

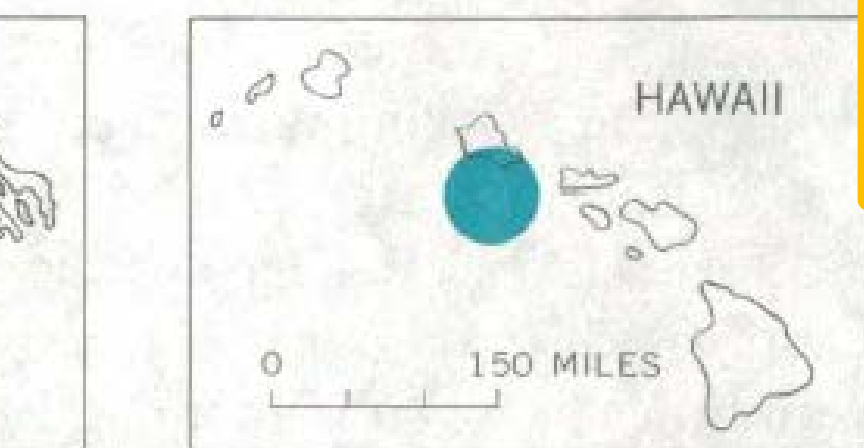
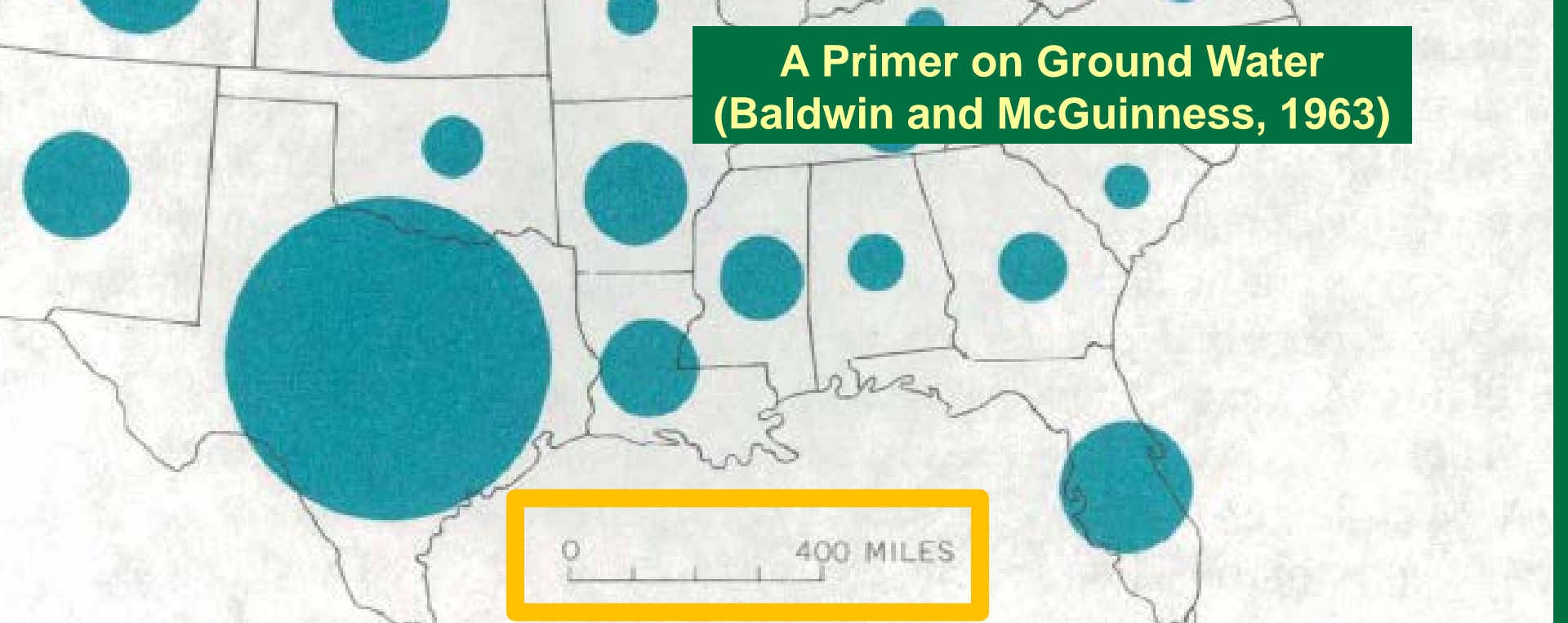


