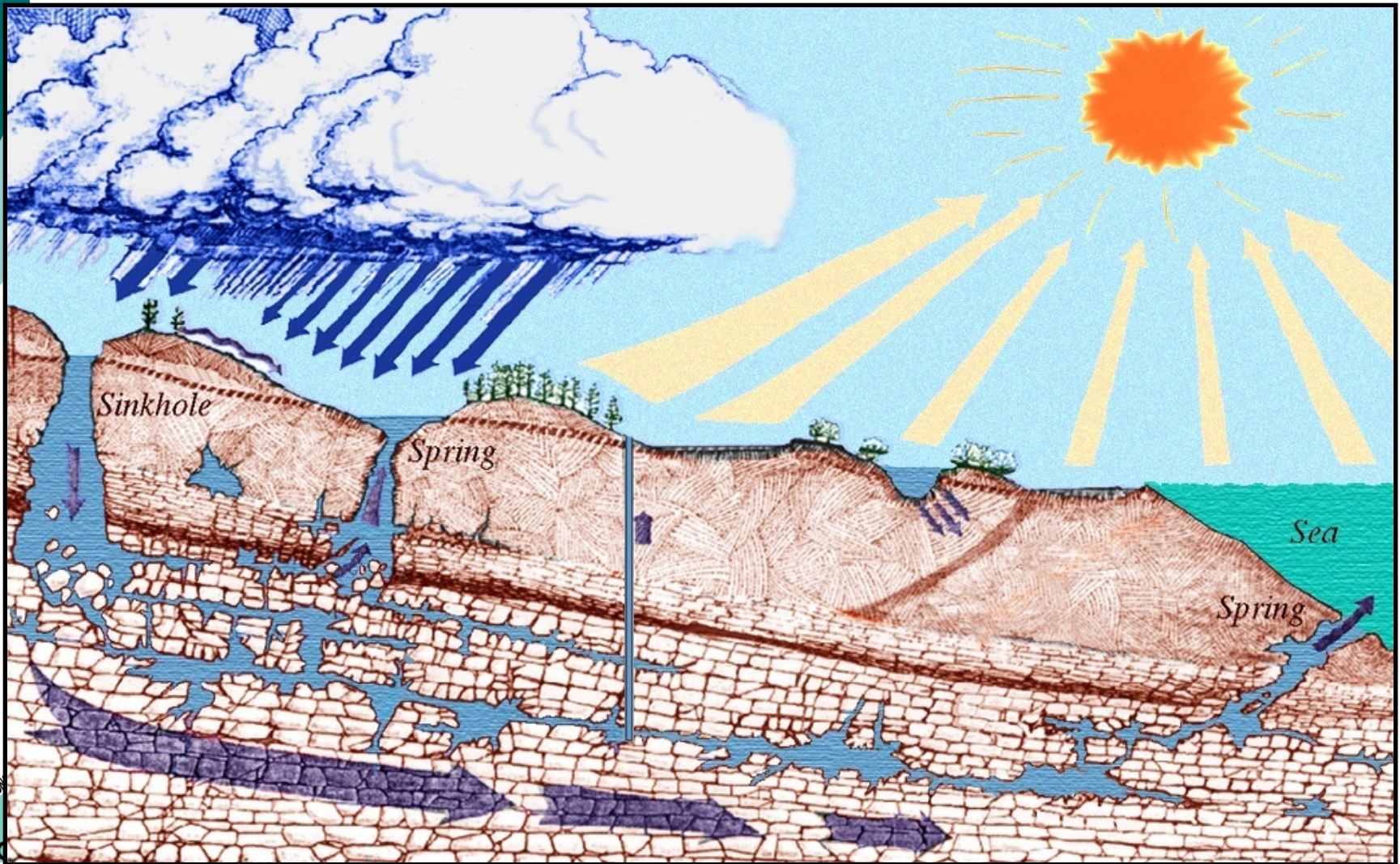


Why should karst Watersheds be Monitored and Modeled as 3-dimensional systems?

