Florida Department of Environmental Protection
Florida Geological Survey

Emerging Issues in Florida Karst Geoscience

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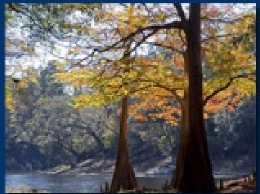
State Geologist and Director

First Annual Karst Symposium
Florida State University
November 3, 2017



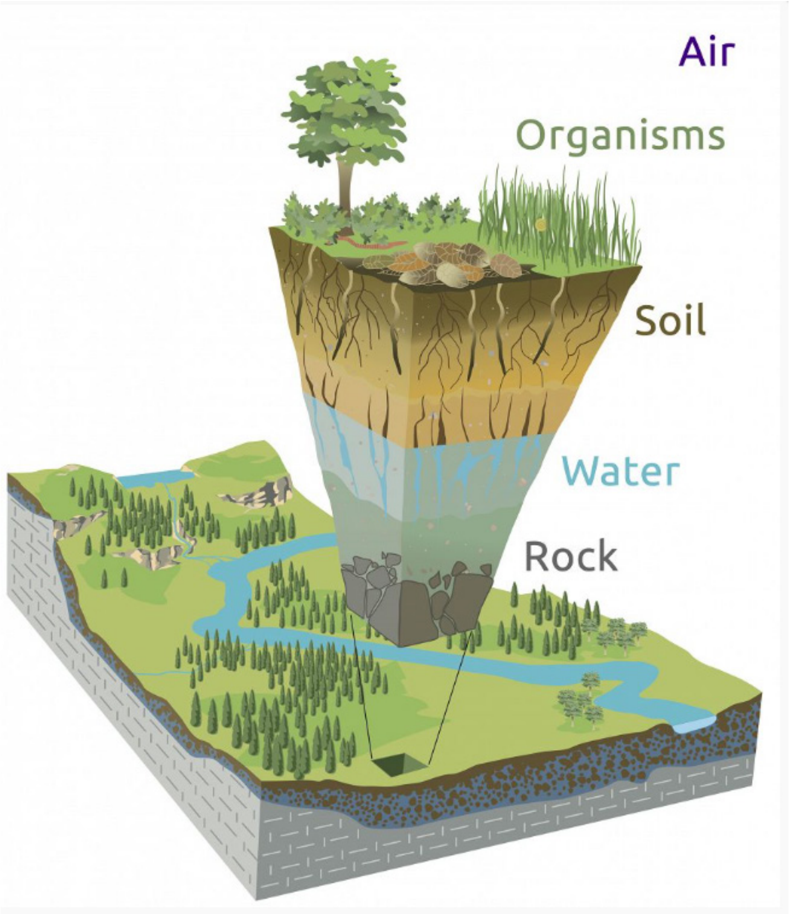




Perspectives

- Holistic and collaborative approaches
- Karst geoscience informing policy
- Basic and applied research (representative)
- Groundwater quality, quantity, flow
- Geohazard mitigation
- Resource management/stewardship
- Public education/awareness
- Economic impact and benefit
- Professional practice and data management

Critical Zone

- Dynamic zone of complex interactions at multiple spatial and temporal scales
- “Earth’s living skin”
- Understanding fluxes and connections
  - Soil
  - Gas
  - Water
  - Energy
  - Sediment
- CZ Observatories



Example: CZO – SW China

Soil Processes and Ecological Services in the Karst CZ…

Objectives (from Green and other, 2016)

- Quantification of soil formation, erosion and deposition budgets along the degradation gradient.
- Mechanistic understanding of spatial variation in carbon, nitrogen and phosphorus cycling, and soil function along and within the degradation gradient.
- Improved representation of degraded / transient states in soil and ecosystem models.
- Analysis of the control exercised on ecosystem service delivery and resilience by spatial structure of land use.

