Proposed Tools and Approach for Ground-Water Vulnerability Assessment (GWAVA) Using a Geographic Information System and Simulation Modeling

Jack Barbash
National Water-Quality Assessment
Pesticide National Synthesis Team
U.S.Geological Survey
Tacoma, WA
jbarbash@usgs.gov / 253-428-3600 x 2610

2006 National Water-Quality Monitoring Conference
San Jose, California

USGS
science for a changing world

What is Ground-Water "Vulnerability"?

<u>Ground-Water Vulnerability (V_{gw})</u> = *Probability that a given contaminant will be detected at or above a specified concentration in the subsurface at a specific location.*

$$V_{gw} = f\left\{ \text{“intrinsic” susceptibility} \; ; \; \text{chemical input} \; ; \; \text{chemical mobility and persistence} \right\}$$

- "intrinsic" susceptibility ← Natural features affecting chemical transport and fate (e.g., soil permeability, %OC, DO)
- chemical input ← Parameters affecting mass loading (e.g., use, population)
- chemical mobility and persistence ← Partitioning and rate of (bio)chemical transformation

<u>Potentially significant confounding factors</u>: Well construction and operation

USGS

science for a changing world

Main Points

- **Previous approaches to ground-water vulnerability assessment (GWAVA)**
  - **Most have <u>not</u> been tested against actual field observations**
  - **Mechanistic methods <u>uncommon</u>**

- **Proposed approach for NAWQA GWAVA**
  - **Key (initial) customers – Agencies charged with assessing vulnerability across entire counties or states**
  - **<u>National</u> <u>scale</u> input data**
  - **Maximal incorporation of <u>process</u> <u>understanding</u>**
  - **<u>Open-source</u> development**
  - **Testing of predictions against NAWQA results**

- **Tools for each component of method already exist—main focus is on <u>connecting the dots</u>**

USGS
science for a changing world

Previous Approaches

(Site-based methods only – Chemical ranking methods not included)

- Scoring and index methods
- Statistical methods
- Overlay methods
- Hydrogeologic and chemical indicator methods
- Process-based simulation modeling

USGS
science for a changing world

Methods Explored To Date by NAWQA (√)

- ~~Scoring and index methods~~
  (Use discouraged by USGS Office of Ground Water [Tech. Memo 00.01])

√ Statistical methods

√ Overlay methods

√ Hydrogeologic and chemical indicator methods

√ Process-based simulation modeling

USGS
science for a changing world

Methods Explored To Date by NAWQA (√)

- ~~Scoring and index methods~~
  (Use discouraged by USGS Office of Ground Water [Tech. Memo 00.01])

√ Statistical methods

√ Overlay methods

√ Hydrogeologic and chemical indicator methods

√ Process-based simulation modeling

Focus of this presentation

USGS
science for a changing world

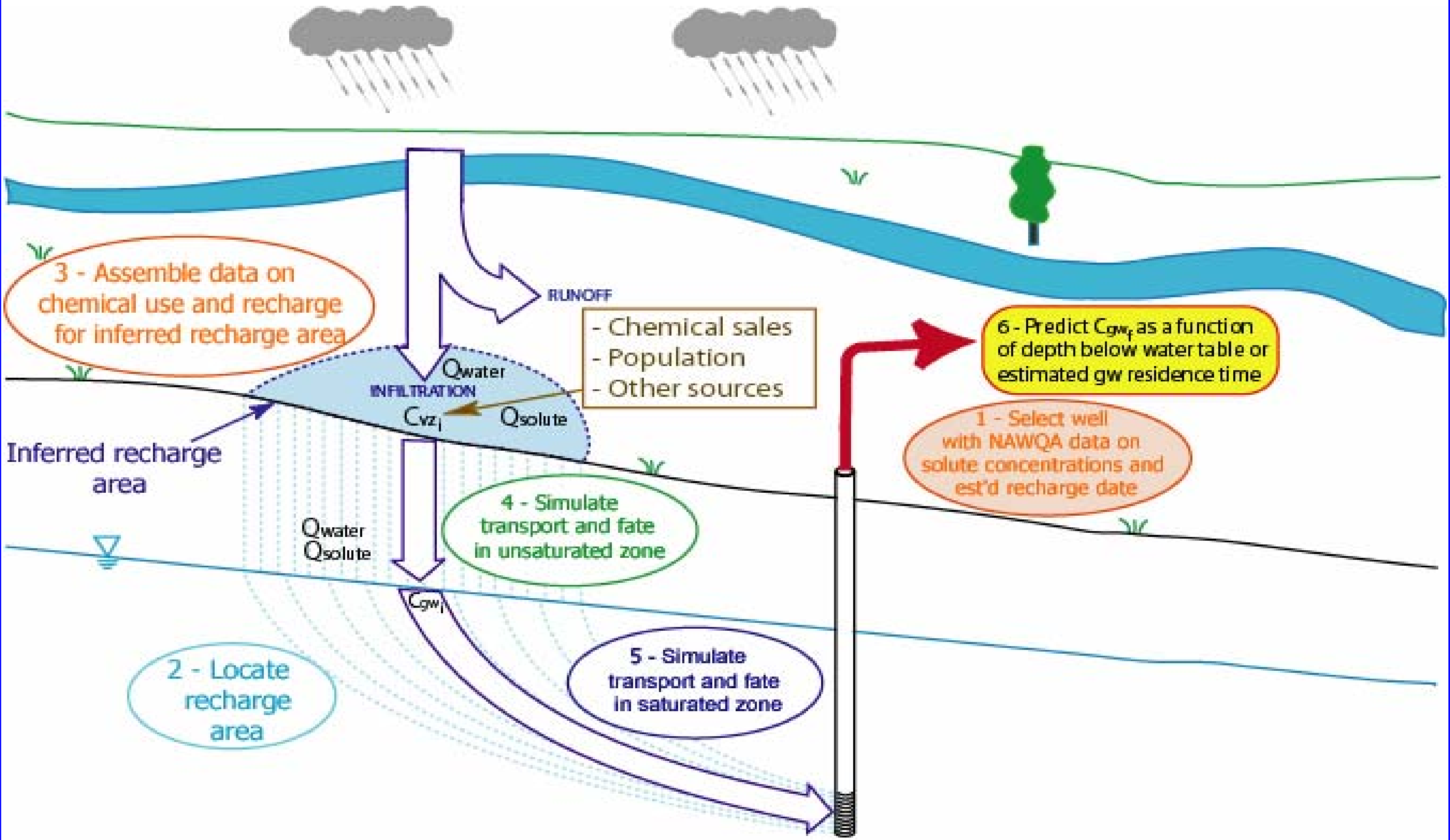
Previous site-based GWAVA studies

Some key aspects

- 122 publications examined (1982 – 2006)
- Most (75) did not test predictions against field observations
- Few (19) employed simulation modeling