A New Mapping Tool for Illustrating Groundwater Withdrawal Magnitudes

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A Primer on Ground Water (Baldwin and McGuinness, 1963)



Note: Area of circle indicates water use.

- 25 million gallons per day
- 150 million gallons per day
- 1,000 million gallons per day

Total use of ground water in the United States, 1960.



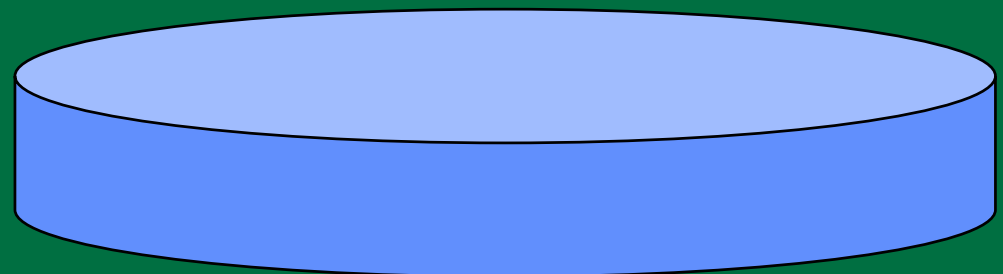
Volume = area of base • height

$$\text{Volume} = \pi r^2 h$$

** The base is a circle, so
the area of a circle is πr^2

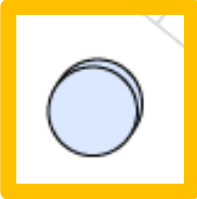
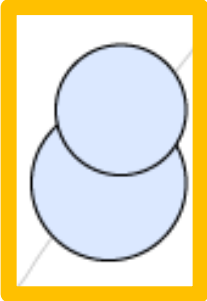
$$\text{Area of Symbol} = \frac{\text{Volume per Time}}{\text{Depth per Time}}$$

