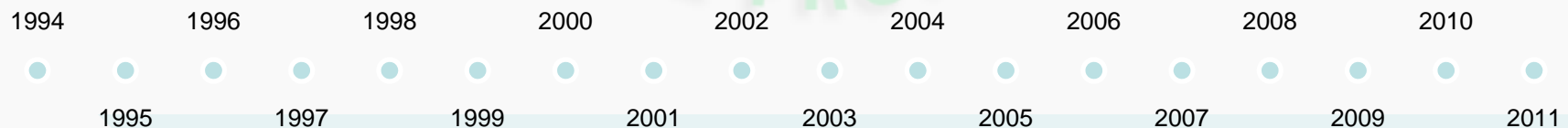


History of Analytic Element Model Development and Applications at the US Environmental Protection Agency (1994 – present)

Stephen Kraemer, Ph.D.
Research Hydrologist
Office of Research and Development
Athens, Georgia

GSA Annual Meeting, Minneapolis, MN
10 Oct 2011

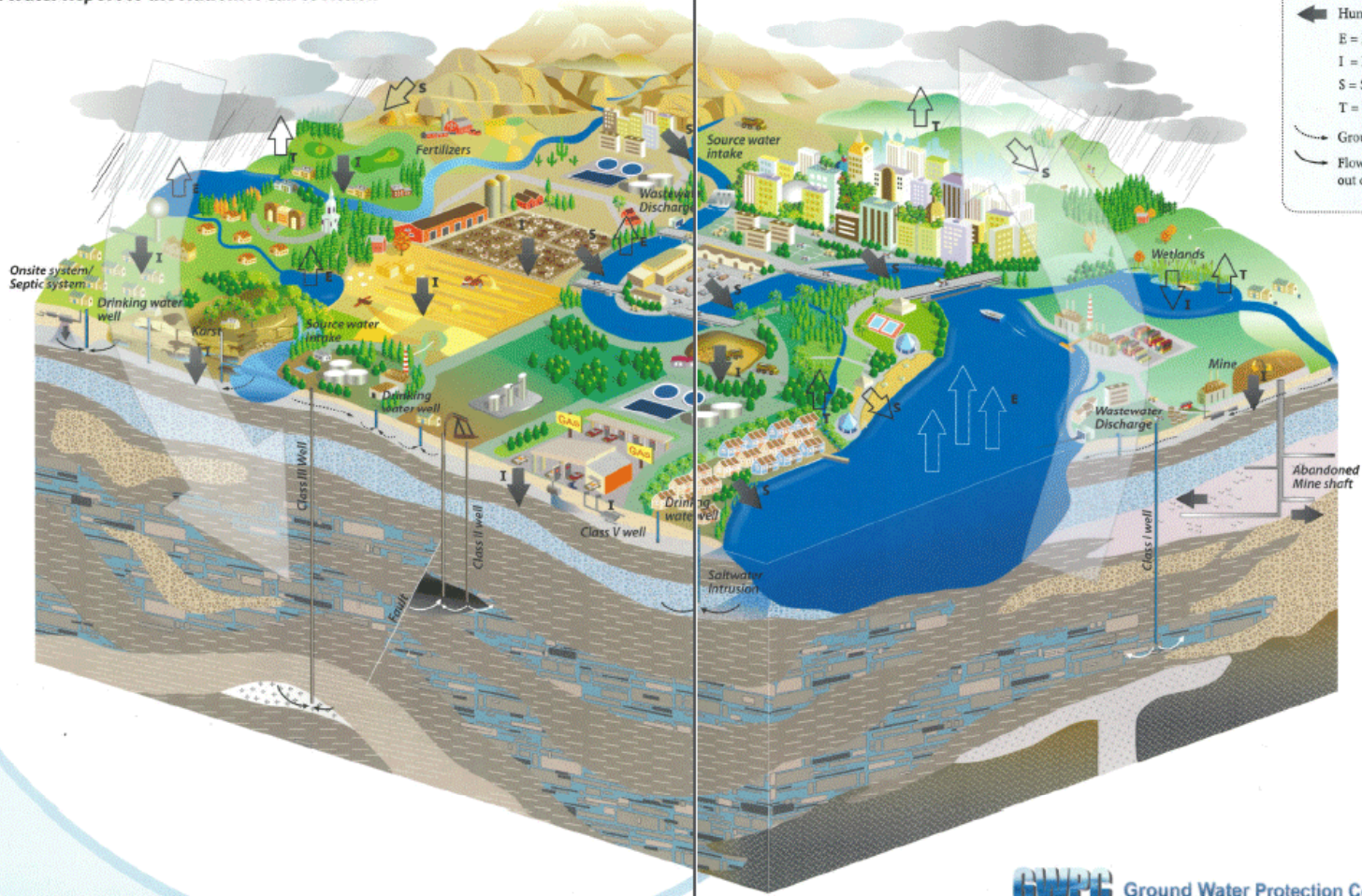


EPA charge: safe and clean water



Ground Water *Interactions*

Ground Water Report to the Nation: A Call to Action



EPA Issue: Source Water Protection



7 ELEMENTS - Wellhead Protection

1 • Specify Duties

2 • Delineate Wellhead Protection Areas

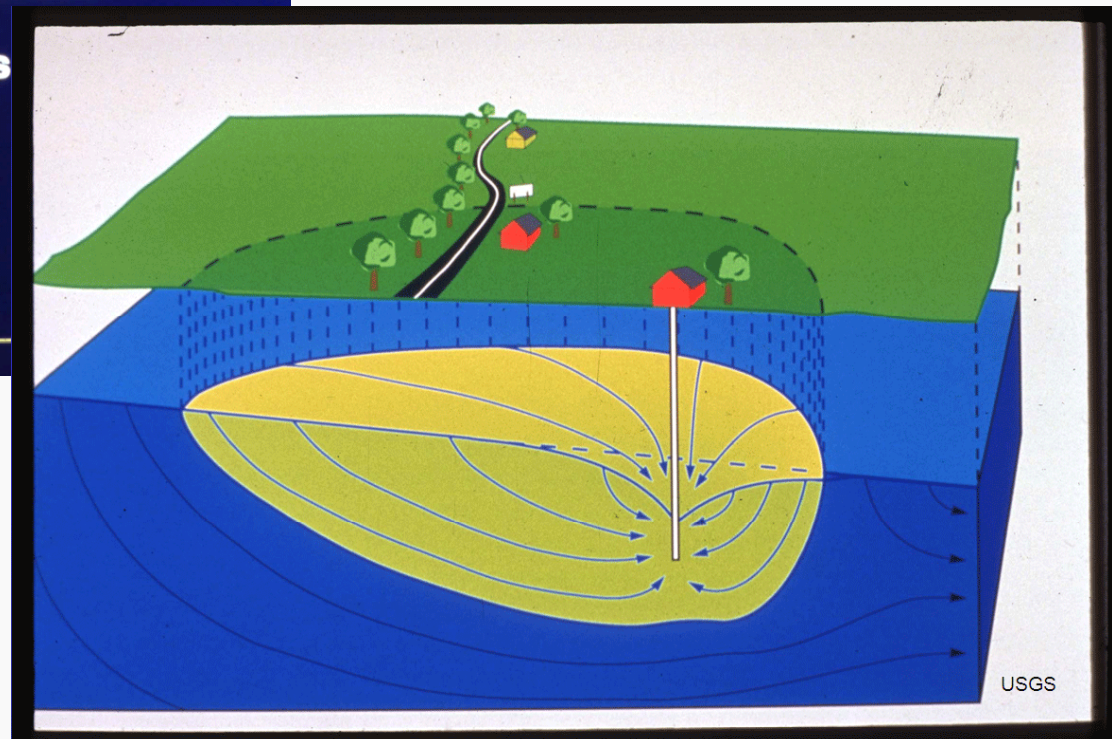