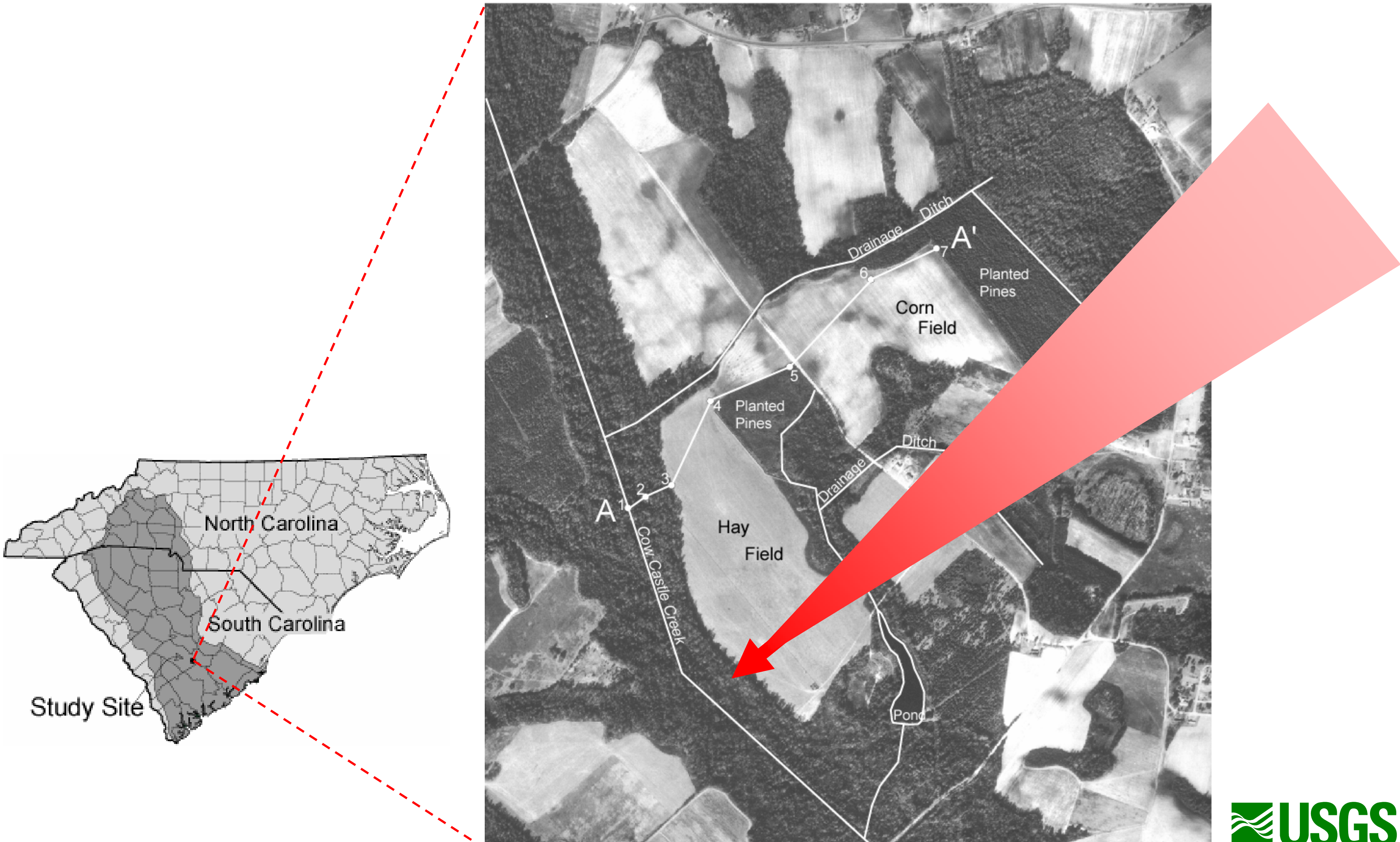
USGS
science for a changing world

Proposed GWAVA – Complete scheme



USGS
science for a changing world

Step 1 - Select Well Site Anywhere in the Lower 48

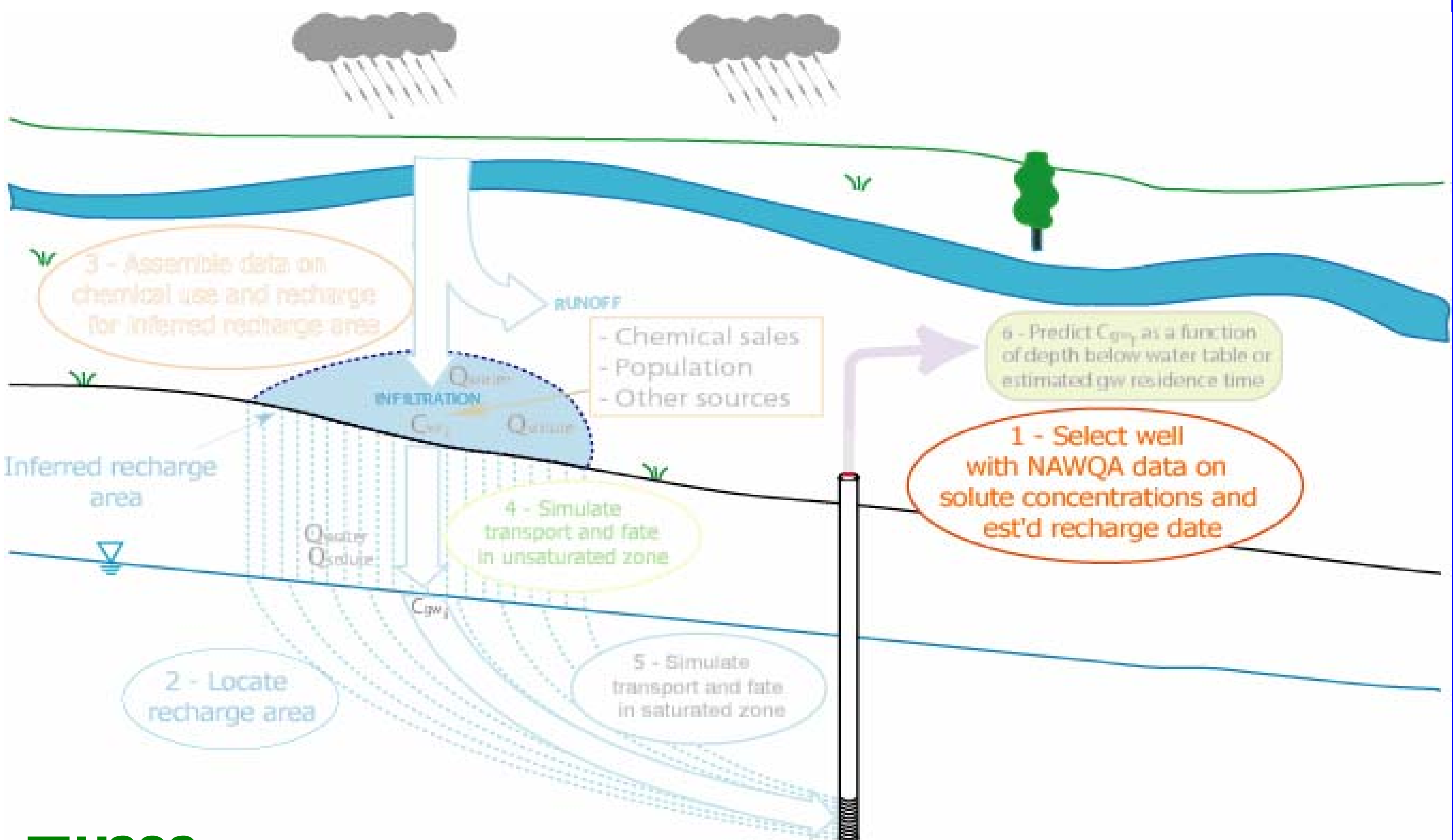


Puckett and Hughes, 2005 (JEQ 34:2278)

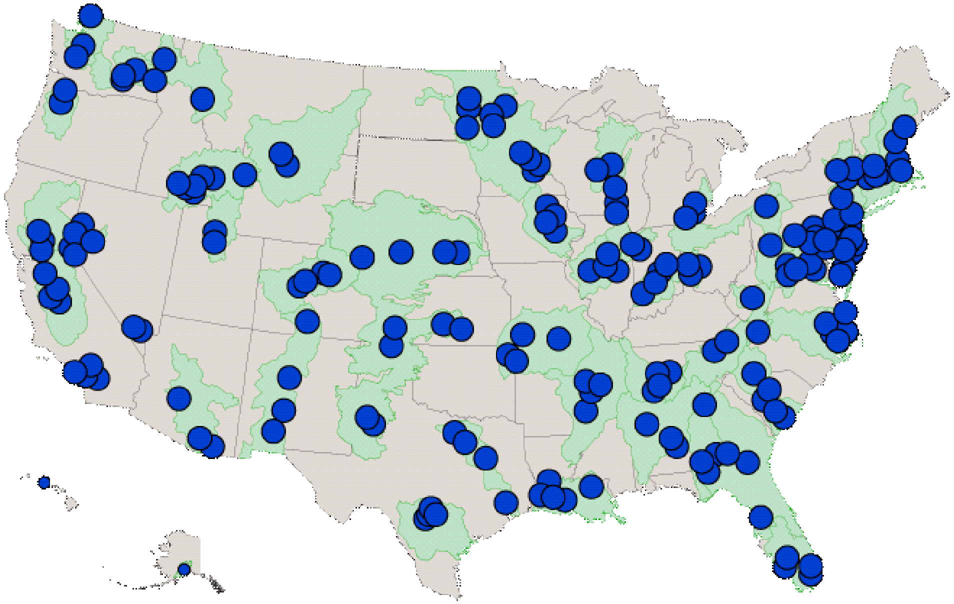
USGS
science for a changing world

Step 1 – Select well site

(Initial testing done using NAWQA wells)



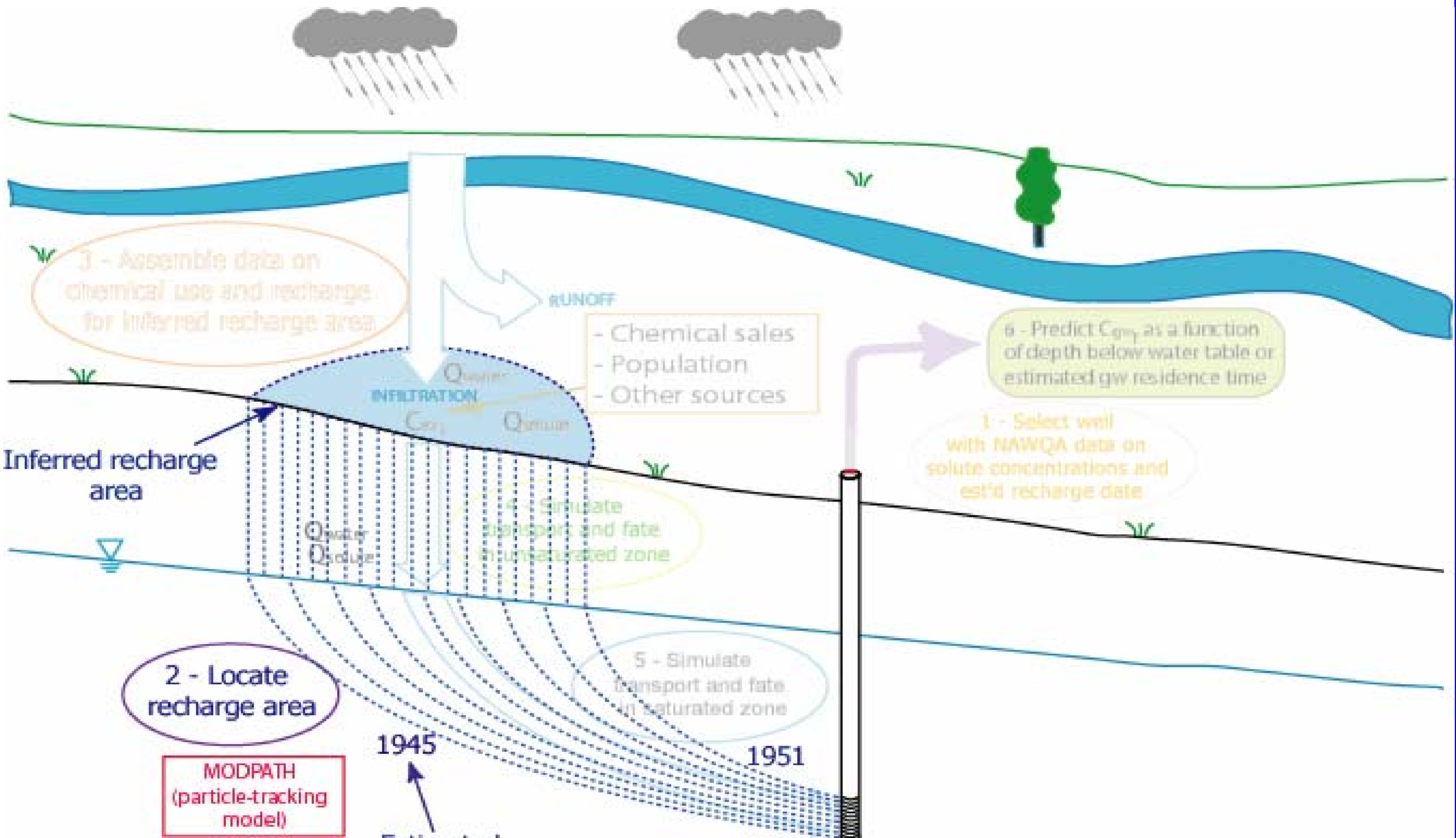
Ground-Water Data Available from the NAWQA Program, 1992-2001



- 187 study areas in agricultural, urban and other land-use settings
- More than 5,000 wells
- Sampled for pesticide compounds (83), VOCs (60), other solutes

USGS
science for a changing world

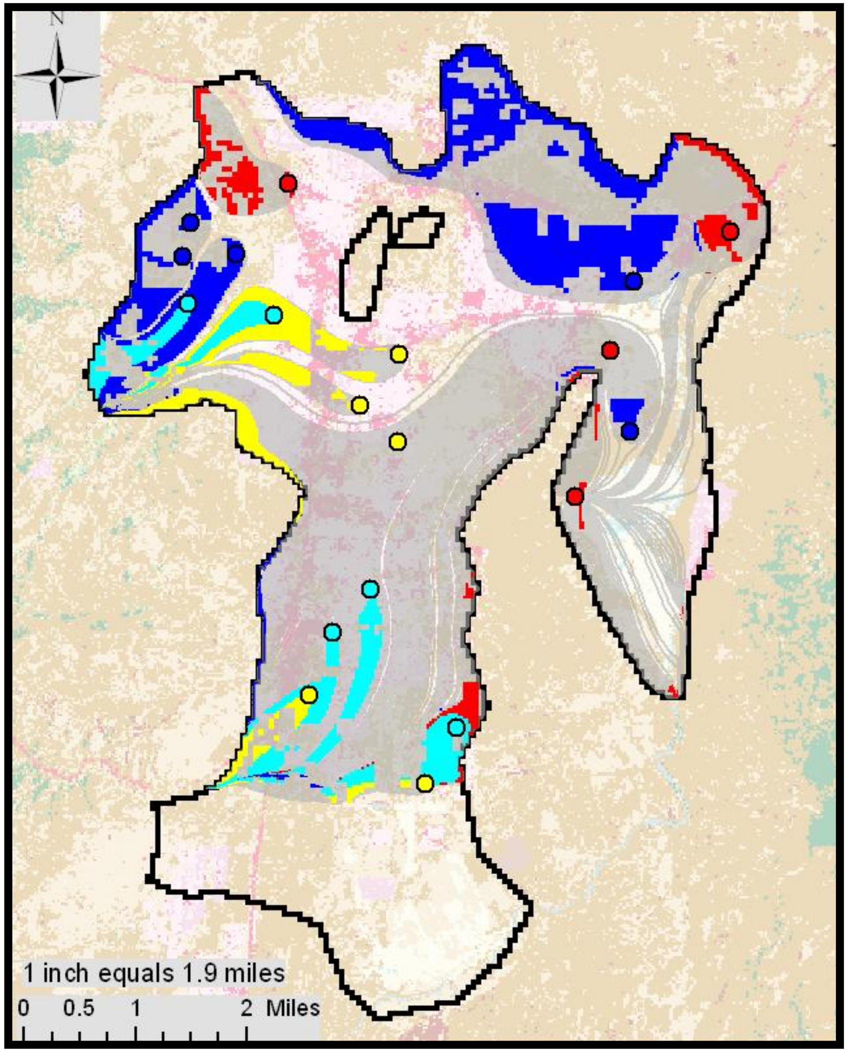
Step 2 – Locate recharge area



USGS
science for a changing world

Example - Contributing Areas for Wells in a Western Basin

(Particle-tracking simulations for Eagle Valley, Nevada by Leon Kauffman)