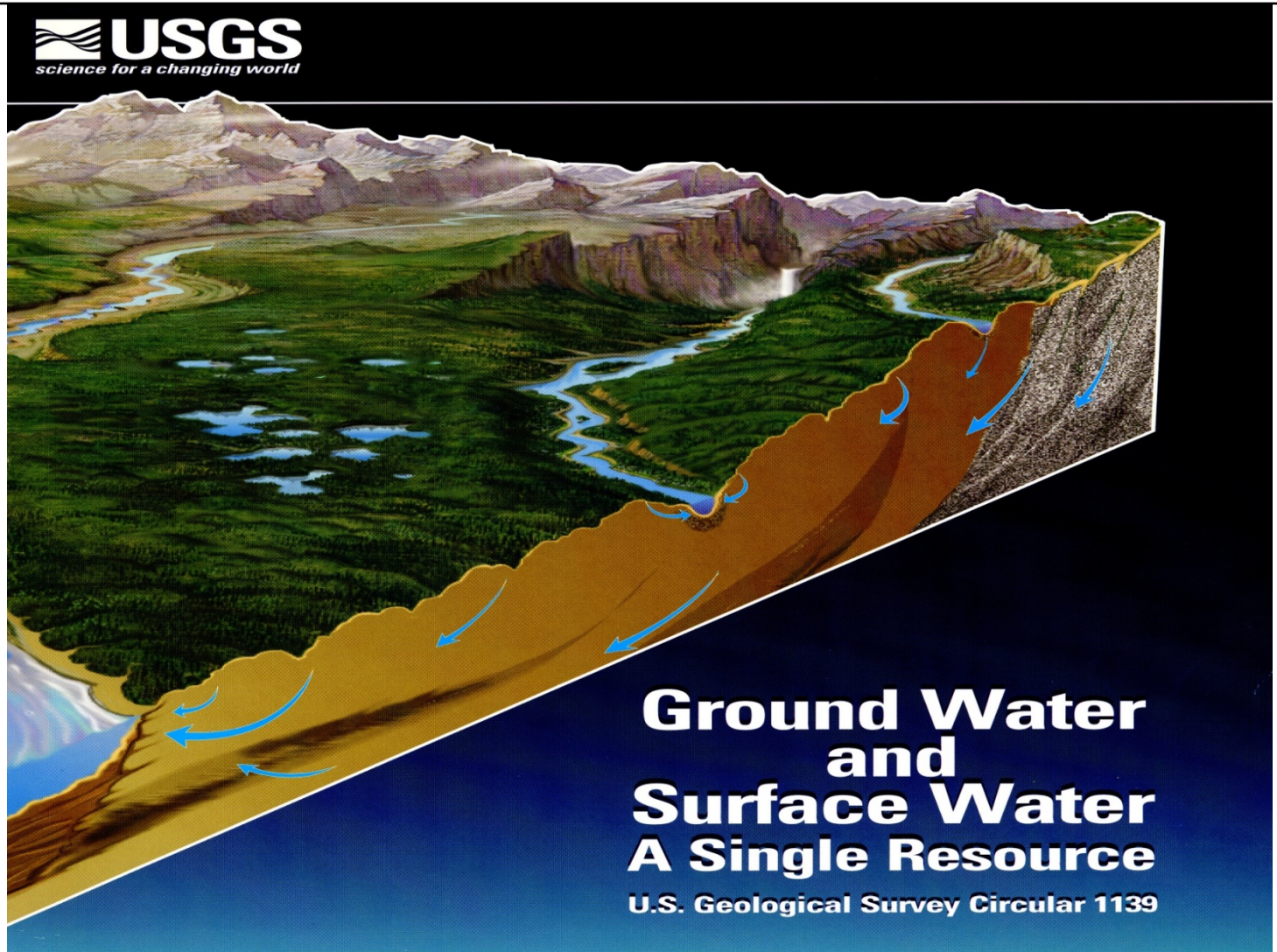
By:
Rodney DeHan, Ph.D.



