DEM Derivatives

University of Oklahoma/HyDROS
Module 1.4
Outline – Day 1

WELCOME
INTRODUCTION TO HYDROLOGICAL MODELS
EF5 OVERVIEW
DEM DERIVATIVES

- Topographical information
- Digital Elevation Models
- Flow Direction Maps
- Flow Accumulation Maps
- Data sources
- Create basic files for Example 2
Topographical information is a key component of any hydrological model.

Topographical data tells the model where ridges and valleys, mountains and hills, rivers and streams, and other important features are.

Without topographical information, it would be impossible to route water downstream or to produce any forecast of stream flow or soil moisture.
It takes many different forms, but in EF5 we need three pieces of topographical data:

- **DEM** – Digital Elevation Model
- **FDR** – Flow DiRection (also called DDM in EF5)
- **FAC** – Flow Accumulation (also called FAM in EF5)

These follow a specific order:

You always have to start with a DEM
An FDR is created from a DEM
And the FAC is created from the FDR
This DEM → FDR → FAC process only works in this direction
A DEM is a digital model of the earth’s surface created from terrain elevation data

- Stored as a grid of numbers
- Each grid cell has one number and that number is the elevation of the grid cell in the units of the DEM
- These grid cells match *exactly* with the EF5 model grid cells we discussed in Module 1.2
We all know water flows from high points to low points

So if we have a DEM and we give it to the hydrological model, the model will know where water flows across the entire domain.

In the cartoon, the columns are like an exaggerated DEM. The arrows mark the direction of the flow of water.

The blue arrows are collecting water from a lot of upstream cells, or area, so we can think of them as sort of a main river channel.

The red arrows have less area, so we can think of them as “overland cells”
How is a DEM created?

If the area is small enough, it might be created by direct survey (that is, going out and measuring elevation at many points)

But usually, remote sensing techniques are used

The earth’s surface is scanned from space to create a DEM

Done via radar satellite from space

- RADARSAT, SRTM, ASTER
One of the most important characteristics of a DEM is resolution.

One of these is at 4km horizontal resolution (~6.5 MB).
The other is at 30 arcsecond resolution (~1km at the equator) (~56 MB).

Can you tell the difference?
Digital Elevation Models

What if we zoom in?

Still hard to tell, right?
Let's zoom in one more time...
And finally we see…

If you look carefully at the streams in the yellow box and it becomes clear that the left image is a much higher-resolution DEM than the right.
This exercise demonstrates an important point about resolution:

• In general, the larger the model domain, the coarser the resolution can be
• Hydrologic models require computing power, and the number of cells being modeled is directly related to the computing requirement
• The number of cells being modeled increases as the DEM resolution increases
• To run large areas at high resolution, fast computers or more time to run the model are needed
A flow direction grid, or FDR, is a grid containing values that tell you where water is flowing.

Imagine flipping our DEM cartoon forward.
Flow Direction

Let’s keep rotating it until we’re looking at it dead-on

Now I have a grid, with the same size, resolution, and extent as my DEM, and this grid exists only to tell me in what direction my water is flowing
Flow Direction

But I need a way for a computer to easily read and understand this direction grid

The obvious solution is to assign each direction a number and assign the appropriate number to each grid cell.
This is called a coding scheme

← This is the scheme I used (it’s also the scheme in the TauDEM program)

There are other schemes out there, though, including the one used by ArcMap →
You probably noticed that some cells flow into two or more other boxes.

In that case, the computer picks the cell with the biggest elevation difference (that is, the steepest descent) and the water flows into it.
This is called the eight-direction flow model (or D8)

Some important things to keep in mind:
- Your DEM needs to be larger than the entire river basin you want to model, because the outer edge of FDR cells will not actually have values in the real world, because the computer doesn’t know what’s outside your DEM.
The third and final necessary component is the flow accumulation, or FAC

The FAC is a grid of numbers corresponding to the number of cells flowing into *that cell*.
Note all the FAC cells with a value of 5 or greater are in **blue**

Like we mentioned when we first started discussing DEMs, think of these as cells in the river channel.

You may recall we briefly mentioned the TH parameter in EF5 back in Module 1.3. That parameter is the threshold for a river channel cell, so here TH would be 5.
So where do we get the DEMs needed to make this cool stuff?

Luckily, there are several free, good quality DEM sources around the world.

We will focus our discussion on SRTM – the Shuttle Radar Topography Mission.

This was STS-99 in February 2000.
SRTM data characteristics

The SRTM data are available around the world at 3 arcsecond (90m) resolution.

The original SRTM data have been processed and corrected for hydrological use.