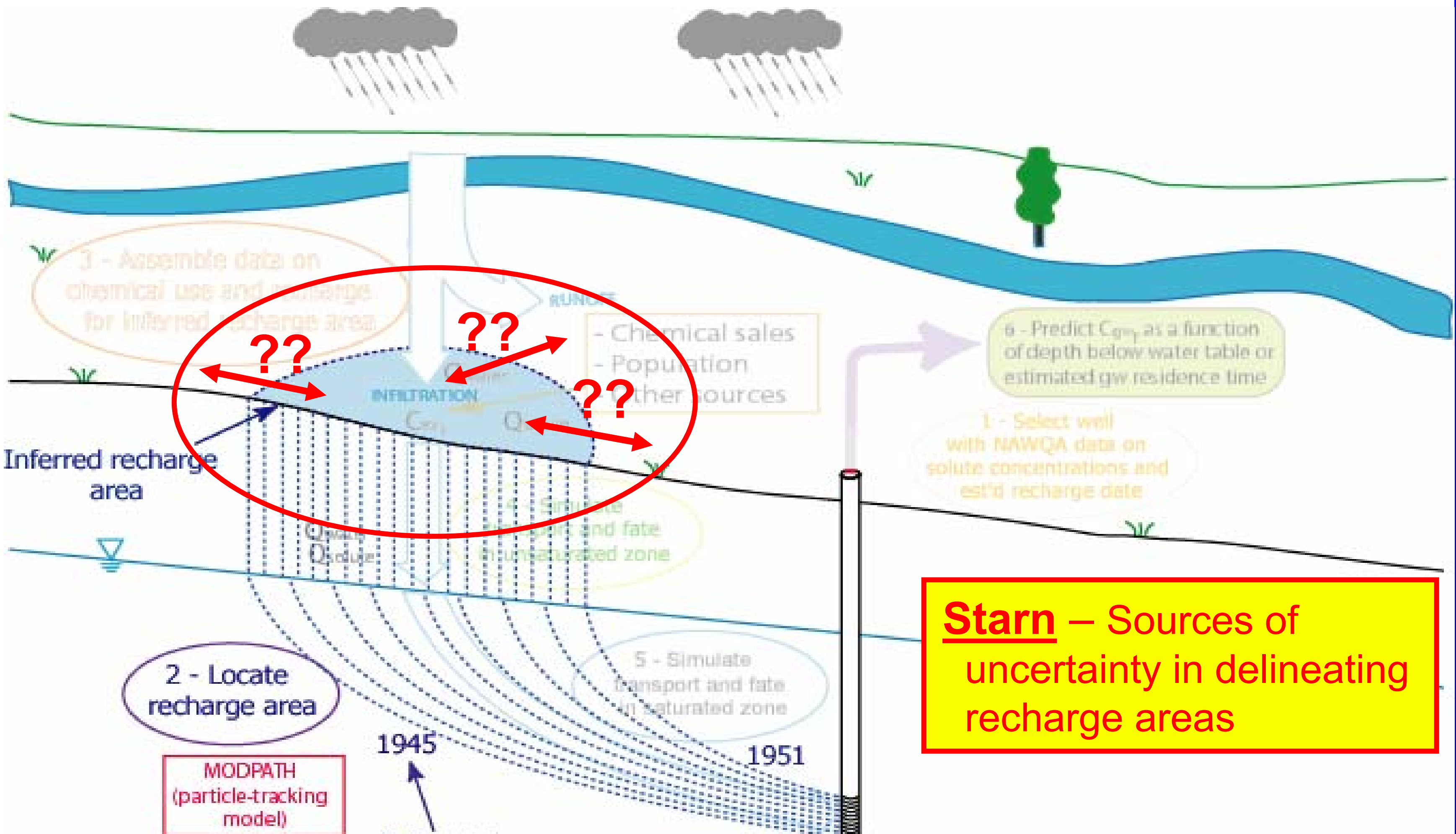
Legend

Well pumping rate			Area Contributing Recharge	
Low	●	1st Quartile	(red)	1st Quartile
↓	●	2nd Quartile	(yellow)	2nd Quartile
	●	3rd Quartile	(cyan)	3rd Quartile
High	●	4th Quartile	(blue)	4th Quartile

Kauffman, 2006 (Poster from 2005 Theis Conference on Ground-Water Age,Tahoe City, CA)

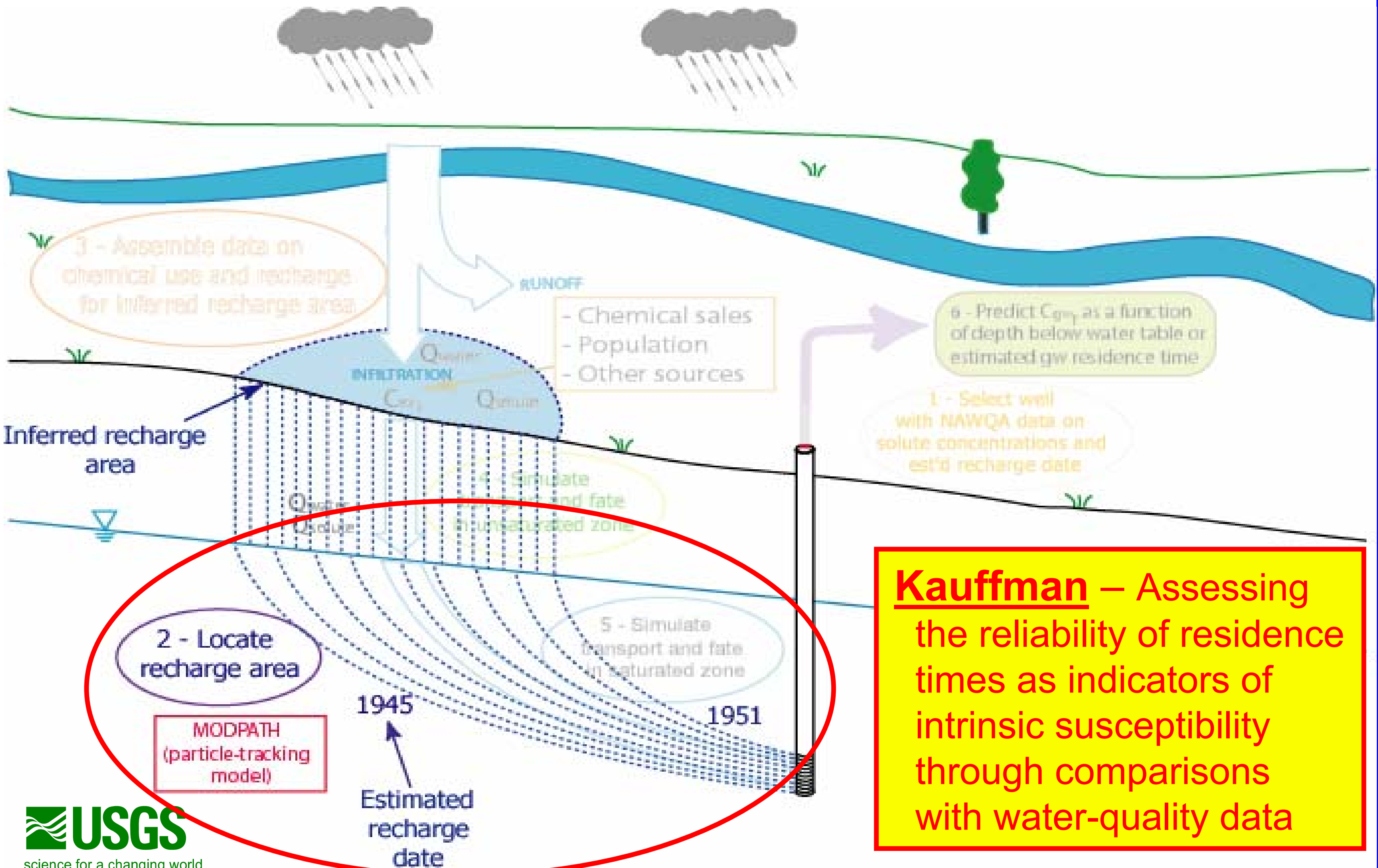
USGS
science for a changing world

Step 2 – Locate recharge area



Starn – Sources of uncertainty in delineating recharge areas

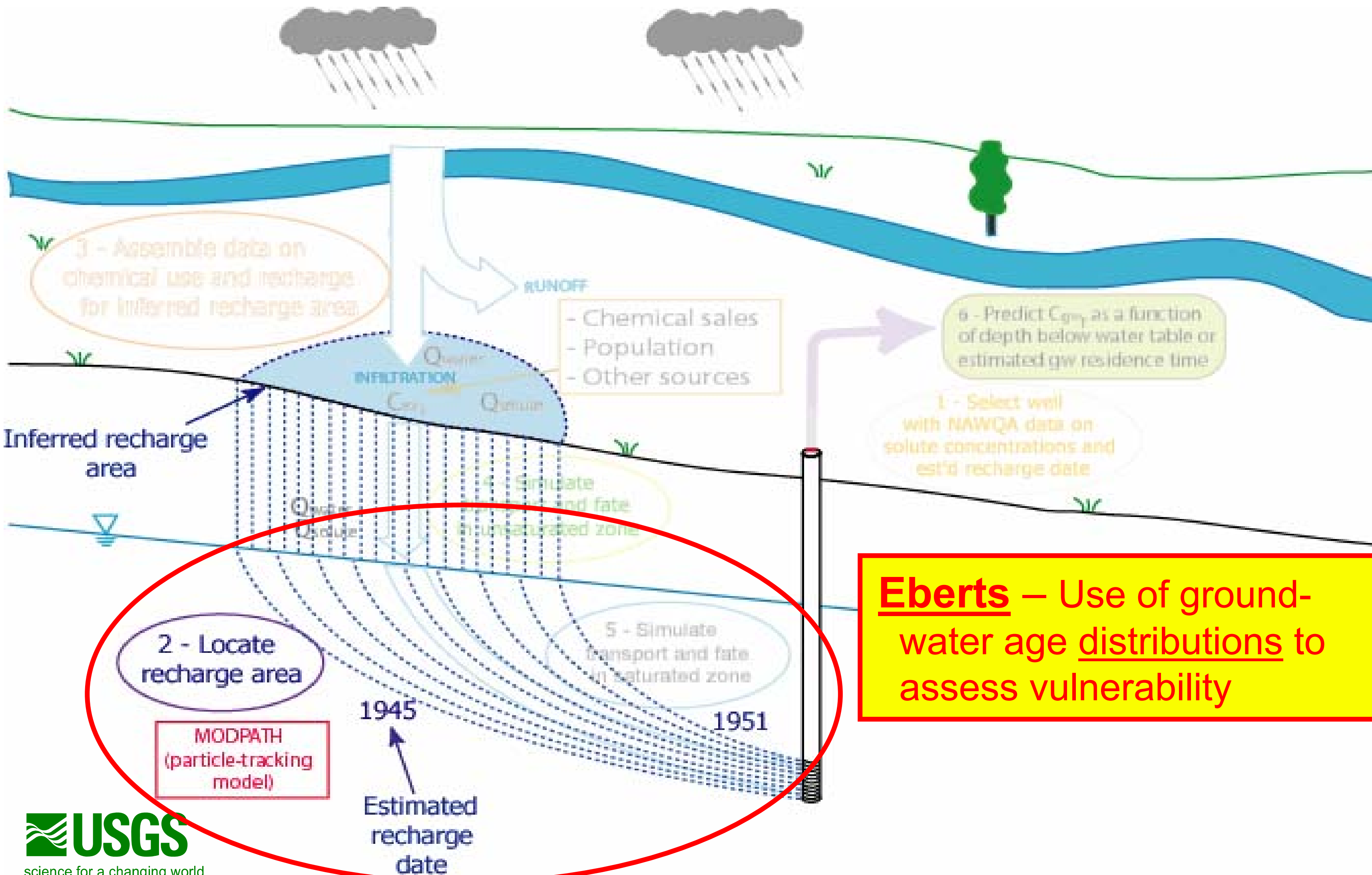
USGS
science for a changing world



Kauffman – Assessing the reliability of residence times as indicators of intrinsic susceptibility through comparisons with water-quality data