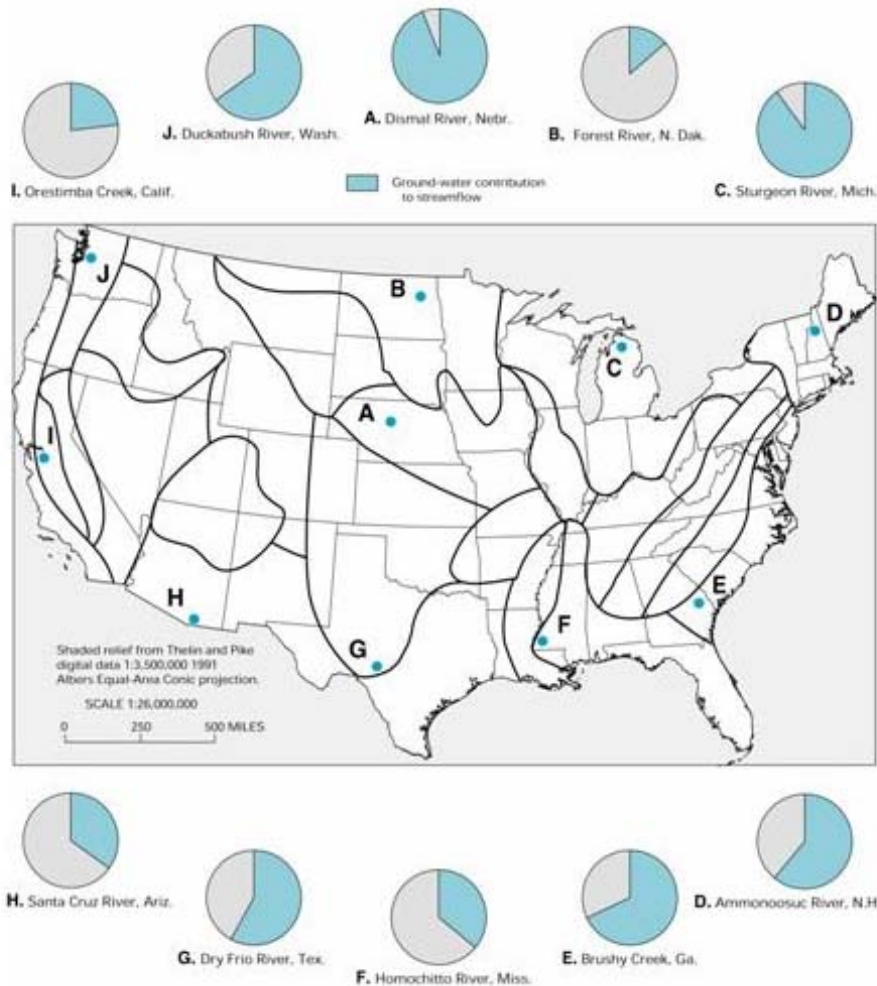
The hydrologic cycle says it all: Obvious interaction between watershed components is maximized in karstic settings necessitating the need to monitor water quality of these systems as 3D entities containing water in the soil, on the surface, in sediments, in atmospheric deposition and in aquifers collectively comprising the system's *water budget*.



A Three-dimensional Watershed (3-D) is a universally-accepted concept in hydrogeology: *Below is the cover of a publication that is an excellent summary for interested scientists.*



It is not a “Florida issue” only! Ground water as “base flow” in selected streams and the extent of karst in the US: In some Florida streams, base flow can contribute almost 100% of stream flow during draught and low flow periods.

