U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 00-429-A

Slide Show on Hierarchical Systems Analysis in Karst Terrains: Part A - Approaches and Applications to Environmental Characterization

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Hierarchical Systems Analysis in Karst Terrains:

Part A

Approaches and Applications to Environmental Characterization

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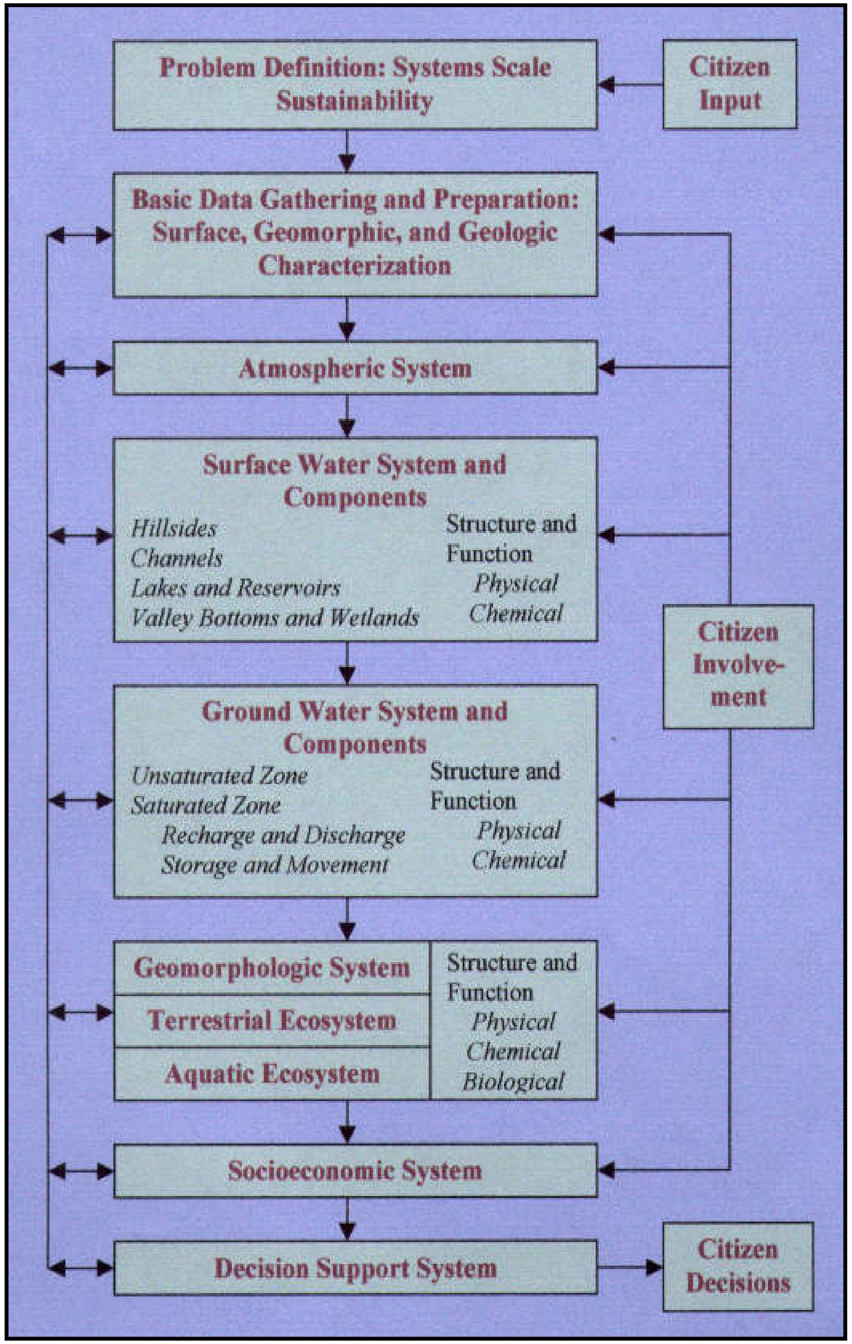
Purpose of Presentation

- Discuss the concept of integrated, hierarchical systems analysis (HSA).
- Describe HSA procedure.
- Discuss advantages of using HSA.

(Why bother?)

HIERARCHICAL SYSTEMS ANALYSIS APPLICATIONS:

ECOSYSTEMS CHARACTERIZATION AND SUSTAINABILITY



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Integrated, Hierarchical Systems Analysis

- Landscape or site is mosaic of dynamic systems that operate through complex, interrelated processes.

- Understanding dynamic systems separately, and then collectively allows for broader understanding of environmental system.

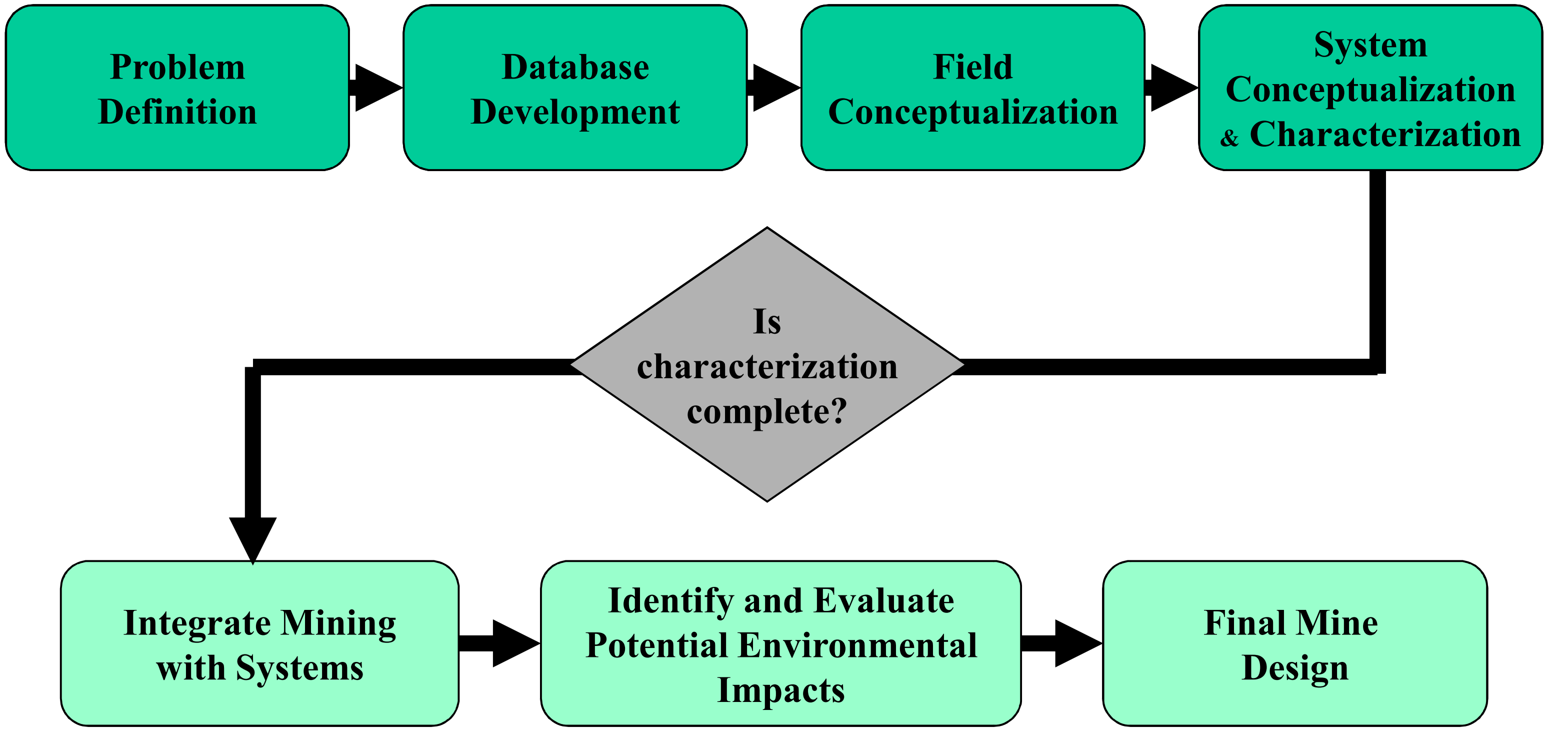
- Dynamic systems may include climate, land surface, surface water, geomorphology, geology, and ground water.

Integrated, Hierarchical Systems Analysis

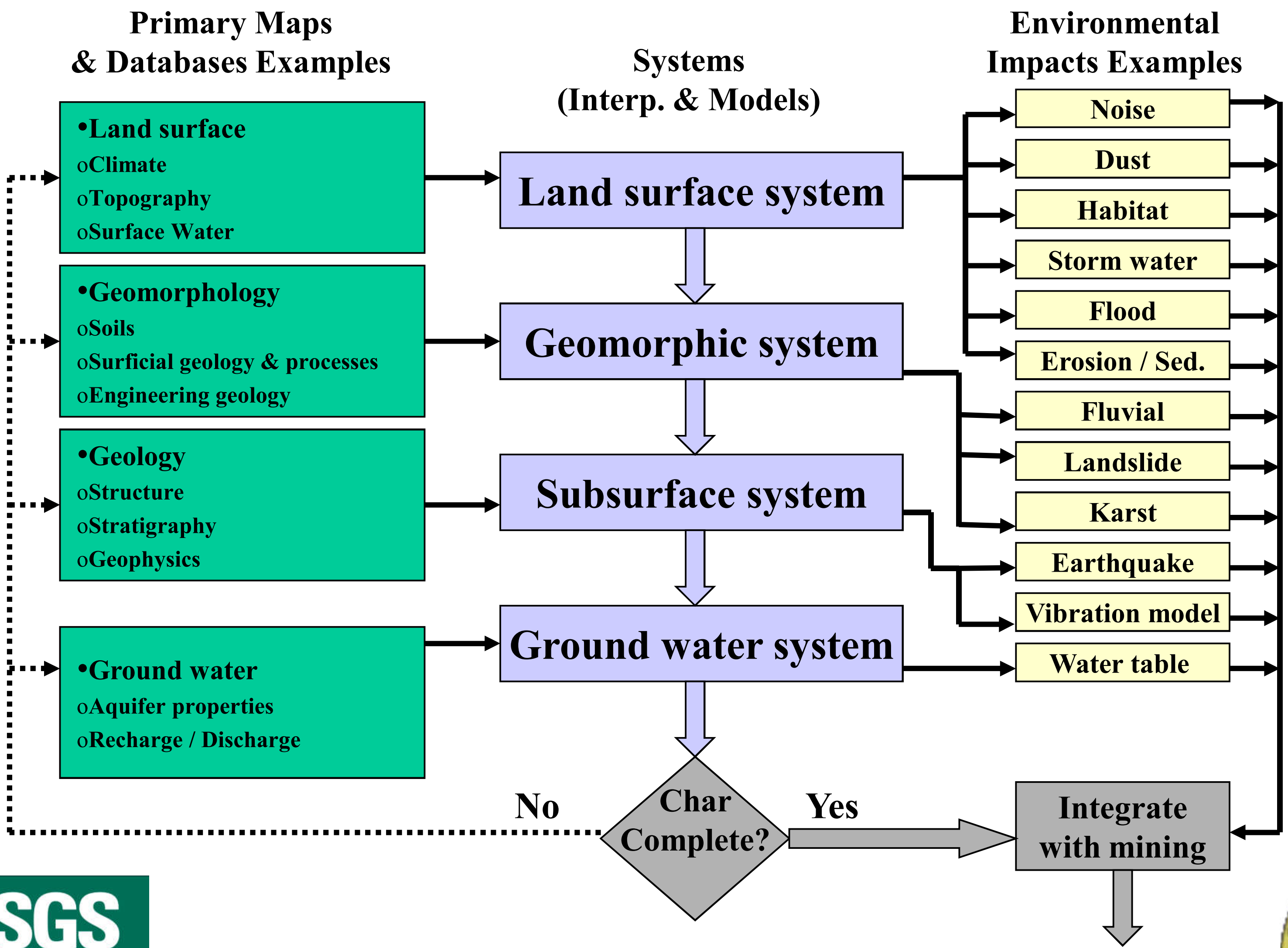
- Understanding each system hierarchically depends on the understanding of the other systems.

- Stepwise approach breaks complicated issues into smaller, easier to understand, components.

Hierarchical Systems Analysis in Karst Terrains



Hierarchical Systems Analysis



Hierarchical Systems Analysis Applications

- Ground water system water quality analysis
- Ground water flow system analysis
- Wetlands system analysis
- Watershed system analysis (integrated surface water and ground water system)
- Ecosystem characterization
- Site specific system analysis (for example, aggregate mining).