Nomenclature Frameworks

- Ecosystem
- Hydrologic
  - Defining seasons, etc.
- Hydrogeologic
  - Springshed or spring basin; springs group
- Regulatory/restoration
  - BMAP
  - OFS
  - MFL
  - TMDLs and impaired waters
  - WUCA
  - Priority focus areas

Springshed dynamics

- Temporal variation
  - Anthropogenic
  - Flow reversals
  - Seasonal/climatic
  - SLR – Coastal zone
- Multiple springs within single or overlapping catchment

- Need:
  - Consistent mapping methodology
  - Further study of relation between flow, catchment area, and degree/nature of confinement
  - Hierarchy

Chemistry

- Age tracers, ions and decadal precipitation (Martin, Kurz and Khadka and others, 2016)
  - Regional water withdrawal increased 5-fold across 1980-2005
  - Withdrawals represent 2-5% of river flow
  - Decadal variations in precipitation more important
  - "The results suggest that groundwater management should consider climate cycles as predictive tools for future water resources."
- Phytoforensics (Burken, 2016)
  - Plants are masters of mass transfer
  - Plant-contaminant interactions
  - Relationship of in-plant VOCs and in-home exposures
- Paleoclimate and paleoenvironment
  - Speleothems
  - CO2 cycling
  - Carbon sinks
  - Cave air gas

From Climate to Microbes

Karst Science: A National and International Review and Status Report By George Veni, Executive Director, NCKRI

“The lines between basic and applied research are blurring. Speleothem dating and paleoclimate studies are conducted internationally, no longer for purely academic purposes but to advance models of modern climate ... China has taken a special interest in the karst carbon cycle to identify carbon sinks. The US currently leads the way in geomicrobiological cave research, with other important work in this field occurring primarily in Europe. Funding for many of these investigations is often tied to the development of new medicines, materials, and industrial processes. This exciting field has amazing implications for karst science and despite rapid advances, is certainly in its infancy”

https://pubs.usgs.gov/sir/2017/5023/sir20175023.pdf

Water Quality

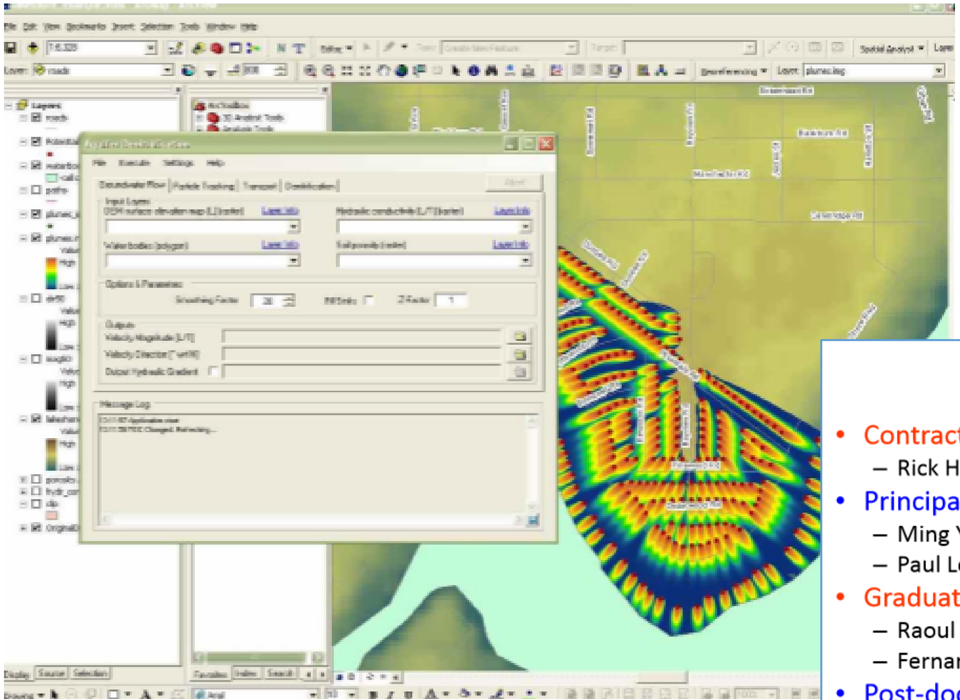
- Groundwater flow
  - Micropollutants as indicators of catchment area
- Pattern recognition
  - Temporal WQ
- Contaminant transport
  - Solids/sediment
  - Dissolved constituents
- Redox and mobilization
  - Sinkholes
  - Along flow path
- Administrative controls
  - Monitoring
  - Wellhead protection
  - Well construction guidelines
  - Karst management plans
- Nomenclature (above)

Nutrient loading

What is ArcNLET?