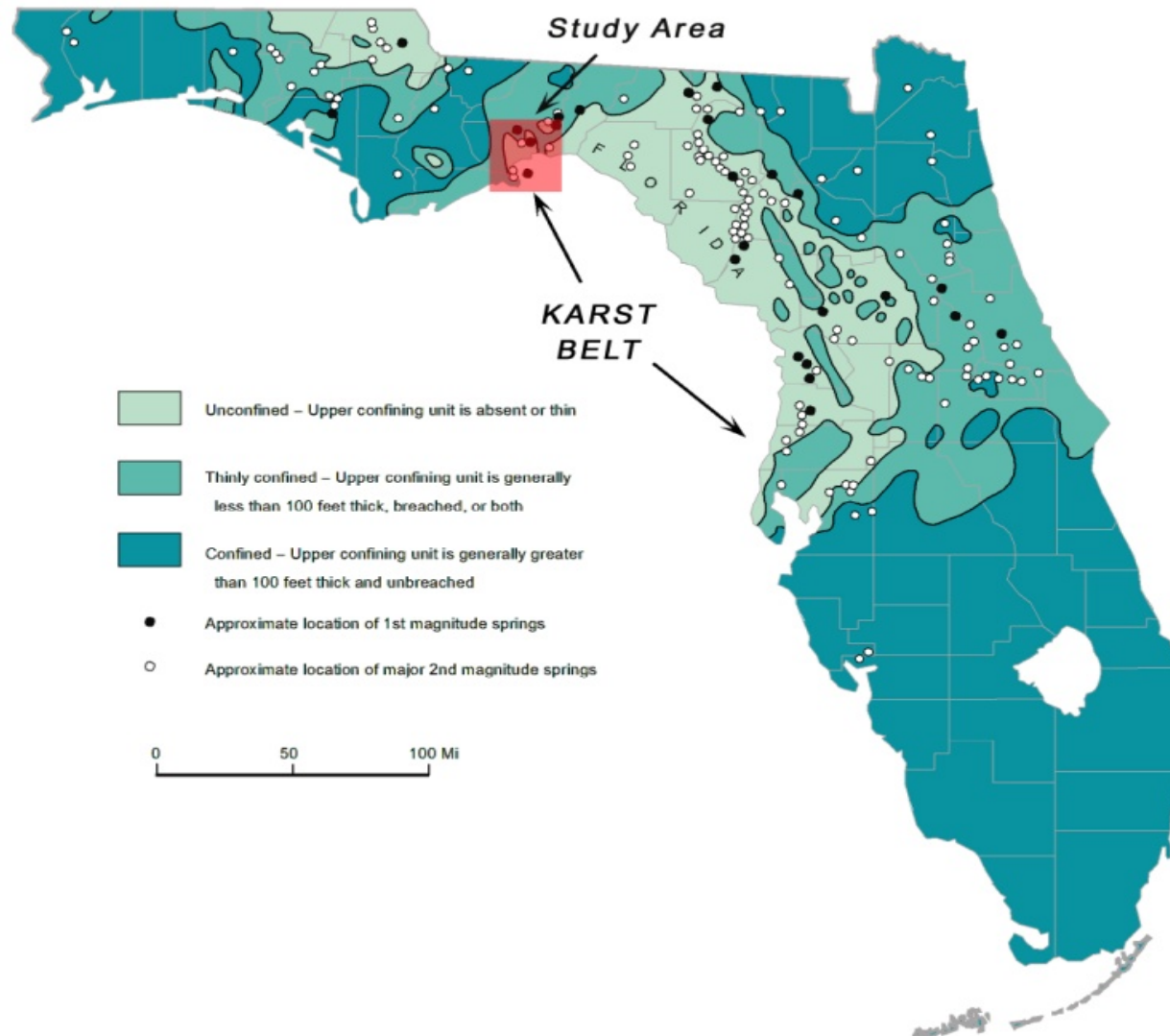


Karst regions of the contiguous United States



(after Davies and others, 1984, U.S. Geological Survey, National Atlas, Engineering Aspects of Karst)

Florida's Karst belt: the Woodville Karst Plain (highlighted in red) is the location of the FGS's watershed characterization and modeling studies, on-going since 2003. Our data confirmed the need for monitoring karstic watersheds as 3D systems.



The interplay between hydrogeology, microbiology and chemistry in determining water quality in karstic watersheds