Carlsbad Case History

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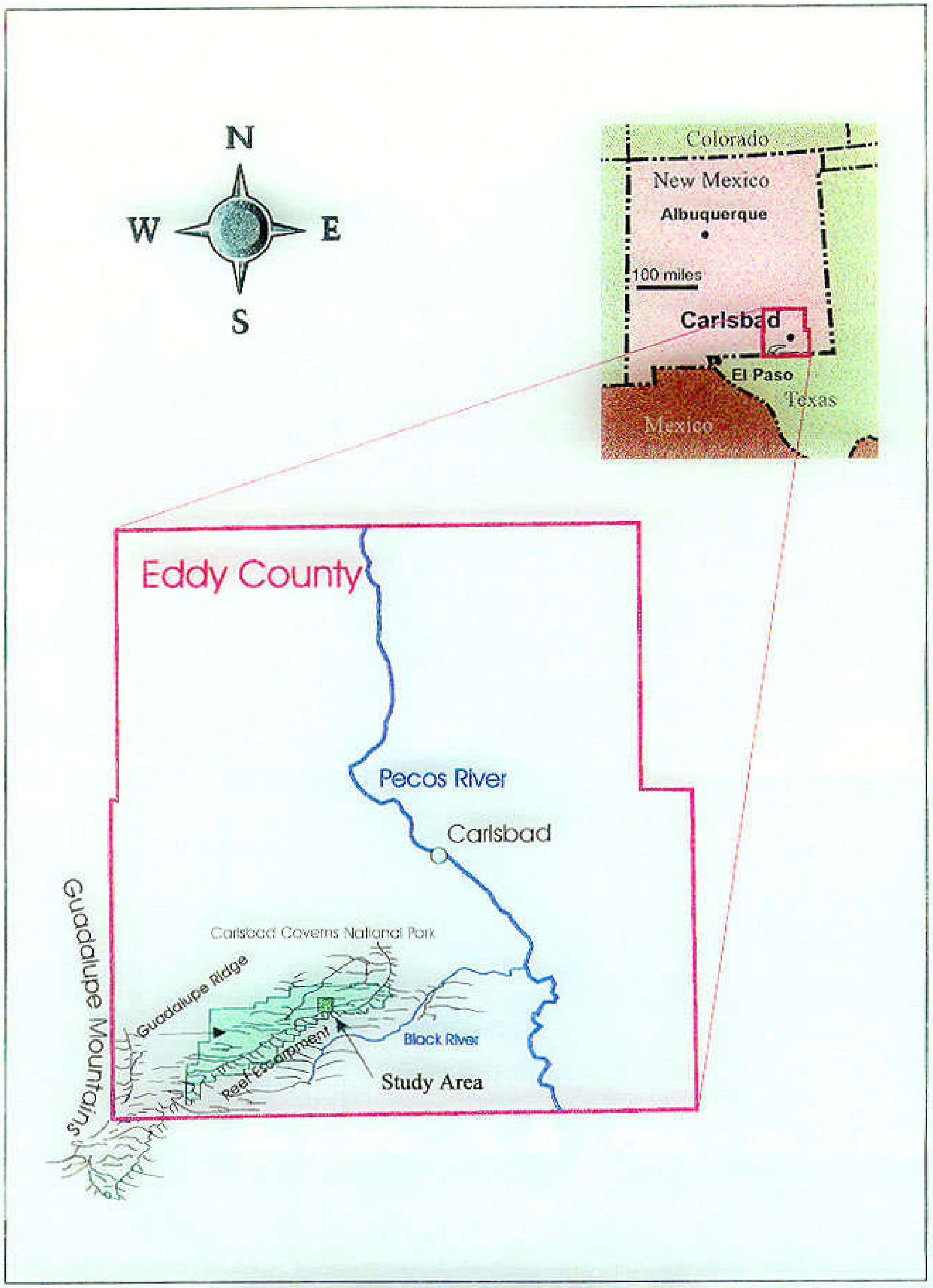


Figure 1. Location of study area (from Brooke, 1996).

Carlsbad Caverns National Park

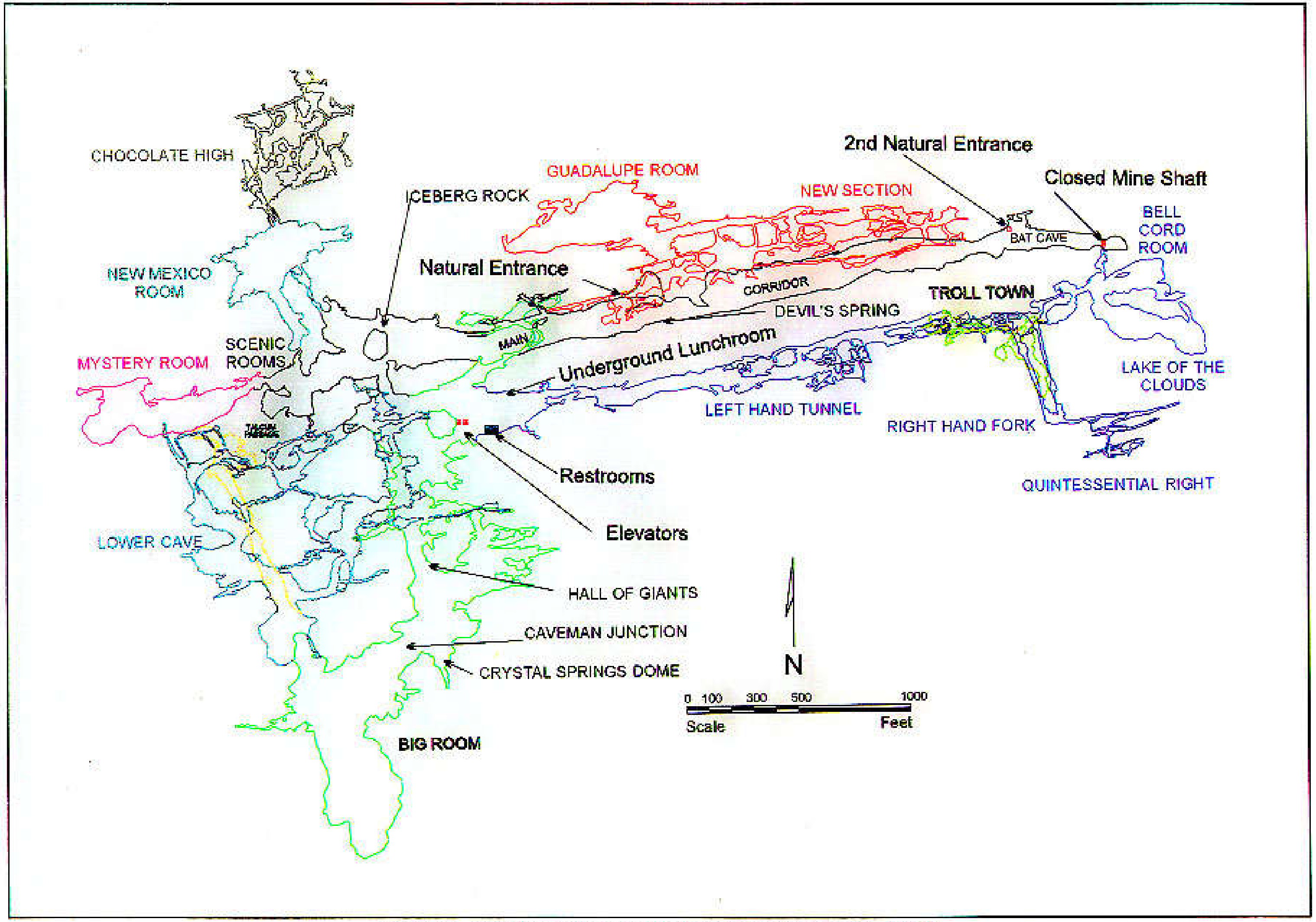


Figure 3. Carlsbad Cavern room locations (from Brooke, 1996).

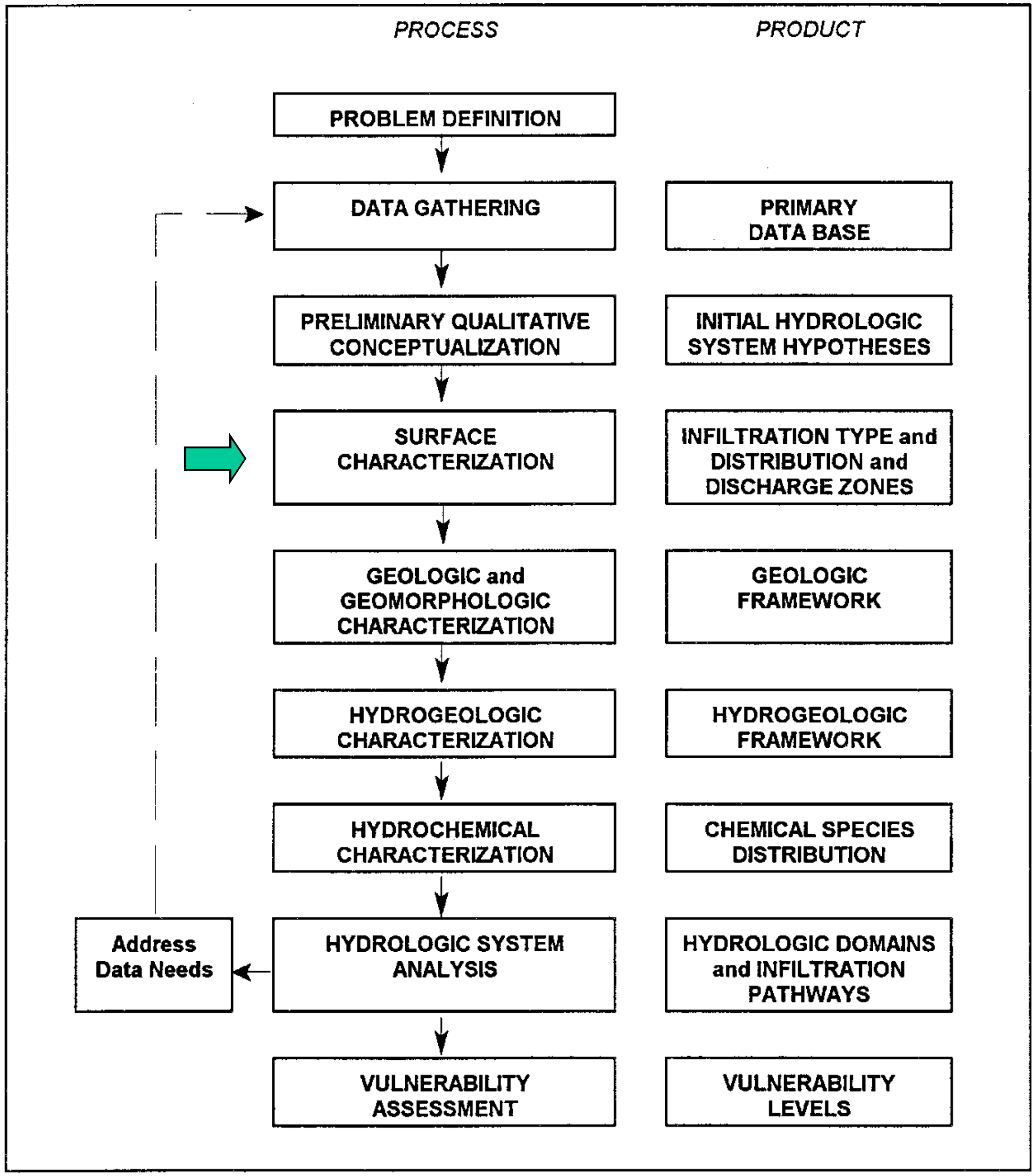


Figure 5. Flow diagram of hydrologic system analysis for Carlsbad Cavern (modified from Kolm et al., 1996).