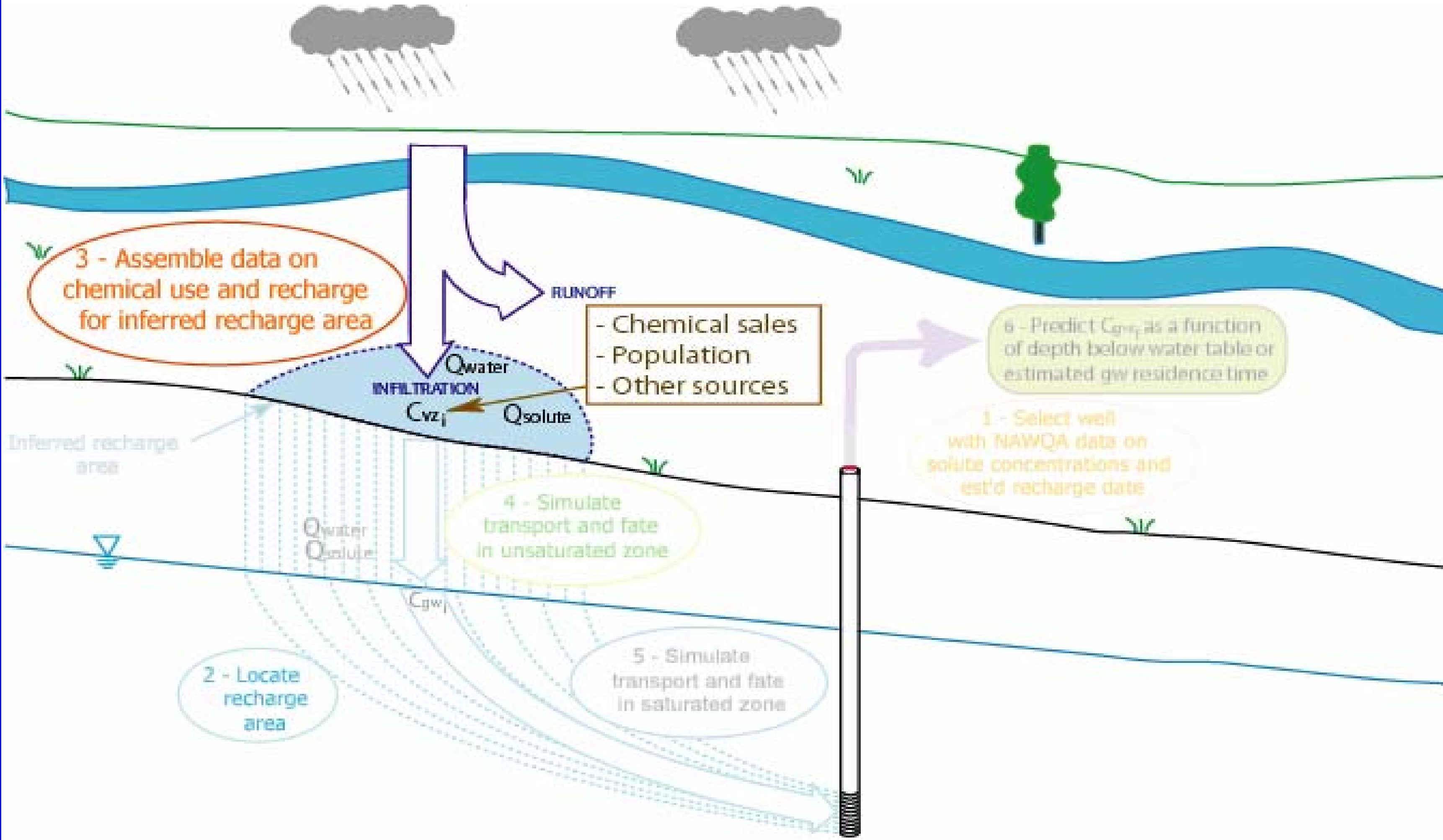
USGS
science for a changing world

Eberts – Use of ground-water age distributions to assess vulnerability



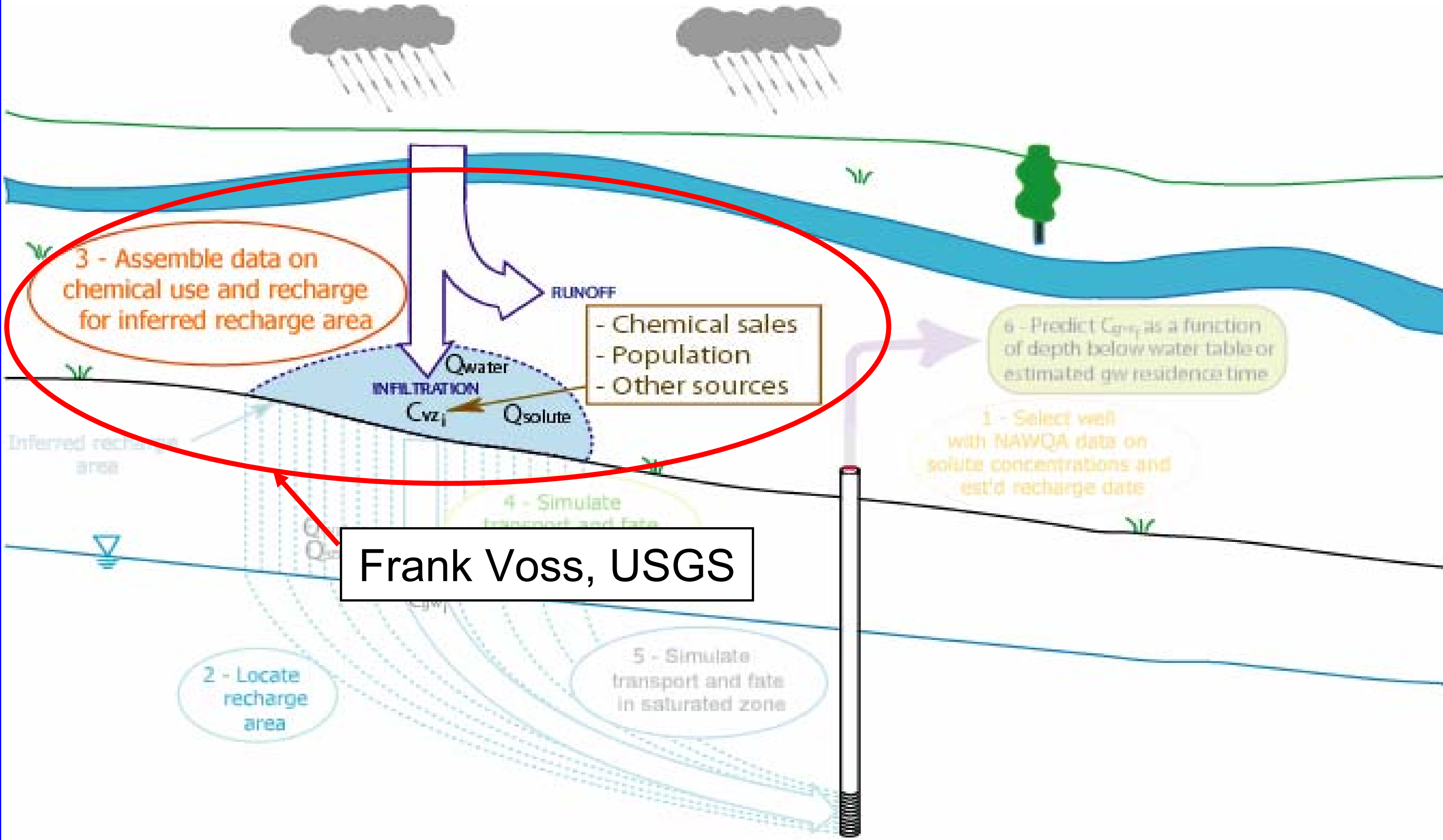
USGS
science for a changing world

Step 3 – Assemble input data



USGS
science for a changing world

Step 3 – Assemble input data



USGS science for a changing world

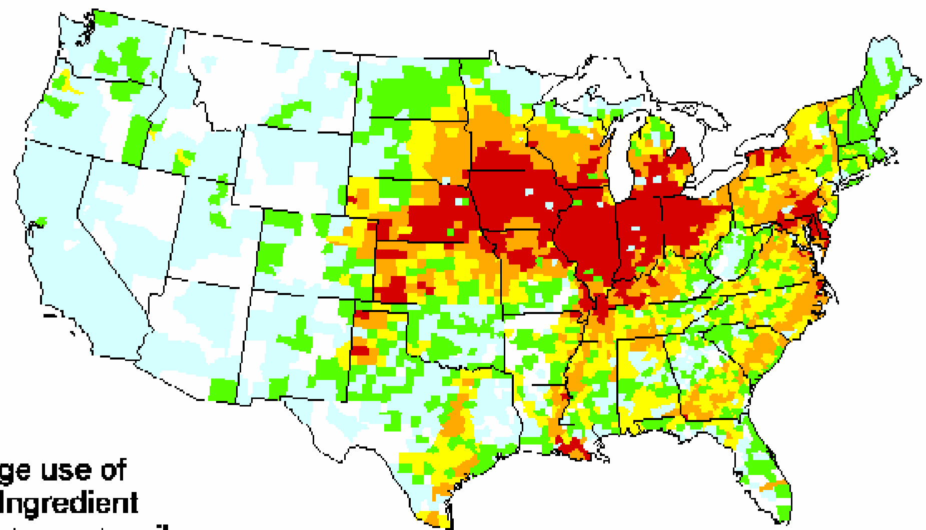
http://www.epa.gov/oppefed1/models/water/przm3_talk_jan2005.htm

Example – Atrazine use on crops

(Data and map from Gail Thelin and Naomi Nakagaki, USGS)

ATRAZINE - HERBICIDES

ESTIMATED ANNUAL AGRICULTURAL USE



Average use of
Active Ingredient
Pounds per square mile
of county per year

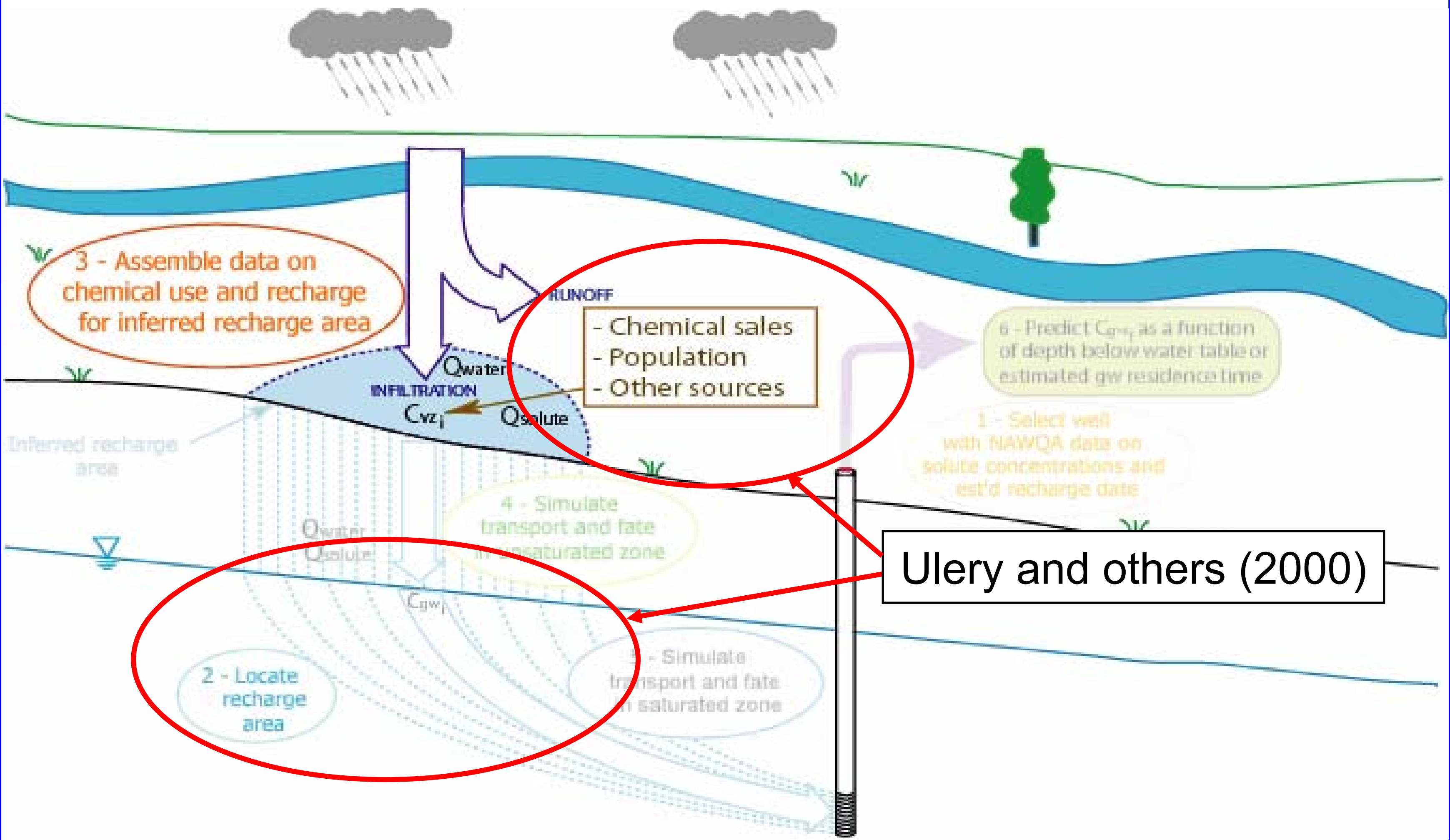
- No Estimated Use
- < 0.572
- 0.572 - 4.108
- 4.109 - 17.601
- 17.602 - 61.920
- >= 61.921

