Informatics for science-based groundwater management and socio-technical interfaces

Suzanne A. Pierce

Center for International Energy and Environmental Policy

Jackson School of Geosciences, The University of Texas at Austin

Networks and Complex Systems Series – March 28, 2011

Integrated Water Resources Management (IWRM)

'All the instances of scientific development and practice . . . are as much embedded in politics and cultures as they are creations of the researchers, practitioners, and industries.'

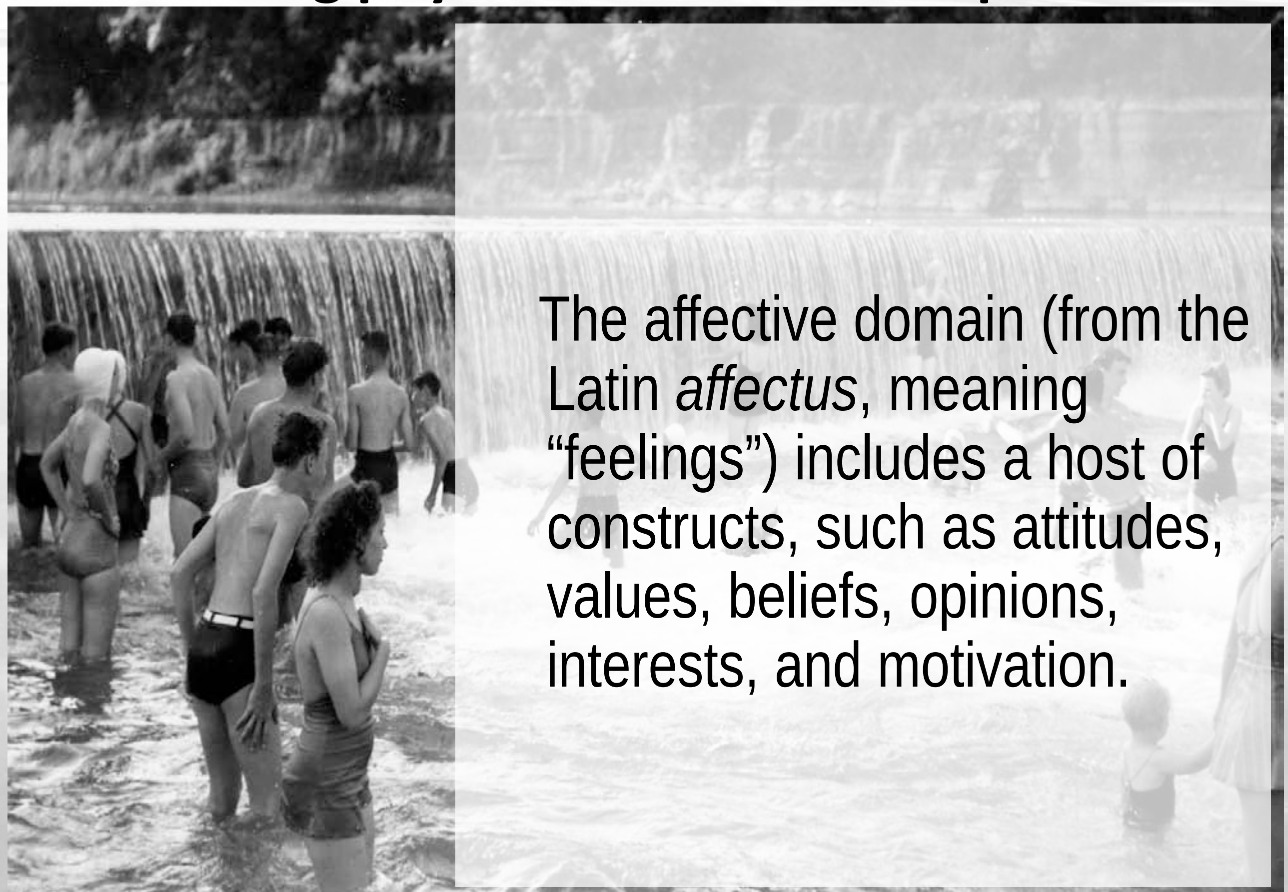
(Paraphrased from Heymann, 2010; Dulay, unpublished image)

IWRM

Collaborative processes meld the use of scientific information with citizen participation and technical decision support systems

Information to Knowledge

Including physical and social components

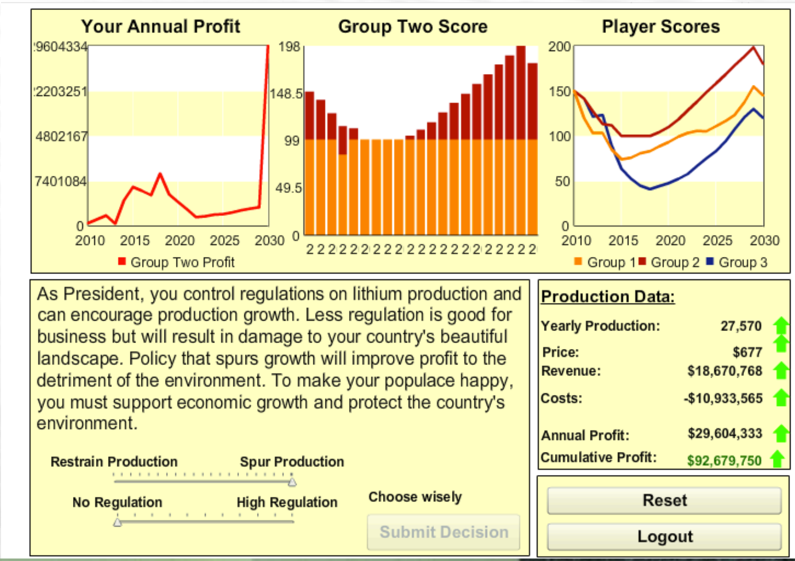


The affective domain (from the Latin *affectus*, meaning “feelings”) includes a host of constructs, such as attitudes, values, beliefs, opinions, interests, and motivation.

Socio-technical Systems are the People and Technology Dyad

(Photo courtesy of Austin History Center, PICA17272)
(Other content modified from Capella, 2007)

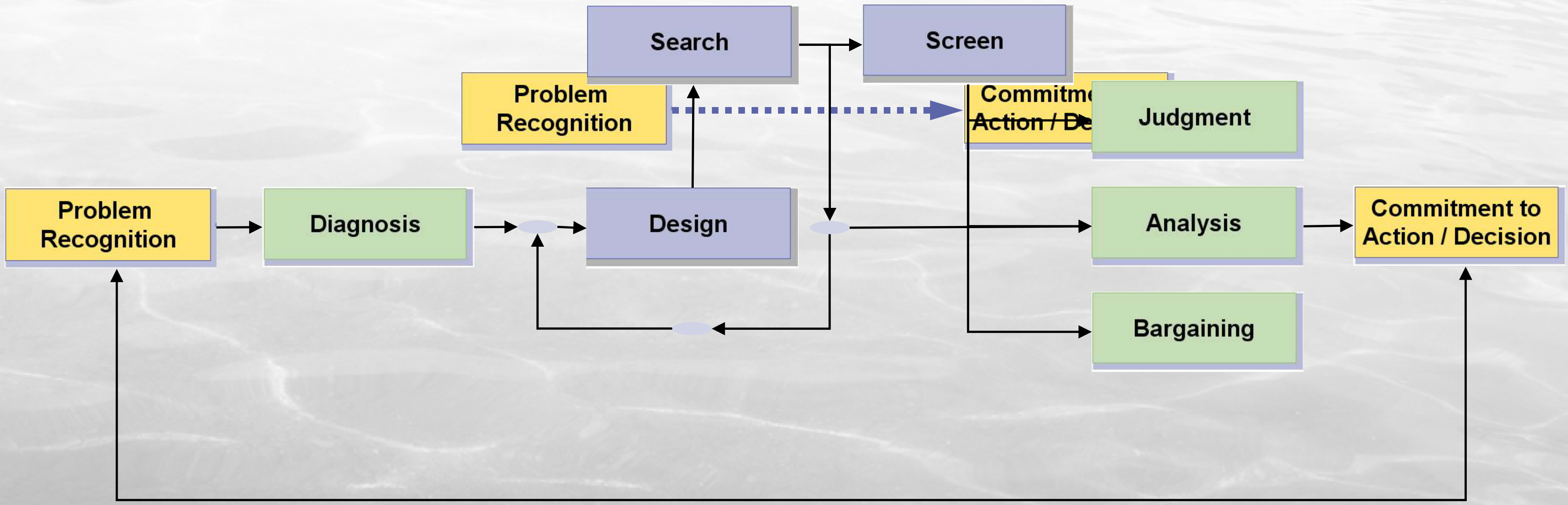
Interactive Science



Aspects of Change Model

Strategic Change	Socio-technical Change
Episodic	Emergent
Executive Lead	Stakeholder Participation
Planned	Continuous
Acute Response	Long-terming Adaptation
Prescriptive	Flexible

Decision Pathway Research Framework



(modified from Mintzberg, 1976; Pierce, 2008)

Approach

- **Stakeholder Elicitation**
  Define narratives, research as a reflective communal act, outcomes provide constraints
- **System architecture design**
  Develop a mechanism for linking disparate information and transforming it into knowledge, outcome a decision system for groundwater problems
- **Linked Simulation-Optimization**
  Quantifying alternatives within physical system boundaries, outcomes management options

Groundwater

Any water that is found beneath the surface of the Earth, including:

a) Moisture that is found in the pores between soil grains

b) Fresh to slightly saline water, in saturated geologic units near the surface, which is used for drinking and irrigation

c) Extremely salty brines associated with petroleum deposits and deep sedimentary units

d) Water found in the lower lithosphere and in the mantle.

Groundwater as a Resource

The predominant reservoir and strategic reserve of accessible freshwater on earth is groundwater.

- 36 states project water shortages by 2013
- The most arid states expect significant growth
- 46% potable water is groundwater in US
- That's a 49% increase since 1970

These demands are expected to increase significantly in the coming years.