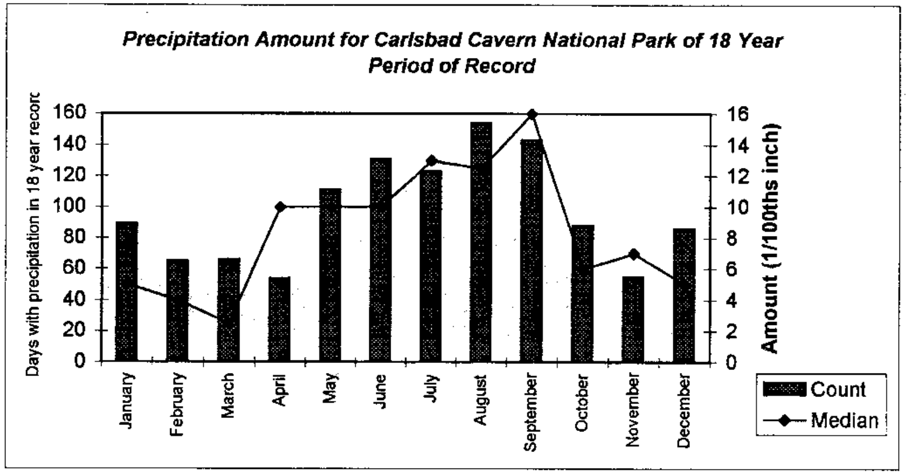


Figure 6: Average precipitation amount for 18 year period of record at Carlsbad Caverns National Park and number of days having precipitation for record (from Brooke, 1996)

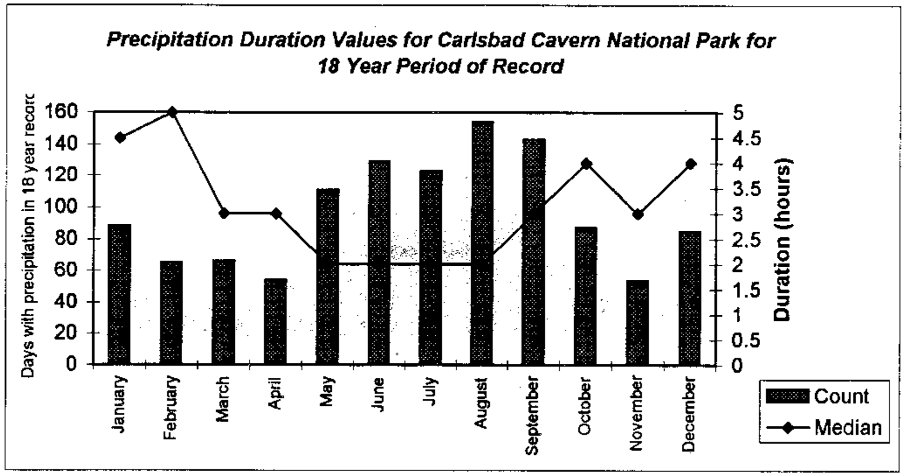


Figure 7: Precipitation duration for 18 year period of record at Carlsbad Caverns National Park and number of days having precipitation for record (from Brooke, 1996)

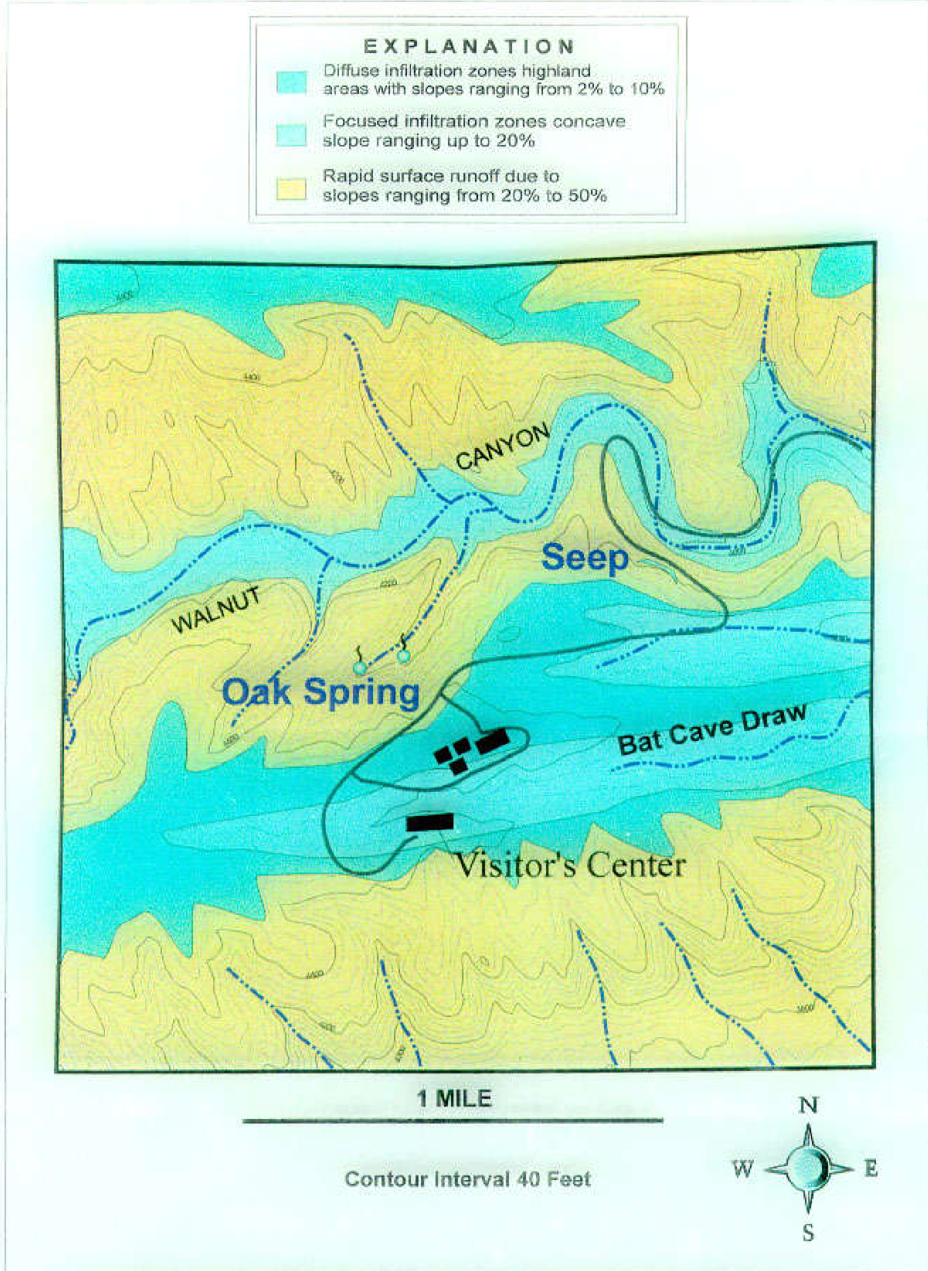


Figure 9: Surface infiltration type, distribution, and surface hydrology (from Brooke, 1996)

Carlsbad Caverns National Park
Walnut Canyon

Carlsbad Caverns National Park

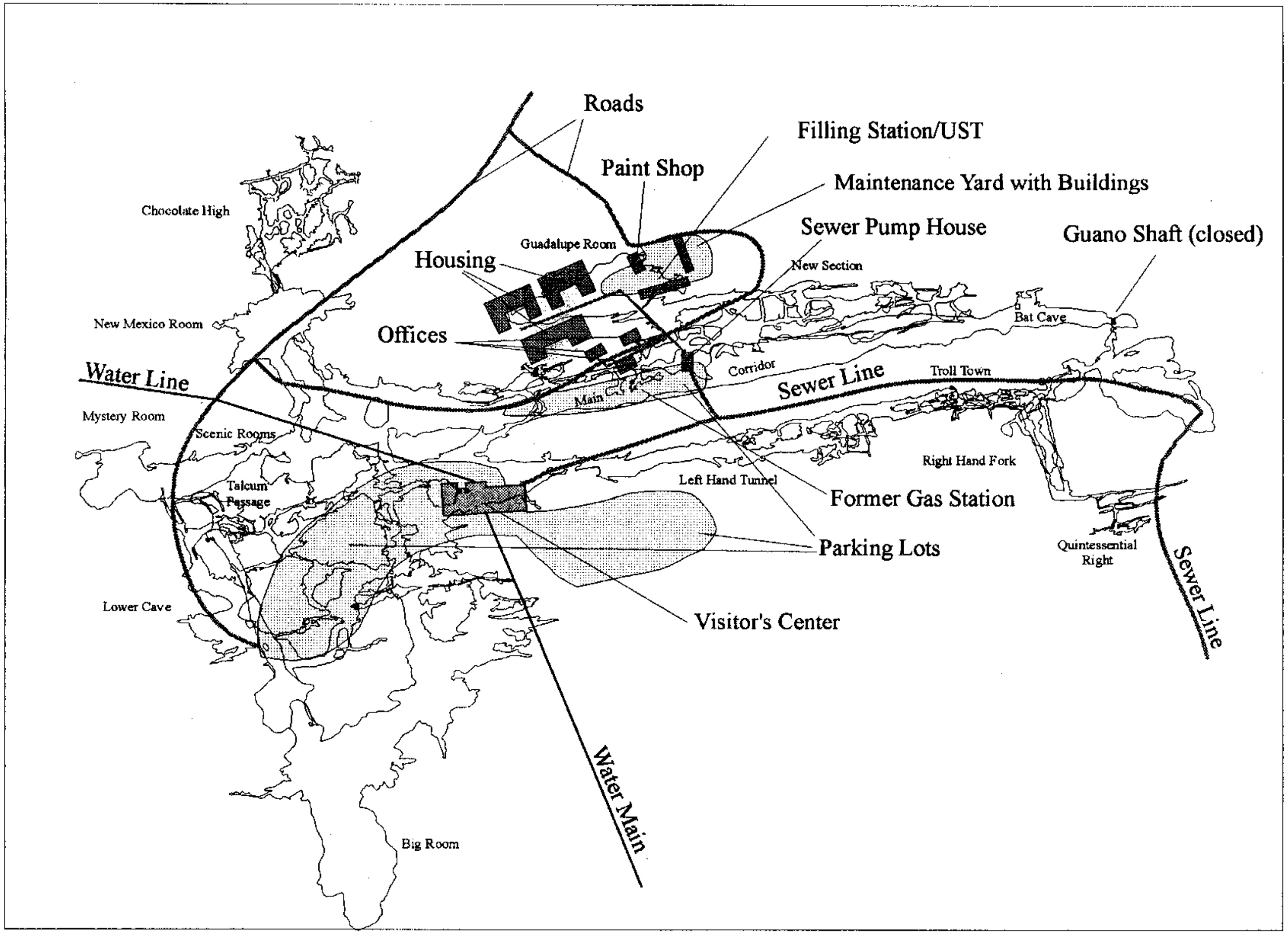
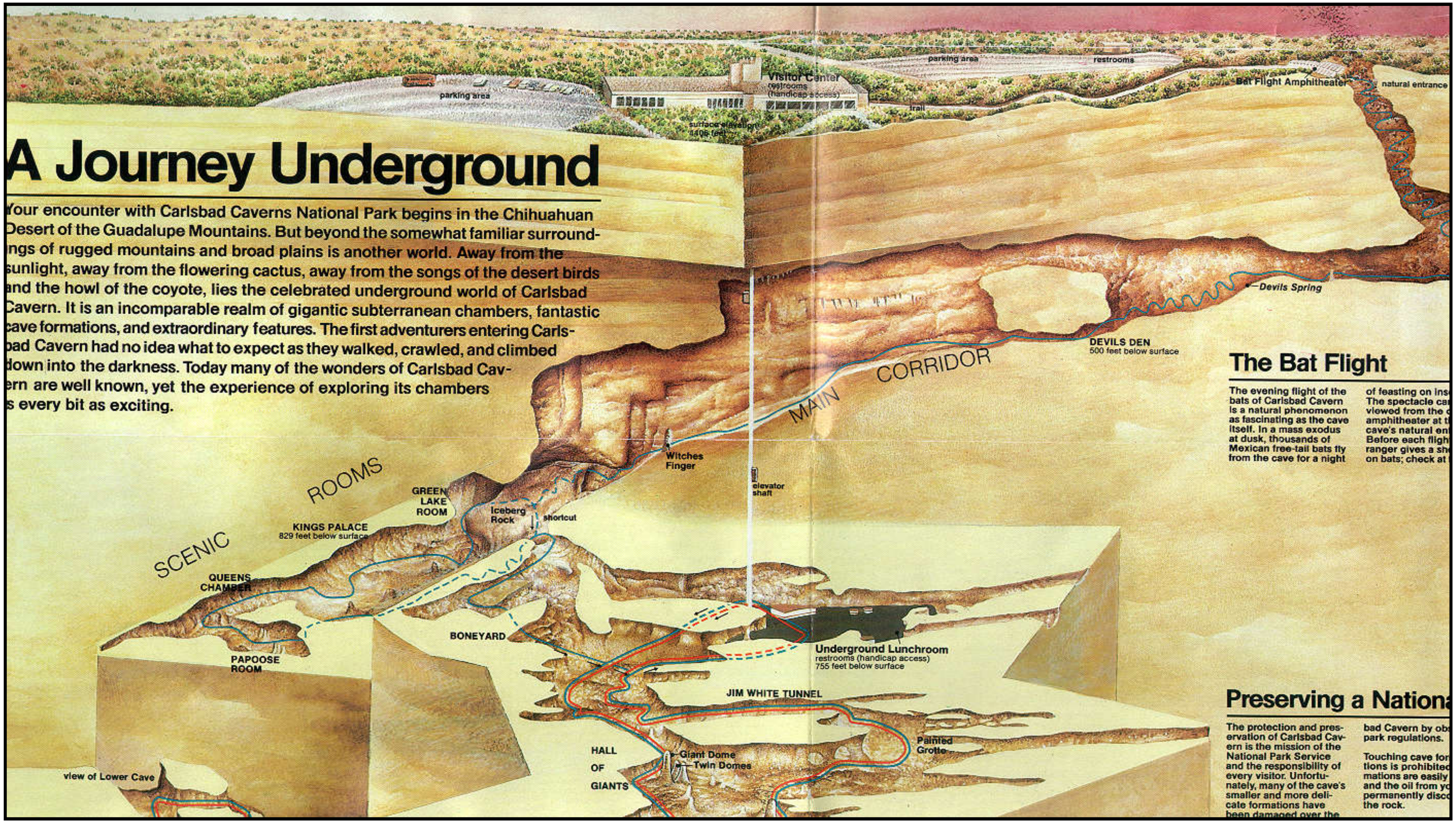


