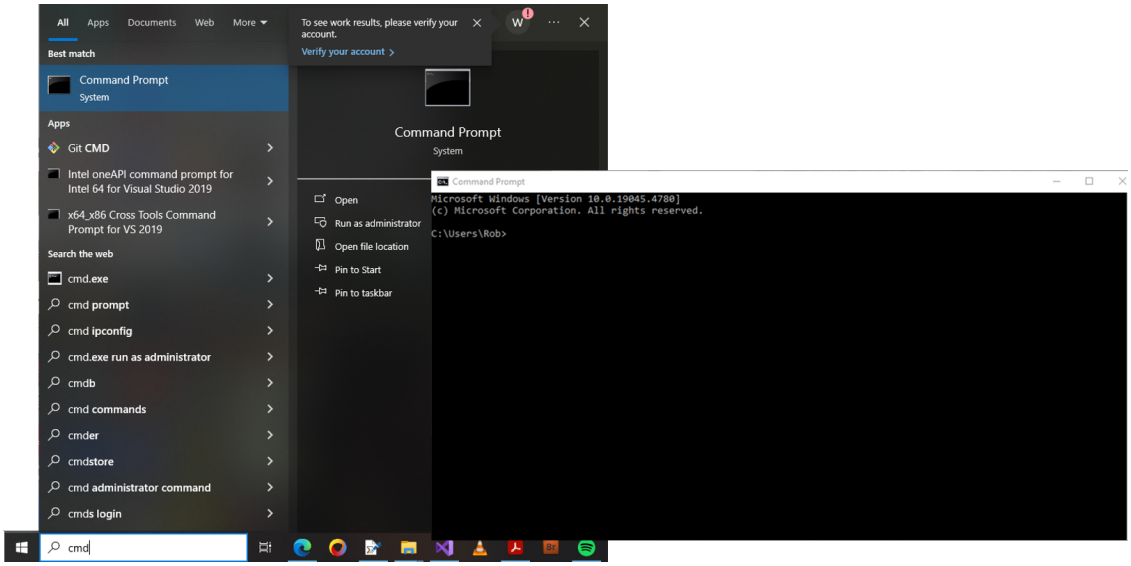
1.
2. Obtain the MUT source from the git repository at https://github.com/Grdbldr/MUT_Source.git.
3.

For those unfamiliar with Git see for example the free software GITHUB at https://en.wikipedia.org/wiki/GitHub.

2.2 All Users

Before you run MUT for the first time, you need to define a windows environment variable called `USERBIN`. An easy way to do this is to start a command prompt window from FILE EXPLORER by clicking an

[1] https://github.com/




```
set USERBIN=c:\bin
```

This can be done through Windows settings or at the command prompt.

The software has been developed and tested under Windows 10 and TECPLOT360 EX 2018 R2.

Build the source in Microsoft Visual Studio. We provide a Visual Studio 2019 solution file for this purpose. Currently, Microsoft is providing a free community version of Visual Studio 2022.

Chapter 3

Model Build

3.1 Suggested Workflow

A well-designed workflow should minimize the introduction of human error into the modelling process and facilitate later review by senior modellers. Below we describe one possible approach that can be used as a starting point for implementing your own personal workflow. We will use the verification example `6_Abdul_Prism_Cell` to demonstrate our suggested workflow. The steps in the workflow are:

1. Copy an existing MUT project folder to a new working folder.
2. Modify the `_build.mut` file (and other input files if necessary) to reflect the new Modflow project.
3. Run MUT to build the new Modflow project, which produces TECPLOT output files for the various Modflow domains (i.e. GWF, SWF and/or CLN) created during the build process.
4. Run TECPLOT and examine the build output files. Repeat steps 2-3 until the new project is defined correctly.
5. Run Modflow to create the new project output files (e.g. time-varying hydraulic head, drawdown etc).
6. Run `_post.mut` to post-process the Modflow project, which produces TECPLOT output files for the various Modflow domains (i.e. GWF, SWF and/or CLN) created during the Modflow simulation.
7. Run TECPLOT and examine the Modflow output files.

