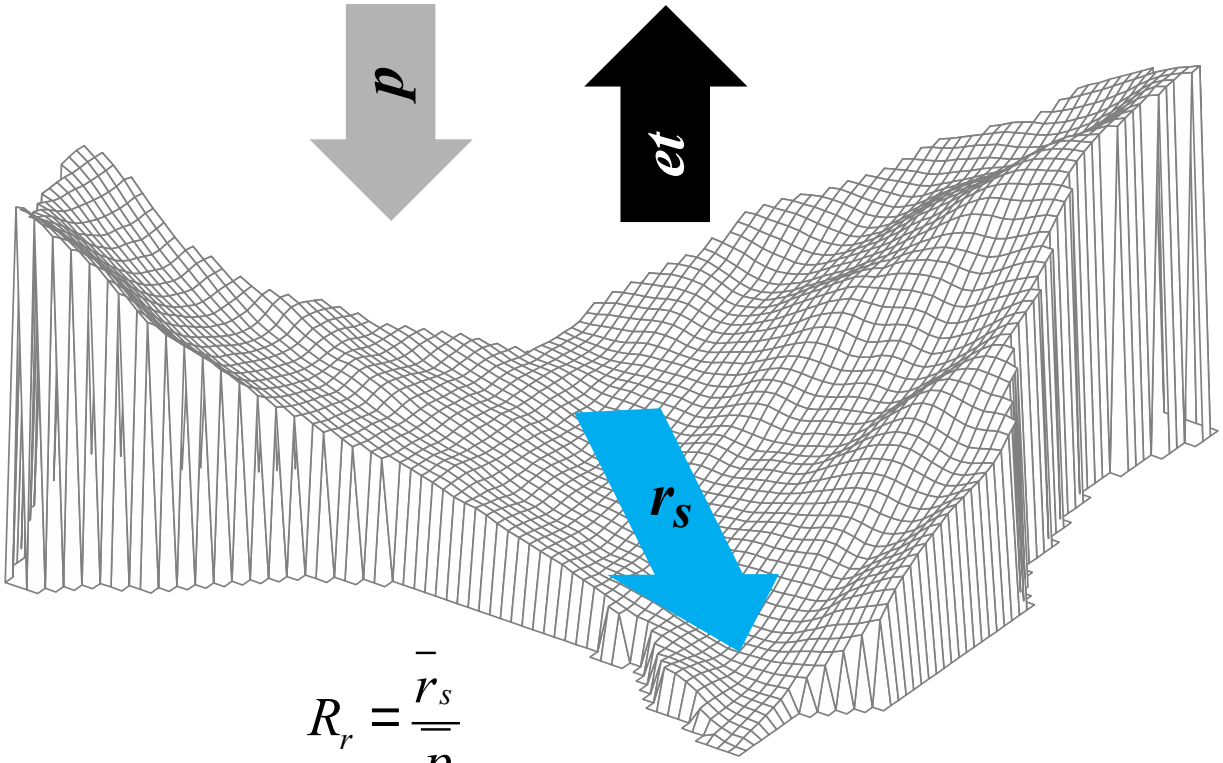
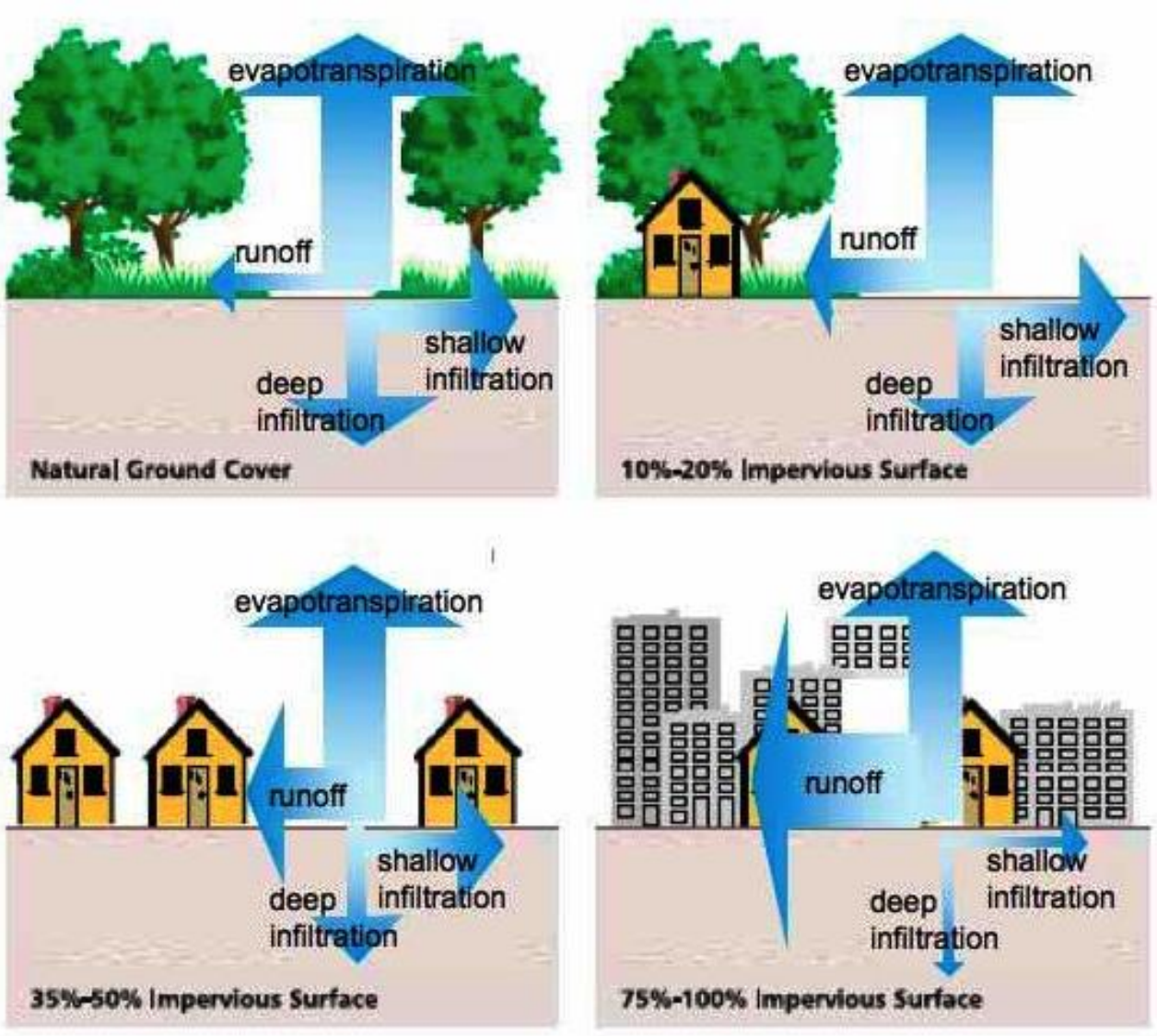
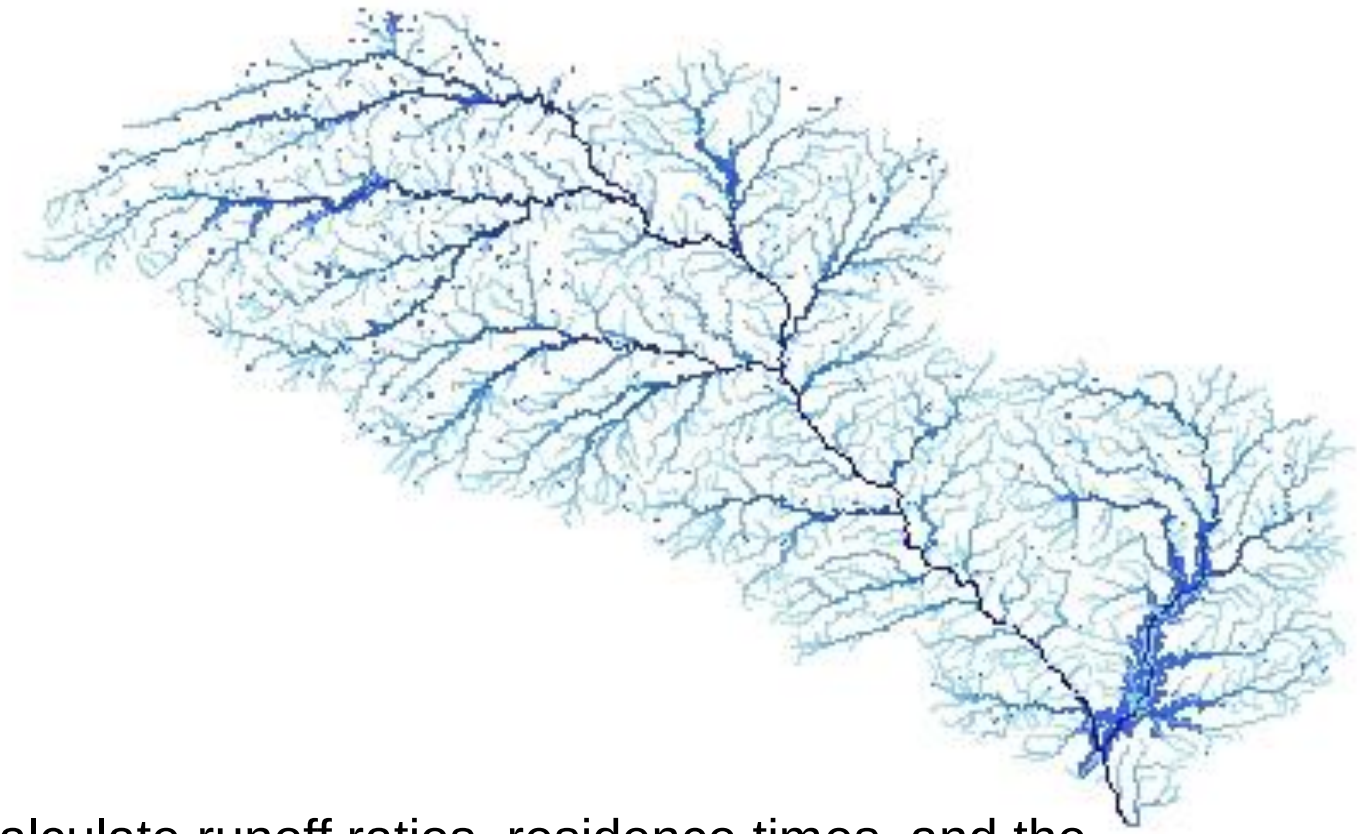