Figure 12: Surface facilities and cave geometry at Carlsbad Cavern (from Brooke, 1996)

Carlsbad Caverns National Park



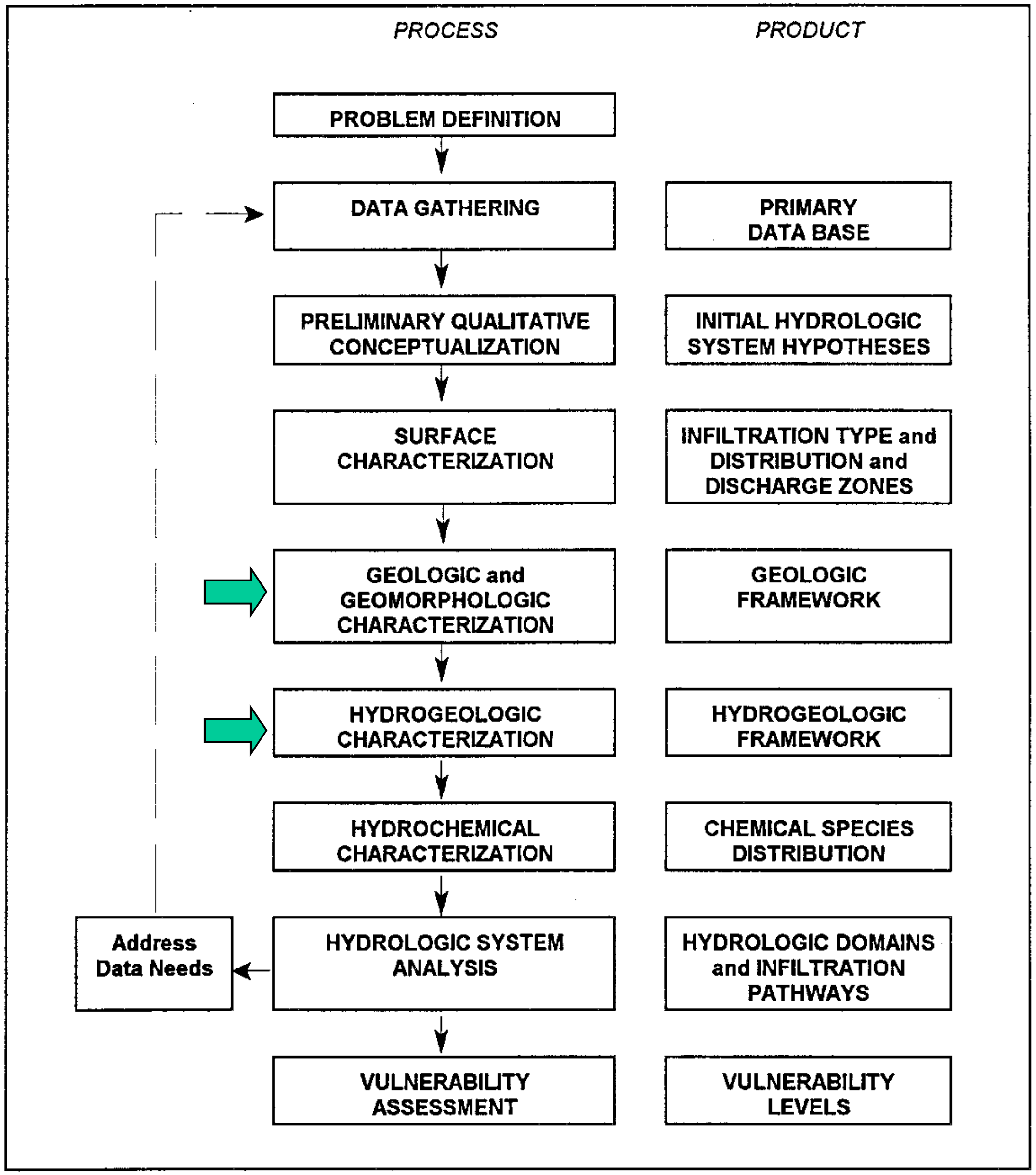


Figure 5. Flow diagram of hydrologic system analysis for Carlsbad Cavern (modified from Kolm et al., 1996).

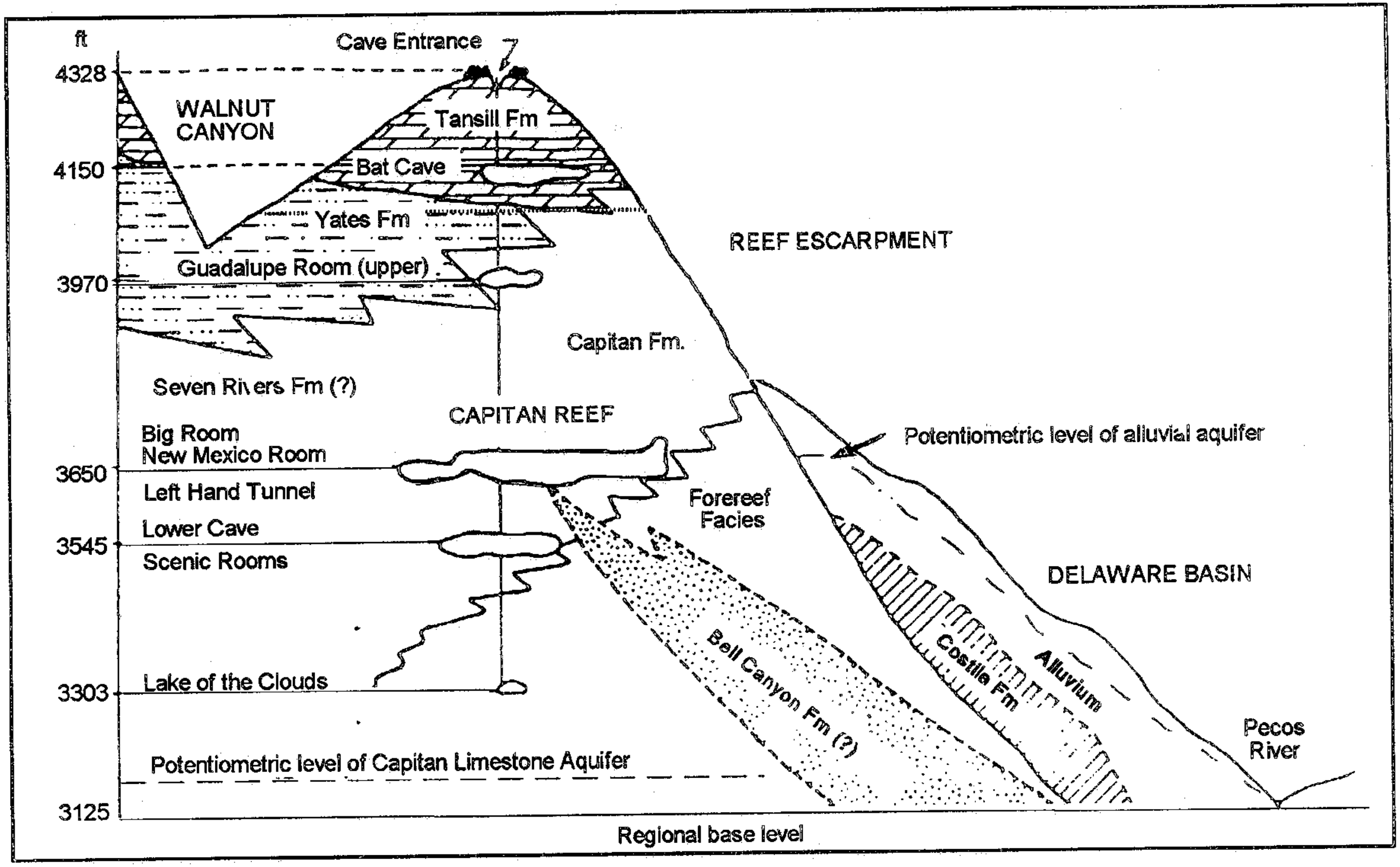


Figure 4. Schematic (geo-)stratigraphic profile of Carlsbad Cavern area (from Hill, 1987).

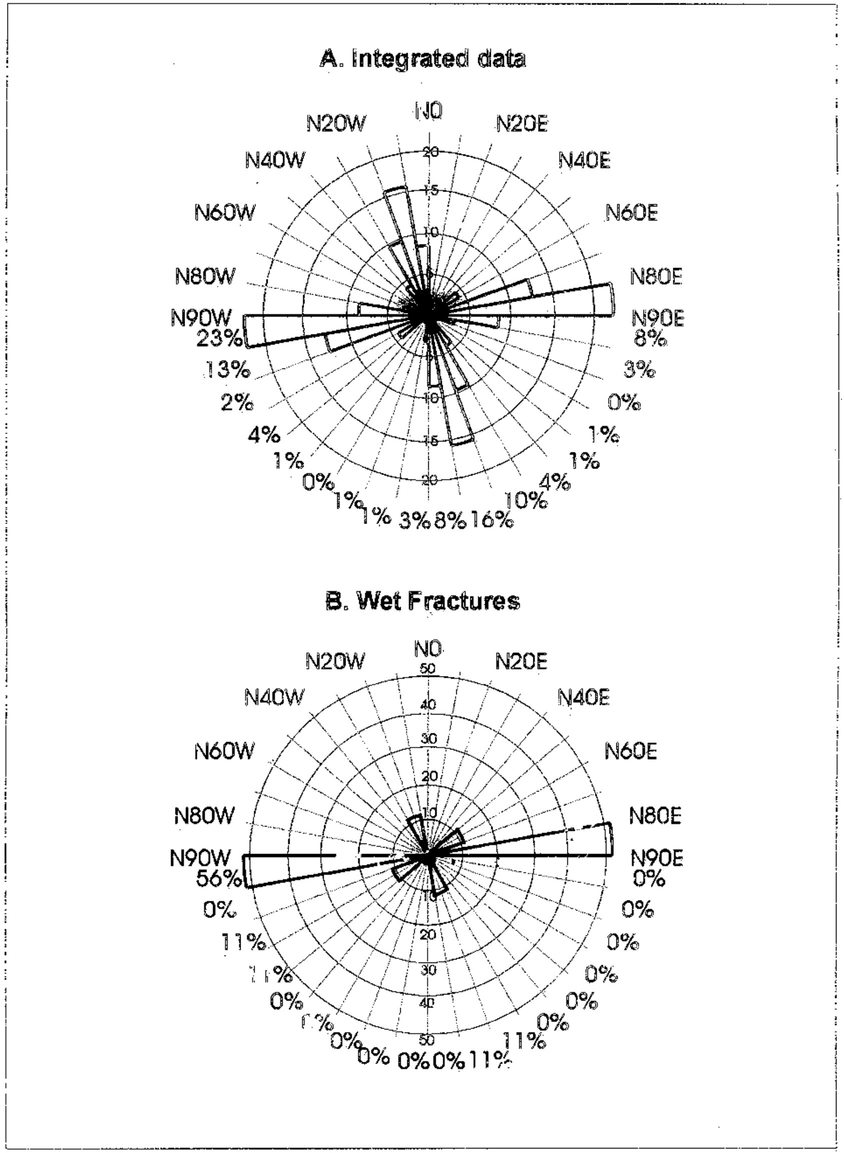


Figure 14: Fracture rose diagrams for Carlsbad Cavern: A. Joint surface and subsurface data; B. subsurface data for wet fractures only (from Brooke, 1996).

Table 2. Hydrogeologic units and properties (after Brooke, 1996).

