DEM Derivatives

University of Oklahoma/HyDROS

Module 2.2

Outline – Day 2

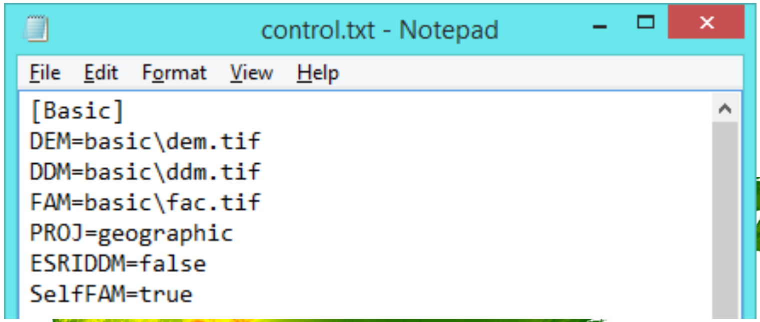
EF5 OVERVIEW

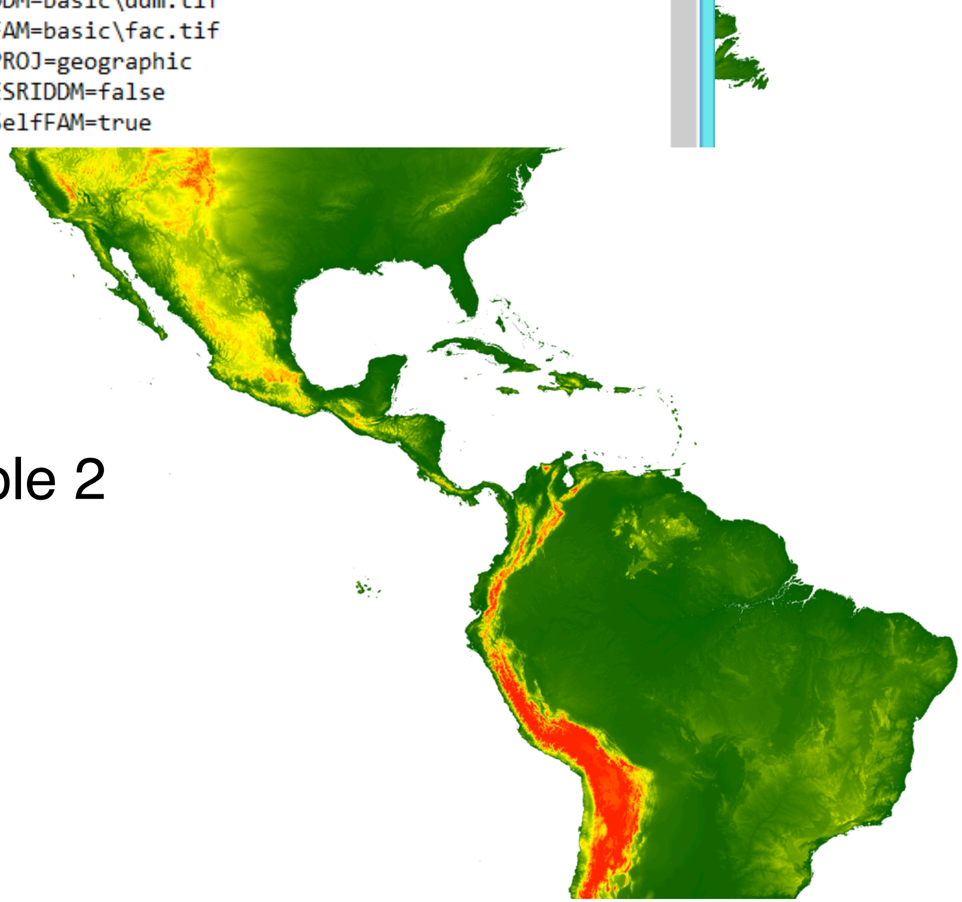
DEM DERIVATIVES

- Topographical information
- Digital Elevation Models
- Flow Direction Maps
- Flow Accumulation Maps
- Data sources
- Create basic files for Example 2

RAINFALL AND PET

AUTOMATIC CALIBRATION





Topographical Information

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

Topographical Information

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)

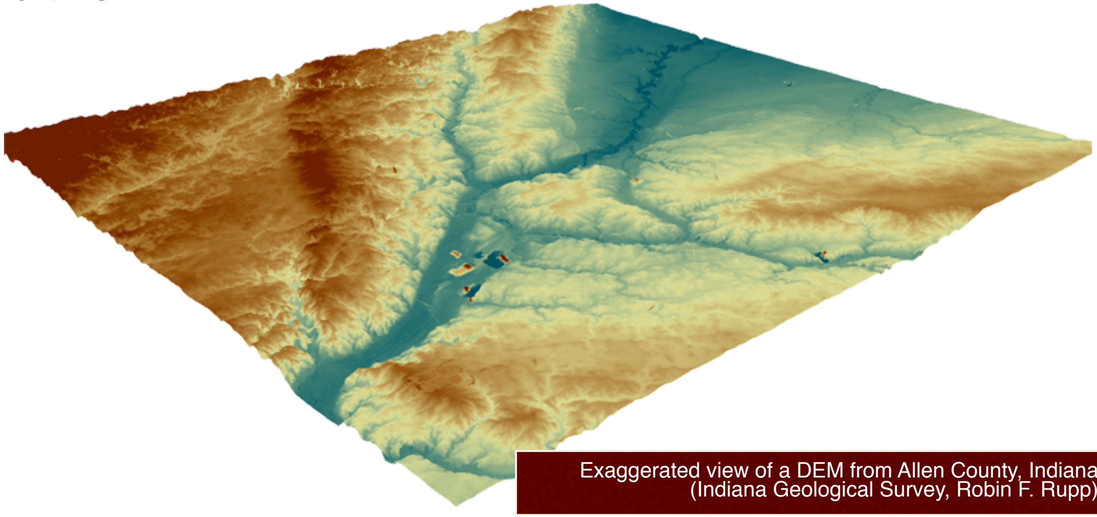
These follow a specific order

- 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

Digital Elevation Models

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 2.1



Exaggerated view of a DEM from Allen County, Indiana (Indiana Geological Survey, Robin F. Rupp)

Digital Elevation Models

We all know water flows from high points to low points

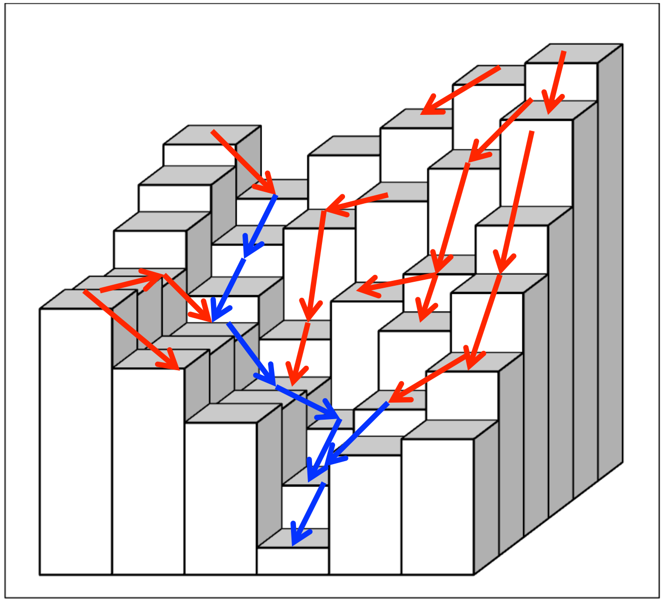
So if we have a DEM and we give it to the hydrological model, the model will know where water flows across the entire domain

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 allows have less area, so we can think of them as “overland cells”



How is a DEM created?

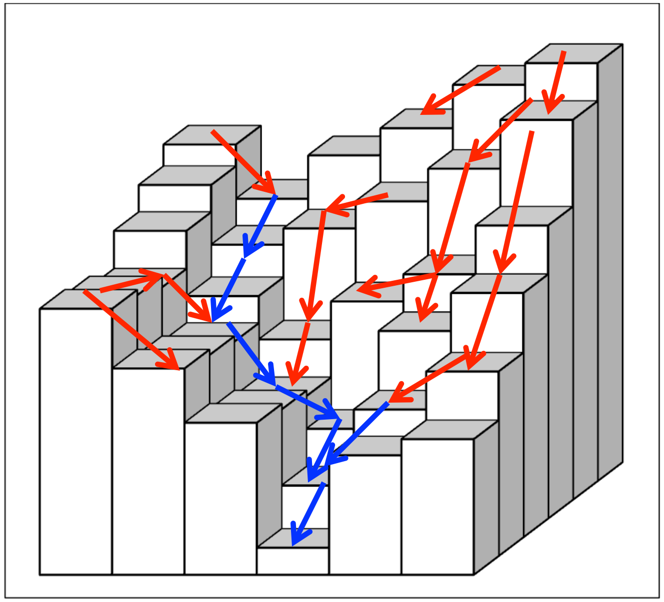
If the area is small enough, it might be created by direct survey (that is, going out and measuring elevation at many points)

But usually, remote sensing techniques are used

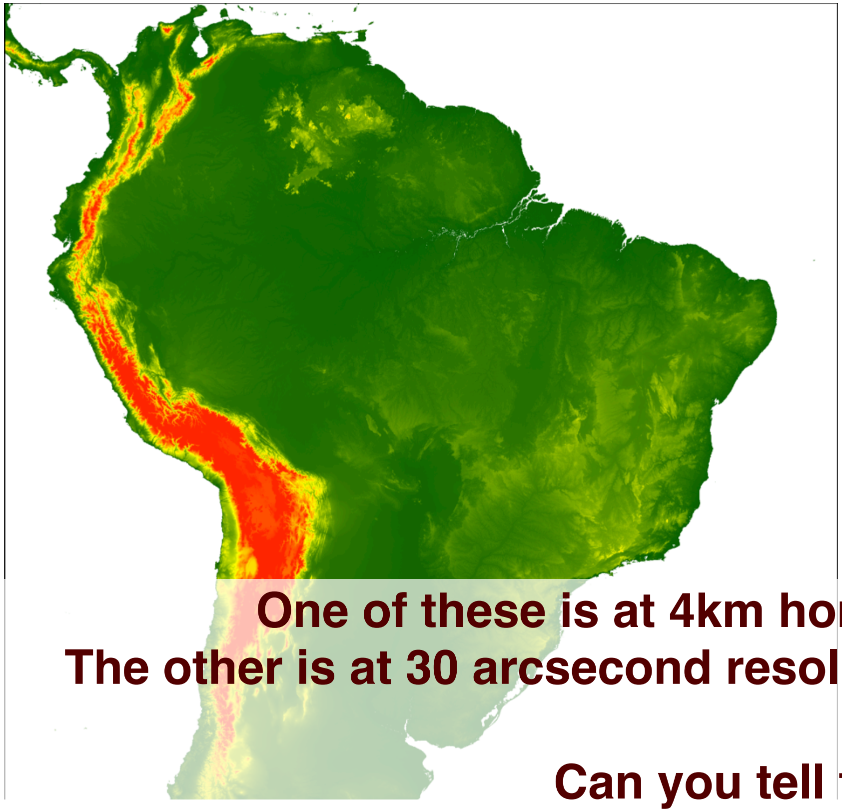
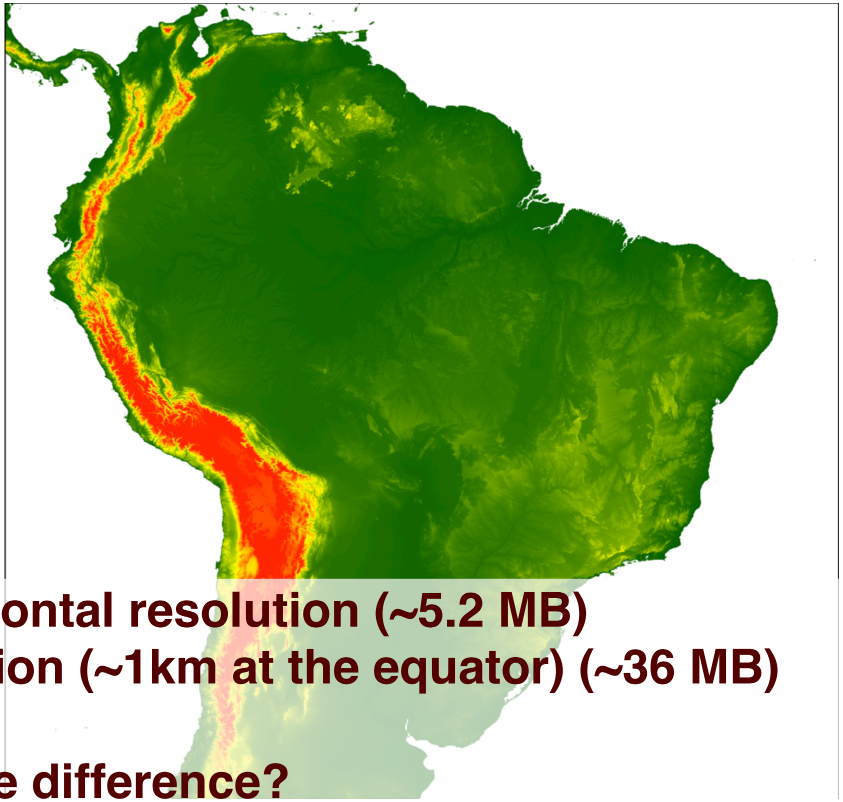
The earth's surface is scanned from space to create a DEM

Done via radar satellite from space

- RADARSAT, SRTM, ASTER



One of the most important characteristics of a DEM is resolution

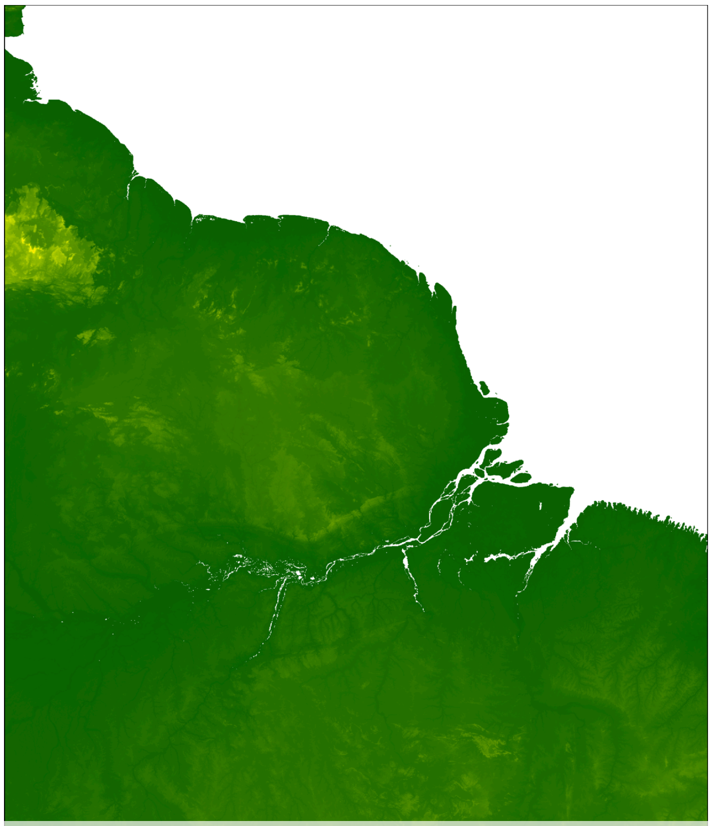



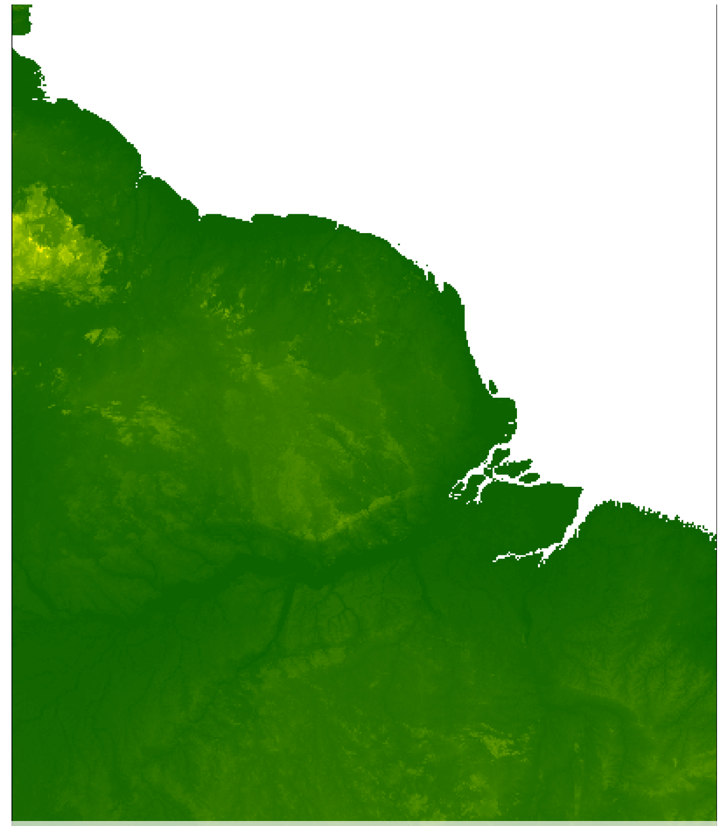
One of these is at 4km horizontal resolution (~5.2 MB)
The other is at 30 arcsecond resolution (~1km at the equator) (~36 MB)

Can you tell the difference?