$$R_r = \frac{\bar{r}_s}{\bar{p}}$$

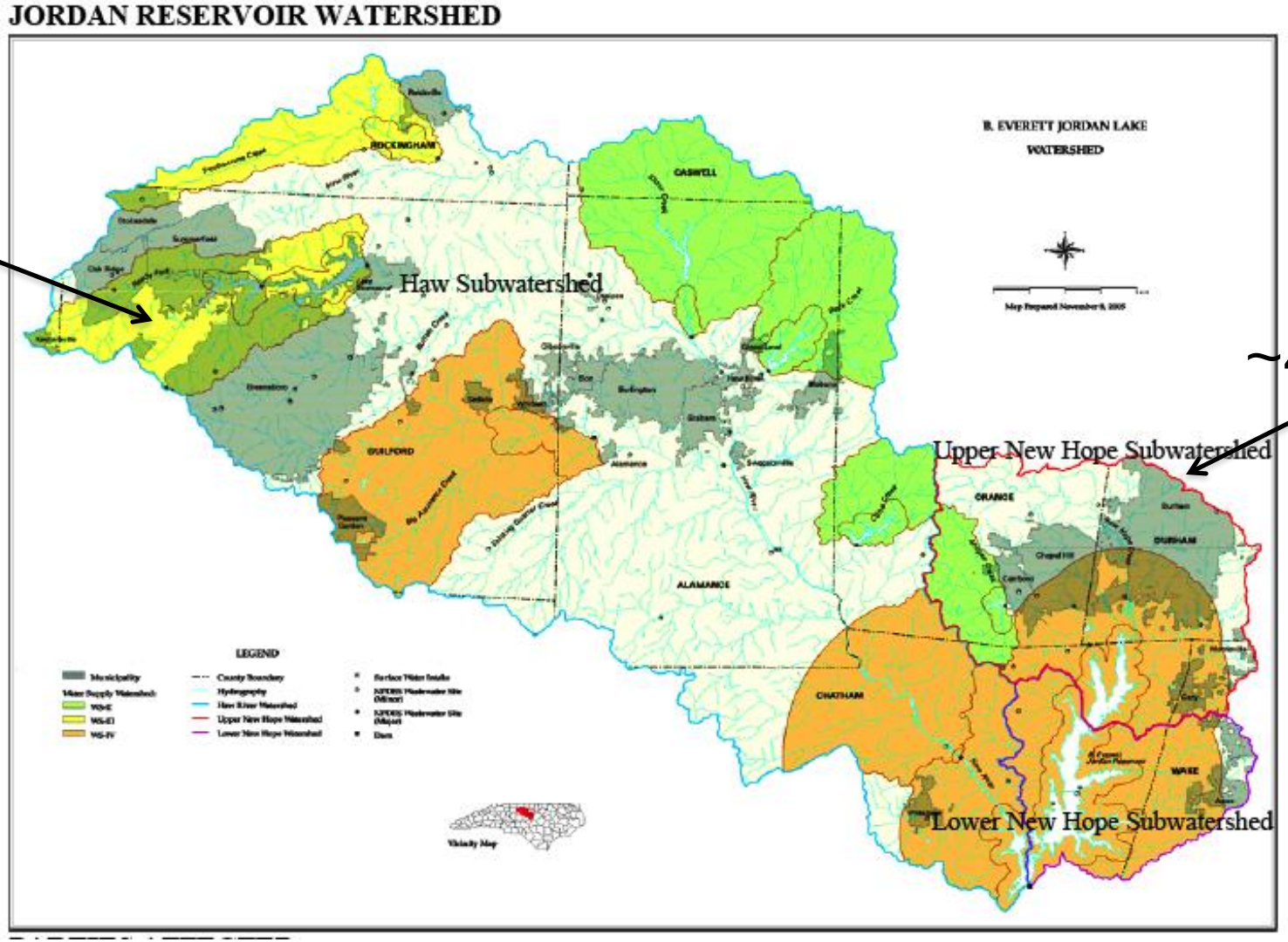

evapotranspiration
runoff
shallow infiltration
deep infiltration
Natural Ground Cover
evapotranspiration
runoff
shallow infiltration
deep infiltration
10%-20% Impervious Surface
evapotranspiration
runoff
shallow infiltration
deep infiltration
35%-50% Impervious Surface
evapotranspiration
runoff
shallow infiltration
deep infiltration
75%-100% Impervious Surface

Stream network and watershed contributing area to Jordan Lake - shading proportional to mean annual flow



How to calculate runoff ratios, residence times, and the water balance for complex (i.e., natural) systems?

Residence time: proportional to reservoir volume, inversely proportional to runoff ratio

