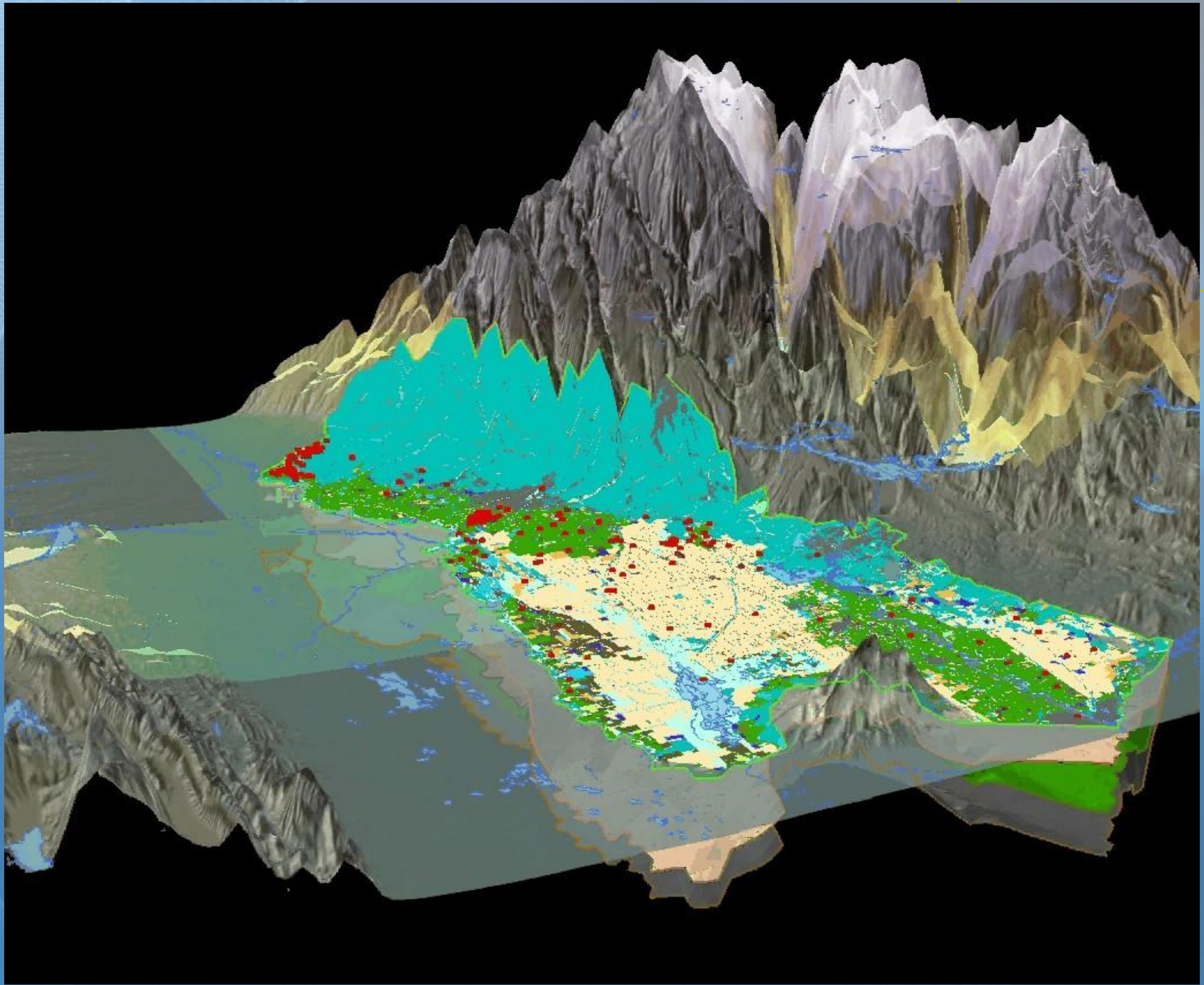
2013 NGWA Summit

DYNSYSTEM – Lessons Learned From 30 Years of Finite Element Modeling Applications



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San Antonio, Texas
April 29, 2013

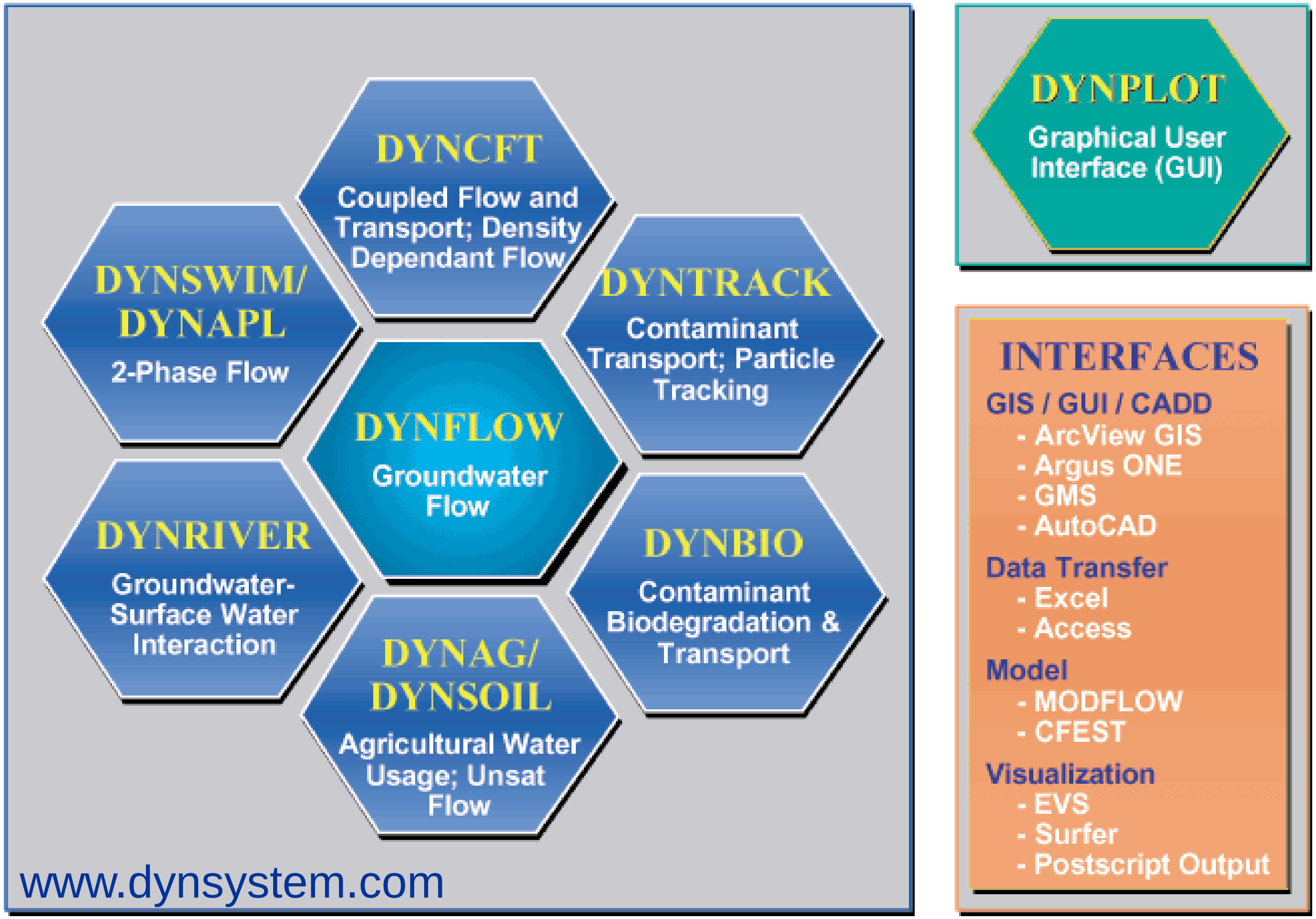
CDM Smith

DYNSYSTEM – Lessons Learned From 30 Years of Finite Element Modeling Applications

- Evolution and development of DYNSYSTEM finite element modeling codes (History - Timeline format)
- Experience
  - 200+ model applications conducted over 30 years
  - Used in litigation cases
- Features - Production-oriented, modeler-oriented code

1976 Aquifem → **1978 Aquifem-N** → **1980 DYNFLOW** → **1982 DYNTRACK** → **Early GUI** → **IGWMC Review** → **Iterative Solvers**