3.2 Mut Input File Structure

MUT recognizes files which have the extension `.mut` as input files and reads and interprets them to produce both MODFLOW-USG-SWF output files and TECPLOT input files. Input files are ordinary text files which contain comments, MUT instructions and data which can be numbers or alphanumeric strings.

Comments begin with an exclamtion point character `!` and are ignored by MUT. MUT initially strips the input file of all comments and creates a clean copy called *prefix*`o.input`, which is then processed by MUT. This means comments can be placed anywhere in the input file.

3.3 Tecplot Useage

3.4 Groundwater Flow(GWF) Domain

In MUT, a 2D template mesh is first defined and then a 3D groundwater flow (GWF) domain is generated from it using the instruction generate layered gwf domain, as shown in this example:

```
    generate layered gwf domain

        top elevation
            elevation from gb file
            ./gb/grid.nprop.Surface elevation
        end

        new layer
            layer name
            Top layer

            uniform sublayering
            5

            elevation from gb file
            ./gb/grid.nprop.Surface elevation - 0.5 m
        end
...
```

3.4.1 Constant Head(CHD)

```
    Pre-requisites:
    Activate one of GWF, SWF or CLN domains
    Choose cells

    Instructions:
    gwf constant head

    Inputs:
    Head    L
```

All chosen cells will be assigned a constant head equal to the specified total head value.

3.4.2 Drains(DRN)

```
    Pre-requisites:
    Activate one of GWF, SWF or CLN domains
    Choose cells
```

```
Instructions:
gwf drain

Inputs:
Drain conductance  L/T
```

All chosen cells will be assigned a drain elevation equal to the top elevation of the cell with the specified drain conductance.

3.4.3 Recharge(RCH)

3.4.4 Pumping

3.5 Connected Linear Networks(CLN) Domain

3.6 Surface Water Flow(SWF) Domain

3.6.1 Critical Depth

3.6.2 Zero-Gradient Depth

Chapter 4

Model Execution and Post-Processing

Chapter 5

Examples

5.1 Verification

5.1.1 Unsaturated flow in a 1D Column

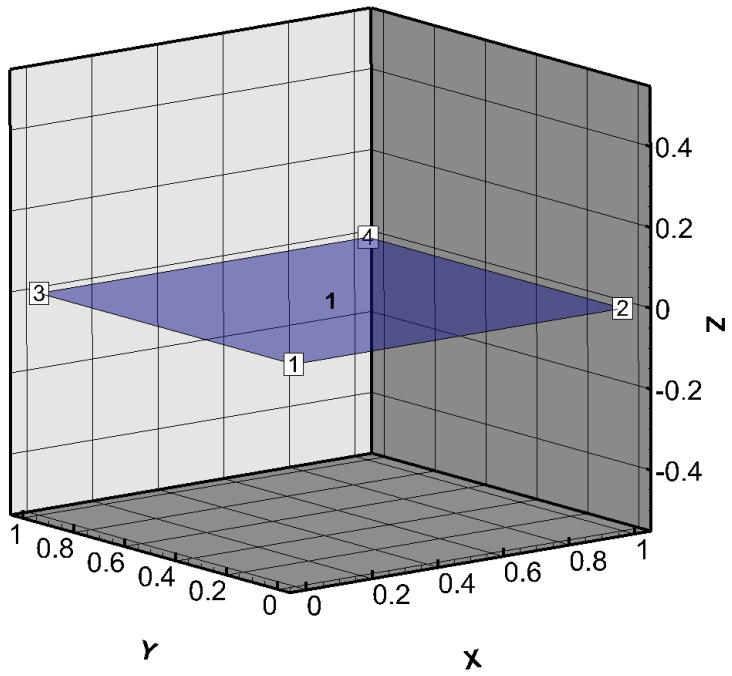
This example can be found in the folder `MUT_Examples\1_VSF_Column`

```
! Examples\1_VSF_Column:
!   A modflow project of a 1D column generated from a simple 2d rectangular mesh
build modflow usg
```

The template mesh is generated using the following instructions:

```
generate uniform rectangles
1.0, 1   !  Mesh length in X-direction and number of rectangular elements
1.0, 1   !  Mesh length in Y-direction and number of rectangular elements
```

The 1D column example uses a single 1m X 1m rectangular element as the template mesh for building



the GWF domain.