3 • Identify Potential Contaminant Sources

4 • Develop Management Approaches

5 • Develop Contingency Plan

6 • Plan for New Wells

7 • Implement Public Participation





United States Environmental Protection Agency
Office of Research and Development
Washington DC 20460
EPA/600/R-94/174
September 1994



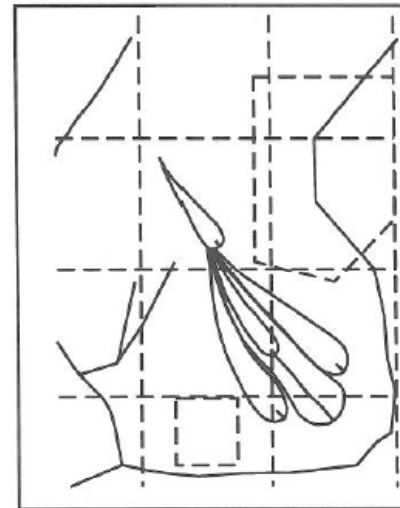
CZAEM User's Guide

Modeling Capture Zones of Ground-Water Wells Using Analytic Elements

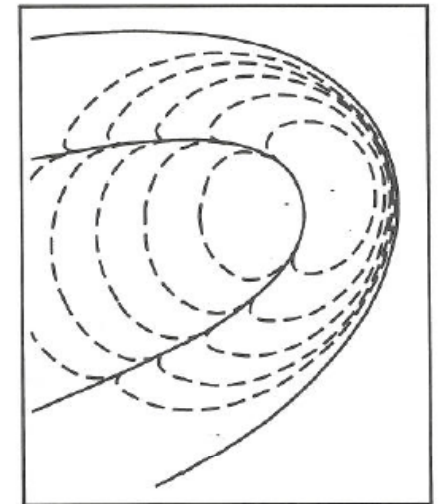
Otto Strack
Erik Anderson
Mark Bakker
Bill Olsen
J.C. Panda
Rich Pennings
David Steward

DOS

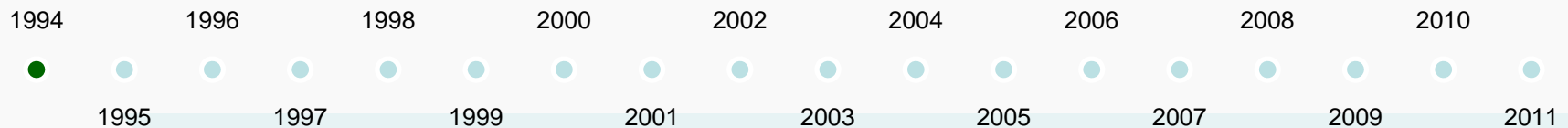
envelopes



sub-zones



(Bakker, Strack, 1996, WRR)