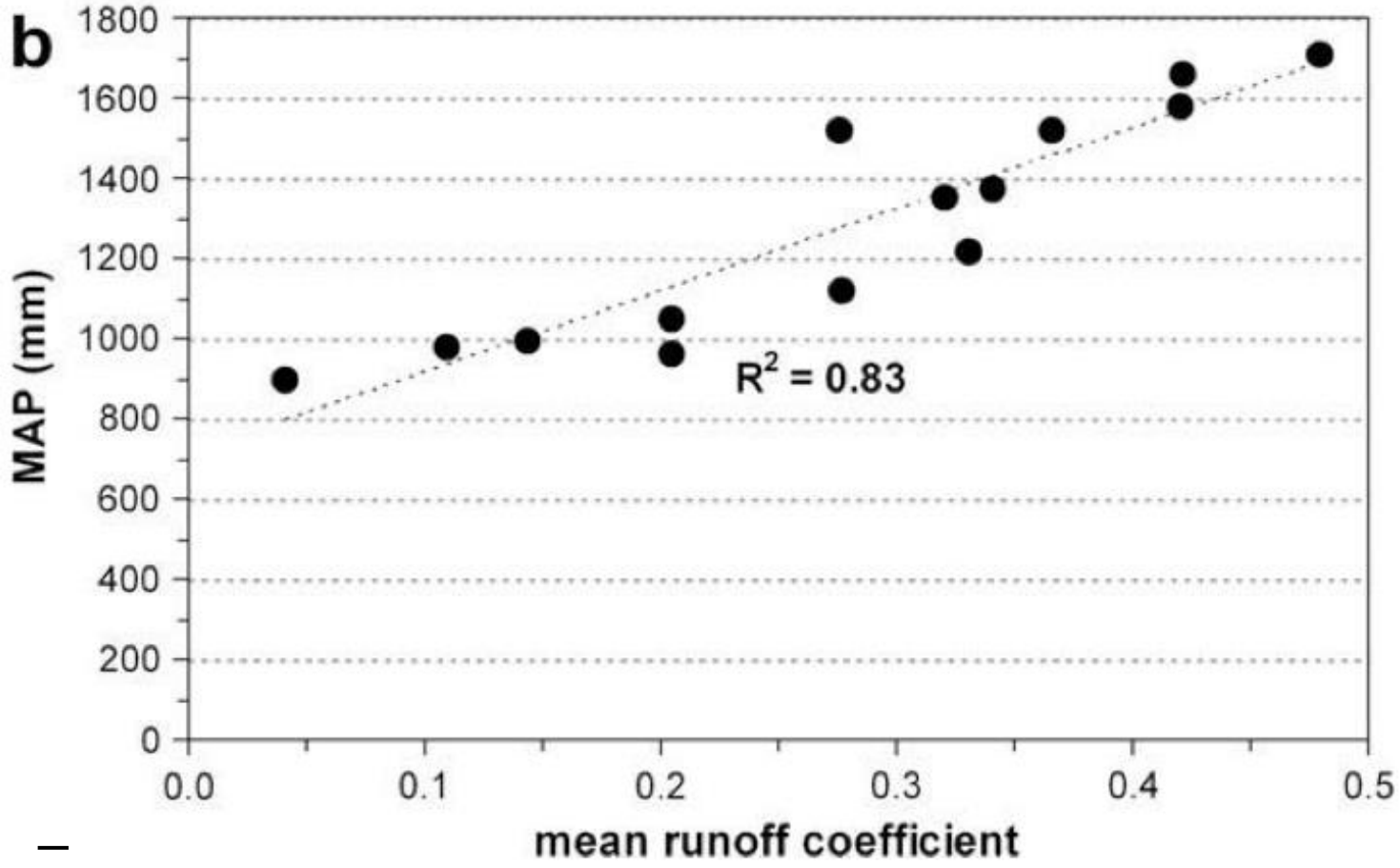


~5 d

~420 d

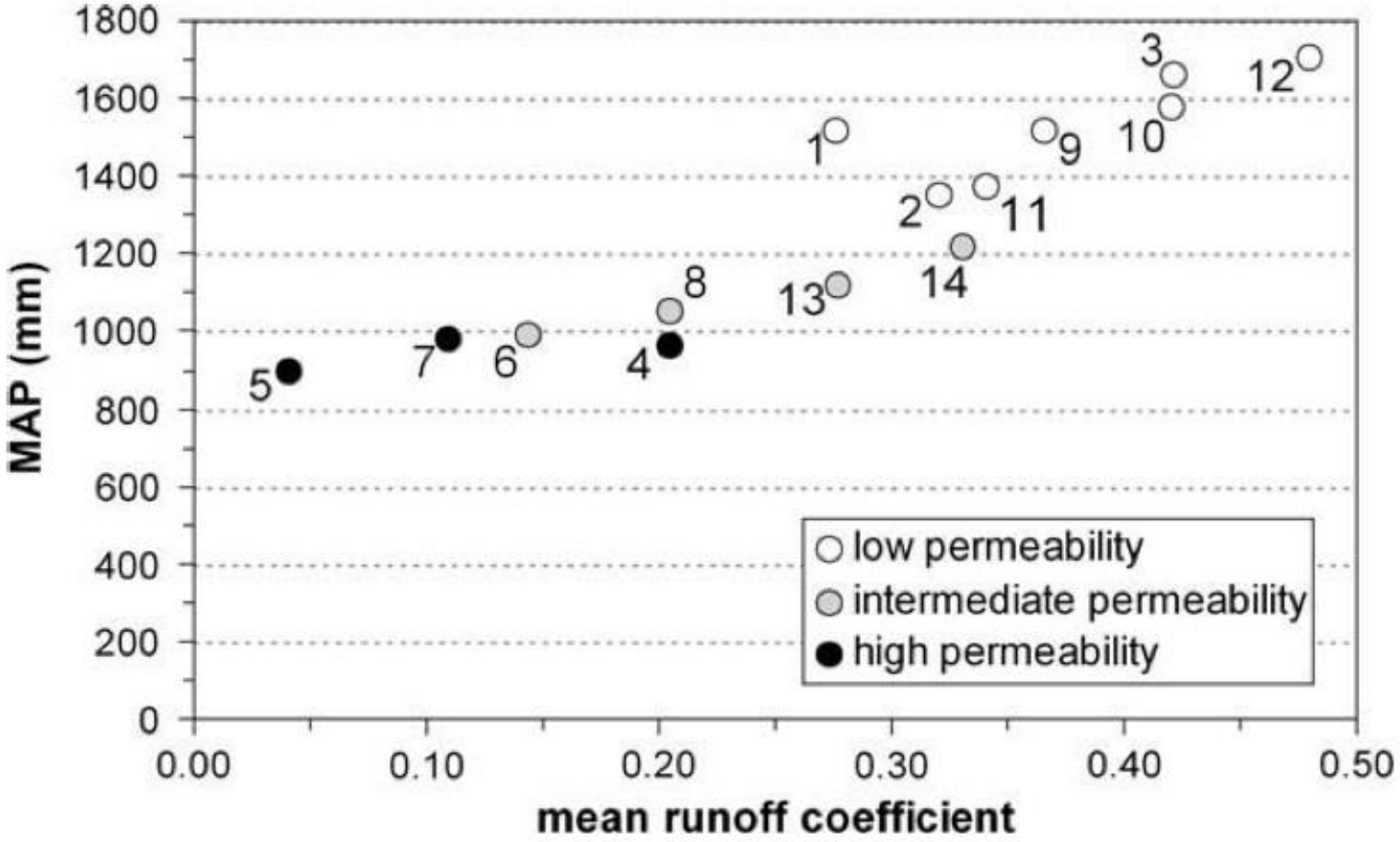
Courtesy of Taehee Hwang

Runoff ratios across the Italian Alps



Norbiato et al., 2009. *Journal of Hydrology*

$$R_r = \frac{\bar{r}_s}{\bar{p}}$$



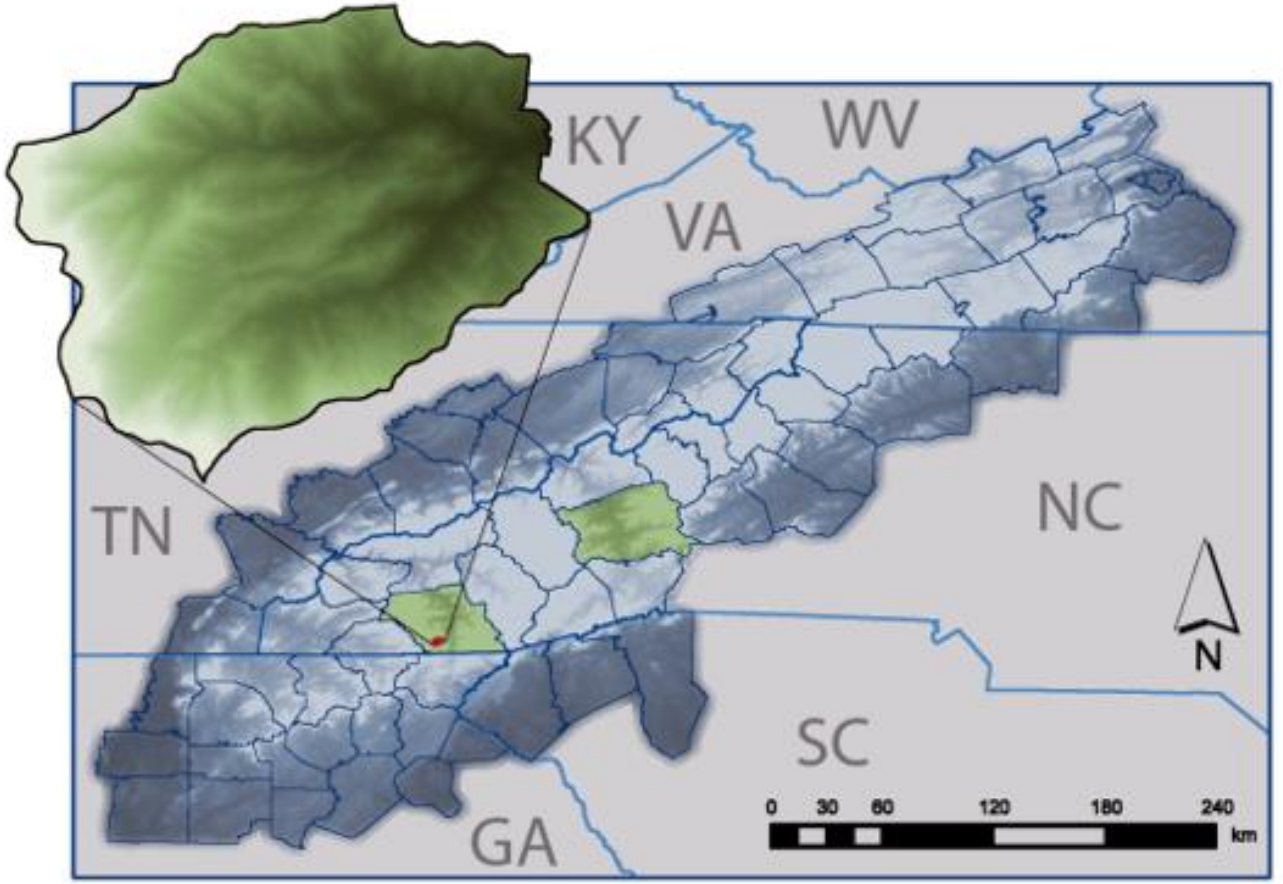
Norbiato et al., 2009. *Journal of Hydrology*

Watersheds are fundamental units, but what is a watershed?

What is a watershed

- An area → single point

Watersheds at the Coweeta Hydrologic Lab

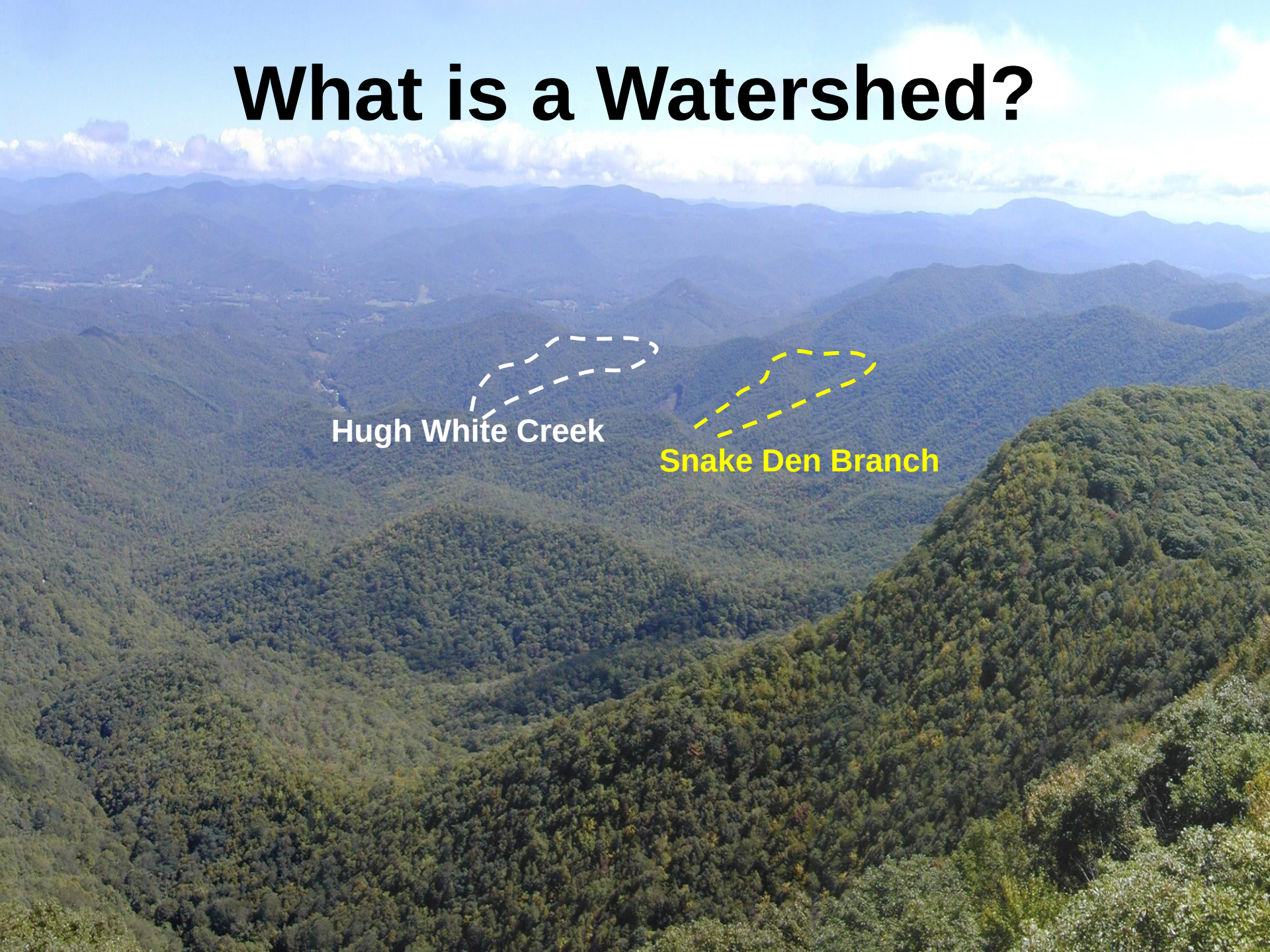


The Southern Appalachian Mountain Study Area, including Macon County and Buncombe County, NC, and the Coweeta Hydrologic Laboratory.

http://coweeta.uga.edu/sitehistory

Established in 1934

What is a Watershed?



Watershed Defined

- The area that appears on the basis of *topography* to contribute all the water that passes through a given cross section of a stream.
- The surface trace of the boundary that delimits a watershed is called a *divide*.
- The horizontal projection of the area of the watershed is called the *drainage area* of the stream at (or above) the cross-section.