(Foster and Chilton, 2003; Huston et al, 2005)

A Modeling Tradition

Traditionally,

- Socioeconomic models include single-cell aquifers **(lack spatial verity)**

- Hydrogeologic models ignore socioeconomics altogether **(neglect a primary influence)**

To solve

Complex Earth System Resource Allocation Problems

we need to look at the problem from both perspectives interactively

Defining Sustainable Yield

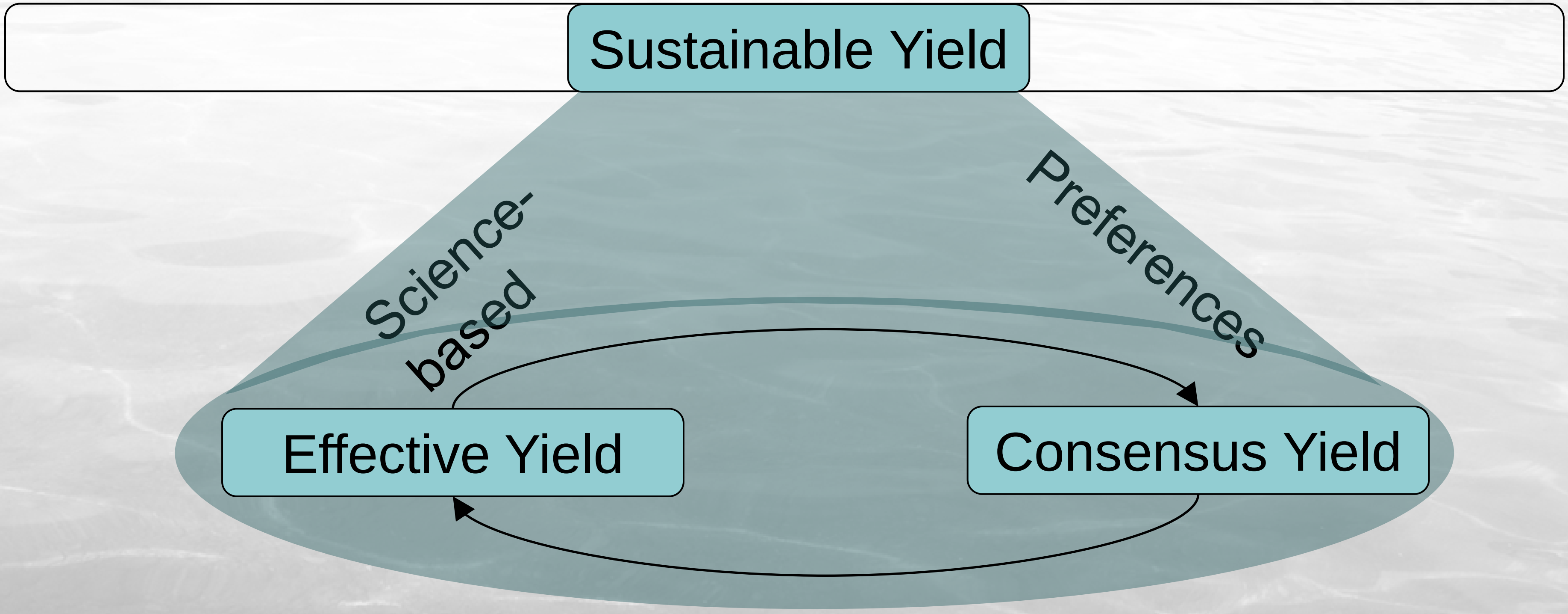
$$dS/dt = I(t) - O(t)$$

The volume of water that can be removed from an aquifer

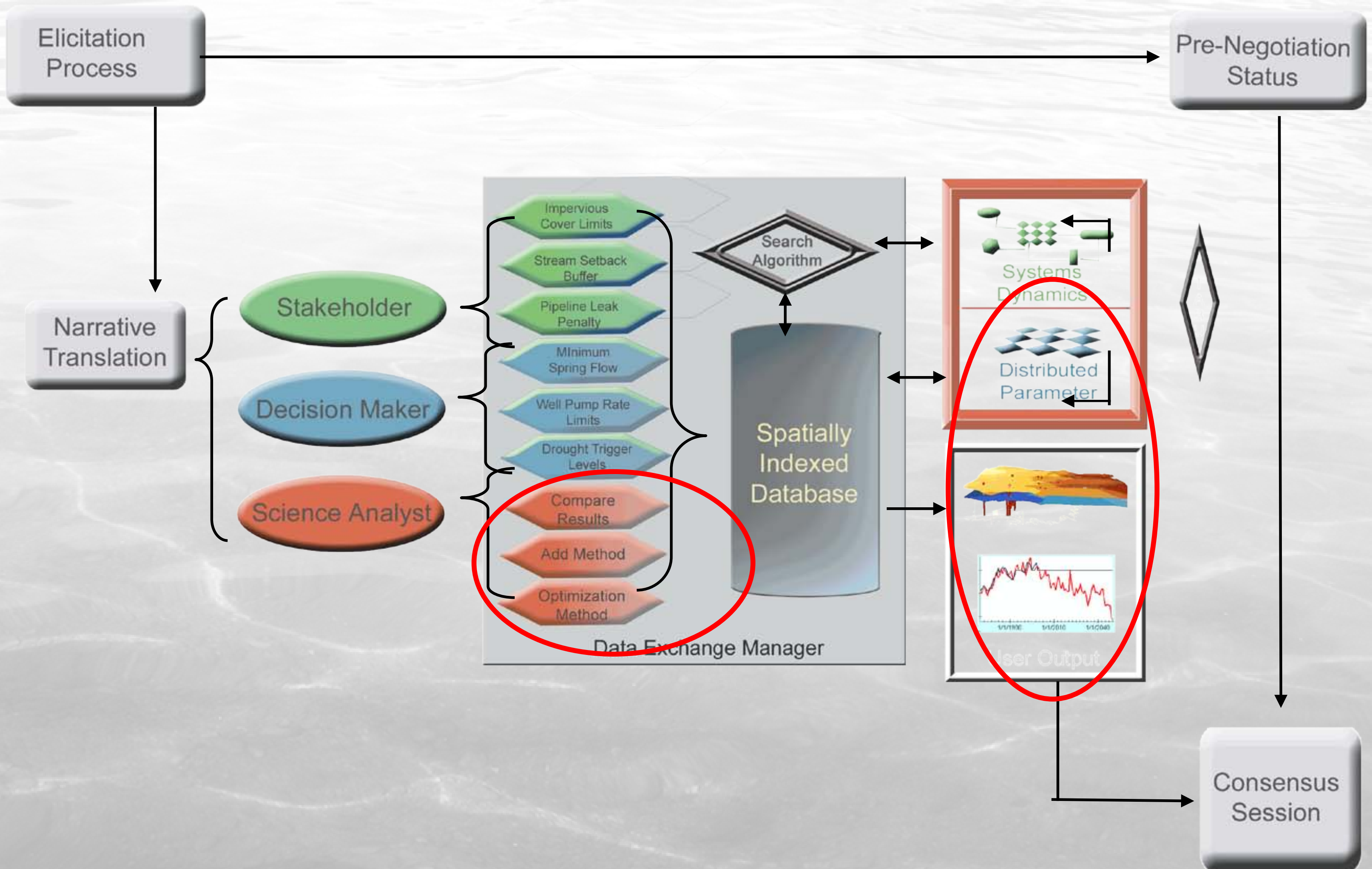
- Without exceeding natural recharge rates
- Avoids negative water quality impacts
- Preserves economic viability
- Complies with existing legal constraints
- Maintains environmental flows, and
- Protects intergenerational equity

(Lee, 1915; Kazmann, 1968; Alley et al., 1999; Sophocleous, 2000)

Conceptualizing the problem



Systems Architecture

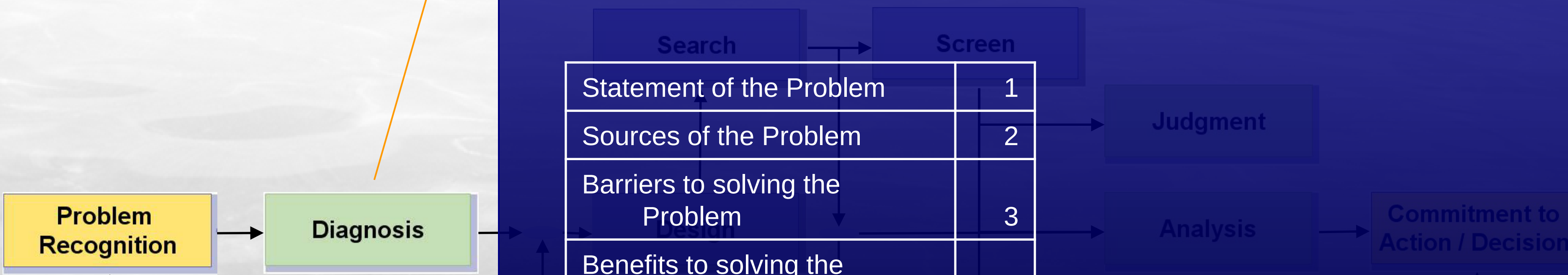


Integrated Modeling to Support Rapid Dispute Prevention

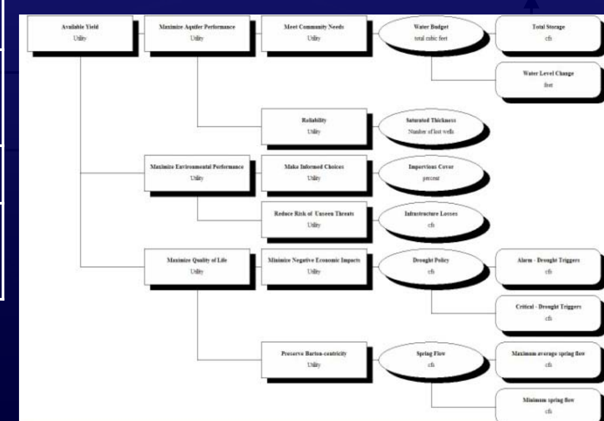
Sustainable Yield for Aquifers

Methods:

- Informal Elicitation
- Narrative Analysis
- Value Focused Thinking
- Decision Problem Mapping with Goals Hierarchies
- Influence Diagrams

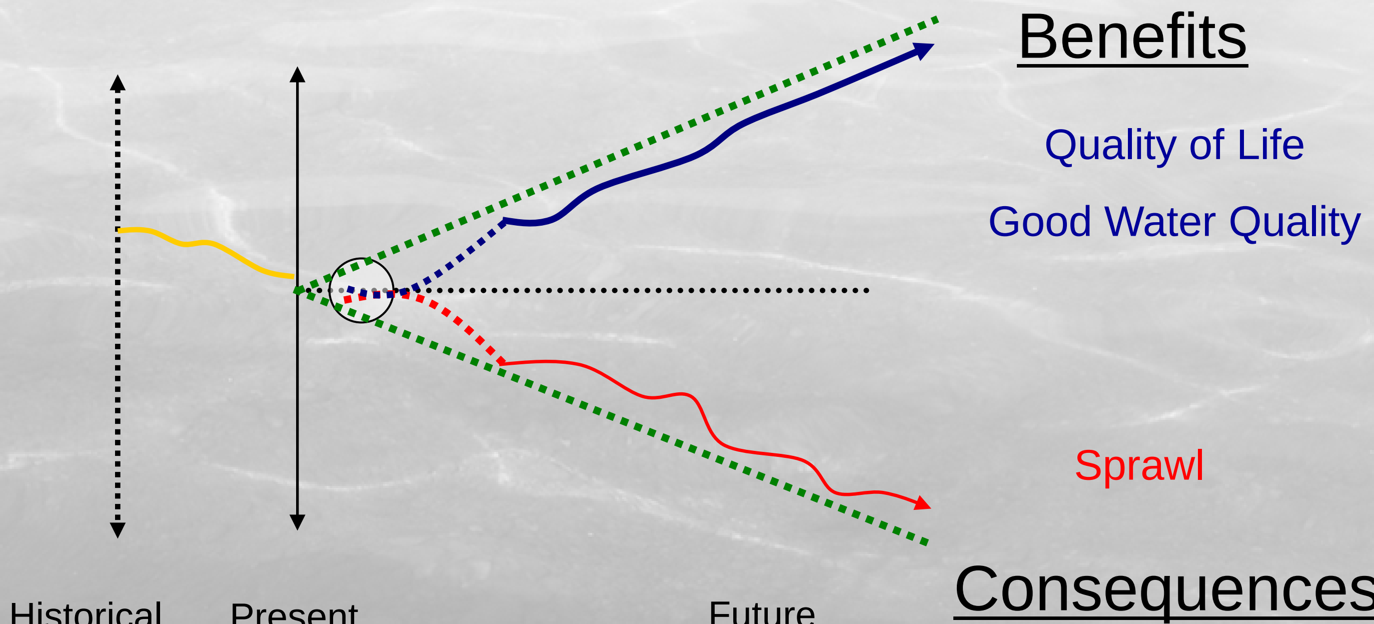


Statement of the Problem	1
Sources of the Problem	2
Barriers to solving the Problem	3
Benefits to solving the Problem	4
Neg. Consequences if left unresolved	5
Power to achieve a Solution	6
Actions and Sacrifices necessary for a Solution	7