DYNSYSTEM


DYNCFT
Coupled Flow and Transport; Density Dependant Flow
DYNSWIM/ DYNAPL
2-Phase Flow
DYNTRACK
Contaminant Transport; Particle Tracking
DYNFLOW
Groundwater Flow
DYNRIVER
Groundwater-Surface Water Interaction
DYNBIO
Contaminant Biodegradation & Transport
DYNAG/ DYNSOIL
Agricultural Water Usage; Unsat Flow
www.dynsystem.com
DYNPLOT
Graphical User Interface (GUI)
INTERFACES
GIS / GUI / CADD
- ArcView GIS
- Argus ONE
- GMS
- AutoCAD
Data Transfer
- Excel
- Access
Model
- MODFLOW
- CFEST
Visualization
- EVS
- Surfer
- Postscript Output

AQUIFEM-DYNSYSTEM "Genealogy"

- Late 1950s-1960s: Early Finite Element model development for structural engineering
- Late 1960s-Early 1970s: CAFE/DISPER coastal simulation and dispersion models
- Early 1970s: CAFE converted to AQUIFEM (single layer groundwater flow simulation)
- Late 1970s – Early 1980s: AQUIFEM-N (multi-layer simulation) and DISPER-GW developed
- Early 1980s: AQUIFEM-N upgraded/converted to DYNFLOW by CDM
- 1980s: DYNTRACK and DYNPLOT

1976 Aquifem → 1978 Aquifem-N → 1980 DYNFLOW → 1982 DYNTRACK → Early GUI → IGWMC Review → Iterative Solvers

AQUIFEM and AQUIFEM-N, 1970s

- 2D and quasi 3D / multi-layer
- Groundwater Flow and Mass Transport
- Example applications:
  - Coal strip-mine dewatering & blow-out prevention
  - Plume impacts on New England pond
- Major limitations:
  - Grid size and detail
  - Numerical problems

1976 Aquifem → 1978 Aquifem-N → 1980 DYNFLOW → 1982 DYNTRACK → Early GUI → IGWMC Review → Iterative Solvers

DYNFLOW and DYNTRACK, 1980s

- Requirements
  - Groundwater flow simulation code with companion mass transport simulation code
  - Fully 3D
  - Limit numerical dispersion
- Solution
  - Finite element codes DYNFLOW and DYNTRACK
  - Mass Transport: Random Walk Method

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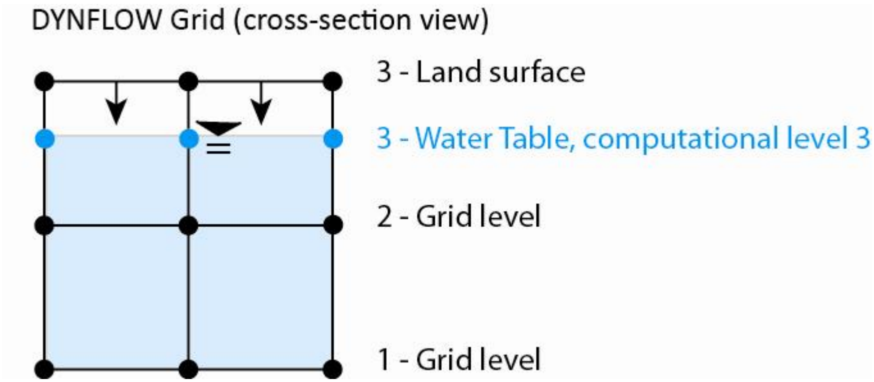
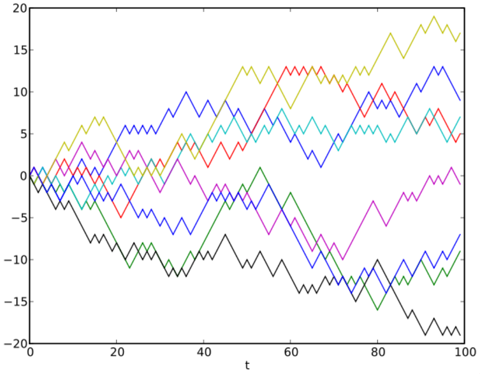
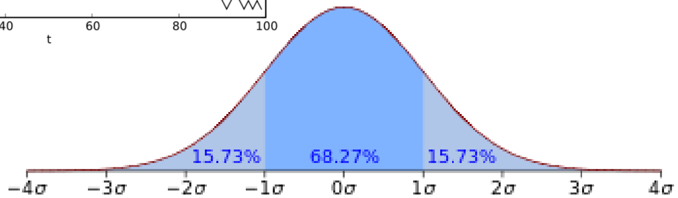
Key Features of DYNFLOW and DYNTRACK

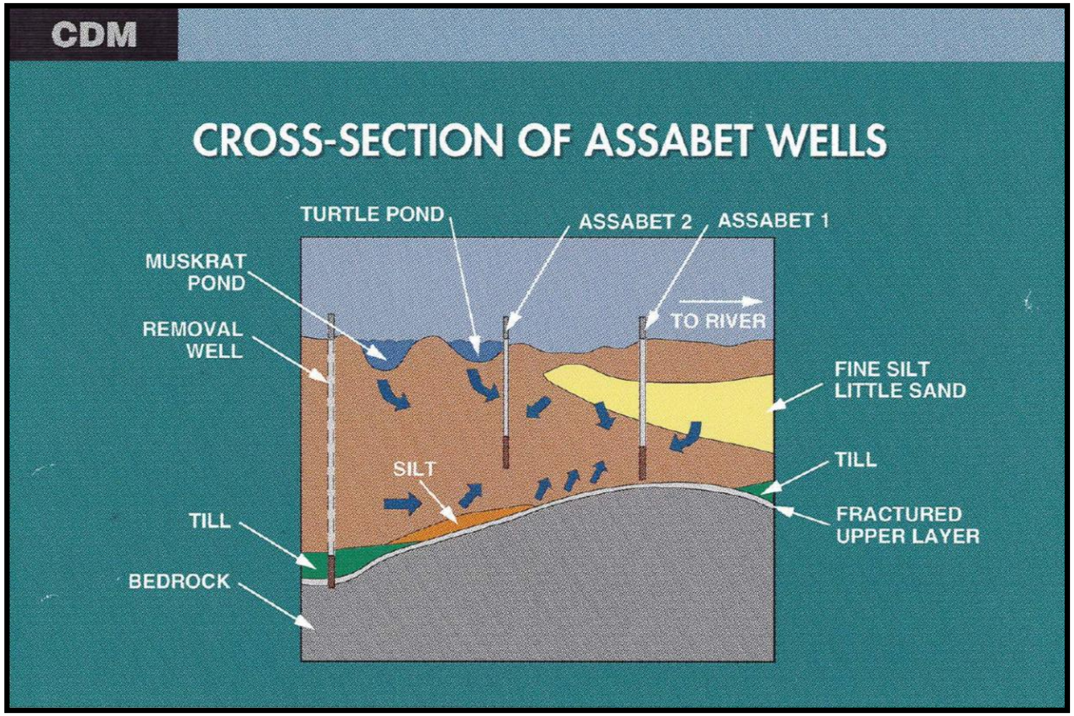
- Node-based calculations
- Explicit representation of model layers
- “Telescoping” water table representation
- Triangular grid
- Random Walk Method – transport independent of model grid







DYNFLOW and DYNTRACK, 1980s
Grace - Acton, Massachusetts



- First DYNTRACK application
- Identified unexpected contaminant pathway through fractured rock to supply wells
- Used to design targeted remedial pumping scheme that successfully protected the supply wells

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DYNFLOW and DYNTRACK, 1980s
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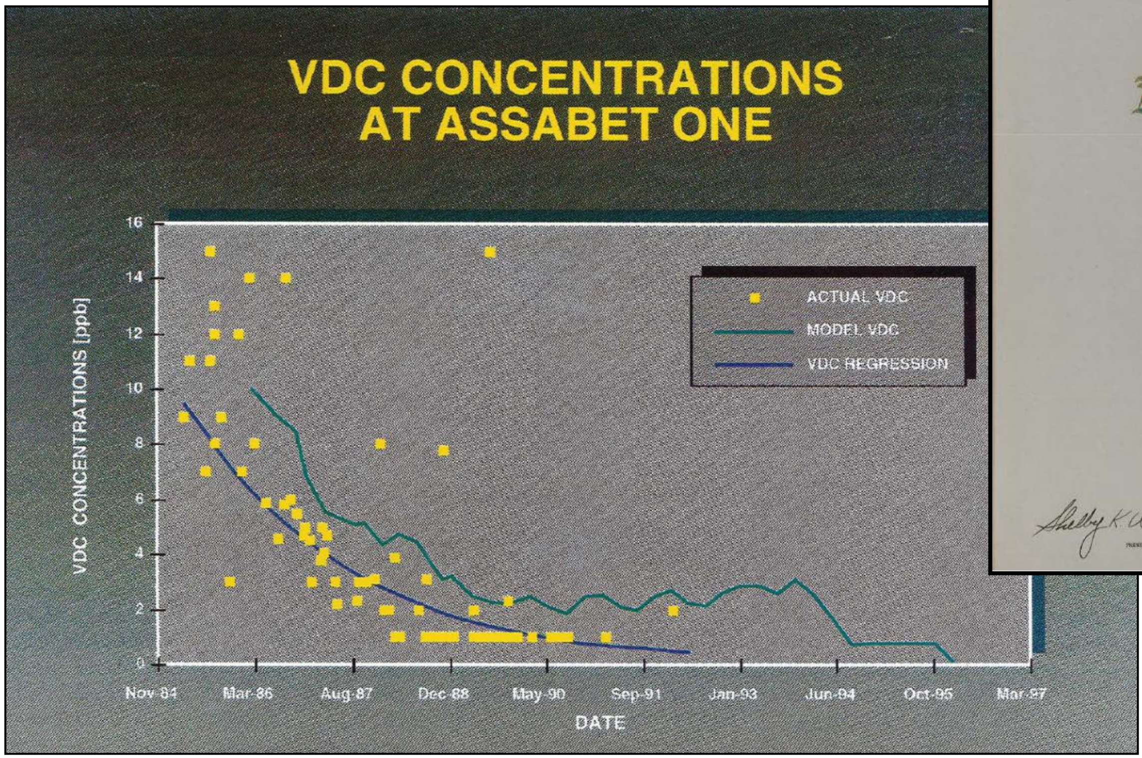

