Development of Numerical Models to Assess Ground-Water Flow Patterns in the Great Basin of Southern Nevada

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History of Numerical Models in Ground-Water Flow and Transport

- R.W. Stallman was one of the first to apply numerical methods in ground-water flow—his paper “Numerical analysis of regional water levels to define aquifer hydrology” was printed in Trans. Am. Geophys. Union, v. 37, 1956.
- Electric analog models continued on as the principal method for analyzing regional ground-water flow until the late 1960’s.

Rapid Development of Numerical Ground-Water Flow Models

- Computer codes for numerically solving ground-water flow grew rapidly in the late 1960’s when computers became more proficient and prevalent.
- By the mid 1970’s numerous computer codes were available to model both ground-water flow and solute transport.

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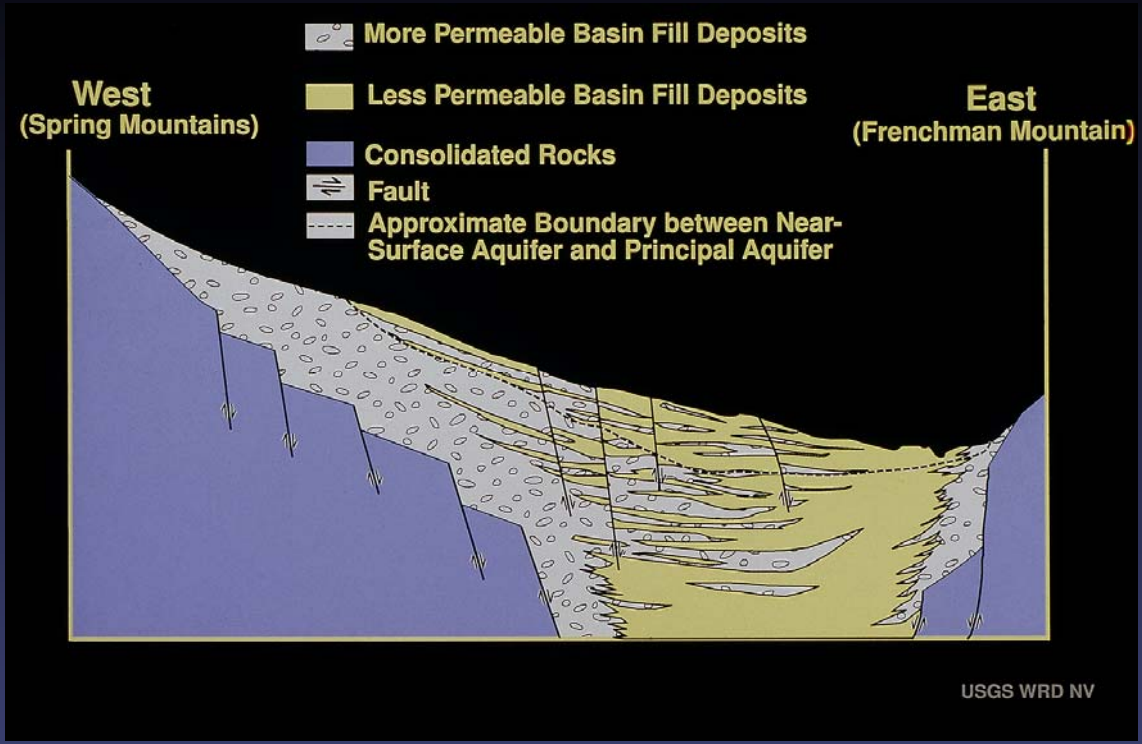
Numerical Models of Ground-Water Flow in Southern Nevada

- First numerical model of ground-water flow in Southern Nevada was by J.R. Harrill for basin fill in Las Vegas Valley.
- Report “Pumping and ground-water storage depletion in Las Vegas Valley, Nevada, 1955-74” was printed in 1976 as Nev. Water Res. Bulletin 44.

- The initial model was two-dimensional and had 525 active cells—each a square mile.



- Since 1976, complexities have been added to several different models of Las Vegas Valley including multiple layers and water released from compaction.

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First Numerical Model of Death Valley Region

- Nevada Test Site and Yucca Mountain are the most intensely studied areas in Southern Nevada.
- First multiple-basin model was of the Death Valley region by R.W. Waddell and was published in 1982 (USGS WRIR 82-4085).

- Model was two-dimensional, steady state, and had less than 1,000 nodes for an area that was about 7,000 square miles.

- Model included hydraulic barriers caused by low-permeability rocks and fault zones.