It All Starts With Topography

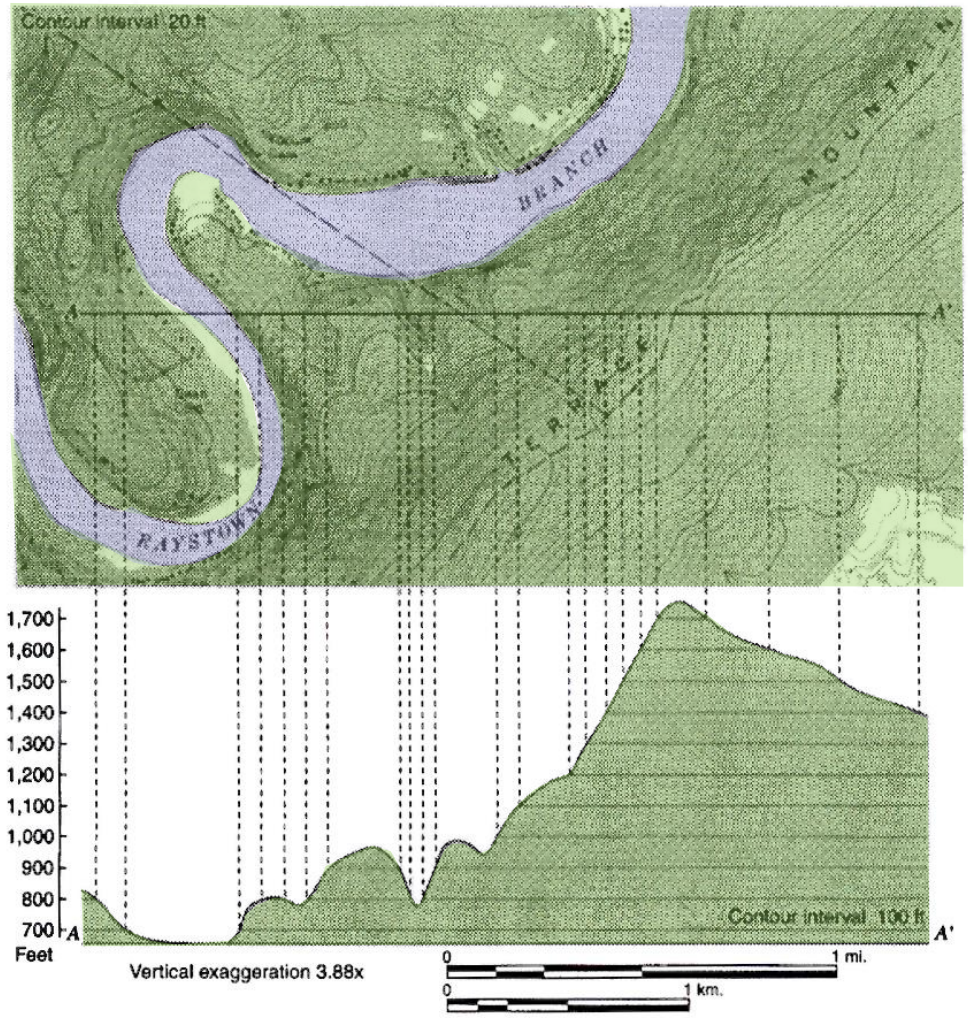
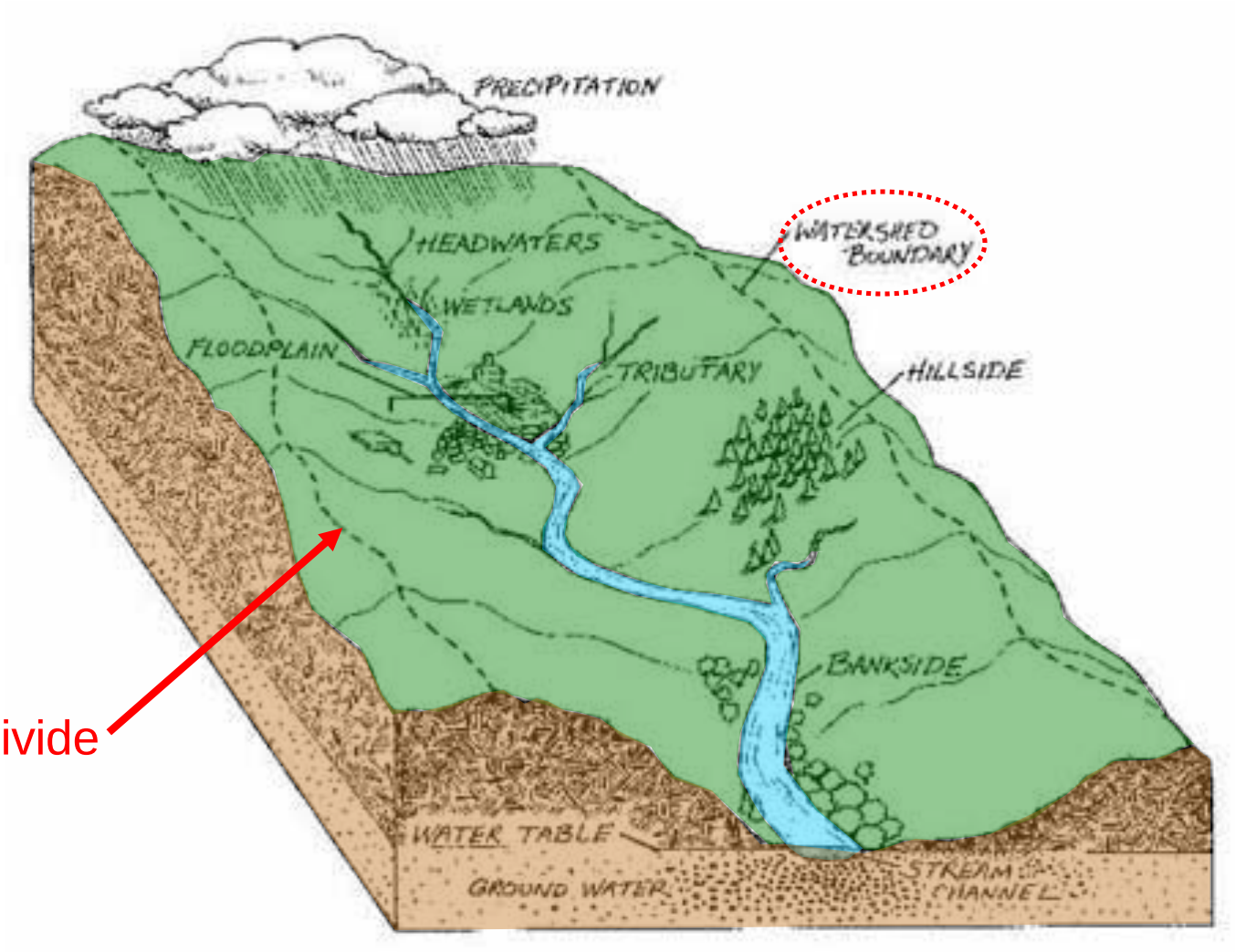


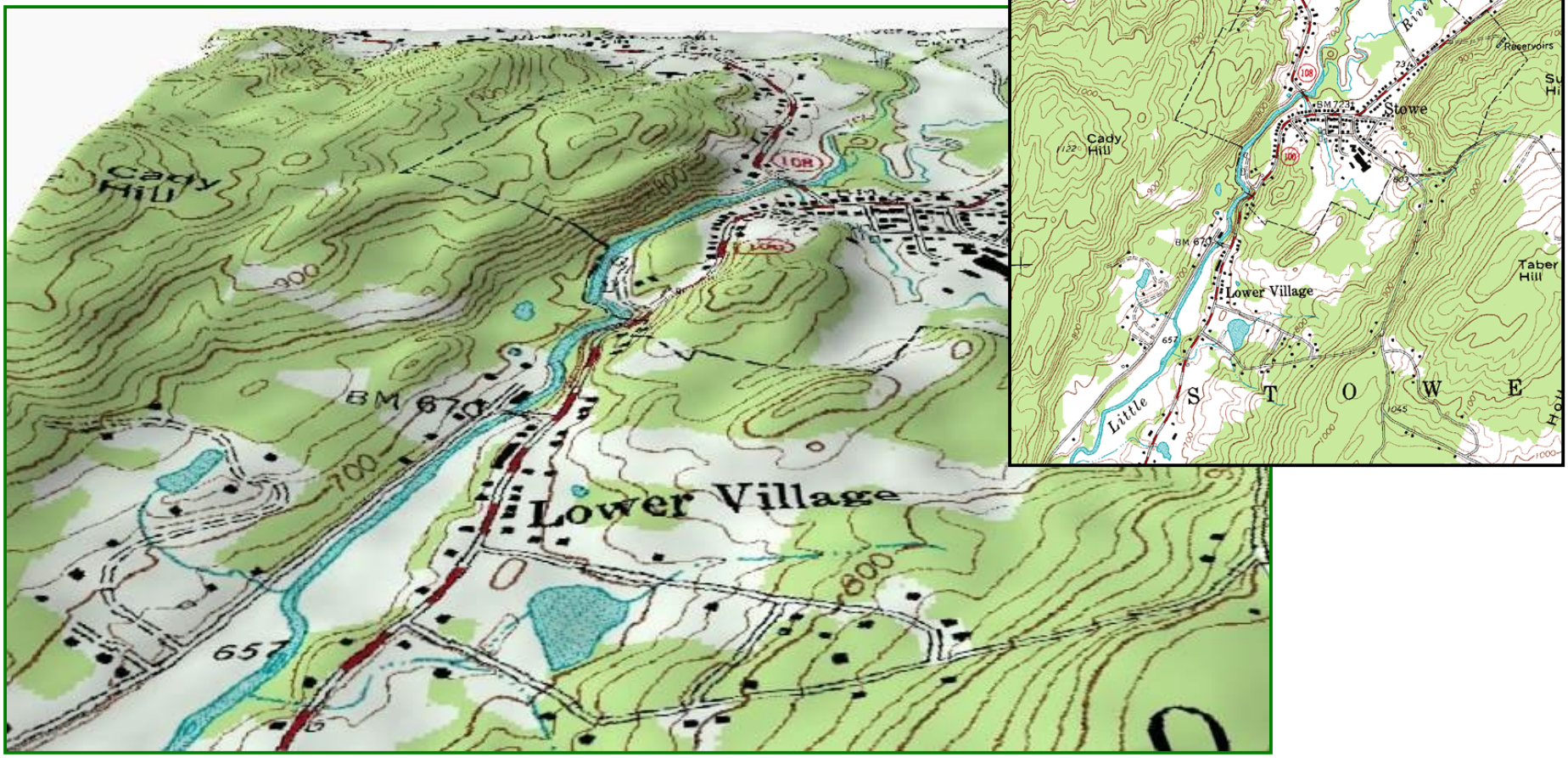
FIG. 3.3 Hills, valleys, and slopes of a topographic map. The steep slopes on the map are represented by closely spaced contour lines. Relatively level areas are shown by contour lines with greater distances between contours (or no contour lines as seen along the surface of the river). The profile below the contour map is exaggerated to make the differences in elevation prominent. Could you determine the general gradient of a river with a topographic map? How?