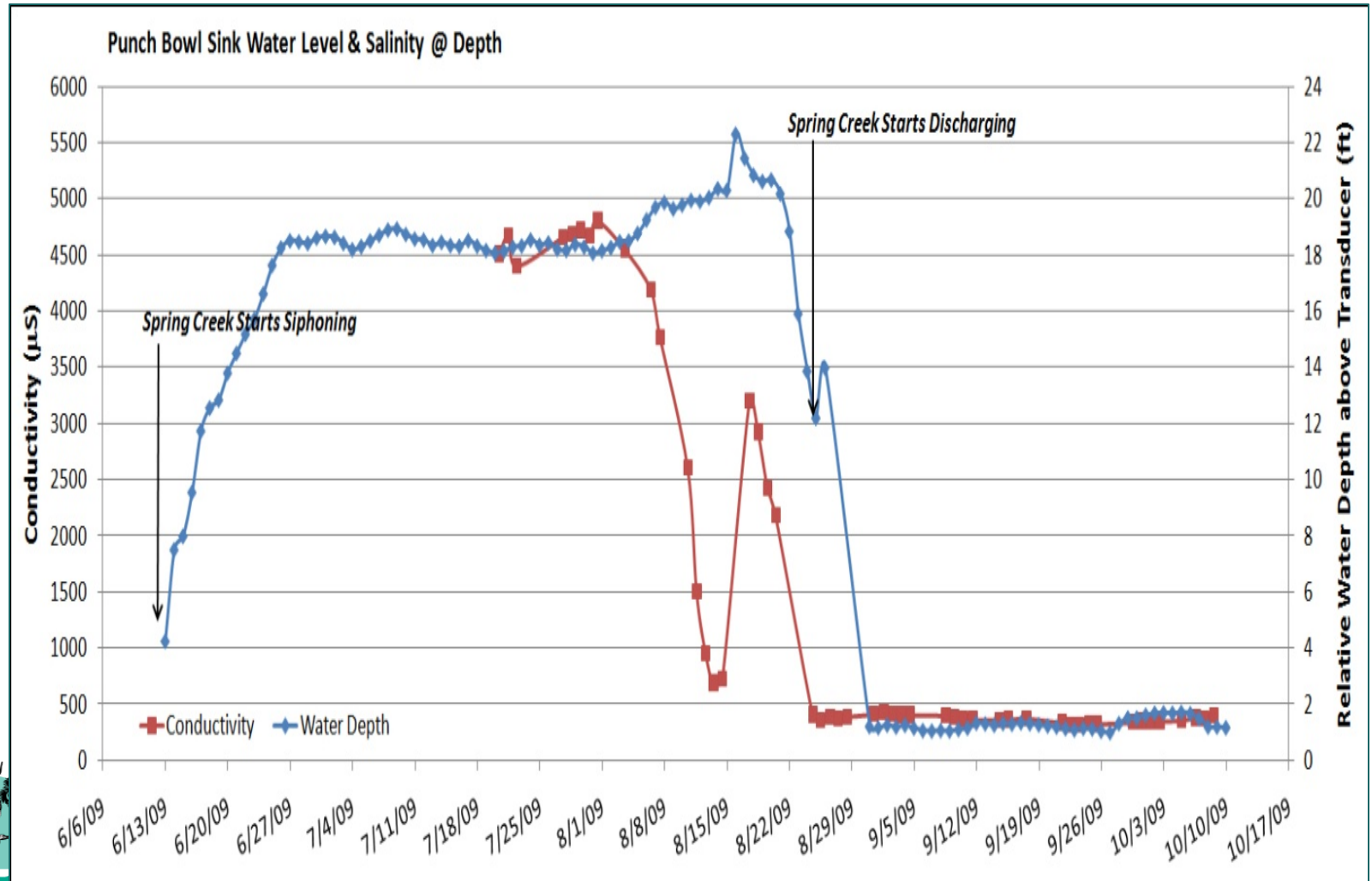
- Highly-disrupted surface water drainage on land surface exhibited as closed-depressions, sinkholes, lineaments, sinking streams, subsidence etc. frequently correspond to the network of underground features such as conduits, caves, cavities and channels demonstrating the most direct and visible evidence of interaction between ground and surface waters
- The dissolution of lime stone and dolomites opens and enlarges these features and invites further interaction between components of the 3-D watershed exhibited not only by changes in water quantity and quality due to mixing, but also due to chemical and microbial processes such as the following that result in additional changes in water quality:
- Relatively quick weathering of dolomitic and lime stone rocks produces calcium and magnesium carbonates that raises the ionic strength of ground water in these aquifers which, in turn, is reflected in surface waters.
- Microbial processes in the soil and the hyporeheic zone (where shallow ground water interacts with surface water) generate CO₂ that affects the carbonate equilibrium as surface water recharges the aquifers.
- These examples demonstrate the need for designing monitoring plans that reflect these processes. Traditional monitoring of surface and ground water as two separate entities will lead to erroneous results and conclusions.