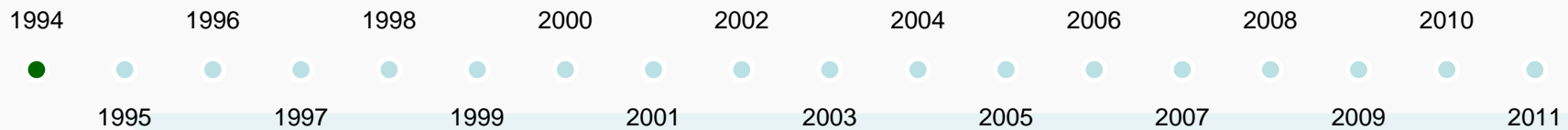
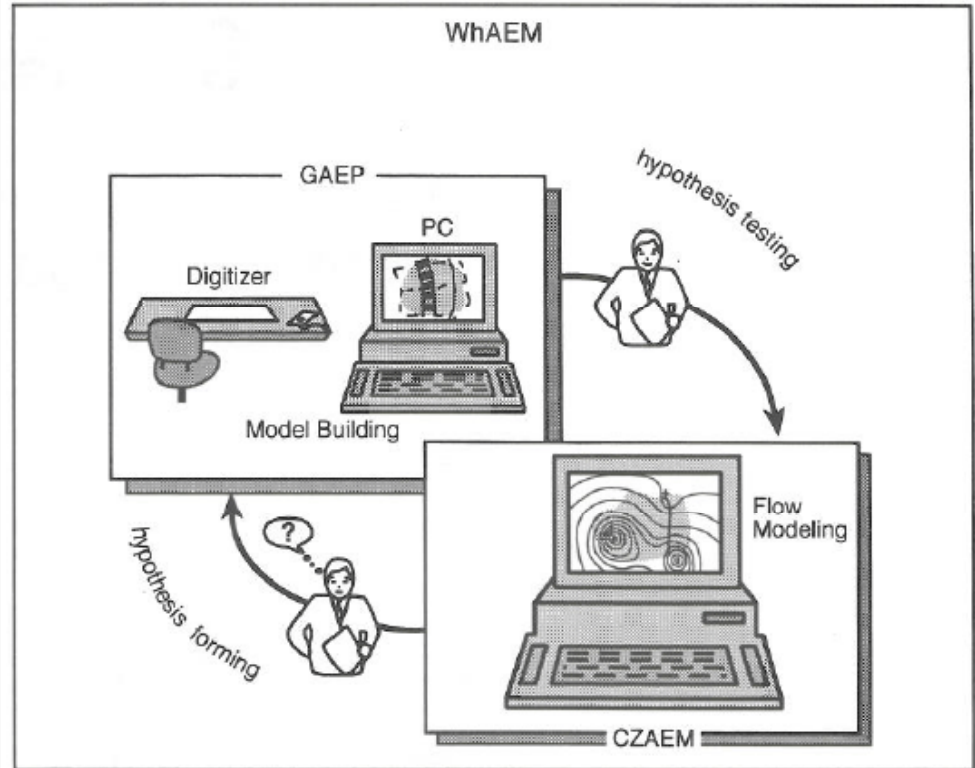


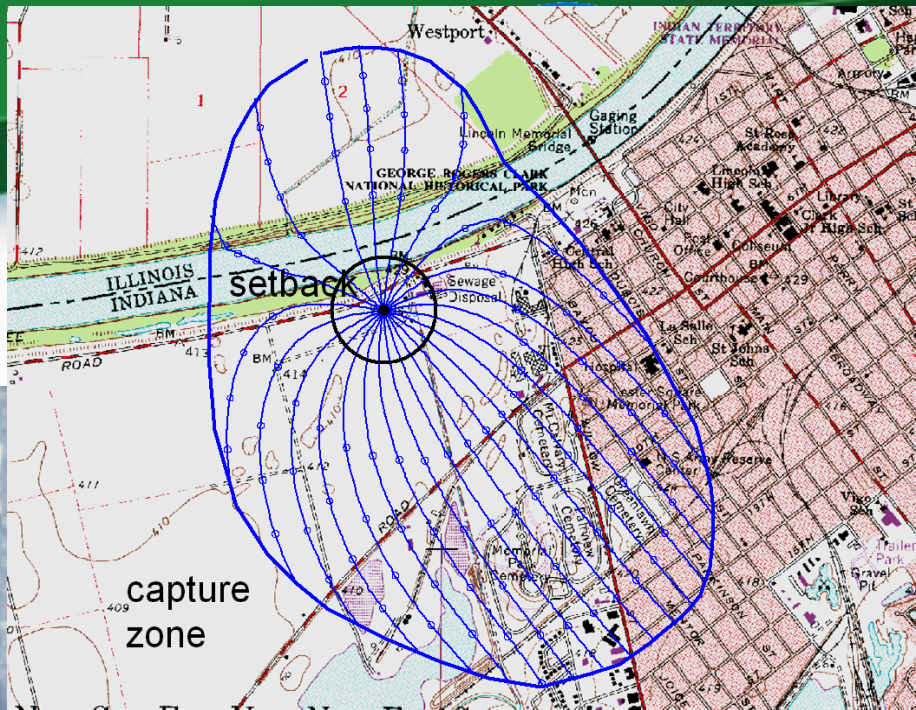
United States Environmental Protection Agency | Office of Research and Development | EPA/600/R-94/210 | Washington DC 20460 | December 1994

WhAEM: Program Documentation for the Wellhead Analytic Element Model

Henk Haitjema
Jack Wittman
Vic Kelson
Nancy Bauch

Win 3.1



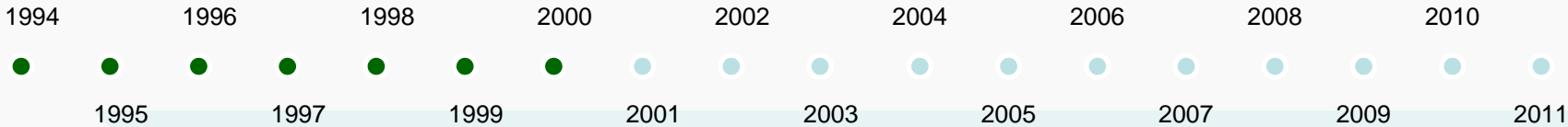


Office of Research and Development
Office of Ground Water and Drinking Water

WHAEMTM2000

Principal Investigator and Solver, Dr. **Henk Haitjema**, Haitjema Consulting, www.haitjema.com
 Graphical User Interface, Dr. **Vic Kelson**, Wittman Hydro Planning Assoc., www.wittmanhydro.com
Mike Galvin, **Stephen Alberty**, **Jim Evans**, Computer Sciences Corp., **Mart Haitjema**, Haitjema Consult.
 Project Officer, Dr. **Steve Kraemer**, EPA Ecosystems Research Division, www.epa.gov/athens
kraemer.stephen@epa.gov