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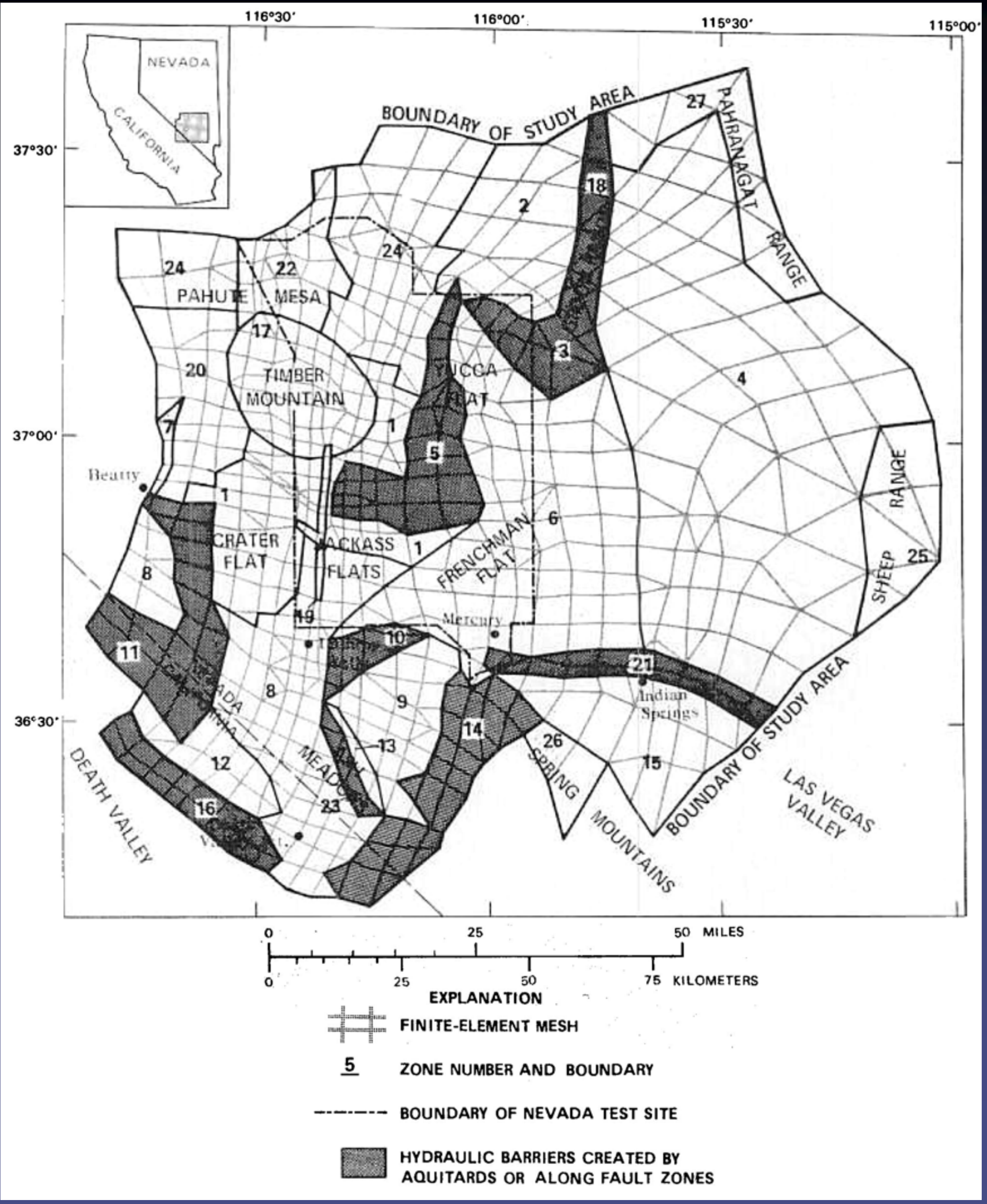
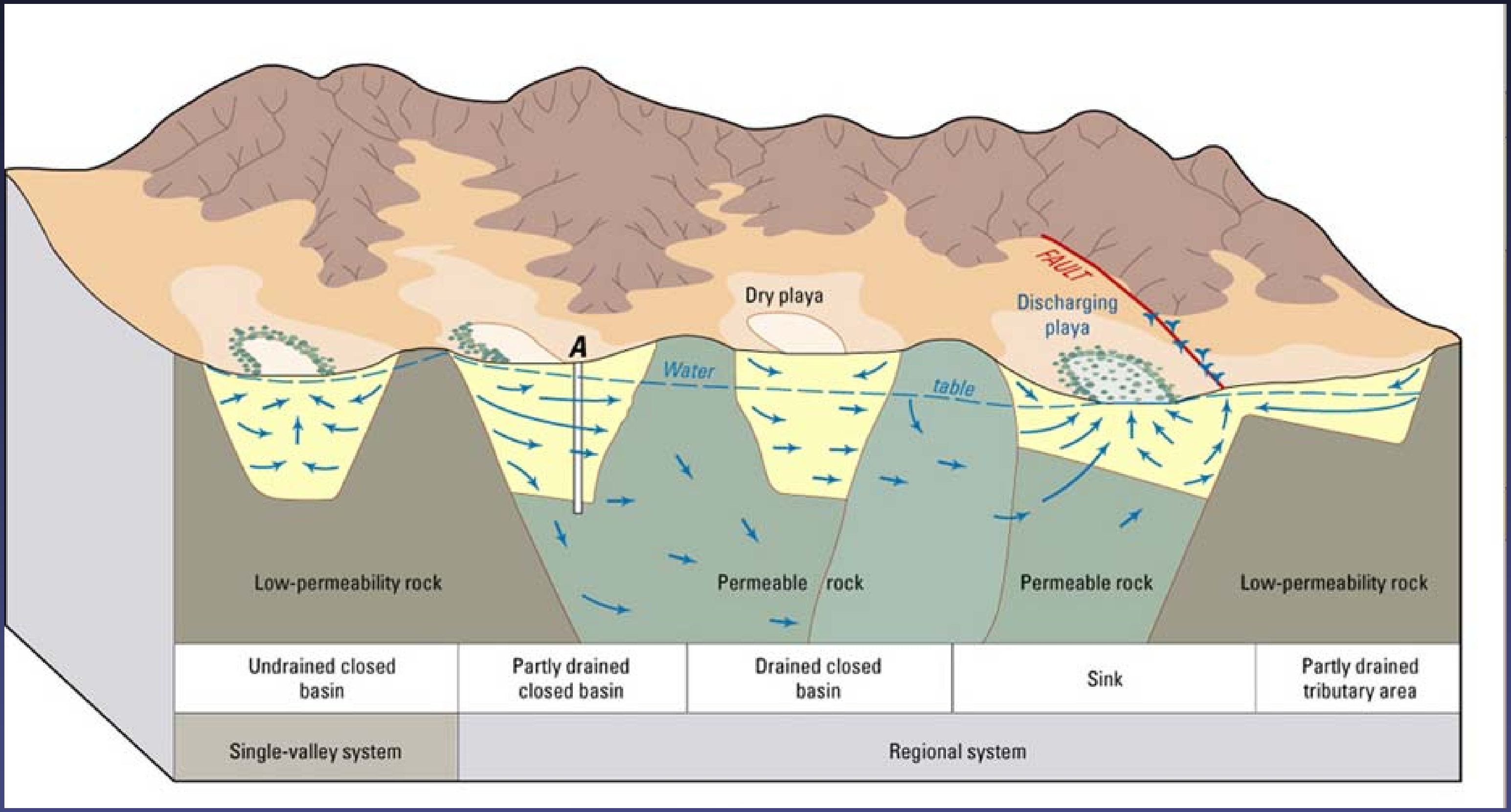


Regional Flow Through Carbonate Rocks

- Much of eastern Great Basin, including southern Nevada and Nevada Test Site, is underlain by thick sequences of Paleozoic carbonate rocks.
- The carbonate rocks, where continuous, form a regional aquifer and allow water to flow tens to hundreds of miles and several thousands of feet deep.