One great source for this is the HydroSHEDS program.
HydroSHEDS is a World Wildlife Fund project

They provide continent-wide (or sub-continent-wide) DEM, drainage direction, and flow accumulation grids

Other useful data include river networks and drainage basin outlines

Their website is hydrosheds.org
As part of the EF5 training course, we include the necessary river networks and DEMs for certain model examples.

The file names work like this:

```
[AREA]_[DATATYPE]_[RESOLUTION]_[FORMAT].zip
```

So, `af_dem_30s_grid.zip` is a .zip file containing the DEM at 30 arcsecond resolution for the continent of Africa in ESRI GRID format.
Other important information:

The DEM quality is very good, but not perfect.

The river network files are in Esri Shapefile format and the DEMs are in Esri GRID format.

Either can be opened in both Esri ArcMap and QGIS.
Example 2

Let’s process our own DEM files and create a DDM/FDR and an FAC

Example 2 will be the Okavango River Basin in Namibia upstream of a gauging station at Rundu
Create a new folder on your Desktop and name it `okavango`.

In `\EF5_training\data\HydroSHEDS`, unzip `af_dem_30s_grid.zip` to your new `okavango` folder.
- Right-click, and click “Extract All…”

- Repeat for `af_riv_30s.zip`
- You should see this →
Clipping a DEM

Now open QGIS Desktop 2.6.1 and “Add Vector Layer…”

At the prompt, navigate to your Okavango folder and select af_riv_30s.shp

Next, select “Add Raster Layer…” and from your okavango folder, open the af_dem_30s folder and then, inside that, the next af_dem_30s folder and then open w001001.adf
You should see something like this...

Now we’re going to add our gauge location to the map (the town of Rundu in the country of Namibia)

Create a shapefile layer…
Clipping a DEM

Click “OK”, then save as rundu.shp within your okavango folder.

In the “Layers” box at the left of the QGIS window, drag “af_riv_30s” up so it’s plotted over “w001001”

And we want to “Select features using an expression”

Type UP_CELLS > 5000, then click “Select”, and then “Close”
Clipping a DEM

You should see large rivers highlighted in a different color

Turn on “Toggle Editing”

And zoom in near the area of 19.767, -17.901 in the “Coordinate:” box at the bottom of the QGIS window

Now select “Add Feature” (note the pencil icon next to “rundu”)

![Image of QGIS window with clipping and editing features]
Clipping a DEM

And then click exactly at 19.767, -17.901 (it should be along one of the highlighted rivers)

Type 1 in the “id” box

Hopefully you see something like this →
Now turn off “Toggle Editing”, save changes to layer “rundu”, and zoom out.

Using your mouse and the “Coordinate:” box, try to guess what the edges of a box covering the *entire* upstream area of our point would be.

You don’t need to be extremely precise, because you want to make sure that you catch all the area you need, plus quite a bit extra on all sides.
Here’s an idea of what to look for →
Let’s pick some nice round numbers for this

- Left side… 14 deg E
- Right side… 21 deg E
- Upper edge… 11 deg S
- Lower edge… 20 deg S

Now go to the “Raster” menu, “Projections” and click “Warp (Reproject)…”
Clipping a DEM

On this screen, click “Select…” by “Output file” and then save to your okavango directory – I use the name clipped_raster.tif

Then check “Resampling method” and pick “Near”

Check “No data values” and type -32768

Then click the pencil icon below “Load into canvas when finished”
Now you should be able to type in the text box at the bottom

After `-r near, type -te 14 -20 21 -11 -tr 0.125 0.125`

“-te” tells QGIS the extent of the grid in latitude and longitude, so we type the left border, then the bottom, then the right, and then the top

And “-tr” tells QGIS the resolution of the grid in degrees – we are going to use an eighth (0.125) of a degree
Clipping a DEM

Click “OK”, “OK”, “OK”, and then “Close”
Now right-click af_riv_30s and select “Save As…”

Click “Browse” and then save in your okavango directory as large_rivers.shp

Check “Save only selected features”

And check “Extent (current: user defined)”

Then type in the appropriate values for north, south, east, and west, and click “OK”
Fixing the DEM

When we change the resolution of a DEM, we tend to break things, from the model’s perspective.

We create “pits” or “sinks” that didn’t exist in the original data.

In “Processing Toolbox”, select “Pit Remove” from “Recently used algorithms”.

Pick “clipped_raster” in the “Elevation Grid” drop down box and for “Pit Removed Elevation Grid” click the “…” and “Save to file…”.

Then pick an appropriate location and name (I used corrected_dem.tif)
Fixing the DEM

Now click “Run”

When the process completes you’ll have a new “Pit Removed Elevation Grid” in your “Layers” panel
Now we want to “burn” our rivers into the corrected DEM to make sure the model knows where the streams are.