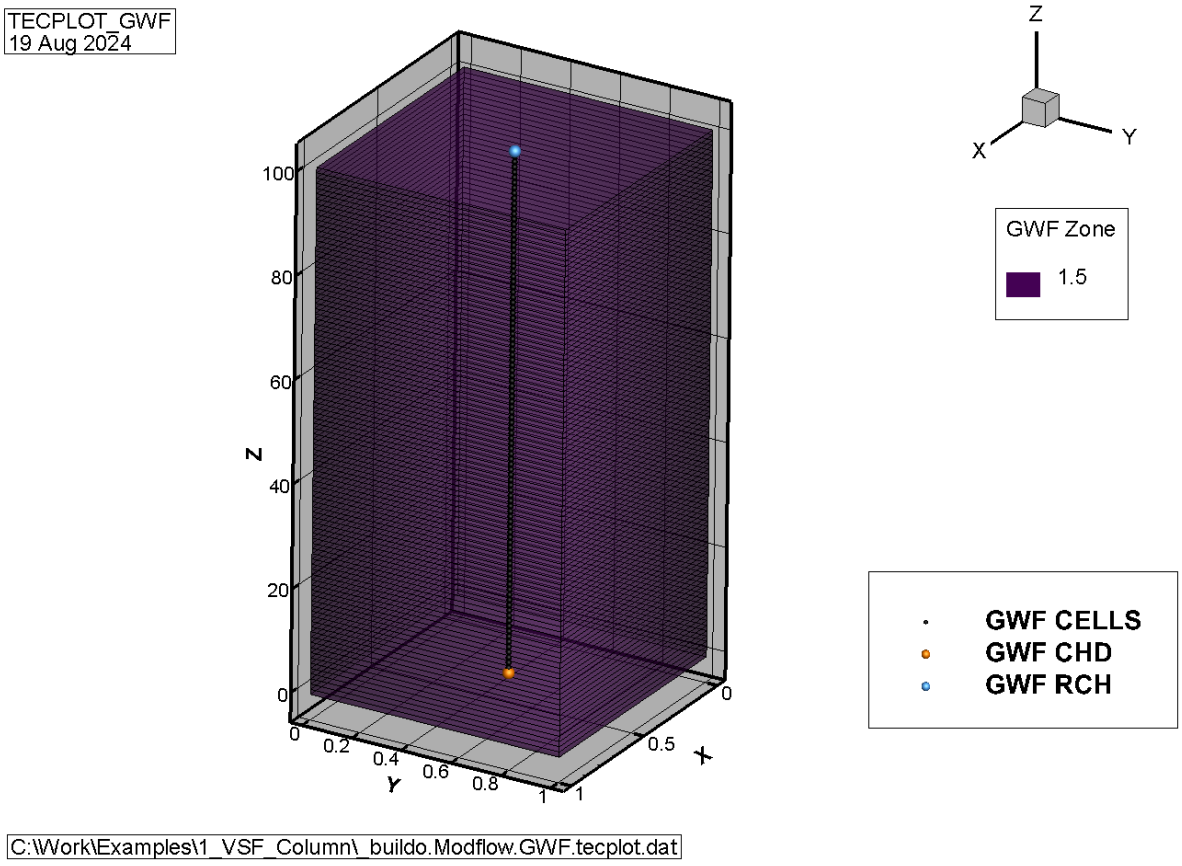


Figure 5.1: 1D column build

Figure 5.1 shows the The 1D column example uses a single 1 m by 1 m rectangular element as the template mesh for building the GWF domain.