Hydrogeo-logic Unit	Description	Thickness [1)] m (ft)	Primary Porosity (fraction)	Primary Permeability m/day (ft/day) [1)]
Walnut Canyon Alluvium	Alluvial deposits in Walnut Canyon with high (primary) permeability. Porous media flow, rapid infiltration and lateral interflow.	0 - 7 (0 - 20)	0.25 - 0.50 [2)]	$0.3 \cdot 10^{1}$ - $0.3 \cdot 10^{3}$ ($1.0 \cdot 10^{1}$ - $1.0 \cdot 10^{3}$) [2)]
Tansill Dolomite and Siltstone	Thinly bedded, dolomitized limestone, interbedded with laterally discontinuous siltstones. Subcutaneous zone present. Vertical microfracture flow and locally lateral movement at bedding planes.	2.5 - 7 (8 - 20) [0 - 1] [(0 - 3)]	0.02 [3)] [0.35 - 0.50] [2)]	$0.3 \cdot 10^{-5}$ - $0.3 \cdot 10^{-3}$ ($1.0 \cdot 10^{-6}$ - $1.0 \cdot 10^{-3}$) [3)] [$0.3 \cdot 10^{-2}$ - 0.3] [($1.0 \cdot 10^{-2}$ - 1.0)] [2)]
Yates Siltstone	Extensive, continuous siltstone beds of fine grained quartz and detrital fragments. Low permeability. Significant lateral flow along lithologic contacts.	0 - 0.3 (0 - 1)		$0.3 \cdot 10^{-2}$ - 0.3 ($1.0 \cdot 10^{-2}$ - 1.0) [2)]
Yates Sandstone and Dolomite	Competent, thinly bedded dolomite interbedded with sandstone and siltstone layers. Some porous media flow, primarily in the sandstone; significant microfracture flow; some (local) flow along facies contacts.	10 - 40 (30 - 120)	0.005 [3)]	$1.7 \cdot 10^{-5}$ ($5.0 \cdot 10^{-5}$) [3)]
Seven Rivers Dolomite	Thinly bedded, fine grained dolomite. Thin sandstone stringers are intercalated with the dolomite and wedge out as they approach the reef. Microfracture flow and some (local) flow along facies contacts.	110 - 200 (335 - 600)		
Massive Capitan Limestone	Permian reef structure with vugs filled with secondary calcite crystallization. This unit is highly fractured and cavernous. Primarily vertical, micro- and macrofracture flow. Convective vapor-phase flow in caves.	250 - 335 (750 - 1000)	0.015 - 0.020 [3)]	$1.2 \cdot 10^{-2}$ ($3.5 \cdot 10^{-2}$) [3)]
Foreslope Capitan Limestone	Foreslope member of Permian reef. Talus slope on basinward edge of reef, dipping at angles of 30 degrees or more. Reef prograded basinward over tallus. Vertical microfracture flow; (local) lateral flow along bedding planes.	250 - 335 (750 - 1000)		

1) Numbers between brackets denote values for Siltstone Member of Tansill Formation.
2) Values taken from Fetter (1994).
3) Values taken from Hill (Table 12, 1987).

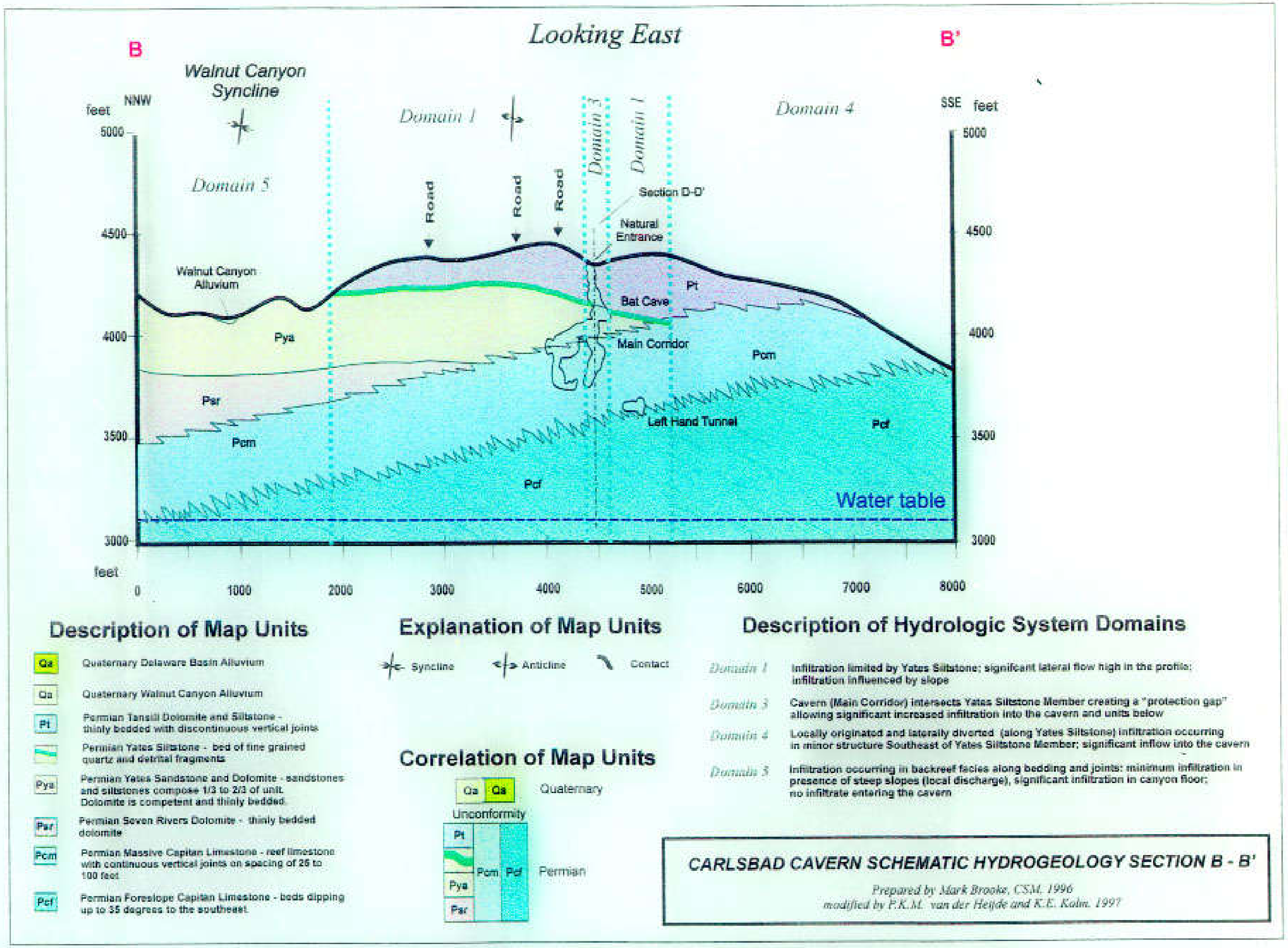


Figure 21. Carlsbad Cavern hydrogeologic cross-section B-B' (modified from Brooke 1996).

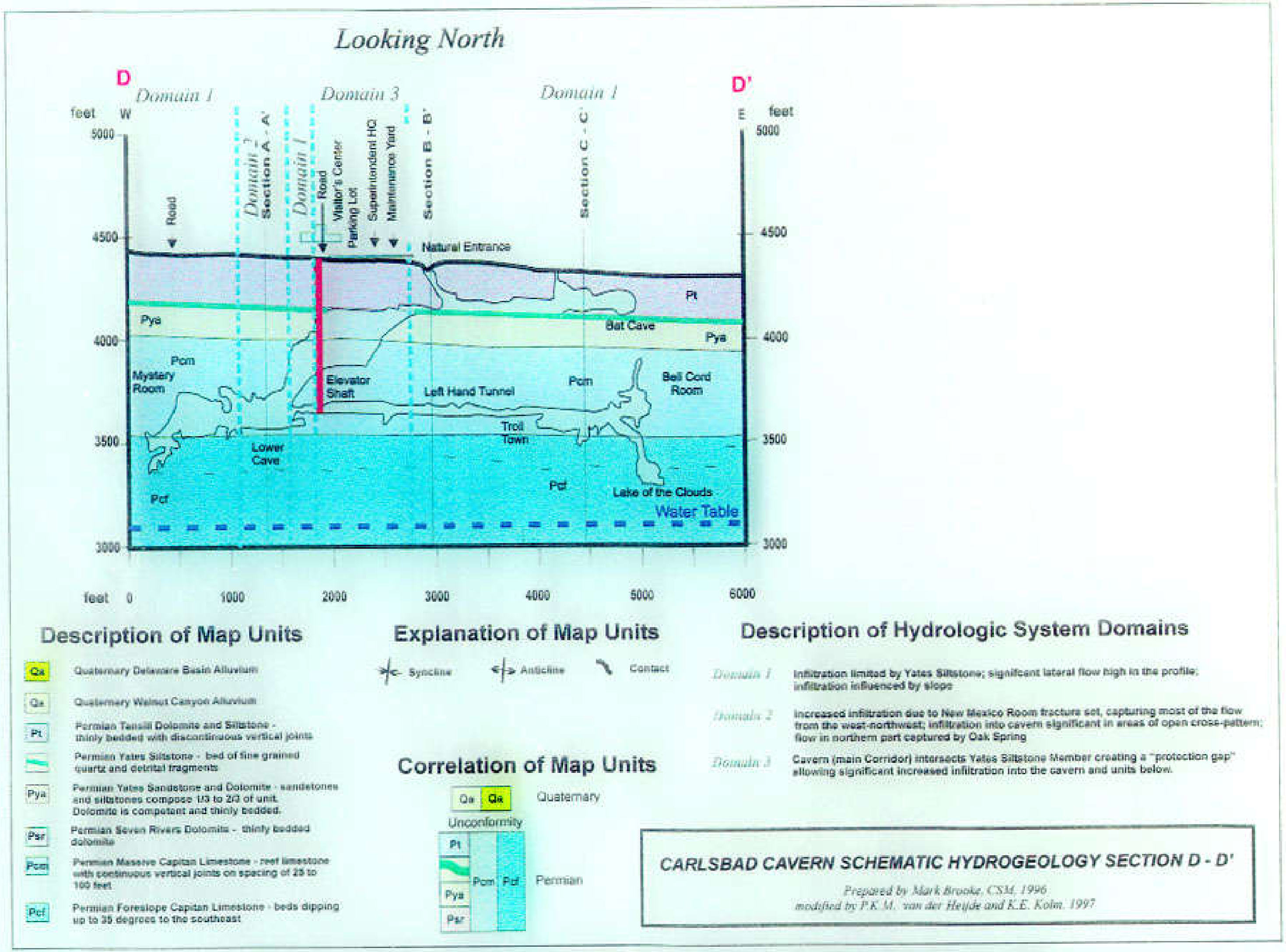


Figure 23. Carlsbad Cavern hydrogeologic cross-section D-D' (modified from Brooke, 1996)

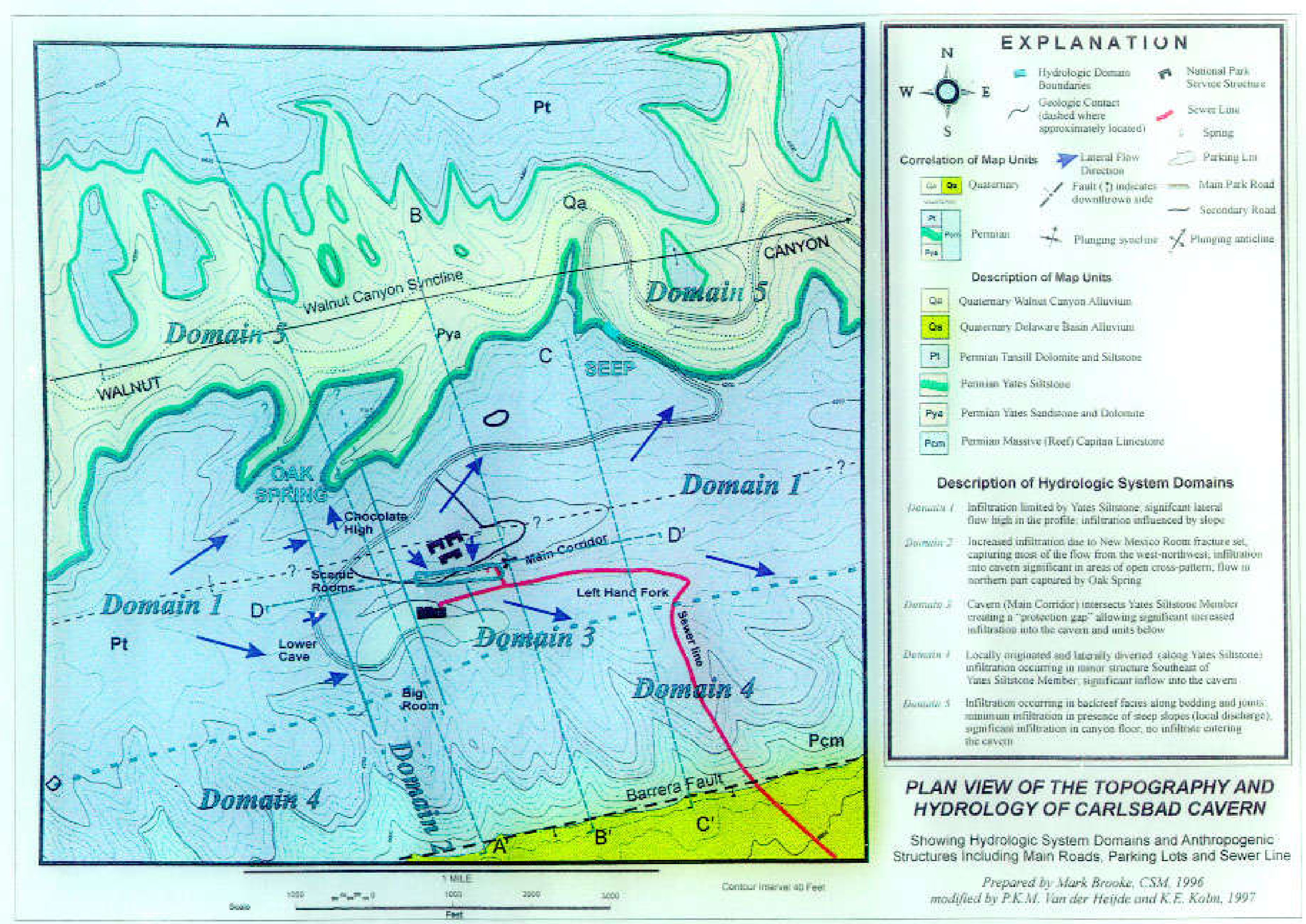


Figure 25. Hydrologic system domains for Carlsbad Cavern (modified from Brooke, 1996)