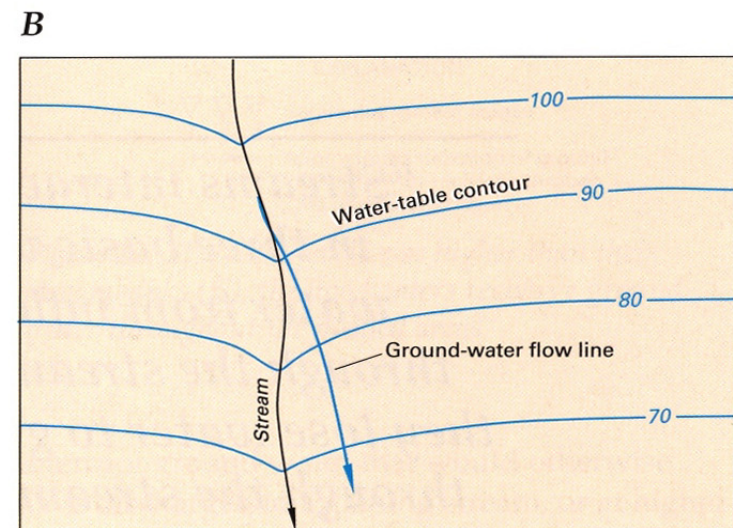
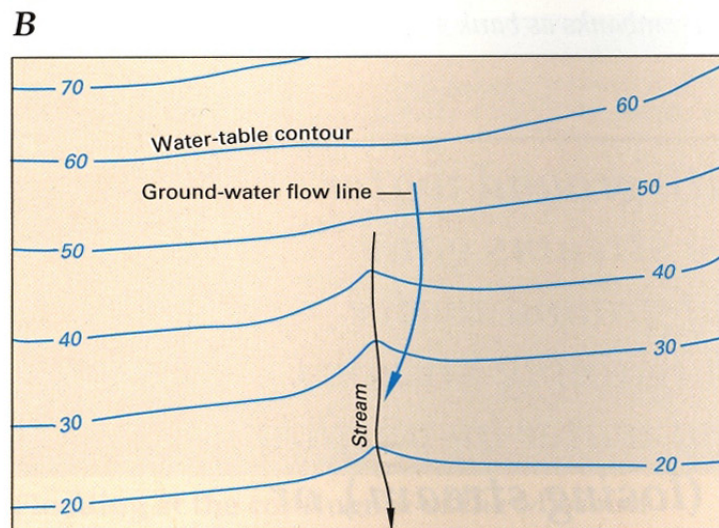
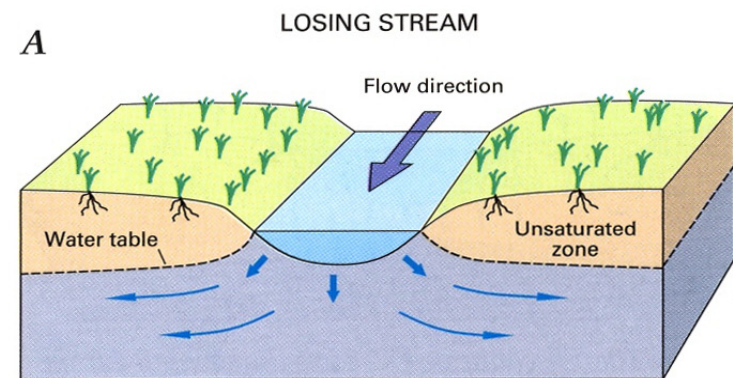
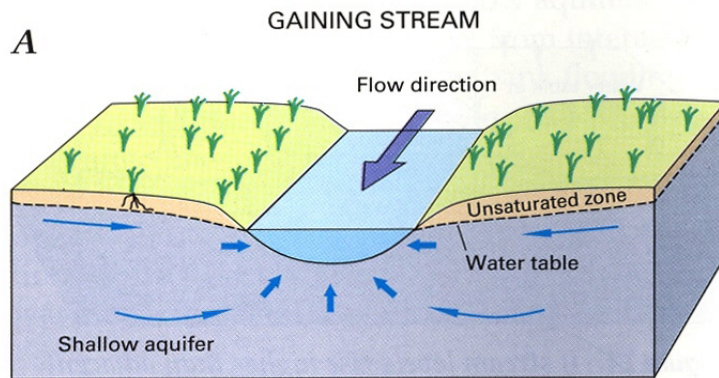
Visible Interaction between SW&GW is demonstrated by reversal of flow from discharge to “siphoning” at the Spring Creek submarine prings system seen in the photos as a “boil” in (AB&D) and as accumulation of debris in (C) over one of 12-14 vents comprising the entire system.