5.1.2 Unsaturated flow in a 2D Hillslope: Drains vs Surfacewater Flow

5.1.3 Abdul's Experiment: 3D Unsaturated GroundwaterFlow

5.2 Illustration

Chapter 6

Tutorial

We will go through the contents of the file and discuss each of the input lines. Here is the start of the file:

```
! This example builds a modflow project of the Abdul Field Experiment
! The SWF mesh and top of the GWF mesh are defined by a 2D Grid Builder triangular mesh
build modflow usg
```

Any input line beginning with is considered to be a comment and will be ignored by MUT.Here we begin the file with two comments describing the project.

The third line activates the MUT 'build modflow usg' environment, which accepts further instructions required to define the project. This environment can be split into roughly 4 sections:

Grid definition Instructions for defining the GWF, SWF and CLN numerical discretizations.

Modflow parameters Instructions for supplying Modflow parameter values (e.g. solver inputs for the SMS package, hydraulic properties for the LPF package etc.)

Stress periods, boundary conditions These instructions are repeated once for each desired stress period and include instructions about time stepping parameters and boundary conditions that are to be applied.

Output control Instructions defining a list of output times at which Modflow output files (e.g. heads, drawdowns, cell-by-cell flows etc.) are to be written.

The first group of instructions are used to build the Modflow unstructured mesh. MUT requires a 2D 'template'

```
! ----------------------------------Grid definition
2d mesh from gb
./gb/grid
```

Step 1: Copy an Existing Mut Project

Reasons to copy an existing project:

- As time passes, a variety of MUT Modflow projects will be developed for specific purposes. If an existing project is similar to one you would like to create, the easiest approach is to copy it and modfy it as required. This will reduce set-up time and avoid potential errors that are introduced when creating input files from scratch.
- During the modelling process, different 'what if?' scenarios are tested by copying the an existing project folder and modifying specific input values such as hydraulic conductivity or recharge rate, for example.

Create a new folder called e.g. `My_Project` and copy the folder `MUT_Examples\6_Abdul_Prism_Cell` into it. Figure 6.1 shows the contents of our `6_Abdul_Prism_Cell` folder. Yours may look different depending on the root drive and folder location.