Topographic maps provide information on surface elevation

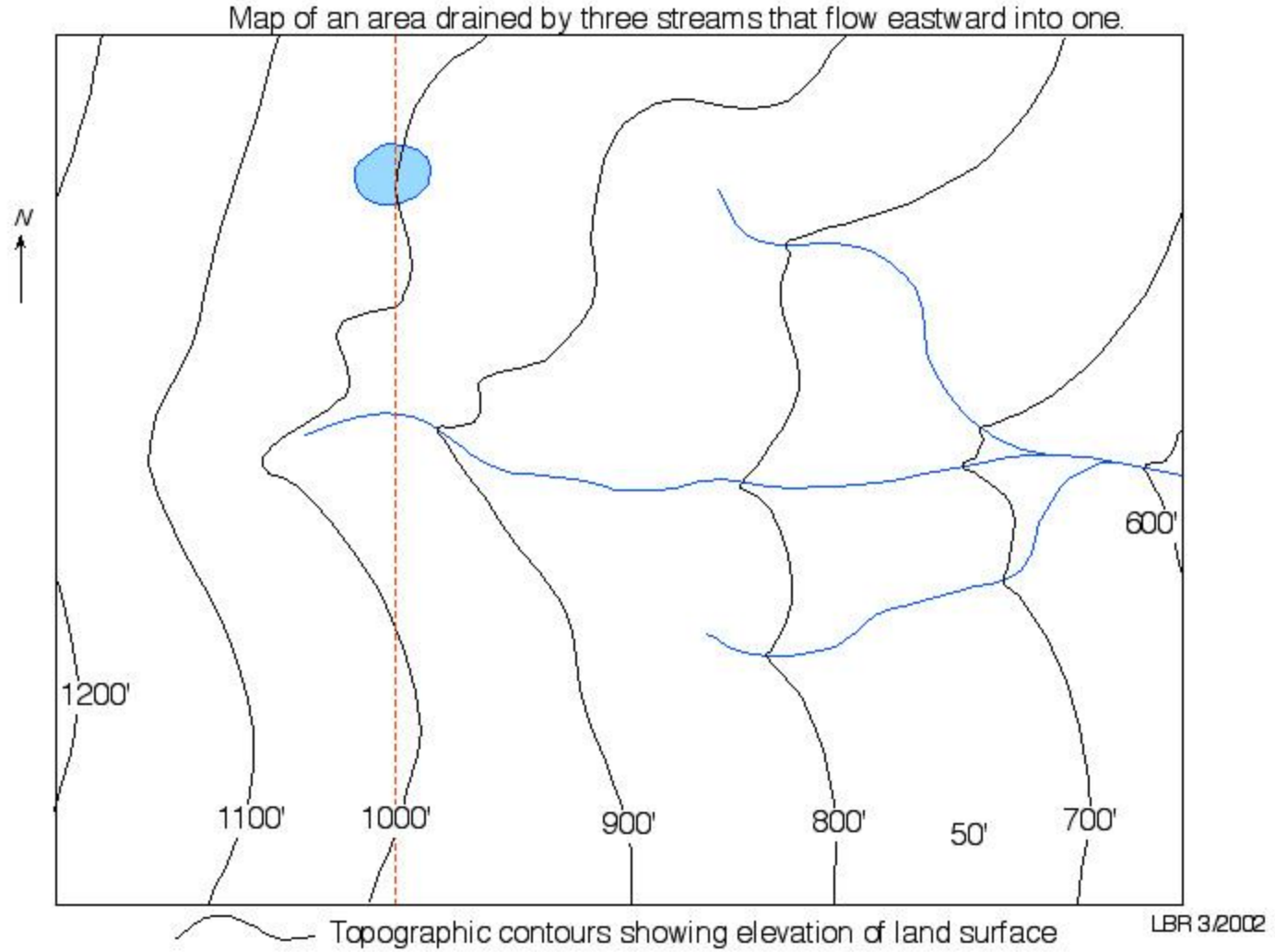
A Typical Model Watershed



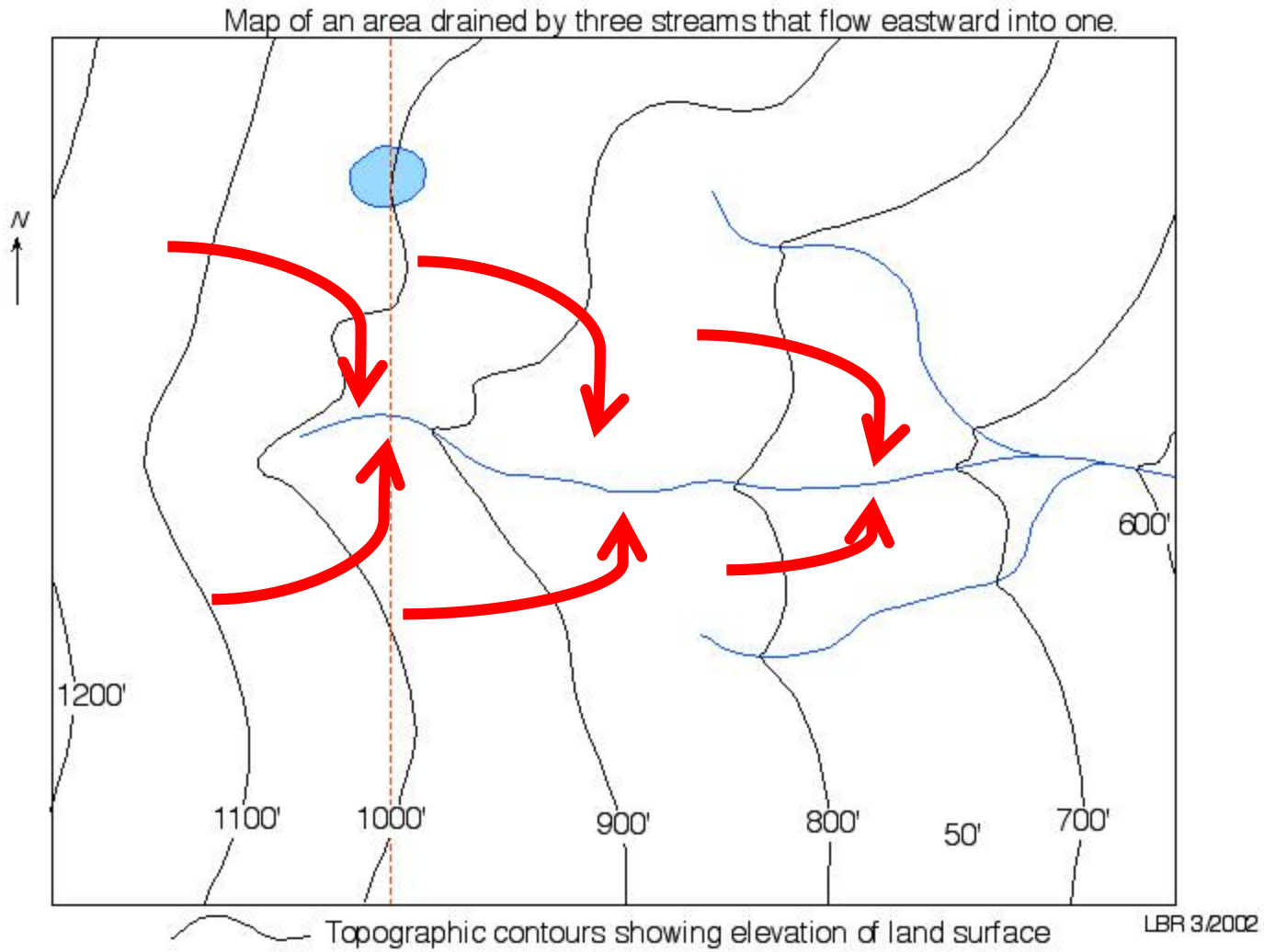
All you need is topographic information



Example Surface Topography



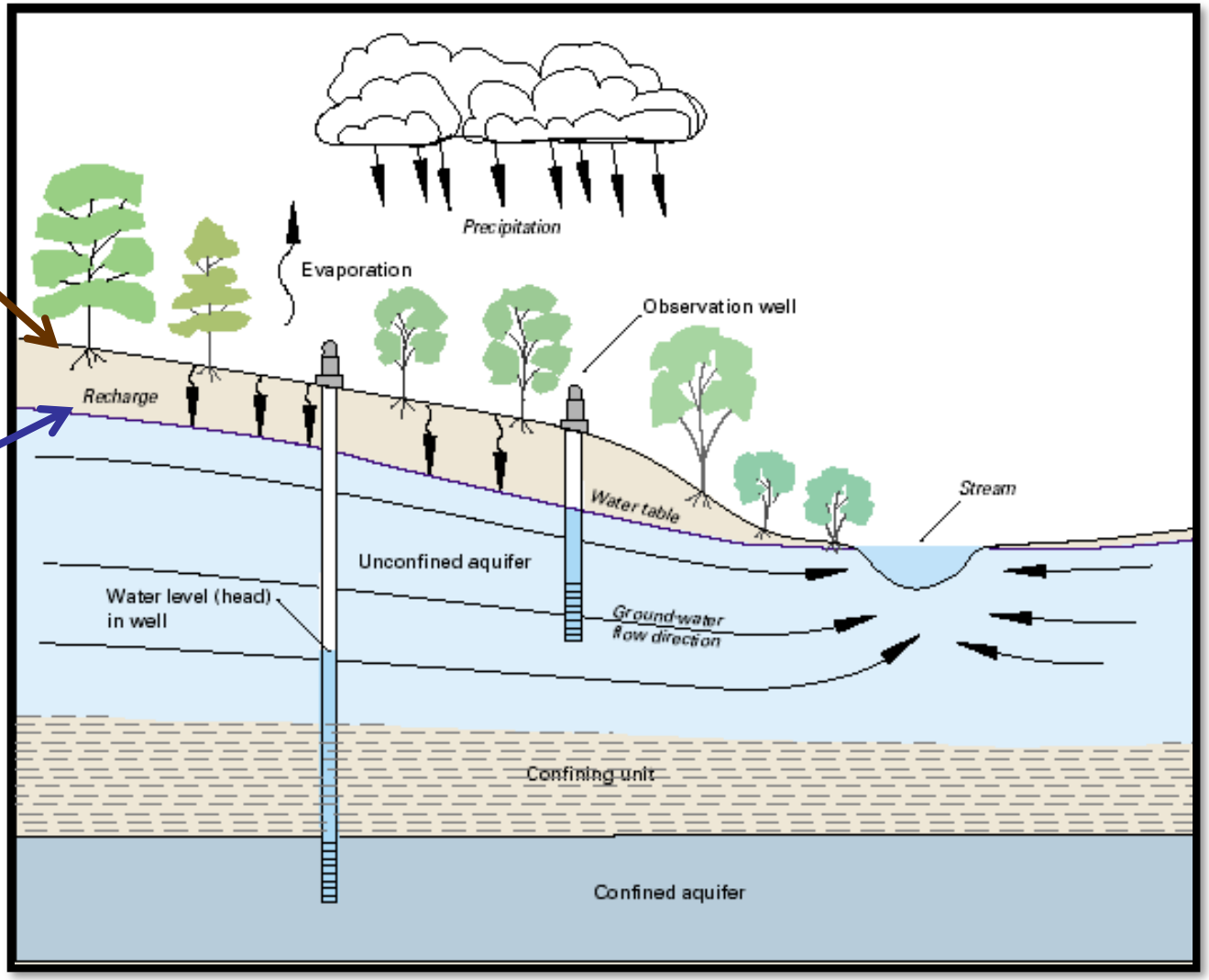
Surface Water Flow



Groundwater & Watersheds

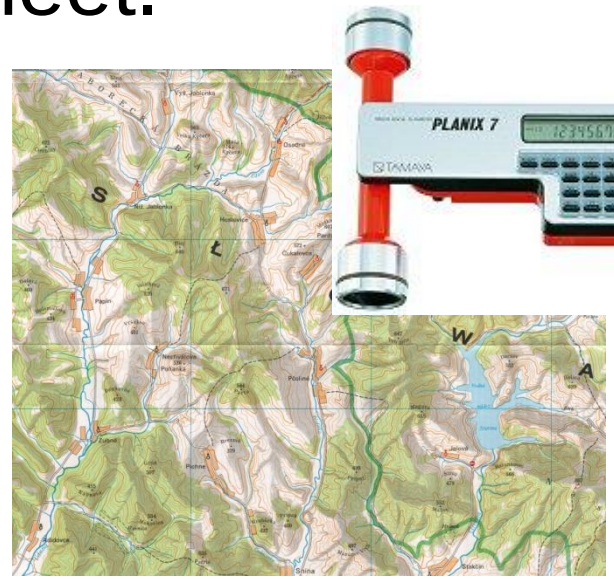
Land Surface Topography

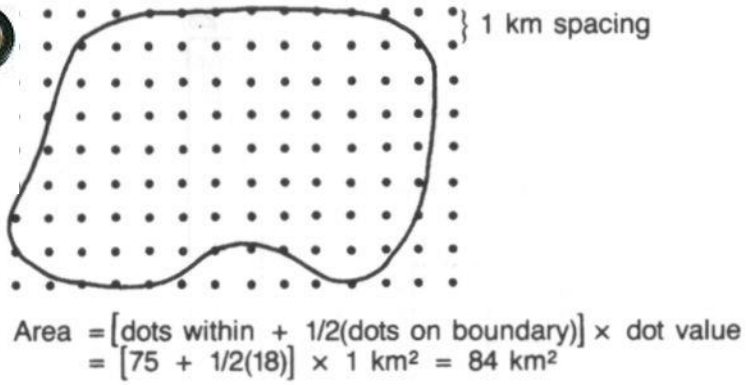
Water Table Topography



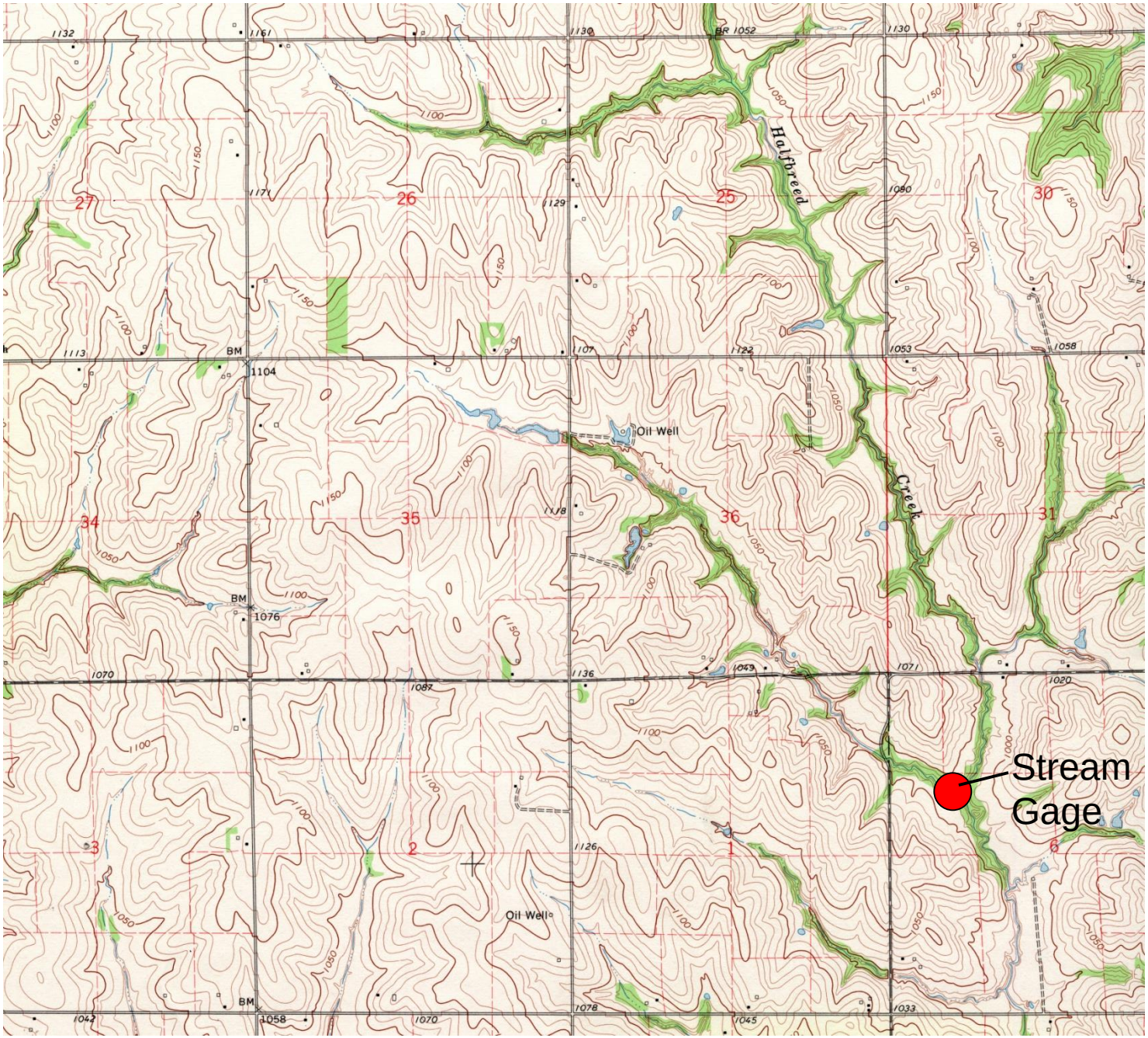
How do we delineate a watershed?

In the “old days” we used a topographic map, a pencil and a planimeter or grid sheet.