Conceptualization of Regional Ground-Water Flow through Carbonate Rocks



Modified from Eakin, Price and Harrill, 1976
U.S.G.S. Prof. Paper 813-G, fig. 3

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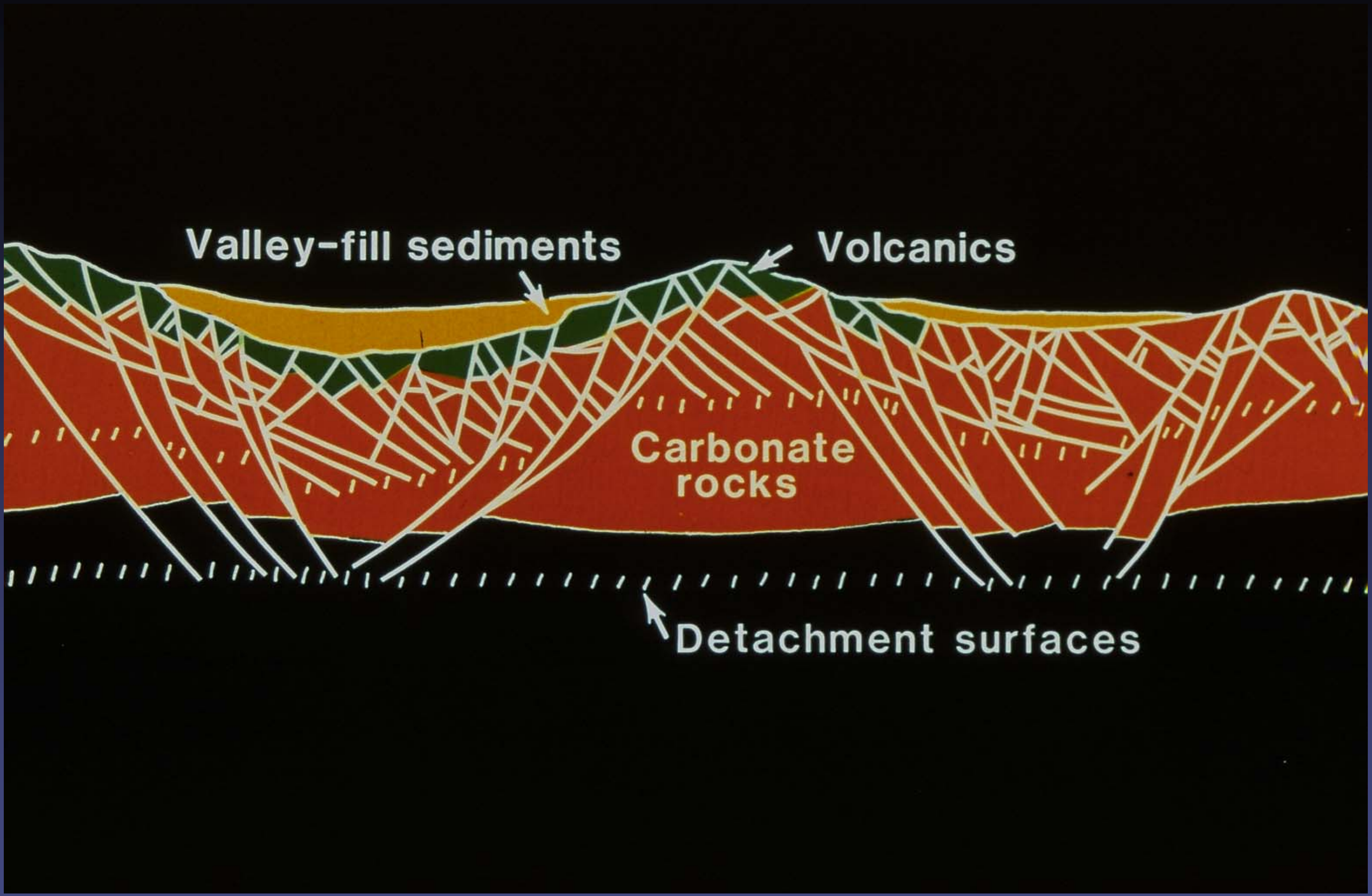

Illustration courtesy of Michael Dettinger, 1988.

Model of Ground-Water Flow Through Carbonate Rocks

- Numerical model of carbonate rock province was done to test concepts of deep regional flow beneath an area of 92,000 square miles as part of the USGS Regional Aquifer Systems Analysis Program.
- Two layers of uniformly spaced cells were used with each cell 5 miles wide and 7.5 miles long oriented in a northeast-southwest direction.
- Total of 4,912 active cells.