Depth (Height)
of Water
per Time



WARRINGTON

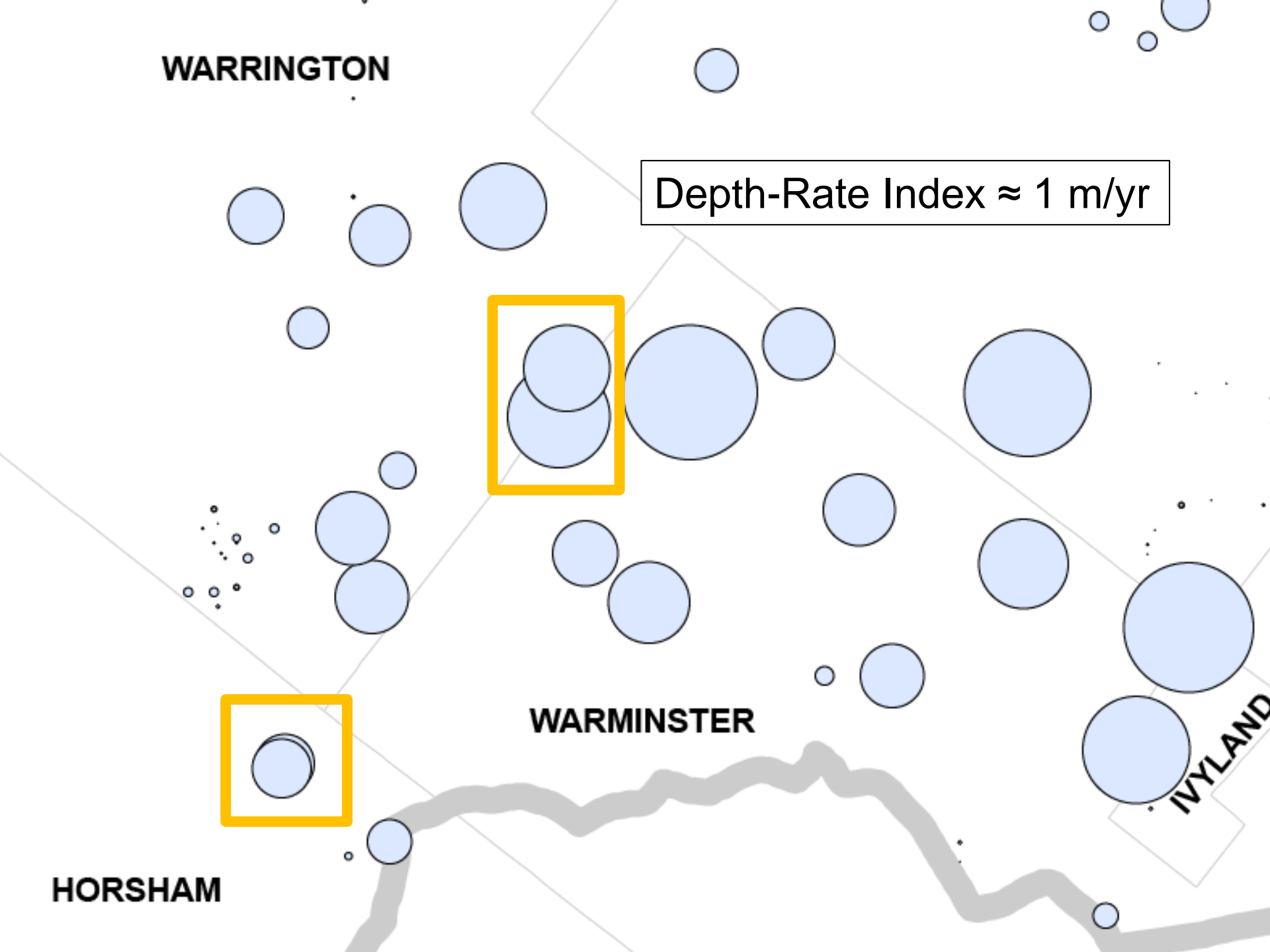
Depth-Rate Index ≈ 1 m/yr



WARMINSTER

IVYLAND

HORSHAM



Depth



**Algorithm
Cascades
Excess Q
to Adjacent
Cells**



DOYLESTOWN

BUCKINGHAM

WRIGHTSTOWN

WARWICK

Footprint for
Depth-Rate Index =
Median Base Flow /
Sub-Basin Area
≈ 0.25 m/yr

WARRINGTON

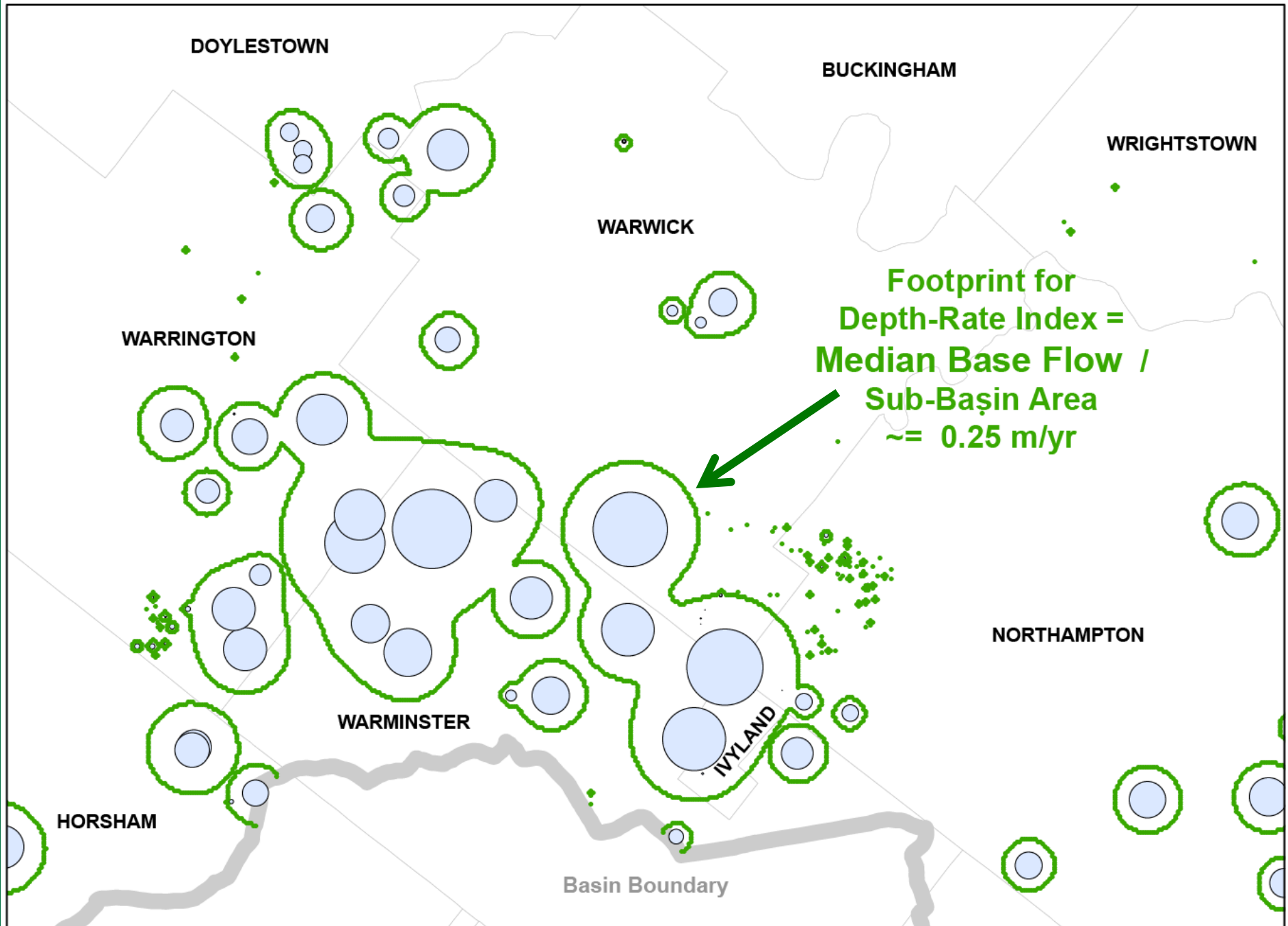
WARMINSTER

NORTHAMPTON

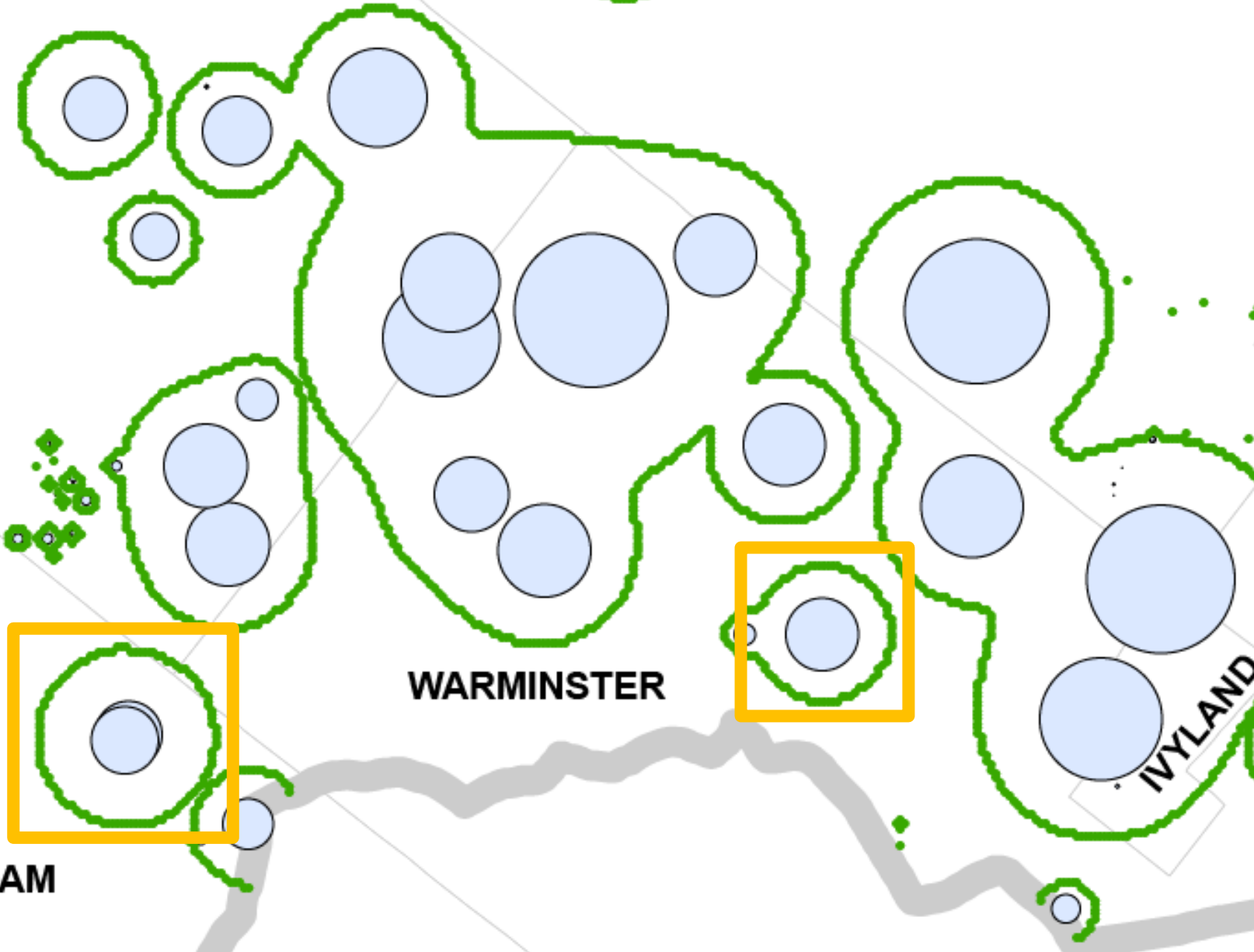
IVYLAND

HORSHAM

Basin Boundary



WARRINGTON



WARMINSTER

IVYLAND

HORSHAM

WellFootprint via ModelMuse GUI

The screenshot displays the ModelMuse software interface. The main window shows a map with a well footprint overlaid on a depth-rate index map. The footprint is represented by a series of black squares. The depth-rate index map is color-coded according to the legend on the left. The 'Footprint Properties' dialog box is open, showing various settings for the footprint calculation.

Depth-rate index

Color legend

Blue	4E-5
Light Blue	5E-5
Cyan	6E-5
Light Green	7E-5
Yellow	8E-5
Red	9E-5

Footprint Properties

- Save results to binary file (Binary_Results_File)
- Save results to text file (Text_Results_File)
- Open listing file in text editor
- Closure criterion: 0.0001
- Minimum depth-rate index: 1E-6
- Maximum number of iterations: 100000
- Initially distribute withdrawals halfway to nearest neighbor
- Redistribution criterion: 0