Go to the “Raster” menu, “Conversion” and “Rasterize (Vector to Raster)”…

Select “large_rivers” for the input file

And for the output file, I chose rasterized_rivers.tif

Click okay on the pop-up warning
Converting Rivers

Click the pencil icon down near the bottom

In the text box, delete `-a ARCID -ts 3000 3000 and replace it with `-burn -10 -te 14 -20 21 -11 -tr 0.125 0.125`

We are telling QGIS to write the number -10 every pixel in which a river occurs, using the same extent and resolution as the DEM we already created
Click “OK”, “OK”, and then “Close”

You should see something like this →

Now remember the dark cells have values of -10

Let’s add the rivers to the DEM…
In the “Raster” menu, select “Raster Calculator”

In the “Output Layer” box, save the file as burned_dem.tif

In “Raster bands”, double-click the “Pit Removed Elevation Grid”

In the box at the bottom, after Pit Removed Elevation Grid@1, type \(+\)(\()\)*3 then move your mouse between the parentheses and double-click “rasterized_rivers@1”
Click “OK” and you should see this →

We basically lowered the elevation of each pixel in the river channel by 30 meters.

This is called “burning the rivers into the DEM”

Run “Pit Remove” on this burned DEM one more time.
Creating an FDR

Save the new Pit Removed Elevation Grid as dem.tif in your okavango folder

This is the final DEM

(Remove the old “Pit Removed Elevation Grid” from the Layers panel to avoid confusion)

Now in “Processing Toolbox”, open the “TauDEM (hydrologic analysis)” section, then “D8 Flow Directions”
Creating an FDR

Save the new FDR as `flow_dir.tif` in your `okavango` folder.

You should see what’s on the lower left…
Creating an FDR

We need to convert this to a format EF5 can read

In the “Raster” menu, select “Conversion” and then “Translate (Convert Format)…”

In “Output file”, save this file as fdr.tif in your okavango folder

Then click the pencil at the bottom and type -ot Float32 in place of -of GeoTIFF after gdal_translate

Click “OK”, “OK”, and “Close”
Finally, it’s time to create the FAC

In the “Processing Toolbox”, go to “TauDEM (hydrologic analysis)” and then “Basic Grid Analysis tools” and then “D8 Contributing Area”

Select “fdr” for the “D8 Flow Direction Grid” and then save the “D8 Contributing Area Grid” as fac.tif in your Okavango folder
Creating an FAC

Click “Run”

You should get something like this →

The lighter the color, the more cells are contributing to the flow at that point.

What’s really important is that the gauge point, in the red box, looks like the river flowing into it properly follows the path of the original rivers shapefile.
The drainage area of the Okavango at Rundu is roughly 82,000 km$^2$

In QGIS I can use the “Identify Features” tool to find the value of the FAC at the outlet point

- I get 553 grid cells
- Each grid cell is $1/8^{th}$ deg by $1/8^{th}$ deg
- And $1/8^{th}$ deg is about 12 km
- So multiply 553 by 12 km and by 12 km again, and you get 79,632 km$^2$, which is about the same as 82,000 km$^2$
- This means our DEM, FAC, and FDR are ready to go!
Prepare Files for EF5

Save your QGIS project in your `okavango` folder and exit QGIS.

Out of all the files now in your `okavango` folder, we care about `dem.tif`, `fac.tif`, and `fdr.tif`.

Copy these three files to `EF5_training\examples\okavango\basic`.
Now copy your `control.txt` file from the Wang Chu example to `EF5_training\examples\okavango`.

Open up `control.txt` to make sure the “DEM”, “DDM”, and “FAM” lines point to the correct location:

- You will need to change `ddm.tif` to `fdr.tif` in the DDM line of the control file.
- Note that we use the backslash character (\) because that is the convention in the Windows operating system.
From EF5_training\data\Observations, copy rundu.csv to EF5_training\examples\okavango\obs

This file is the observed time series of daily discharge at the Rundu station between 22 June 2002 and 11 April 2012

- The first column is the date and time
- The second column is the discharge value in cubic meters per second

EF5 supports 3 formats for reading in observed time series

- YYYY/MM/DD HH:UU:SS (like in the rundu.csv example)
- YYYY-MM-DD HH:UU:SS (so dashes instead of slashes)
- MM-DD-YYYY
- MM/DD/YYYY
- Note that Y = year, M = month, D = day, H = hour, U = minute, and S = second
Prepare Files for EF5

The output folder will be filled with the model results after the simulation.

The params folder would include gridded model parameters.

We will fill pet and precip in Module 2.1.
Coming Up….

The next module is
Rainfall and PET

You can find it in your \EF5_training\presentations directory

Module 1.4 References

EF5 Training Doc 3 – Processing DEMs and Derivatives, (March 2015).

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