

# Steps for building a watershed model in ParFlow

ParFlow Short Course

## 1. Gridded Inputs

Meteorology\*

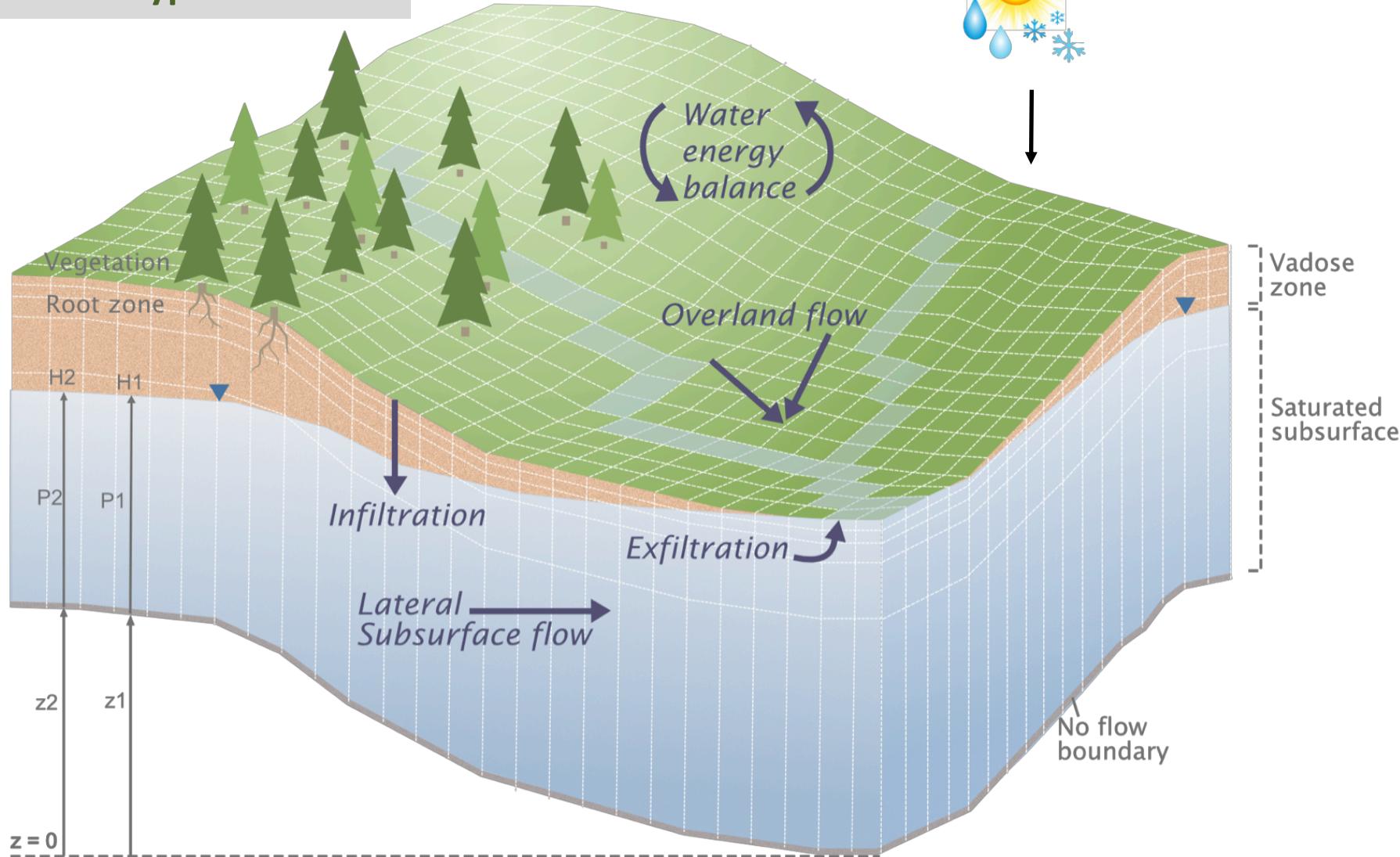
Topography

Subsurface Properties

Vegetation Types\*

## 2. Boundary Conditions

## 3. Initial Conditions



# Workflow Outline

1. Evaluate available model inputs
2. Determine your domain configuration
3. Process topography
4. Setup the subsurface
5. Initialize the model (i.e. spinup)
6. Additional setup for PF-CLM

