The U.S. Geological Survey Modular Ground-Water Flow Model

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Basics

- For flow, simple basic equation (heat equation), advective-diffusion equation more difficult, no turbulence and relatively simple boundary conditions
- Biggest difficulties
  - Subsurface heterogeneity
    - K ranges 14 orders of magnitude in DVRFS
  - Lack of access
  - Quantifying relevant surface processes -- recharge
  - Demand for detailed answers

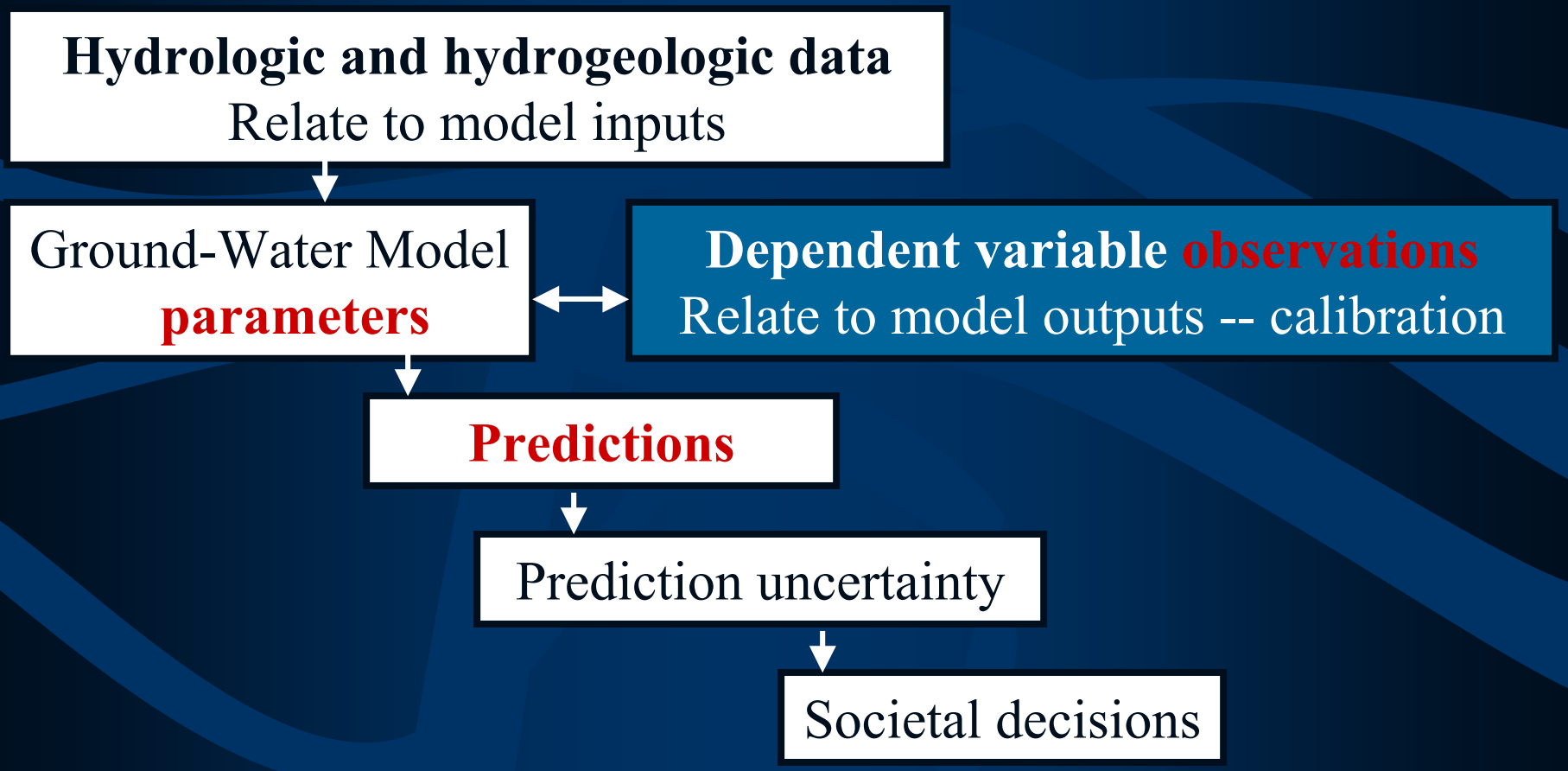
History of MODFLOW

- 1970's: Trescott and Pinder 3D, transient
- Difficulties in USGS
  - Reduce redundancy so efforts more productive
  - Constant innovation needed a foundation
- Response: Gordon Bennett arranges support for McDonald and Harbaugh to revise T&P and initiates a training program
- Computer program reorganized three times
- 1983: Modular model. 7,000 lines.

History of MODFLOW

- 1980's:
  - MODFLOW named by others
  - MODFLOW ESCAPES. External use exceeds USGS use
  - In USGS, progress in projects (like Prudic's Streamflow-Routing Package in Nevada and Leake's Subsidence Package in Arizona), little focused effort from a national level after 1983
  - Commercial effort starts building up around MODFLOW
- 1992: MODFLOWP (Hill) responds to need for better calibration methods – 17,000 lines