Crops	Total Pounds Applied	Percent National Use
corn	62, 382, 160	84. 12
sorghum	6, 750, 001	9. 10
fallowland	2, 539, 169	3. 42
sugarcane	2, 101, 794	2. 83
sweet corn	340, 453	0. 46
sod	30, 214	0. 04
other hay	13, 225	0. 02
	5, 834	0. 01

USGS
science for a changing world

http://ca.water.usgs.gov/cgi-bin/pnsp/pesticide_use_maps_1997.pl?map=W1980

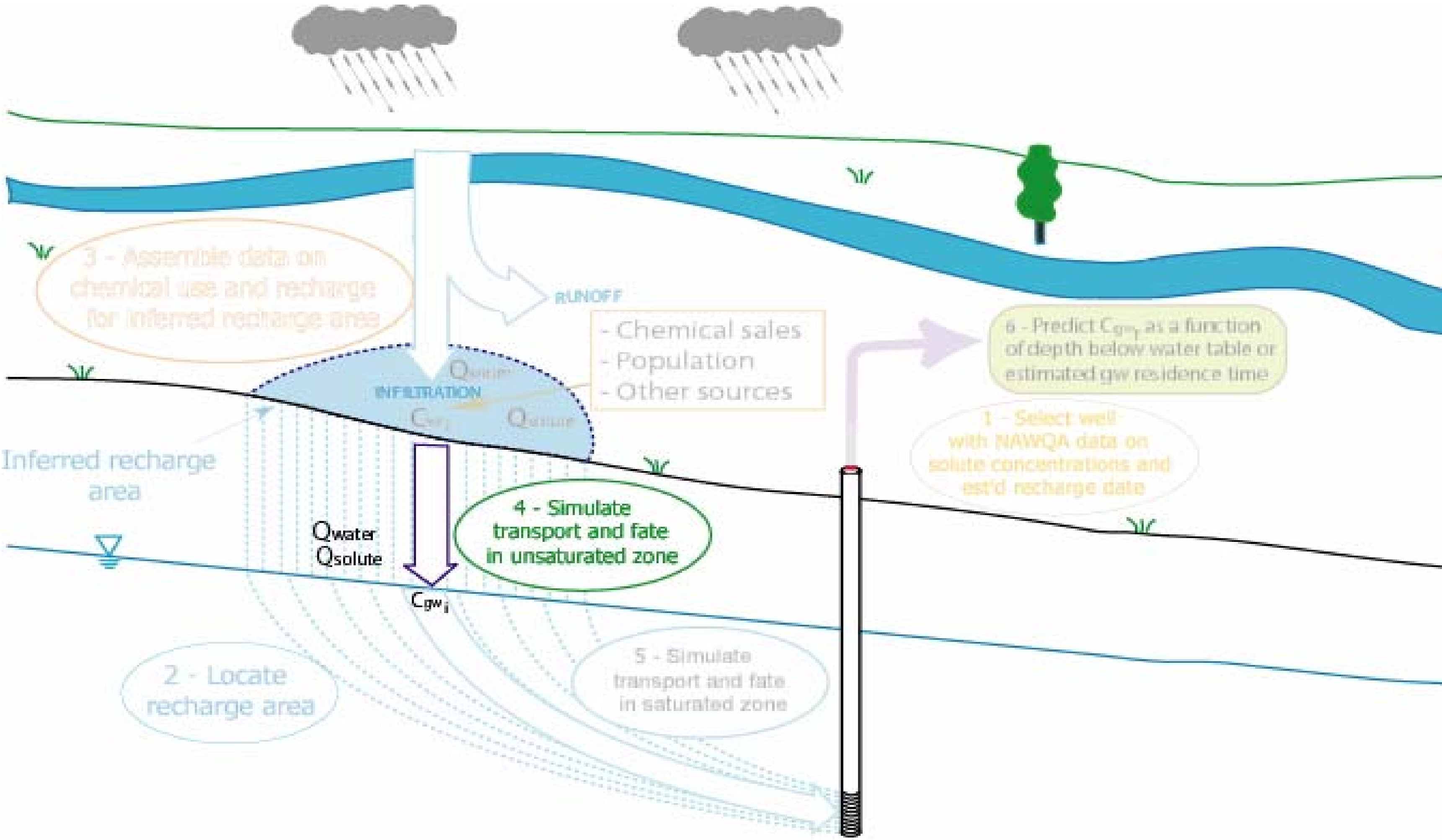
Step 3 – Assemble input data



science for a changing world

http://pubs.usgs.gov/fs/fs-101-00/pdf/FS-101-00.pdf

Step 4 – Simulate transport and fate in vadose zone



USGS
science for a changing world

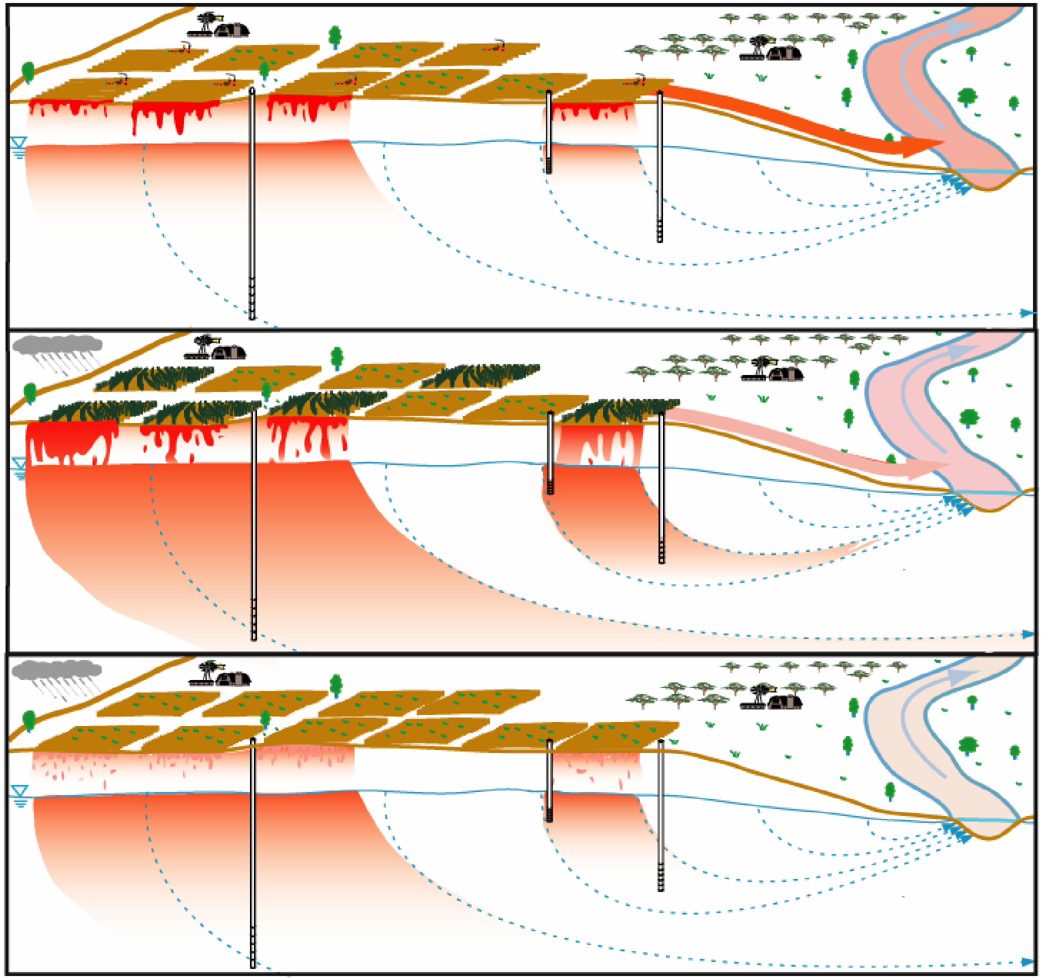
Solute transport in subsurface is usually non-uniform!

(Schematic distributions of an agricultural pesticide in subsurface during the year)

Application

Crop maturation

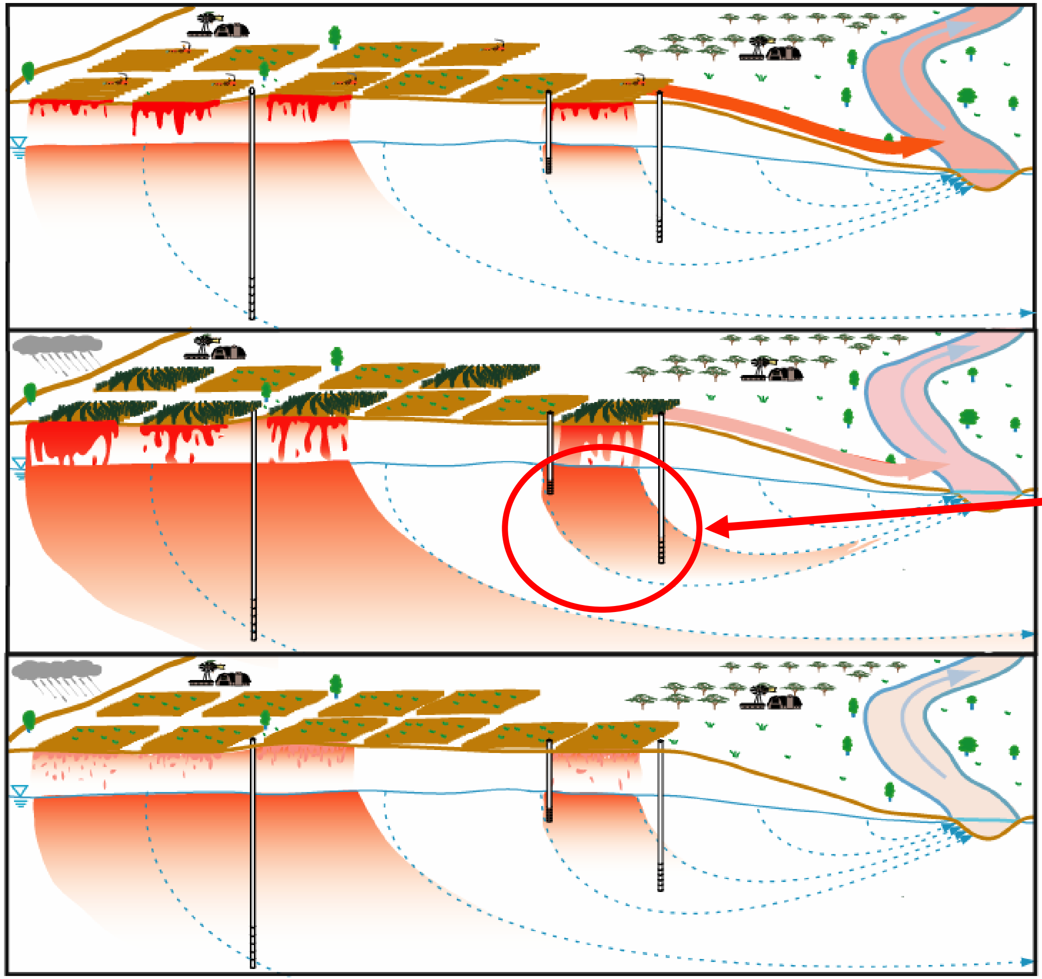
Post harvest



All the proposed GWAVA models are capable of simulating this.