*This is also outlined in section 3.1.2 of the manual*

# 1. Evaluate available model inputs

- Land surface
  - Digital Elevation Model -> slopes
  - Mannings roughness coefficients
- Subsurface configuration: hydrologic properties for soil and deeper geologic units
  - Permeability
  - Porosity
  - Specific storage
  - Relative permeability
  - Saturation

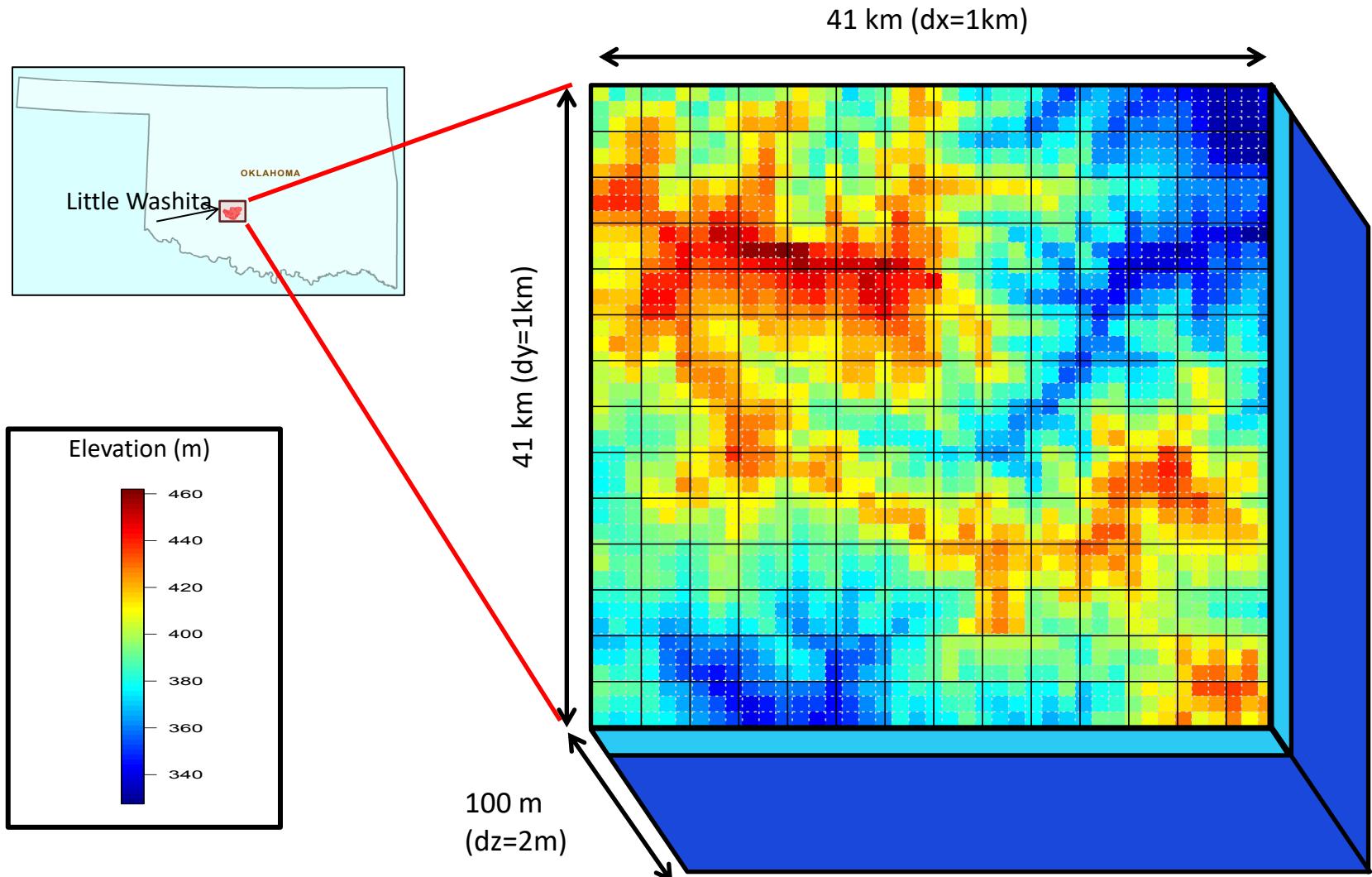
# 1. Evaluate available model inputs

- Atmospheric forcings:
  - ParFlow: moisture flux for surface
  - ParFlow CLM: precipitation, air temperature, wind, incoming short and longwave radiation, atmospheric pressure, specific humidity
- Land cover: vegetation types and properties (for ParFlow-CLM)