ArcGIS-based Nitrate Load Estimation Toolkit

- A simplified conceptual model of groundwater flow and solute transport
- Implementation as an ArcGIS extension
- Calculation of nitrate plume and nitrate load



From Ming Ye

Compatible with ArcGIS 9.3, 10.0, and 10.1

ArcNLET Project Team

- Contract Manager:
  - Rick Hicks (FDEP) (Richard.W.Hicks@dep.state.fl.us)
- Principal Investigators:
  - Ming Ye (FSU) (mye@fsu.edu)
  - Paul Lee (FDEP) (retired in 2012)
- Graduate Students:
  - Raoul Fernendes (Graduated in 2011)
  - Fernando Rios (Graduated in 2010)
- Post-docs:
  - Mohammad Sayemuzzaman (2014 – present)
  - Yan Zhu (2014-present)
  - Huaiwei Sun (2012-2013)
  - Liying Wang (2010-2012)

Nutrients pathways

SWAT-MODFLOW is an integrated hydrological model that couples SWAT land surface processes with spatially-explicit groundwater flow processes.

The objective of the SWAT model is to predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungaged river basins.

SWAT - Methodology for Calculating Karst Watershed Nitrogen Inputs and Developing a SWAT Model By Timothy P. Sullivan and Yongli Gao Department of Geological Sciences, Center for Water Research, University of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249

- The assessment of nitrogen fate and transport in karst watersheds requires gathering and processing significant amounts of data.
- The SWAT model provides an effective means of modeling nitrogen fate and transport in karst watersheds.
- Limitations exist – how to overcome
- Methodologies for calculating nitrogen inputs from atmospheric deposition, fertilizer, manure, and wastewater
- How to develop SWAT models for nitrogen fate and transport.
- Watershed modelers will find these methodologies useful when modeling nitrogen fate and transport in other karst watersheds.

- http://swat.tamu.edu/software/swat-modflow/

https://pubs.usgs.gov/sir/2017/5023/sir20175023.pdf

EMERGING CONTAMINANTS

- Organic Waste Water Compounds
  - Pharmaceuticals and Personal Care Products (PPCP), Synthetic Hormones, Disinfectant By-products
- Current Use Pesticides (over 20,000!)
- Brominated Flame Retardants (found in furniture, mattresses, carpet padding, insulation, & automobile seats)
- Akylphenolic Substances (additives for fuels, and lubricants)
- Perfluorinated Compounds (PFCs) (Surfactants including fire fighting foam. Used in the production of Teflon and other fluorinated polymers.)
- Chlorinated Paraffins (lubricants, plasticizers, flame retardants, plastic products including PVS pipe.)

EMERGING CONTAMINANTS (ECS)

- Chemicals that pose a real or perceived threat to the environment.
- The most common exposure route for all organisms, including humans, is through food ingestion.
- Published health or aquatic criteria for ECs is lacking, criteria development is still evolving.
- Some are endocrine disrupting compounds.
- New industrial and agricultural chemicals may be potential ECs.
- ECs are discharged in trace amounts in wastewater releases and in surface water runoff.

Emerging Contaminants

- DEP STATUS Network sampling since 2014
- Indicator compounds
  - Sucralose
  - Acetaminophen
  - Carbamazepine
  - Primidone
- Sucralose sampling since 2012

Emerging contaminants

Florida Scientist

Volume 79 | Fall, 2016 | Number 4

SPECIAL ISSUE: STATUS OF FLORIDA'S GROUNDWATER RESOURCES
GUEST EDITOR: RICHARD COPELAND

- They are out there and detectible (this has been known for years)
- Just because they can be detected, it is not necessarily a cause for concern
- Scientists are beginning to learn more about their influence in natural systems, e.g. impact on biological or ecological processes, food webs and endangered or threatened species
- MCLs or guidance concentrations do not presently exist
- EC's can serve as tracers for understanding karst systems and have potential for "fingerprinting" catchment areas or contamination sources

Using tracers to infer potential extent of emerging contaminants in Florida's groundwater (pages 279–289)
Thomas Seal, Nathan A. Woeber, and James Silvanima

Karst management plans

A Multi-Disciplined Approach to Understanding and Managing Shared Karst Landscapes

By Dale L. Pate

National Park Service, Geologic Resources Division, P.O. Box 25287, Denver, CO 80225-0287

A report series–Shared Karst Landscapes–has been initiated within the NPS Geologic Resources Division (GRD) to address these basic information needs for park units that contain significant karst landscapes.