Digital Elevation Models

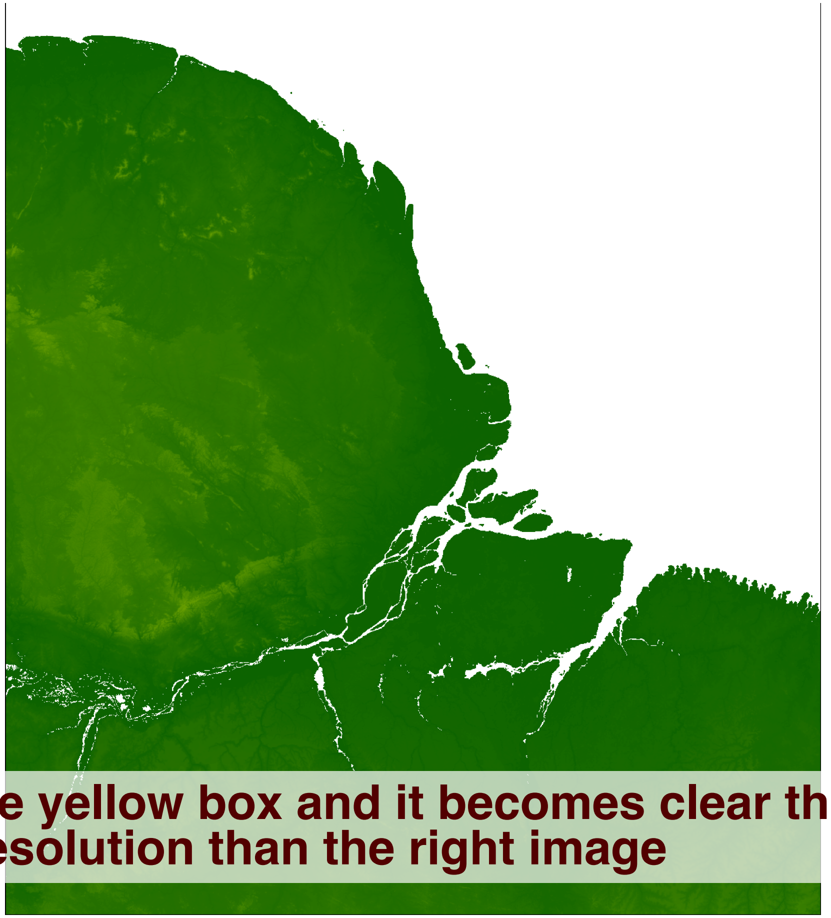
What if we zoom in?





Now you start to see the difference in the Amazon

Let's zoom in one more time…



If you look carefully at the streams in the yellow box and it becomes clear that the left image is has a lower resolution than the right image

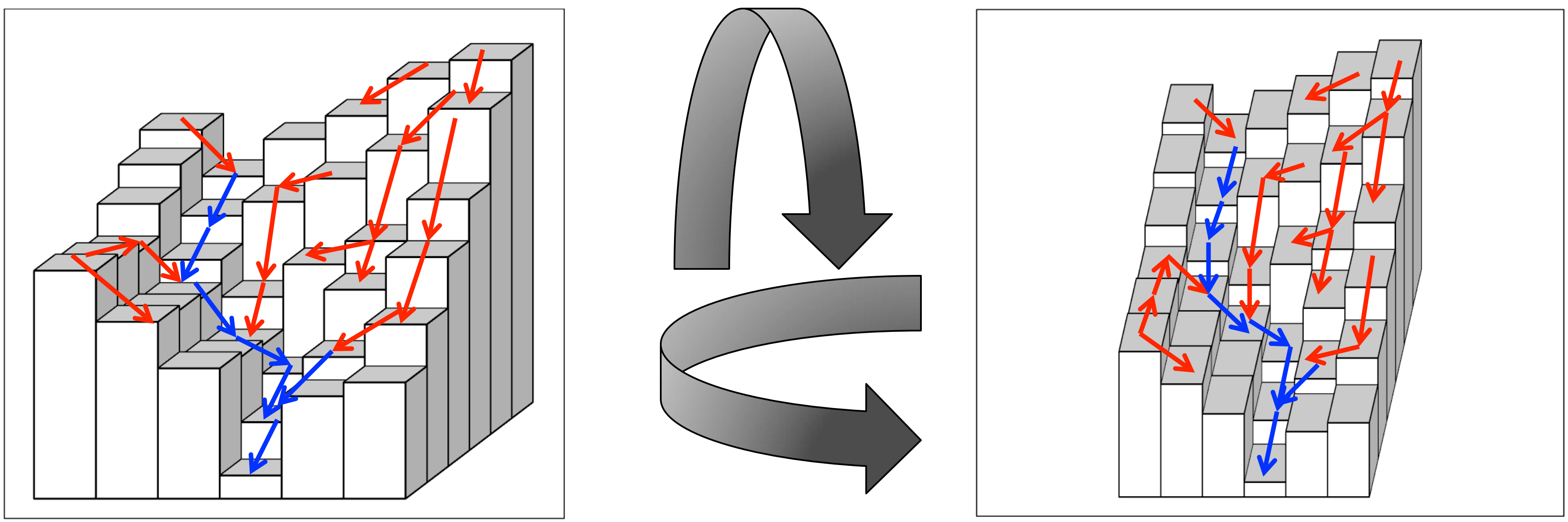
Digital Elevation Models

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

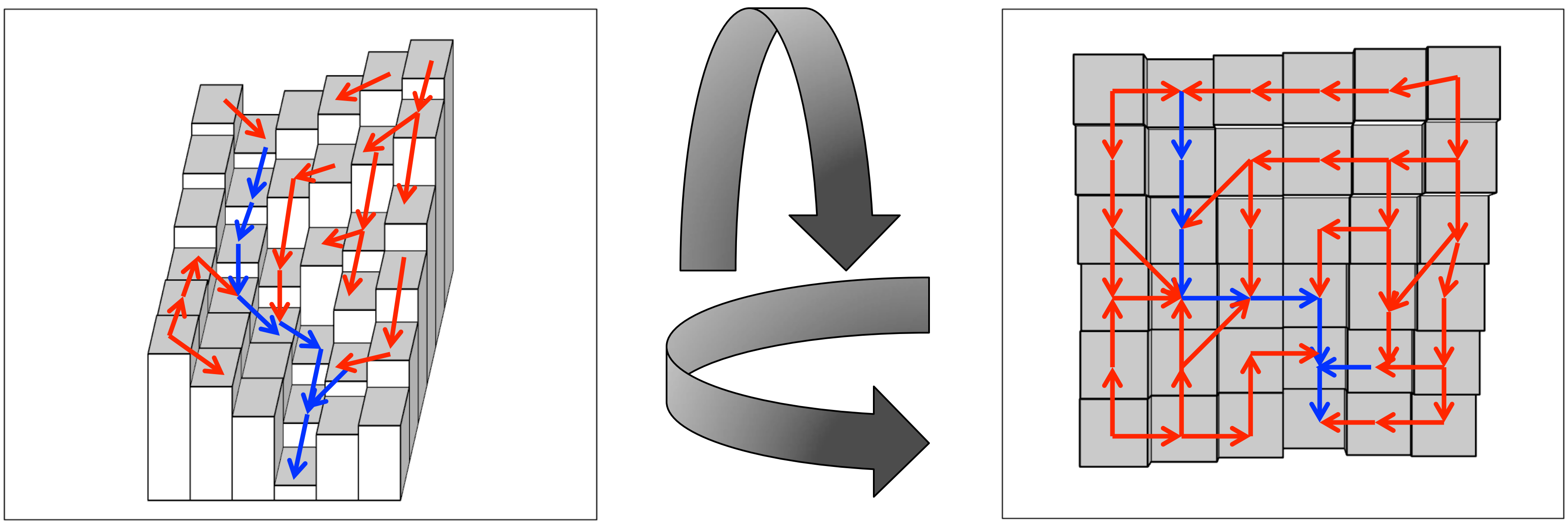
Imagine flipping our DEM cartoon forward



Flow Direction

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

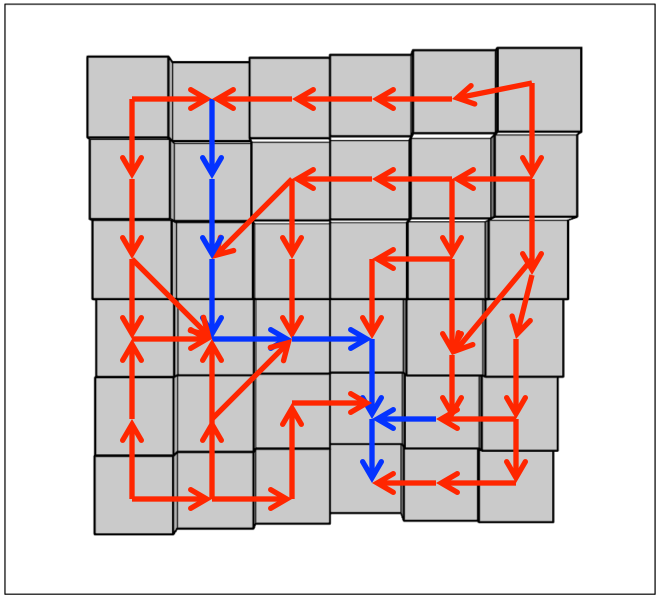
Now I have a grid, with the same size, resolution, and extent as my DEM, and this grid exists only to tell me in what direction my water is flowing



Flow Direction

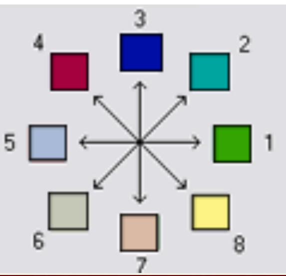
But I need a way for a computer to easily read and understand this direction grid

The obvious solution is to assign each direction a number and assign the appropriate number to each grid cell



1	7	5	5	5	7
1	7	6	5	5	7
8	7	7	7	5	6
1	1	1	7	7	7
3	2	1	7	5	7
3	3	3	7	5	5

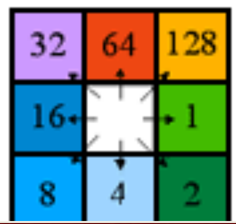
This is called a coding scheme



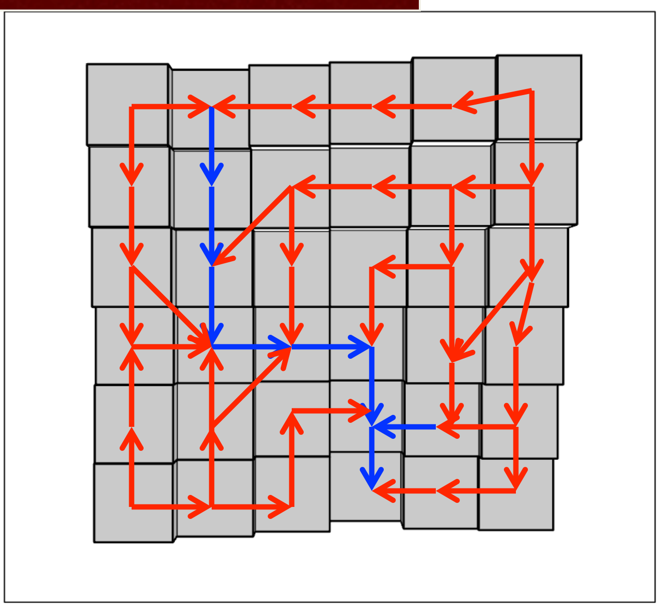
TauDEM D8 Flow Directions Instructions © David Tarboton

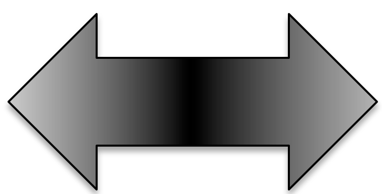
← This is the scheme I used (it's also the scheme in the TauDEM program

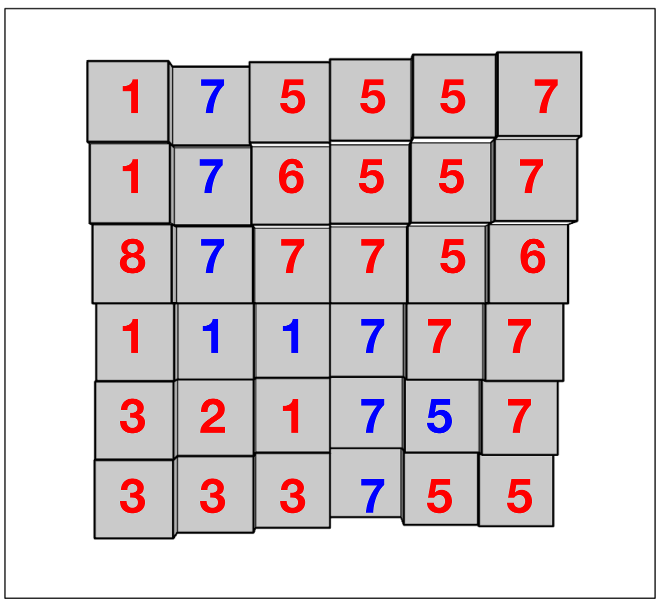
There are other schemes out there, though, including the one used by ArcMap →



ArcGIS Resource Center © Esri



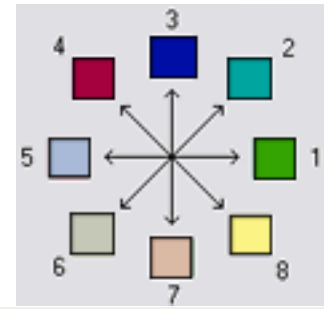




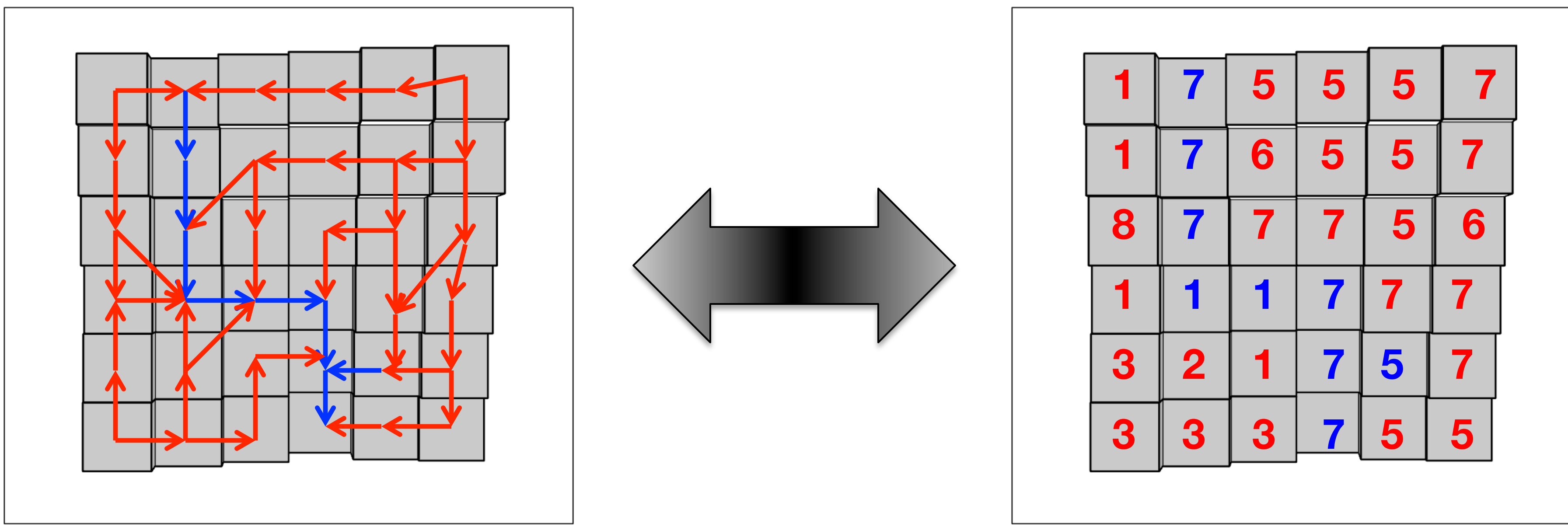
Flow Direction

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



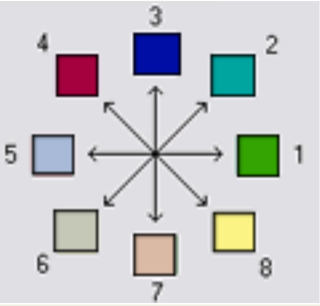
TauDEM D8 Flow Directions Instructions © David Tarboton



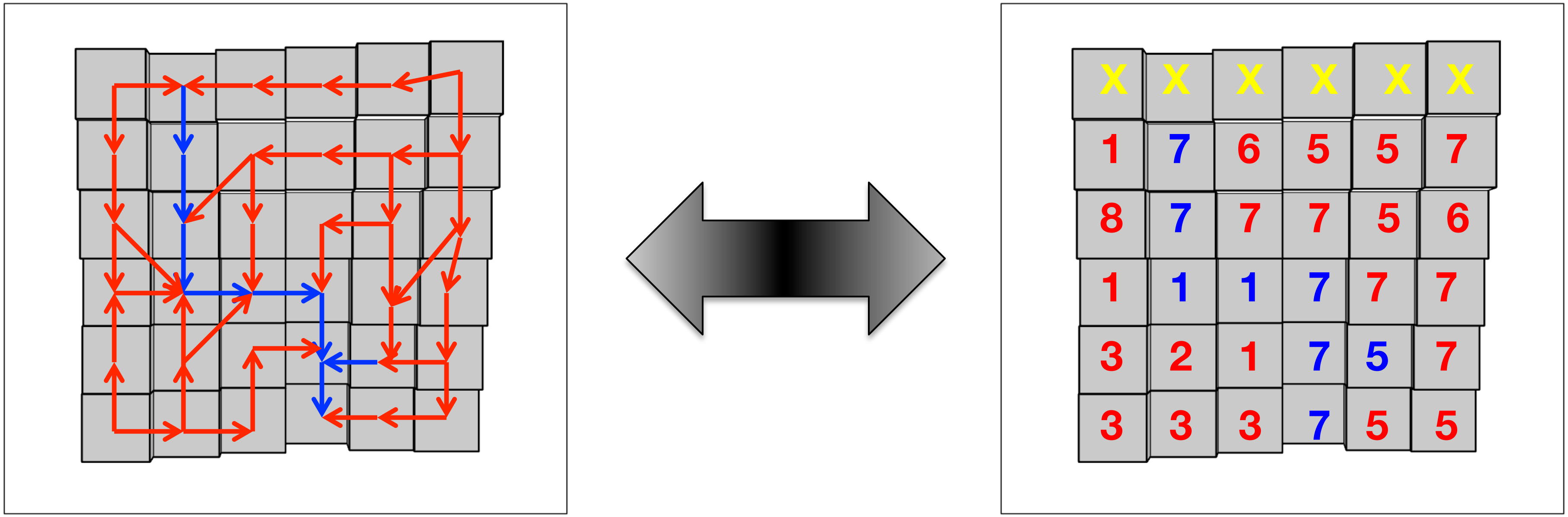
This is called the eight-direction flow model (or D8)