Buttons: ? Help, ✓ OK, ✗ Cancel

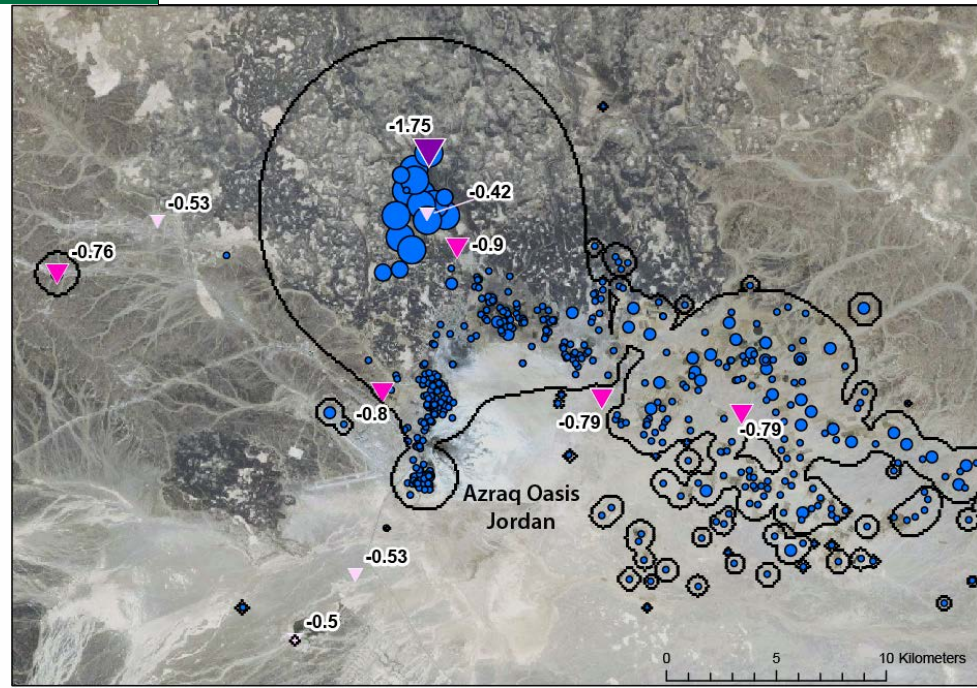
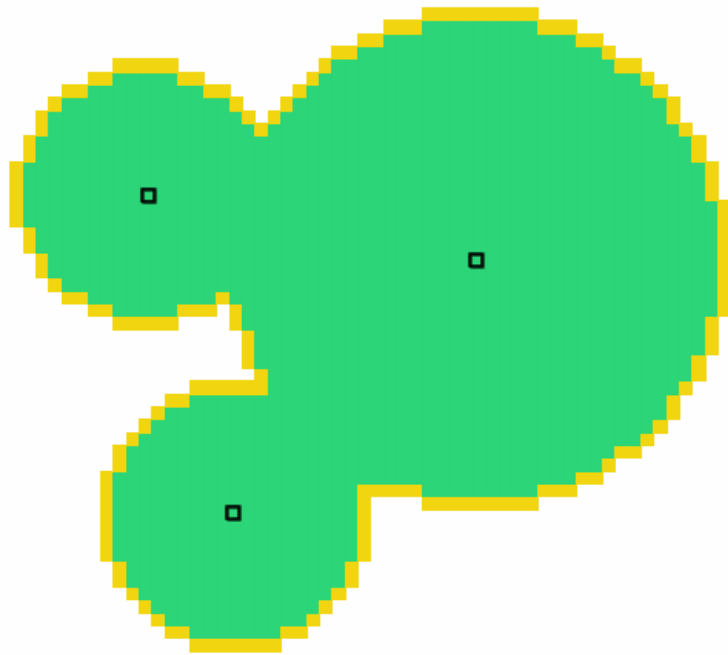
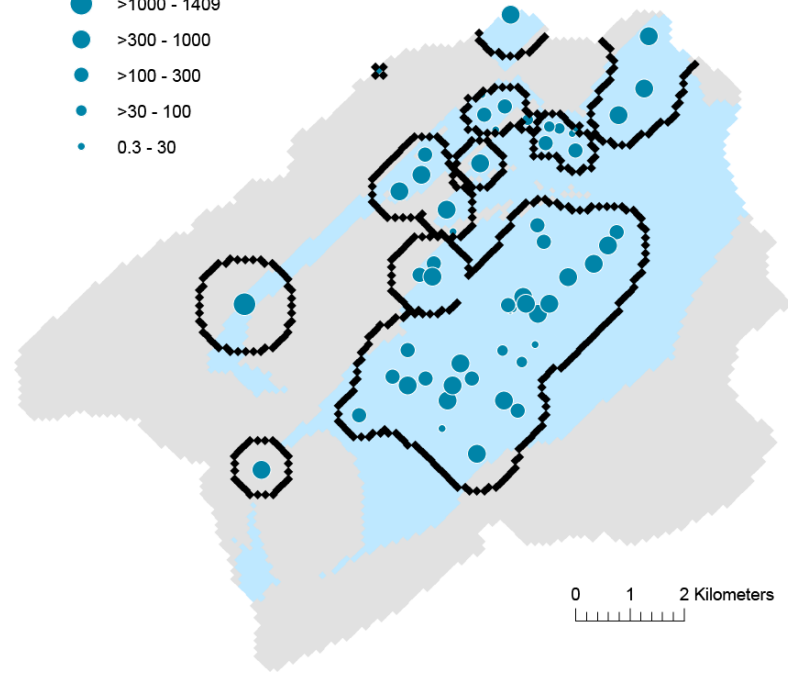
Thank You