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International Groundwater Modeling Center Review 1985

- Early nationwide Superfund applications
- International Ground Water Modeling Center (IGWMC) review of DYNSYSTEM source codes
- Test cases
- June 1985: "… DYNFLOW and DYNTRACK computer codes are appropriate for use in simulating ground-water flow and contaminant transport at the Price Landfill site." (USEPA Office of Waste Program Enforcement, 1985)

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Iterative Solvers – mid to late 1980s

- Gauss Elimination Solver: Memory Intensive and Slow
- Iterative Solvers (successive over-relaxation, conjugate gradient, algebraic multi-grid) advanced practical modeling capability
  - Implementation on PCs
  - More detailed multi-layered models
  - Transient Simulations

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DYNFLOW and DYNTRACK, late 1980s
Nassau County, New York

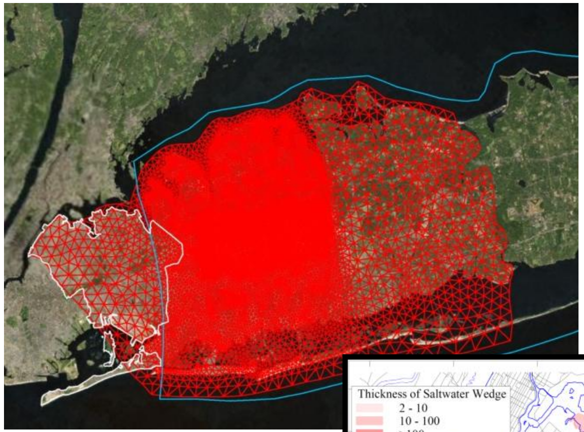
- First PC application of DYNFLOW
- Objective: Evaluate NYSDEC imposed cap on County pumping
- Shared model with County and trained County staff
- County staff continued model applications independently

1976 Aquifem → **1978 Aquifem-N** → **1980 DYNFLOW** → **1982 DYNTRACK** → **Early GUI** → **IGWMC Review** → **Iterative Solvers**

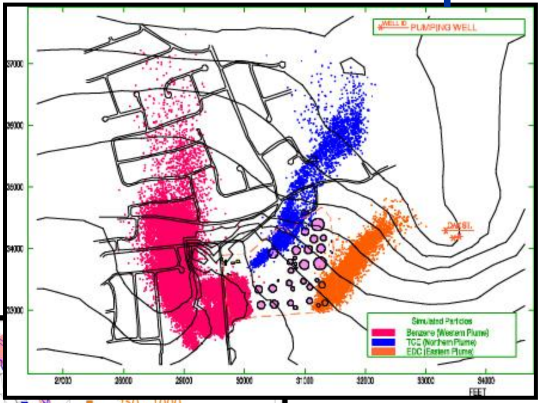
Nassau County Model Expansion and Applications 1990-Present

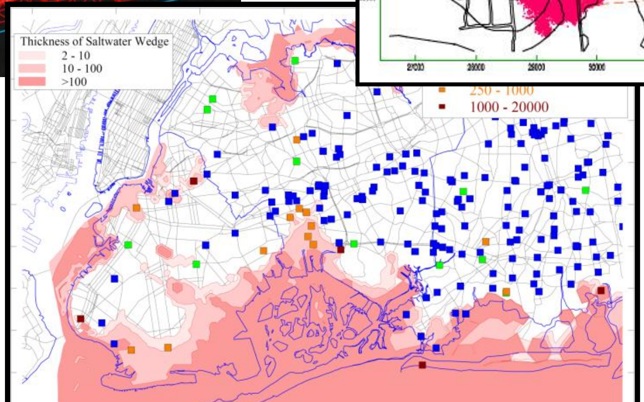
Suffolk County Models

Source Water Assessment



Contaminant Transport





Salt Water Intrusion

Iterative Solvers → 1988 PC Version → 1989 DYNPLOT → 1990 DYNSWIM → 1992 Auto Grid Gen → 1993 DYNAPL → 1995 Link to GIS

Automatic Grid Generation and Grid Editing 1992

Initial Demonstration, 1992

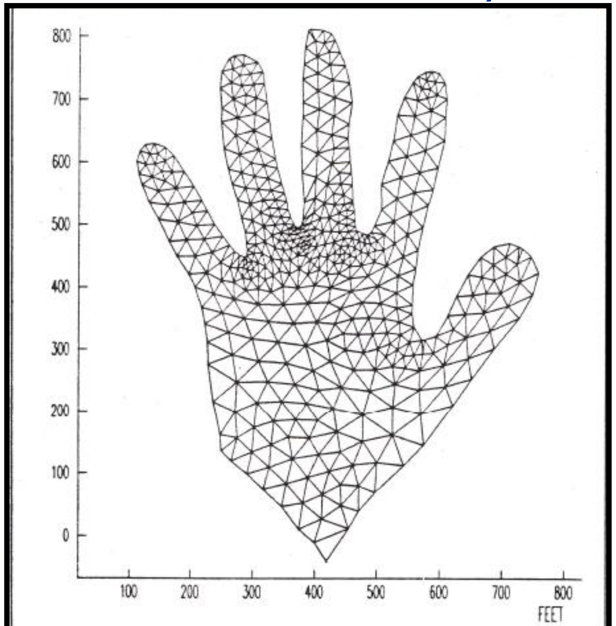


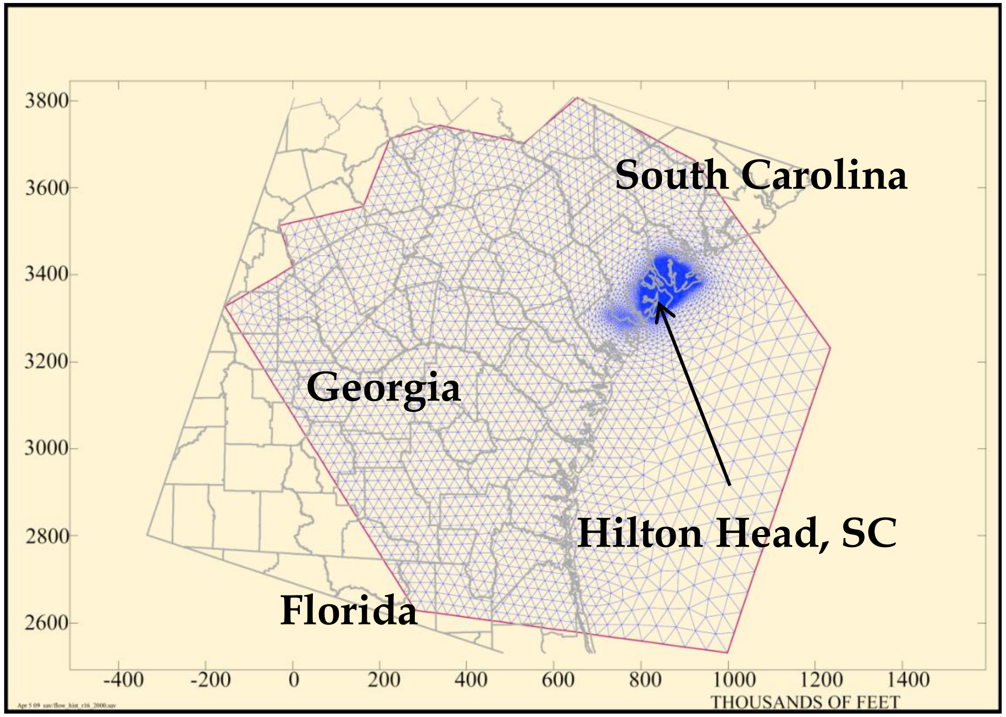
Figure 3 - Example of Grid Created using GRIDGEN

The ability to quickly create and modify computational grids overcame one of the largest impediments to finite element modeling.