http://www.nh.nrcs.usda.gov/technical/WS_delineation.html


Halfbreed
Creek
Oil Well
Oil Well
Stream
Gage
BM
1104
BM
1076
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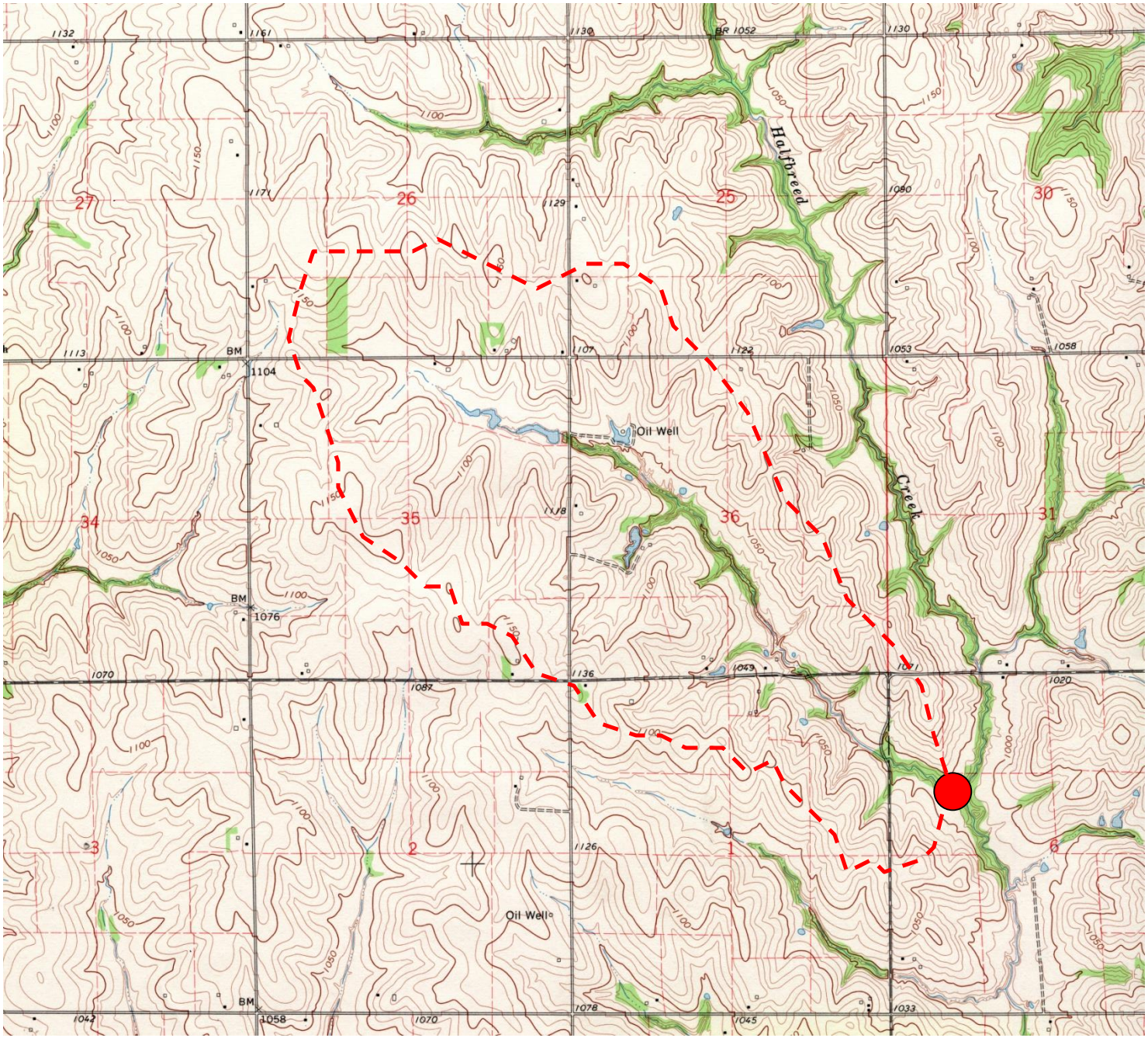
Halfbreed
Creek
Oil Well
Oil Well
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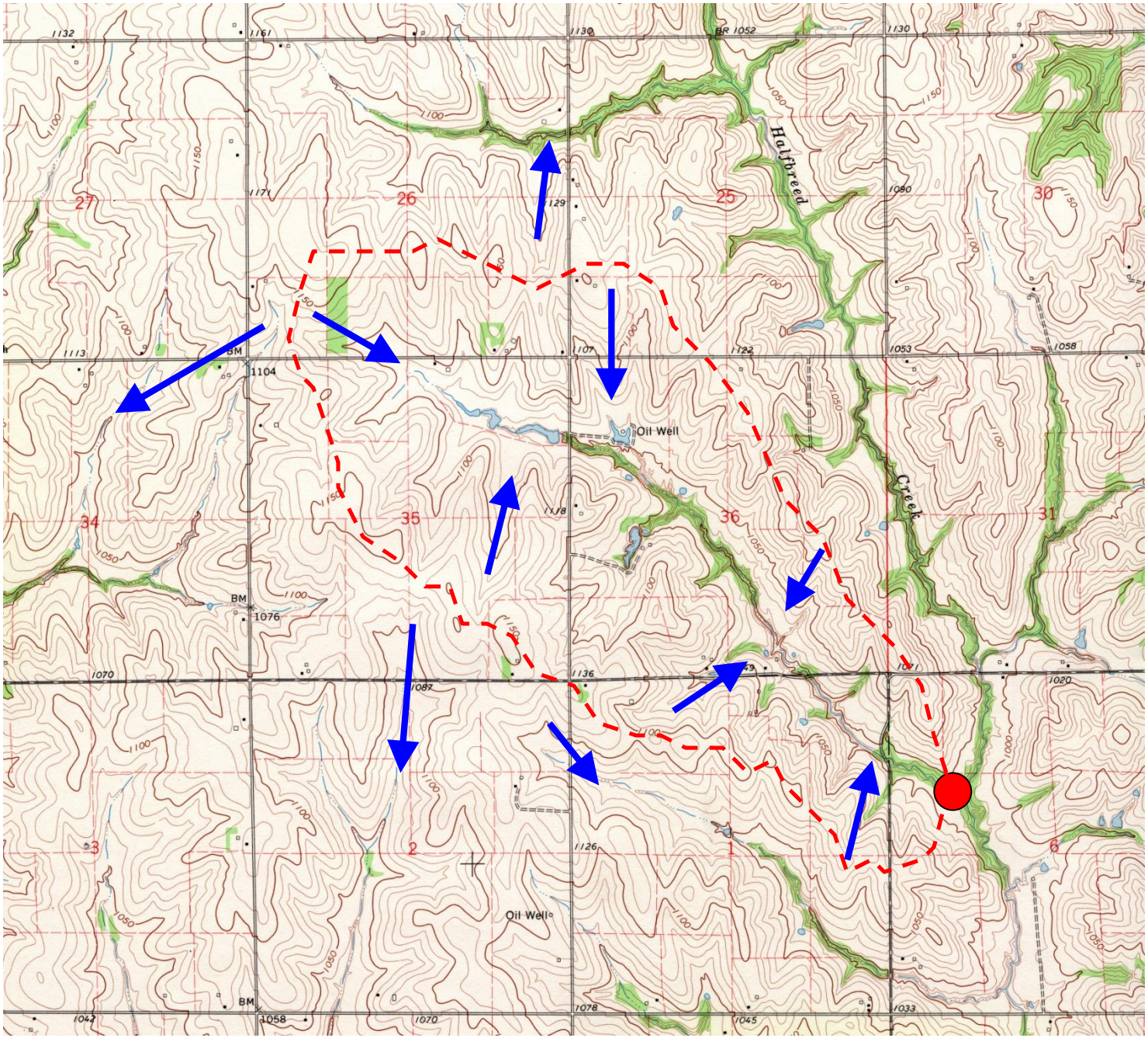