## 2. Determine your domain configuration

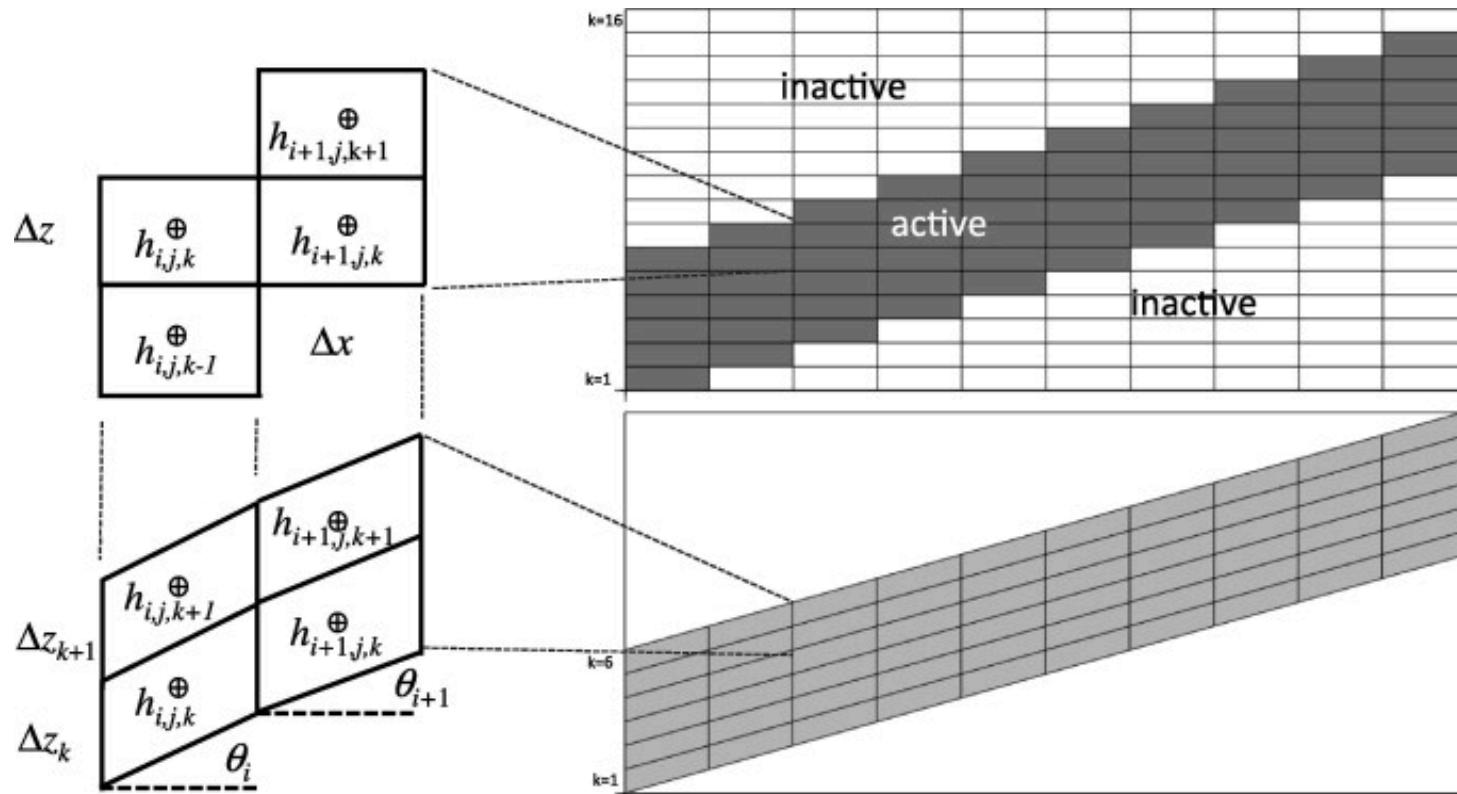
1. *What are the questions you want to answer with your model?*
2. *What kind of inputs do you have available to build your model with?*