Expanding science within the context of society

Elicitation for Science Models



Designing Representative Models of Interacting Systems

Moves – Aspirations – Neighborhoods

Flexible memory structure:

Recency = tabu tenure

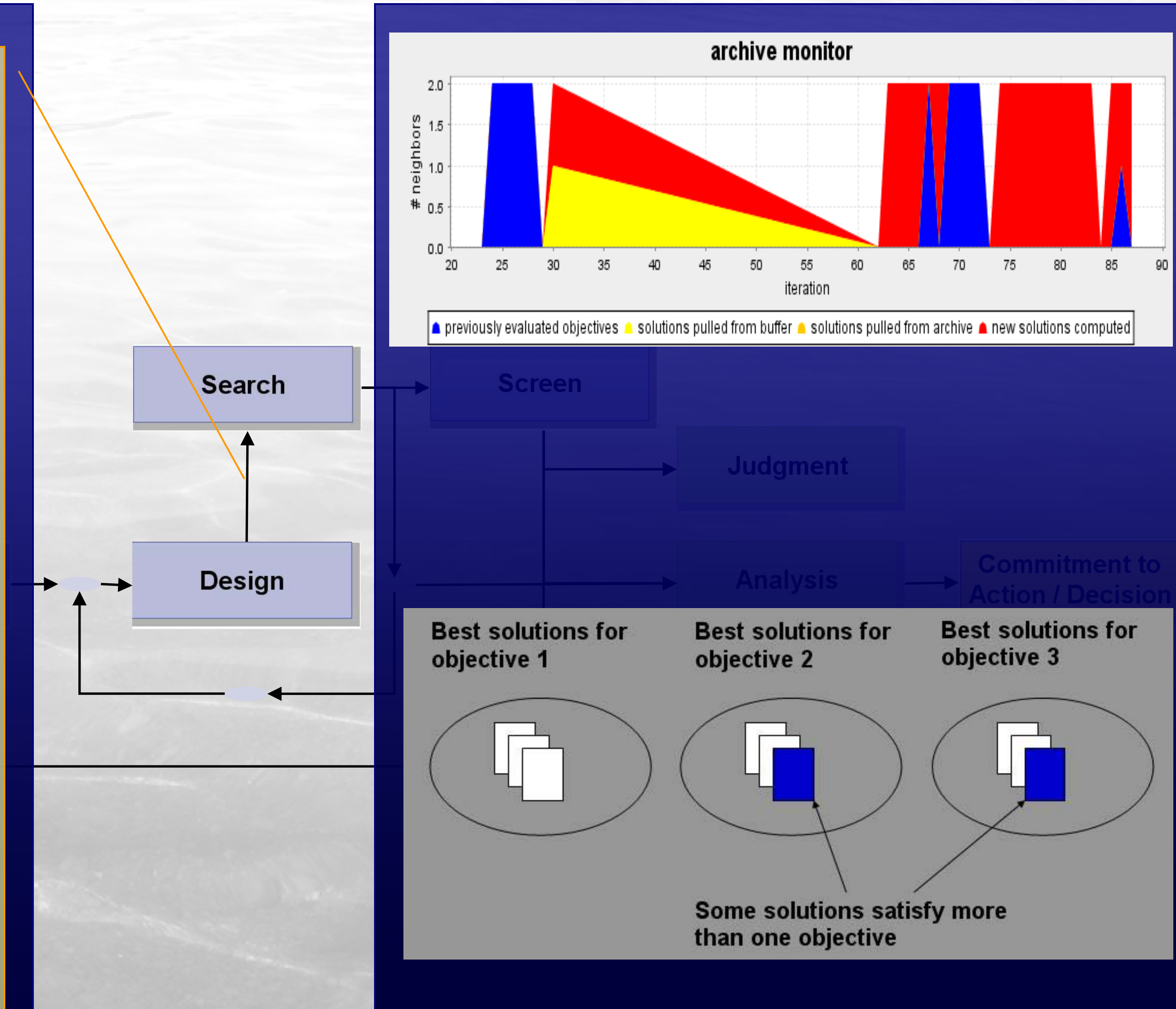
Frequency = diversification

Quality = intensification, looks for “good” attributes

Influence = higher influence moves better

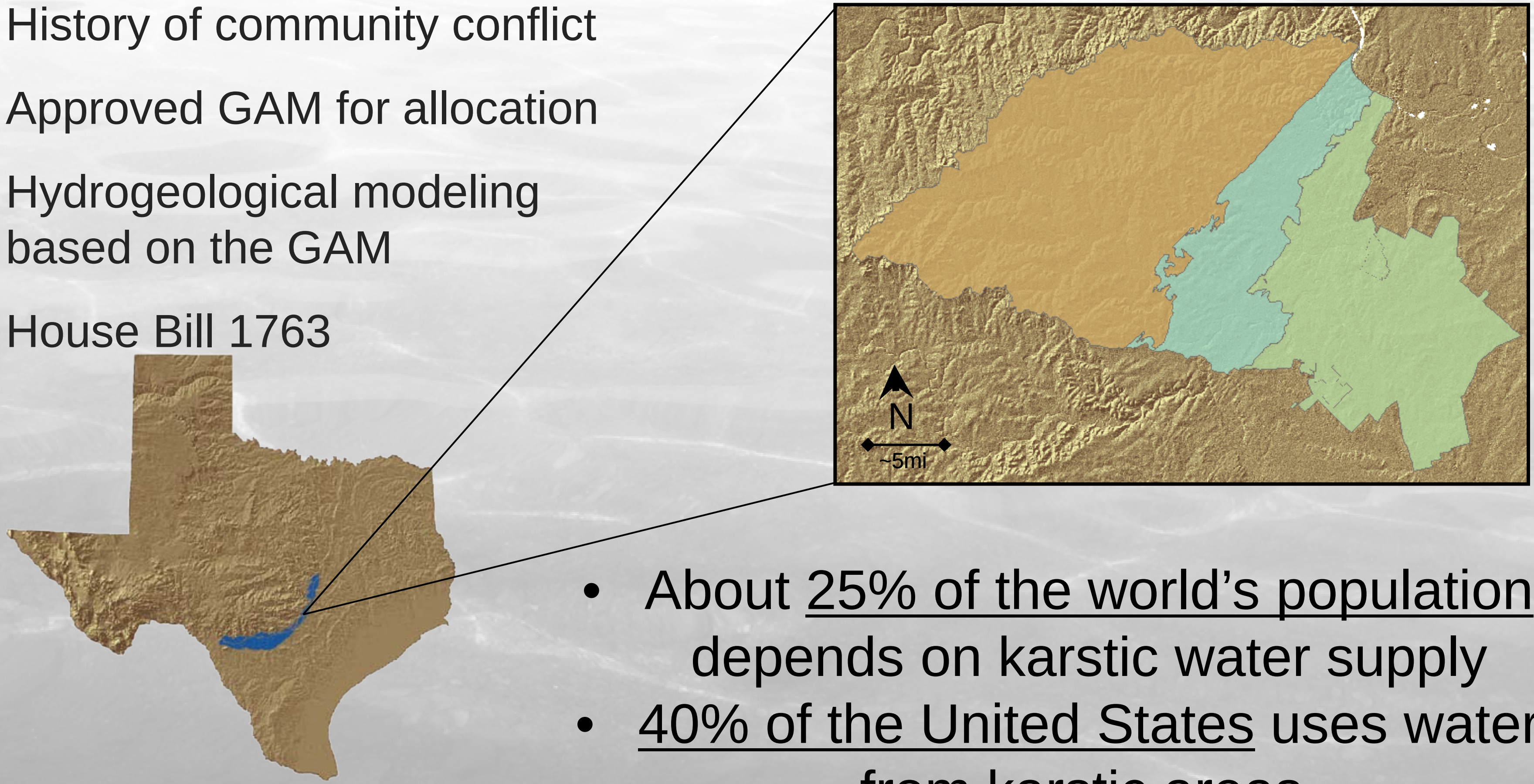
Verbal rules used to define search

Multiple attributes can define stopping criteria



Case study: Barton Springs /Edwards Aquifer

- Well studied karst aquifer
- Rapidly growing urban area
- History of community conflict
- Approved GAM for allocation
- Hydrogeological modeling based on the GAM
- House Bill 1763