In order to provide a park manager a more holistic understanding of entire karst systems, the goals of these reports are to:

- Provide an overview of available scientific information
- Identify essential missing information
- Recommend future research
- Identify current and (or) potential vulnerabilities from anthropogenic activities within and adjacent to the park [or land] unit
- Provide documentation for planning efforts for the long-term protection and viability of significant karst landscapes

https://pubs.usgs.gov/sir/2017/5023/sir20175023.pdf

Karst management and sustainability

- Karst Sustainability Index (Van Beynen and others, 2012)
  - Standardized metric of sustainable development
  - Sustainability measures:
    - social, environmental, economic
- Allows comparison of sustainability practices spatially and temporally
- Tampa case study

- Bauer and others, 2017, Managing small natural features: A synthesis of economic issues and emergent opportunities
- Sustainability and Protection of Springs (CRISPS): UF, SJRWMD

Porosity characterization

Contribution of geophysical methods to karst-system exploration: an overview

Konstantinos, and others, 2011
Hydrogeology Journal (2011) 19: 1169–1180

Evolving technologies

Table 1 Adequacy of ground-based geophysics for karst-system exploration

Ground based geophysics		Adequacy of the method — With sedimentary covering				
Method	Measurement technique	Boundaries	Fractured zone	Preferential pathways	Cavities: Air-filled	Cavities: Water-filled
Electrical	ES	+++	++	+	0	0
	ERT	++	++	++	++	++
	Mise-à-la-masse	0	0	++	0	++
	SP	0	++	+++	0	++
EM	Slingram	++	++	++	+	+
	TDEM	+++	+	0	0	0
	GPR	0	+	+	+	+
	CSAMT	+++	++	++	+	+
	VLF res.-RMT	++	++	++	+	+
	VLF EM	+++	+++	+++	+	+
Seismic	Tomography	+++	++	++	++	++
	MASW	++	++	++	++	++
Microgravity	Profiling or mapping	0	++	+	+++	++
Magnetic	Profiling or mapping	0	0	0	0	0
MRS	Sounding	0	0	0	0	+++

+++ recommended; ++ appropriate but incomplete; + appropriate but limited; *0* not
I <300 €; *II*301–600 €; *III*601–1000 €; *IV*1,001–2,000 €; *V*>2001 €—sources: ABI
Rental prices can vary depending on the geographical area, equipment type and mod
CSAMT controlled source audio magnetotelluric; *EM* electromagnetic; *ERT* electrical r
analysis of surface waves; *MRS* magnetic resonance sounding; *RF-EM* radio frequency
wave; *SP* self potential; *TDEM* time domain electromagnetic; *VLF* very low frequenc

.....

Porosity characterization

- Electrical resistivity tomography
  - Downhole electrode profiles and cross hole (Kiflu and others, 2016)
- GPR
  - Offset
  - Off ground
  - Cross hole
  - Data collection and processing variations

WHY?

World class remediation

Flow Simulation

Numerical Simulation of Karst Groundwater Flow at the Laboratory Scale

By Roger Pacheco Castro[1], Ming Ye[1], Xiaohu Tao[2], Jian Zhao[2], and Xiaoming Wang[3]

[1]Florida State University, Geophysical Fluid Dynamics Institute and Department of Scientific Computing, 600 W. College Avenue, Tallahassee, FL 32306

[2]Hohai University, College of Water Conservancy and Hydropower Engineering, 1 Xikang Road, Nanjing 210098, P.R. China

[3]Florida State University, Department of Mathematics, 600 W. College Avenue, Tallahassee, FL 32306

Abstract

A three-dimensional sand box was built to explore flow exchange between porous media and karst conduits in order to improve our understanding of groundwater flow in karst aquifers. A tank is filled with sand as the porous medium, which is coupled with a pipe used to simulate a conduit. Measured heads and flow rates of the laboratory experiments, development of a numerical model with MODFLOW-Conduit Flow Process mode 1 (MODFLOW-CFP1), and model calibration are discussed. The calibration is performed manually using FloPy, which allows the integration of MODFLOW-CFP1 with Python to make the modeling process more user friendly. With the use of FloPy, we adjusted hydraulic gradient and the exchange coefficient of MODFLOW-CFP1 within a given range, and generated response surfaces for flow rates. This allowed us to find a combination of calibration parameter values that yielded satisfactory agreement between simulated and measured flow rates. Our future work is to focus on the integration of automatic calibration tools and the comparison of simulated results with other models such as the Darcy-Stokes model.

https://pubs.usgs.gov/sir/2017/5023/sir20175023.pdf

Remediation challenges

Field and Kresic, 2016

- Complex hydrogeologic settings and conduit flow
- Impact of epikarst
- Contaminant complexities (reactivities, densities, miscibilities)

