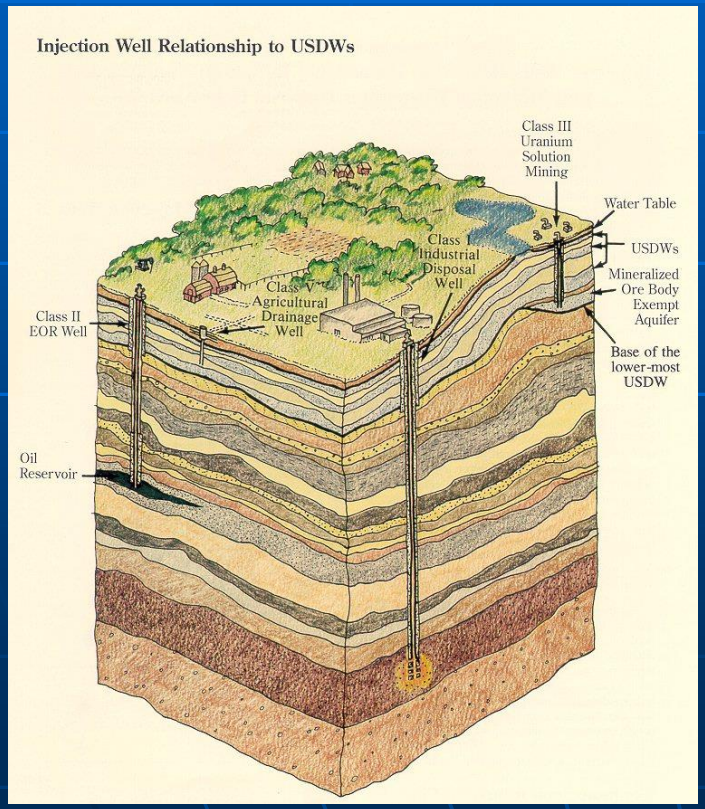
UNDERGROUND INJECTION AND SEQUESTRATION AND UNDERGROUND SOURCES OF DRINKING WATER (PROTECTING A VALUABLE RESOURCE)



Jerry W. Taylor, PG

Presented by
Richard T. Brown, CHMM
Subsurface Technology, Inc.

PARSONS BRINCKERHOFF

SUBSURFACE

INTRODUCTION

Continued population growth and relocation, combined with changing climate conditions, will result in:

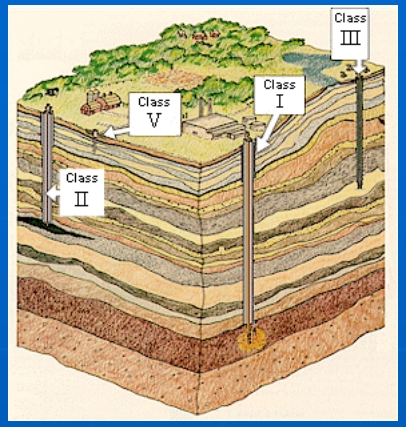
- Increased need for reliable, clean, safe sources of groundwater; and
- Greater demand for liquid waste management

UNDERGROUND INJECTION AND SEQUESTRATION

- Underground injection and sequestration has proved to be a safe and effective method for permanent disposal of industrial, municipal, and petroleum produced liquid wastes

- Emerging uses of permanent underground injection and sequestration include:
  - Anthropogenic CO2 geologic sequestration
  - Disposal of “reject” from groundwater desalination plants

- Emerging uses of cyclical underground injection and sequestration include:
  - Natural gas storage and recovery
  - Aquifer storage and recovery
  - Compressed air energy storage



UNDERGROUND INJECTION WELLS

- Class I — Industrial and municipal liquid waste disposal
- Class II — Saltwater disposal, enhanced oil recovery, and hydrocarbon storage
- Class III — Solution mining (salt, sulphur, uranium)
- Class IV — Banned, limited use with regulatory approval
- Class V — Wells not included in Classes I through IV
- Class VI — CO2 geologic sequestration

CLASS I INJECTION WELLS

- Industrial (hazardous and non-hazardous) and municipal liquid waste disposal
- Approximately 550 Class I injection wells currently operating in the United States
- Most Class I wells located in the Gulf Coast and Great Lakes regions

CLASS II INJECTION WELLS

- Salt water disposal, enhanced oil recovery, and hydrocarbon storage
- Approximately 145,000 Class II injection wells currently operating in the United States
- Class II salt water disposal wells and enhanced oil recovery operations located in oil and gas producing regions of the Unites States
- Inject approximately 2 BILLION gallons per day (over 700 BILLION gallons per year)