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

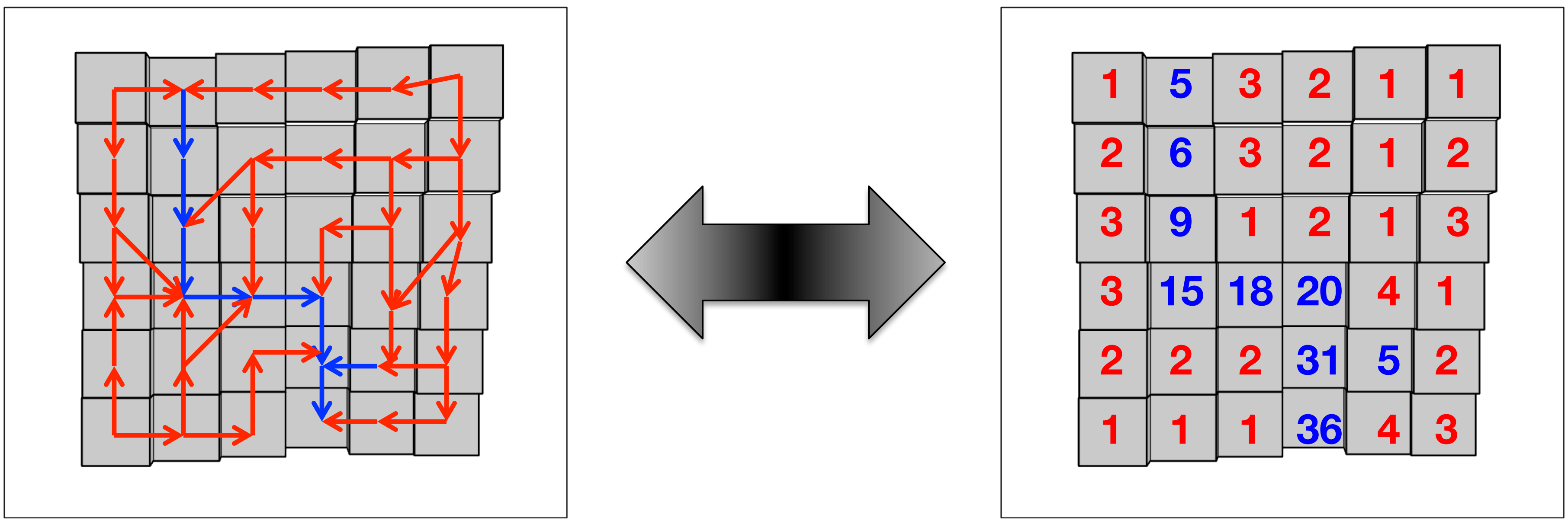


TauDEM D8 Flow Directions Instructions © David Tarboton



The third and final necessary component is the flow accumulation, or FAC

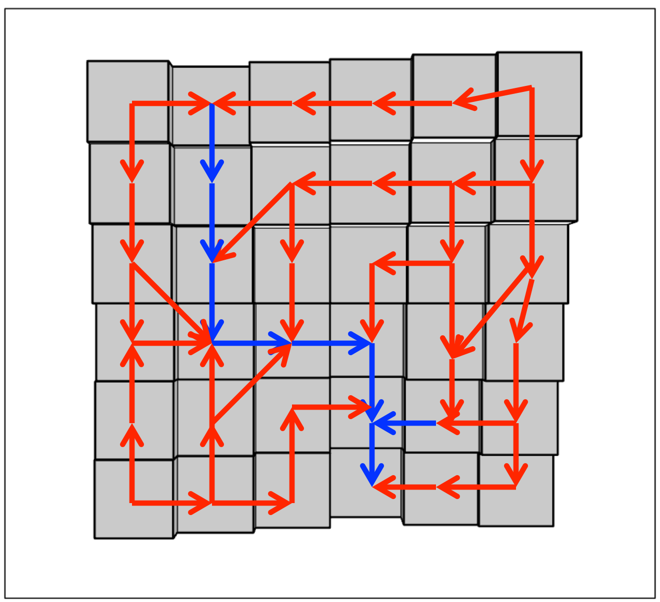
The FAC is a grid of numbers corresponding to the number of cells flowing into *that cell*



Flow Accumulation

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 2.1
- That parameter is the threshold for a river channel cell, so here TH would be 5



1	5	3	2	1	1
2	6	3	2	1	2
3	9	1	2	1	3
3	15	18	20	4	1
2	2	2	31	5	2
1	1	1	36	4	3

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

Space Shuttle Endeavor landing at the end of STS-99, 22 February 2000, Merritt Island, Florida

STS-99 Mission Insignia

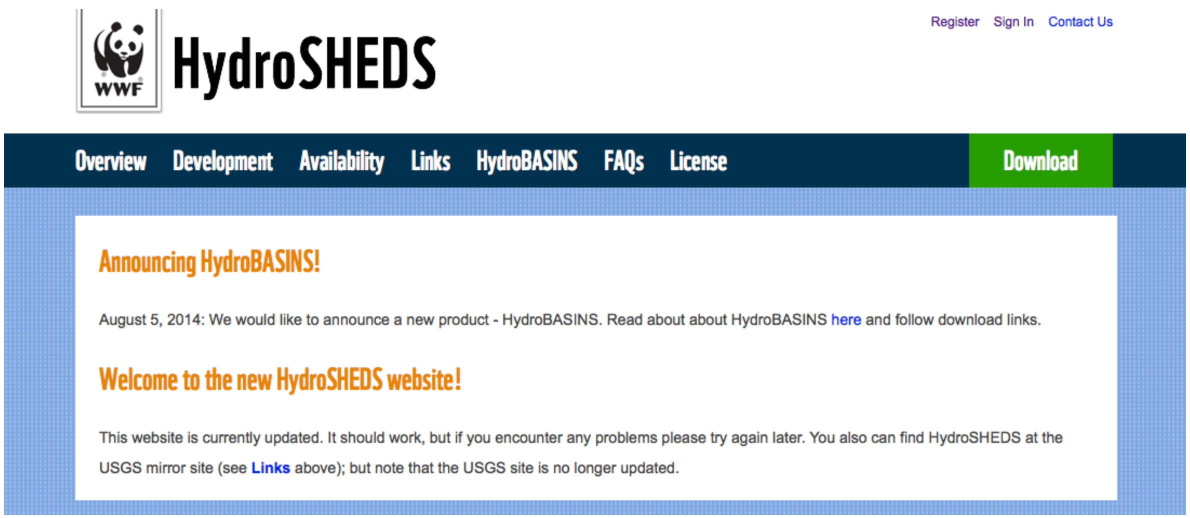
Sources

SRTM data characteristics

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

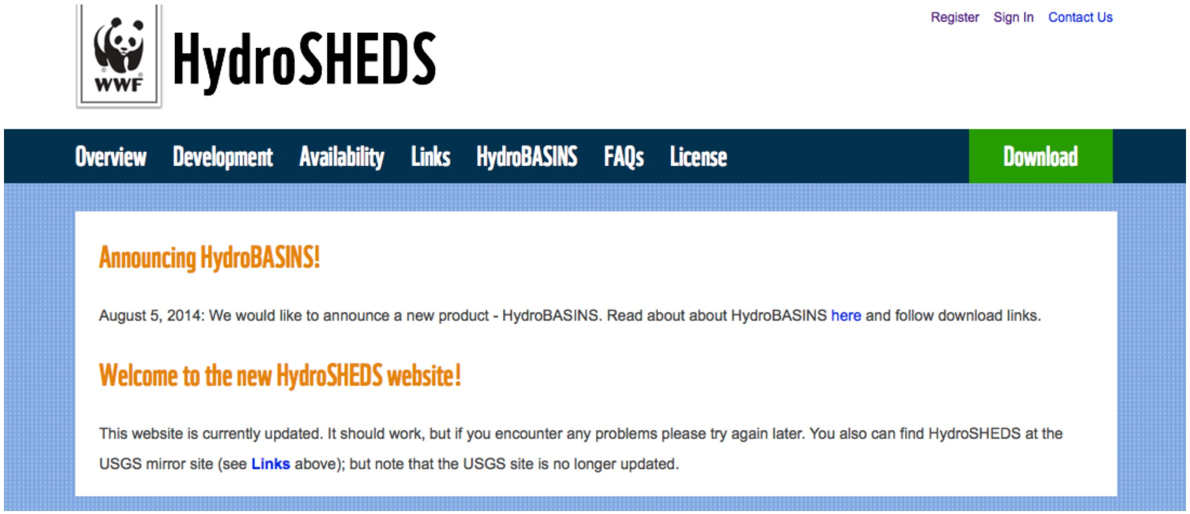
The original SRTM data have been processed and corrected for hydrological use

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

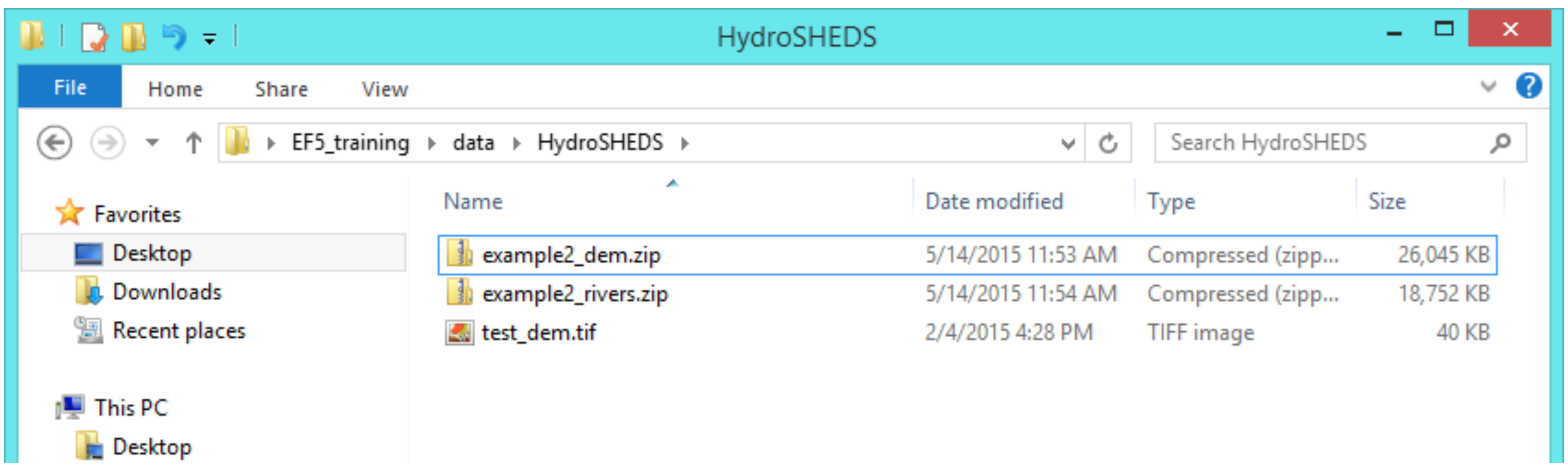


HydroSHEDS

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: `example[number]_[type].zip`

So, `example2_dem.zip` is a .zip file containing the necessary to complete Example 2 in the training

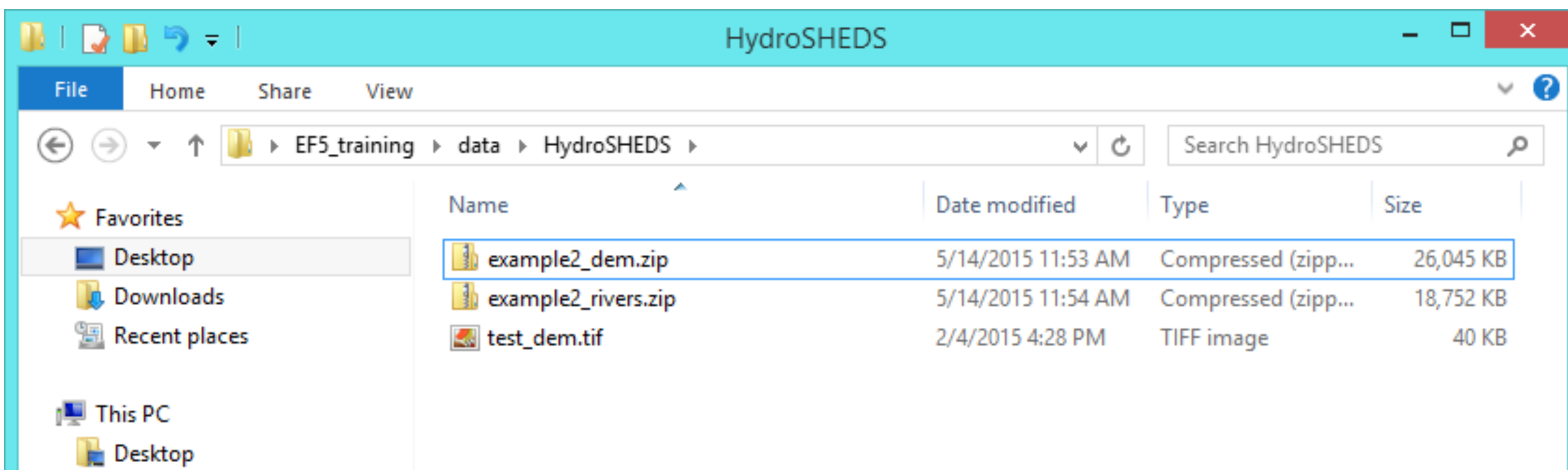


Other important information:

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



Other DEM Sources

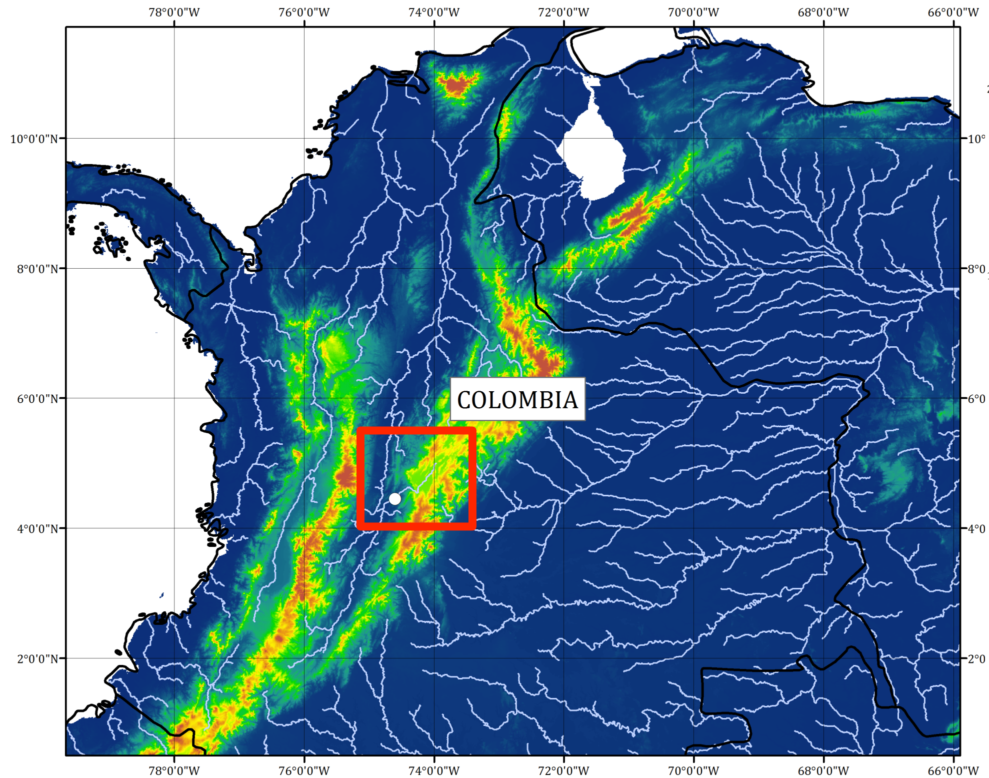
There's also the GTOPO30 project at USGS, which is a 30 arc second (1 km) world DEM derived from SRTM