WHAEM2000 is placed in the public domain, with some restrictions. The software and documentation may be freely copied and distributed. The graphical user interface and solver (GFLOW1) are copyrighted by Haitjema Software, a subdivision of Haitjema Consulting, Inc., and are open source (see the Artistic License in the file AL.txt). The utilities "gzip/gunzip" and "tar" are free software and available from www.gnu.org/directory/GNU/ (see the file COPYING.txt).

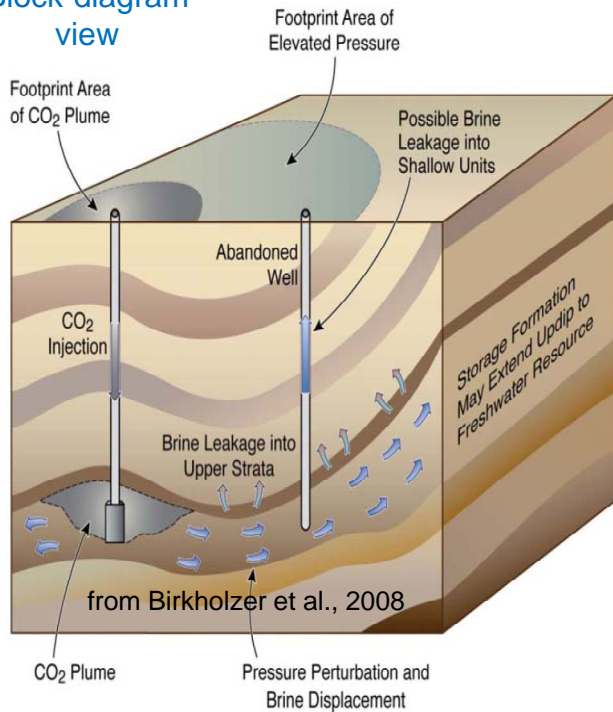


EPA Issue: Underground Injection Control

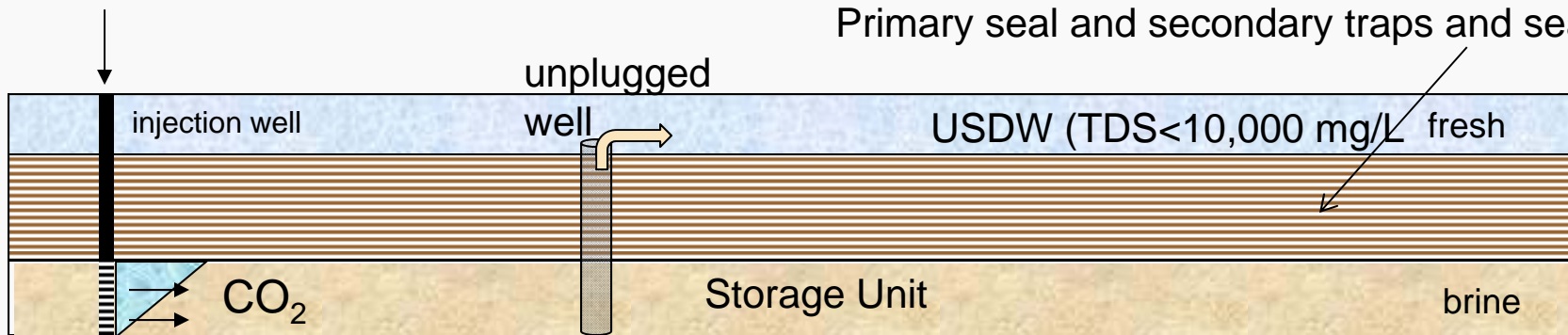
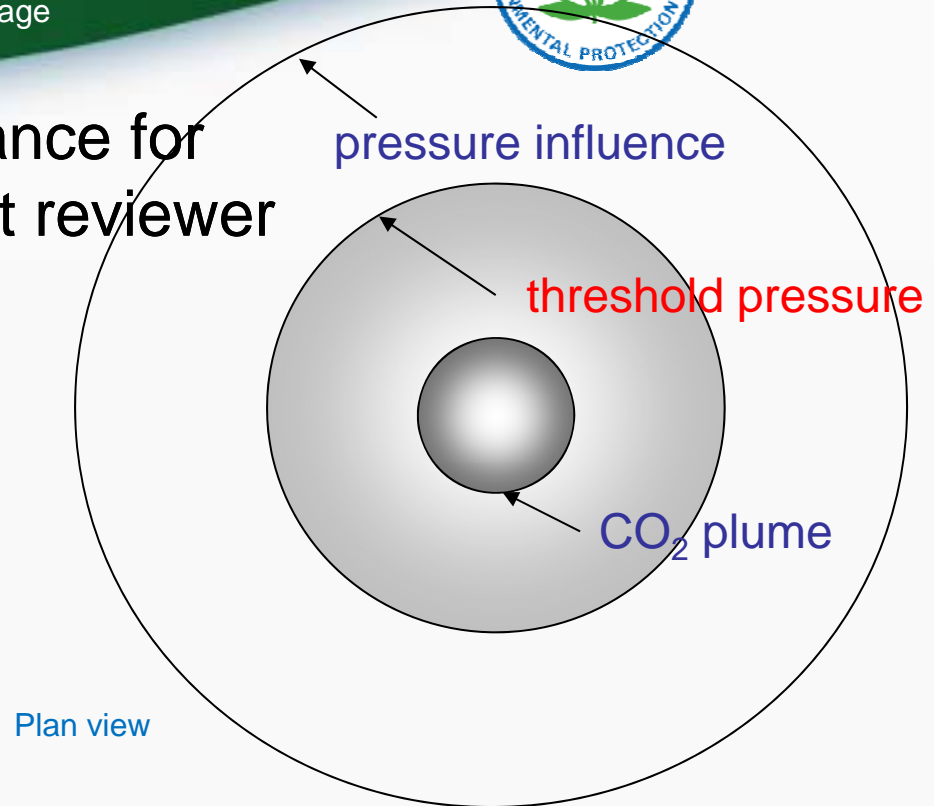