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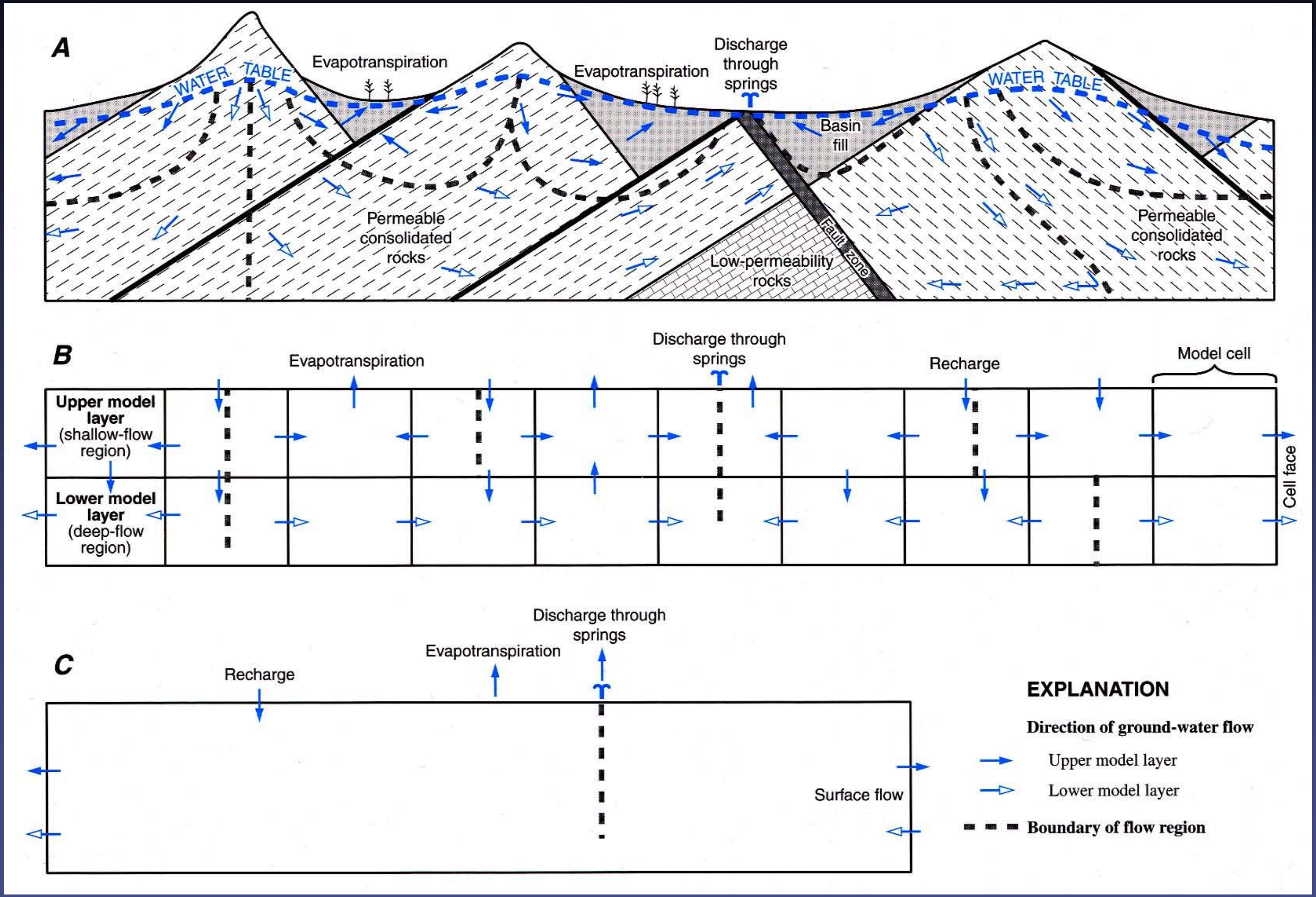
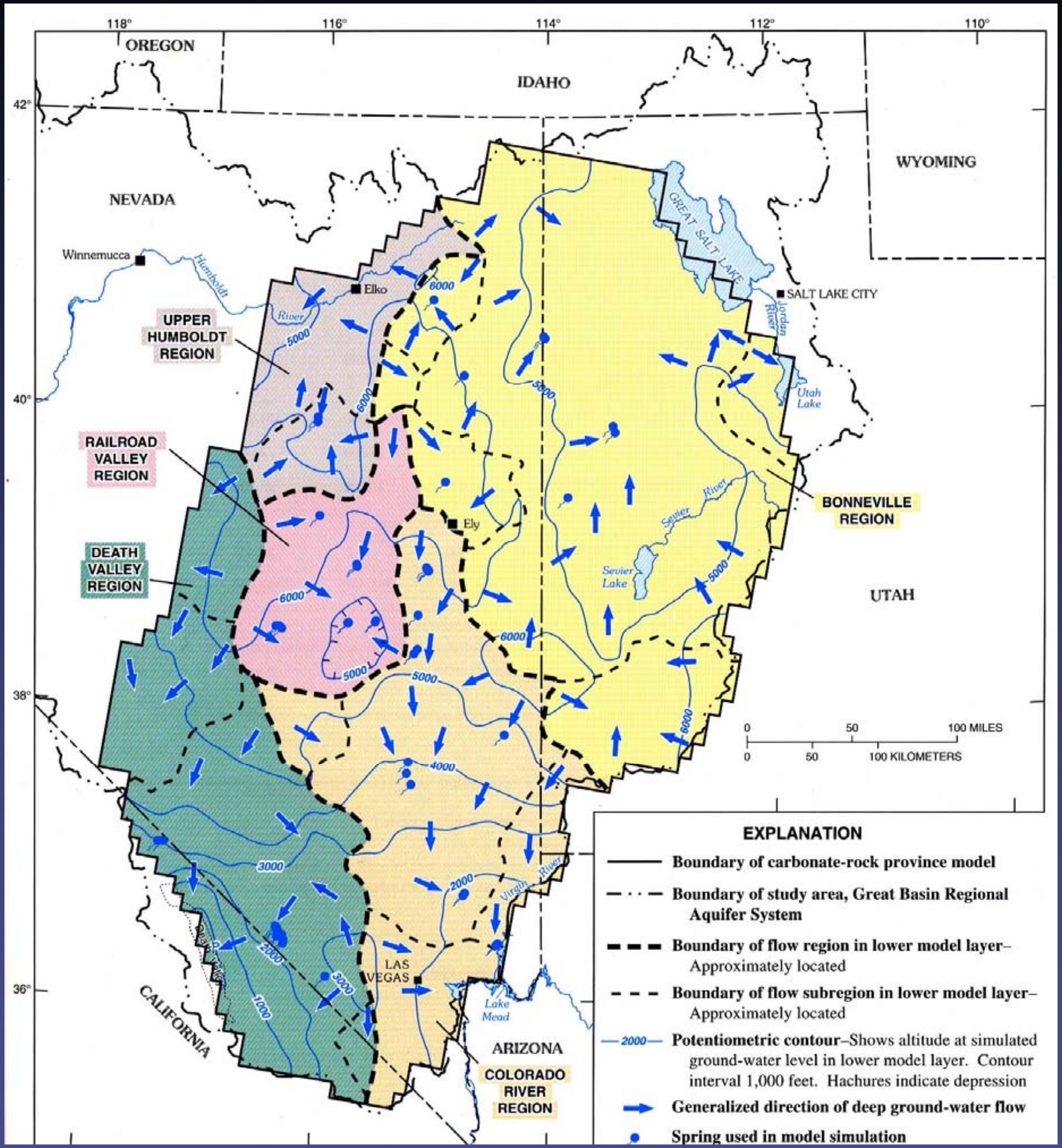


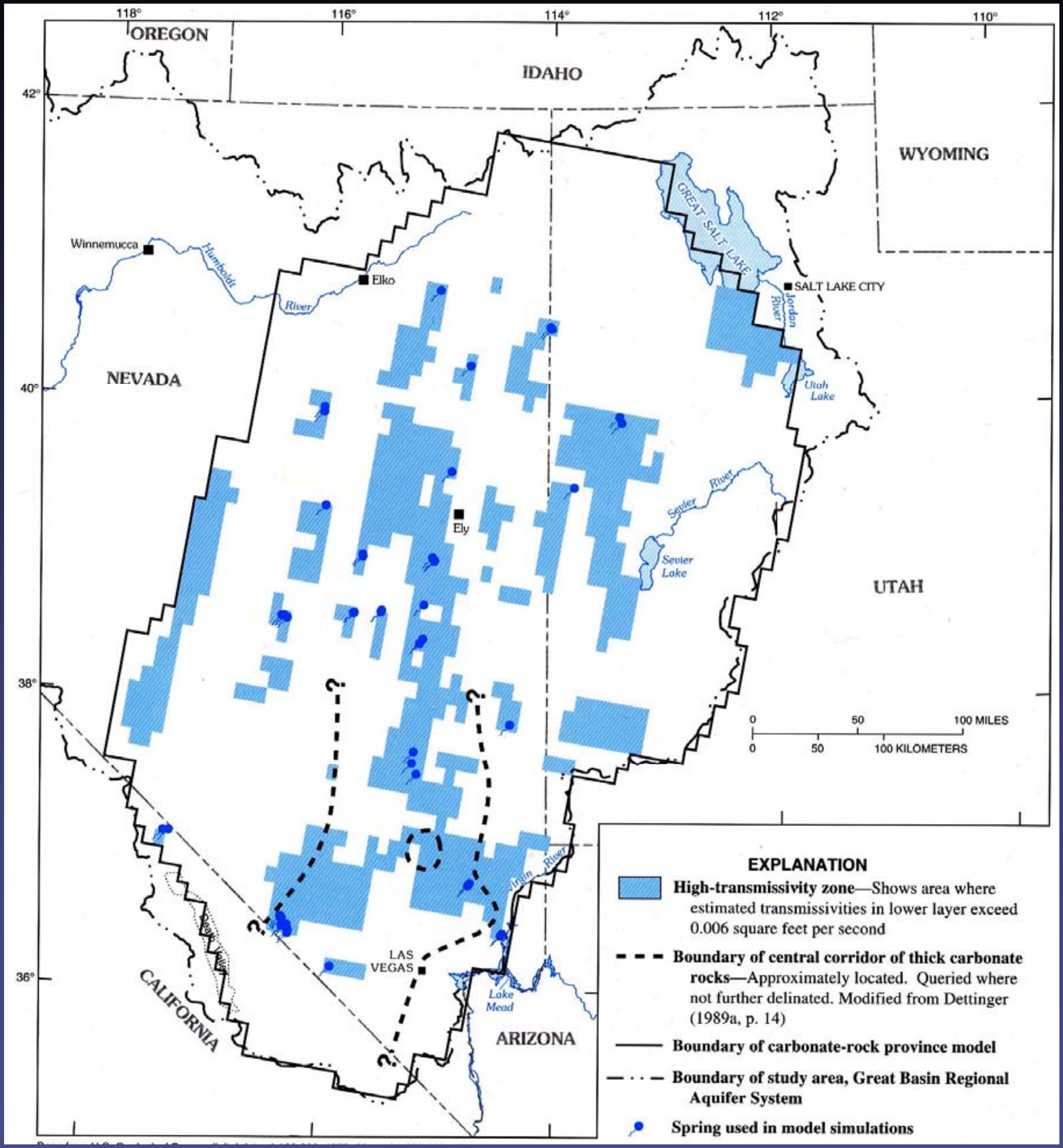
From Prudic and others, 1995, USGS Professional Paper 1409-D