USGS
science for a changing world

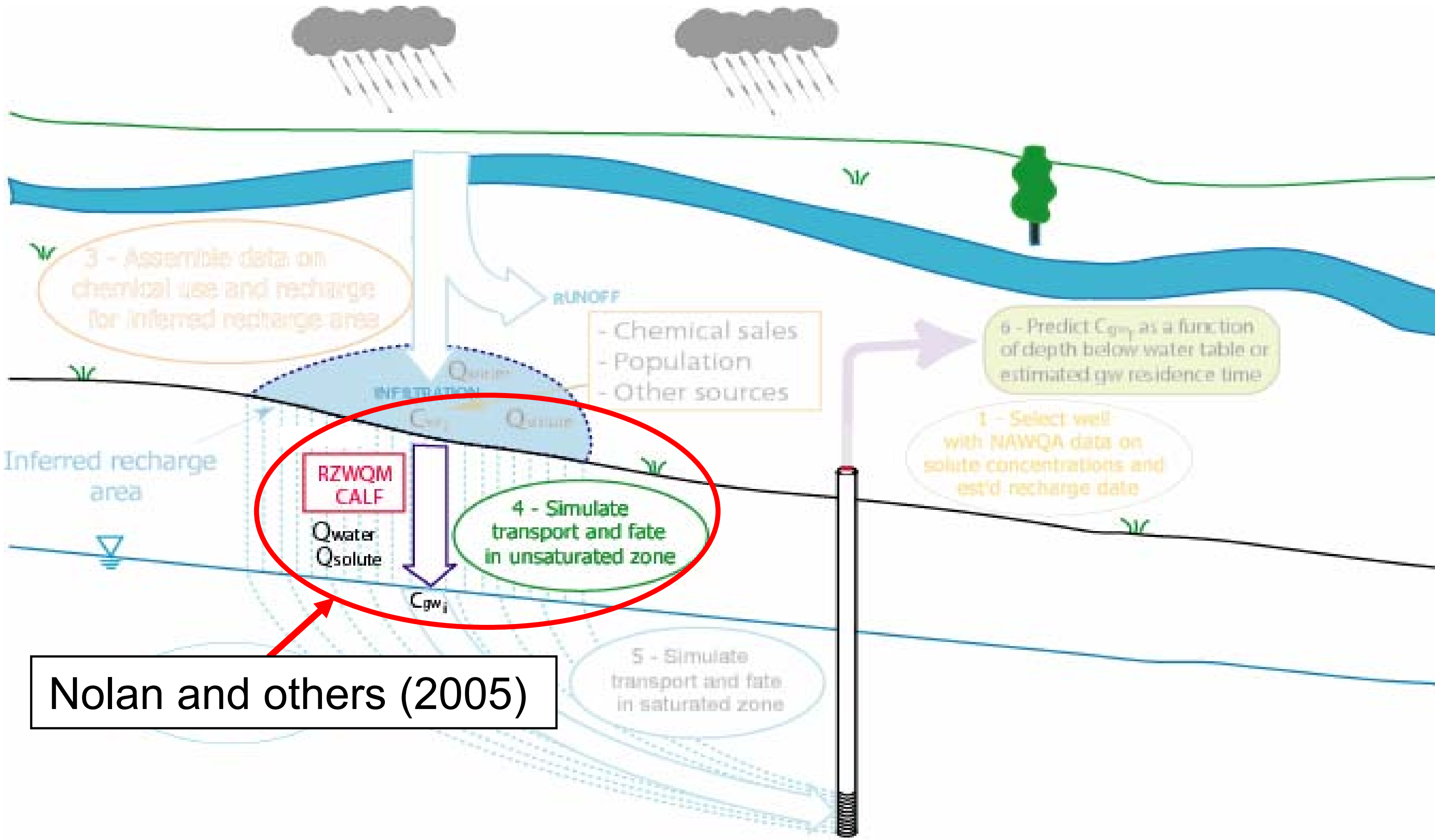
Solute transport in subsurface is usually non-uniform!



Clark – Simulation of short-circuit flow paths and transient conditions to assess vulnerability

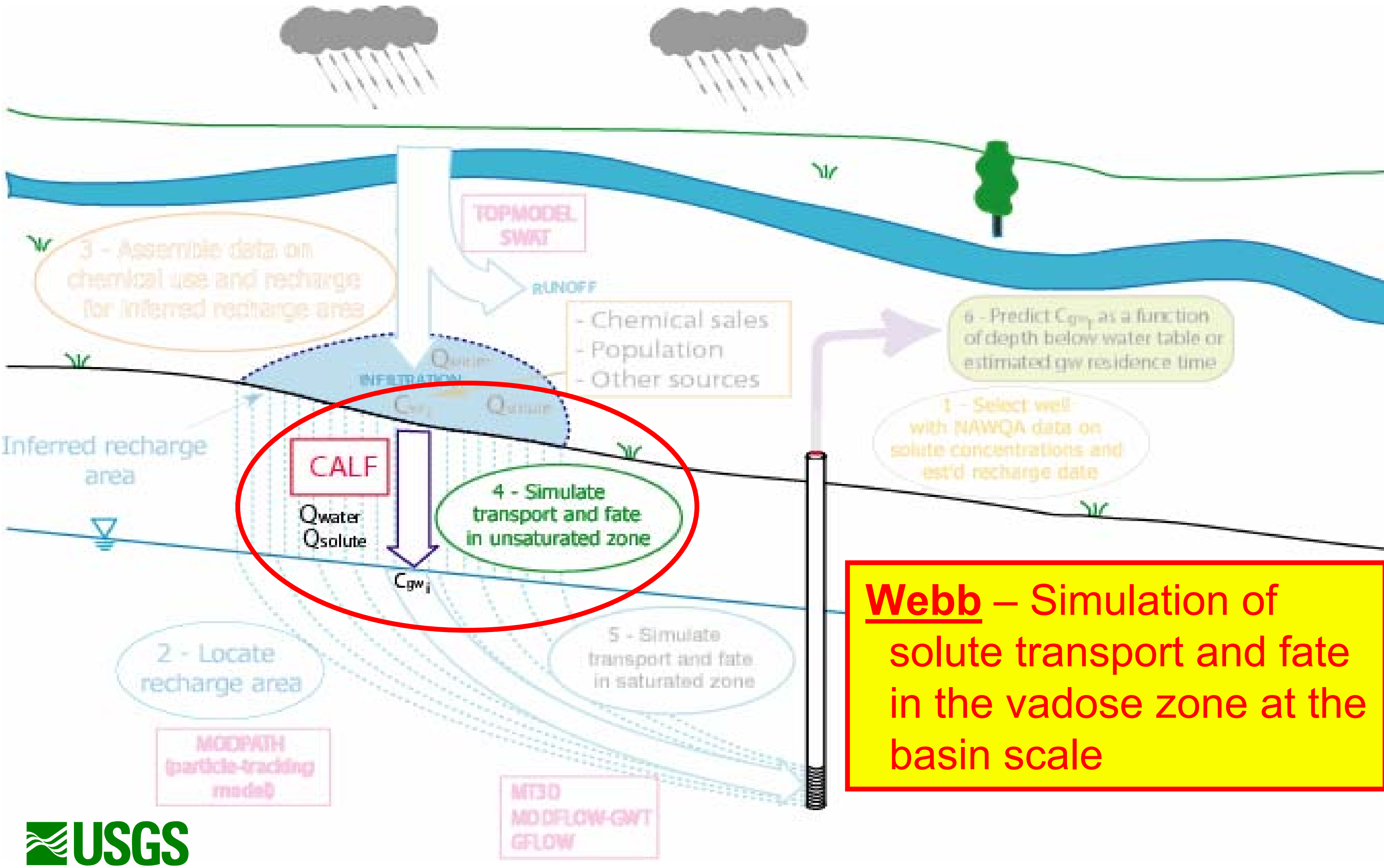
USGS
science for a changing world

Step 4 – Simulate transport and fate in vadose zone



http://pubs.usgs.gov/of/2005/1196/

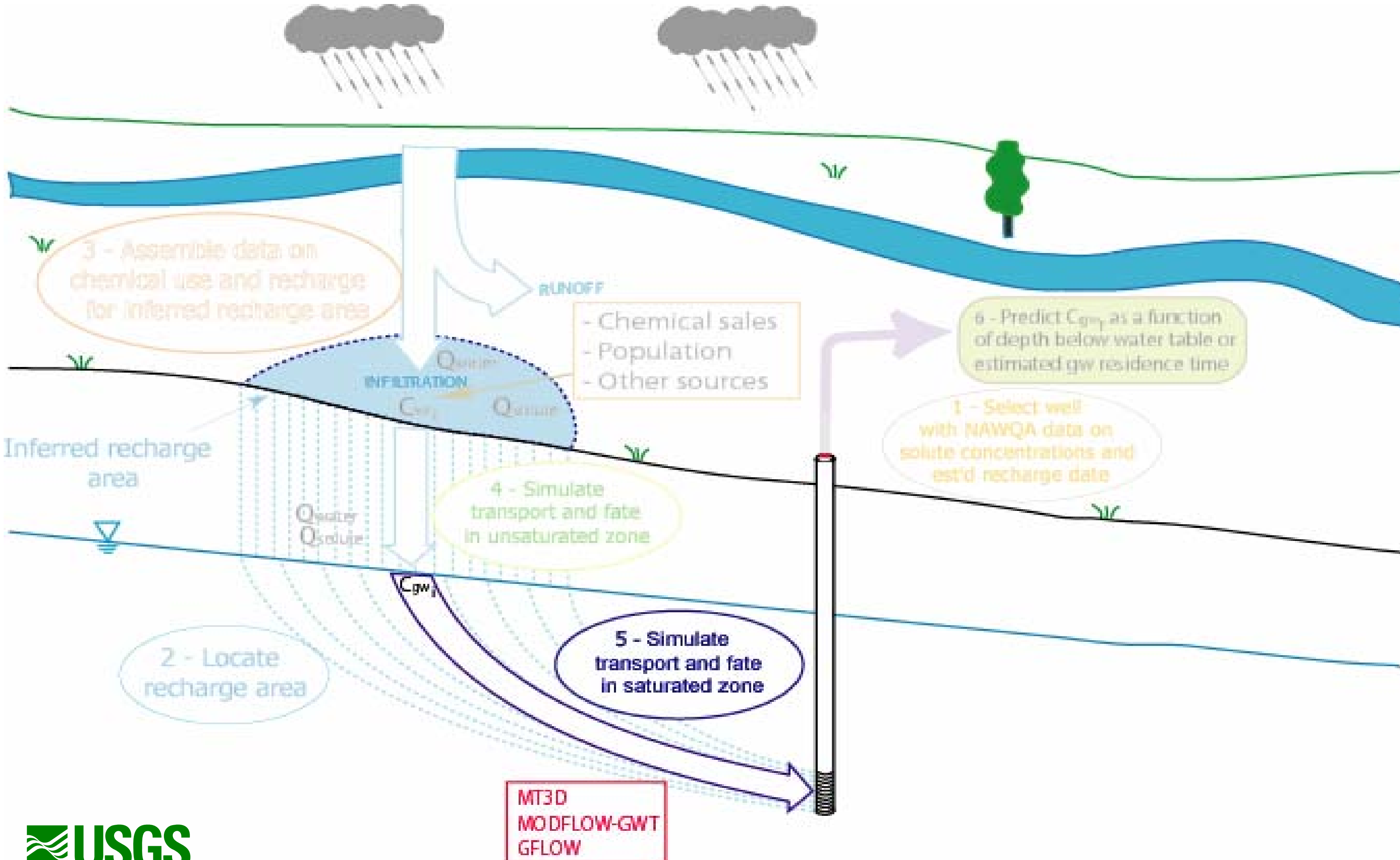
Step 4 – Simulate transport and fate in vadose zone



Webb – Simulation of solute transport and fate in the vadose zone at the basin scale