# Lateral resolution and domain extent



# Subsurface configuration:

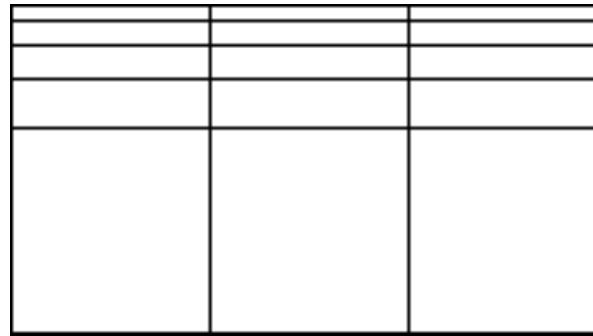
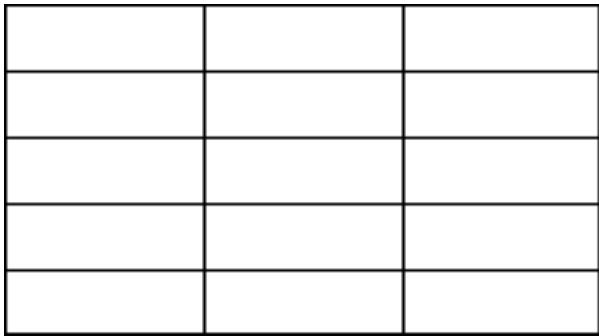
- Domain thickness
- Terrain following grid or orthogonal grid



Maxwell, 2013

# Subsurface configuration:

- Constant or variable layer thickness ( $dz$ )



- Variable  $dz$  allows for thin layers at the surface and thicker layers at the bottom of the domain to maintain high resolution in the upper layers and total domain thickness without too many layers

# Boundary Conditions

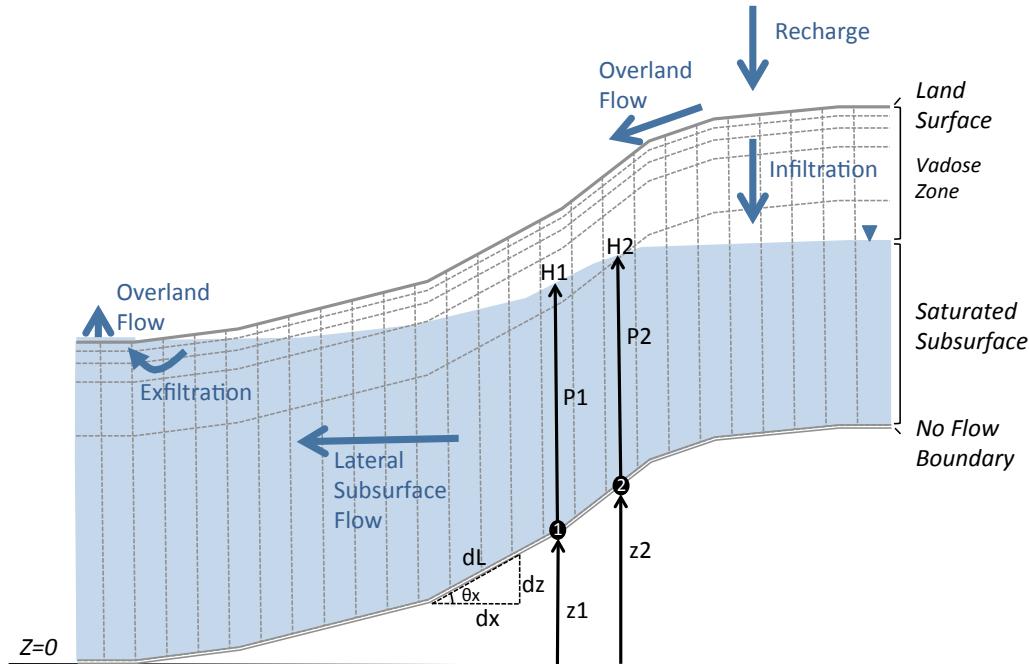
- Boundary conditions must be set for all of the external patches on the domain
- 9 types of pressure boundary conditions (*manual 6.1.24*):
  1. DirEquilRefPatch: pressure will be in hydrostatic equilibrium with reference pressure
  2. DirEquilPLinear: pressure will be in hydrostatic equilibrium with piecwise line at elevation  $z=0$
  3. FluxConst: Constant flux (L/T) normal to the patch
  4. FluxVolumetric: Constant volumetric flux normal to the patch
  5. Pressure File: Defines hydraulic head boundary conditions. Only the values on the specified patch will be used
  6. FluxFile: Flux boundaries read in from a pfb file
  7. OverlandFlow: Turns on fully-coupled overland flow routing for uniform fluxes (e.g. rainfall or ET over the entire domain)
  8. OverlandFlowPFB: Turns on fully-coupled overland flow routing for uniform fluxes with grid based spatially variable fluxes read in from a pfb
  9. Exact Solution: Exact know solution applied as a Dirichlet boundary condition on the patch
- Internal Dirichlet boundary conditions can also be defined by setting the pressure at internal points in the domain (*see the manual section 6.1.23*)