- Simulation resulted in five regions of flow in the lower model layer (deep flow).
- Boundaries did not always correspond to boundaries in upper model layer.



From Prudic and others, 1995, USGS Professional Paper 1409-D

Relatively high transmissivity was not present everywhere in the lower model layer.



From Prudic and others, 1995, USGS Professional Paper 1409-D

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Model of Ground-Water Flow in Vicinity of Nevada Test Site

- Concerns regarding radioactive migration from the Nevada Test Site and proposed repository at Yucca Mountain have driven the need for integrating detailed geologic models into ground-water flow models.
- First such model was done by Geotrans and IT Corporation in 1997 “Regional Groundwater Flow and Tritium Transport Modeling, and Risk Assessment of the Underground Test Area, Nevada Test Site, Nevada” DOE/NV--477/UC-700.

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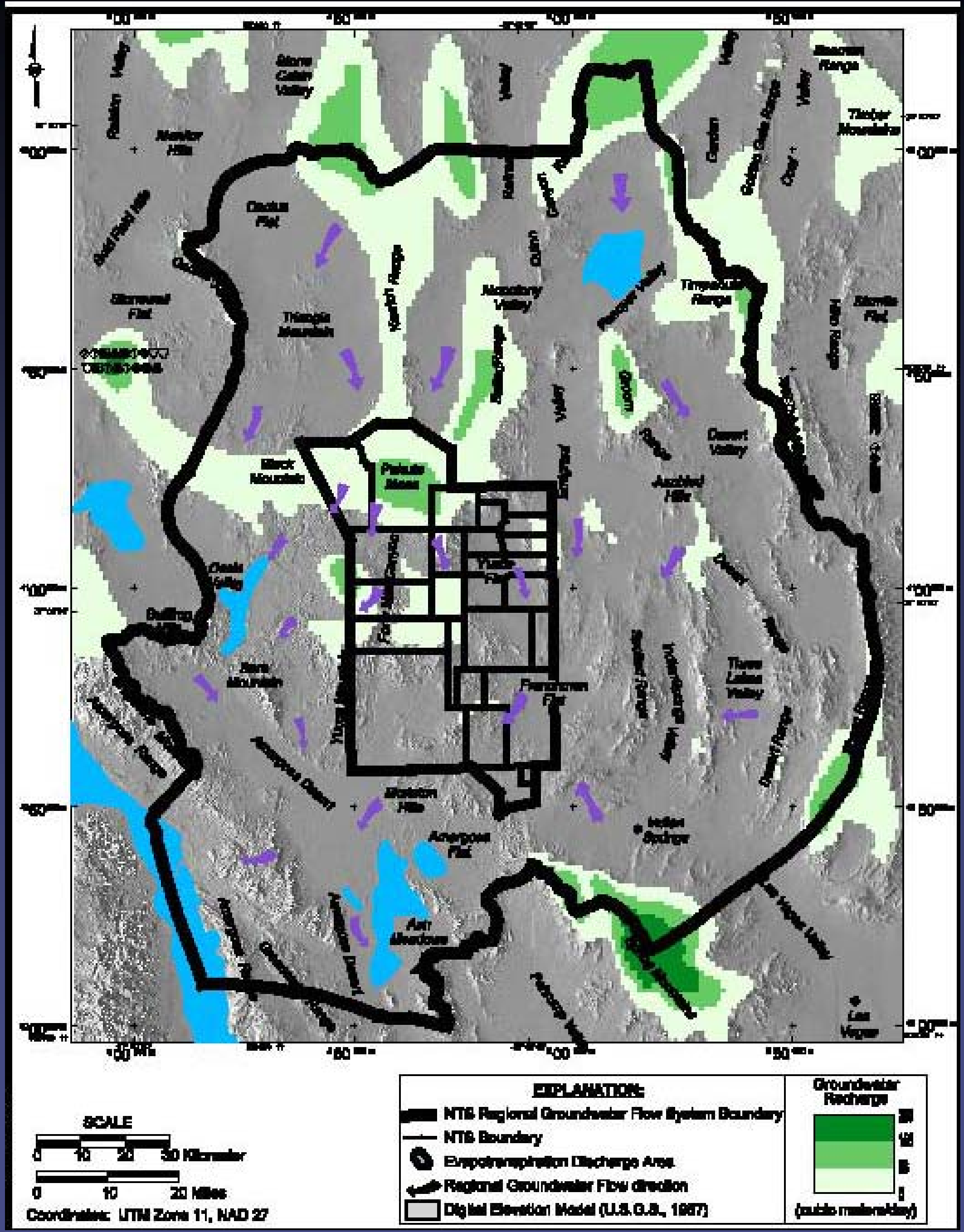
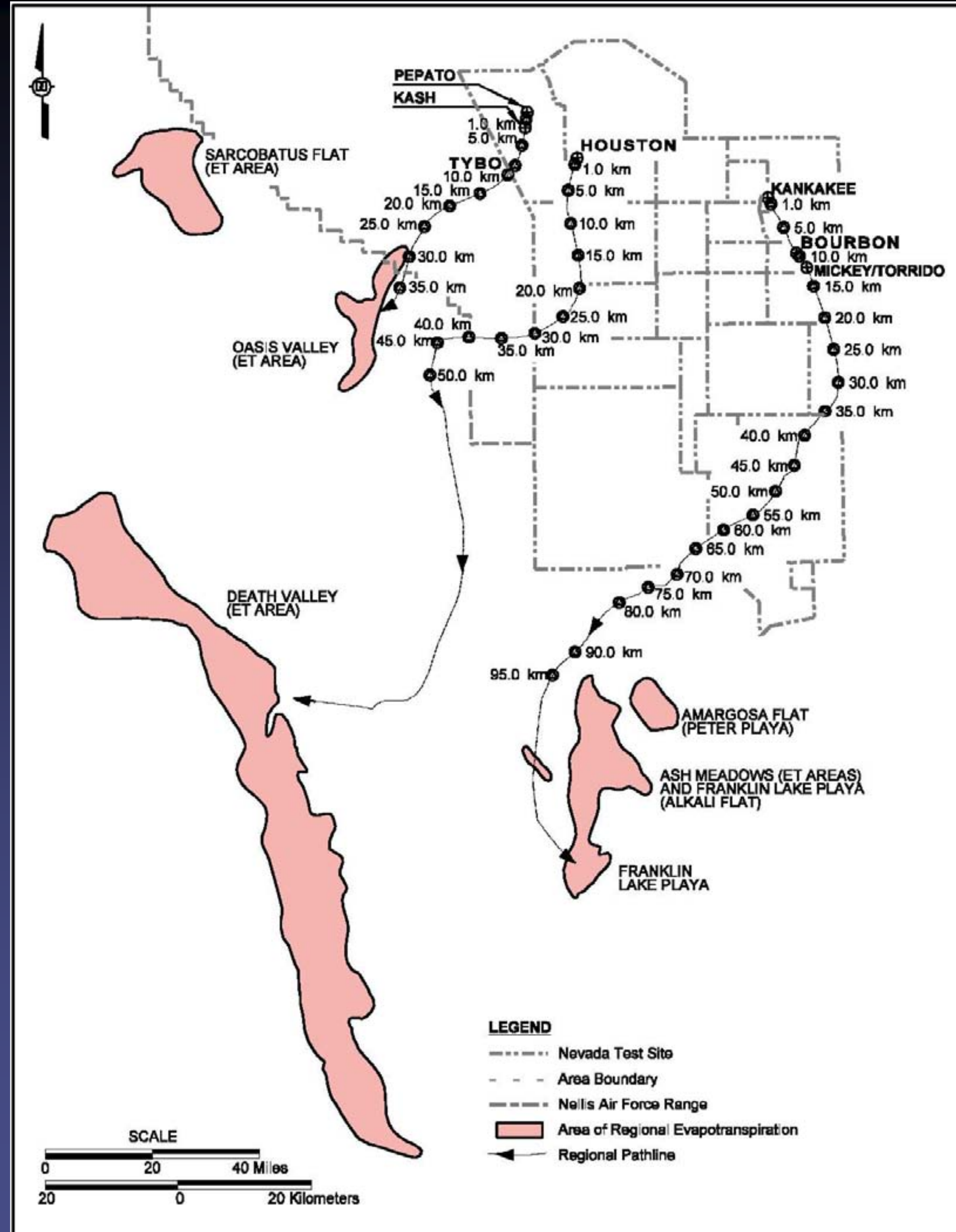
- Finite-difference model had 140 rows, 114 columns, and 20 layers.
- Assumed steady state.
- Surface area was about 9,000 square miles.
- Figure ES-6 from DOE/NV--477/UC-700.