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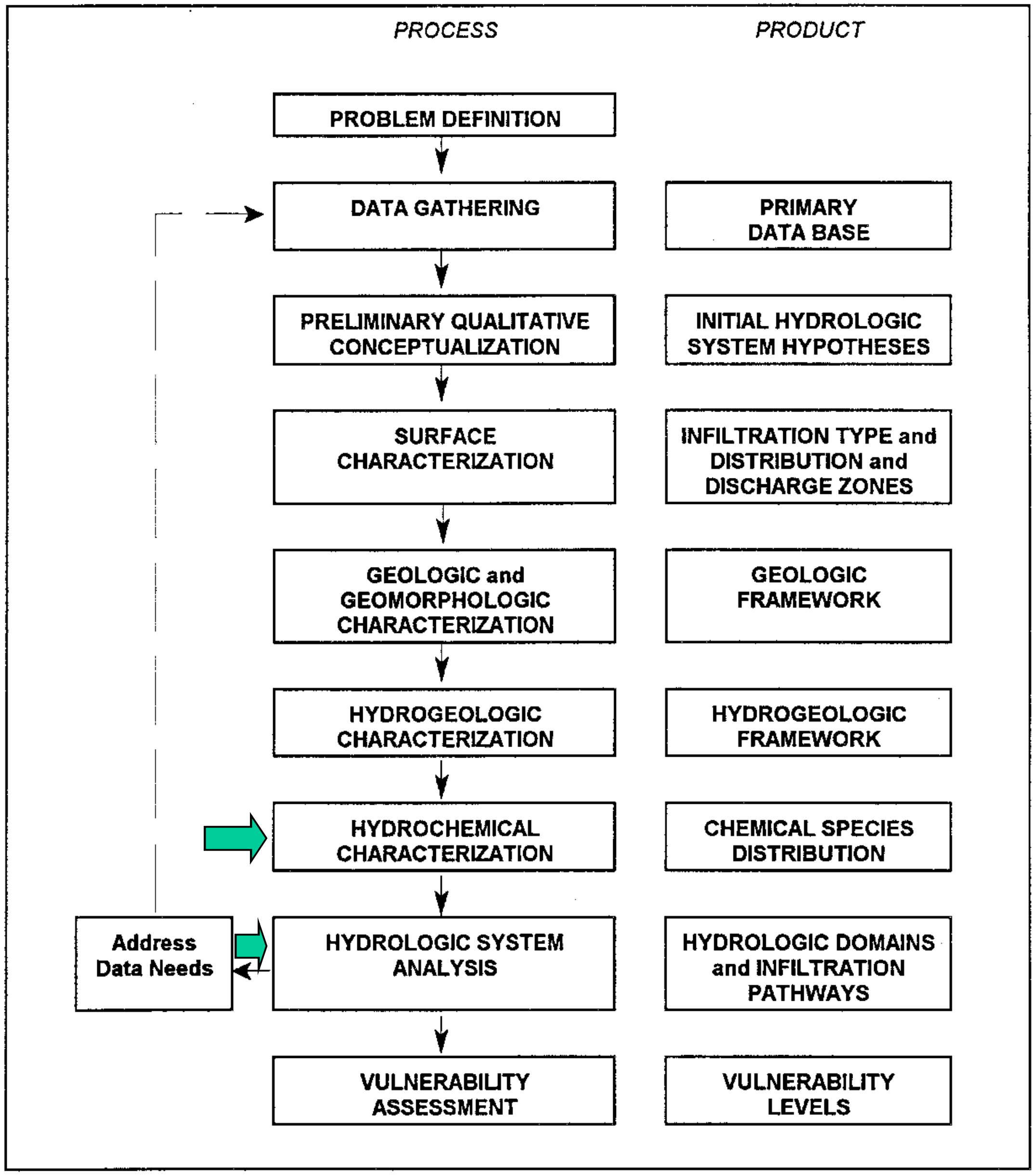

Figure 5. Flow diagram of hydrologic system analysis for Carlsbad Cavern (modified from Kolm et al., 1996).

WATER QUALITY AND REGULATORY LIMITS

- MCL: Maximum Concentration Level
  (Safe Drinking Water Act)
- SMCL: Secondary Maximum Concentration Level
  (Safe Drinking Water Act)
- NAWQC: National Ambient Water Quality Criteria
  (Clean Water Act)

<u>Findings</u>:

- Nitrate: highest observed = 238 mg/l; MCL = 10 mg/l as N (ppm); aquatic life NAWQC not set.

- Aluminum: highest observed = 455 ppb; SMCL = 50 to 200 µg/l (ppb); acute NAWQC = 750 ppb, chronic NAWQC = 87 ppb.

- Zinc: highest observed = 78 ppb; tap water (at park) = 205 ppb; SMCL = 5000 ppb; acute NAWQC = 120 ppb, chronic NAWQC = 1120 ppb.

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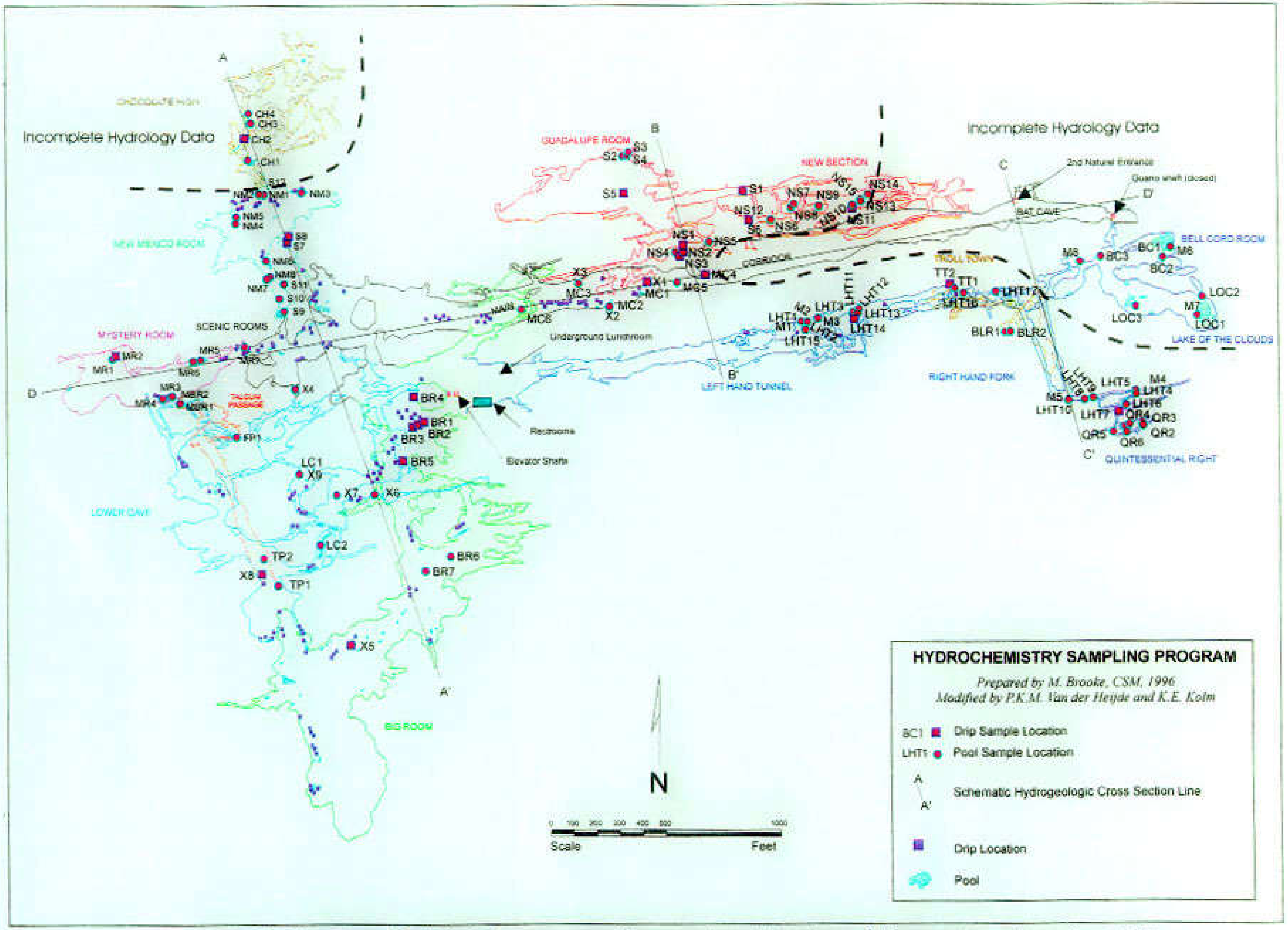

Figure 19. Plan view of Carlsbad Cavern area with cavern layout, locations of drips, pools and sampling points, and the location of the hydrogeologic cross-secrtions (modified from Brooke, 1996).

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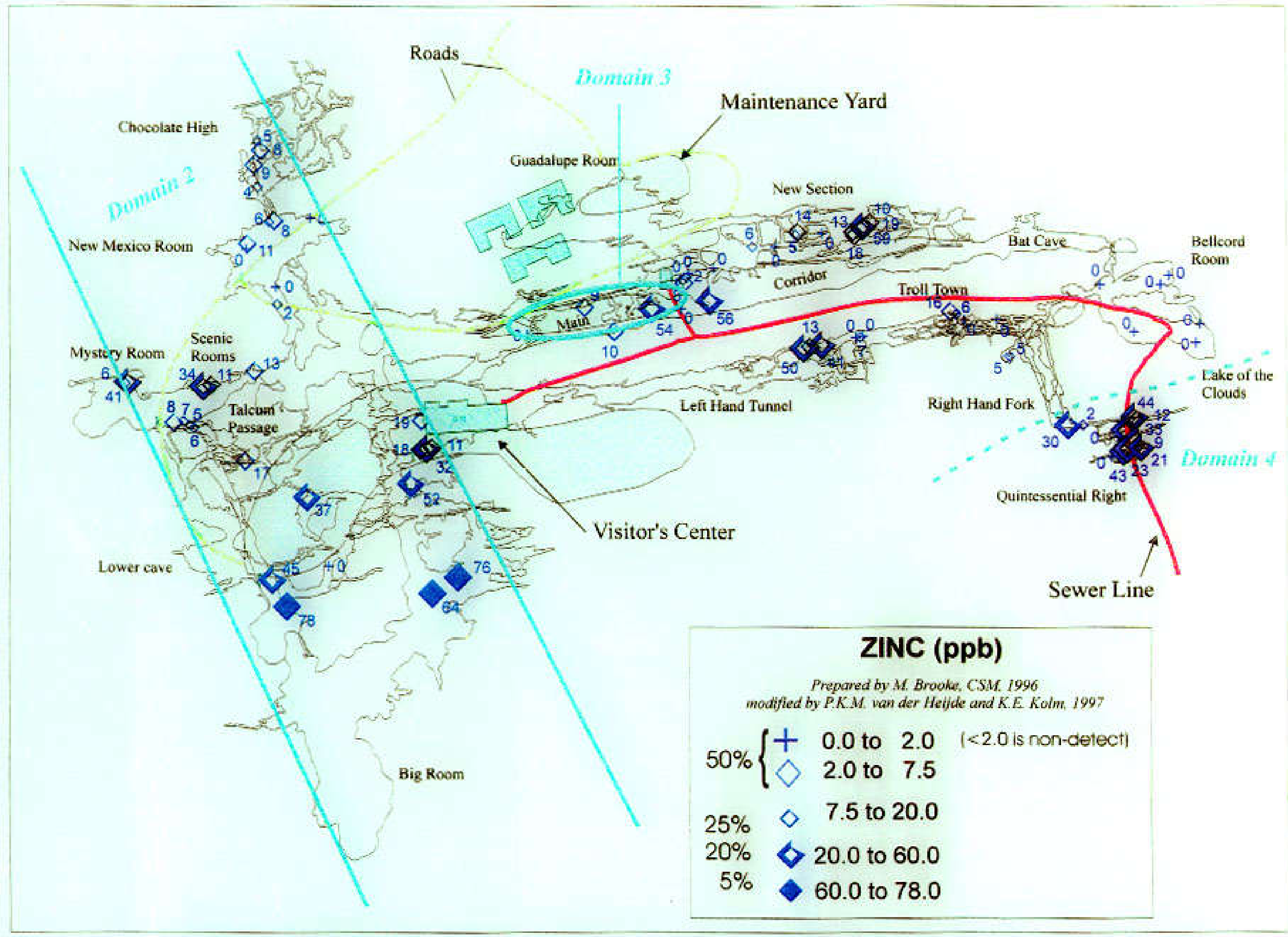