# 3. Processing Topography

*Convert from a digital elevation model to slopes and  
adjust values to ensure a realistic drainage network*

# Processing Topography

- ParFlow requires slopes not elevations



Built in PFTools commands can be used to calculate slopes from elevations, but this is not the recommended approach for watershed domains.

# Processing Topography: Why shouldn't you use slopes from your raw DEM directly?

- When you calculate slopes from DEMs you are not guaranteed to get a fully connected drainage network
- This is particularly problematic for lower resolution DEMS

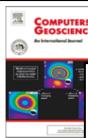
# This is a well known problem and there are many approaches to address this



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HYDROLOGICAL PROCESSES

*Hydrol. Process.* **30**, 846–857 (2016)  
Published online 20 September 2015 in Wiley Online Library  
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10648

Routing overland flow through sinks and flats in interpolated raster terrain surfaces<sup>☆</sup>

Frank Kenny <sup>\*</sup>, Bryce Matthews, Kent Todd

Water Resources Information Program, Ontario Ministry of Natural Resources, 300 Water St., Peterborough, Ontario, Canada K9J 8M5

EARTH SURFACE PROCESSES AND LANDFORMS  
*Earth Surf. Process. Landforms* **41**, 658–668 (2016)  
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(wileyonlinelibrary.com) DOI: 10.1002/esp.3888

## The practice of DEM stream burning revisited

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*Hydrol. Earth Syst. Sci.*, **14**, 1153–1165, 2010  
[www.hydrol-earth-syst-sci.net/14/1153/2010/](http://www.hydrol-earth-syst-sci.net/14/1153/2010/)  
doi:10.5194/hess-14-1153-2010  
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## On the uncertainty of stream networks derived from elevation data: the error propagation approach

T. Hengl<sup>1</sup>, G. B. M. Heuvelink<sup>2</sup>, and E. E. van Loon<sup>1</sup>

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## Efficient hybrid breaching-filling sink removal methods for flow path enforcement in digital elevation models

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Priority-flood: An optimal depression-filling and watershed-labeling algorithm for digital elevation models



Richard Barnes <sup>a,\*</sup>, Clarence Lehman <sup>b</sup>, David Mulla <sup>c</sup>  
*Ecology, Evolution, & Behavior, University of Minnesota, USA*  
*College of Biological Sciences, University of Minnesota, USA*  
*Soil, Wat*

WATER RESOURCES RESEARCH, VOL. 34, NO. 4, PAGES 897–901, APRIL 1998

## Extraction and representation of nested catchment areas from digital elevation models in lake-dominated topography

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# This is a well known problem and there are many approaches to address this



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Pit filling algorithms ensure drainage and can achieve globally optimal solutions but may not match the drainage network

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(wileyonlinelibrary.com) DOI: 10.1002/cag.2000

The practice of DEM stream burning revisited



Computers & Geosciences

journal homepage: [www.elsevier.com/locate/cageo](http://www.elsevier.com/locate/cageo)

Stream burning methods match the spatial configuration of the drainage network but can result in deeply incised channels that alter the terrain attributes of the DEM



, APRIL 1998

On the uncertainty of stream networks derived from elevation data: the error propagation approach

T. Heng<sup>1</sup>, G. B. M. Heuvelink<sup>2</sup>, and E. E. van Loon<sup>1</sup>

Extraction and representation of nested catchment areas from digital elevation models in lake-dominated topography