Pathlines from selected underground tests to points of discharge were used for risk assessment (figure ES-7 from DOE/NV--477/UC-700).

Pathlines may encounter many geologic units and model layers.



Transient Model of Regional Flow

- Steady-state models of the Death Valley region have developed into a transient model for the purpose of simulating effects of pumping on regional flow.
- Transient model was developed by a host of people from the USGS.
- As with the other regional models in the Death Valley Region, development of this model was funded by the U.S. Depart. of Energy.

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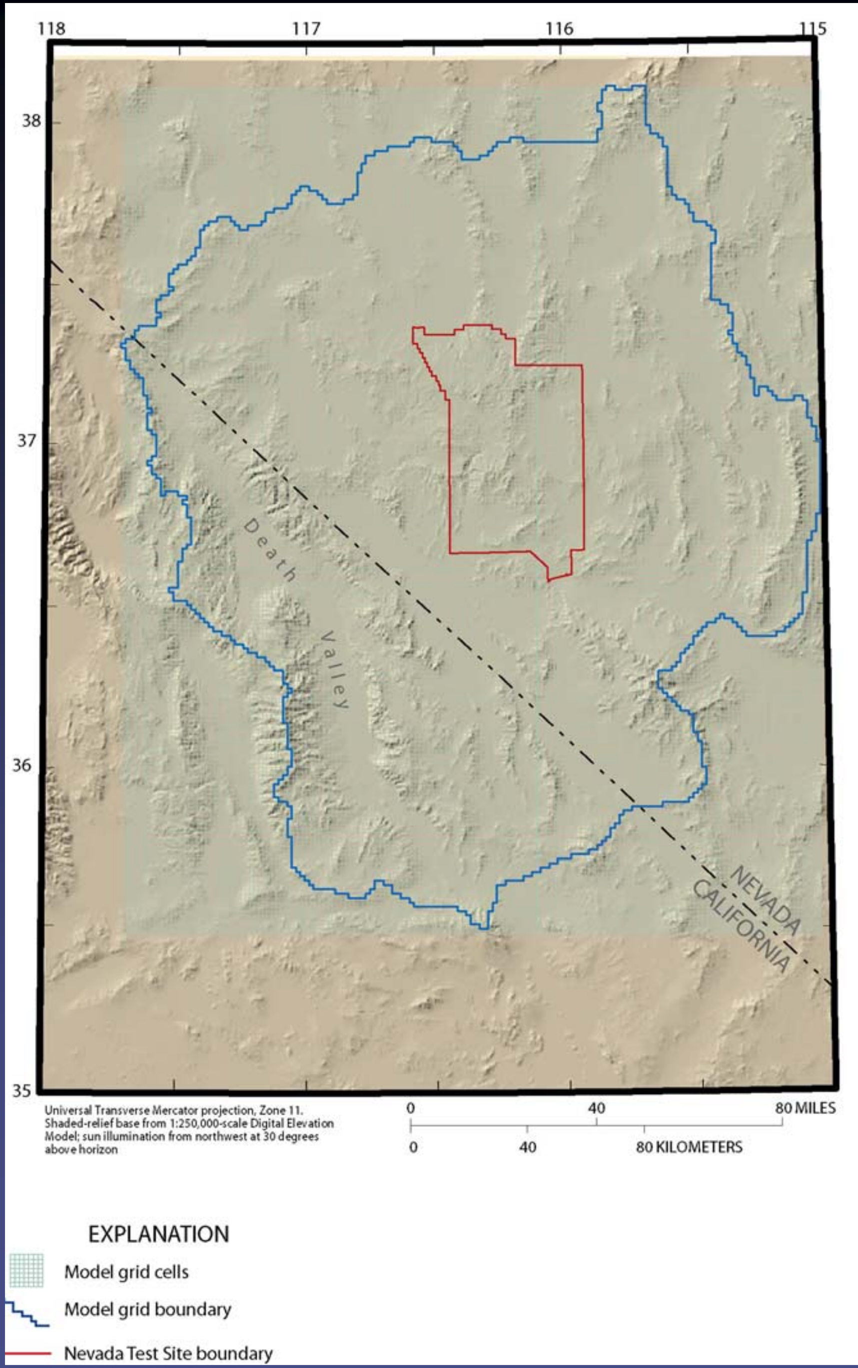
- Transient model has 190 rows, 160 columns that are 1,500 meters on side, and 16 layers.
- It has a total of 350,000 active cells.
- Used to simulate changes in ground-water flow and storage for the period 1913-98 (history matching).