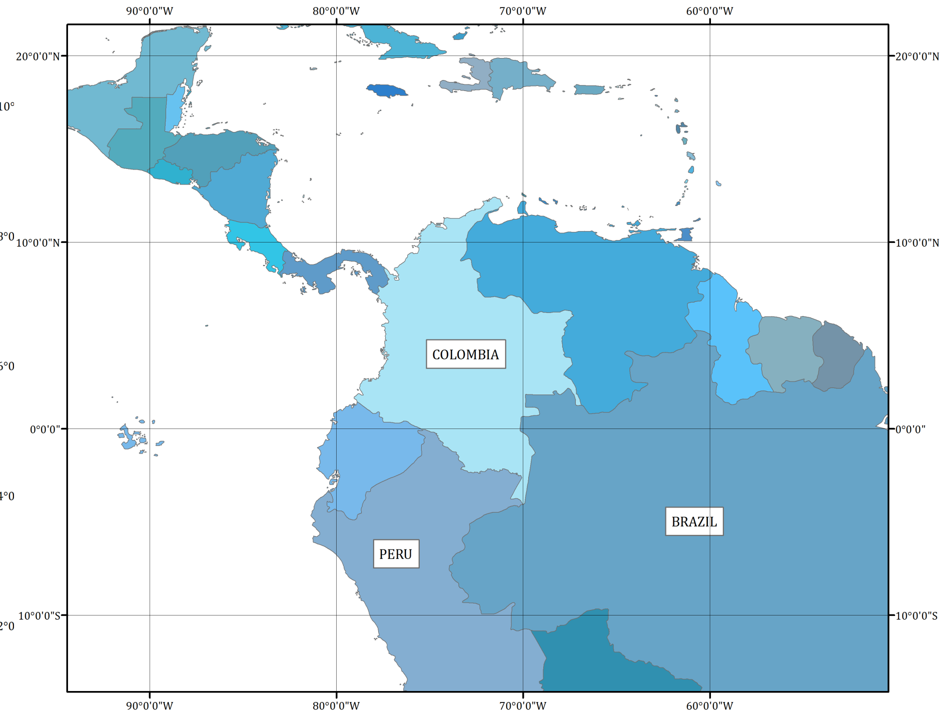
The raw SRTM data was collected at 1 arc second (30 m), so at 9x the size of the finest HydroSHEDS DEM

Until 2014, this 30 m data was only available in the U.S., but is now being released for the rest of the world as "SRTM-2"

We'll talk more about SRTM-2 later in the training

Example 2





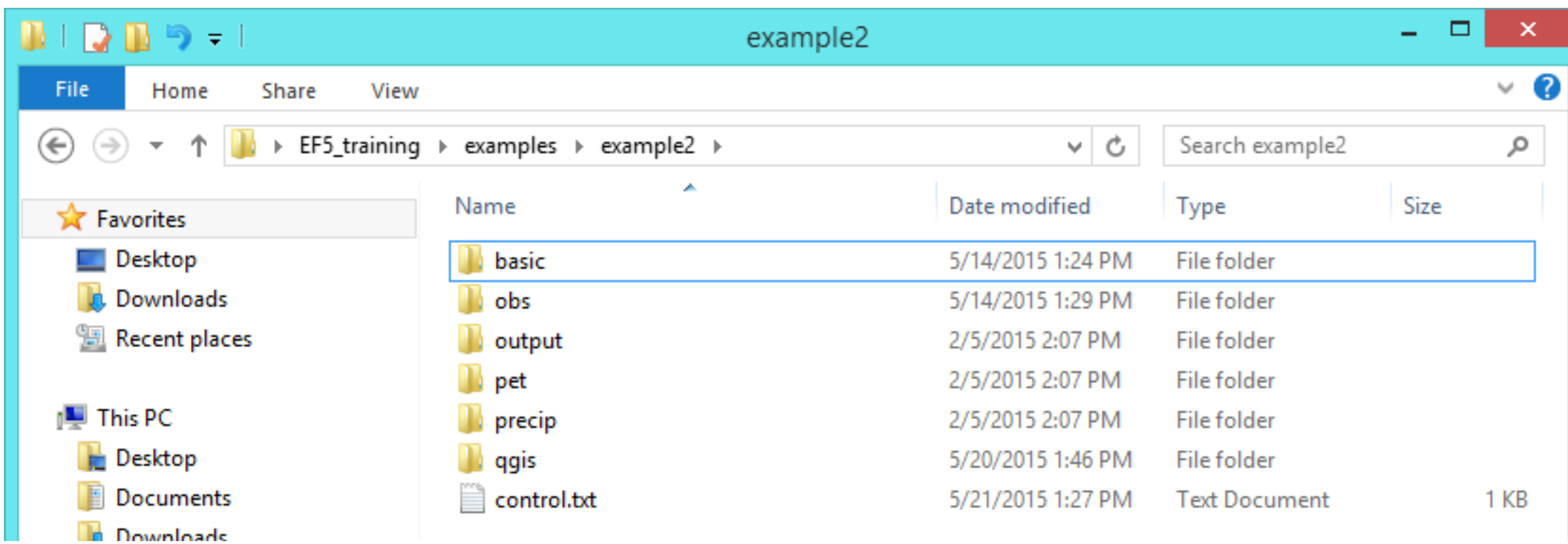
Let's process our own DEM files and create a DDM/FDR and an FAC

Example 2 will be the Bogota River Basin in Colombia upstream of a gauging station at Puente Portillo

Getting Ready

In `\EF5_training\examples\example2`, create a new folder called `qgis`

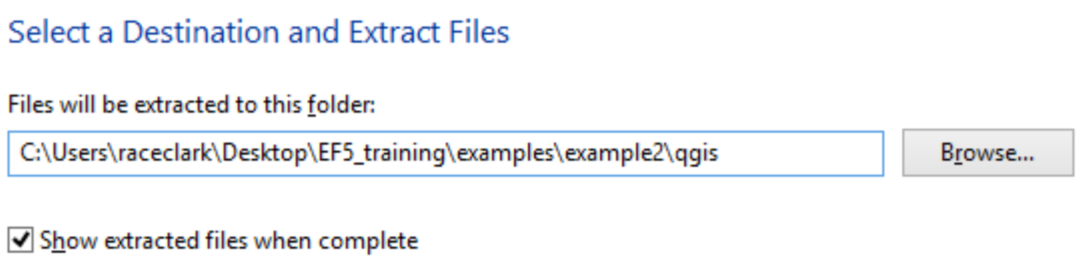
This will be our project folder where we do all the processing steps prior to running the model



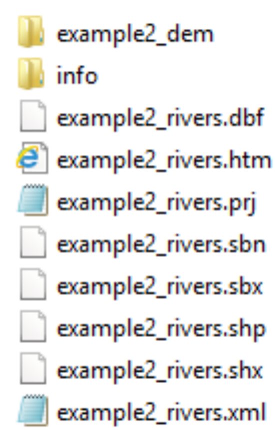
Getting Ready

In `\EF5_training\data\HydroSHEDS`**, unzip** `example2_dem.zip` **to your new** `qgis` **folder**

- Right-click, and click "Extract All…"



- Repeat for `example2_rivers.zip`
- You should now have these files in your `qgis` folder →



Getting Ready

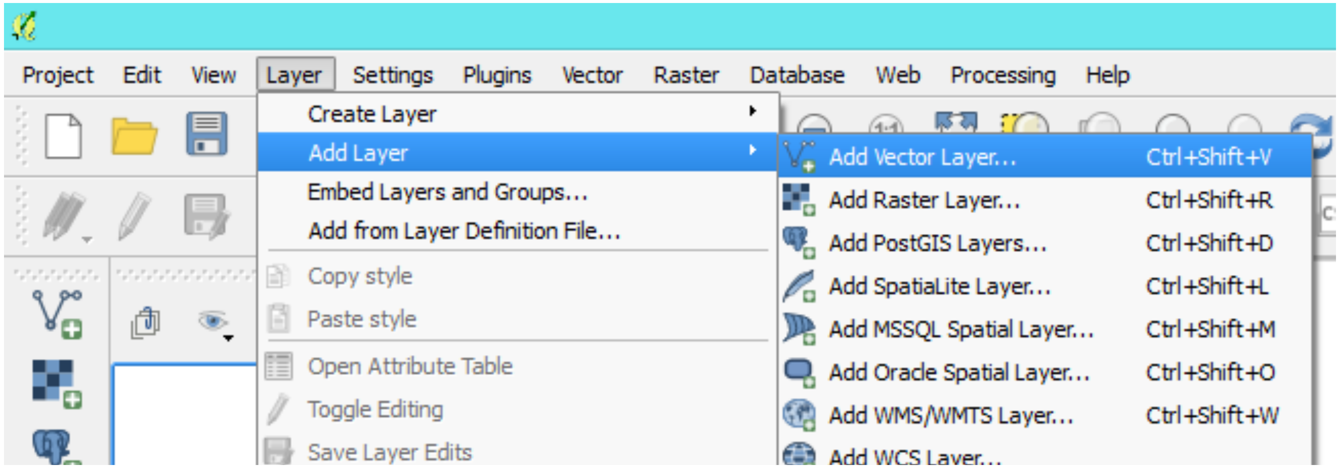
Once you've extracted the rivers and DEM into your `qgis` folder, we're ready to get started

First, check again that your `qgis` folder has the files shown below

Name	Date modified	Type	Size
example2_dem	5/14/2015 12:01 PM	File folder	
info	5/14/2015 12:01 PM	File folder	
example2_rivers.dbf	5/3/2006 12:00 AM	DBF File	7,291 KB
example2_rivers.htm	5/3/2006 12:00 AM	HTML Document	18 KB
example2_rivers.prj	5/3/2006 12:00 AM	PRJ File	1 KB
example2_rivers.sbn	5/3/2006 12:00 AM	SBN File	3,782 KB
example2_rivers.sbx	5/3/2006 12:00 AM	SBX File	112 KB
example2_rivers.shp	5/3/2006 12:00 AM	SHP File	57,804 KB
example2_rivers.shx	5/3/2006 12:00 AM	SHX File	3,432 KB
example2_rivers.xml	5/3/2006 12:00 AM	XML File	11 KB

Set up the QGIS Project

Now open `QGIS Desktop 2.6.1` **and "Add Vector Layer..."**

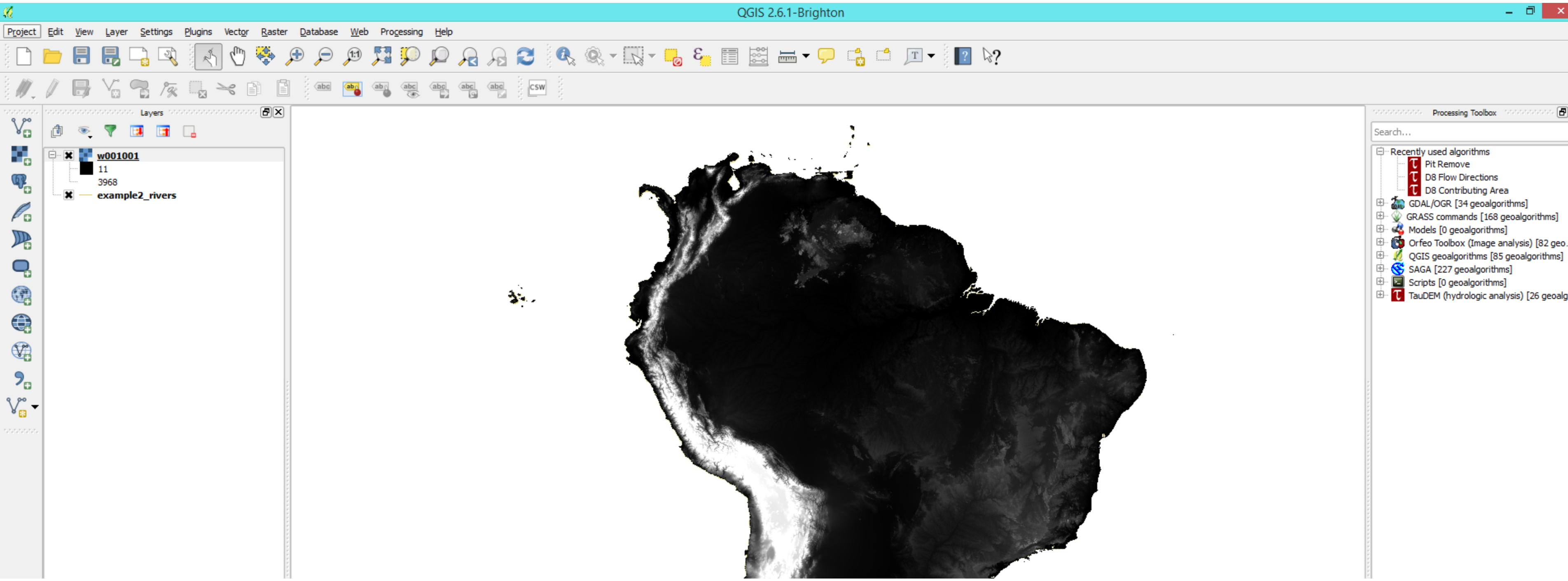


At the prompt, navigate to your `qgis` **folder and select** `example2_rivers.shp`

Next, select "Add Raster Layer..." and from your `qgis` **folder, open the** `example2_dem` **folder and then** `w001001.adf`

Set up the QGIS Project

You should see something like this…

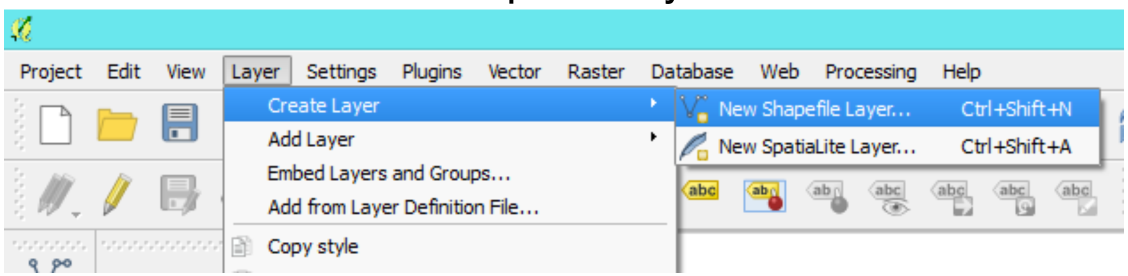


Let's go ahead and save our QGIS project – I named mine `example2.qgs` and saved it in my `qgis` folder

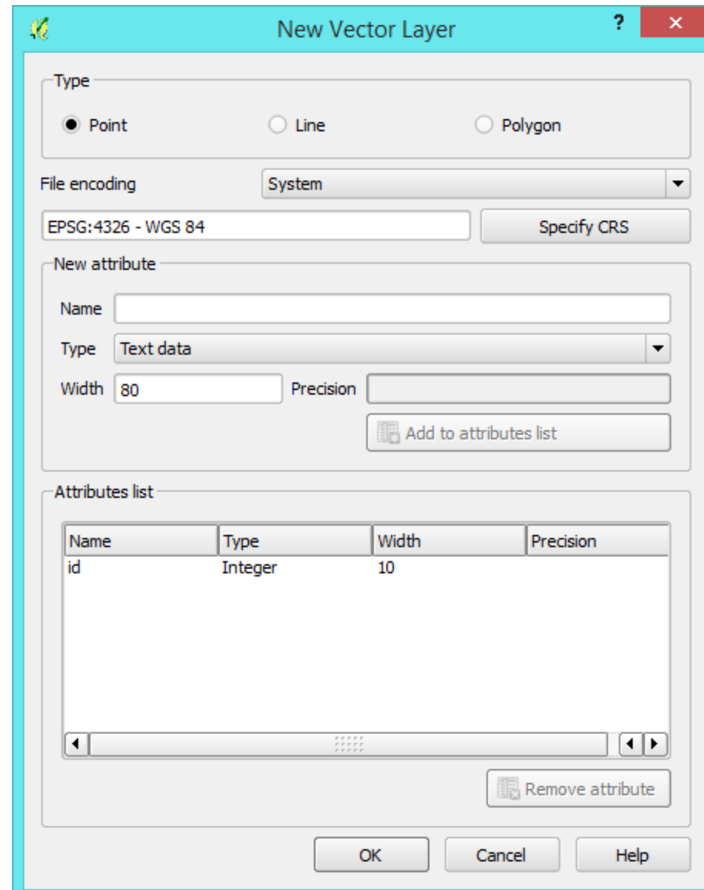
Now we’re going to add our gauge location to the map

Our gauge is named “Puente Portillo” and it’s on the Bogota River in the nation of Colombia

Create a shapefile layer…

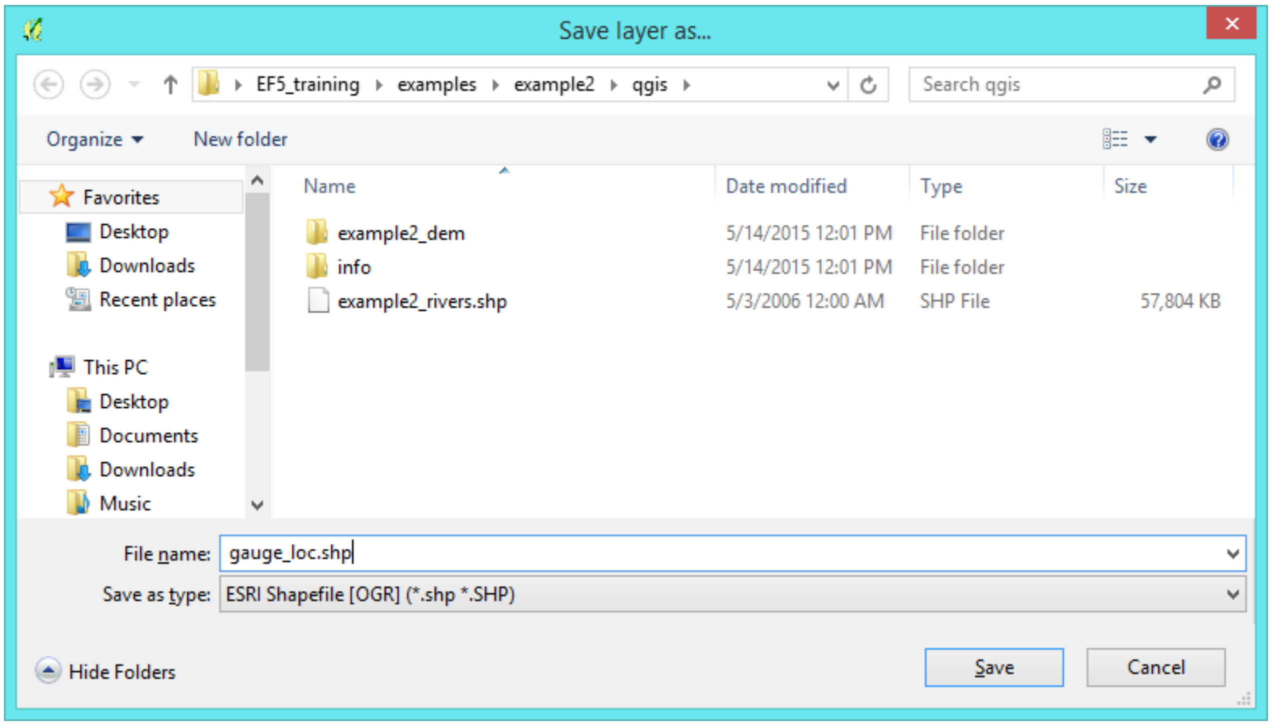


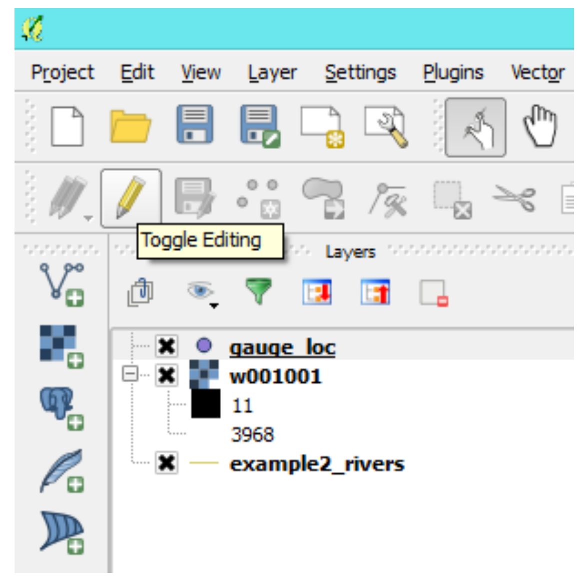
Click “OK” when the dialog box appears →