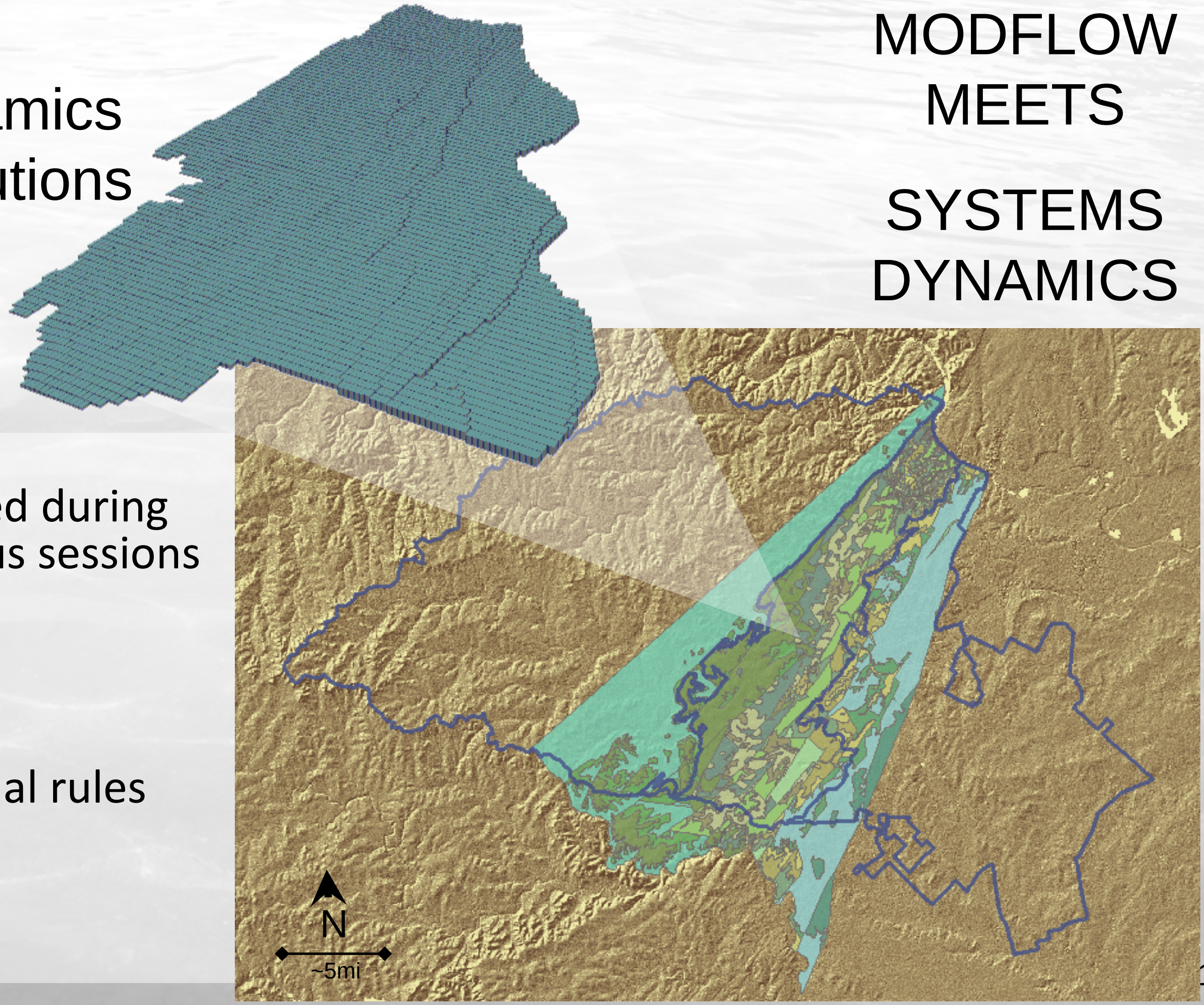
- About 25% of the world's population depends on karstic water supply
- 40% of the United States uses water from karstic areas.

Melding Values and Groundwater Models

Systems dynamics helps find solutions that:

MODFLOW MEETS

SYSTEMS DYNAMICS



1) Can be identified during active consensus sessions

AND

2) Include relational rules

Combinatorial Searches

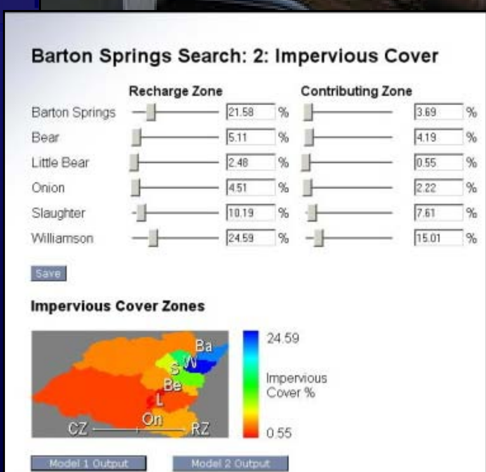
TABU SEARCH

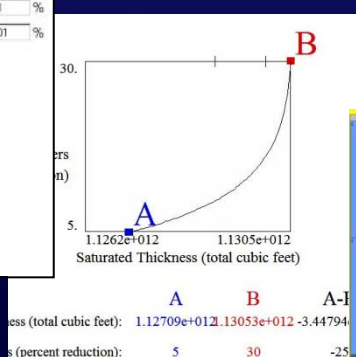
A metaheuristic for difficult optimization problems. This global optimization technique uses a memory structure to search the solution space efficiently. The algorithm is deterministic and solutions can be ordinally ranked.

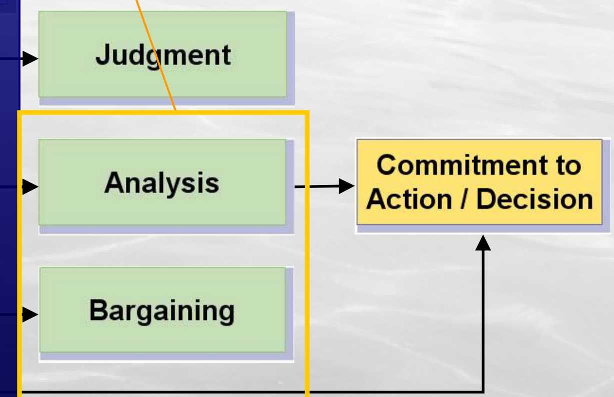
Ranking Candidate Solution Set

Methods:

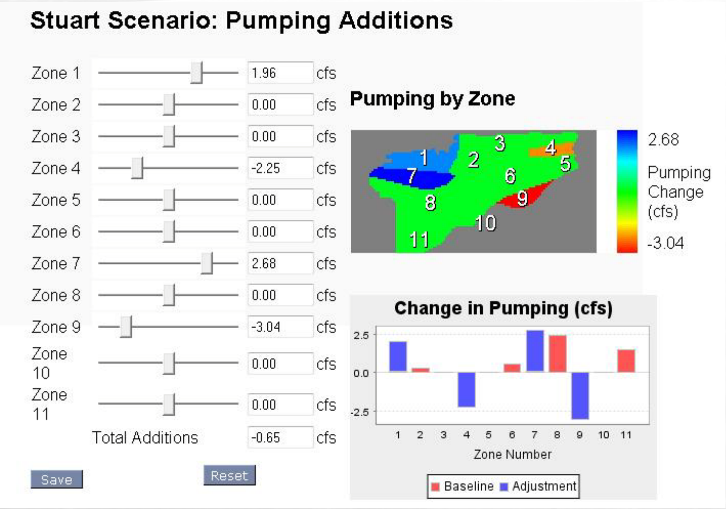
- Participatory Model Interaction
- Facilitated Dialogue
- Decision Analysis
- Value-based, Non-spatial Visualization