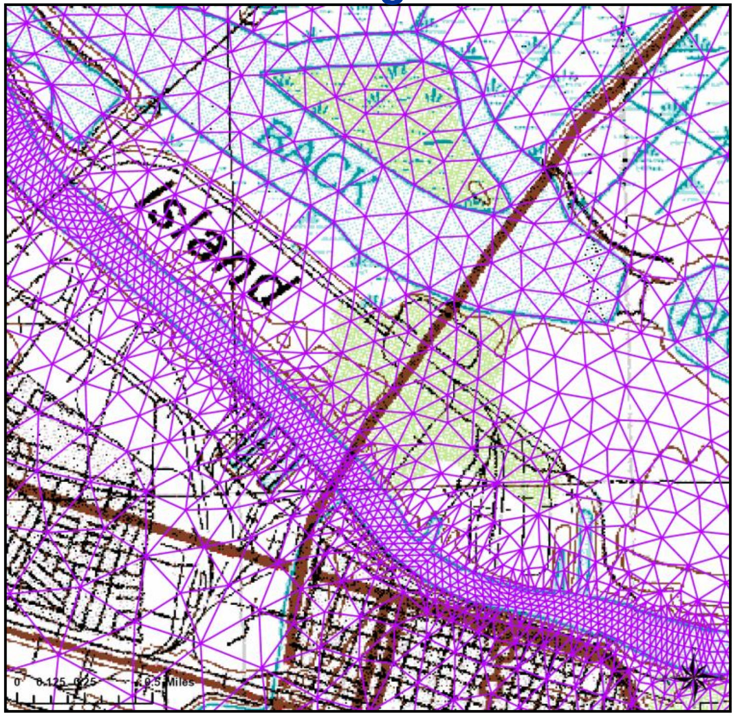
Iterative Solvers → 1988 PC Version → 1989 DYNPLOT → 1990 DYNSWIM → **1992 Auto Grid Gen** → 1993 DYNAPL → 1995 Link to GIS

Automatic Grid Generation

Savannah and Hilton Head Studies, Converted USGS Coastal Model



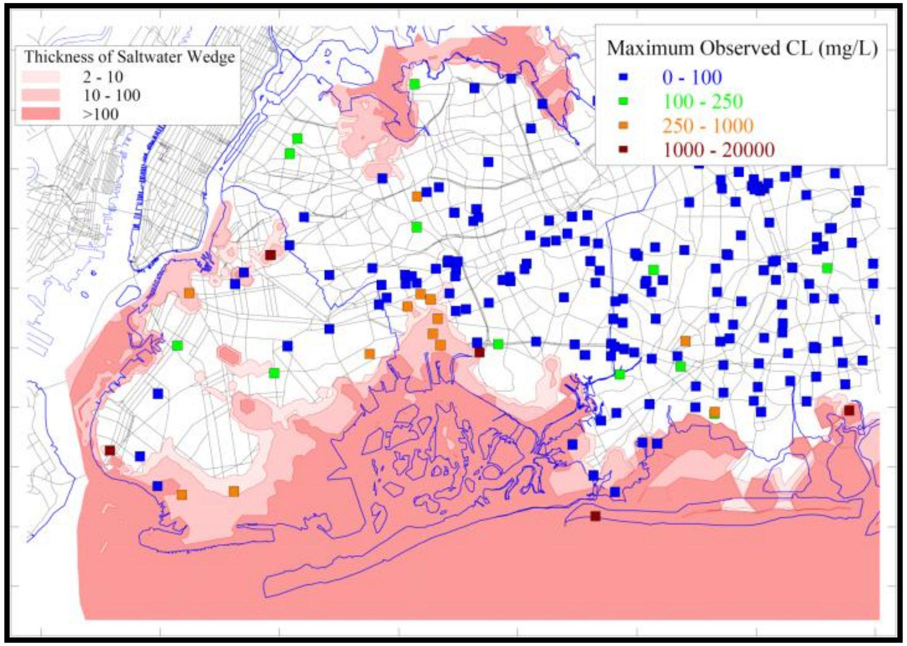
Savannah Harbor Study, Grid Detail Along River



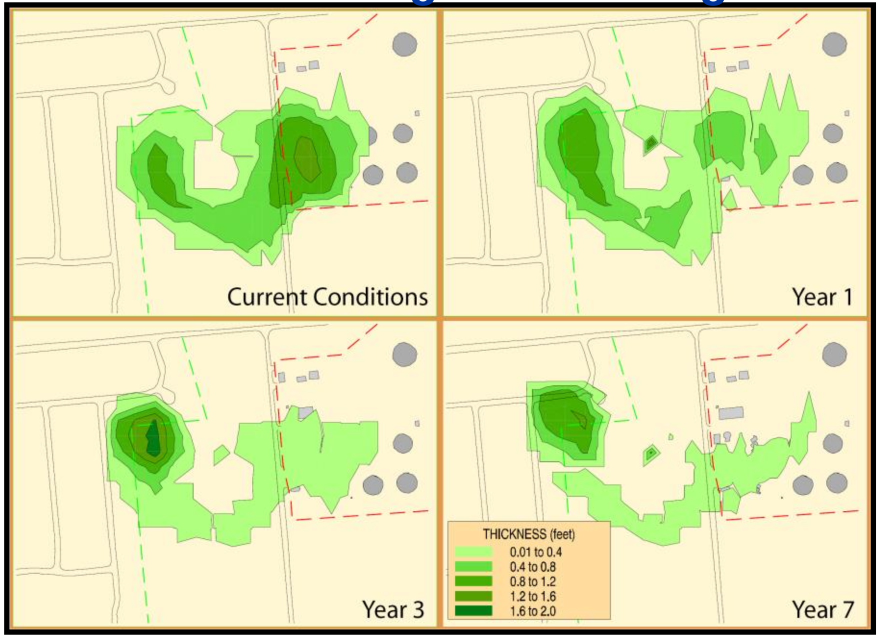
Iterative Solvers → 1988 PC Version → 1989 DYNPLOT → 1990 DYNSWIM → **1992 Auto Grid Gen** → 1993 DYNAPL → 1995 Link to GIS