Set up the QGIS Project

Then you'll be asked to save your new layer – I named mine `gauge_loc.shp`





Then turn on "Toggle Editing" →

A pencil will appear to the left of "gauge_loc"

Set up the QGIS Project

Now use the "Coordinate:" box at the lower right of the QGIS window to zoom in to the gauge location

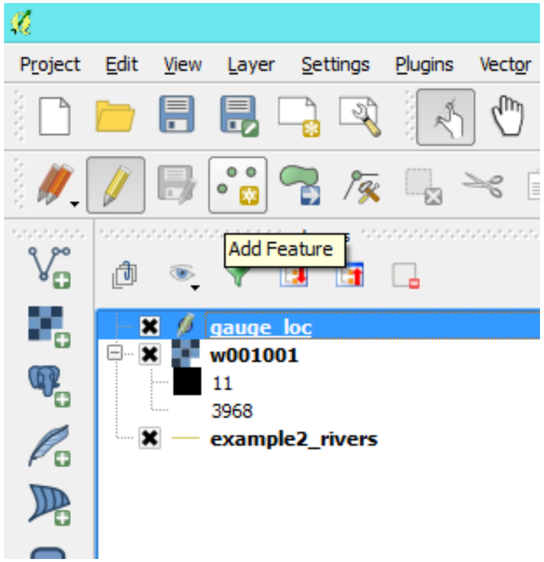
We are looking for -74.6, 4.45

As you zoom in, the numbers in the box get more precise (there will be more numbers to the right of the decimal)

We know the river is somewhere in the mountains in NW South America, which appear as white on the DEM

Set up the QGIS Project

Once you're satisfied with how you've zoomed in, select "Add Feature" →

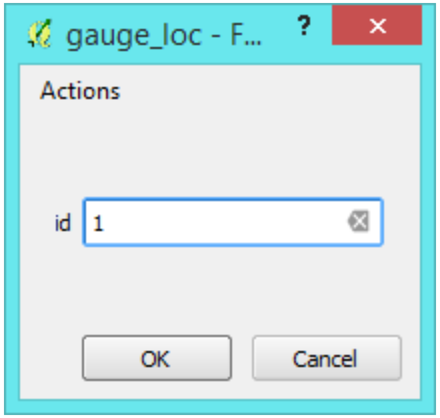


Your cursor will become a circle with crosshairs

Click once at the point on the map where the "Coordinate:" box says -74.6, 4.45

Set up the QGIS Project

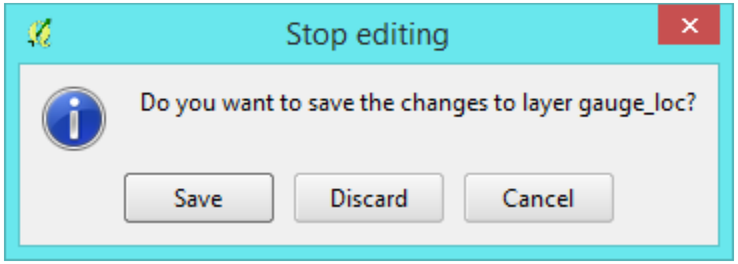
A small box will appear



Type "1" in the box and click "OK"

A dot will appear on the map where you just clicked

Click the pencil above the "Layers" pane of QGIS to turn editing off, and at the pop-up, click "Save"



Review

Let's review what we've done and why we've done it

So far, we've set up our QGIS project

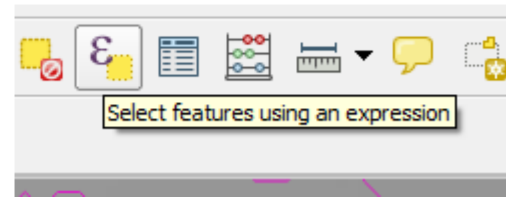
1. We've extracted our DEM into our project's folder
2. We've also done that with our river network
3. We've created a shapefile that contains one feature, a point at the location of our river gauge

These three pieces of information are all we need to create hydrologically-conditioned topographical grids for EF5

Now on to the next step: Identifying the Basin Extent

Identifying the Basin Extent

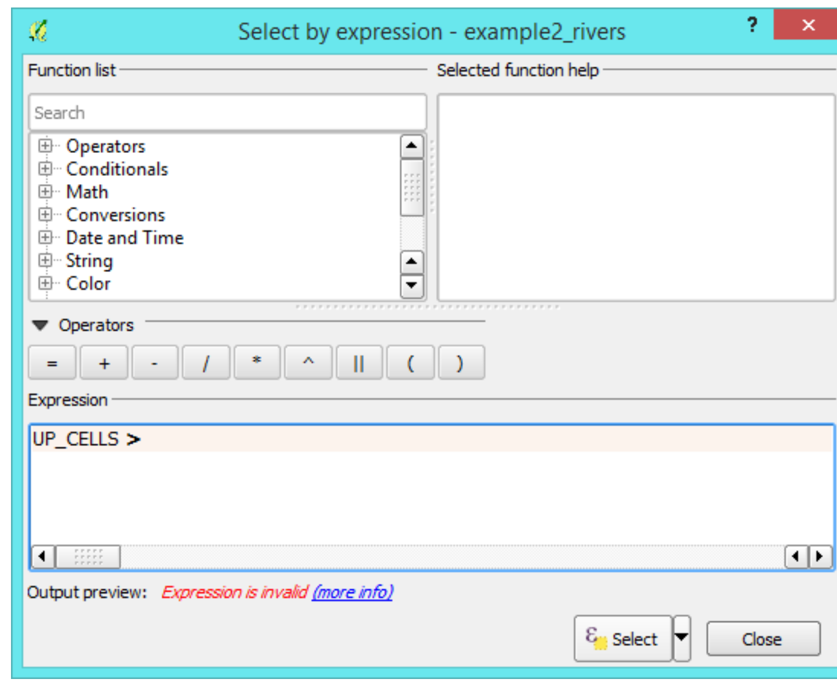
In the "Layers" pane, drag "example2_rivers" above "w001001" so that the rivers are plotted on top of the DEM



Now we want to "Select features using an expression"

In the "Expression" part of the dialog box, type `UP_CELLS >`

Note how you see "Expression is invalid" at the bottom of the box in red



Identifying the Basin Extent

Now type a number after `UP_CELLS >`, like `UP_CELLS > 1000` and the red text goes away

Click "Select" and you should also see some rivers change color in QGIS

When you pick larger numbers, you see only larger rivers highlighted

When you pick smaller numbers, many more rivers will be highlighted

<u>You want to pick a threshold that is small enough to capture the character of the river you're modeling, plus its major tributaries, but not so small that you've highlighted almost every river. Try to capture the main river channel and the major tributaries.</u>

Identifying the Basin Extent

The appropriate value varies from basin to basin, but here let's try `UP_CELLS > 400`

Click "Close"

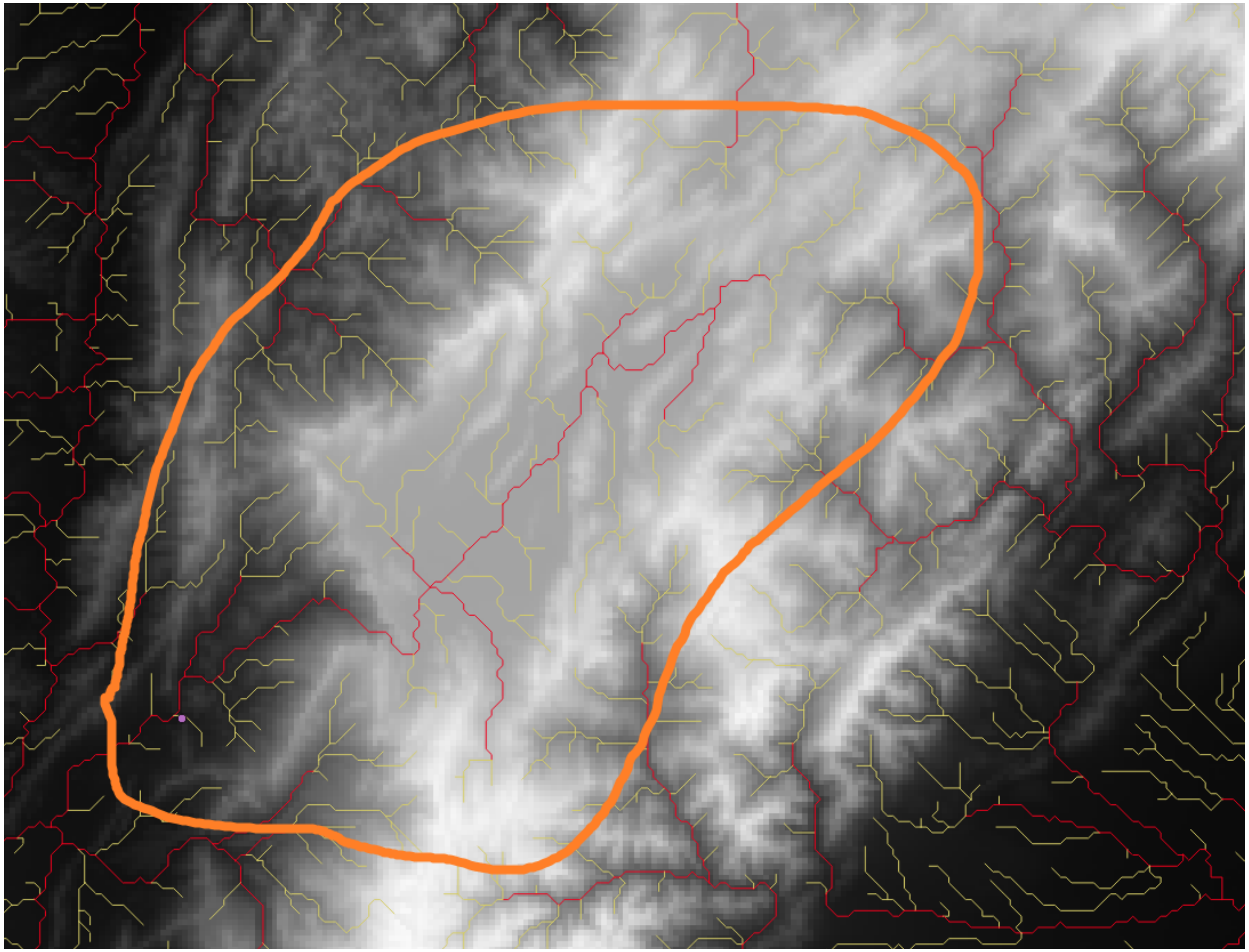
Now we are going to use the "Coordinate:" box, our gauge location, and our highlighted rivers to try to find the edges of our basin in latitude and longitude

You don't have to be perfect, but it is better to pick too much area instead of too little

In other words, err on the side of including excess area

Clipping a DEM

Here's an idea of what to look for →



Clipping a DEM

Let's pick some nice round numbers for this

- The left, or west edge… 75 deg W (or -75 deg)
- The right, or east edge… 73 deg W (or -73 deg)
- The top, or north edge… 6 deg N
- The bottom, or south edge… 4 deg S

There are two advantages to these edges:

1. They're much larger than the actual edges of the river basin, so we erred on the side of caution!
2. They're round numbers, so if we need to do any calculations later, it will be easy!

Now go to the "Raster" menu, "Projections" and click "Warp (Reproject)…"

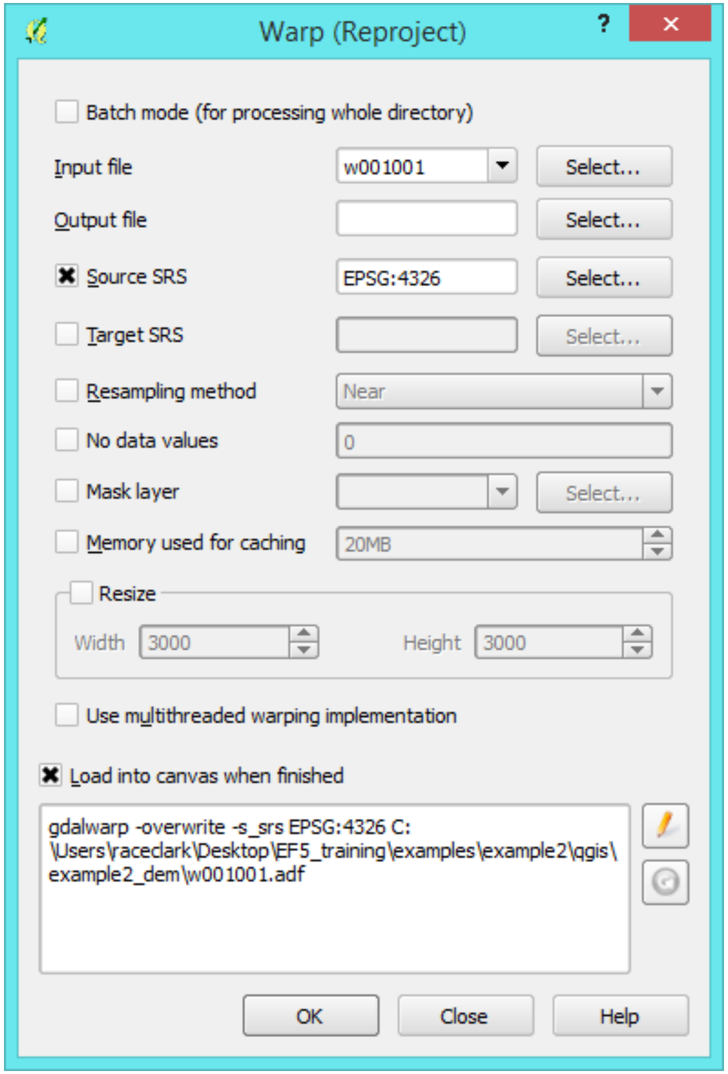
Clipping a DEM

On this screen, click "Select…" by "Output file" and then save to your `qgis` **directory – I use the name** `clipped_dem.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"