Area of Potential Impact (AoPI) , semi-analytical modeling and mapping
 Maximum monitoring area, greenhouse gas leakage

Block-diagram view



Guidance for permit reviewer



Cross-sectional view



TTim

TTim
A Multi-Aquifer Transient Analytic Element Model
Version 0.01

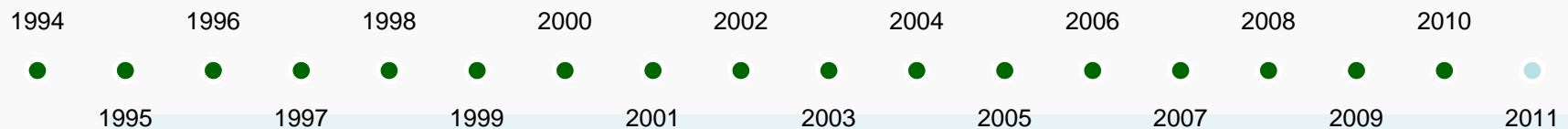
Mark Bakker
Water Resources Section, Civil Engineering and Geosciences
Delft University of Technology, Delft, The Netherlands
mark.bakker@tudelft.nl
December 9, 2010



Developed in cooperation with SS
Papadopolus & Associates

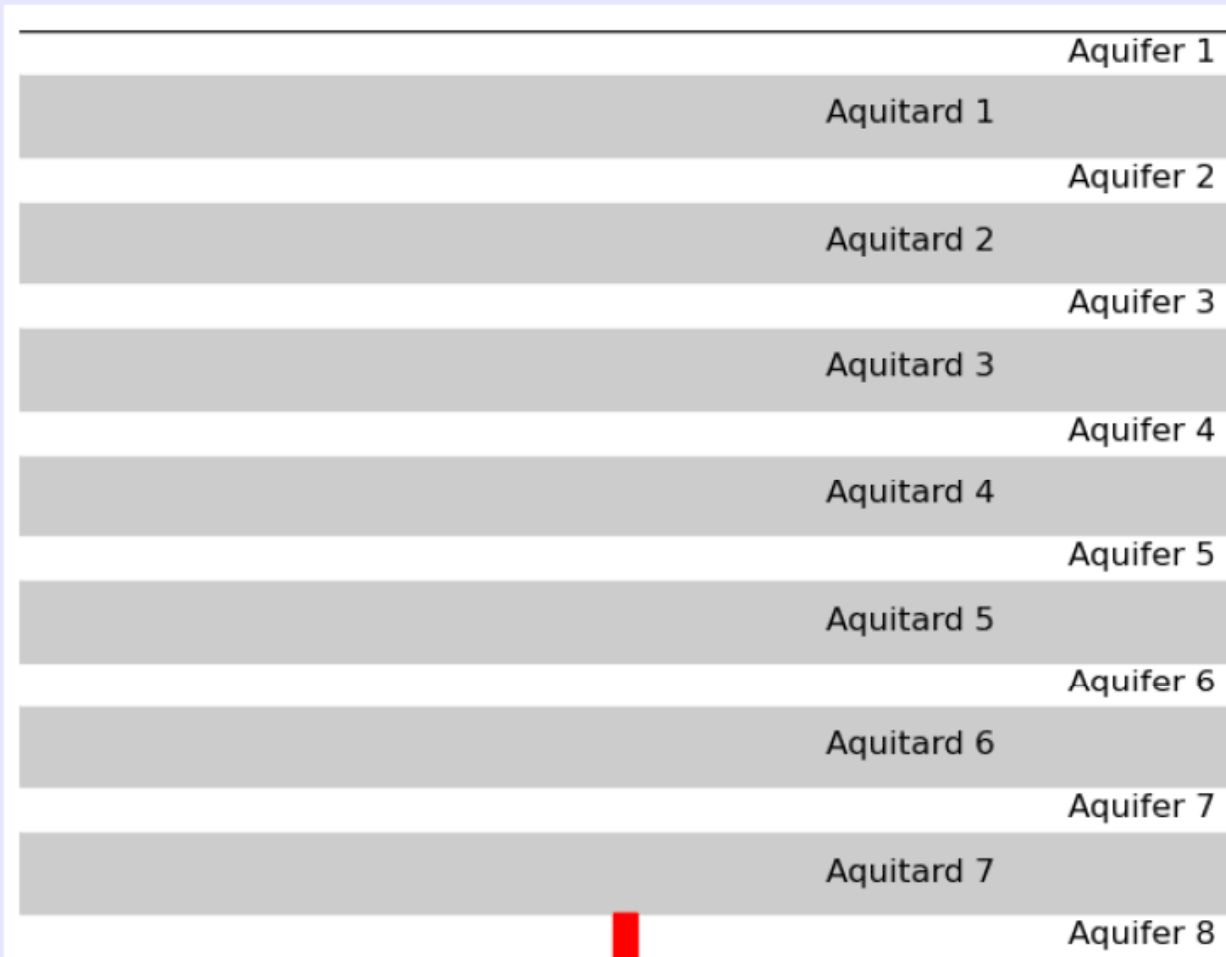
Sponsor:
EPA Athens, GA

(Bakker, Kuhlman, 2011, AWR)