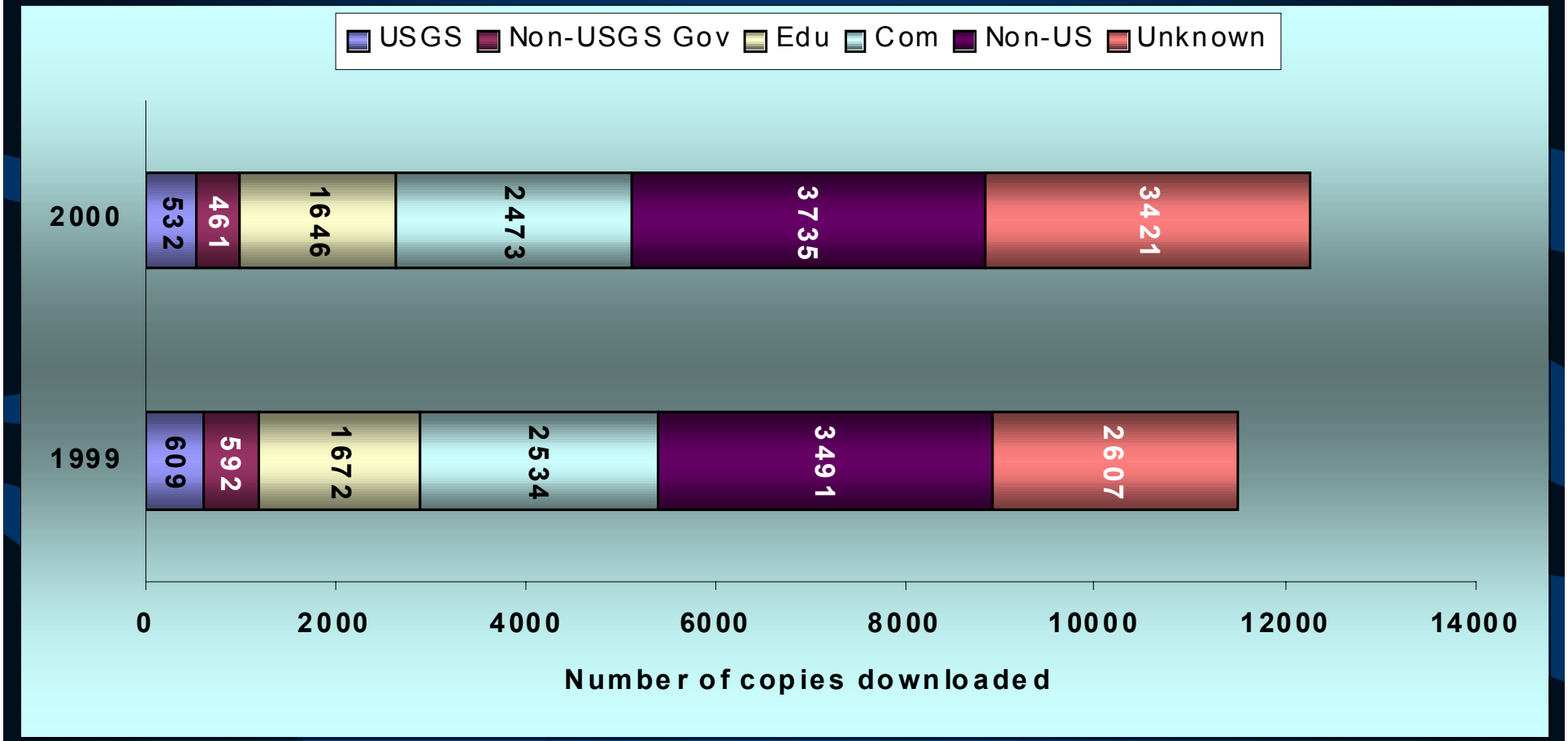
Major steps of ground-water modeling



History of MODFLOW

- 1990's:
  - Increased national effort (2-3 full-time people)
  - Harbaugh is the guru -- keeps MODFLOW modular
  - Development within the Yucca Mountain effort (DOE) and within some district projects
  - Plan MODFLOW-2000 to improve modularization and mainstream parameter estimation
  - Commercial effort continues – MODFLOW-SURFACT
- 2000: MODFLOW-2000
- 1999-2000: 23,000 copies downloaded free from USGS. Also sold by others.

1999-2000 downloads



Publications

- Basic: McDonald and Harbaugh, 1988; Harbaugh +, 2000; Hill +, 2000
- Solvers: Hill, 1990; Mehl and Hill, 2001
- New physical capabilites: Prudic, 1989; Leake, 1990;
- Transport: Zheng and Wang, 2000; Anderman and Hill, 2001
- Integrate geology: Anderman and Hill, 2000
- Comments:
  - Take advantage of personal pride and support personal recognition