- Remediation typically less successful in karst
  - Pump and treat
  - In-situ thermal
  - In-situ chemical oxidation
  - Bioremediation
  - Monitored attenuation
- Beyond a solution?
  - EPA Technical Impractibility waiver
  - Rare
  - “Vagaries of karst terranes fully justify the concept of a TI waiver at some complex sites”

https://karstwaters.org/sp19-karst-groundwater-contamination-and-public-health/

Remediation solutions

Byl, Bradley and Painter, 2016

Despite these challenges…

- Supplements have been used to stimulate specific microbial populations and foster geochemical conditions which enhance or stimulate degradation or immobilization of the contaminants in a karst aquifer.
- Karst system indigenous bacteria are well adapted to a variety of metabolic capabilities and aquifer conditions.
- Non-traditional groundwater models that incorporate residence time distribution and decay rates are useful tools in the remediation decision-making process.

https://karstwaters.org/sp19-karst-groundwater-contamination-and-public-health/

Karst Engineering

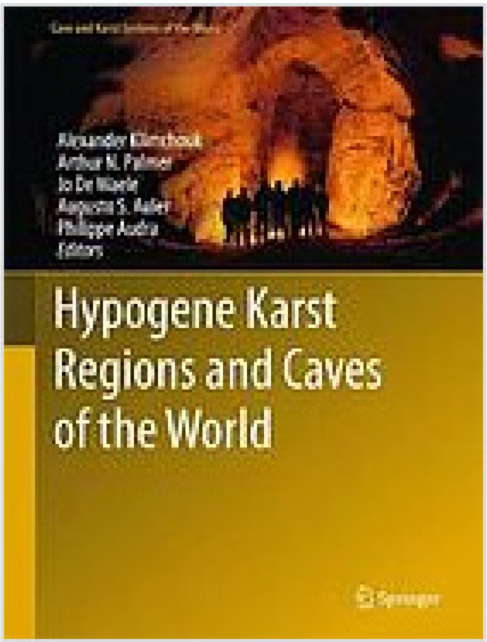
Sustainable utilization in China (Riyuan, 2016 *in* Journal of Groundwater Science and Engineering, December, 2016, Vol. 4, Issue 4, pp. 301-309)

- Water storage
- Water diversion irrigation
- Electricity generation

International Research Center on Karst Training Course, July 2017

- Flood management
- Conduit flow capture for aquaculture

Hypogene Karst



From Preface:

"Recognition of hypogene karst and the scale of its phenomena dramatically expand both the boundaries of karst and the significance of karst science far beyond the traditional, dominantly epigenic, karst paradigm. This has numerous scientific and practical implications. Hypogene karst studies hold a promise to help solve many problems in prospecting and exploration of deep petroleum, ore, and geothermal resources in soluble rocks. Proper reservoir characterization and modeling requires a skillful genetic interpretation of void-conduit systems and understanding of their hydraulic function. The role of hypogene karstification lies not only in enhancing reservoir properties but also in facilitating vertical fluid migration across heterogeneous strata."

Alexander Klimchouk	Kiev, Ukraine
Arthur N. Palmer	Oneonta, USA
Jo De Waele	Bologna, Italy
Augusto S. Auler	Belo Horizonte, Brazil
Philippe Audra	Sophia Antipolis Cedex, France