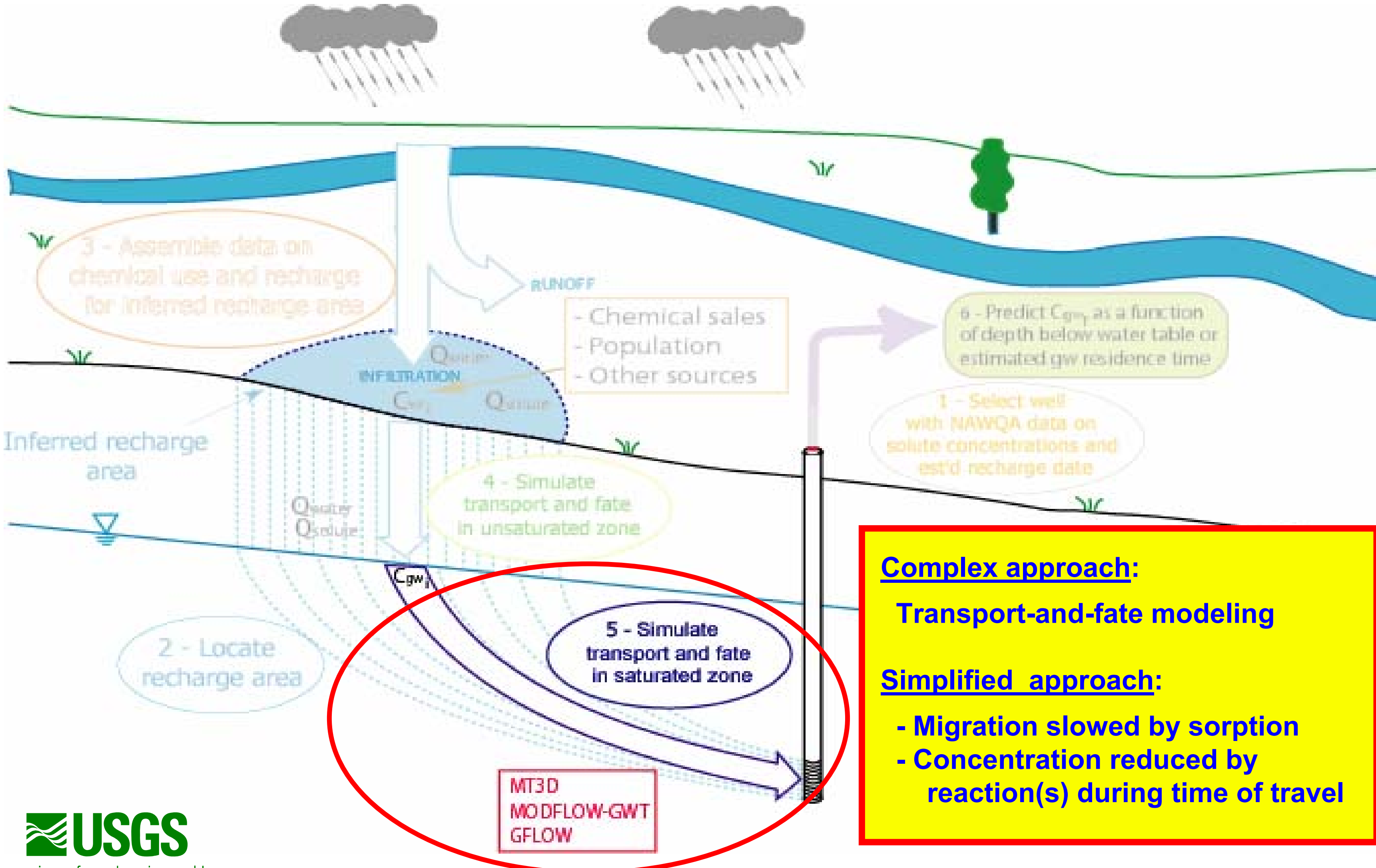
USGS
science for a changing world

Step 5 – Simulate transport and fate in saturated zone



USGS
science for a changing world

Step 5 – Simulate transport and fate in saturated zone



Complex approach:

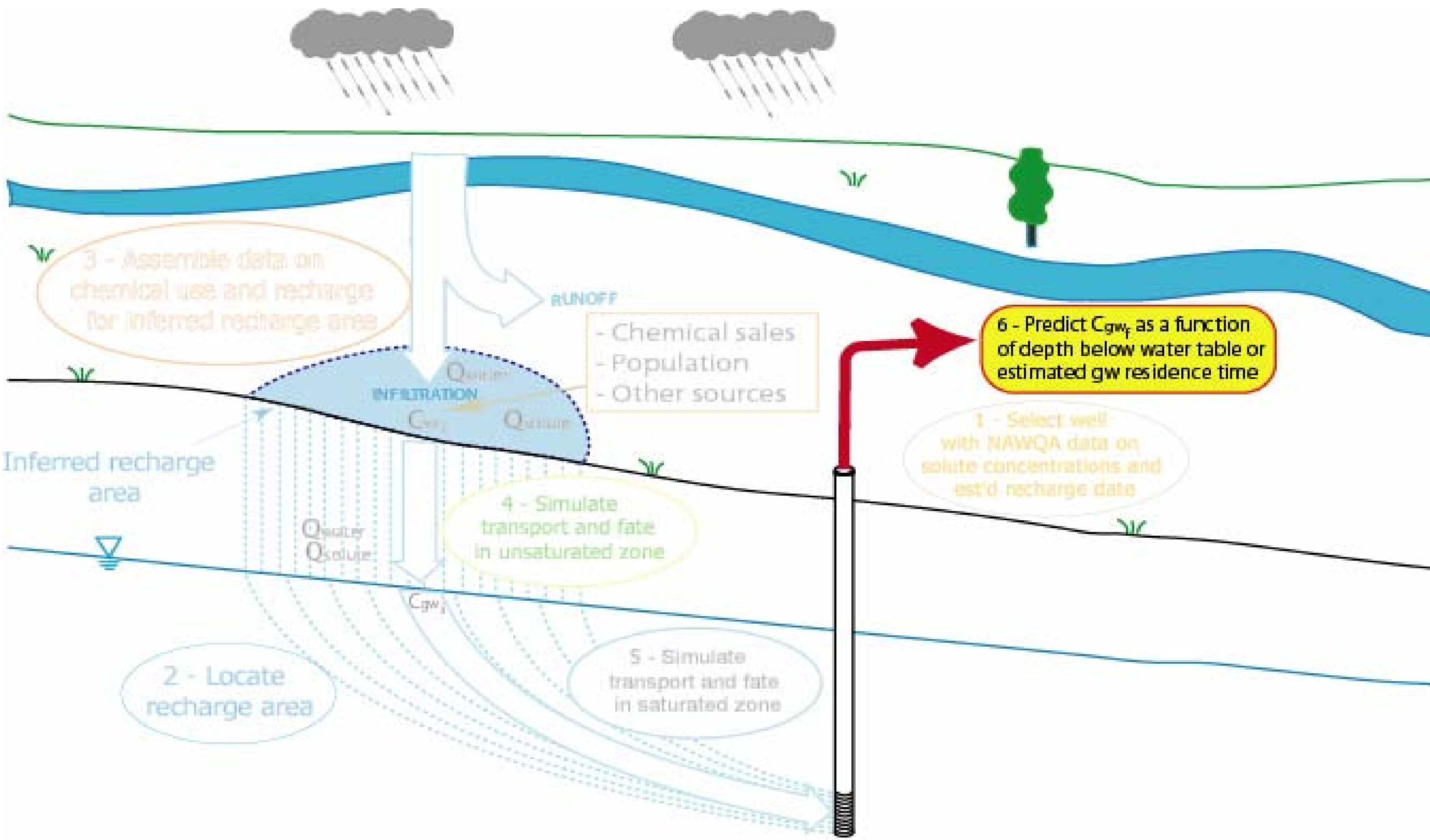
Transport-and-fate modeling

Simplified approach:

- **Migration slowed by sorption**
- **Concentration reduced by reaction(s) during time of travel**