DYNSWIM/DYNAPL

Salt Water Intrusion



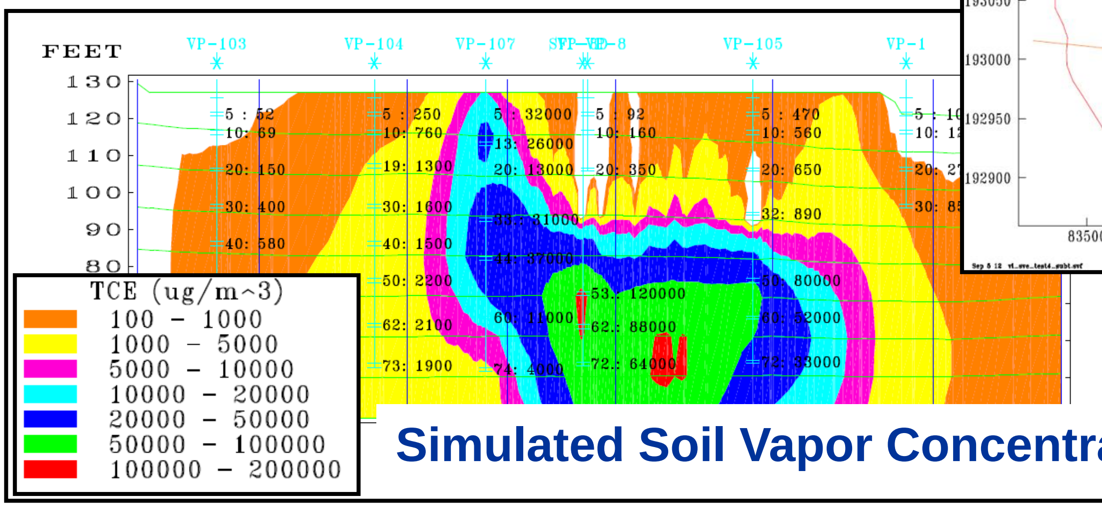
Floating Product Migration



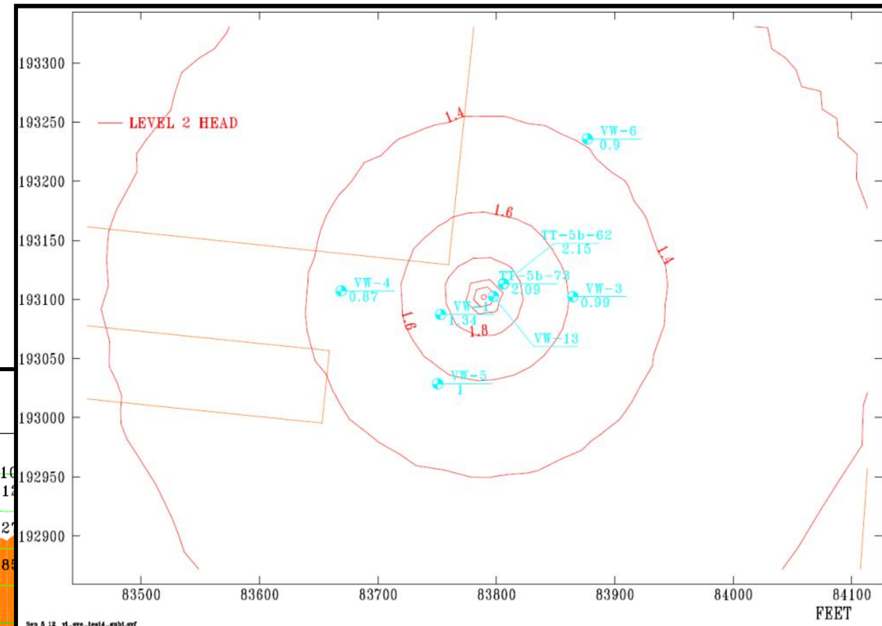
Iterative Solvers → 1988 PC Version → 1989 DYNPLOT → **1990 DYNSWIM** → 1992 Auto Grid Gen → **1993 DYNAPL** → 1995 Link to GIS

Vadose Zone Air Flow and Vapor Transport

- Modified DYNFLOW/DYNTRACK
- Applications: SVE and VOC Diffusion Studies



Simulated Soil Vapor Concentrations



Simulated Pressures during SVE Operations

1995 link to GIS → **DYNAIR DYNVAP** → 3-D and Animation → 2000 Couple F-T → Transient Input → Nonlinear Sorption → Unsat Zone Proc

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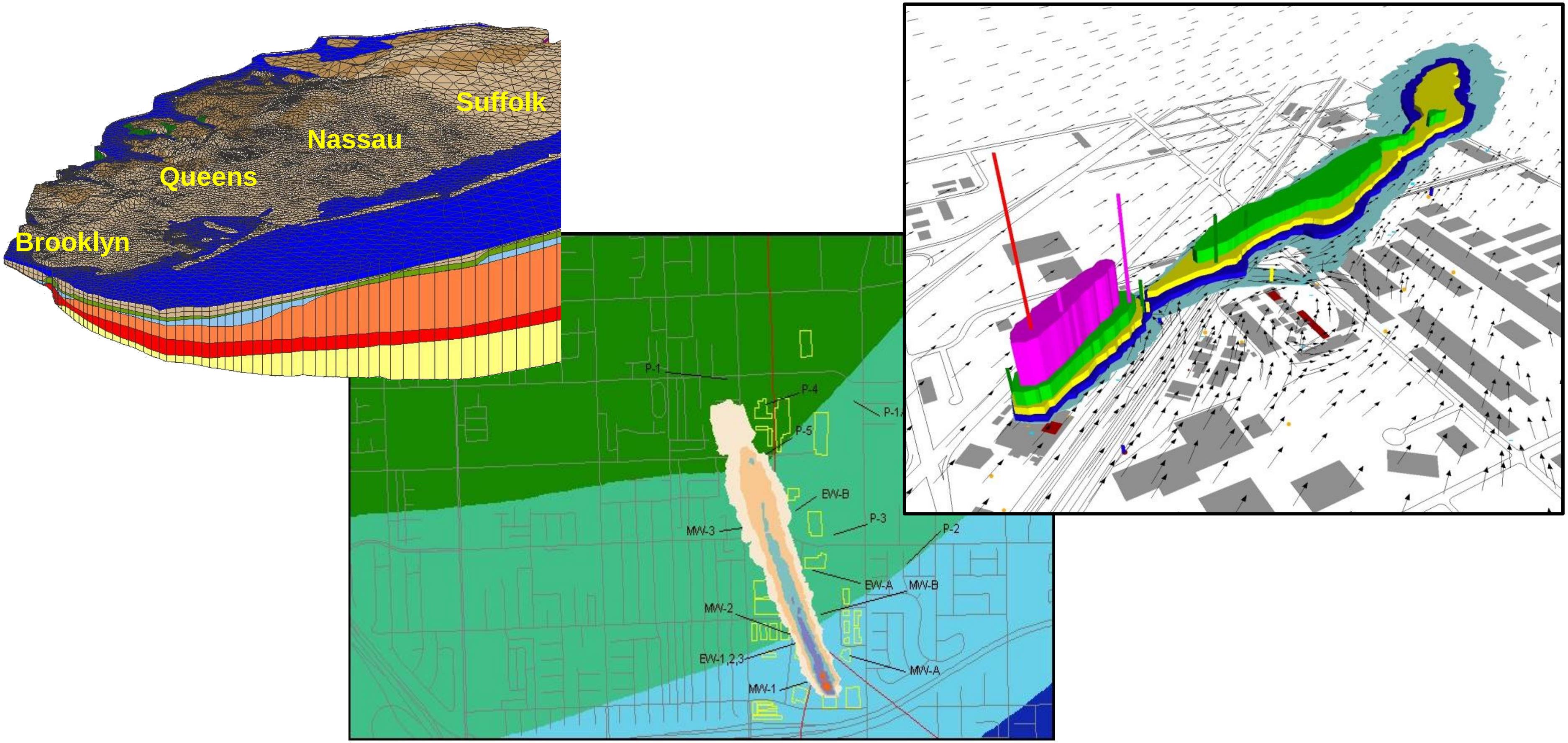
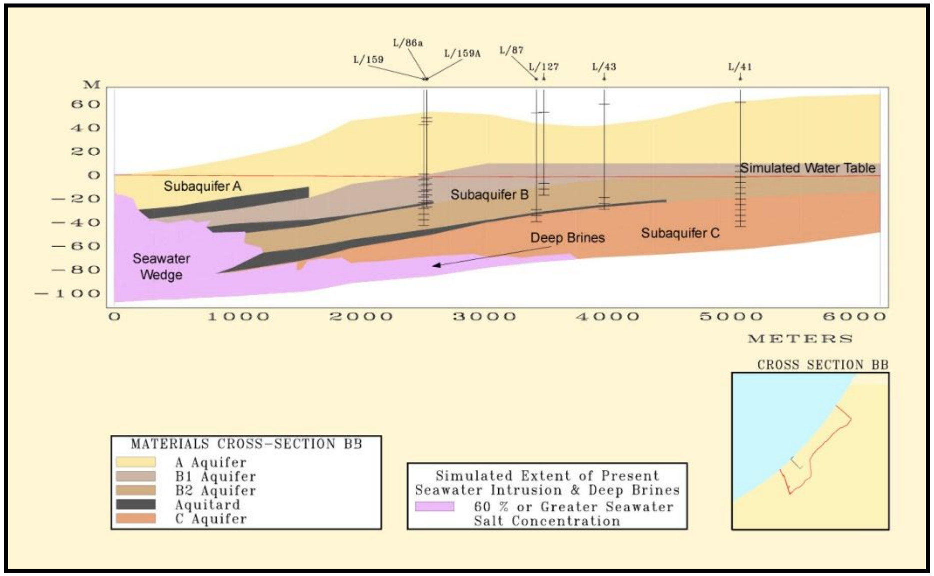
3D Graphics and Animation



1995 link to GIS → DYNAIR DYNVAP → **3-D and Animation** → 2000 Couple F-T → Transient Input → Nonlinear Sorption → Unsat Zone Proc

Coupled Flow and Transport (DYNCFT), 2000
Gaza Coastal Management Plan

Simulated Extent of Seawater

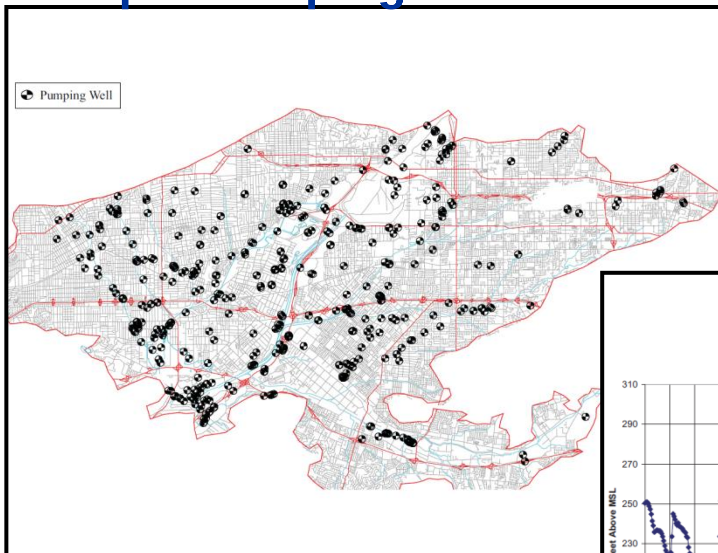


- Objective: Limit salt water intrusion
- SWI simulation requires detailed stress input
- Result: Input data processing developments (gage commands)
  - Long simulation periods
  - Overlapping data sets
  - Data gaps
  - Multiple sources