  - Profusion of reports and be confusing, but web pages can now be used to keep people informed

However well you document level, the group with the next level down in terms of competence will use it

Structure of MODFLOW

Processes – Packages -- Procedures

- **Processes** – one for each basic equation
  - Ground-Water Flow (GWF) Process
  - Observation (OBS) Process
  - Sensitivity (SEN) Process
  - Parameter-Estimation Process
  - Ground-Water Transport (GWT) Process

Structure of MODFLOW

Processes – Packages -- Procedures

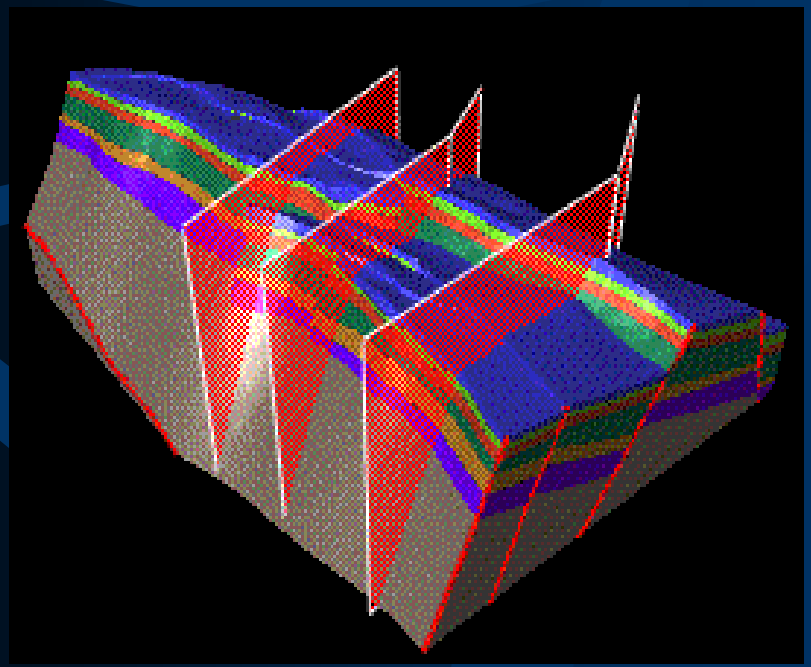
- **Packages** – generally one for each system feature
  - Well (WEL) Package
  - Hydrogeologic Unit Flow (HUF) Package
  - etc
- **Procedures** – one for each type of calculation or input/output needed
  - Read and Prepare (RP)
  - Formulate (FM)
  - etc
- Typical subroutine name: GWF1WEL6RP