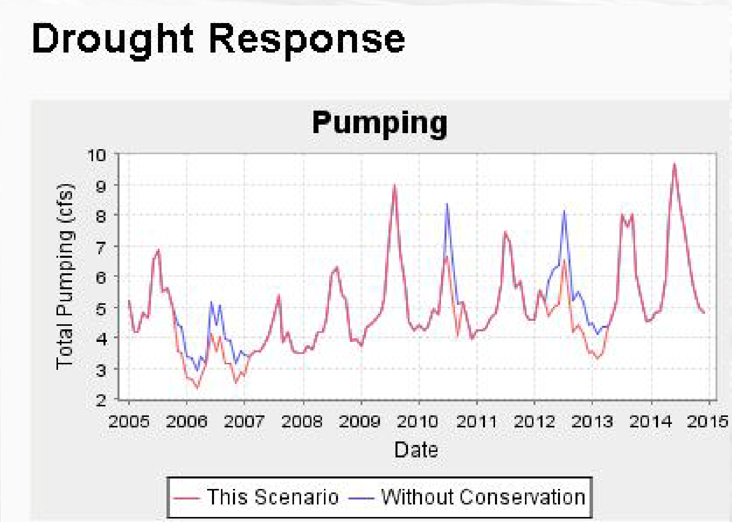


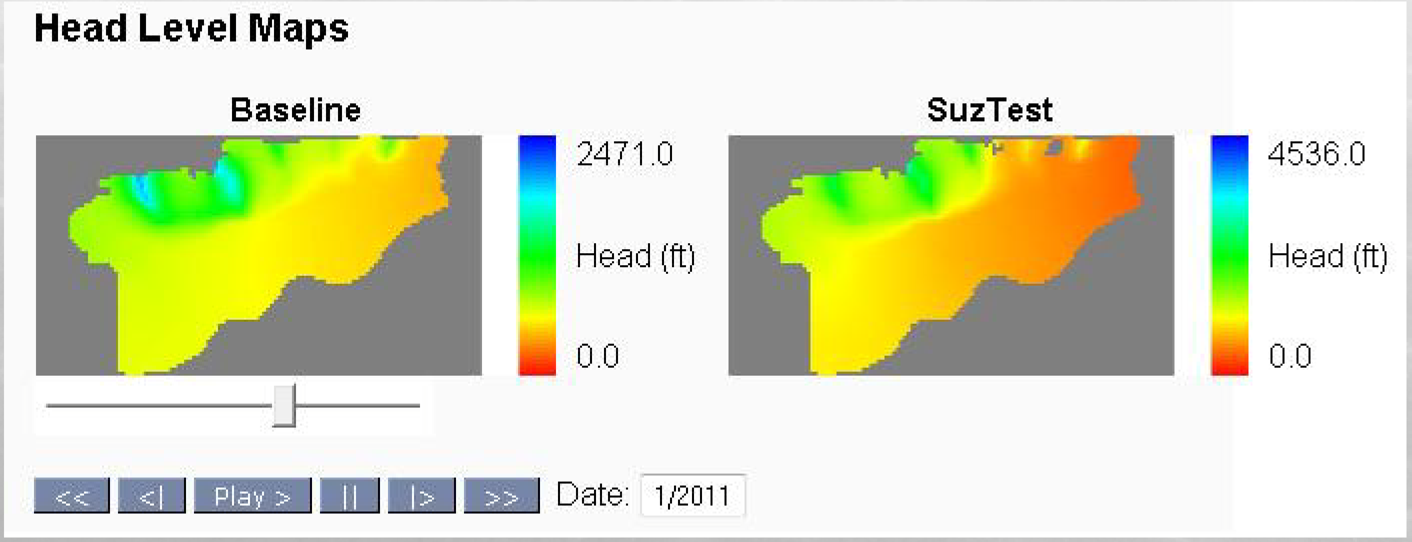




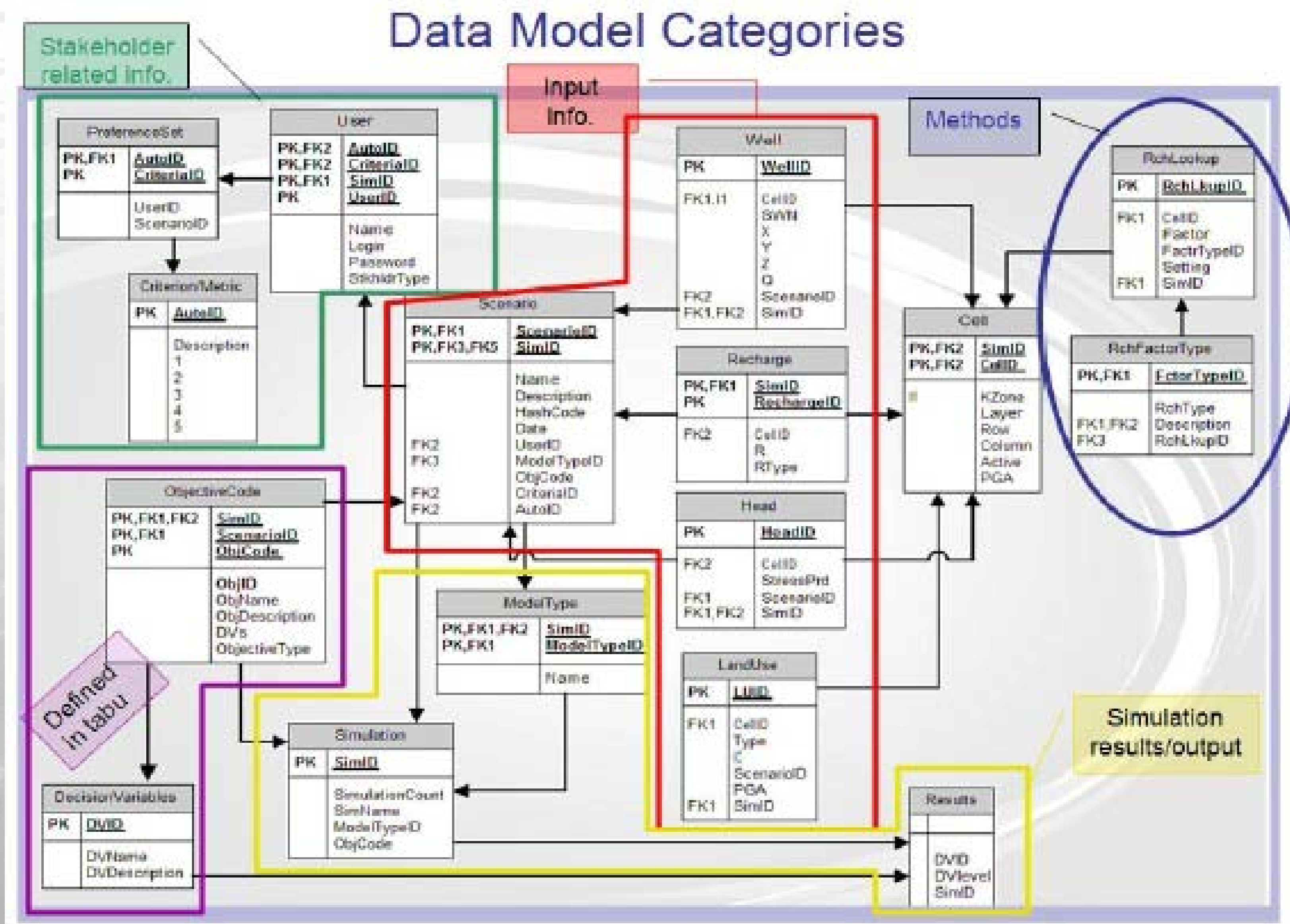
Scenario Selection & Comparison







Finding Better Viz for Dialogue



Next Steps: Workflow with Sci2

- Utilized informatics methods
  - Created visualizations, bar graphs and charts for analysis of documents
- Categorized words to highlight themes
- Utilized Microsoft Excel, Science to Science (Sci2), Lexical Analysis, and Microsoft Word
- Looked for :
  - coherency between stated objectives and policy recommendations within documents
  - Shift in goals of water resource management overtime
  - What was stated when, and how much was it talked about

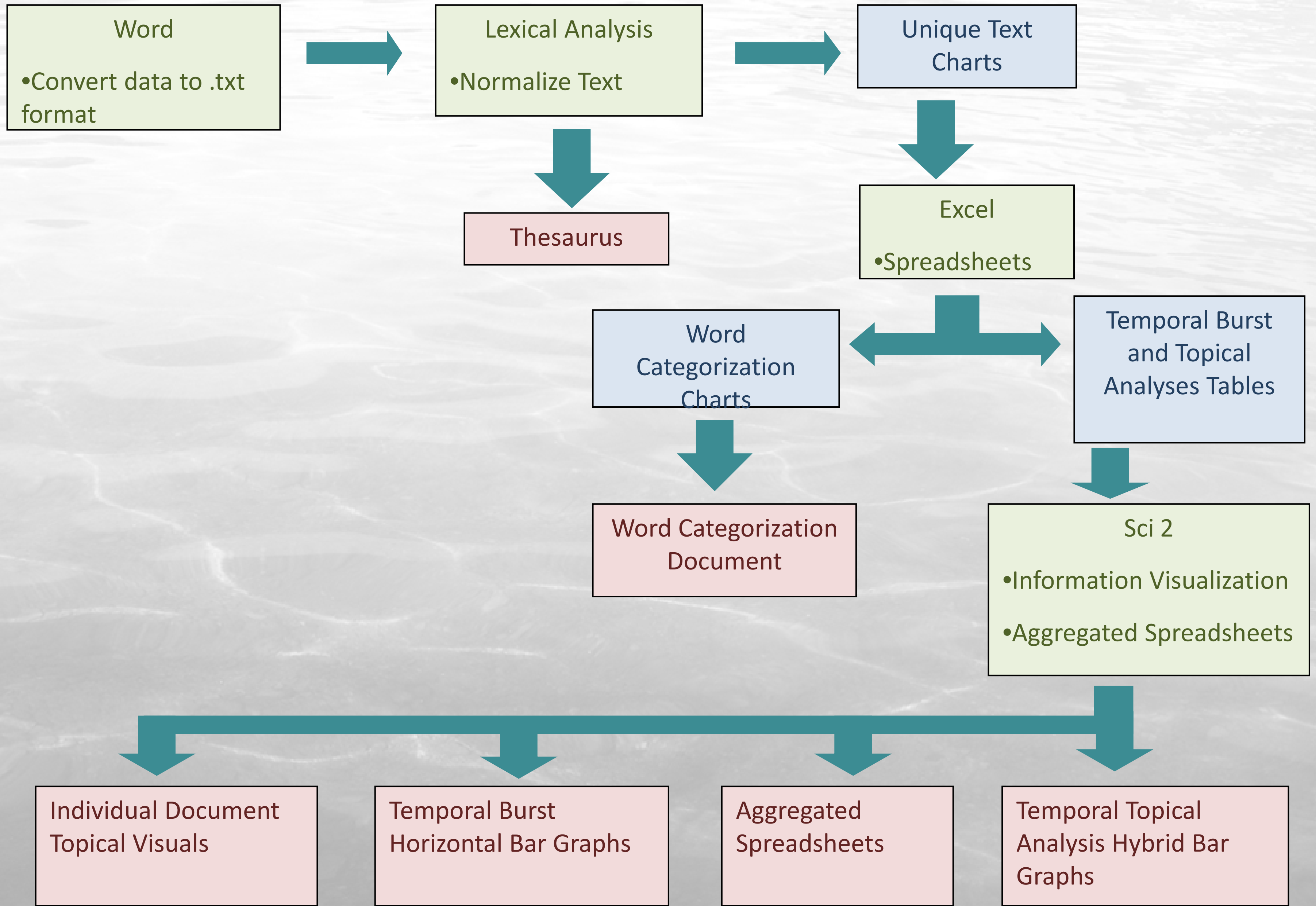
Information Visualization

- Two types used in this investigation:
  - ***Directed Network*** – concepts illustrated by nodes and lines illustrating connections between concepts
  - ***Temporal Burst*** – indicates how a data set changes over a certain time period
- ***Cluster theory*** – the space between nodes inversely indicates the amount of similarity between the two nodes

Data Source: Texas State Water Plan

- Utilized all eight volumes of the Texas State Water Plan, from the following years: 1961, 1968, 1984, 1990, 1992, 1997, 2002 and 2007
  - Only looked at Recommendations and Objectives or Goals sections
- Created by Texas Water Development Board (TWDB)
  - 1961 adopted, rest written by TWDB

Workflow


Word
•Convert data to .txt format
Lexical Analysis
•Normalize Text
Unique Text Charts
Thesaurus
Excel
•Spreadsheets
Word Categorization Charts
Temporal Burst and Topical Analyses Tables
Word Categorization Document
Sci 2
•Information Visualization
•Aggregated Spreadsheets
Individual Document Topical Visuals
Temporal Burst Horizontal Bar Graphs
Aggregated Spreadsheets
Temporal Topical Analysis Hybrid Bar Graphs

Word Categories

Word Category	Explanation
Name	Word is found in the name of the document
Uses	Who is using water or for what purpose
Geographic	Geographic terms, either generic (ie “coast”) or specific (ie “Houston”)
Authority	Who is making the management decisions or implementing them
Method	How water will be provided; includes policy, action and science based plans
Filler	Does not aid to overall meaning of the text
Uncertain	Categorization depends on the context of the word within the sentence
Concern	Terms is deemed related to a concept pertaining to water quality or quantity issues