Halfbreed
Creek
Oil Well
Oil Well
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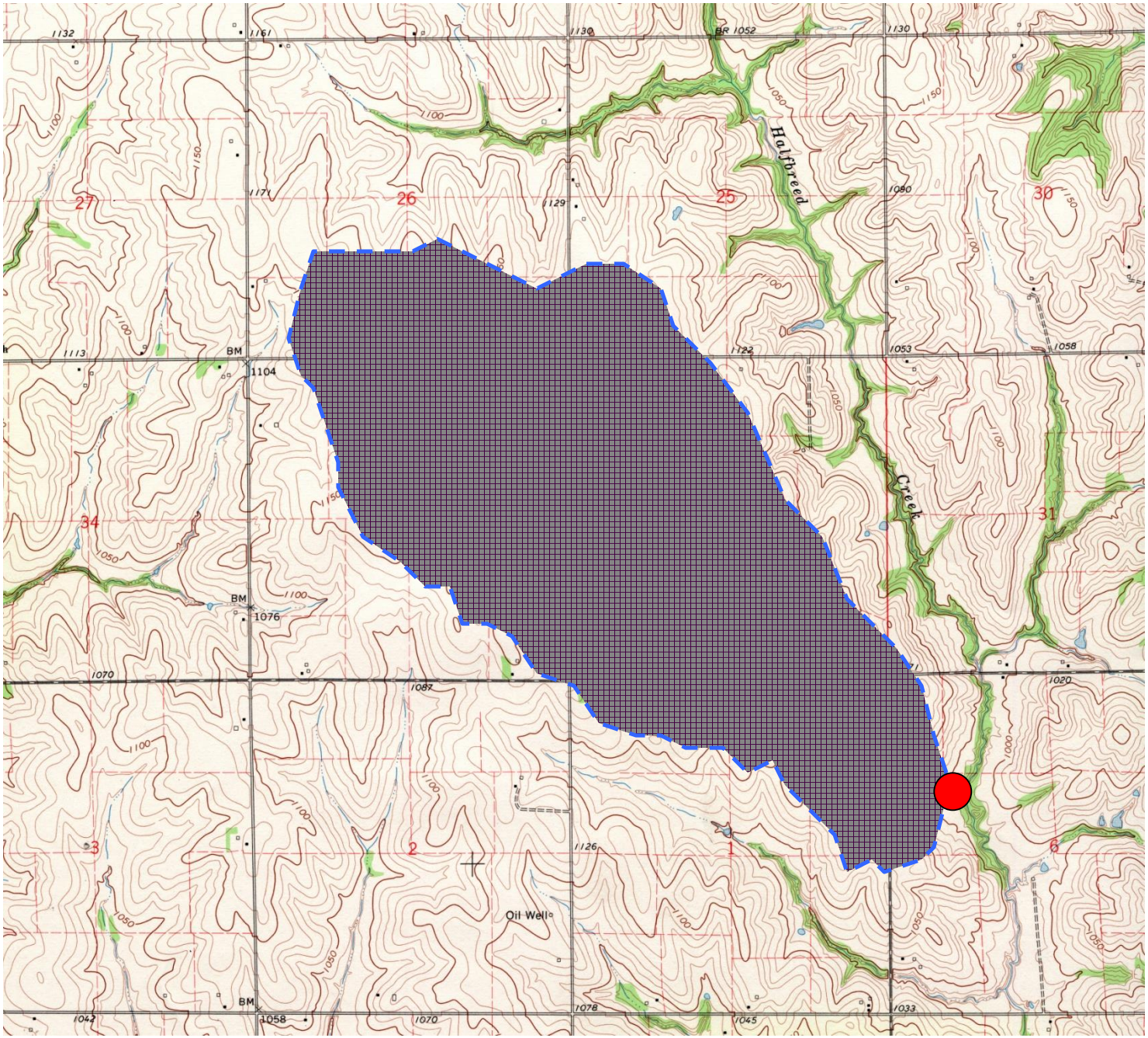
Halfbreed
Creek
Oil Well
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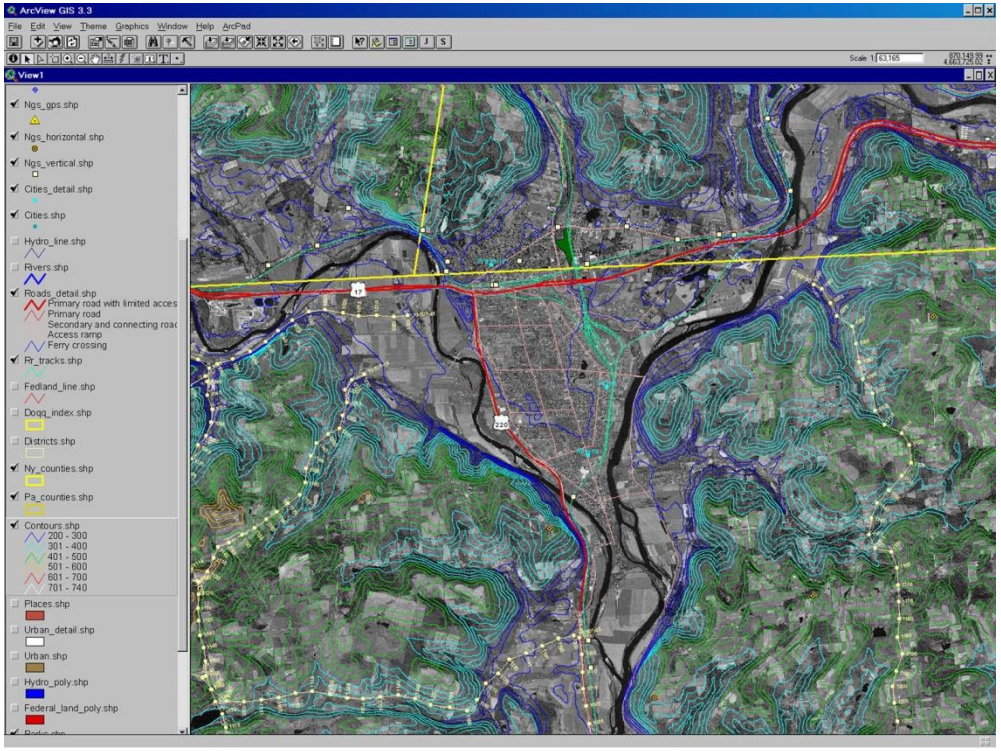
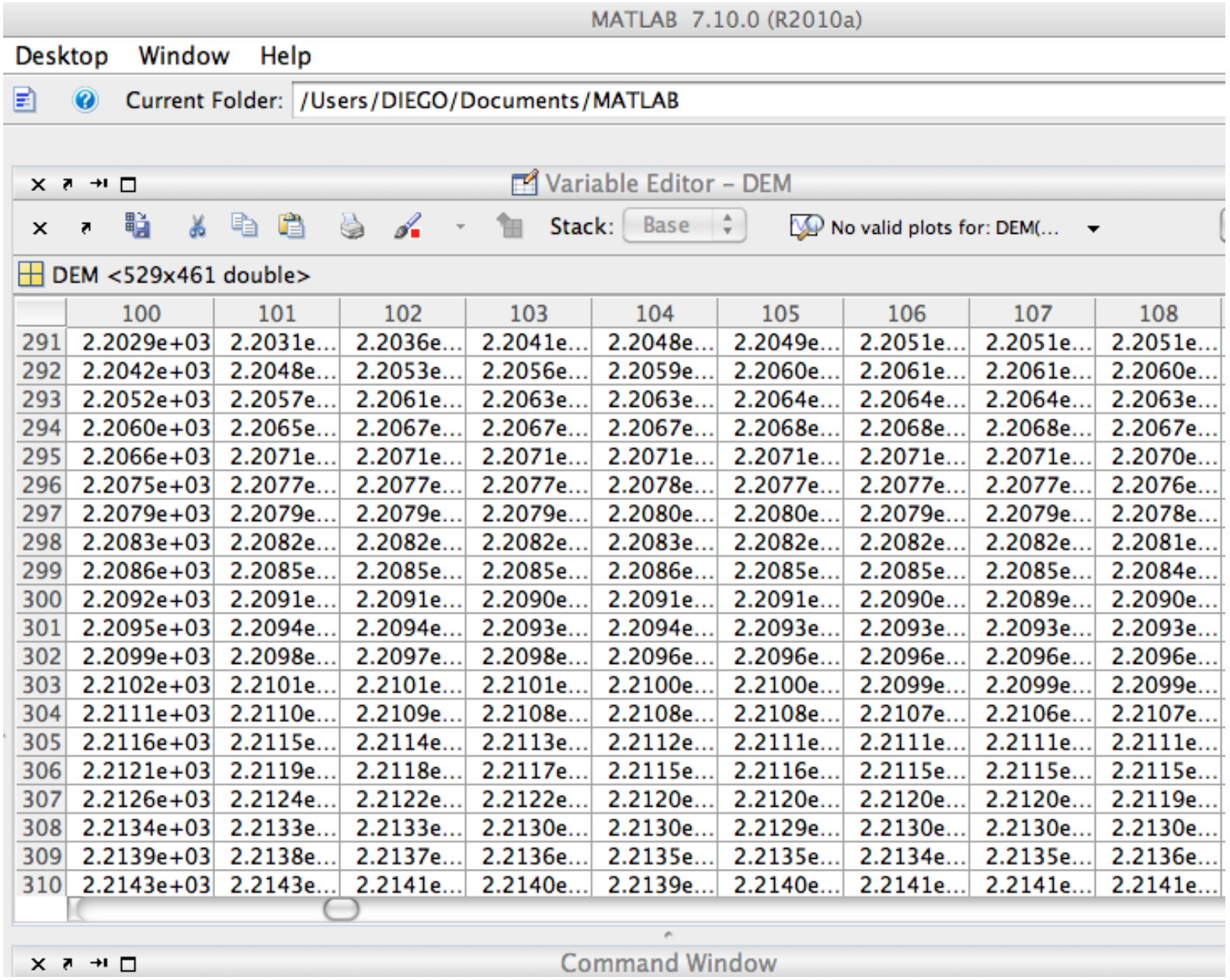
How do we delineate a watershed?