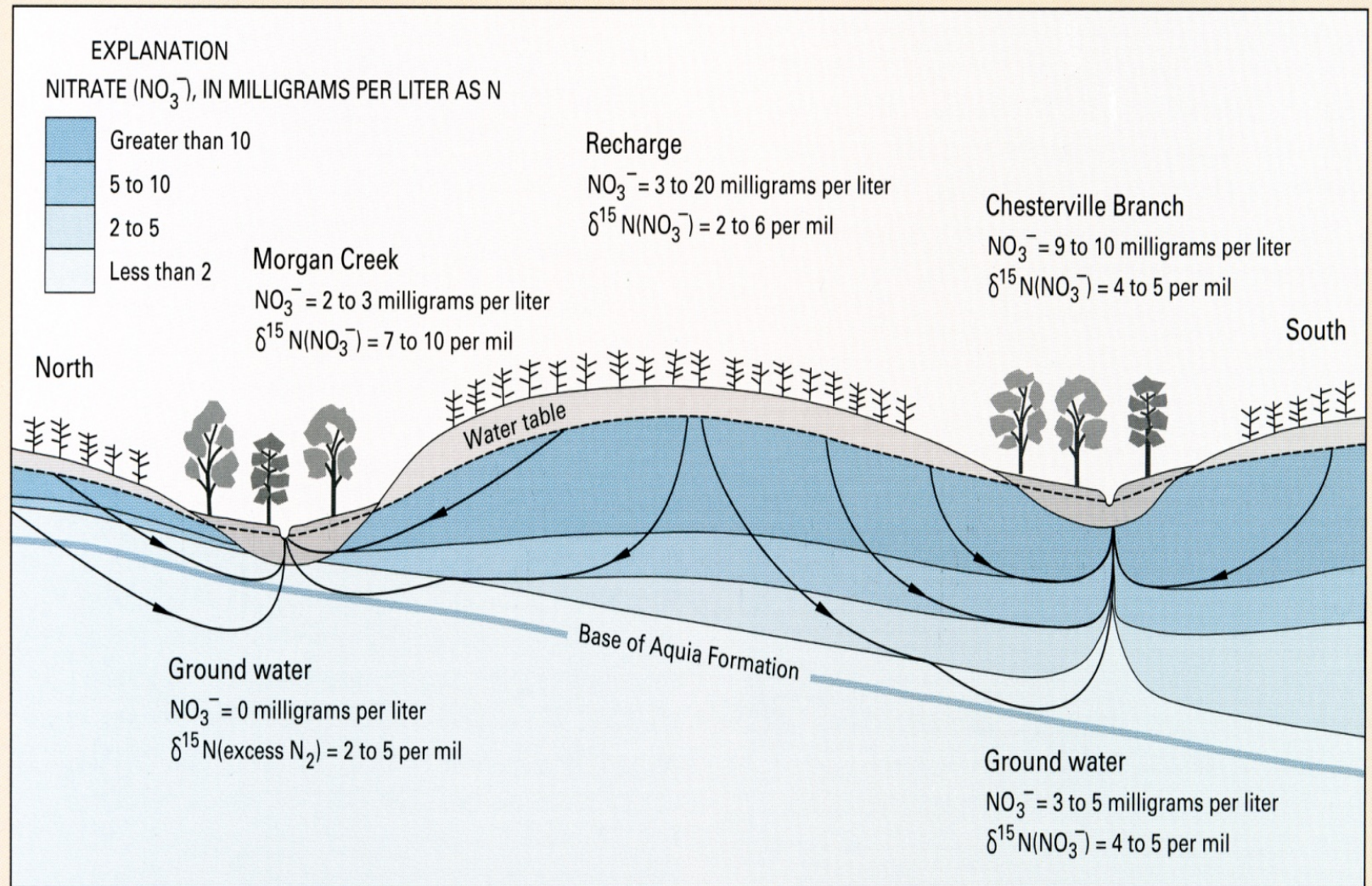
Transducer-generated data reflecting siphoning and discharging in Spring Creek submarine springs system: Weights must be used by divers to anchor themselves against the high velocity of discharge through the vents