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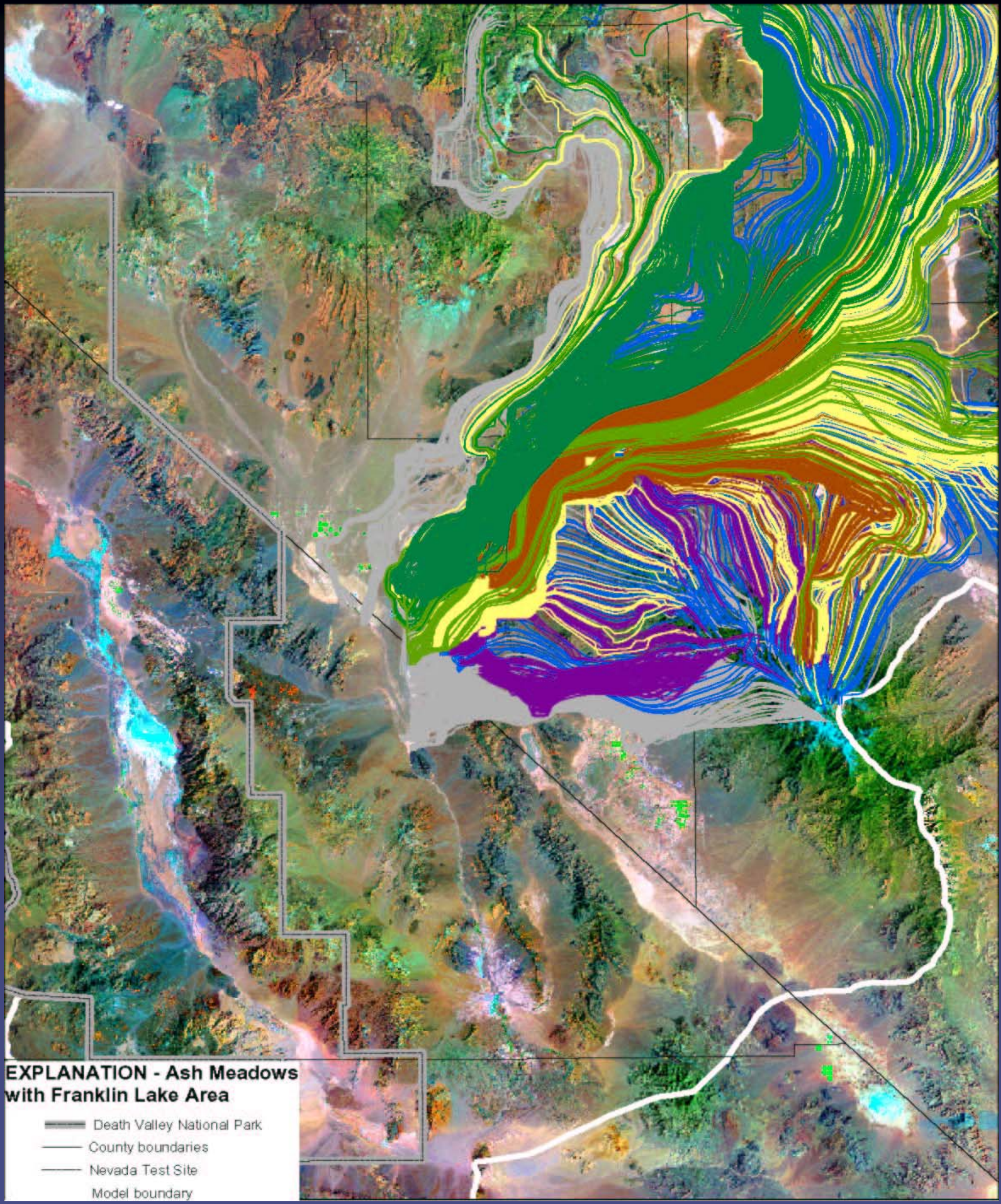
Example of transient model showing source area of discharge to Ash Meadows in southern Amargosa Valley.



Belcher, 2004, USGS Scientific Investigations Report 2004-5205

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Use of Regional Models

- Regional models are used to test concepts, evaluate effects caused by ground-water withdrawals and estimate distances and time of travel of contaminants (such as radioactive particles) from their source to places of discharge.

- Regional models are also used to estimate fluxes across boundaries in support of more detailed models of specific areas.

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Detailed Models

- Most detailed models in southern Nevada are related to transport of radionuclides from specific areas beneath the Nevada Test Site and from Yucca Mountian.
  - Evaluation of the hydrologic source term from underground nuclear tests on Pahute Mesa at the Nevada Test Site: the CHESHIRE Test (G.A. Pawloski, A.F.B. Thompson, and Steven F. Carle, May 2001, UCRL-ID-147023).
  - TYBO/BENHAM—Model analysis of groundwater flow and radionuclide migration from an underground Nuclear Tests in Southwestern Pahute Mesa, NTS (Andrew Wolfsberg and others, May 2002, LA-13977).