Today we use GIS & DEMs



http://pasture.ecn.purdue.edu/~engelb/abe526/wshddelin/wshddelin.html



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293	2.2052e+03	2.2057e...	2.2061e...	2.2063e...	2.2063e...	2.2064e...	2.2064e...	2.2064e...	2.2063e...
294	2.2060e+03	2.2065e...	2.2067e...	2.2067e...	2.2067e...	2.2068e...	2.2068e...	2.2068e...	2.2067e...
295	2.2066e+03	2.2071e...	2.2071e...	2.2071e...	2.2071e...	2.2071e...	2.2071e...	2.2071e...	2.2070e...
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297	2.2079e+03	2.2079e...	2.2079e...	2.2079e...	2.2080e...	2.2080e...	2.2079e...	2.2079e...	2.2078e...
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301	2.2095e+03	2.2094e...	2.2094e...	2.2093e...	2.2094e...	2.2093e...	2.2093e...	2.2093e...	2.2093e...
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304	2.2111e+03	2.2110e...	2.2109e...	2.2108e...	2.2108e...	2.2108e...	2.2107e...	2.2106e...	2.2107e...
305	2.2116e+03	2.2115e...	2.2114e...	2.2113e...	2.2112e...	2.2111e...	2.2111e...	2.2111e...	2.2111e...
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308	2.2134e+03	2.2133e...	2.2133e...	2.2130e...	2.2130e...	2.2129e...	2.2130e...	2.2130e...	2.2130e...
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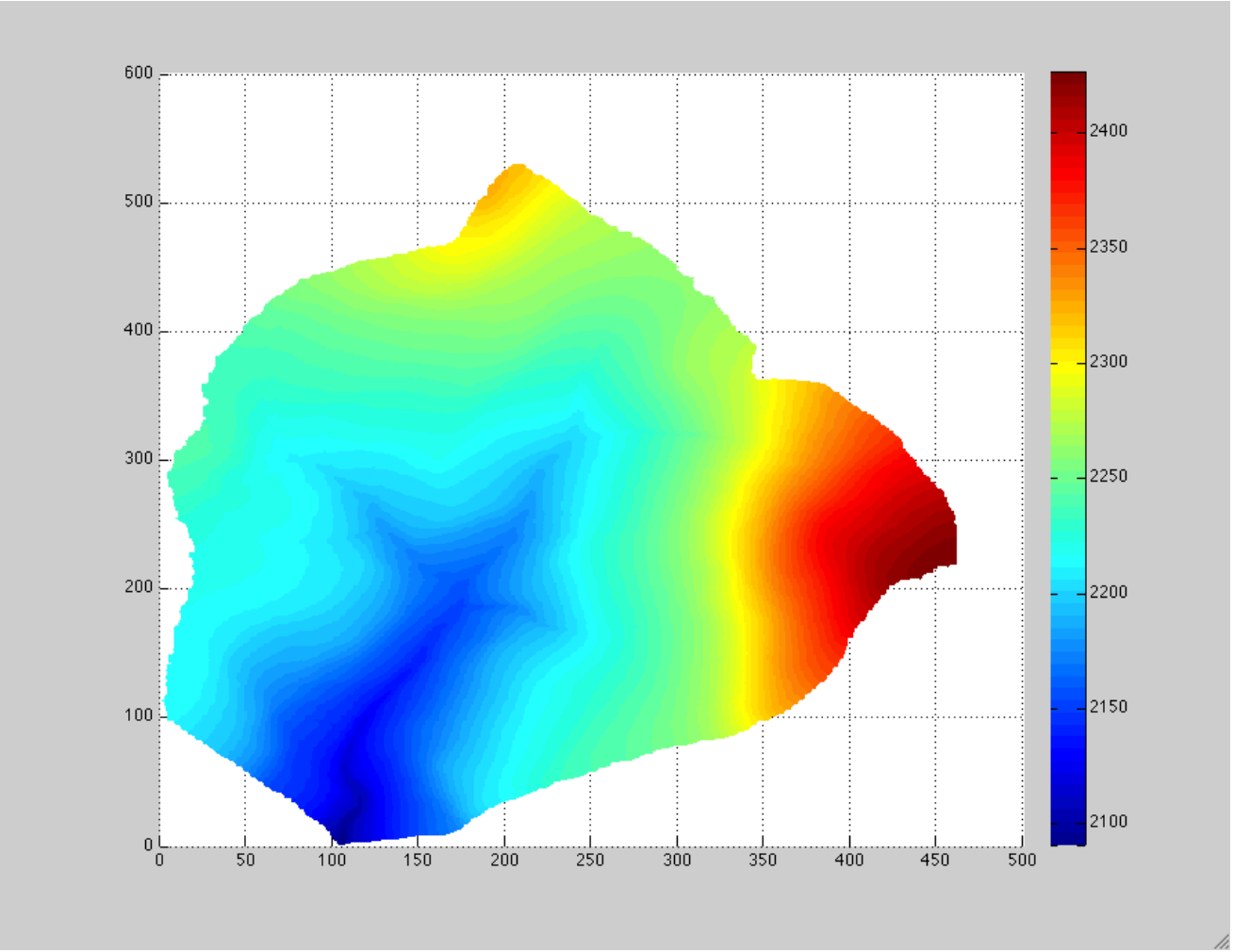
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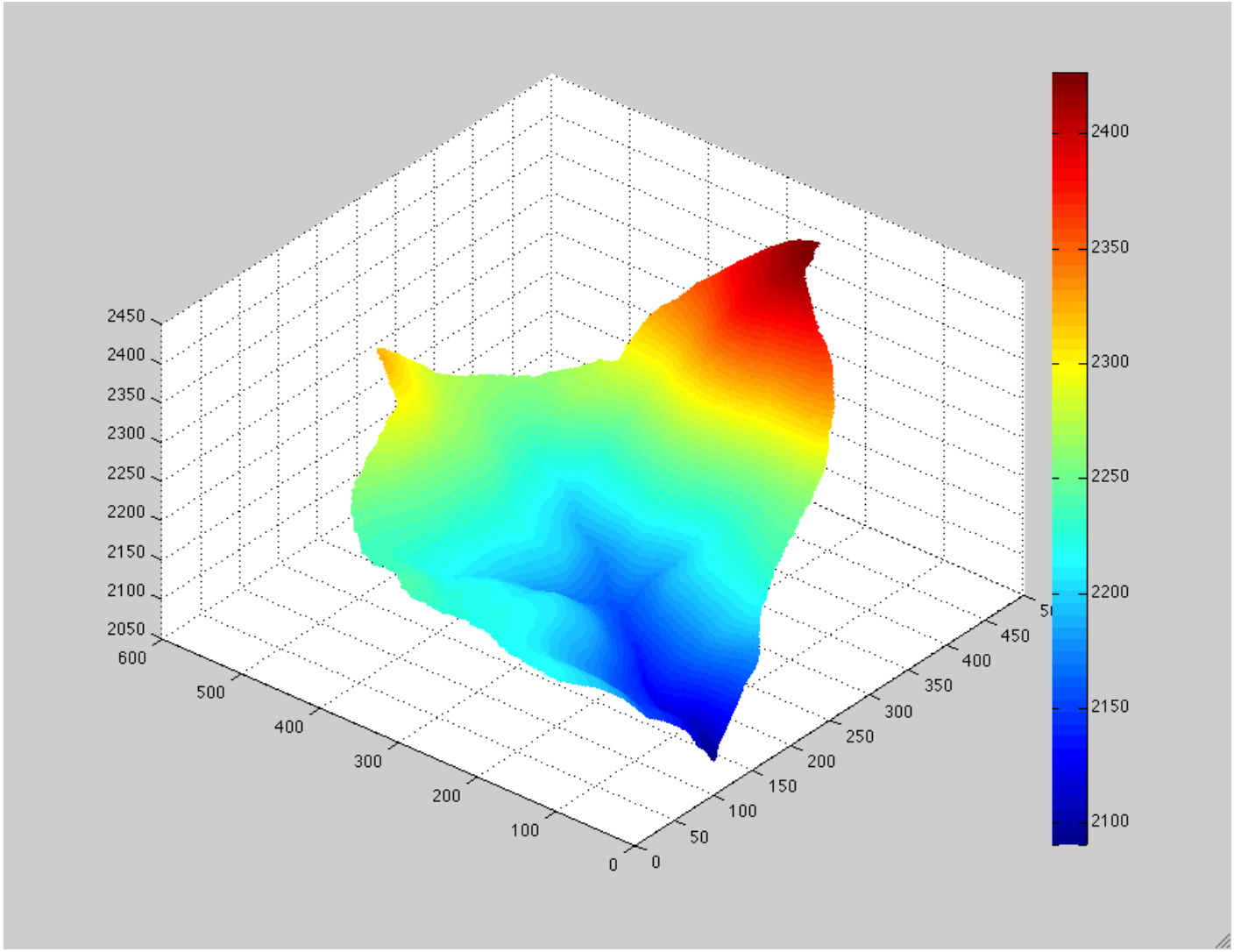
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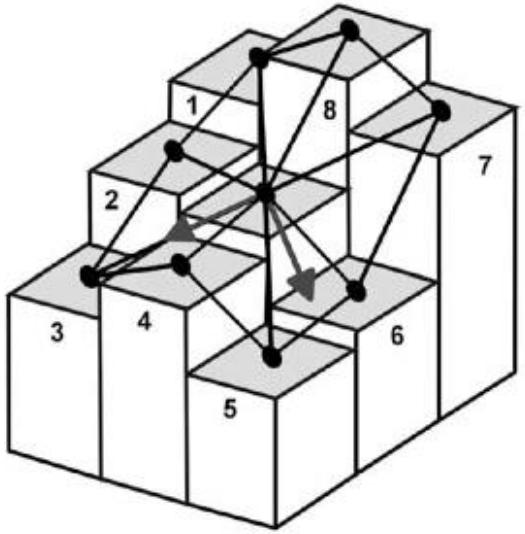
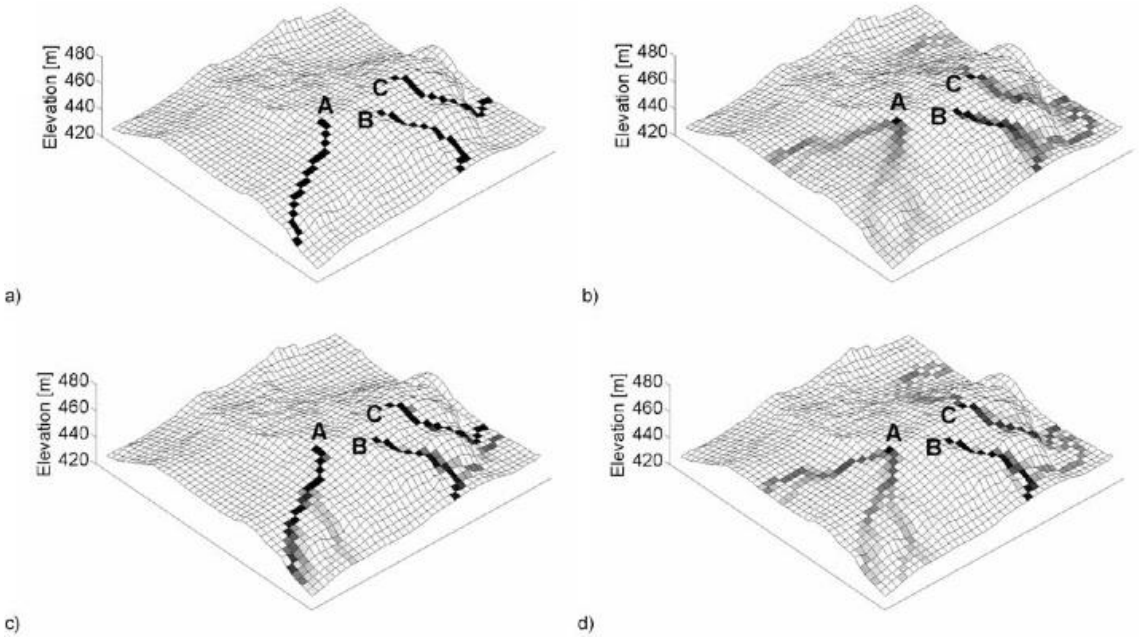


Surface flow paths are calculated using relative elevations and applying ‘flow algorithms’



Seibert et al. 2007 Water Resources Research

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- Hornberger et al., (1998) Elements of Physical Hydrology
- Norbiato et al., (2009) Controls on event runoff coefficients in the eastern Italian Alps. *Journal of Hydrology* 375: 312-325