TTim is introduced through an example of a system with eight layers

Example: Jens T. Birkholzer, Quanlin Zhou, Chin-Fu Tsang, 2009, international journal of greenhouse gas control 3 181–194



injection

Thickness:
Aquifer $H = 60$ m
Aquitard $H = 100$ m

Permeability:
Aquifer $k = 10^{-13}$ m²
Aquitard $k = 10^{-18}$ m²

Injection of CO₂:
1.52 million tons/year
for 30 years

Pressure build-up in injection layer, 10 km from injection well.

TTim gives almost same results as Tough2/Eco2N

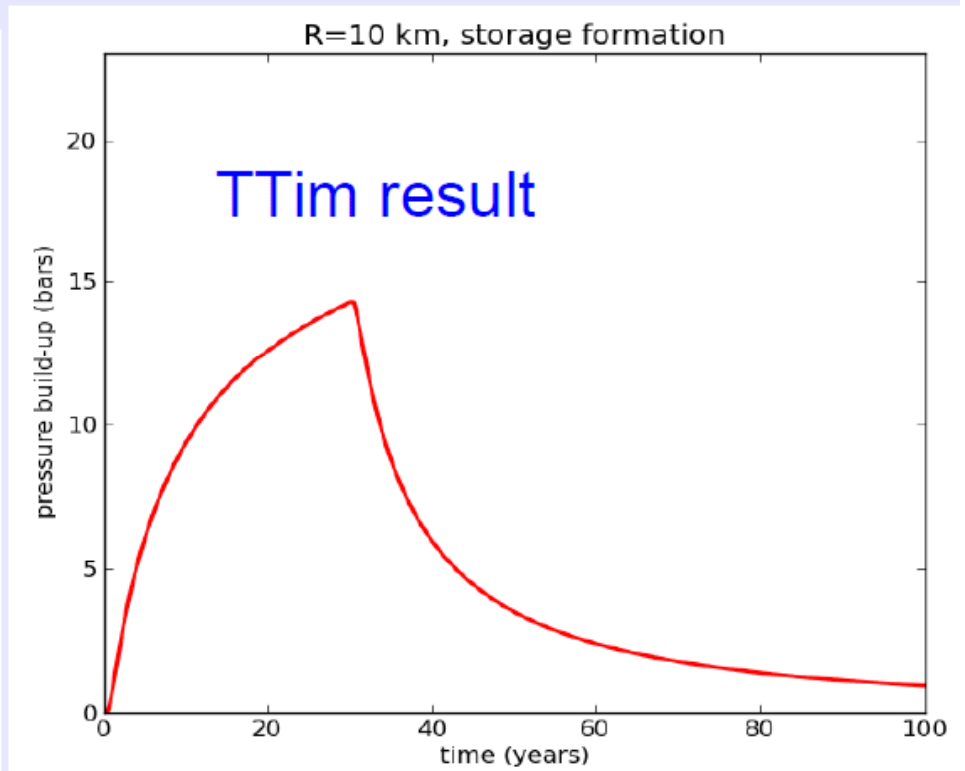
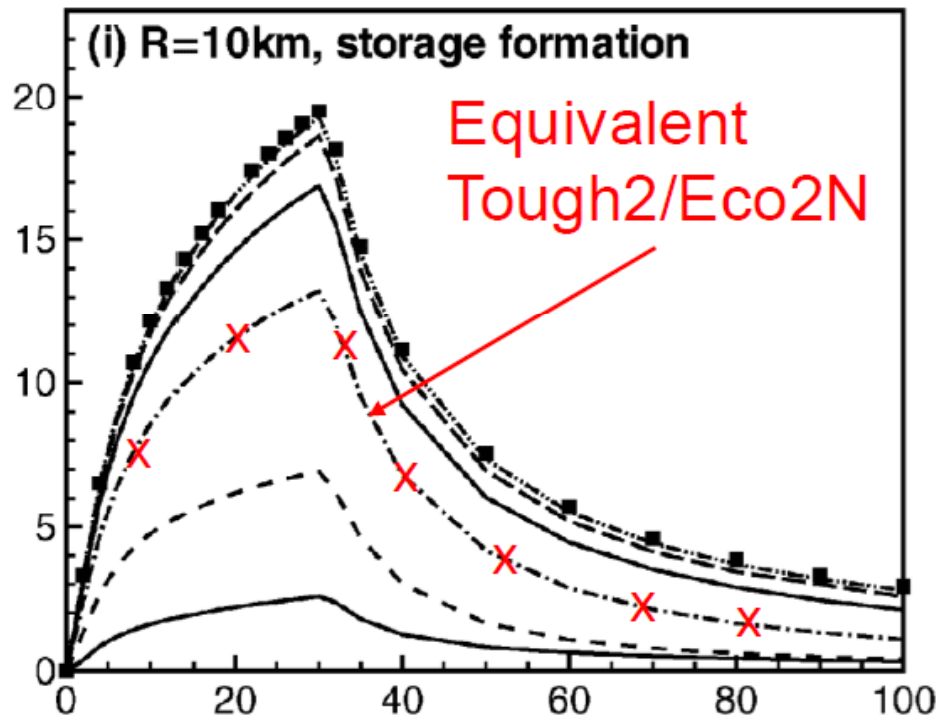
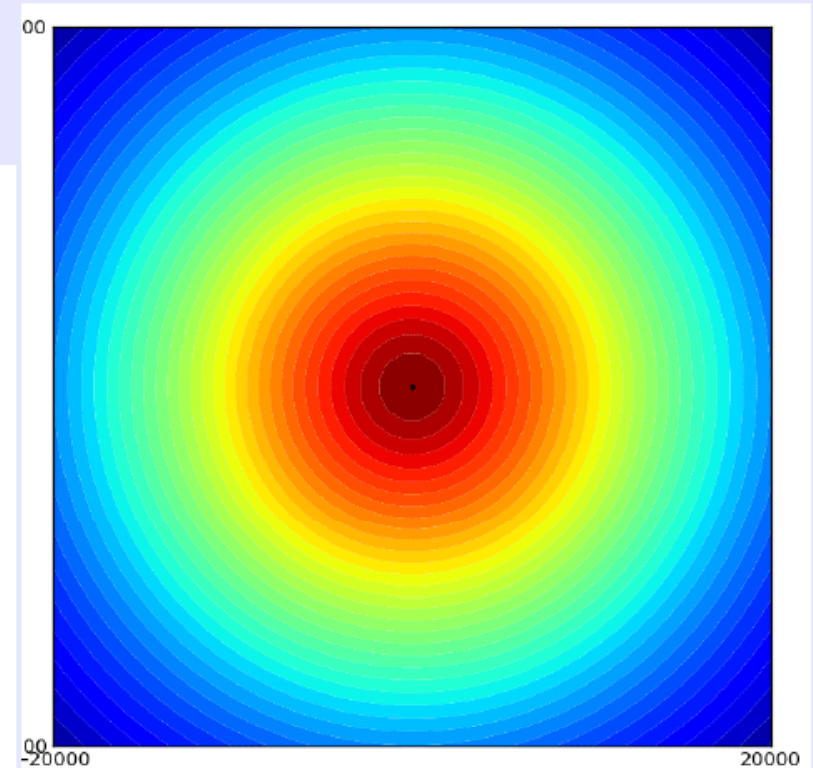
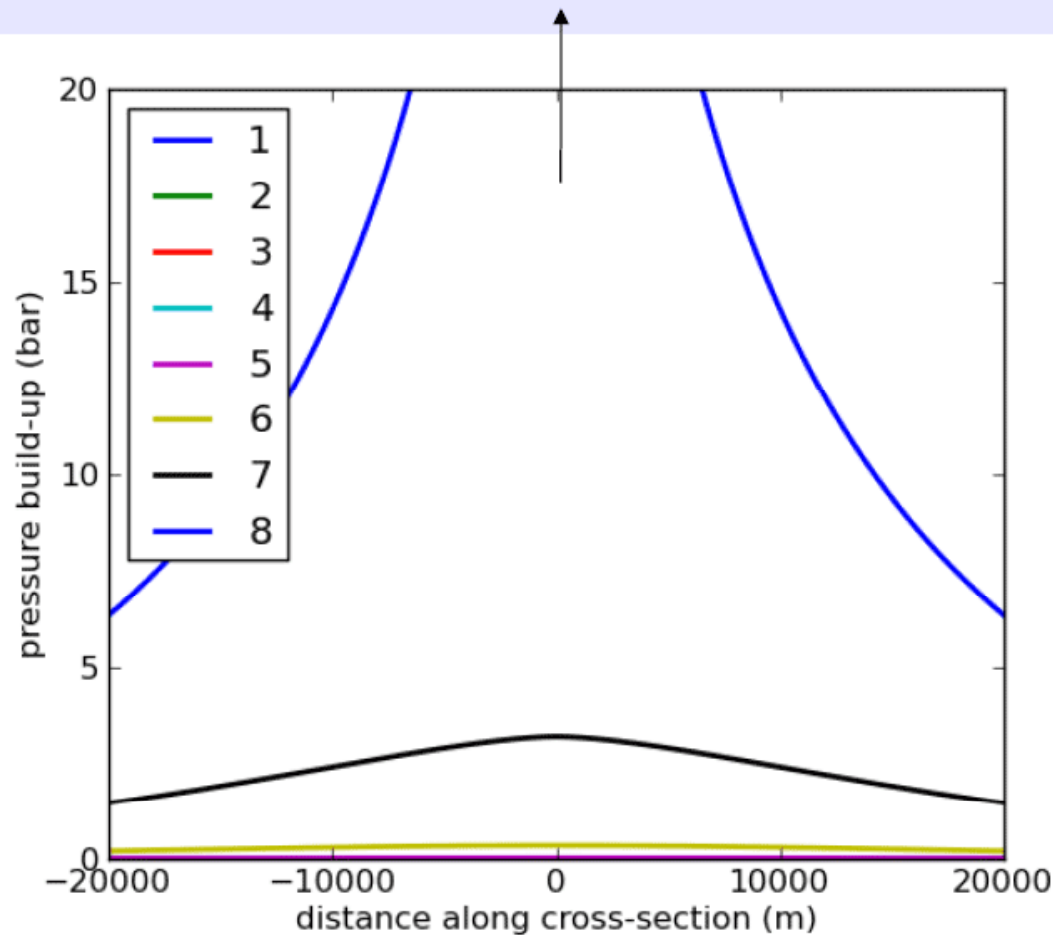


Figure 7, Birkholzer et al., 2009, International journal of greenhouse gas control 3 181–194