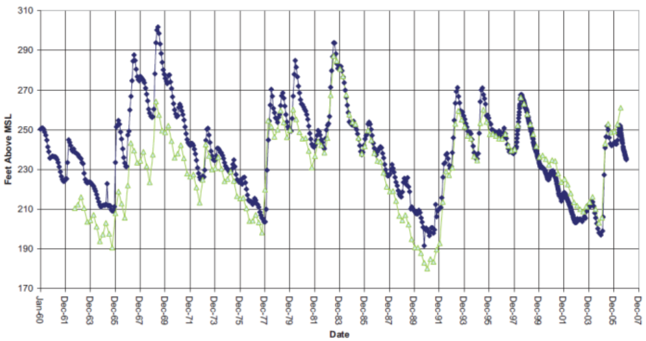
1995 link to GIS → DYNAIR DYNVAP → 3-D and Animation → **2000 Couple F-T** → **Transient Input** → Nonlinear Sorption → Unsat Zone Proc

San Gabriel Basin

Multiple Pumping Locations



- Transient boundary conditions input directly from tables independent of grid and time stepping has made extensive transient simulations

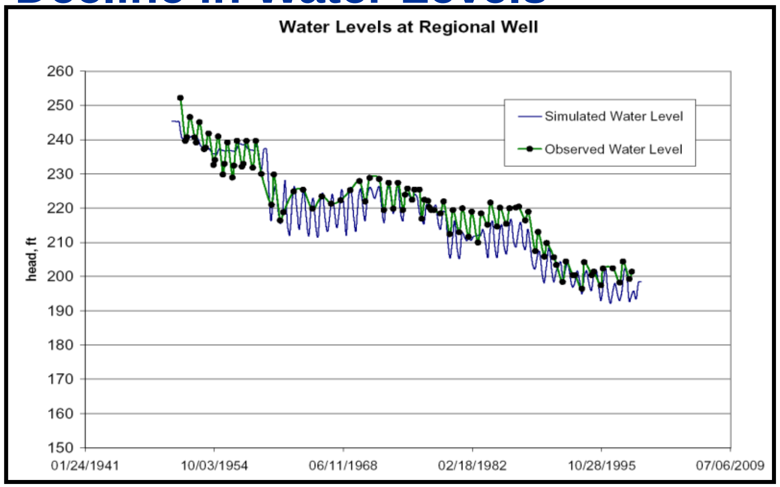


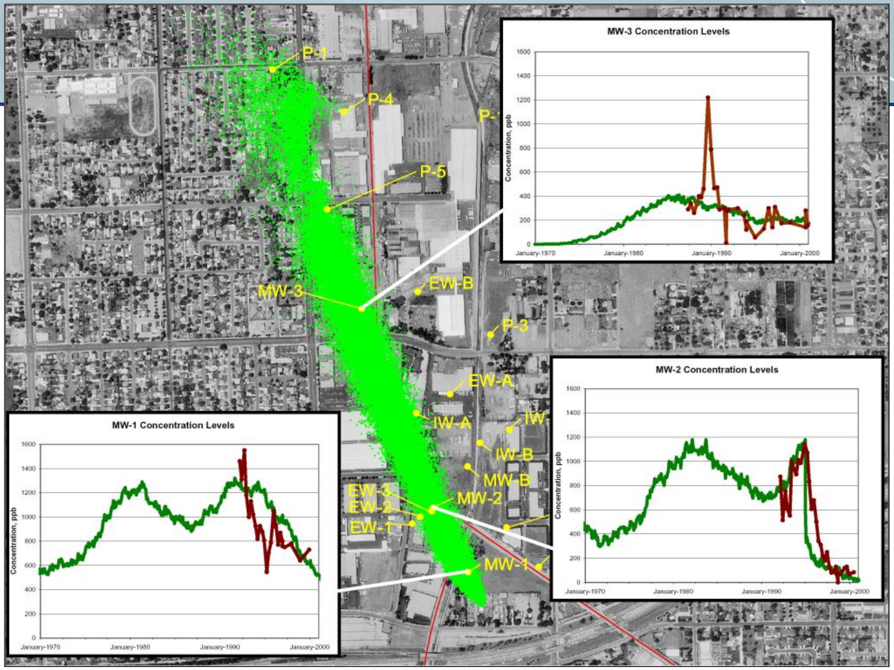
Water Level Variation

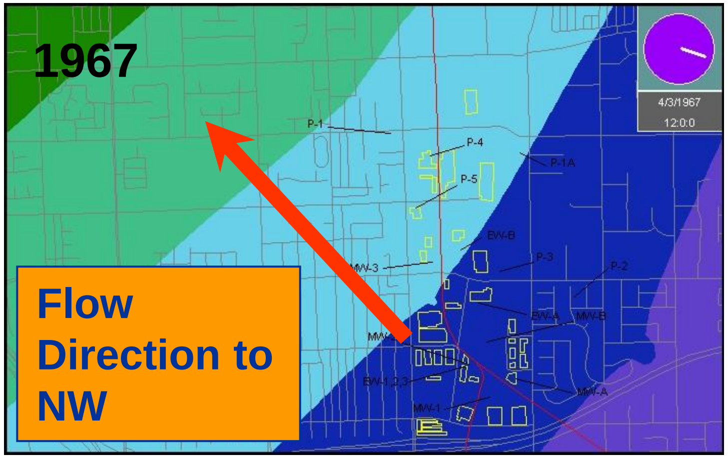
1995 link to GIS → DYNAIR DYNVAP → 3-D and Animation → 2000 Couple F-T → **Transient Input** → Nonlinear Sorption → Unsat Zone Proc

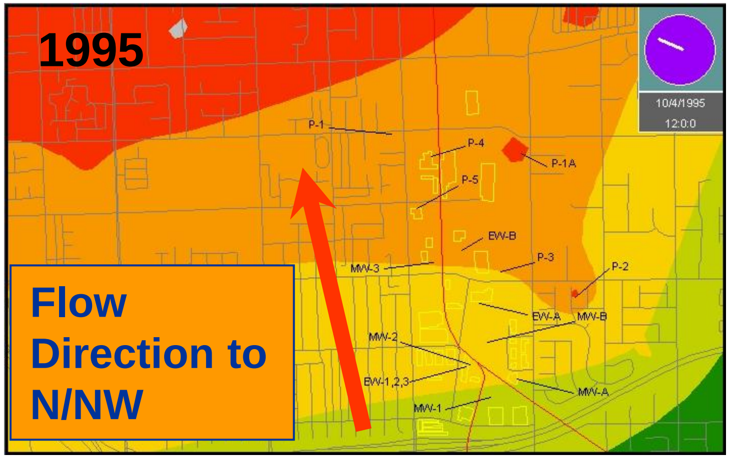
Impacts of Transient Conditions on Groundwater Plume Transport