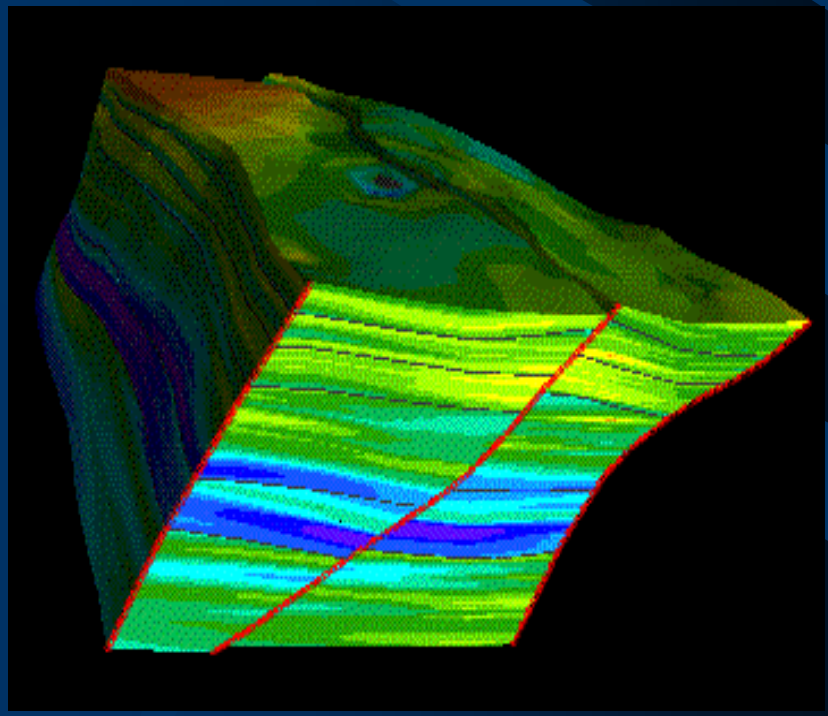
Future of MODFLOW

- Links with surface-process models like HEC and MMS (Prudic)
- Variable-direction anisotropy
- Improved local grid refinement
- Less structured grids
- Evaluate uncertainty and reliability
- Better integration with geology
- Use it better!

Integration with Geology

Your sedimentation creates my porous media, so your efforts are very important to me!