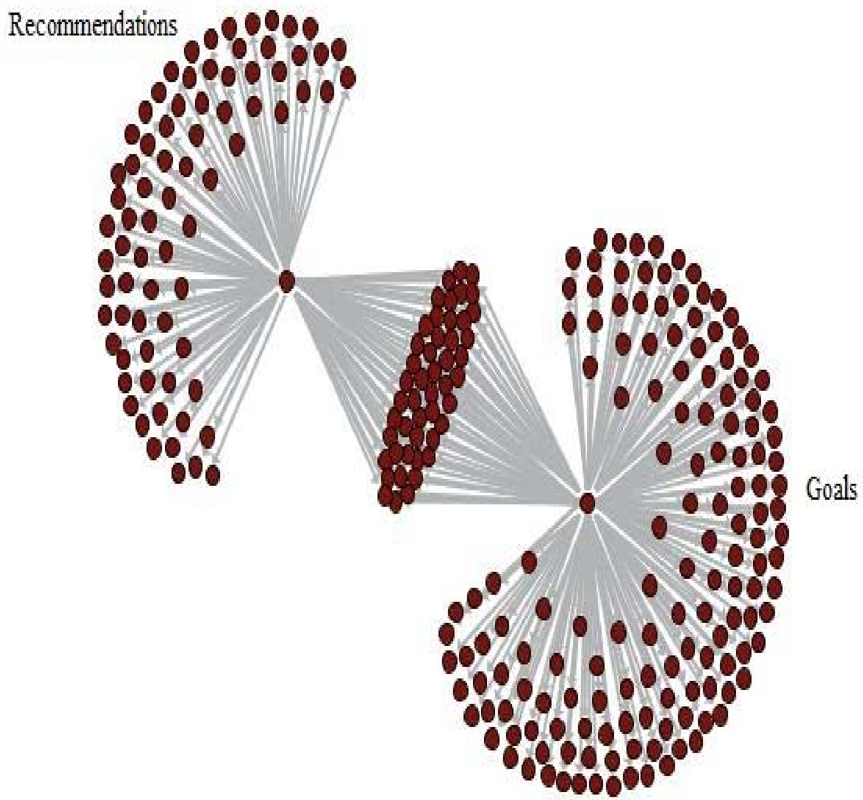
Thesaurus - Results

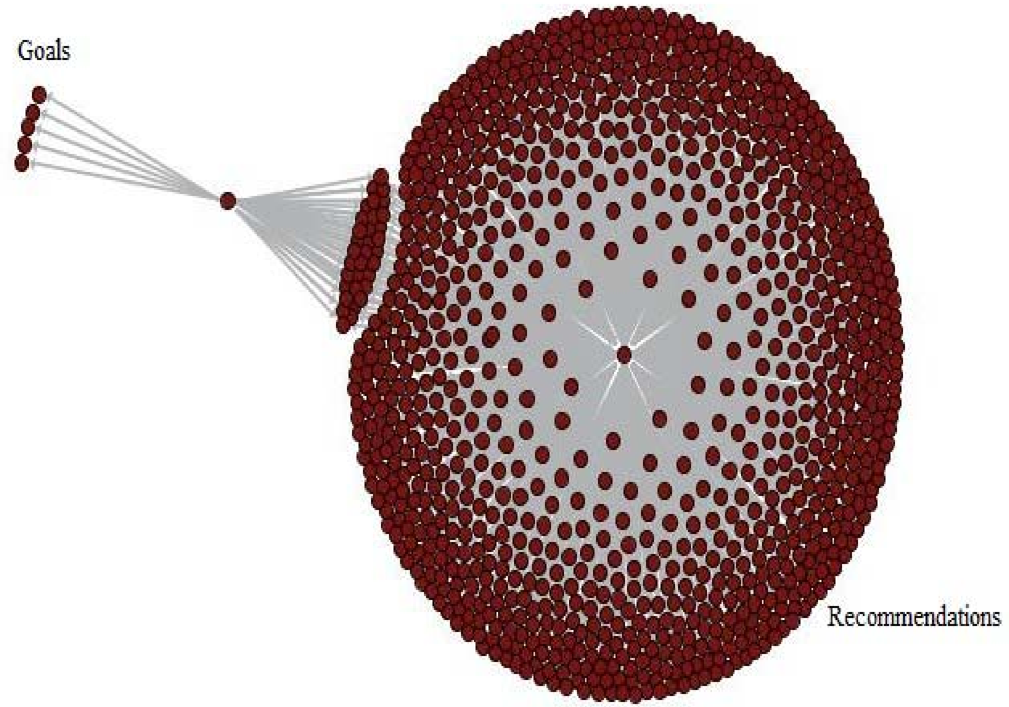
- Looked at top ten percent of words overall and in each section separately
- 2701 unique words in aggregation
  - Water most frequently found, 1163 times in the 16 sections
  - Next seven most frequently found words: state, conservation, planning, funding, provide, and management, respectively
- 2521 words in Policy Recommendations sections
  - Most common words in order: Water (890), State (338)
  - Financial considerations mentioned twice (funding and fund)
- 737 words in Objectives sections
  - Economic considerations low
  - Similar to overall word lists, water most commonly found

Topical Analysis

- Reviewed each document individually for coherency between Objectives and Policy Recommendation Sections
  - Assumed should talk about the same concepts with roughly same relative frequency
- Utilized unweighted directed networks
- Purpose was to determine if internal coherence existed, or that the goals and the policy recommendations addressed the same issues

Topical Analysis – Two Sample Images





1961

2007

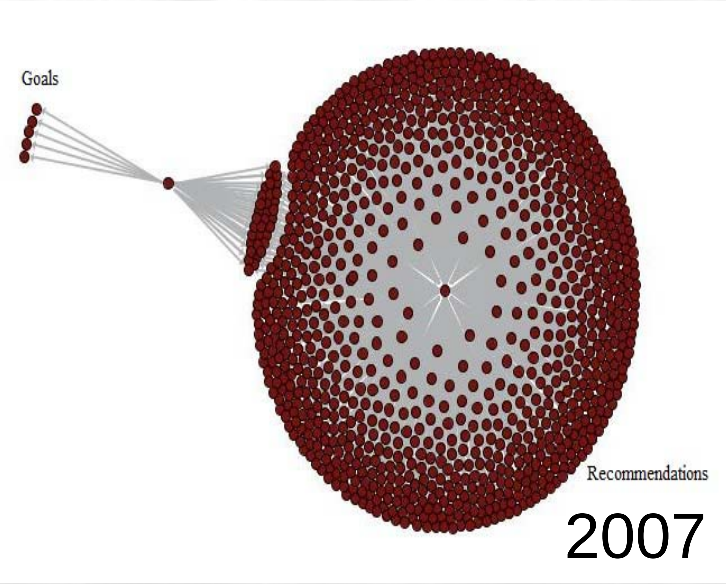
Topical Analysis – Coherency Results

Year	Counts	Visualization	Categorizations	Coherency
1961	Equal unique, few shared	Not a lot of similarity	Great amount of similarity	Yes
1968	Equal shared and in Obs, not with Recs	Obs nodes close, diverse in Recs	Agree for part, different concerns and methods	Yes
1984	More words in Rec, Obs shared most	Uneven spacing and counts	Both cover wide range of users and uses	Yes, Obs less specific
1990	Overwhelming more in Recs than in rest	Shared close, unique for both far apart	Obs more environmental, Rec more about balance	Yes
1992	More words in Recs than Obs	All spaced apart, even shared	Obs emphasize change, Recs state what to do	No
1997	Few cases of overlap between sections	Unique spread apart, shared overlap	Both focus on creating and updating policies	Yes
2002	Most Rec shared, many unique Obs	Unique evenly spaced, shared overlap	Both focus who should be planning, and uses	Yes
2007	Most of Obs shared, >1000 unique Recs	Obs very similar, Recs vary in difference	Recs covered Obs and more, not a lot of legal	Yes, but not congruent

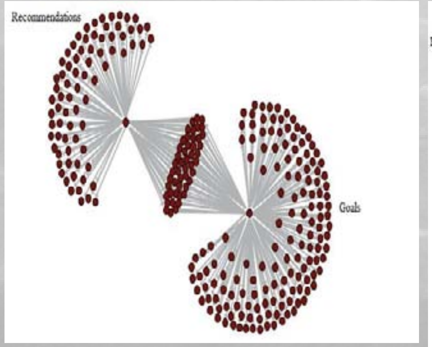
Time Series - Results

- Recommendations – gap between 1992/1997 and 2002, but no shift in word usage/themes
  - Ex: “Public” mentioned 1968-1992 and 2002-2007
- Objectives – shifts: 1968 &1984, 1984 &1990, 1997 & 2007
  - Words changed from anthropogenic needs to environmental and conservation concerns
- Aggregation- gaps in words from 1992 through 2002 with few exceptions, no shift in themes

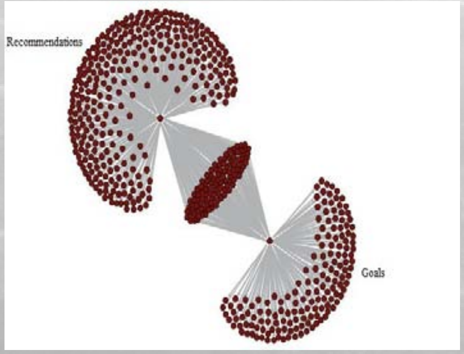
Water Policy Informatics – Topic and Time Series Analysis



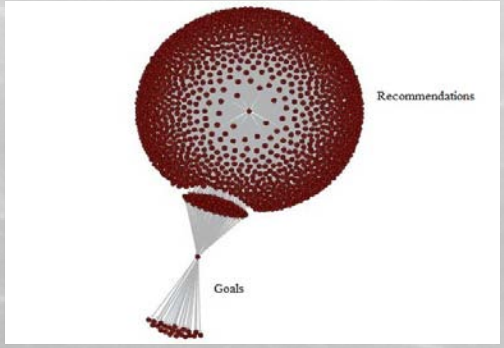
2007



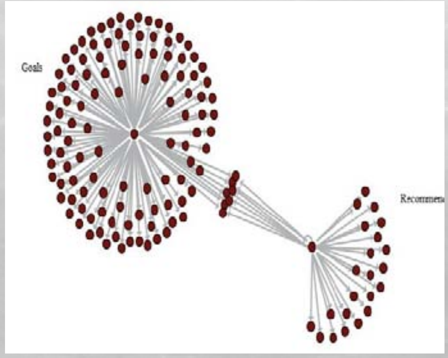
1961



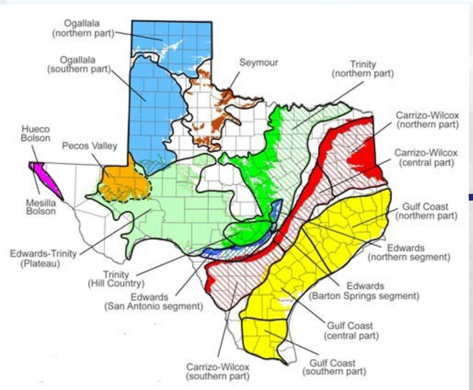
1968



1990



1997

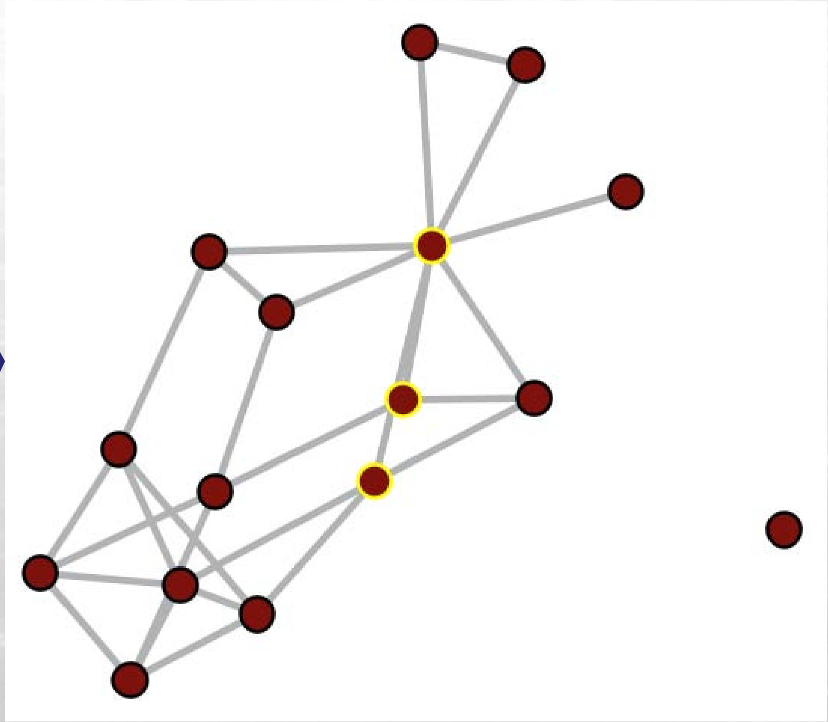


A Streetcar Named Desired Future Conditions

Planning

Models

People



Many thanks to Joseph Biberstine for creating with this image today!