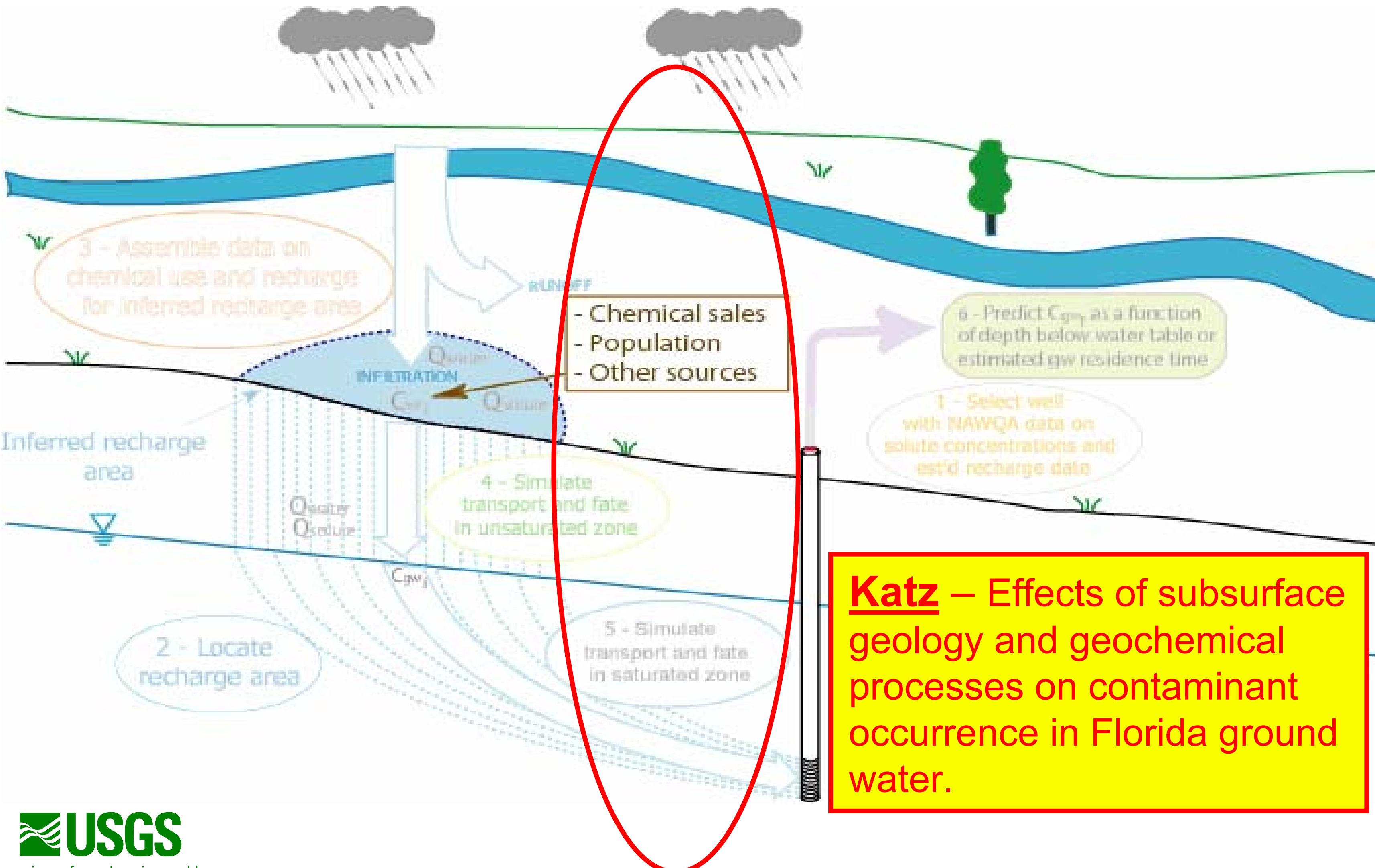
USGS
science for a changing world

Step 6 – Compare predicted concentrations with field data



USGS
science for a changing world

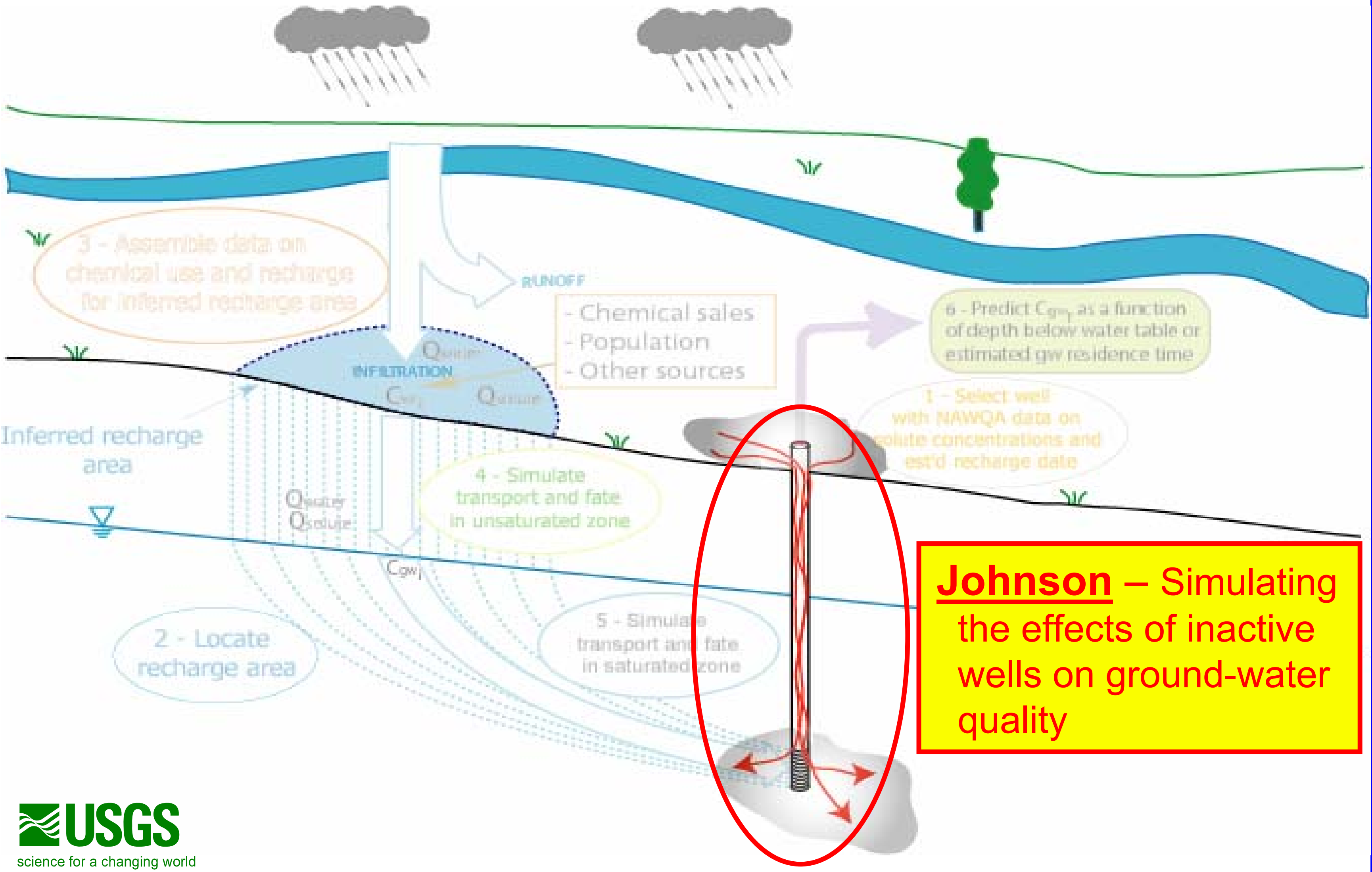
Vulnerability Assessment - Additional Considerations



Katz – Effects of subsurface geology and geochemical processes on contaminant occurrence in Florida ground water.

USGS
science for a changing world

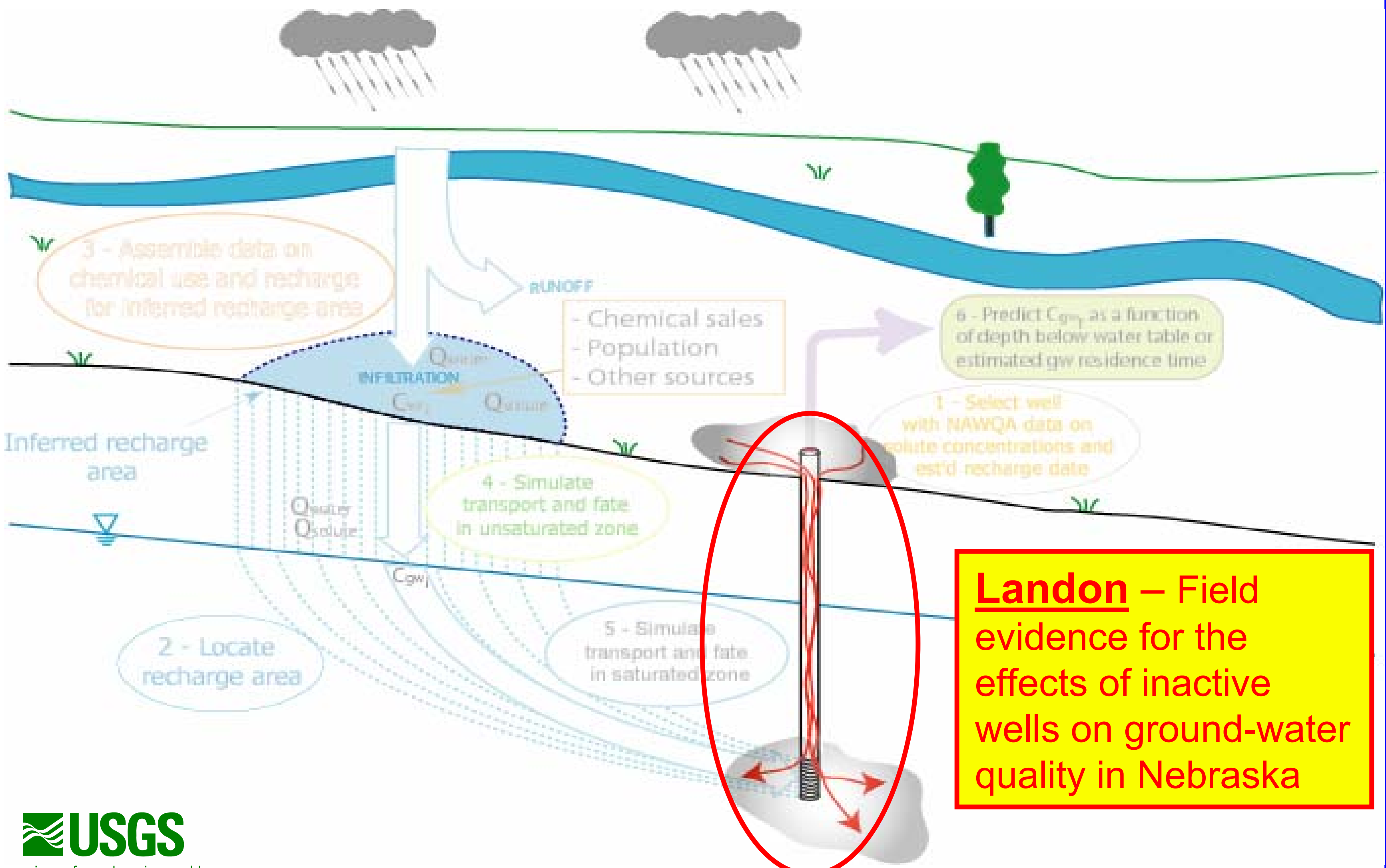
Vulnerability Assessment - Additional Considerations



Johnson – Simulating the effects of inactive wells on ground-water quality

USGS
science for a changing world

Vulnerability Assessment - Additional Considerations



<u>Landon</u> – Field evidence for the effects of inactive wells on ground-water quality in Nebraska

USGS
science for a changing world

Main Points

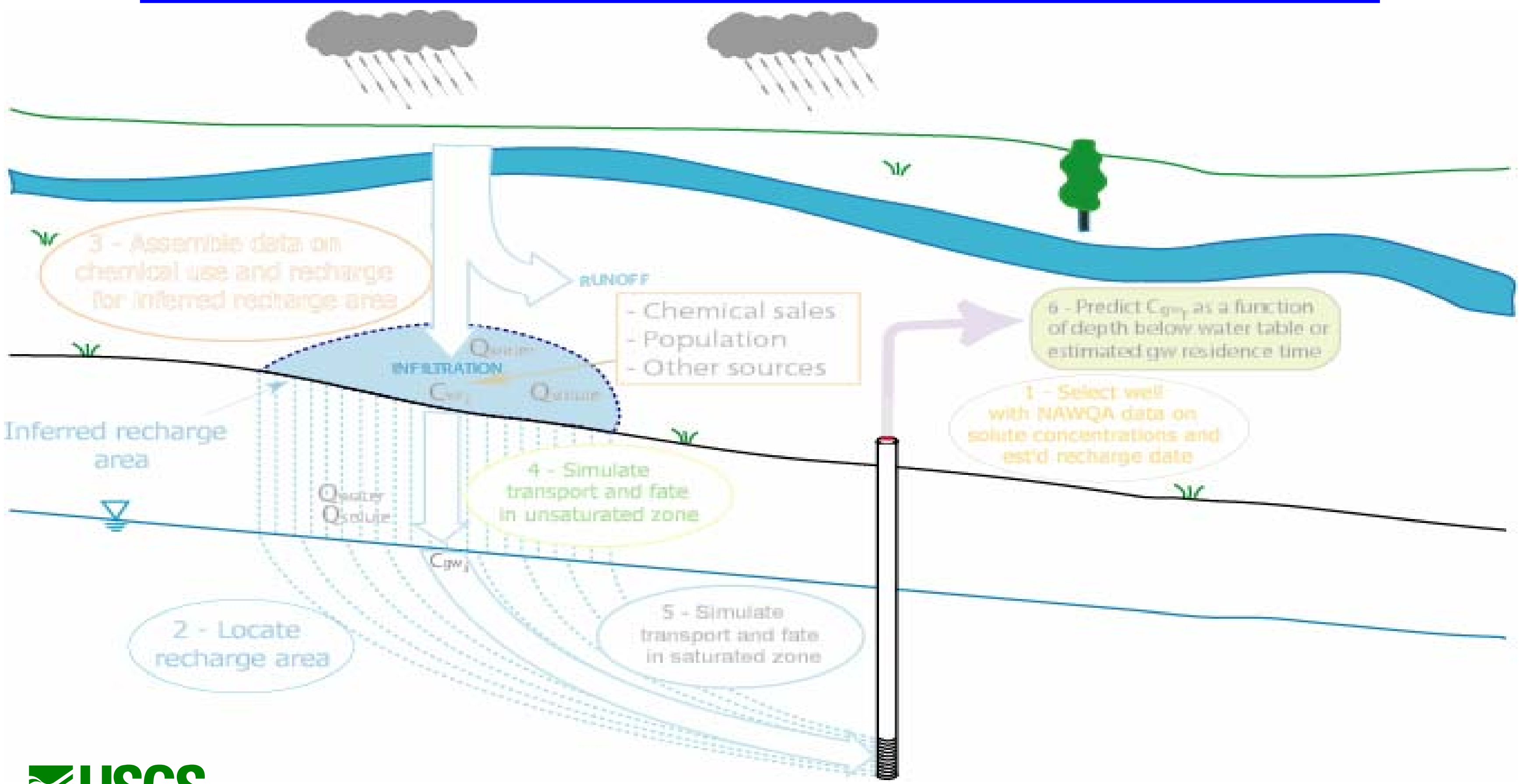
- **Previous approaches to ground-water vulnerability assessment (GWAVA)**
  - **Most have <u>not</u> been tested against observations**
  - **Mechanistic methods <u>uncommon</u>**
- **Proposed approach for NAWQA GWAVA**
  - **Key (initial) customers – Agencies charged with assessing vulnerability <u>across</u> <u>entire</u> <u>states</u>**
  - **<u>National</u> <u>scale</u> input data**
  - **Maximal incorporation of <u>process</u> <u>understanding</u>**
  - **<u>Open-source</u> development**
  - **Testing of predictions against NAWQA results**
- **Tools for each component of method already exist— main focus is on <u>connecting the dots</u>**

USGS
science for a changing world

Acknowledgements

- Leon Kauffman
- Brian Katz
- Wayne Lapham
- Gary Rowe
- Brian Hughes
- Larry Puckett
- Frank Voss
- David Saad
- Michael Focazio
- Gary Turney
- Cynthia Barton

SUGGESTIONS?



USGS
science for a changing world