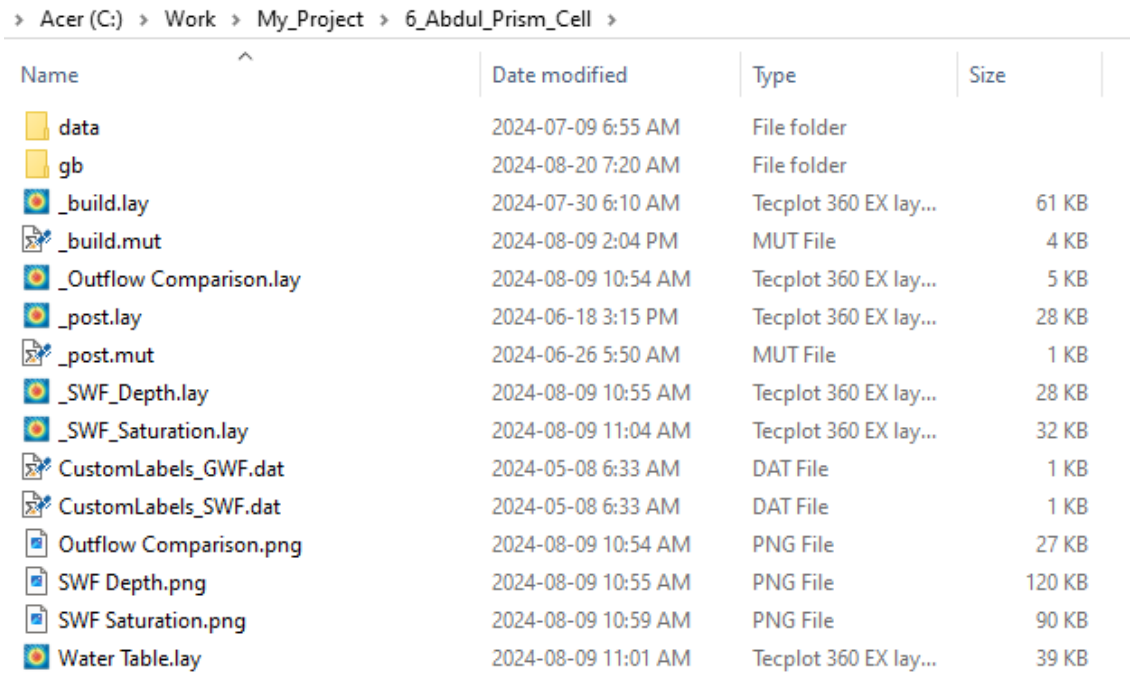


Figure 6.1: The contents of the 6_Abdul_Prism_Cell folder

This example contains several files you might typically find in a MUT Modflow project, including MUT input files (extension .mut), TECPLOT layout files (extension .lay), TECPLOT input files (extension .dat). For now, our focus will be on the MUT input file `_build.mut`.

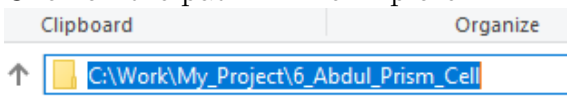
Step 2: Modify the Input File(s)

The input file `_build.mut` is set up to build a Modflow project. If you open the file in a text editor you will see that it consists of a sequence of comments (lines beginning with an exclamation mark `!`), MUT instructions and data (numbers or alphanumeric strings). Details of the input file contents are described in detail in Section **??**. For now, we will only make a minor change to the input file before moving on to the next step, which is to add a new comment line of your choice at the start of the file.

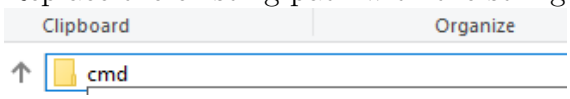
Step 3: Execute Mut to Build the Project

We suggest running the required executables, of which MUT is one, from a Windows command prompt. To start a command prompt that is rooted in the `6_Abdul_Prism_Cell` folder:

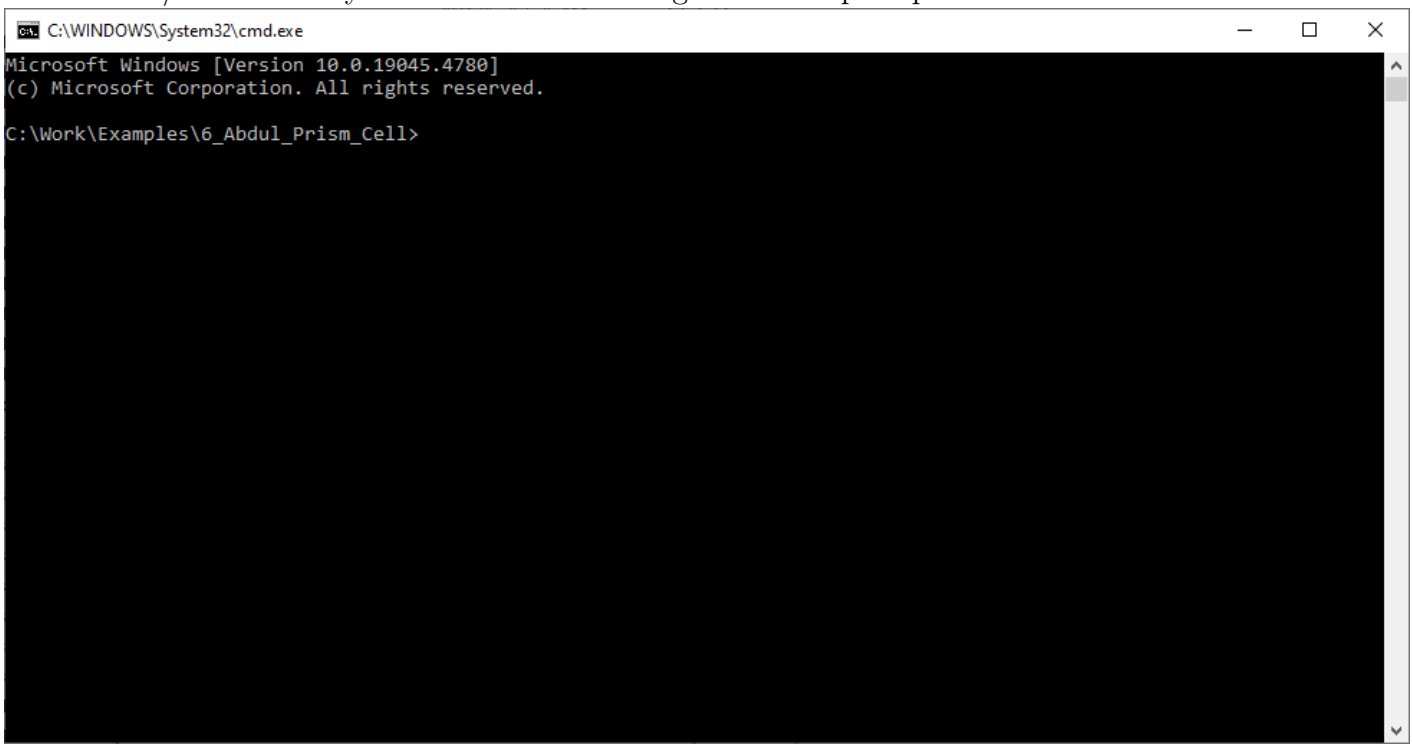
- Click on the path in File Explorer:



- Replace the existing path with the string 'cmd':



- Press Enter/Return and you will see the following command prompt:



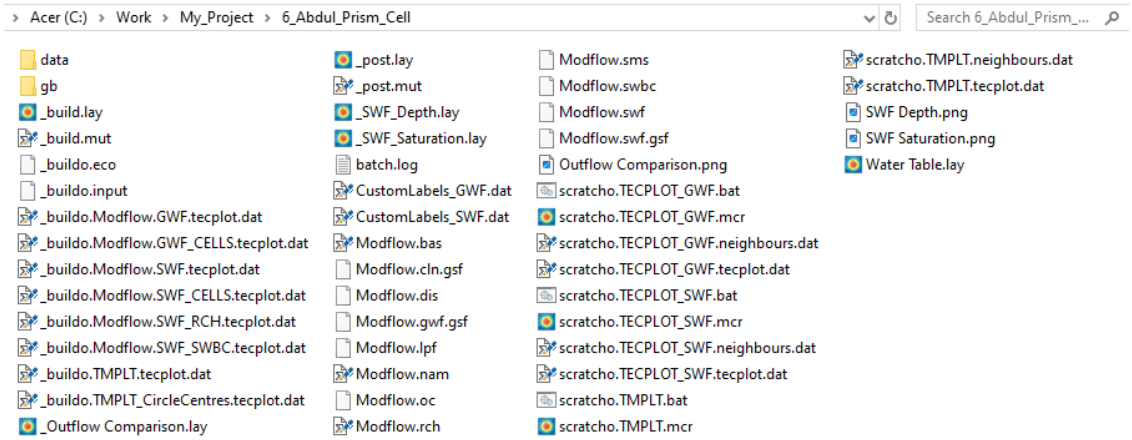
Assuming you have followed the set-up instructions in Section **??**, you can execute MUT with the input file `_build.mut` by typing:

```
mut _build
```

Note the following as MUT processes the input file:

- Output is written to both the screen and the file `_buildo.eco` as execution progresses. If the run is successful the last line written will be 'Normal exit', otherwise an error message will be given.

- Several new output files are created:



- The first thing written is the MUT version number. Check that it is the expected version you are running.
- Comment lines are stripped from the input file and echoed to the screen and file. You should see your added comment here.
- MUT output files have the prefix `_buildo.` and appear near the start of the list if sorted by name because the names begin with a leading underscore.
- There are several TECPLOT output files that are indicated by the suffix `.Tecplot.dat`.
- Modflow files are written using the default prefix `Modflow.`, e.g. (Modflow.nam, modflow.bas etc.) The prefix can be customized if desired but there are advantages to keeping this 'generic' one, such as portability of post-processing scripts or TECPLOT layout files that follow the generic naming convention.
- Several scratch files are written which may be useful for debugging during, for example, code development. These can be ignored in most cases.
- MUT always deletes previously generated output files and writes a fresh set each time it is run. This prevents confusion that can arise when out-of-date output files are present. For example, if we define a recharge (RCH) boundary condition, MUT will write the file `_buildo.Modflow.SWF_RCH.Tecplot.dat` which shows the locations and recharge values assigned to Modflow cells. If we then removed the recharge condition from the input file, but did not delete this output file, it may lead us to think that recharge condition is still being applied.