Wide Range of Uses

These Translations Could Have a Multitude of Uses

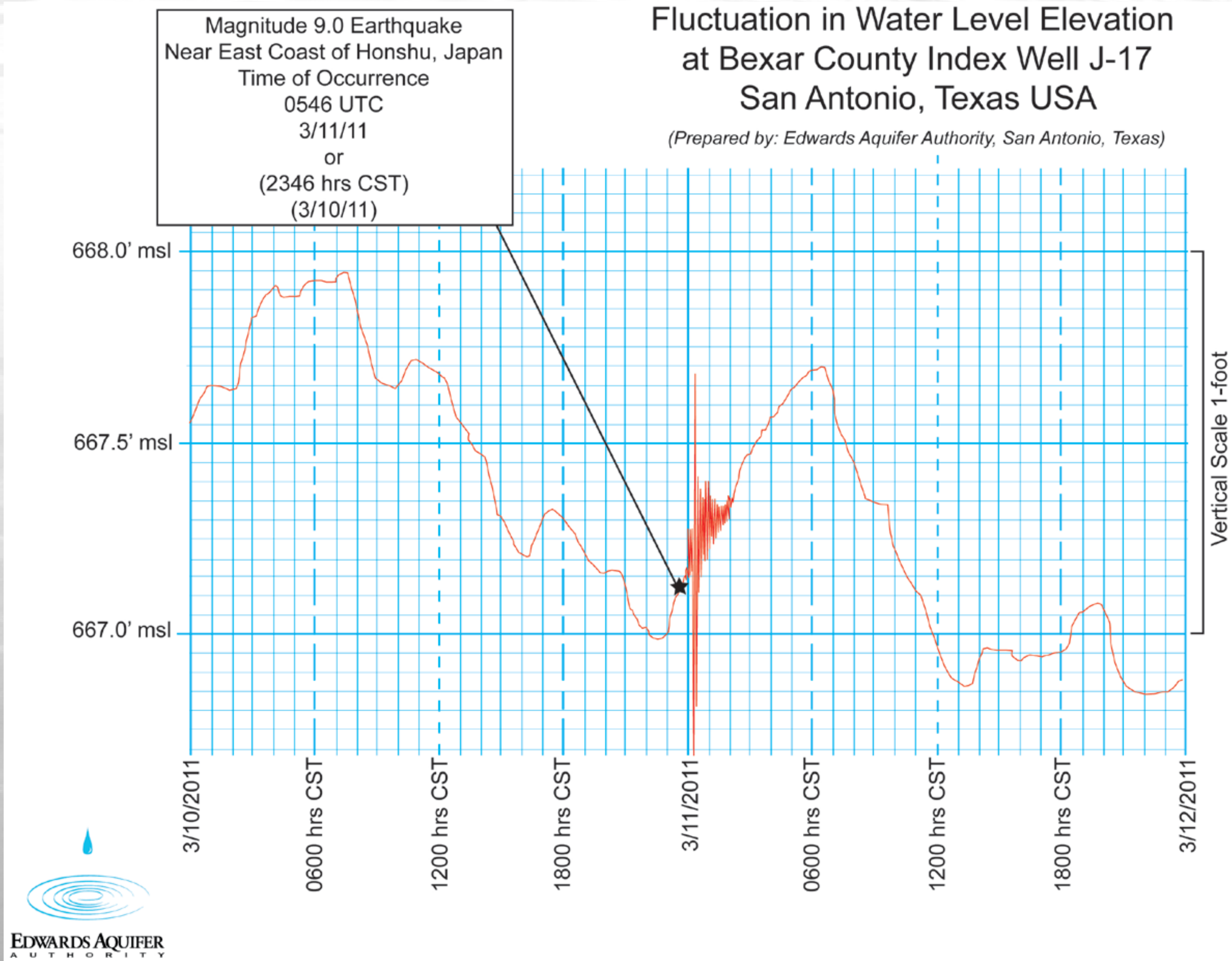
Different places:

- Australia & Brazil

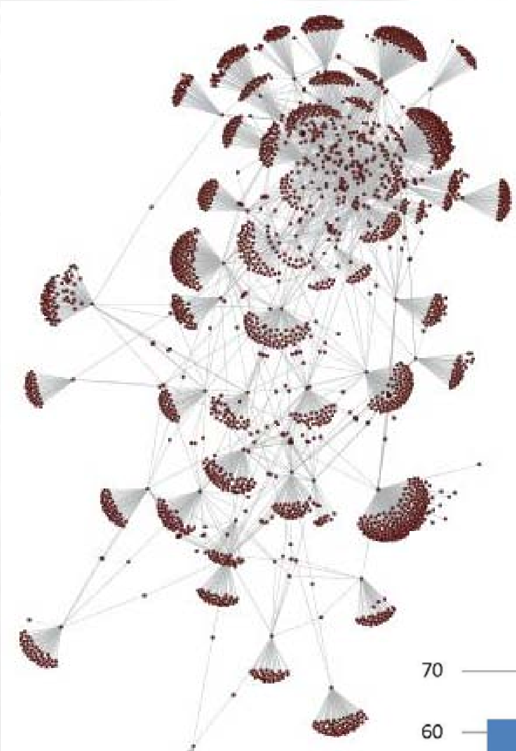
Different Problems:

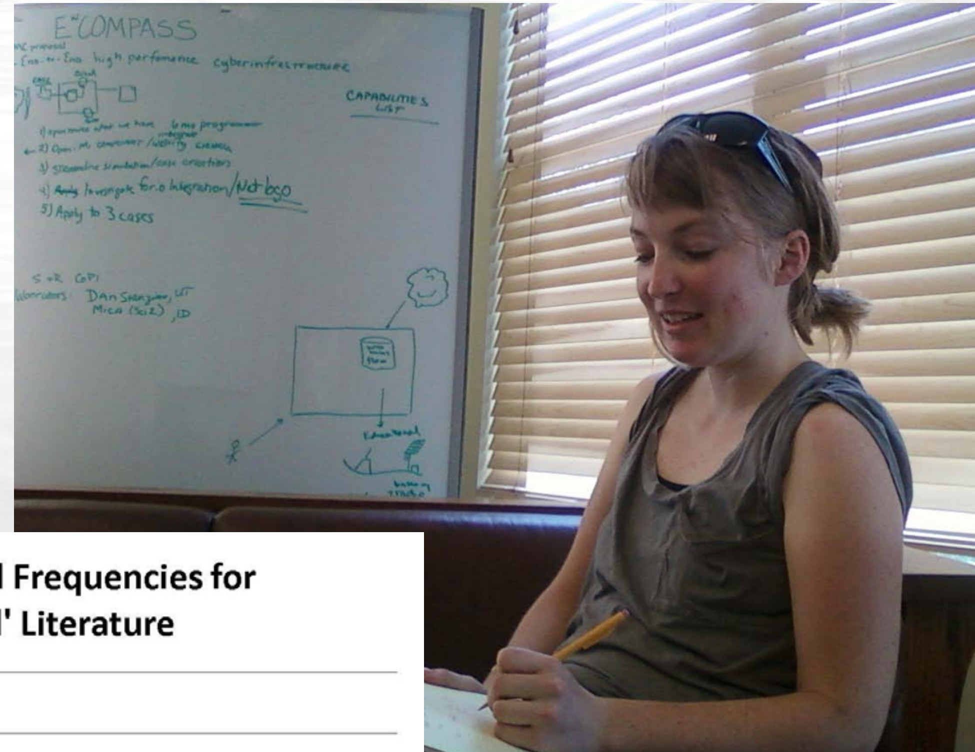
- Seismic Hazards & Energy Development
- STEM Education K-99

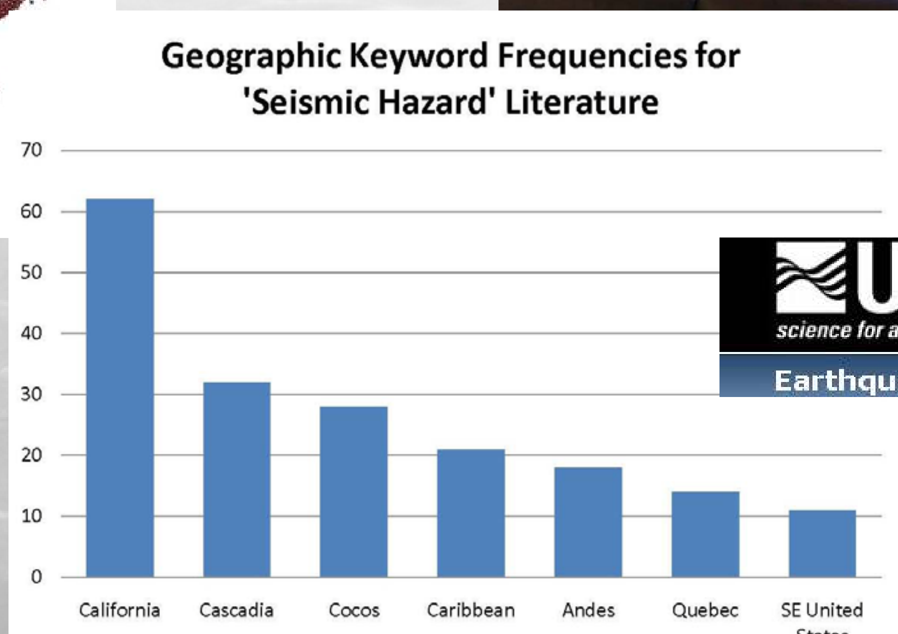
Magnitude 9.0 – Coast of Honshu, Japan
(2011 March 11 05:46:23 UTC)