Figure 16: Carlsbad Cavern zinc hydrochemistry, cavern layout and hydrologic domains (modified from Brooke, 1996)

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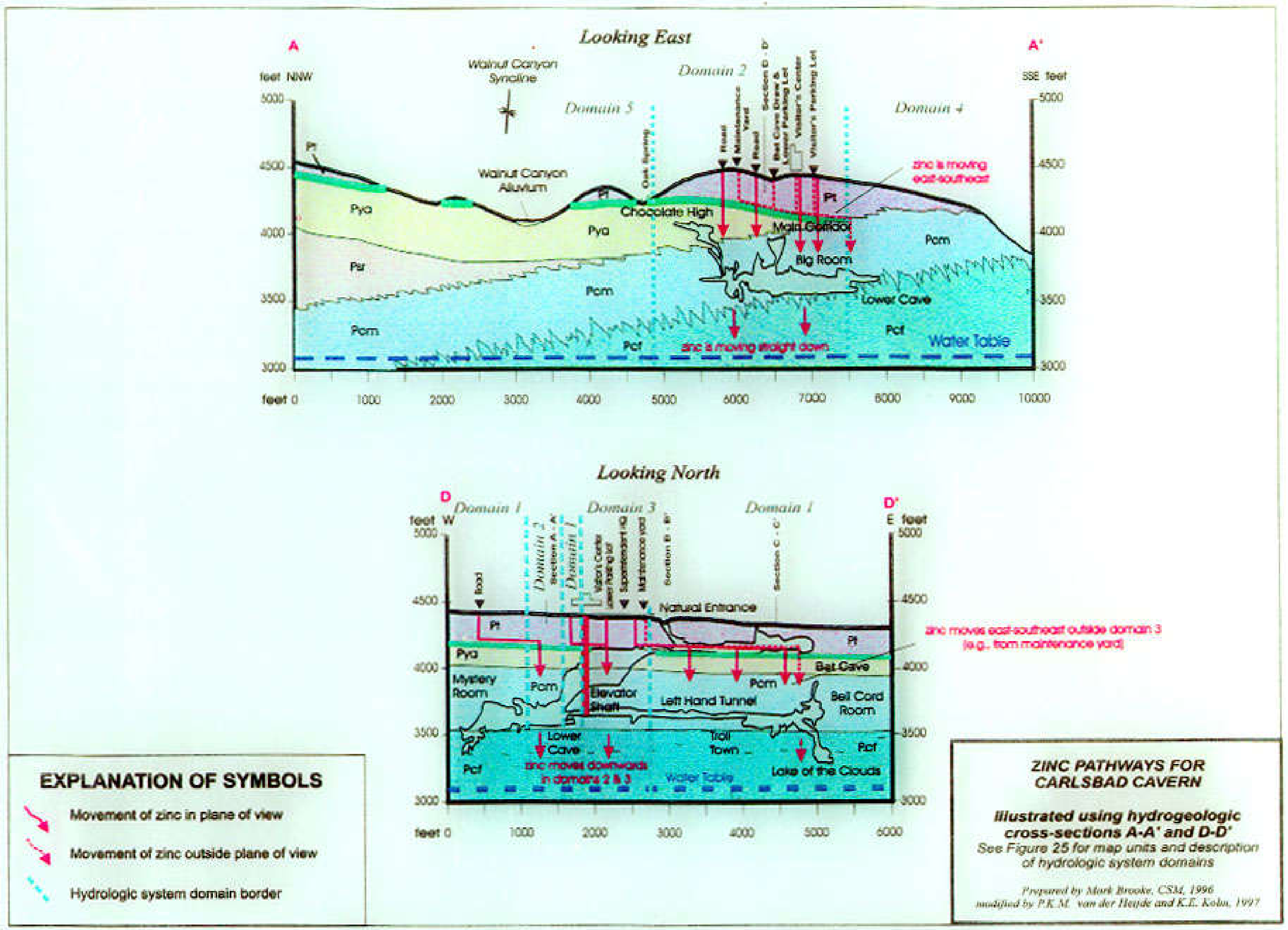

Figure 27. Zinc pathways for Carlsbad Cavern (modified from Brooke, 1996)

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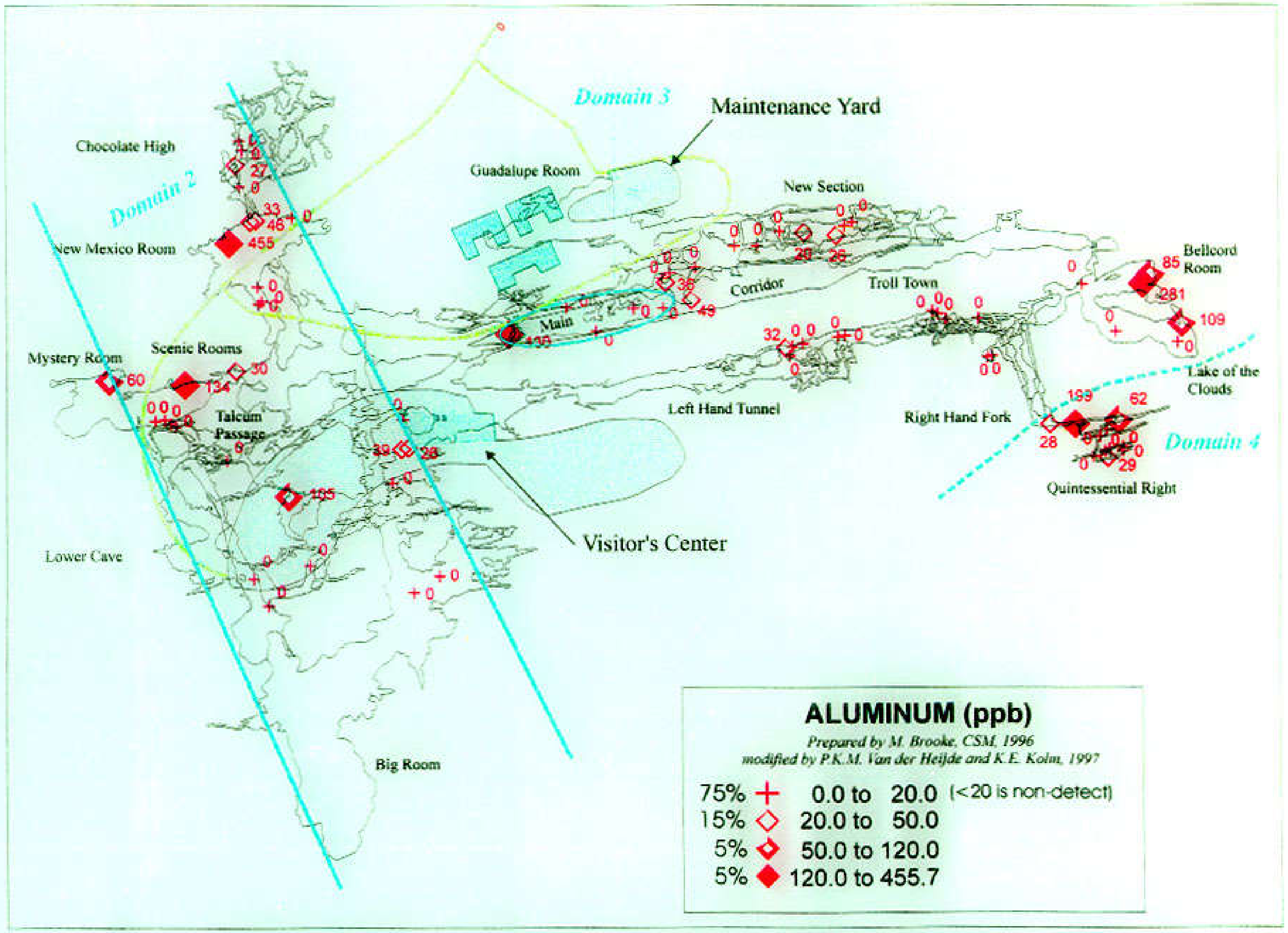

Figure 15: Carlsbad Cavern aluminum hydrochemistry, cavern layout and hydrologic domains (modified from Brooke, 1996)

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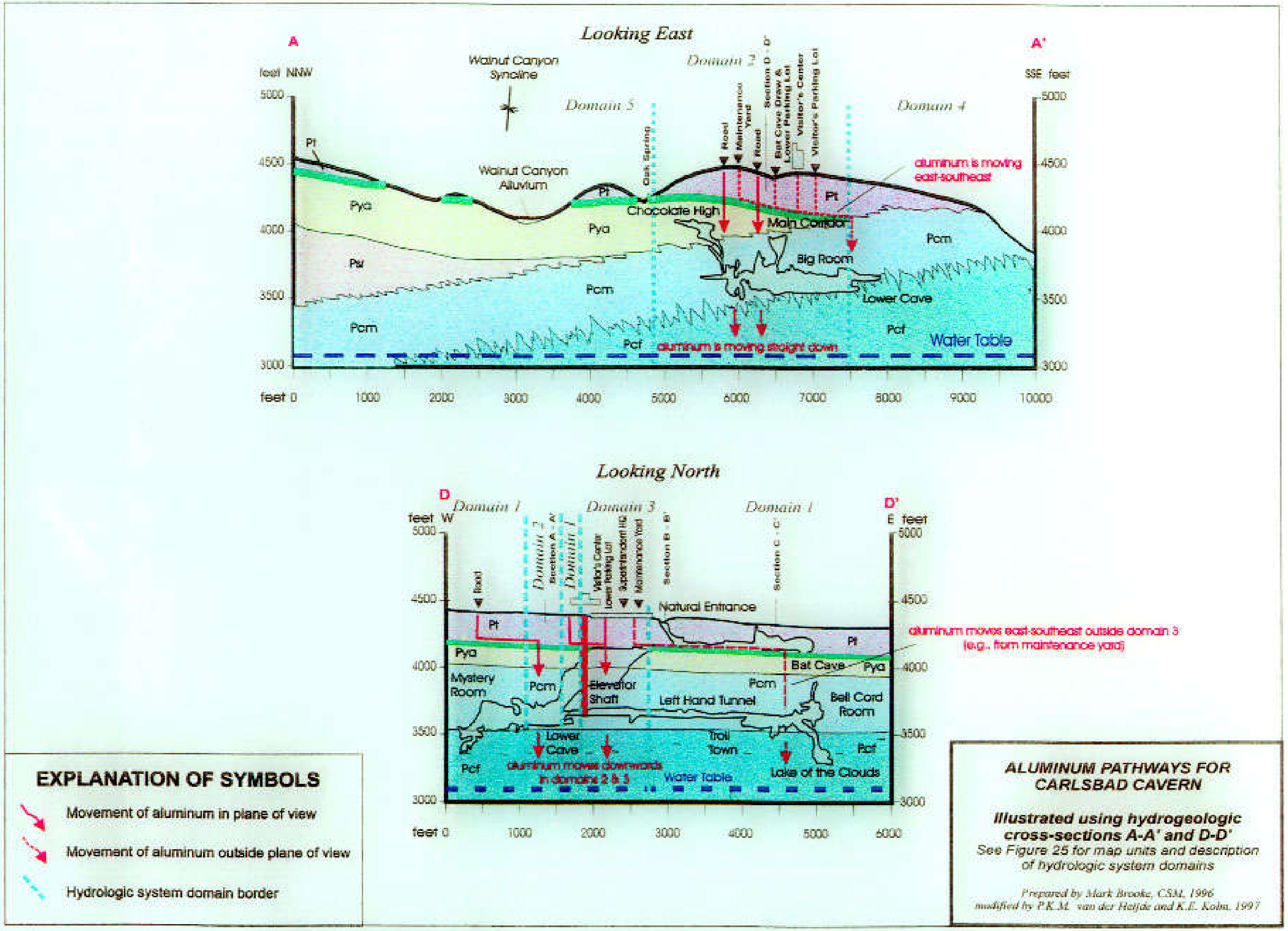

Figure 26. Aluminum pathways for Carlsbad Cavern (modified from Brooke, 1996)