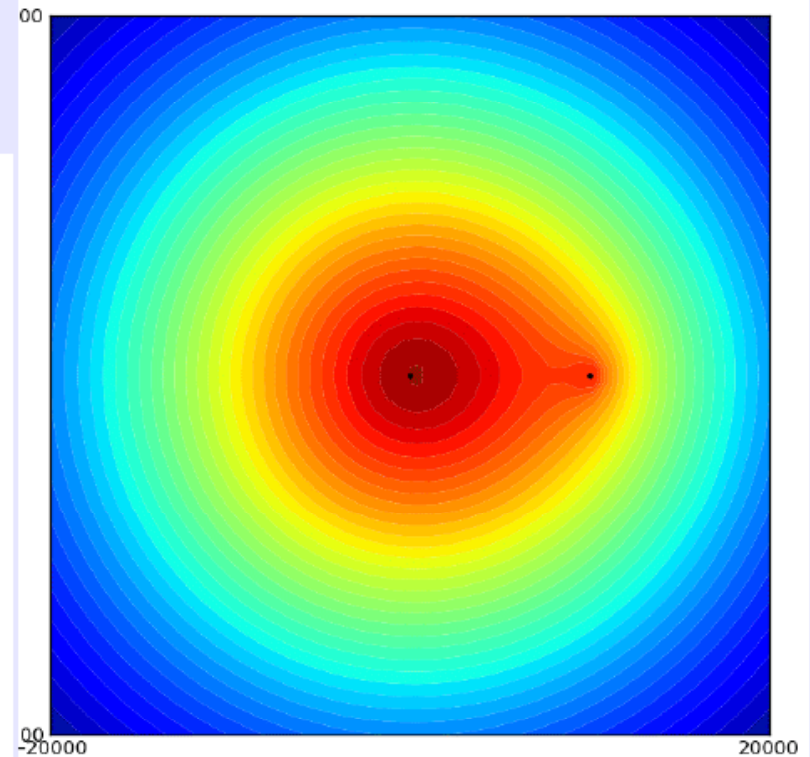
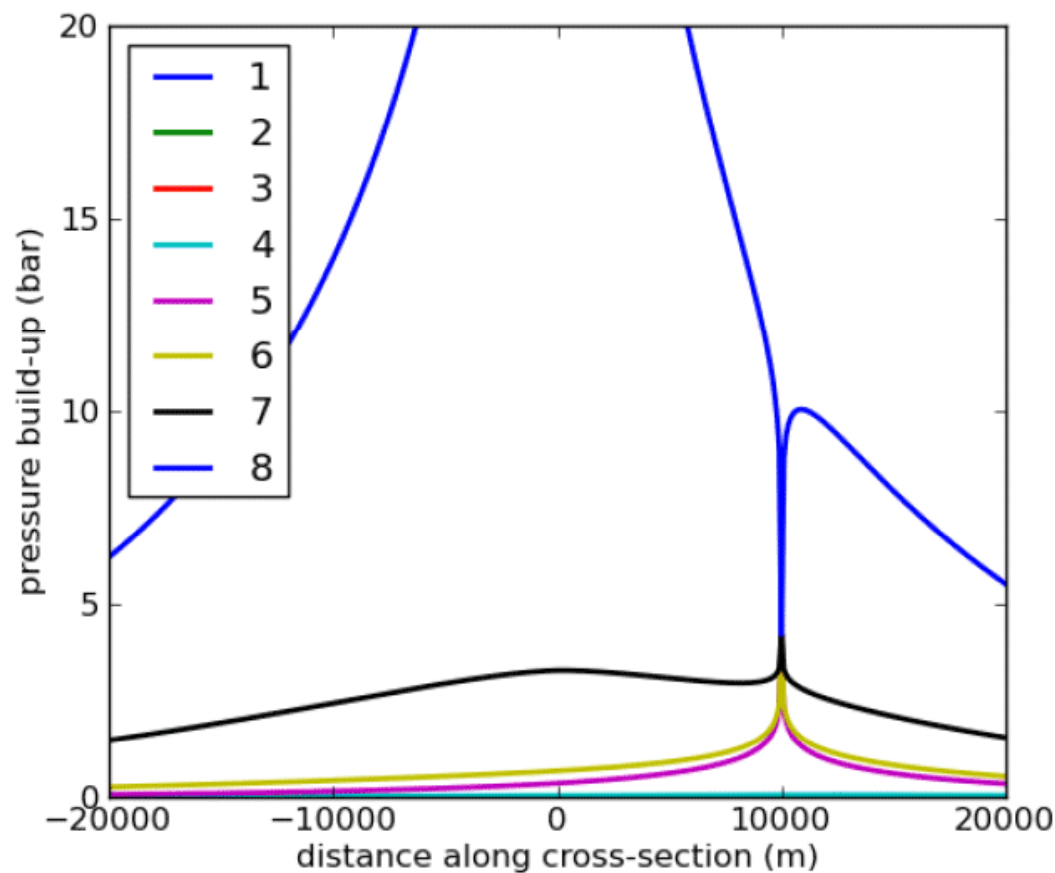
TTim contour plot and cross-section along line through injection well, after 30 years of injection

pressure build-up in injection layer much higher (~100 bar)



injection layer

Time pressure distribution with abandoned well 10 km from injection well screened in layers 5-8



injection layer

BAEM v0.1 – desktop interface

BASINS Analytic Element Model



CAMELOT plug-in

TTim plug-in



CZAEM (you will need DOS virtual machine)

<http://www.epa.gov/ada>

WhAEM²⁰⁰⁰

<http://www.epa.gov/athens>

T Tim

<http://ttim.googlecode.com>

BAEM

(coming soon)

<http://www.analyticelements.org>