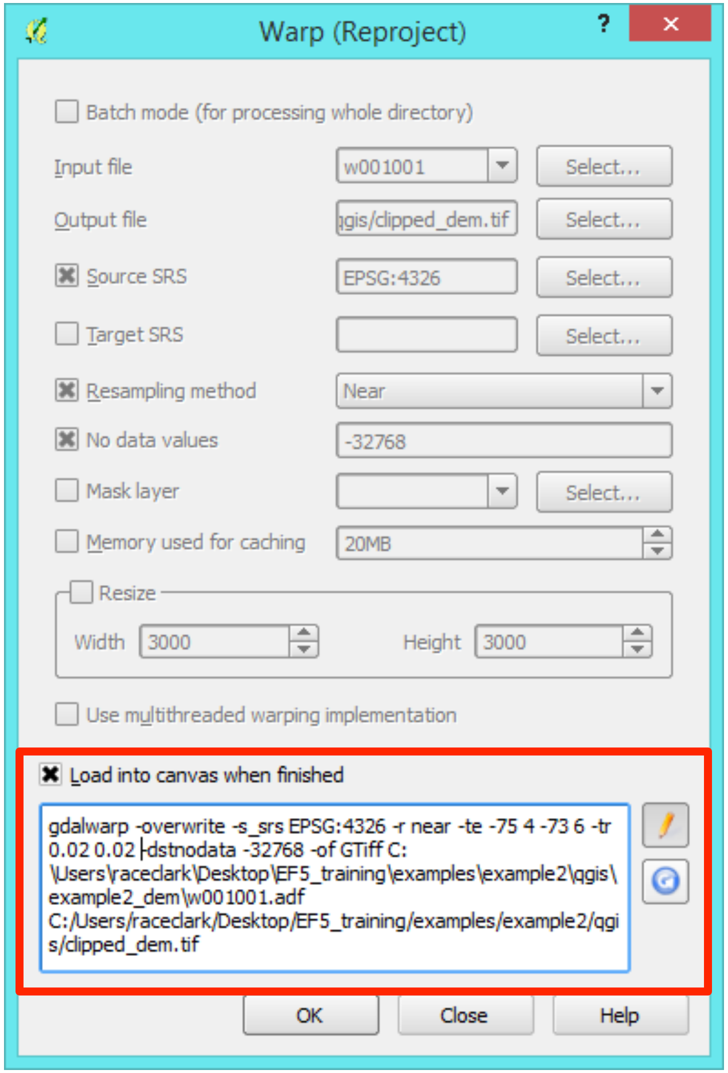
Clipping a DEM

Now you should be able to type in the text box at the bottom

After `-r near`**, type** `-te -75 4 -73 6 -tr 0.02 0.02`

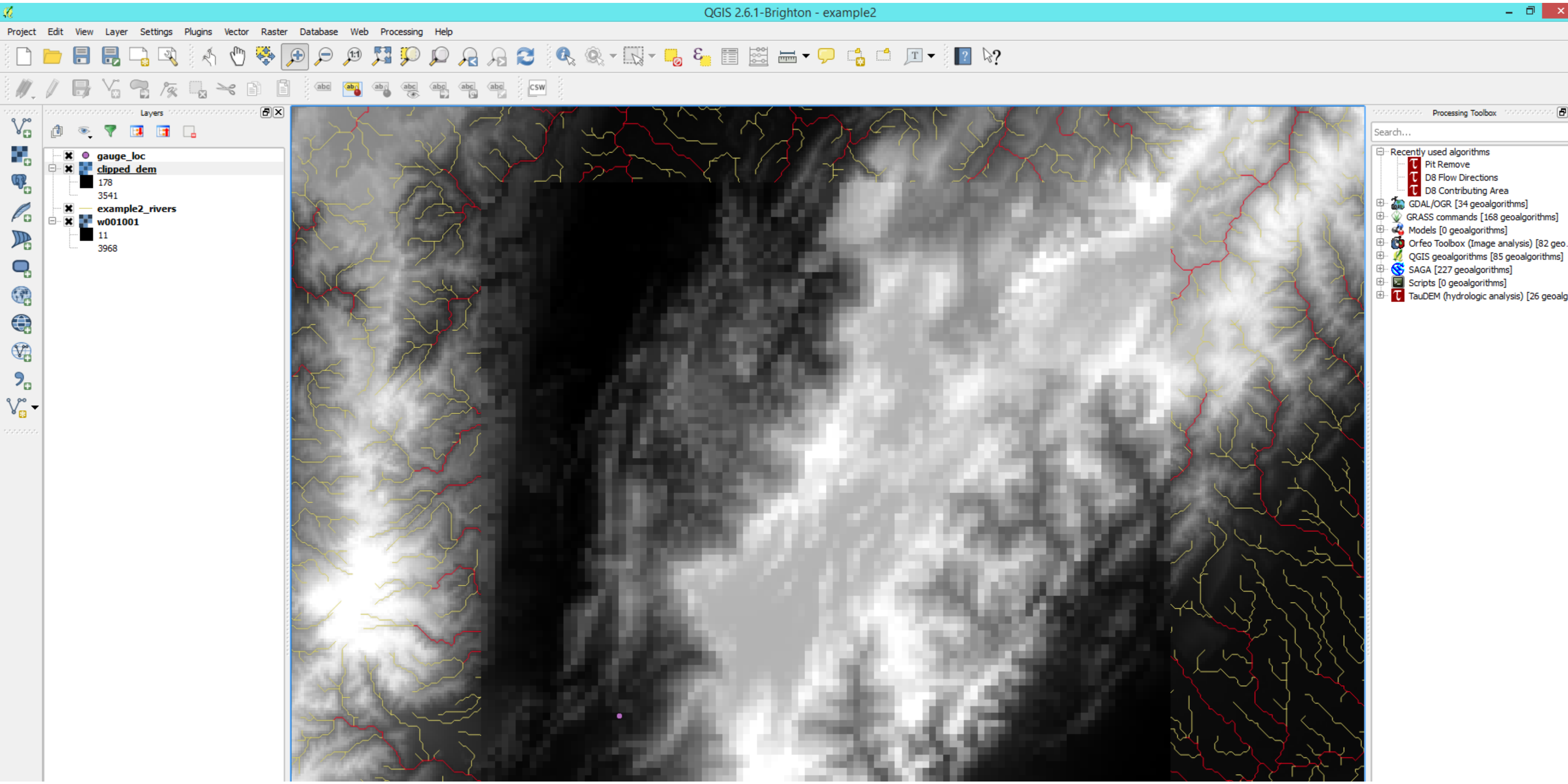
"-te" tells QGIS the extent of the grid in latitude and longitude, so we type the left border, then the bottom, then the right, and then the top

And "-tr" tells QGIS the resolution of the grid in degrees – we are going to use 0.02 degrees in each direction, ~2 km



Clipping a DEM

Click “OK”, “OK”, “OK”, and then “Close”



Filtering and Clipping Rivers

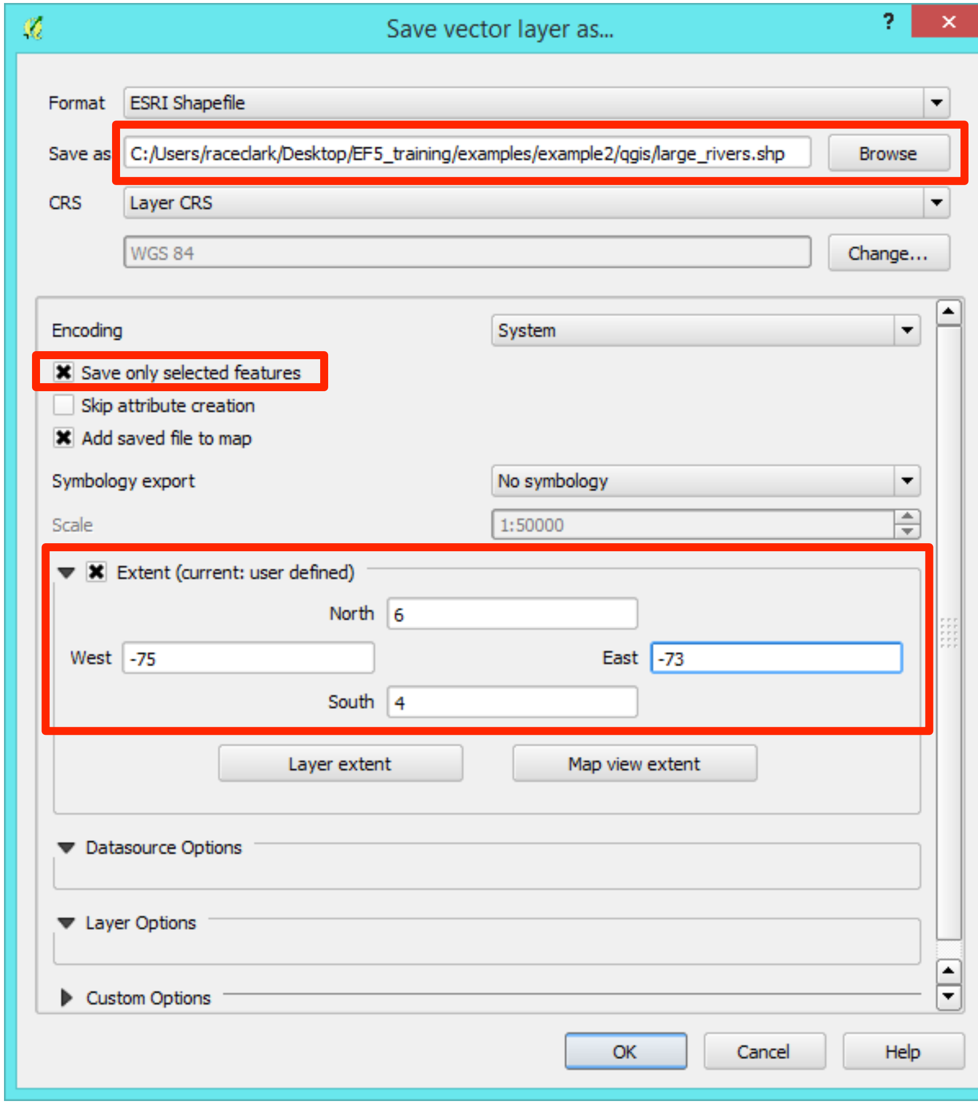
Now right-click example2_rivers and select "Save As…"

Click "Browse" and then save in your `qgis` 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, the same as we used before, and click "OK"



Review

Let's review again

We already set up the QGIS project

Then we filtered out smaller rivers

We used that information to determine the extent of our river basin

Then we clipped the DEM to that extent and reduced its resolution to make the model run faster

Finally, we saved the filtered rivers (which are also now on the same exact extent as our DEM)

Now on to the next step: Repairing the DEM

Repairing the DEM

When we change the resolution of a DEM, we tend to break things

We create "pits" or "sinks" that didn't exist in the original data

In "Processing Toolbox", open "TauDEM (hydrologic analysis)" and then "Basic Grid Analysis tools", and then double-click "Pit Remove"

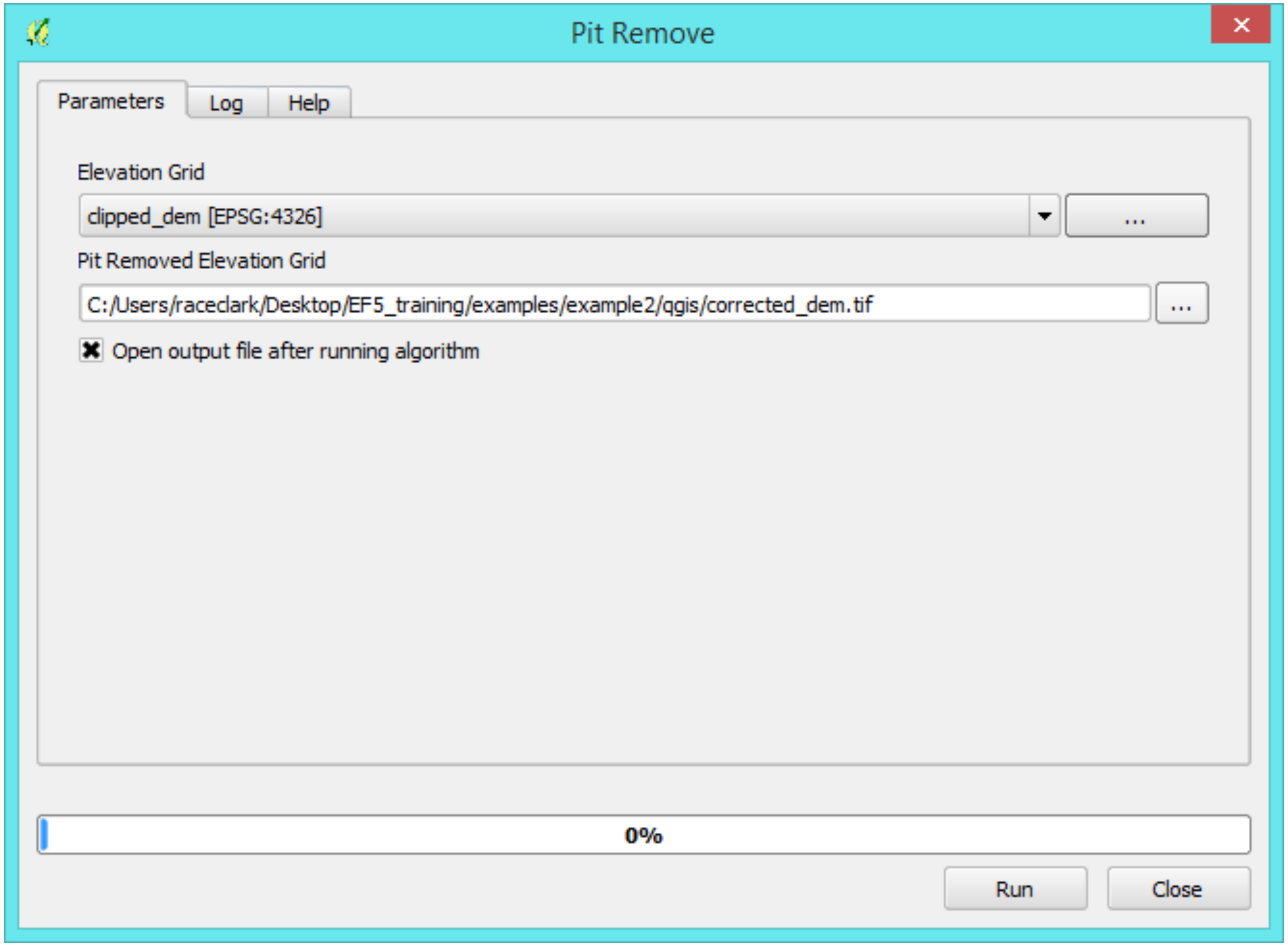
Pick "clipped_dem" in the "Elevation Grid" drop down box and for "Pit Removed Elevation Grid" click the "…" and "Save to file…"

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



Converting Rivers

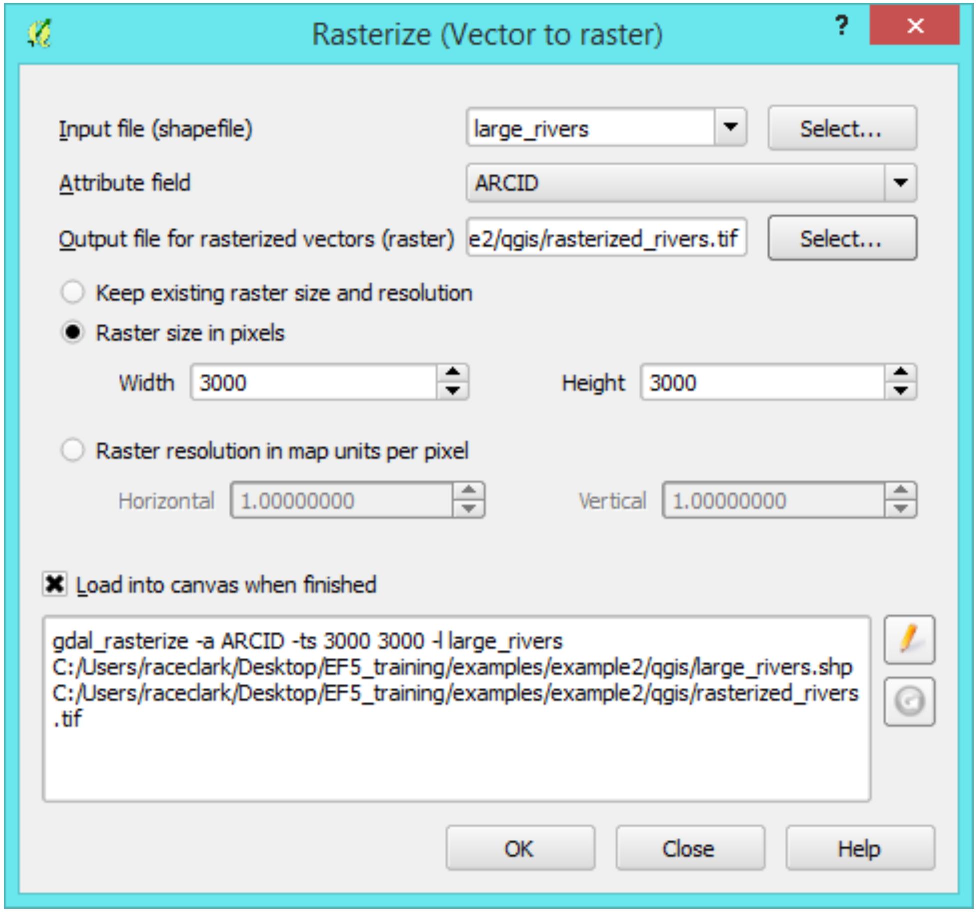
Now we want to "burn" our rivers into the corrected DEM to make sure the model knows where the streams are

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

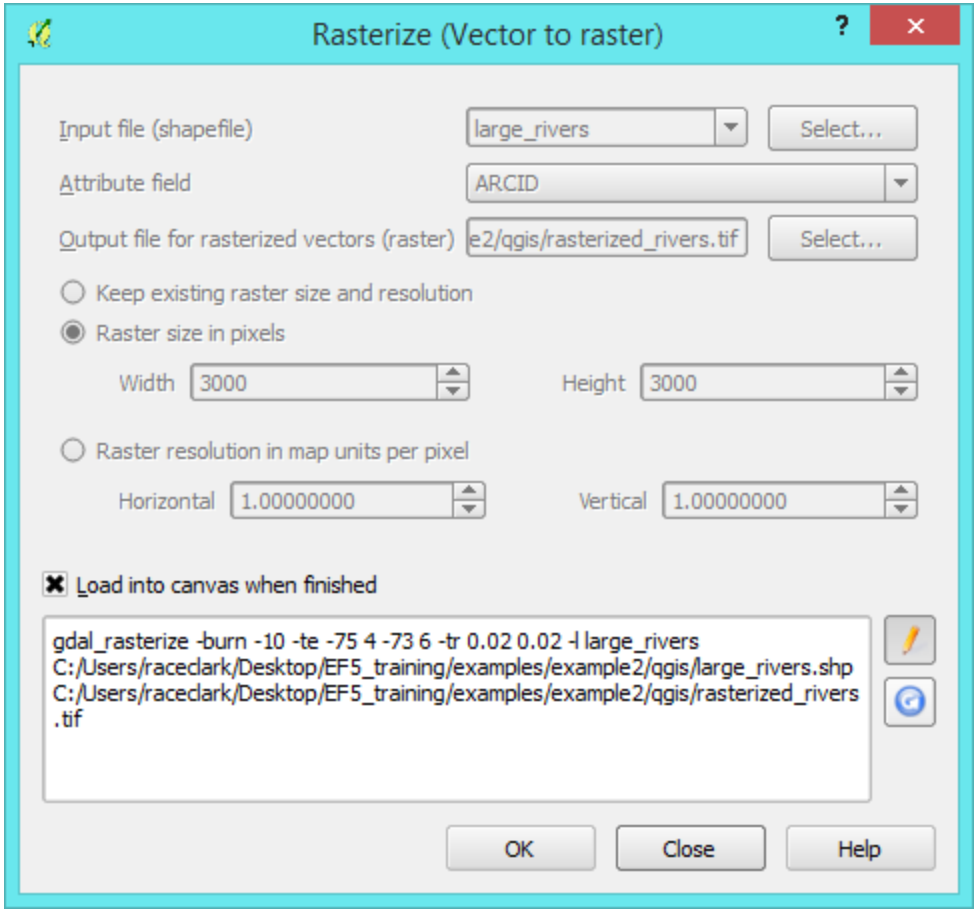


Converting Rivers

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 -75 4 -73 6 -tr 0.02 0.02`

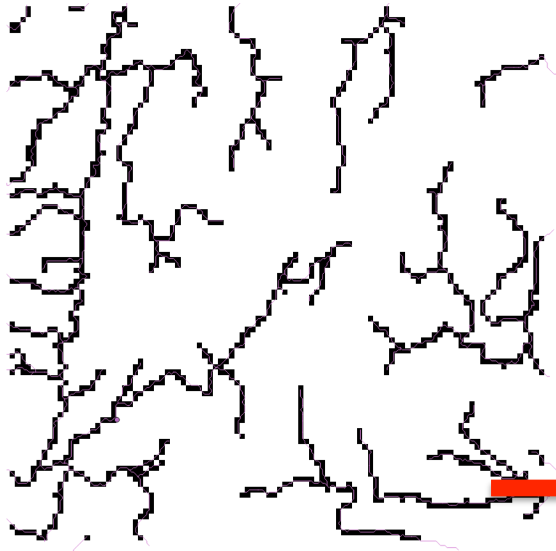
We are telling QGIS to write the number -10 every pixel in which a river occurs, using the same extent and resolution as the DEM we already created