Understanding Geosciences : Seismic Hazards



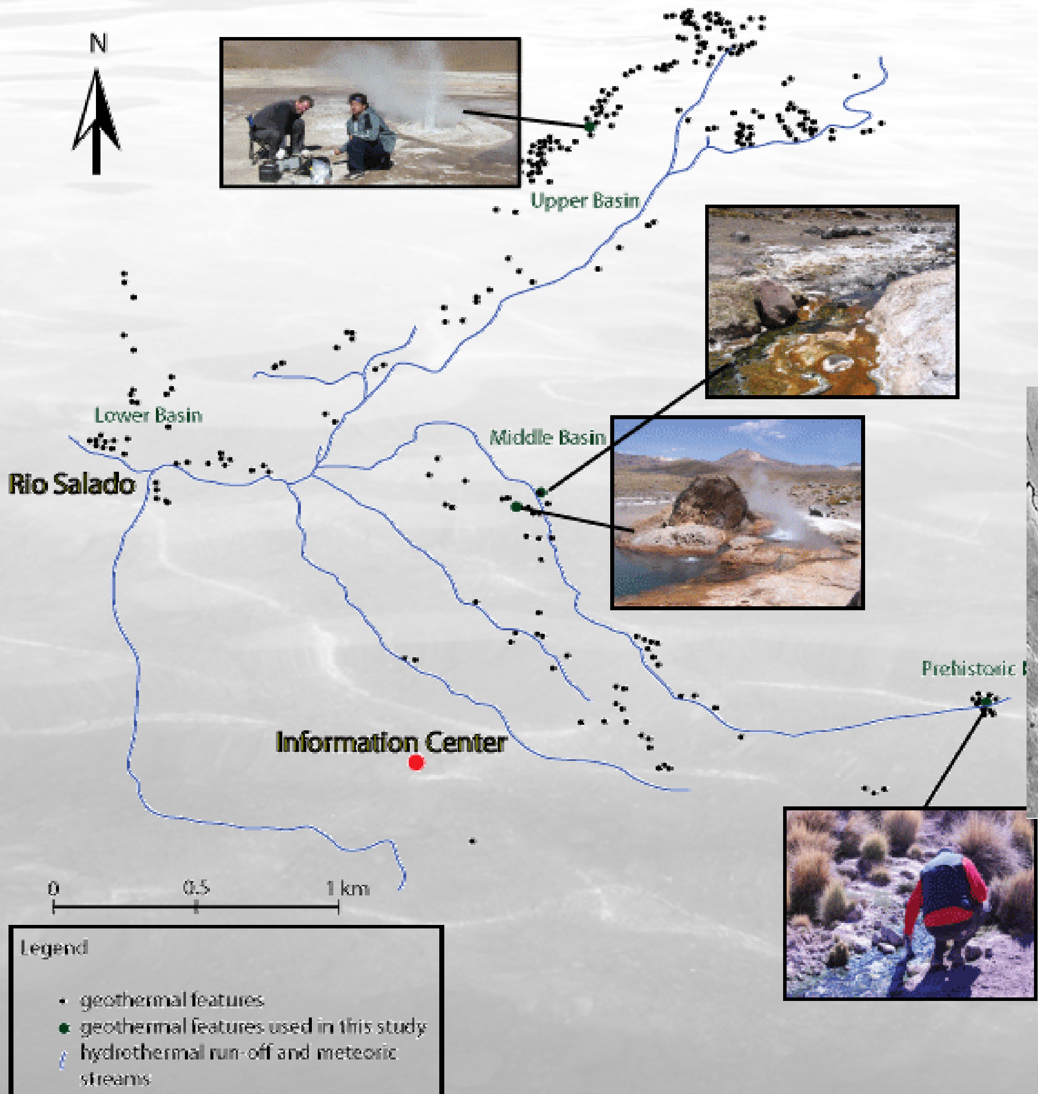


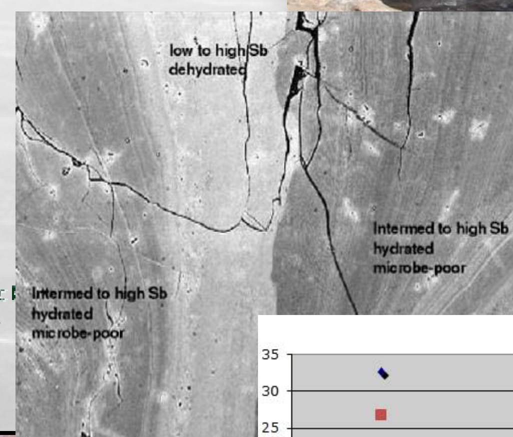


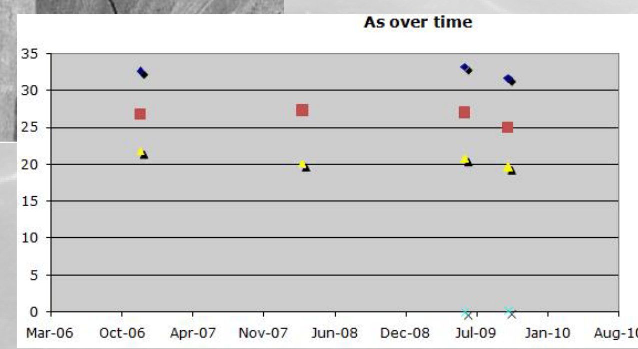
USGS
science for a changing world
Earthquake Hazards Program

Blog:http://capstonespring2011.posterous.com/

El Tatio Natural Laboratory



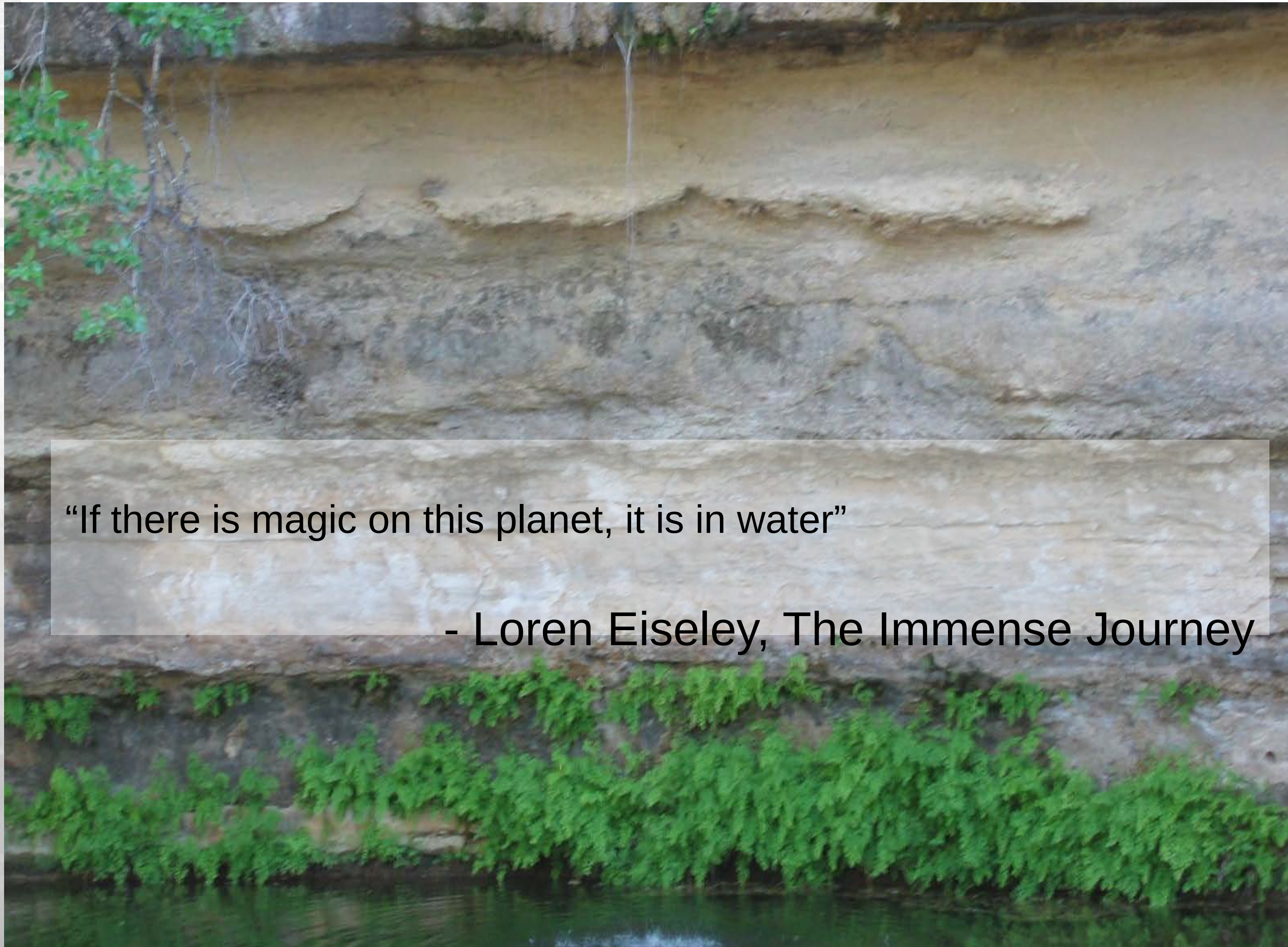




ENCOMPASS Pilot Case

- Geothermal Resources in Chile
- Fulbright Nexus Program
- Longhorn Fund for Innovation & Technology

Visual Analytics to Inspire Learning and Dialogue


“If there is magic on this planet, it is in water”
- Loren Eiseley, The Immense Journey

References

- Alley, W., T. Reilly, et al. (1999). "Sustainability of ground-water resources." US Geological Survey Circular 1186: 79.
- Foster, S. S. D. & Chilton, P. J. 2003 Groundwater: the processes and global significance of aquifer degradation. Phil.Trans. R. Soc. Lond. B 358, 1957–1972.
- Heymann, M. (2010). Studies in history and philosophy of science Part B. Studies in history and philosophy of modern physics, 41(3), 193-200.
- Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., Maupin, M.A., 2005, Estimated Use of Water in the United States in 2000, U.S. Geological Survey Circular 1268.
- Kazmann, R.G., 1968, From Water Mining to Water Management: Ground Water, v. 6, no. 1, p. 26-28.
- Lee, C. H., 1915, The determination of safe yield of underground reservoirs of the closed basin type: Trans. Amer. Soc. Civil Engrs., v. 78, p. 148-151.
- Mintzberg, H., Raisinghani, D., and Theoret, A.; 1976: The Structure of "Unstructured" Decision Processes: Administrative Science Quarterly; v. 21, no. 2, p. 246-275.
- Pierce, S.A.; 2008: Pieces of a puzzle: Why trans-disciplinary socio-technical tools are necessary to address water resource policy: American Institute of Professional Geologists and Arizona Hydrological Society: 3rd International Professional Geology Conference: Flagstaff, Arizona, USA; September 20-24, 2008.
- Sophocleous, M. (2000). "From safe yield to sustainable development of water resources--the Kansas experience." Journal of Hydrology 235(1-2): 27-43.

References

- Texas Board of Water Engineers. (May 1961). *A Plan for Meeting the 1980 Water Requirements of Texas.* Austin: State of Texas.
- Texas Water Development Board. (2010, Febuary 1). *Composite Map of All Regions.* Retrieved January 21, 2011, from Water Reesources Planning and Information: http://www.twdb.state.tx.us/mapping/maps/pdf/sb1_groups_8x11.pdf
- Texas Water Development Board. (November 1968). *The Texas Water Plan.* Austin: State of Texas.
- Texas Water Development Board. (August 1997). *Water for Texaas.* http://www.twdb.state.tx.us/publications/reports/State_Water_Plan/1997/WPindex.asp. Austin: Texas Water Development Board.
- Texas Water Development Board. (January 2002). *Water for Texas - 2002.* Austin: Texas Water Development Board.
- Texas Water Development Board. (January 2007). *Water For Texas 2007.* Texas Water Development Board, Austin.
- Texas Water Development Board. (November 1984). *Water For Texas: A Comprehensive Plan for the Future.* Texas Department of Water Resources. Austin: Texas Department of Water Resources.
- Texas Water Development Board. (December 1990). *Water for Texas: Today and Tomorrow.* Austin: Texas Water Development Board.
- Texas Water Development Board. (December 1992). *Water for Texas: Today and Tomorrow, Recommendations for the 1992 Update of the Texas Water Plan.* Austin: Texas Water Development Board.