Decline in Water Levels









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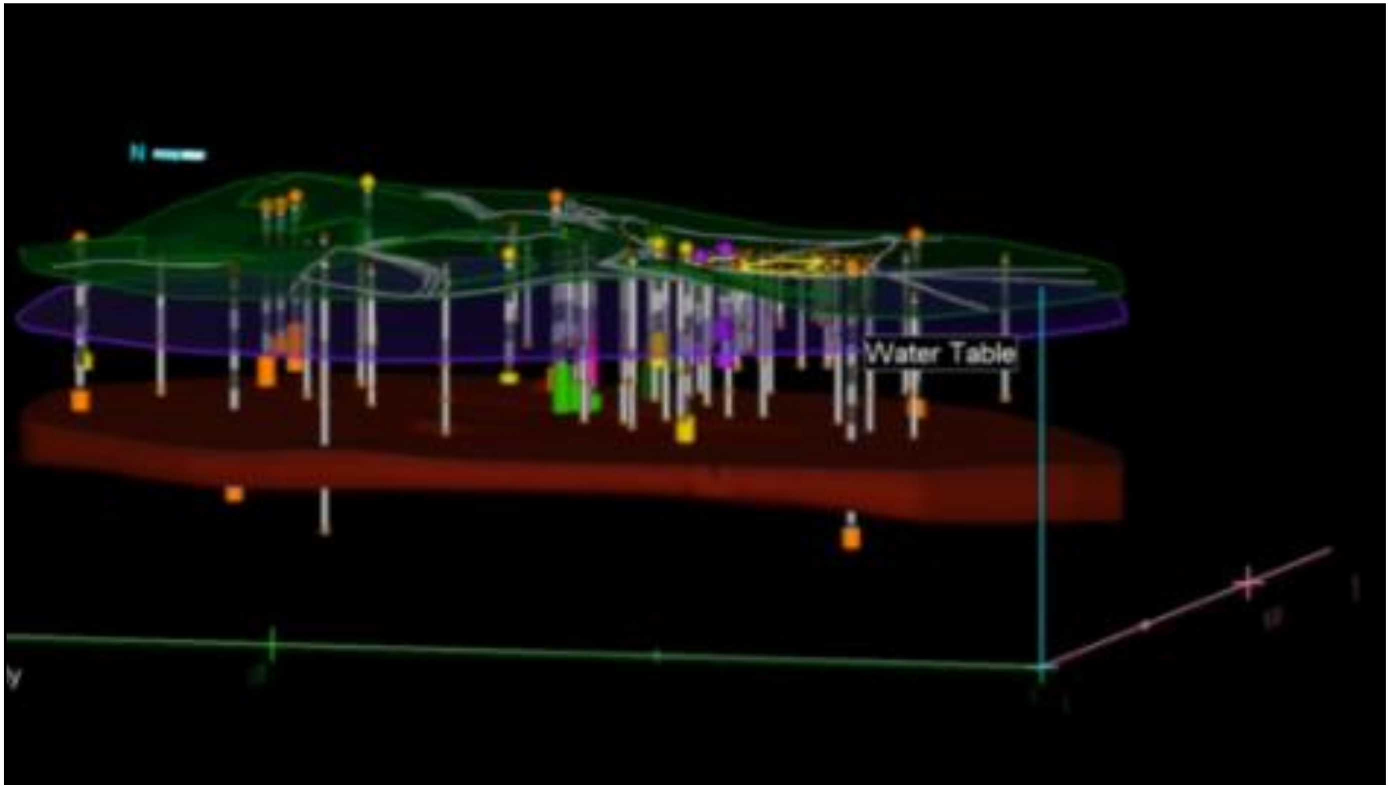
Ongoing Development - Linkage to 3D Visualization Software



Unsat Zone Proc → Non-Equil Sorption → Multiple Const → **2010 EVS/MVS** → 2011 Dual Porosity → 2012 Mass Flux → 2013 ISWMM

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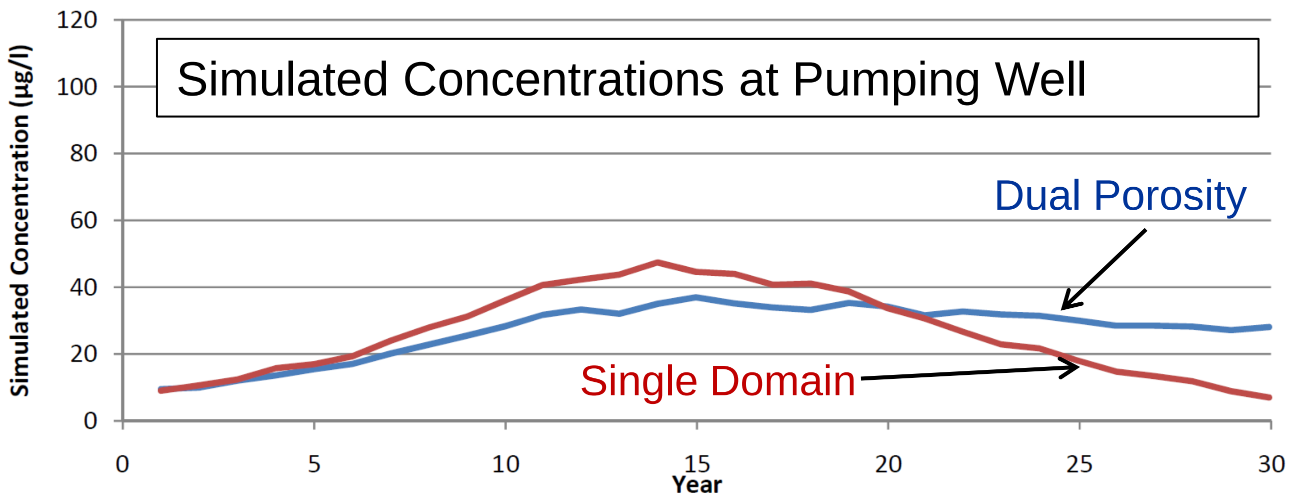
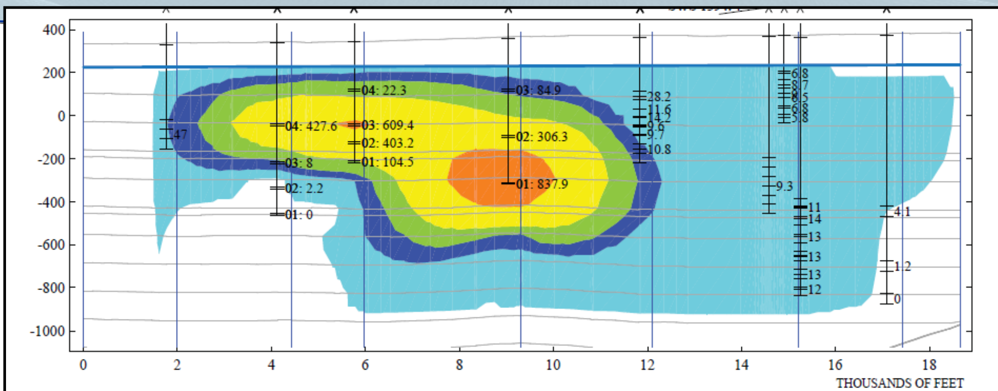
Ongoing Development - Dual Porosity

- Solute transport in heterogeneous formations
- Accounts for relatively mobile and immobile aquifer fractions
- Solute storage in immobile fraction can create "tailing"

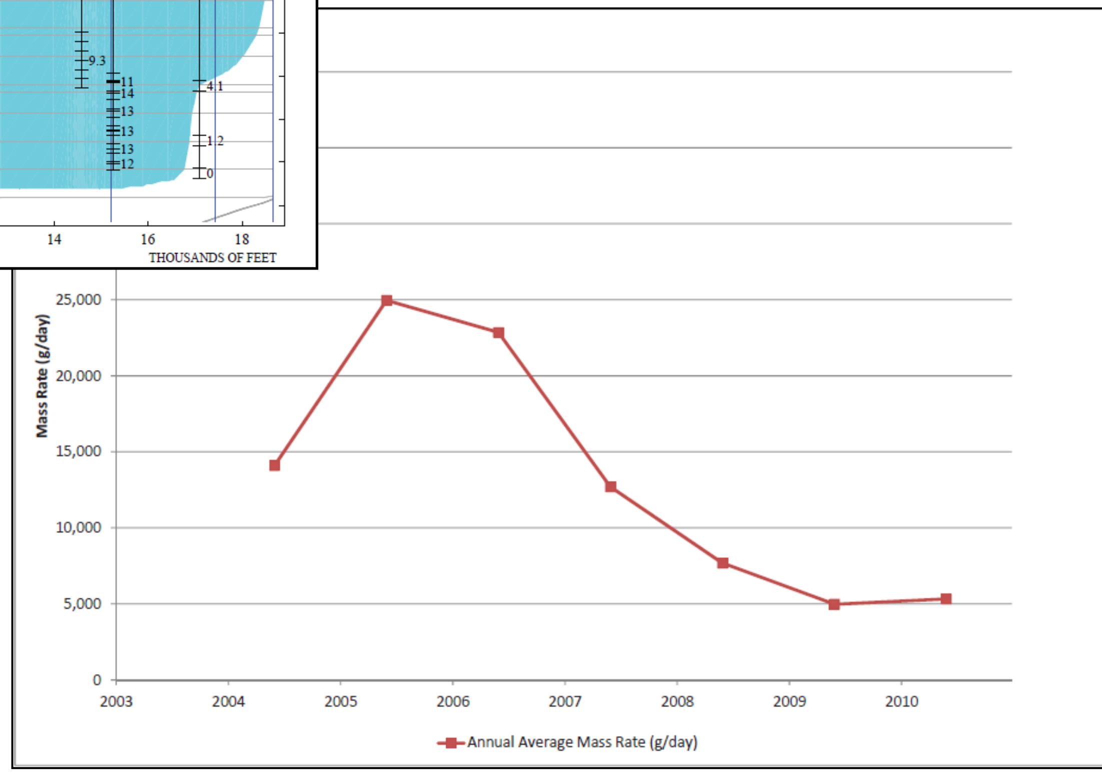


Unsat Zone Proc → Non-Equil Sorption → Multiple Const → 2010 EVS/MVS → **2011 Dual Porosity** → 2012 Mass Flux → 2013 ISWMM