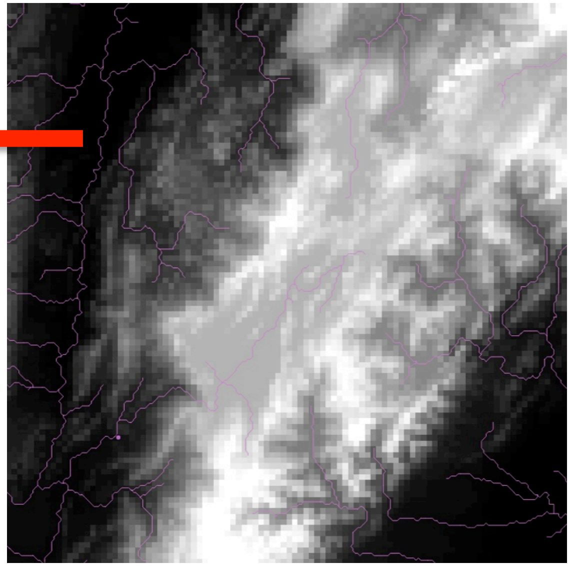
Burning Rivers

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…

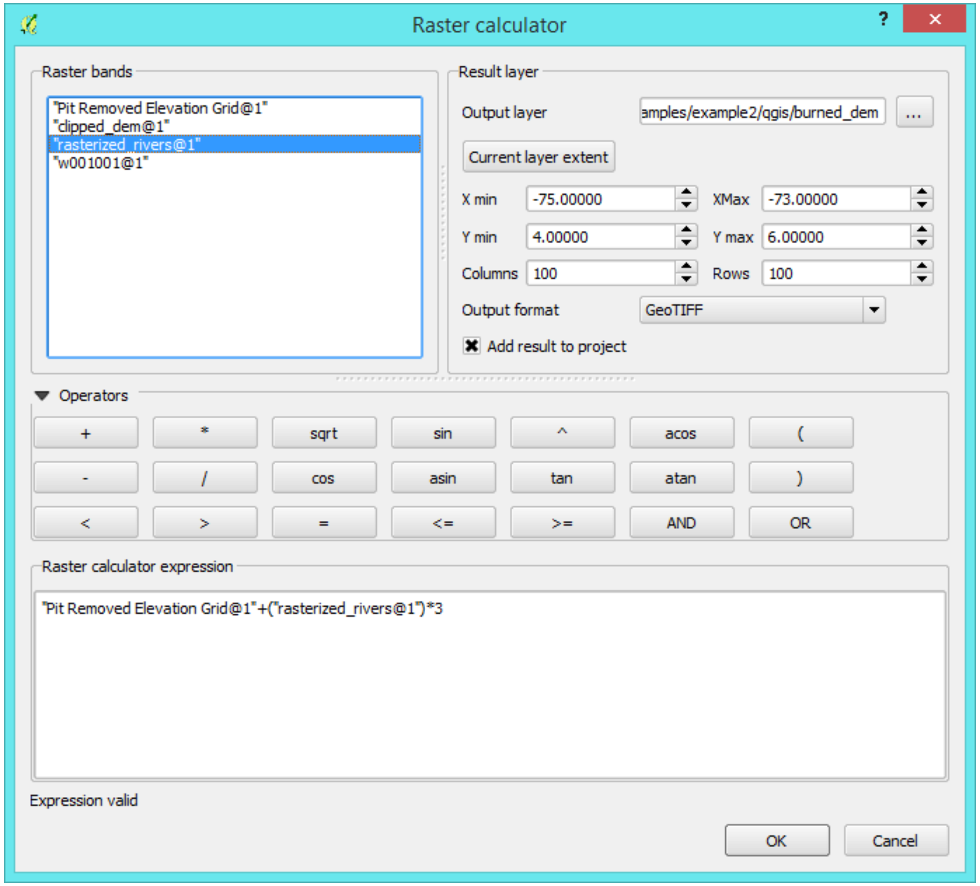
Burning Rivers

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 cursor between the parentheses and double-click "rasterized_rivers@1"



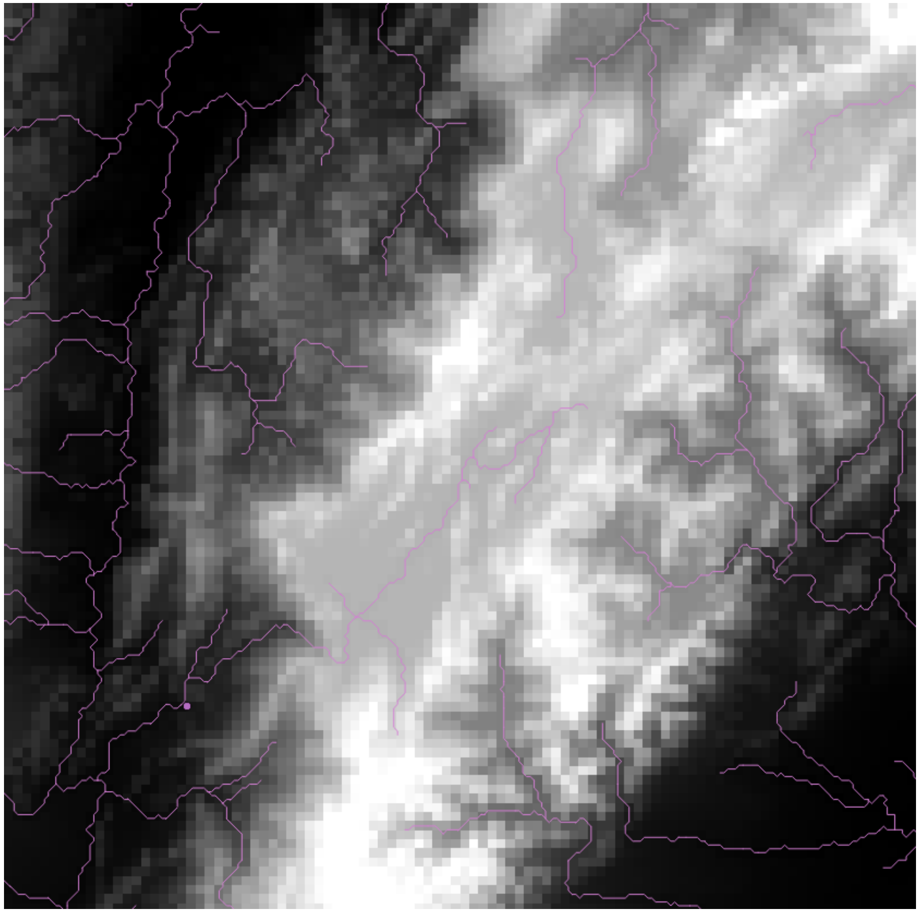
Burning Rivers

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”

To be safe, we’re going to remove pits one last time



Creating the Final DEM

In "Recently used algorithms", double-click "Pit Remove"

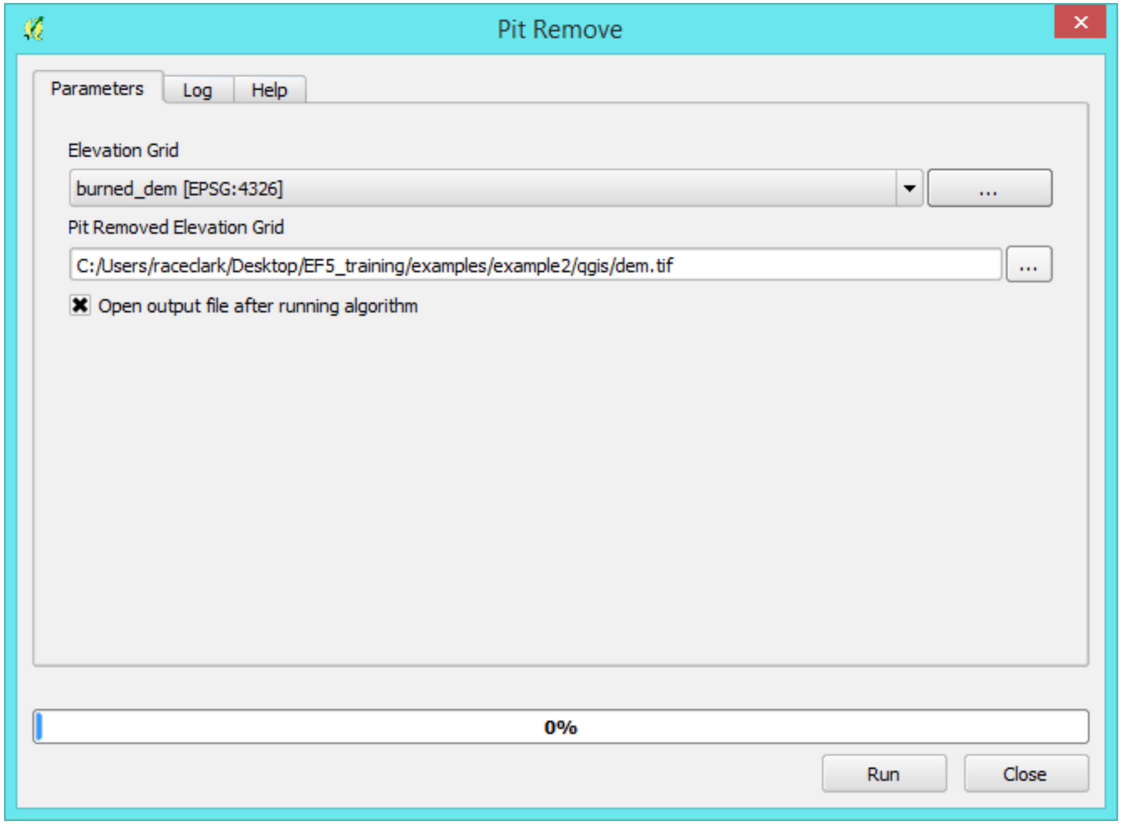
For "Elevation Grid", select "burned_dem"

Use the "…" button and click "Save to file…" to save your Pit Removed Elevation Grid as `dem.tif` in your `qgis` folder

This is the final DEM

(I recommend removing the old "Pit Removed Elevation Grid" from the Layers panel to avoid confusion)

Do this by right-clicking on it and selecting "Remove"



Let’s review again

1. We set up our QGIS project with rivers, a gauge outlet, and a DEM
2. We used the gauge outlet and the rivers to identify the edges of our river basin
3. We resampled the DEM to a new resolution and extent
4. We used our filtered rivers to “burn” the streams back into the resampled DEM, while also removing the pits and other errors

Now on to the next step: Creating flow direction and flow accumulation maps

Creating a Flow Direction

In "Processing Toolbox", open "TauDEM (hydrologic analysis)", then open "Basic Grid Analysis tools" and finally double-click "D8 Flow Directions"

For "Pit Filled Elevation Grid" select "Pit Removed Elevation Grid"

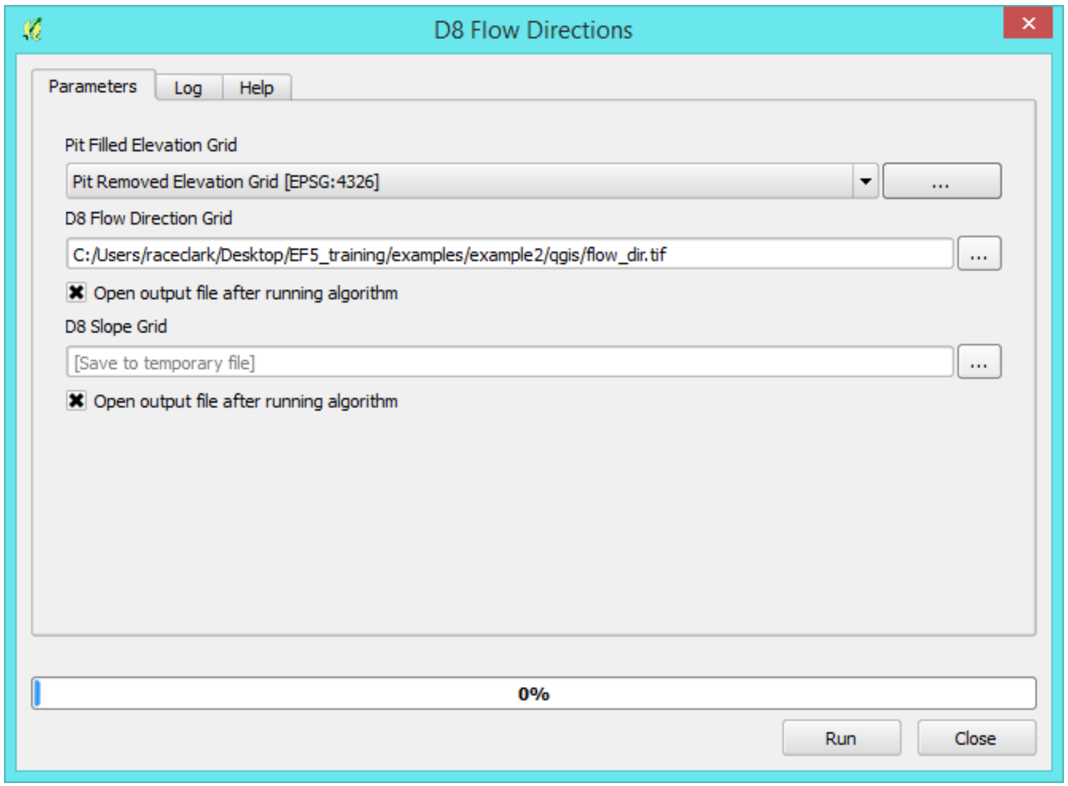
By "D8 Flow Direction Grid", select "…" and then "Save to file…"

Save the file as `flow_dir.tif` in your `qgis` folder

Creating a Flow Direction

Click “Run” and remove “D8 Slope” from your “Layers” panel…

You should see what’s on the lower right



Converting the Flow Direction

We need to convert this to a format EF5 can read

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

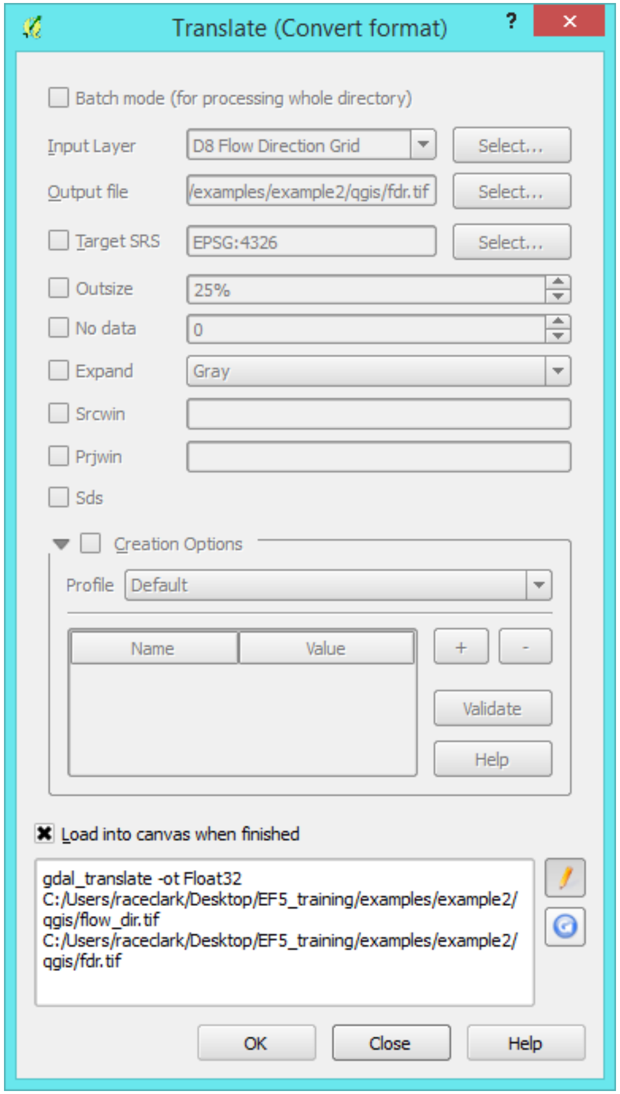
In “Input Layer”, select “D8 Flow Direction Grid”

In “Output file”, save this file as `fdr.tif` in your `qgis` 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”