Hypogene Speleogenesis on the Florida Platform, Chapter 49, Sam Upchurch

http://www.springer.com/us/book/9783319533476

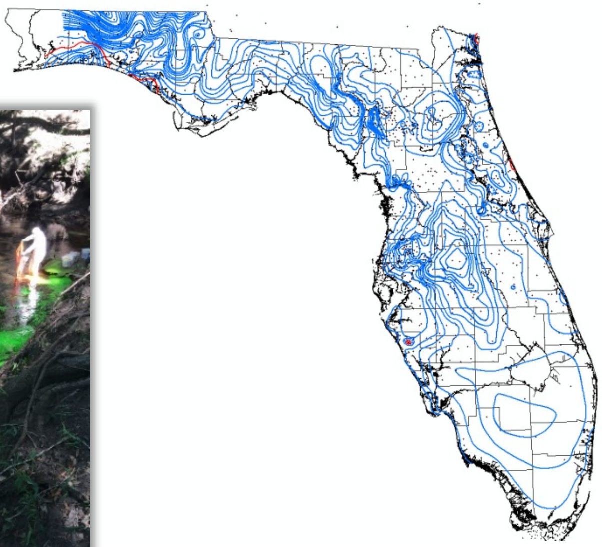
Karst Geoscience Literacy

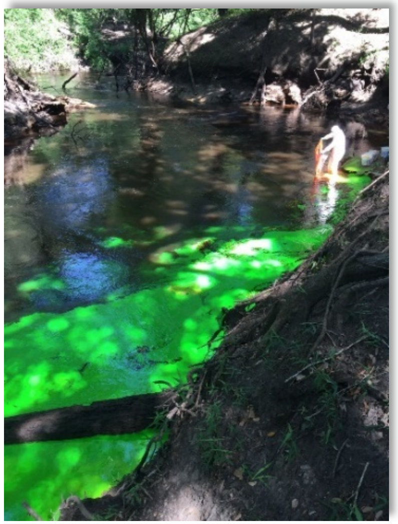
- The nexus of karst geohazards and politics
- Public engagement in the Twitter and post-Twitter(?) era
- Citizen scientists – crowd sourcing

- Florida karst Geotourism – designing visitor experiences
  - Teachers/students
  - Family learning
  - Casual/social
  - Intellectual
  - Multidiscipline
    - Geology
    - Archeology
    - Biology

FGS Applied Geosciences

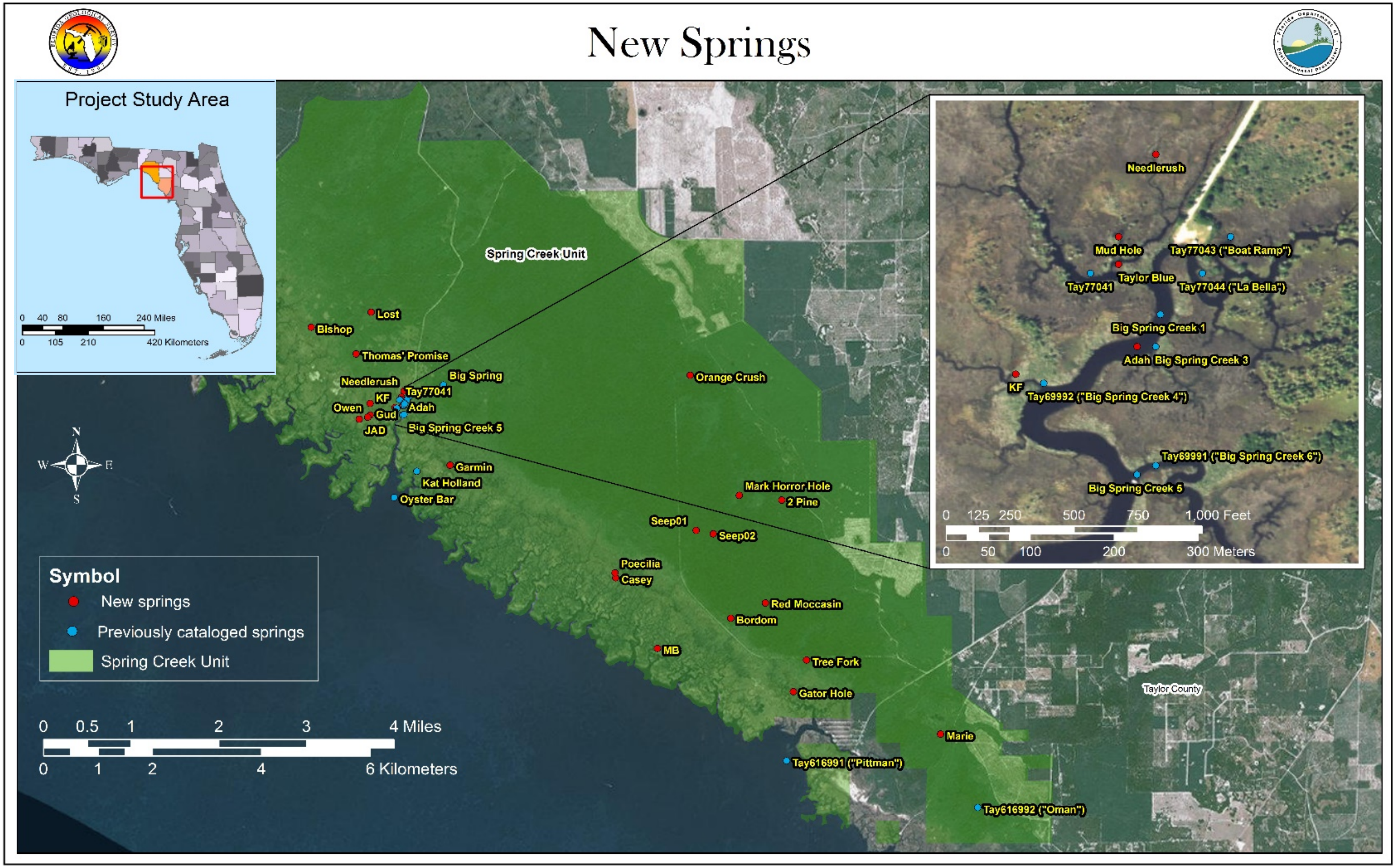
- Potentiometric mapping
- Spring basin delineation
- Hydrogeologic frameworks
- Water-rock interactions
- Aquifer vulnerability
- Sinkhole Liklihood
- Springs mapping?