Ongoing Development - Mass Flux



- 3-D interpolation of concentrations onto transect nodes
- Computation of mass flux time history at transect



Unsat Zone Proc → Non-Equil Sorption → Multiple Const → 2010 EVS/MVS → 2011 Dual Porosity → **2012 Mass Flux** → 2013 ISWMM

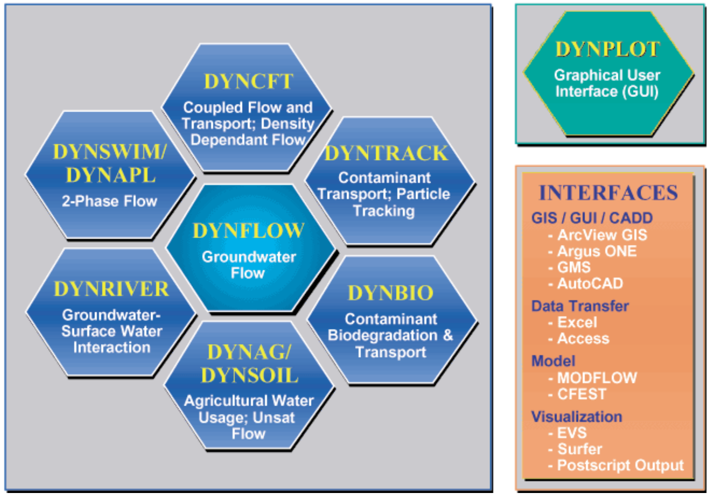
Current Developments

- Linkage with Leapfrog Hydro to streamline development of complex model stratigraphic layering
- ISWMM – Linkage of DYNFLOW to USEPA SWMM stormwater model to quantify groundwater impact on collection system flows
- DYNAIR/DYNVAP – Vapor Intrusion Studies

Unsat Zone Proc → **Non-Equil Sorption** → **Multiple Const** → **2010 EVS/MVS** → **2011 Dual Porosity** → **2012 Mass Flux** → **2013 ISWMM**

Takeaways

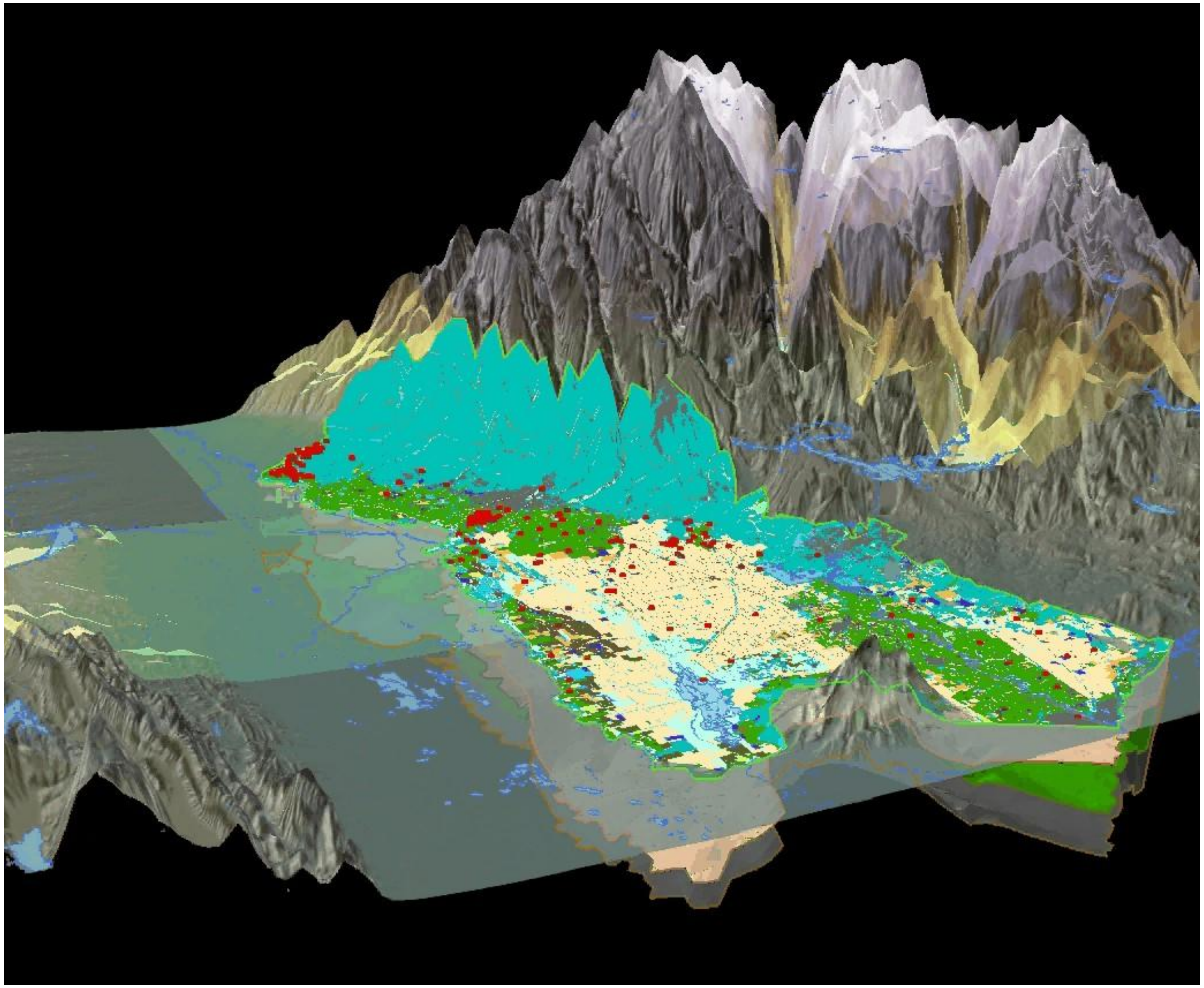
- Finite Element model grid flexibility
- Streamlined transient input & output - increased productivity and improved simulation and understanding
- Benefits of “live” code - frequently applied and updated to meet new modeling challenges
- Benefits of creating links to new tools and technologies (e.g. animation, 3D visualization)



Acknowledgements

- Early FE: Jerome J. (Jerry) Connor
- Café/Disper: Jim Pagenkopf, Bryan Pearce
- Aquifem: John L. Wilson, Antonio Sa Da Costa
- DYNFLOW/DYNTRACK: Peter Riordan, Robert P. Schreiber, Brendan M. Harley
- Aquifem-N: Lloyd Townley
- DYNPLOT: Peter Shanahan, Bruce Jacobs
- Code Developer: Robert Fitzgerald

Questions – www.dynsystem.com

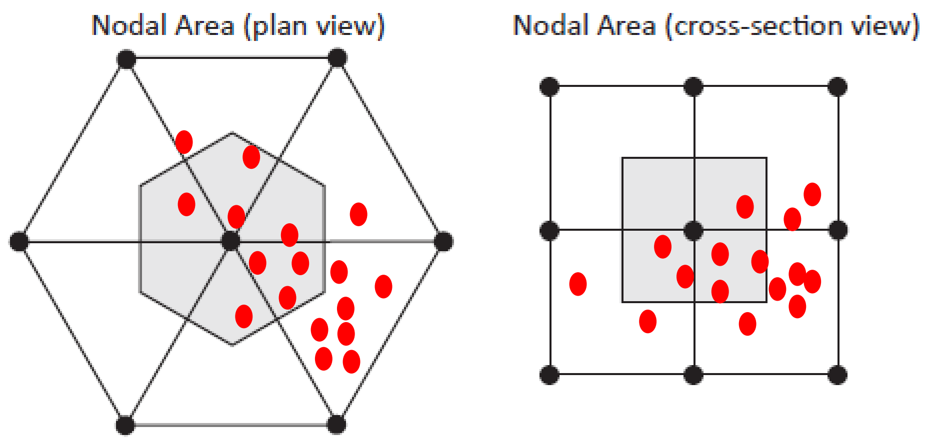


DYNTRACK Computations

Concentration

- Nodal concentrations are calculated at a given node/level by dividing the total weight [M] of all particles located within the nodal area by the nodal pore volume [L^3] at the end of each time step

Model Grid and Computations



DYNTRACK Computations

Computed Concentration

- Extraction well concentrations are calculated as the total weight [M] of all particles entering the nodal area associated with the well (or defined radius) by the volume of water extracted [L^3] during each time step
- Particles entering the nodal area associated with an extraction well are removed from the mode

Model Grid and Computations