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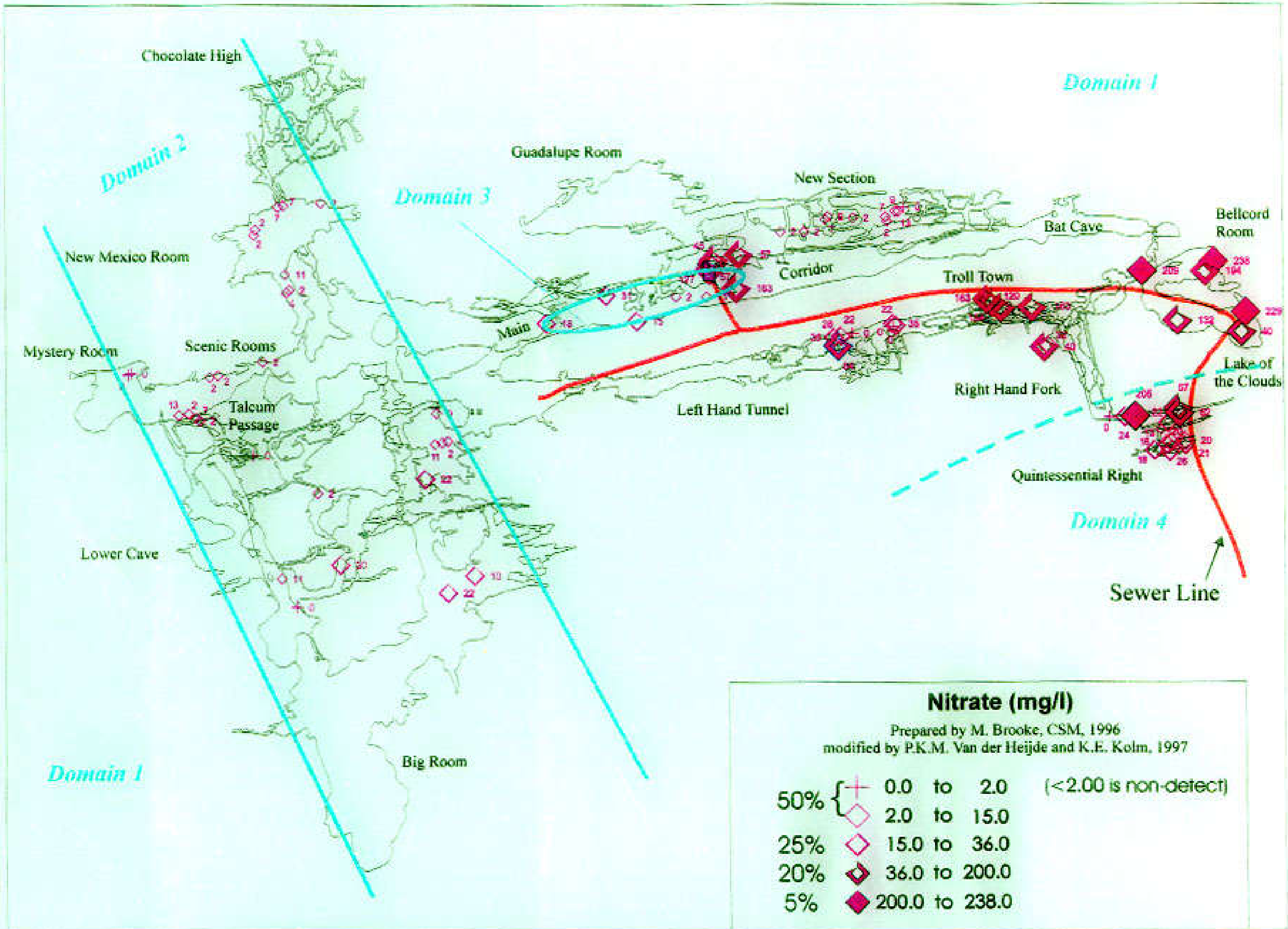

Figure 18: Carlsbad Cavern nitrate hydrochemistry, cavern layout and hydrogeologic domains (modified from Brooke, 1996)

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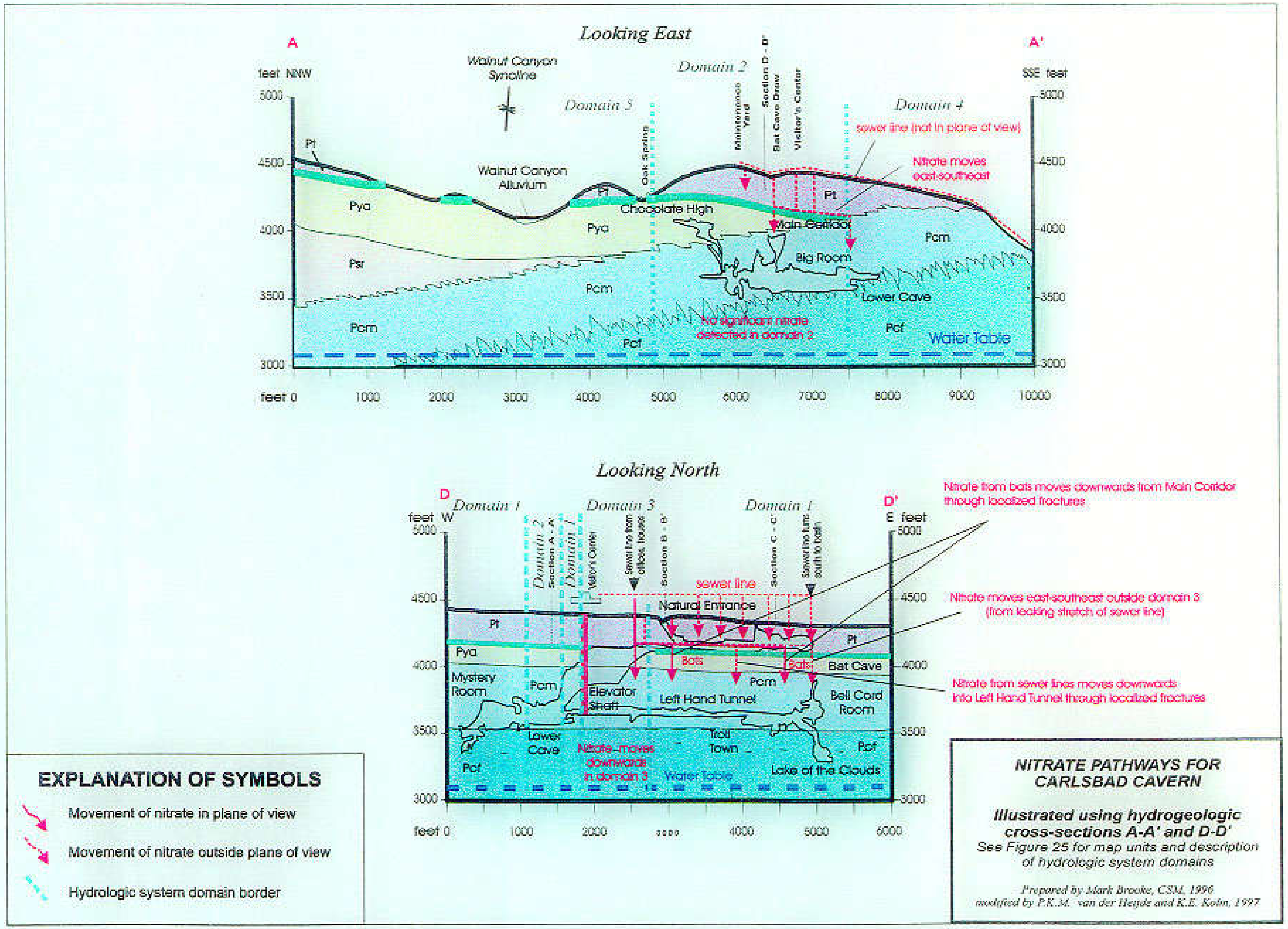

Figure 29. Nitrate pathways for Carlsbad Cavern (modified from Brooke, 1996)

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Table 4. Pathways and potential exposure locations for contamination.

Source	Domains	Infiltration Zones	Pathways	Recipient Cavern Area	Vulnera-bility
RV/bus parking lot west of visitor's center	1 and 2	Diffused and focused infiltration	A. Parking lot runoff towards Bat Cave Draw in domain 1 infiltrates into the Tansill, followed by lateral down-dip flow at the Yates Siltstone towards the facies change at the boundary with domain 4; some localized vertical percolation possible through the Yates. B. Infiltration through parking lot cracks in domain 2 percolates vertically through macrofractures to the caves.	A. Quintessential Right B. Crystal Springs Dome area of Big Room	A. High B. Moderate
Car parking lot east of visitor's center	1	Diffused and focused infiltration	A. Parking lot runoff towards Bat Cave Draw in domain 1 infiltrates into the Tansill, followed by lateral down-dip flow at the Yates Siltstone to the facies change at the boundary with domain 4; some localized vertical percolation possible through the Yates. B. Infiltration through parking lot cracks in domain 1 percolates vertically through the Tansill, followed by lateral down-dip flow at the Yates Siltstone to the facies change at the boundary with domain 4.	A, Quintessential Right B. Unmapped cavern area between Big Room and Quintessential Right; probably percolates straight to regional water table.	A. High B. Moderate
Visitor's center	1	Focused infiltration	A. Rain water runoff towards Bat Cave Draw in domain 1 infiltrates into the Tansill, followed by lateral down-dip flow at the Yates Siltstone to the facies change at the boundary with domain 4; some localized vertical percolation is possible through the Yates in the Bat Cave Draw area. B. Fluids from leaks/spills in/behind buildings may seep through cracks in the foundation into domain 1 and percolate through the Tansill, followed by lateral flow at the Yates Siltstone to facies change at the boundary with domain 4; they may also seep directly into the elevator shafts.	A. Quintessential Right B. Unmapped cavern area between Big Room and Quintessential Right, or collects (infiltrates?) At the bottom of the shaft(s).	A. Moderate B. Moderate
Underground lunchroom	1	Focused infiltration	Leaks/spills will infiltrate and percolate to the Lower Cave and ultimately to the water table.	Lower Cave	Low
Park offices	3	Focused infiltration	Fluids from leaks/spills (sewer, car parking) infiltrate into the Tansill and move vertically through the Yates into the Main Corridor because of the localized absence of the Yates Siltstone.	Main Corridor between Devil's Spring and Iceberg Rock	High
Employee housing	1	Diffuse infiltration	Precipitation infiltrates locally, as do fluids from (sewer) leaks, spills, yard chemicals and percolates through the Tansill, followed by lateral flow at the Yates Siltstone to domain 3, or to the fracture zone near the anticline axis with downward percolation through the Yates.	Main Corridor between Devil's Spring and Iceberg Rock; Guadalupe Room, Left Hand Tunnel, and New Section	Low

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Table 5. Sources, potential contamination problems, and prevention or mitigation measures.

Source	Potential Problems	Recipient Cavern Area	Risk of Exposure	Prevention or Mitigation Alternatives
RV/bus parking lot west of visitor's center	1. chronic release of metals, oil, etc. from cars, displaced/ dissolved by runoff 2. car fire/crash with spill and subsequent infiltration	A. Quintessential Right B. Crystal Springs Dome area of Big Room	A1. Moderate A2. High B1. Low B2. Moderate	1. close parking lot to traffic (prevention) 2. ensure that the surface is sealed and no open cracks exist (prevention) 3. ensure rain water is routed to south side of parking lot (prevention) 4. ensure that water used to clean up is routed to south side of parking lot (mitigation)
Car parking lot east of visitor's center	1. chronic release of metals, oil, etc. from cars, displaced/ dissolved by runoff 2. car fire/crash with spill and subsequent infiltration	A. Quintessential Right B. unmapped cavern area between Big Room and Quintessential Right; probably percolates straight to regional water table.	A1. Moderate A2. High B1. Low B2. Moderate	1. close parking lot to traffic (prevention) 2. ensure that the surface is sealed and no open cracks exist (prevention) 3. ensure rain water is routed to south side of parking lot (prevention) 4. ensure that water used to clean up is routed to south side of parking lot (mitigation)
Visitor's center	1. utility line breaks (utility shaft) 2. storage tank leak (chronic) or spill (while filling) 3. sewage problems (restrooms, lines)	A. Quintessential Right B. unmapped cavern area between Big Room and Quintessential Right, or collects (infiltrates?) At the bottom of the shaft(s).	A1. Low A2. Moderate A3. Moderate B1. Low B2. Low B3. Low	1. regular inspection and maintenance of utility lines (prevention) 2. ensure that bottom of utility shaft is sealed high enough to capture any spill (prevention) 3. use latest technologies replacing storage tank and related lines (prevention) 4. sample soil around storage tank to determine if leaks are present (detection)
Underground lunchroom	1. utility line breaks (utility shaft) 2. sewage problems (pump room, restrooms)	A. Lunchroom B. Left Hand Tunnel C. Big Room	A1. Moderate A2. Moderate B. Low C. Low	1. move lunch facilities and shops above ground (prevention) 2. perform engineering evaluation of restroom/sewer facilities with respect to risk (prevention)
Park offices	1. sewage problems	A. Main Corridor between Devil's Spring and Iceberg Rock	A1. High	1. inspect and improve sewer lines (prevention) 2. remove offices from above the caves to distant area (prevention)

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Advantages of Using HSA

- Uses established methods and approaches
  - ASTM Standard Guides (Expedited Site Characterization; Conceptualization and Characterization of Ground Water Systems)
  - Established field and laboratory protocols
  - Established modeling tools (for example, MODFLOW and HSPF).

Advantages of Using HSA

- Differs from most approaches that are component and/or discipline-specific.
- Incorporates geological, hydrological, chemical, and biological factors and associated interactions at a level of scientific credibility that satisfies stand-alone disciplines yet is accessible to managers and decision-makers.

Summary

- Hierarchical systems analysis (HSA) provides a rapid, cost effective scientific and management approach for:
  - Characterizing an environmental system
  - Identifying type and extent of human impacts to the system.

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