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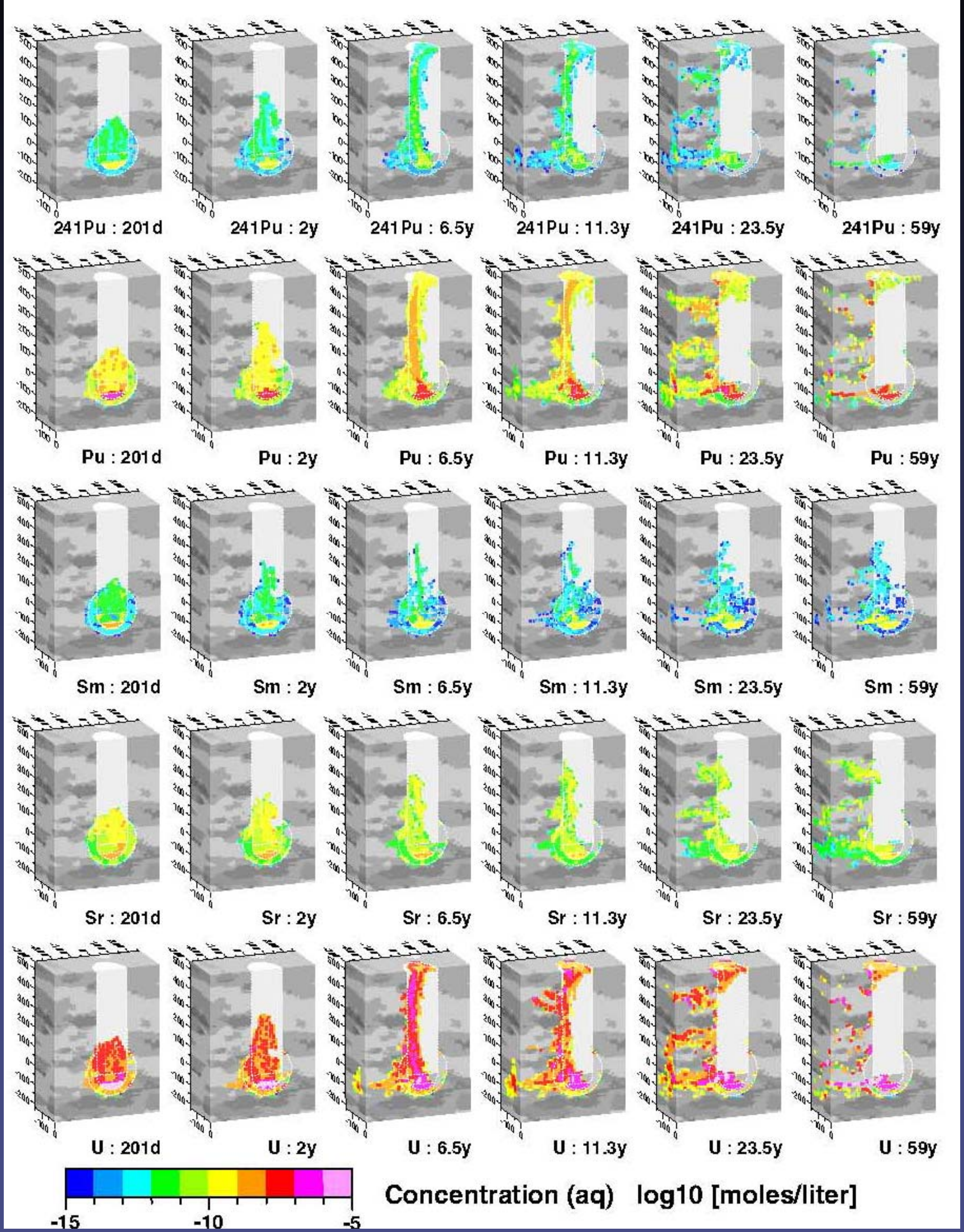
Figure 7.11—Cross sectional perspective views of particle simulations of aqueous Pu, ^{241}PU, Sm, Sr, and U concentrations at 201 days and at 2, 6.5, 11.3, 23.5, and 59 years after CHESHIRE test for realization 9, and mineralization 1.



Graph courtesy of Andrew F.B. Thompson

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Detailed Models

- Desert Research Institute has also developed models of ground-water flow and transport at the Nevada Test Site and for offsite underground nuclear tests.
  - Evaluation of groundwater flow and transport at the FAULTLESS underground nuclear test, Central Nevada Test area (Karl Pohlmann, Jenny Chapman, Ahmed Hassan, and Charalambos Papelis, September 1999, DRI Publication 45165).

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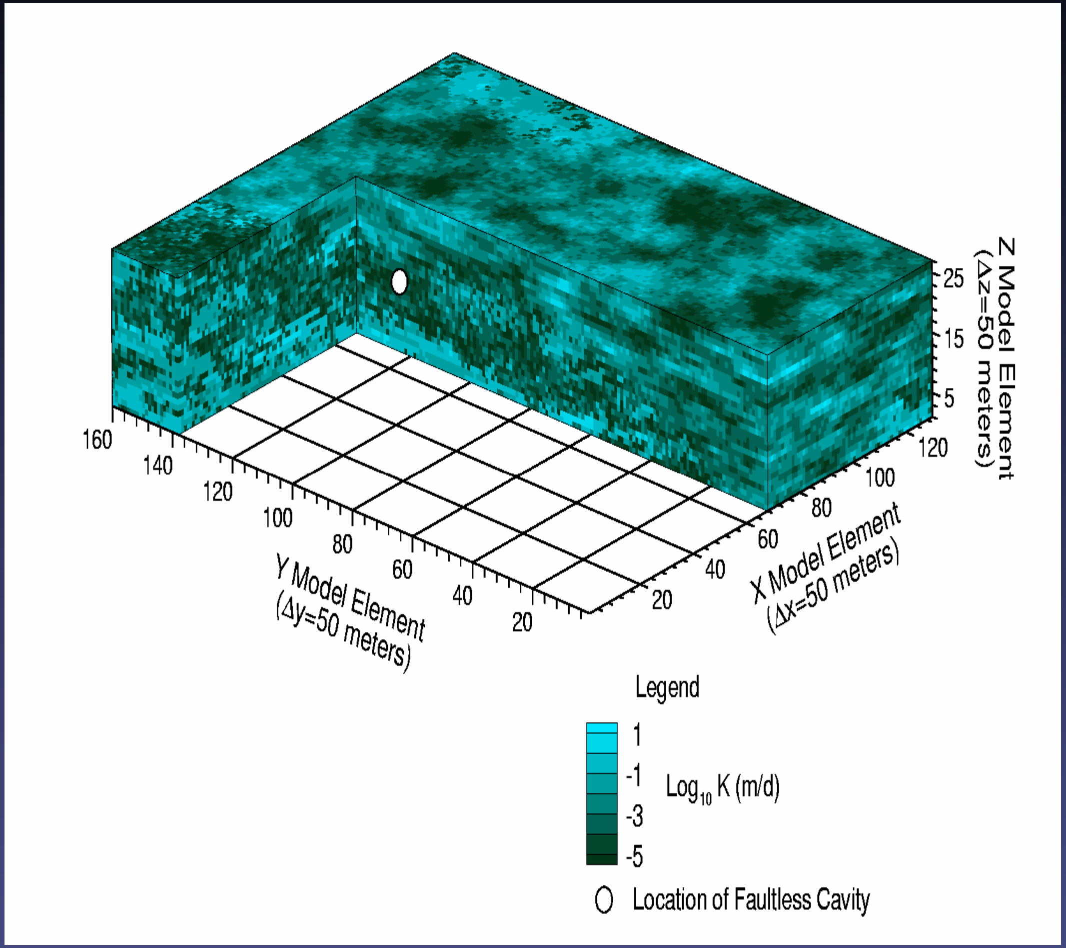
- Model of FAULTLESS test in central Nevada showing distribution of hydraulic conductivity for one realization.
- Hydraulic conductivity is based on distributions in alluvium, non-welded, and welded tuffs.
- Area is about 20 square miles and there were more than 580,000 active cells.



Graph courtesy of Jenny Chapman

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What Have We Learned?

- Models allow us to integrate a variety of information that can be used to test concepts, to guide where additional information is most needed, or to make “predictions” about system behavior.
- Results (often unexpected) can show where our understanding and knowledge is inadequate.
- The act of developing models has increased our ability to understand flow and transport.

Where Do We Go From Here?

- Models can not be considered as absolute for nowhere do we have a complete understanding of the **hydrogeology** and **chemistry**.
- Where we go from here will depend largely on the need for water by humans in relation to the need for water to sustain the environment.

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