CLASS III INJECTION WELLS

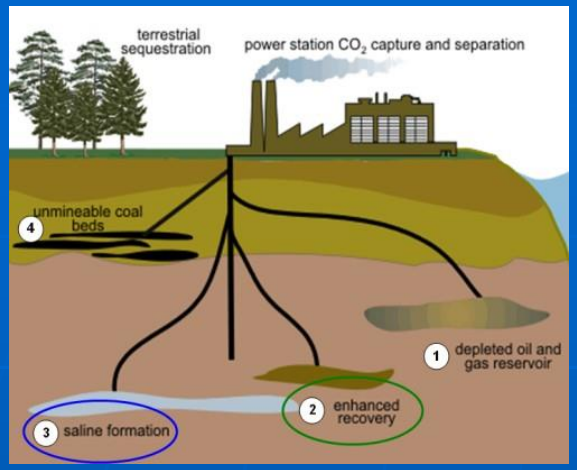
- Solution mining (salt, sulphur, uranium)
- Approximately 18,500 Class III injection wells currently operating in the United States

CLASS IV INJECTION WELLS

- Class of injection wells used to inject above a USDW
- USEPA Banned Class IV wells in 1984
- Class IV Wells can only be used in conjunction with regulatory authorized groundwater cleanup action
- Currently approximately 32 waste cleanup sites using Class IV wells

CLASS V INJECTION WELLS

- Wells not included in Class I through IV
- CO2 geologic sequestration test wells
- Aquifer storage and recovery wells



CLASS VI INJECTION WELLS

- Anthropogenic CO2 geologic sequestration
- Several ongoing DOE funded testing programs
- Geologic sequestration is nothing new!
- As with other classes of injection wells, Class VI injection well siting is critical element
- Most geologic basins being considered for CO2 geologic sequestration have available subsurface data to allow for evaluation of siting criteria

GROUNDWATER PROTECTION

- Groundwater protection associated with underground injection and sequestration is driven by stringent state and federal UIC regulatory programs
- UIC regulations were established specifically to protect groundwater

MULTI-LAYERED GROUNDWATER PROTECTION MEASURES BUILT INTO UIC REGULATORY PROGRAM

I. Injection well siting criteria ("Site Evaluation/Permitting")
- Area of review
- Groundwater susceptibility
- Defined injection zone
- Defined confining zone(s)
- Artificial penetrations
- Faulting
- Seismic activity
- Potential interactions with other injection wells
- Potential interactions with oil & gas or geothermal resources

AREA OF REVIEW

- Varies with injection well classification/regulatory agency
- Minimum Area of Review Radius:
  Class I: 2-mile or 2.5-mile
  Class II and III: 0.25-mile
- Class I hazardous wells modeled plume movement
  (10,000 years following injection period)
- Class VI wells modeled plume movement
  (set time frame or until plume movement ceases?)

GROUNDWATER SUSCEPTIBILITY

- Aquifer recharge area
- Sole source aquifer
- Area of groundwater concern
- Base USDW depth (<10,000 ppm TDS)

INJECTION ZONE AND CONFINING ZONE

- Depth (below land surface/below base of USDW)
- Continuity
- Injection zone injectivity and storage capacity
- Confining zone containment capability
- Geochemistry (waste stream interaction with injection zone and confining zone matrix)