More details in Goode (2016) (see reference list)

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Cubic meters per day

- >1000 - 1409
- >300 - 1000
- >100 - 300
- >30 - 100
- 0.3 - 30



References

- Baldwin HL, McGuinness CL (1963) A primer on ground water. US Geol Surv General Interest Pub, 26 pp, <http://pubs.usgs.gov/gip/7000056/report.pdf>
- Conlon, M.D., D.J. Goode, R.B. Winston, and D.W. Risser, 2016, Visualizing the “footprint” of Groundwater withdrawals in parts of Centre and Adams Counties, Pennsylvania: (abs.) Pennsylvania State University, Pennsylvania Groundwater Symposium, May, 2016.
- ESRI (2015) World Imagery, accessed May 13, 2015 at <http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9>
- Gleeson T, Wada Y, Bierkens MFP, van Beek LPH (2012) Water balance of global aquifers revealed by groundwater footprint. *Nature* 488:197–200. doi:10.1038/nature11295
- Goode, D.J., 2016, Map visualization of groundwater withdrawals at the sub-basin scale: *Hydrogeology Journal*, v. 24, no. 4, p. 1057-1065.
- Goode DJ, Senior LA, Subah A, Jaber A (2013) Groundwater-level trends and forecasts, and salinity trends, in the Azraq, Dead Sea, Hammad, Jordan Side Valleys, Yarmouk, and Zarqa groundwater basins, Jordan. US Geol Surv Open-File Rep 2013–1061, 80 pp, <http://pubs.usgs.gov/of/2013/1061>
- Miller RA, Balthrop BH (1995) Standards for illustrations in reports of the U.S. Geological Survey. US Geol Surv Open-File Rep 95-415, 239 pp, <http://pubs.usgs.gov/of/1995/ofr95415/>
- Schreffler CL (1996) Water-use analysis program for the Neshaminy Creek basin, Bucks and Montgomery Counties, Pennsylvania. US Geol Surv Water-Resour Invest Rep 96-4127, 85 pp, <http://pubs.er.usgs.gov/publication/wri964127>
- Schreffler CL, Bird PH (1996) Maps of difference between ground-water contributions to base flow for the various recurrence intervals and ground-water withdrawals in the Neshaminy Creek basin, Pennsylvania. US Geol Surv Open-File Rep 96-359, 6 plates, <http://pubs.er.usgs.gov/publication/ofr96359>
- Senior LA, Goode DJ (2013) Investigations of groundwater system and simulation of regional groundwater flow for North Penn Area 7 Superfund site, Montgomery County, Pennsylvania. US Geol Surv Sci Invest Rep 2013-5045, 95 pp, <http://pubs.usgs.gov/sir/2013/5045/>
- Winston, R.B., 2009, ModelMuse-A graphical user interface for MODFLOW-2005 and PHAST: U.S. Geological Survey Techniques and Methods 6-A29, 52 p.
- Winston, R.B., 2014, Modifications made to ModelMuse to add support for the Saturated-Unsaturated Transport model (SUTRA): USGS Techniques & Methods, book 6, chap. A49, 6 p.
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