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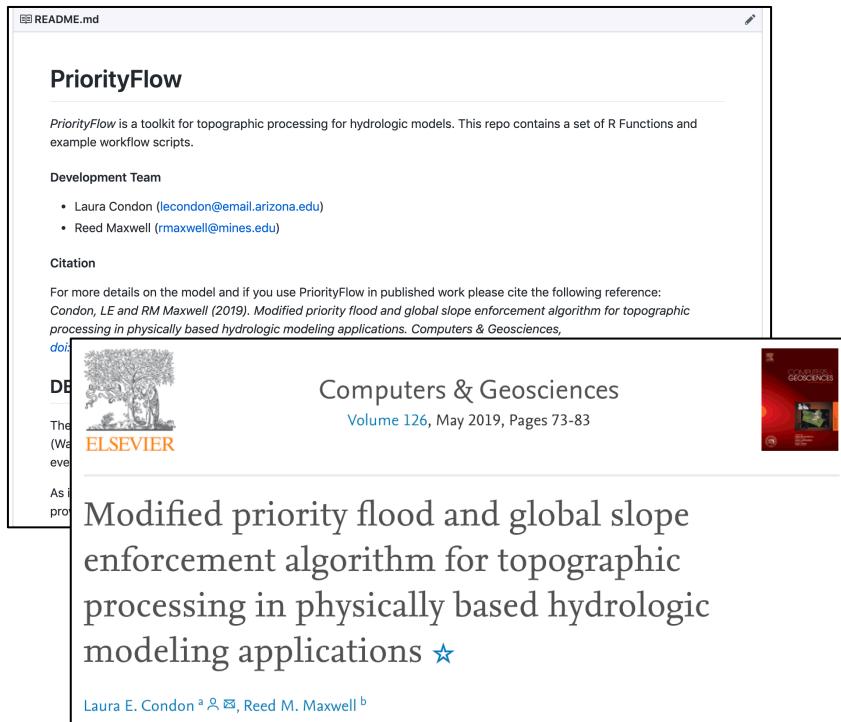
# Processing Topography: GRASS Workflow

- GIS tools can help you evaluate your drainage network
- Example workflow using the watershed analysis tool in grass is documented on the ParFlow Blog (<http://parflow.blogspot.com/2015/08/terrain-processing.html>)
- This uses the A\* algorithm to ensure that every cell n the domain drains out
- Make sure to look closely at the drainage network developed by GRASS to ensure its consistent with what you expect.

# Processing Topography: PriorityFlood Tool

## GitHub Repo

<https://github.com/lecondon/PriorityFlow>



- Modified priority flood algorithm for depression filling and stream enforcement
- Slope processing tools and workflows for D4 and D8 routing
- Options for stream network smoothing
- Additional options for handling primary and secondary flow directions
- More control of DEM Processing and generated PF Consistent slope outputs

# Parking lot test

- Make your domain impervious, rain on it and look at the drainage network



# 4. Setup the subsurface

*Developing a gridded representation of subsurface*

# Subsurface inputs

1. Identify unique subsurface units and provide subsurface geometries to ParFlow
  - Either using solid files or indicator files
2. Assign the hydrologic properties to each unit
  - permeability, specific storage, porosity and van Genuchten parameters

# 5. Initializing the model (spinup)

*Determining the starting groundwater configuration for your simulations*

# Spinup

- Goal: develop a domain that is stable and solving nicely before you start making runs to answer questions
- There is no best practice for spinup, results and approaches will vary depending on your domain and the questions you want to answer with your model
- Groundwater is the slowest moving part so its often easiest to start with a simplified system and get a stable water table before adding in land surface processes

<http://parflow.blogspot.com/2015/08/spinning-up-watershed-model.html>

# One Approach to Spinup

1. Initialize your water table somewhere
  - Completely saturate the domain
  - Make it completely dry
  - Make an intelligent guess about where you think the water table should be
2. Run for a long time with a constant or periodic forcing at the land surface until you get a ‘stable’ configuration

# 6. Additional setup for PF-CLM

# Additional Inputs needed:

1. Land cover type
2. Properties of each land cover type (IGBP land cover classifications already setup)
3. Meteorological forcing data which can be spatially heterogeneous or homogeneous
  - Visible or short-wave radiation [W/m<sup>2</sup> ]
  - Long wave radiation [W/m<sup>2</sup> ]
  - Precipitation [mm/s]
  - Air Temperature [K]
  - East-west wind speed [m/s]
  - South-to-North wind speed [m/s]