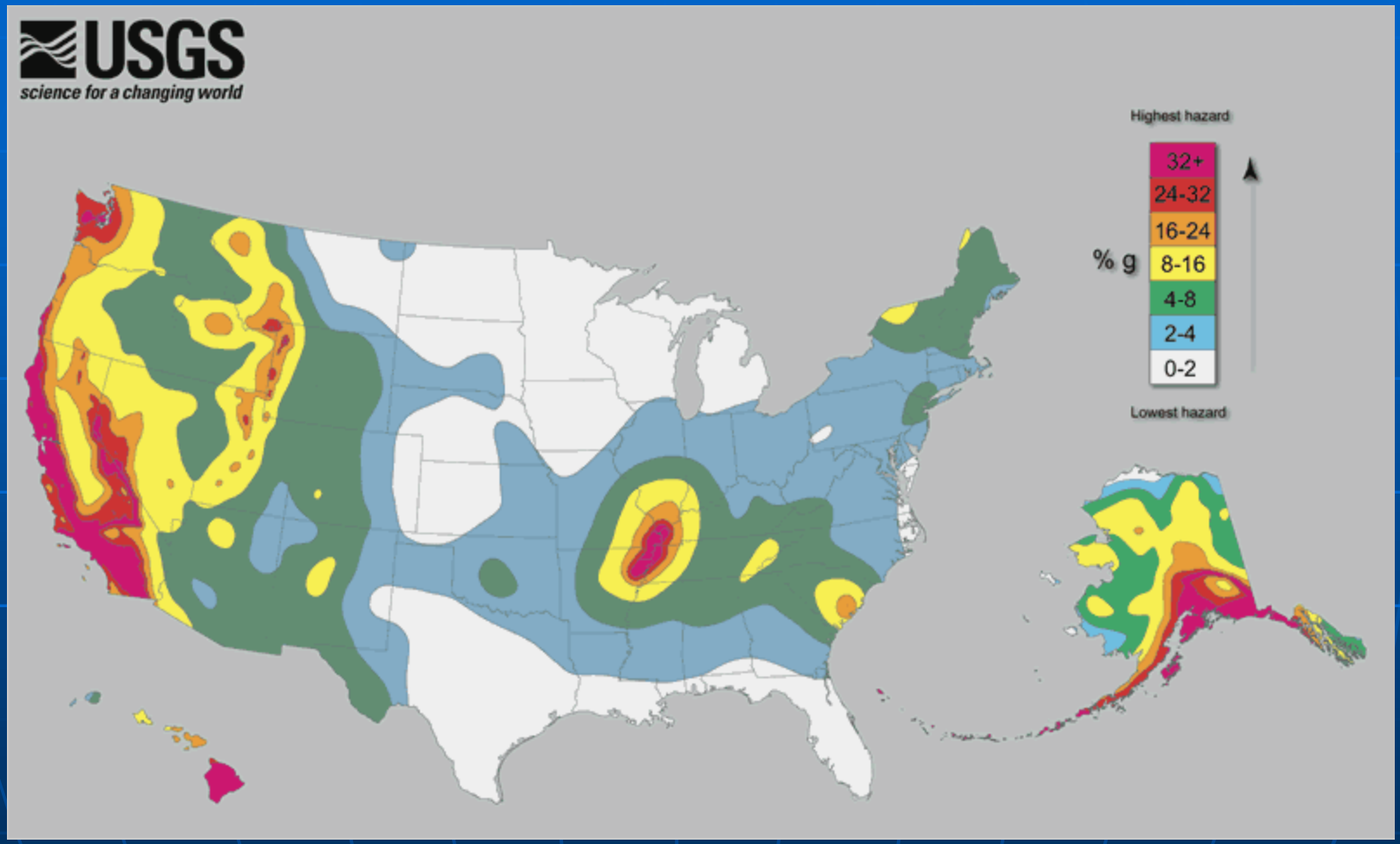
ARTIFICIAL PENETRATIONS (POTENTIAL "MAN MADE VERTICAL CONDUIT")

- How many in Area of Review?
- Location
- Depth
- Casing program
- Cementing program
- Plugging and abandonment method

FAULTING
(POTENTIAL "NATURAL VERTICAL CONDUIT")

- Are faults present in Area of Review?
- Do faults transect injection and/or confining zones?
- Does a potential vertical pathway exist?

SEISMIC ACTIVITY



INTERACTION WITH OTHER INJECTION WELLS

- Are there other injection wells in Area of Review?
- Are they injecting in similar subsurface depths?
- Are waste streams compatible?
- Formation pressure increase interaction?

INTERACTION WITH OIL & GAS AND GEOTHERMAL RESOURCES

- Oil & gas producing formations?
- Geopressured geothermal resources?
- Injection zone = non-oil & gas producing zone? (except Class II EOR)

MULTI-LAYERED GROUNDWATER PROTECTION MEASURES BUILT INTO UIC REGULATORY PROGRAM

II. Injection well construction ("Site Development")

- External protective casings cemented into place to isolate USDW
- Internal injection tubing and packer
- Waste stream compatibility analyses

MULTI-LAYERED GROUNDWATER PROTECTION MEASURES BUILT INTO UIC REGULATORY PROGRAM

III. Injection well operation/monitoring ("Site Management")

- Injection pressure and rate limitations
- Continuous monitoring programs (annulus, lowermost USDW, etc.)
- Periodic mechanical integrity testing
- Waste analysis program

MULTI-LAYERED GROUNDWATER PROTECTION MEASURES BUILT INTO UIC REGULATORY PROGRAM

IV. Injection well closure requirements ("Site Closure")

- Regulatory approved closure plan
- Documentation of closure procedures to regulatory agency, i.e., certified closure report
- Property deed restriction

MULTI-LAYERED GROUNDWATER PROTECTION MEASURES BUILT INTO UIC REGULATROY PROGRAM

V. Post-injection monitoring requirements ("Post-Closure")

- Injection zone residual pressure decline
- Plume movement
- Water quality (injection zone and any monitored zones)
- Discontinue after satisfactory demonstration to regulatory agency

MOVING FORWARD

Emerging underground injection and sequestration applications:

- Anthropogenic CO2 geologic sequestration
- Reject from groundwater desalination plants
- Aquifer storage and recovery
- Compressed air energy storage
- Other potential applications?

CONCLUSIONS

Underground injection and sequestration:

- An excellent method for permanent disposal of industrial, municipal and O&G produced liquid wastes; and captured CO2 if properly sited, operated, monitored and closed
- An excellent method for cyclical underground storage of gases (natural gas storage) and compressed air (compressed air energy storage)
- Will be a critical component to ensure continued availability of reliable, clean, safe groundwater for a growing population (aquifer storage and recovery and desalination plant reject disposal)
- Can be utilized for all these, and other, applications without endangering valuable groundwater resources