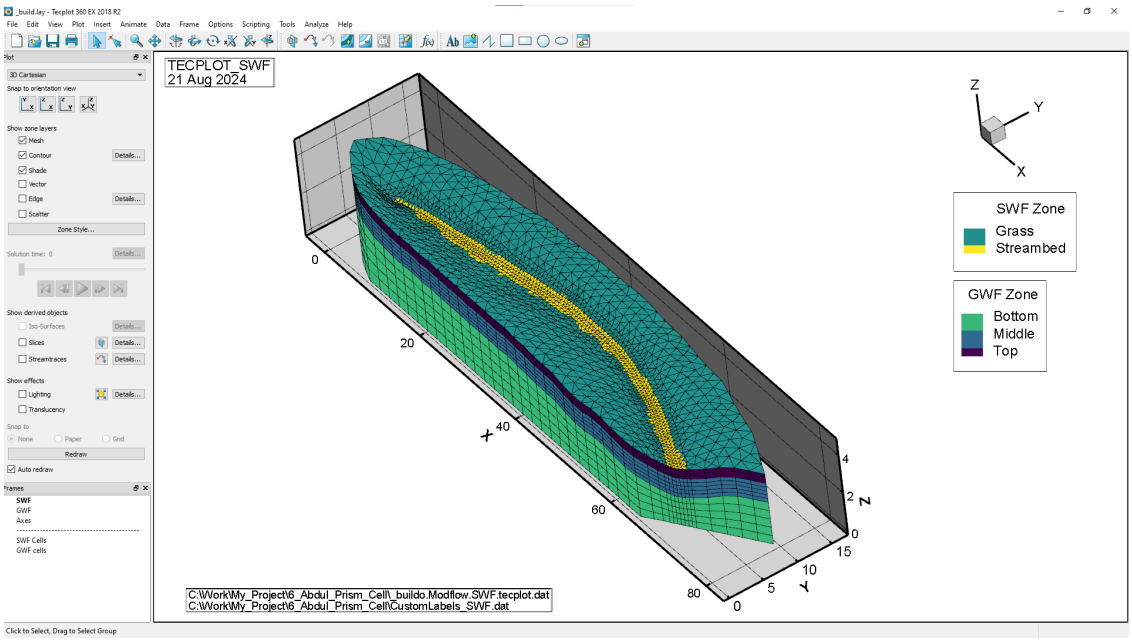
Step 4: Run Tecplot to Examine the Built Project

You can run TECPLOT and load the TECPLOT layout file `_build.lay` by typing:

```
tec360 _build.lay
```

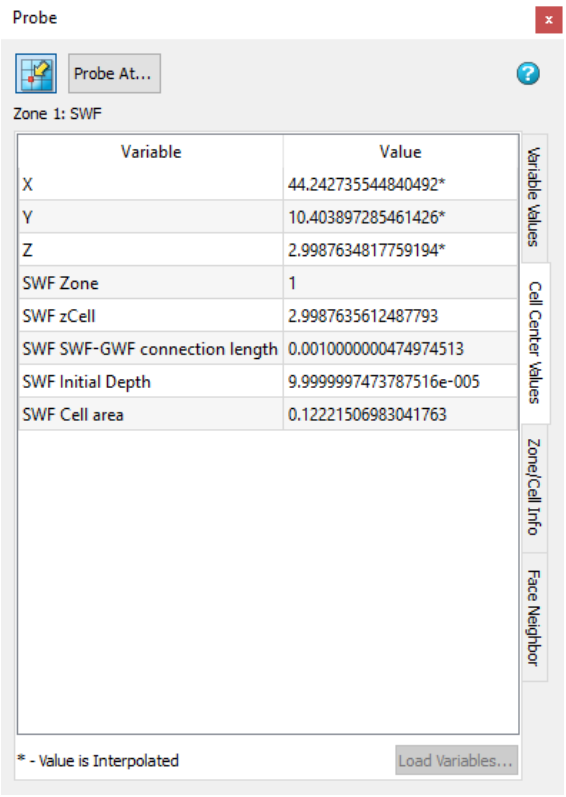
Note the following:

- A TECPLOT window should open:



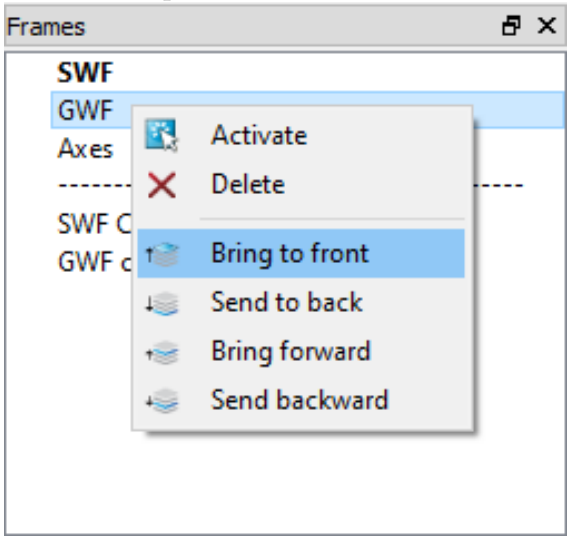
This TECPLOT layout file has been constructed with multiple frames (see lower left 'Frames' window) showing details about the SWF and GWF model domains. This default view shows the distribution of the various materials defined in the model, such as the SWF domain materials called 'Grass' and 'Streambed'. Detailed information about manipulating the data in TECPLOT to produce the desired plots is discussed in Section **??**.

- TECPLOT data can be probed using the probe tool  . Here we see the results of probing a location in the SWF domain:

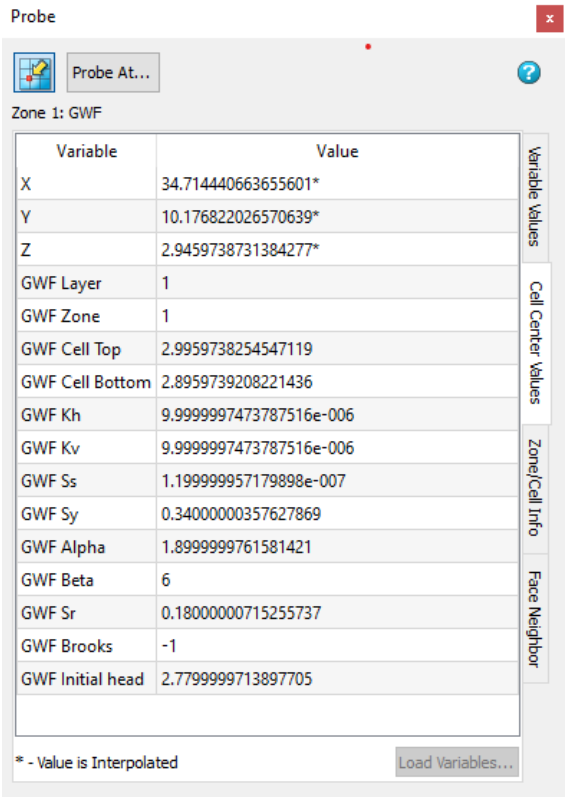


SWF results were returned because the SWF frame is at the front of the frame stack.

- In order to probe the GWF domain we have to move it to the front of the stack:



Here we see the results of probing a location in the GWF domain:



Step 5: Run Modflow to Generate Output

Step 6: Run Mut to Post-Process the Modflow Output

Step 7: Run Tecplot to Visualize the Modflow Output

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