This is your final flow direction grid

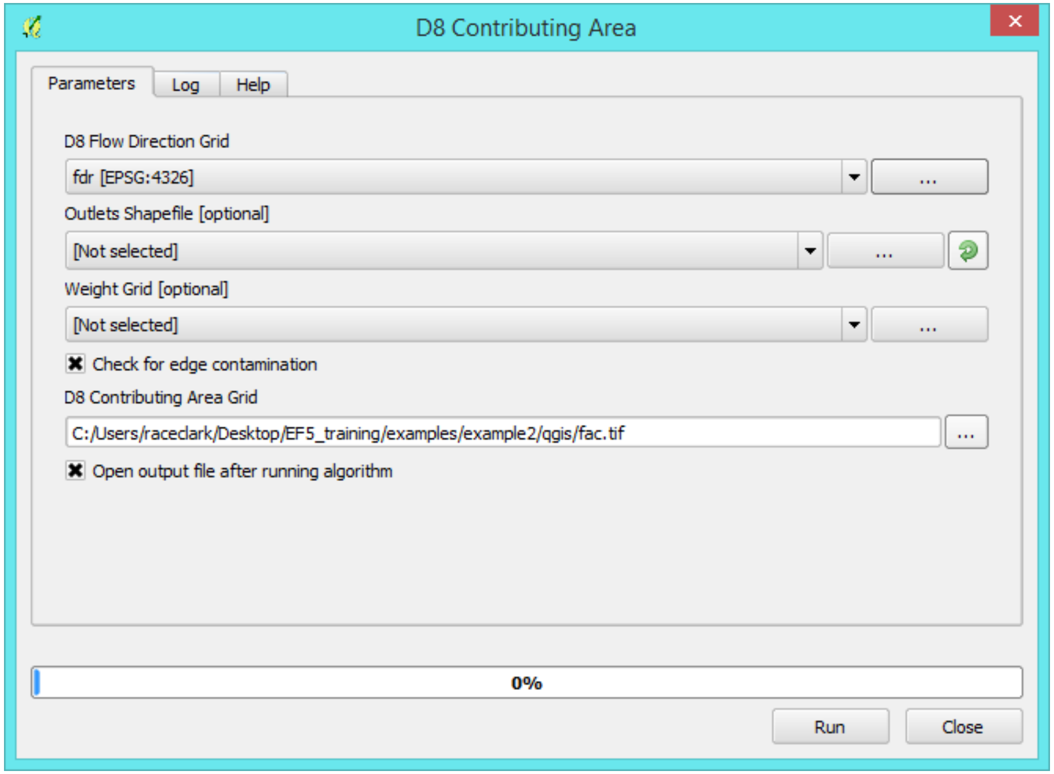


Creating an FAC

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 `qgis` folder



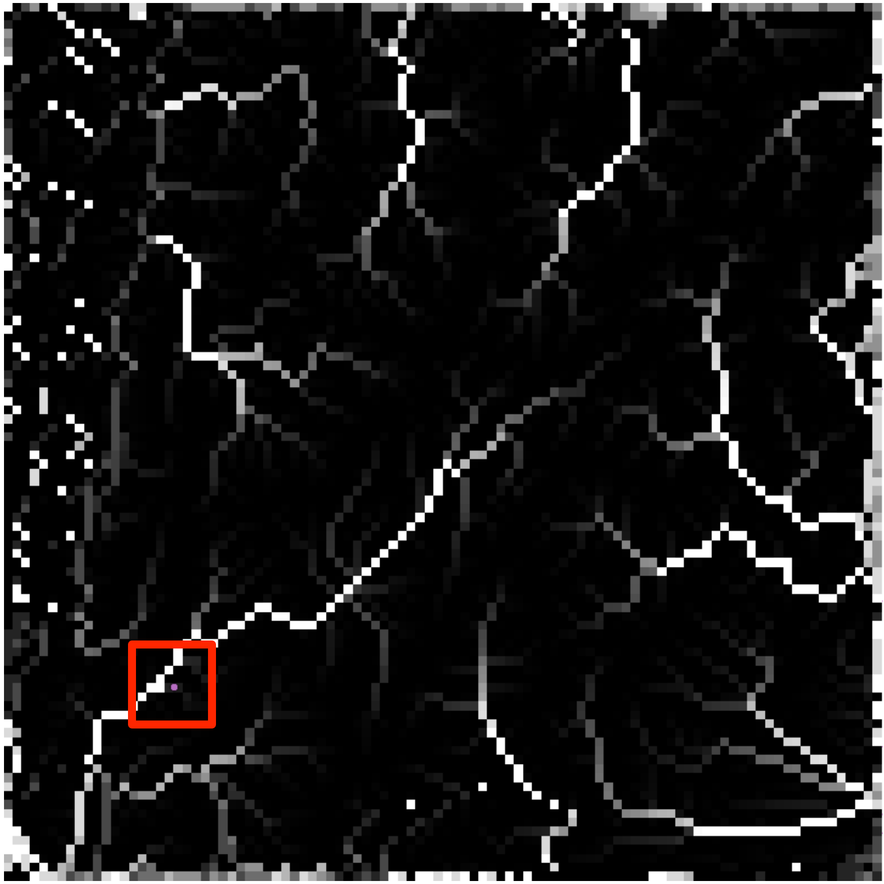
Creating an FAC

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



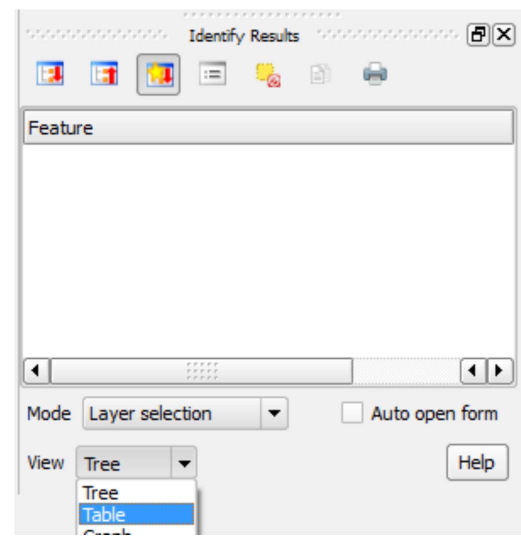
Check the FAC

The drainage area of the Bogota at Puente Portillo is about 6,000 km^2

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

Click the “Identify Features” icon →

Then at the lower left, a new pane called “Identify Results” appears



Use the drop-down menu to select “View” as “Table”

Now click a white cell near your gauge point, and on the popup menu, select “D8 Contributing Area Grid”

Check the FAC

Scroll to the right in the "Identify Results" pane until you reach the "Value" column

I got a "Value" of 1075

So, 1075 grid cells are draining into the point I selected

Each grid cell is 2 km on a side, or 4 km^2

1075 times 4 km^2 yields 4250 km^2

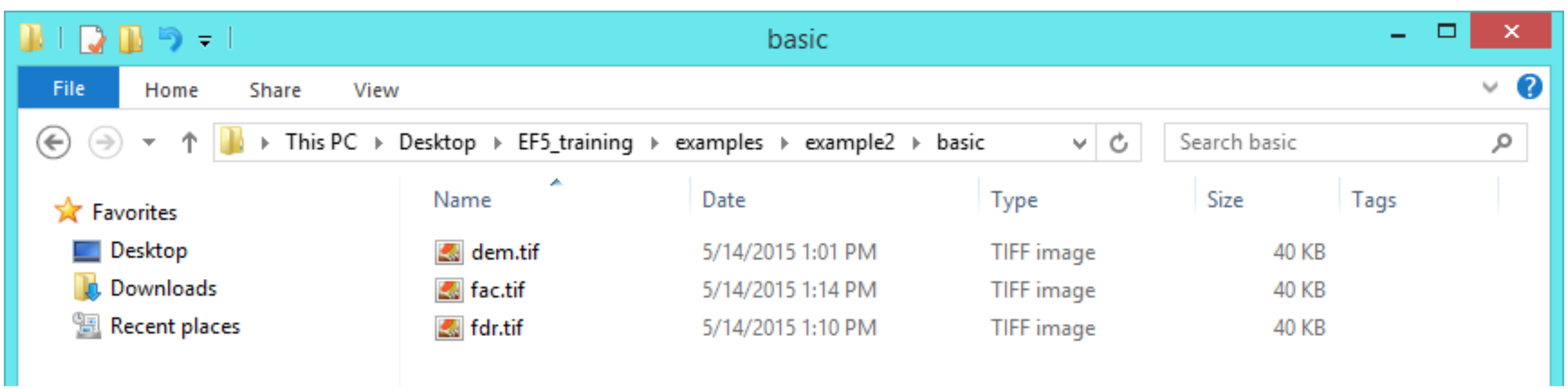
We should get an area somewhere between 5000 and 6000 km^2 and the shortfall is probably due to changing the resolution of the DEM

Prepare Files for EF5

Save your QGIS project in your `qgis` folder and exit QGIS

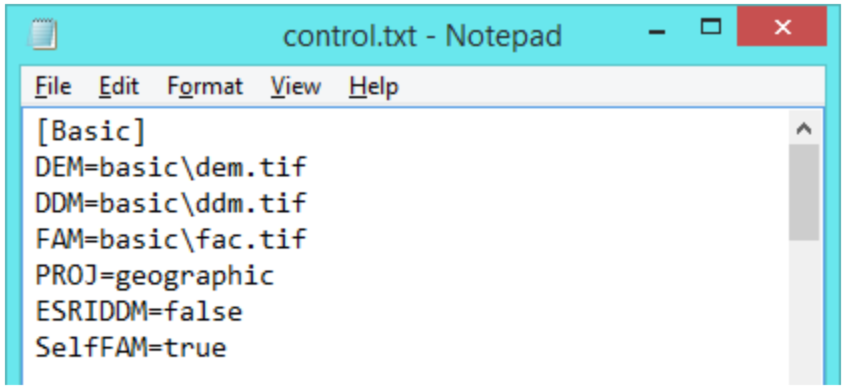
Out of all the files now in your `qgis` folder, we care about `dem.tif`, `fac.tif`, and `fdr.tif`

Copy these three files to `EF5_training\examples\example2\basic`



Prepare Files for EF5

Now open the control.txt file in the example2 folder

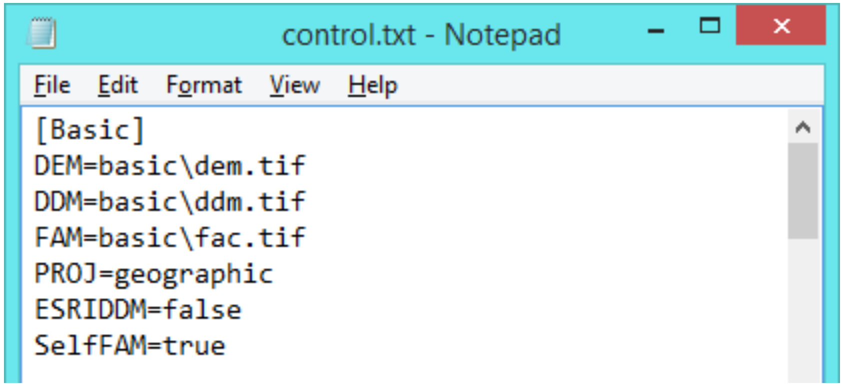


Our first job is to check the Basic block

- This block tells EF5 where the topographical information is stored relative to the location of control.txt
- So, DEM= should be the file path to the DEM, and so on
  - control.txt is in the example2 folder, and from there to find my DEM, DDM/FDR, and FAC, I simply enter the basic folder and the appropriate files are inside

Prepare Files for EF5

- `PROJ=geographic` tells EF5 that all three files (DEM, DDM/FDR, and FAC) are in the geographic projection (and we know they are, because we used latitude and longitude to add the gauge outlet)
- `ESRIDDM=false` tells EF5 what coding scheme is used in the DDM/FDR file; since it is `false` we are saying we used the TauDEM coding scheme (1, 2, 3, 4, 5, etc.) and not the ArcMap coding scheme (1, 2, 4, 8, 16, etc.)
- Finally, `SelfFAM=true` means that the lowest value of any cell in the FAC is 1 (in other words, a cell counts itself in the FAC generation process); you can test this by looking in the "Layers" panel of QGIS, which shows that the lowest FAC value is 1



Prepare Files for EF5

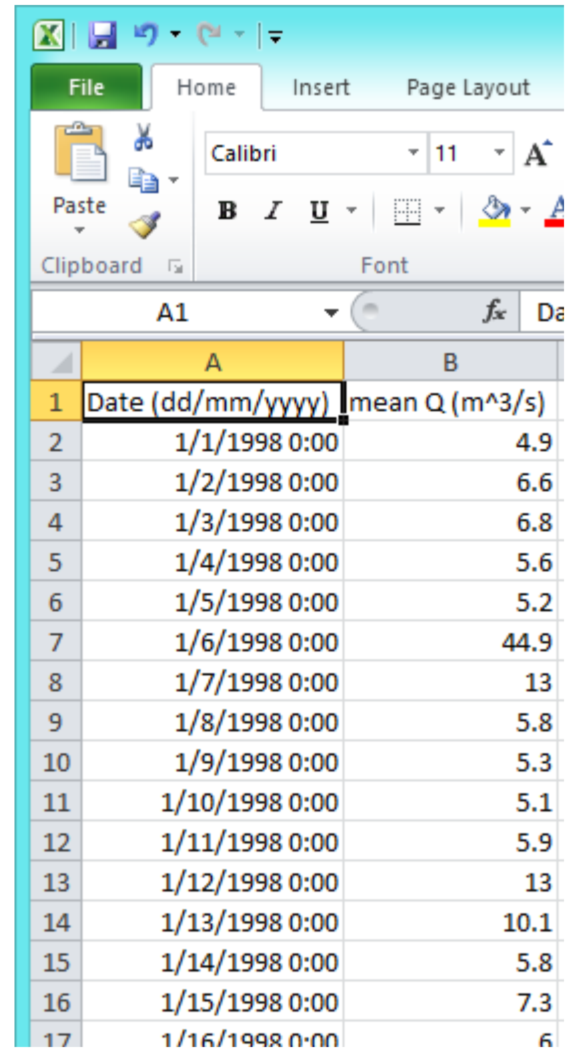
From `EF5_training\data\Observations`**, copy** `puente_portillo.csv` **to** `EF5_training\examples\example2\obs`

This file is the observed time series of daily discharge at the Puente Portillo station between 1 January 1998 and 31 December 2010

- 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 `puente_portillo.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



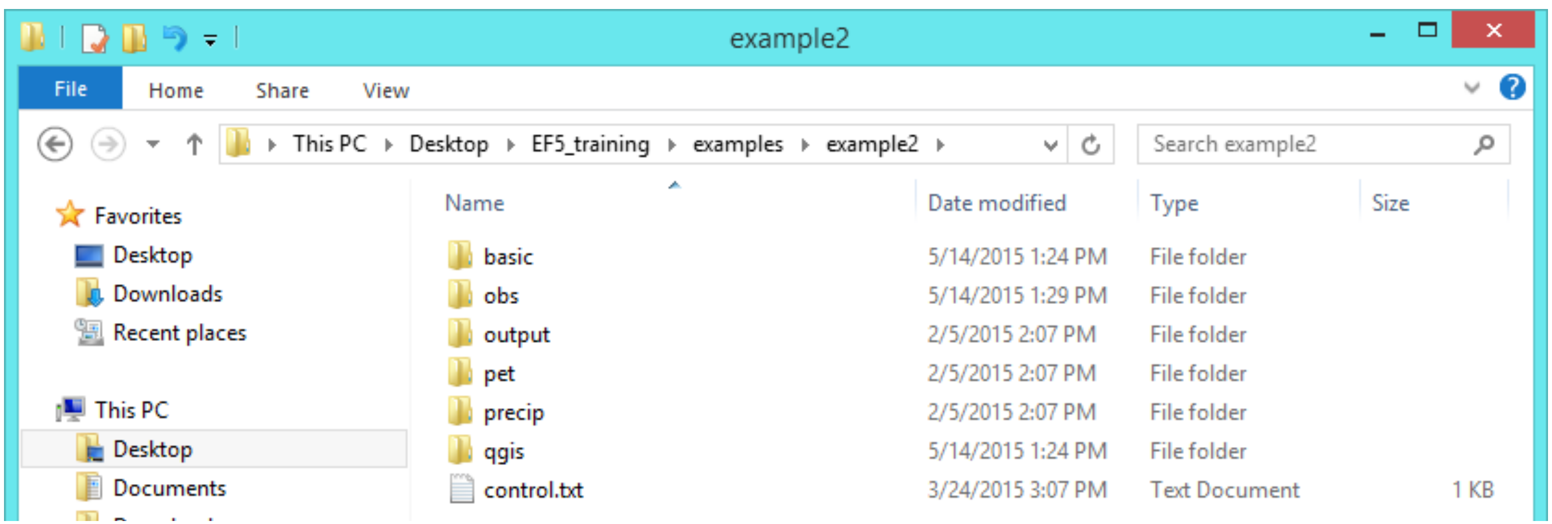
	A	B
1	Date (dd/mm/yyyy)	mean Q (m^3/s)
2	1/1/1998 0:00	4.9
3	1/2/1998 0:00	6.6
4	1/3/1998 0:00	6.8
5	1/4/1998 0:00	5.6
6	1/5/1998 0:00	5.2
7	1/6/1998 0:00	44.9
8	1/7/1998 0:00	13
9	1/8/1998 0:00	5.8
10	1/9/1998 0:00	5.3
11	1/10/1998 0:00	5.1
12	1/11/1998 0:00	5.9
13	1/12/1998 0:00	13
14	1/13/1998 0:00	10.1
15	1/14/1998 0:00	5.8
16	1/15/1998 0:00	7.3
17	1/16/1998 0:00	6

Prepare Files for EF5

We've added files to the `basic` folder and to the `obs` folder

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

We will fill `pet` and `precip` in Module 2.3



Coming Up….

The next module is

Rainfall and PET

You can find it in your `\EF5_training\presentations` directory

Module 2.2 References

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

EF5 Training Doc 6 – Properties of Example Basins, (March 2015).

Jenson, S. K. and J. O. Domingue, (1988). Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing* , 54: 11, 1593-1600. (Paper 9 – DEM Processing.pdf)