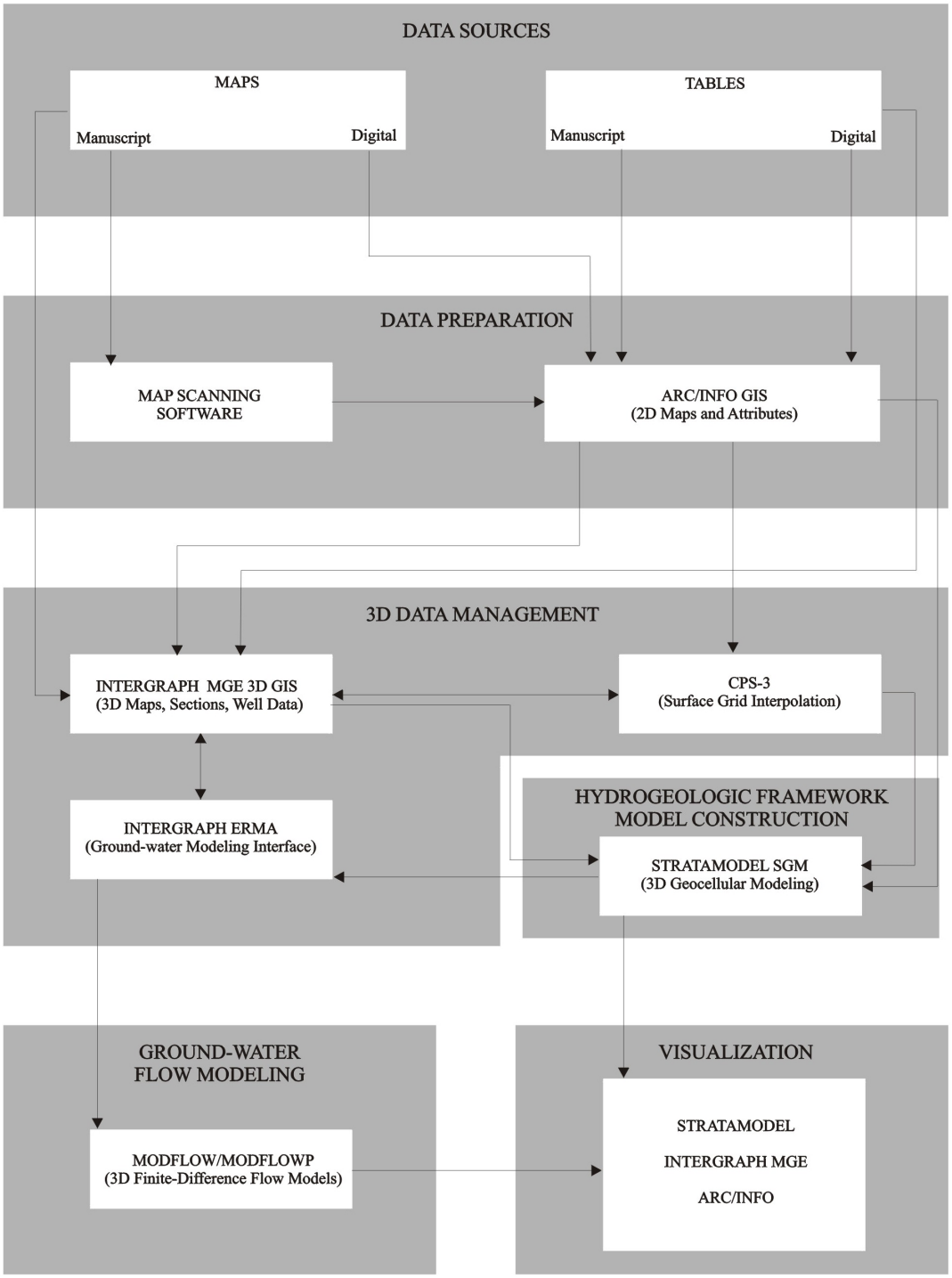


Use it better! Graphical Interfaces and Database Management

- Difficult because of the many kinds of data (point well data, 2D and 3D geophysics, etc) and the complexity of the subsurface. Some capabilities exist, but integration is difficult if the problem is difficult

System designed for DVRFS in early 1990's

- System very complicated because of the extensive faulting and volcanics
- Required a sophisticated system



Graphical Interfaces and Database Management

- Difficult because the hardware and software change so much and the commercial effort has not been dependable or comprehensive.
- MODFLOW graphical interfaces have been produced commercially since mid-80's.
  - Now, 5 major interfaces. One funded in part by military money, one in part by USGS money. Very good for some systems.
  - $500-$3500

Lessons

- Only modular, neatly programmed, well documented software can form a foundation for good future science.
- Achieving this takes substantial extra time.
- Arranging for this extra effort to be rewarded is very important and can be very difficult.
- Some of those involved also need to publish white literature to stay current and avoid isolation.
- Need a ‘keeper of the code’ who keeps things modular. This person’s edicts can seem burdensome and petty, but if done well is worth the aggravation. It’s very important to support this person because they will get hassled a lot.

Thoughts

- Such a program can provide a superhighway for researchers to get their ideas used
- Contributions from many types of efforts can be invested instead of lost – from NSF and ONR research to consulting projects
- Public domain versus commercial product?
  - Need a viable cash flow and reward system. Will NSF and ONR support this? Get USGS involved nationally and by project?
  - All efforts do not need to be one or the other