https://floridadep.gov/fgs

27 previously uncatalogued springs using thermography, drone videography, and field observations/hiking



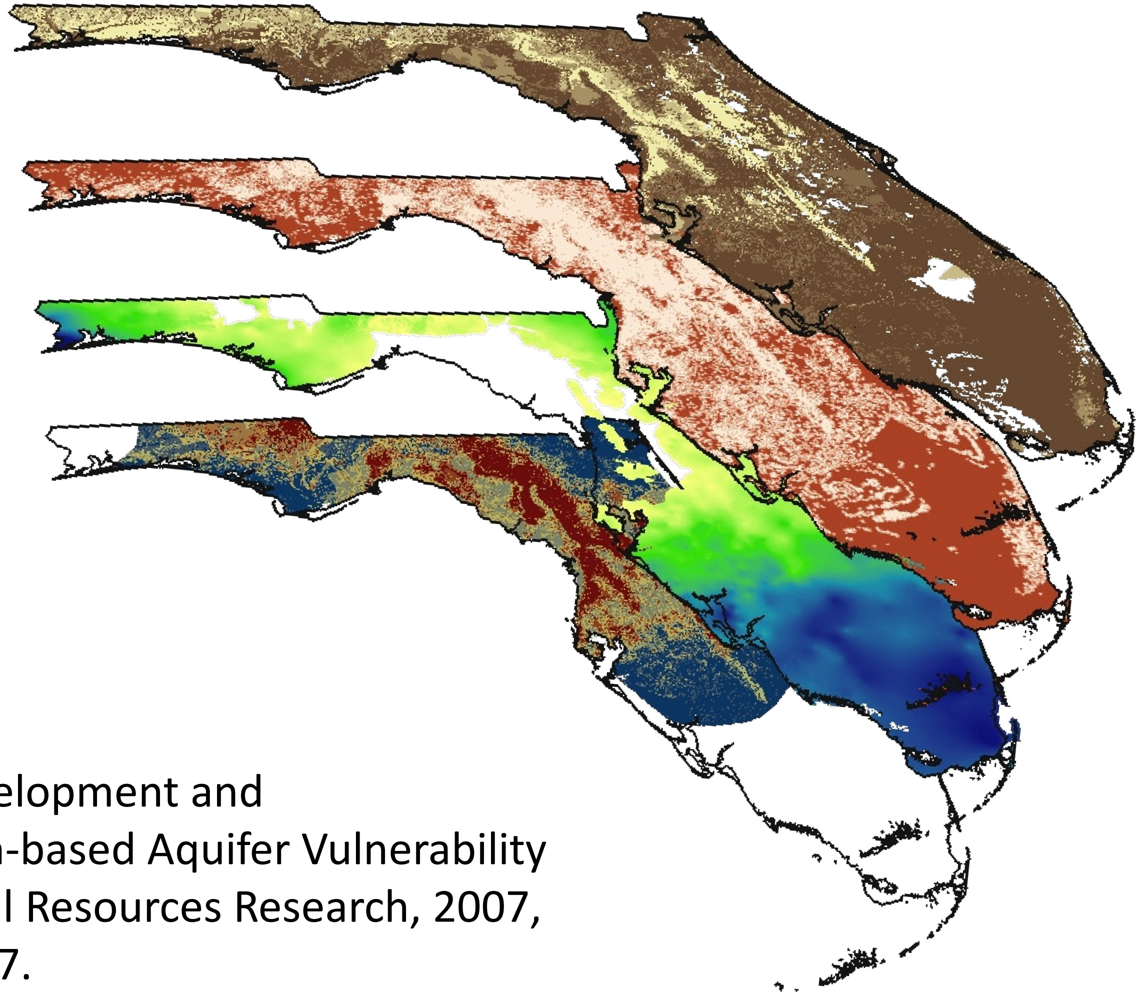
Vulnerability: Floridan Aquifer System

Soil Drainage

Proximity to Karst Feature

Intermediate Confining Unit Thickness

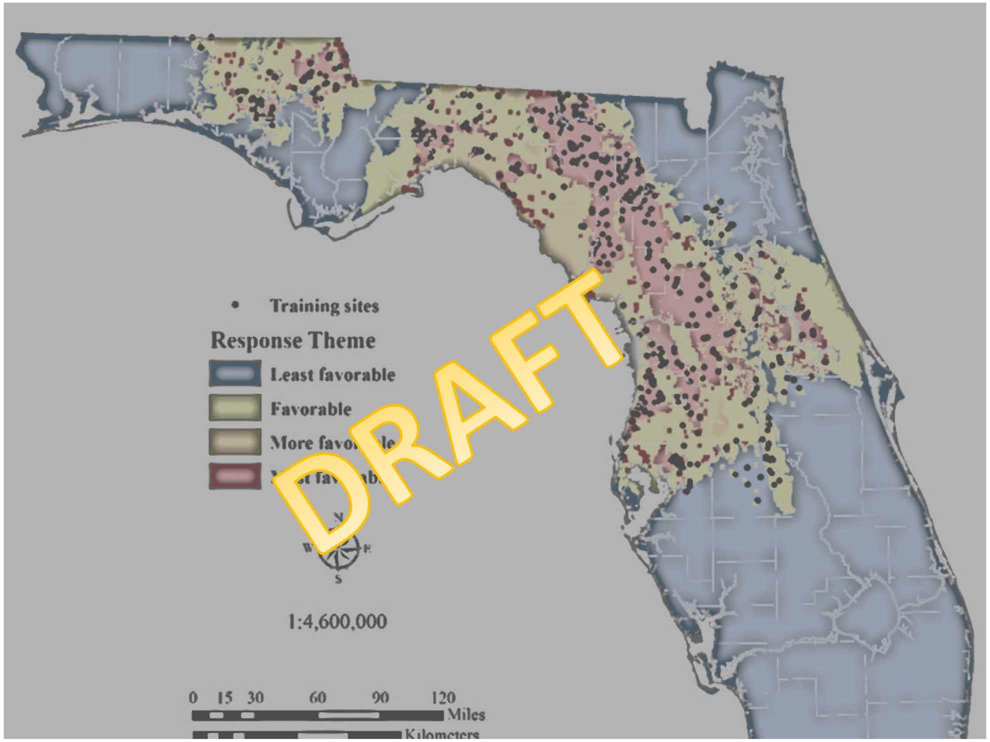
Relative Vulnerability – Model Output



Arthur and others, 2007, Development and Implementation of a Bayesian-based Aquifer Vulnerability Assessment in Florida, Natural Resources Research, 2007, Volume 16, Issue 2, pp 93–107.

Sinkhole Hazard Mitigation

- A favorability map using the Weights of Evidence methodology was generated using the three evidential themes that showed the strongest association with the training point theme and therefore were considered the strongest for identifying areas with geology favorable for sinkhole formation
- Each of these evidential layers were evaluated relative to the study area training sites



- A calculated weights table was used to identify the break between areas that are associated with training sites and areas less associated with sites

On the radar at FGS

- Objective: Develop cave and karst database, an essential scientific input for planning and restoration of water resource protection.
  - Action: Populate karst data and metrics within the database, such as but not limited to tracer study data and results.
- Long term goals:
  - Develop relative recharge or vulnerability maps for four first-magnitude springs by 2018-2019
  - Develop karst database module for GEODES by 2022-2023
- Dye trace registry?

Looking ahead

- International Year of Caves and Karst – **IYCK 2021**
- Union Internationale de Spéléologie ⟶ UNESCO
- Goals (after UIS Bulletin, 2015):
    - Improve public understanding of karst in everyday life
    - Demonstrate importance of karst feature management to global economic and environmental health
    - Global scale educational activities with a focus on developing countries and emerging economies
    - Promote the importance of caves and karst in sustainable development particularly in water quality and quantity, agriculture, geotourism/ecotourism, and natural/cultural heritage
    - Promote awareness of the interdisciplinary nature of cave and karst science and management, its role in environmental protection
    - Enhance international cooperation by coordinating activities between societies, educational establishments and industry, focusing specifically on new partnerships and initiatives in the developing world
    - Establish durable partnerships to ensure that these activities, goals and achievements continue in the future beyond the International Year of Caves and Karst.

Contact

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