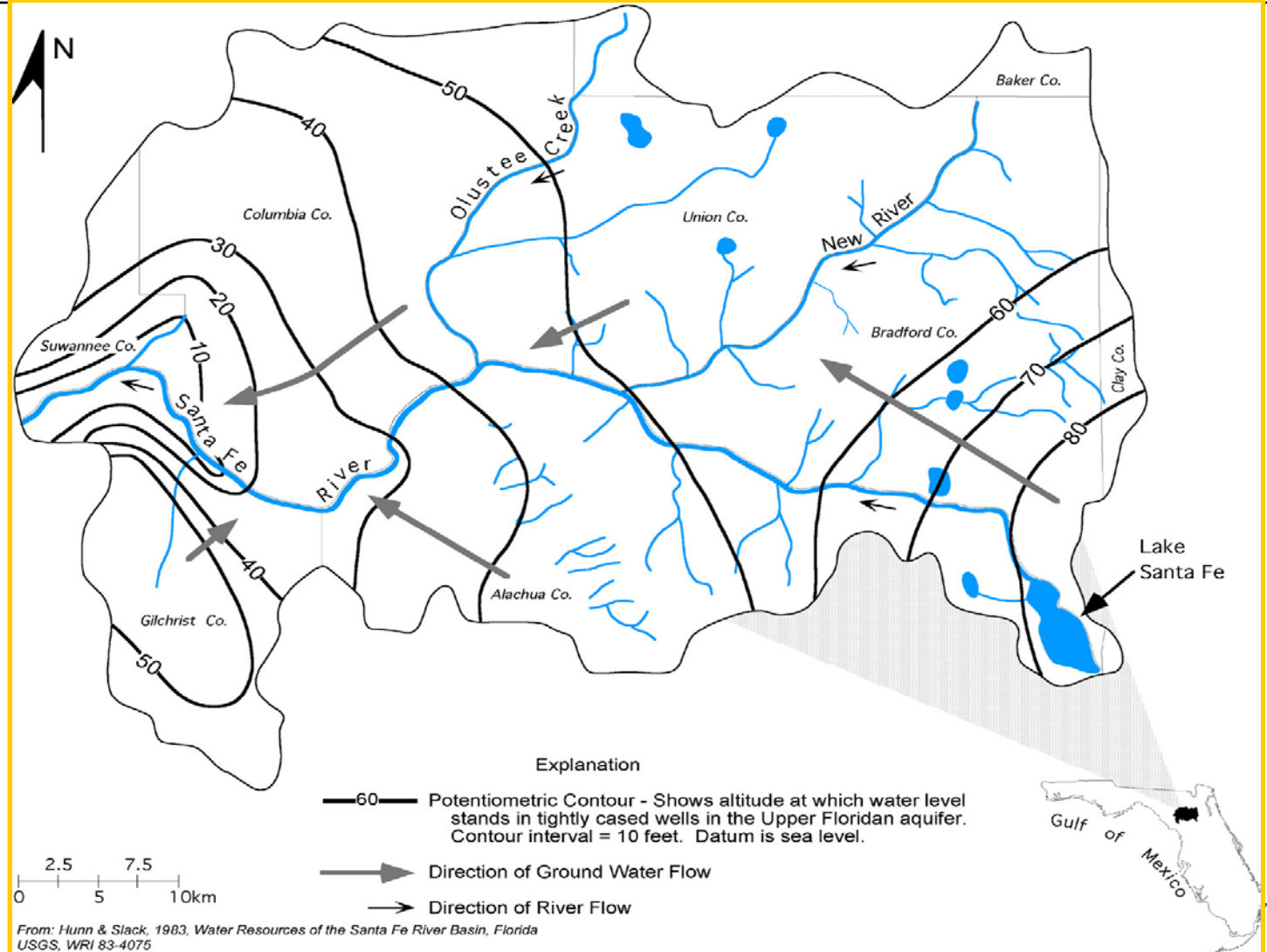
Significant changes in water flow and quality seen in Gaining and Losing Streams in karstic settings, illustrates the need for specially-designed monitoring plans and tools such as: Water table contour lines shown below to determine the direction of ground water flow to or from streams.



- Influence of GW/SW interaction on water quality: Quality improved in one gaining stream (Morgan Creek, Maryland) compared to another gaining stream (Chesterville) due to variation in the volume of de-nitrified ground water discharged into each stream.



Impacts of GW/SW interaction on the design of monitoring plans: Example from Florida: Santa Fe River at O'leno State Park (see explanation in the next slide).



Standard monitoring practices in karstic settings will result in misleading conclusions: Florida example.

Standard potentiometric surface maps would indicate that the Santa Fe River is a **gaining stream**, ignoring the fact that the entire river disappears underground some 3.5 miles down stream making it a **Losing stream**.

Any contaminants entering the river upstream of O'Leno State Park will end up in the Floridan Aquifer.

Monitoring plan designers must therefore be intimately familiar with the location of points of interaction between SW and GW.

Lack of such familiarity will result in a “domino-effect” beginning with miscalculating the watershed’s water budget which, in turn, is essential to the hydrogeological characterization of the watershed which is critical to the development of predictive numerical models



Concluding Remarks:

- 1) Karstic watersheds are unique hydrogeological systems where classic approaches to describing ground water flow, such as Darcy's equation, are not applicable.
- 2) This is primarily due to the heavy interaction between surface features (such as sinkholes and sinking streams) with aquifers that are riddled with caves, conduits, channels and cavities of varying sizes, orientation and depth.
- 3) These features dictate that water in such aquifers must follow a **multi-porosity flow** which presents a very challenging problem facing those interested in characterizing such watersheds for the ultimate purpose of developing predictive mathematical models of the system's behavior in response to natural and anthropogenic events.
- 4) Effective characterization of these systems is highly site-specific and requires knowledge of cave development and interaction between ground and surface water,
- 5) Multi-porosity flow is created and facilitated by the quick weathering of dolomites and limestone which lead to the creation of a feedback loop for permeability and flow path enhancement. Velocities of ground water flow in karstic aquifers are not matched in homogenous aquifers, leading to the term "underground rivers" used in describing flow in karstic aquifers.



Concluding Remarks-Continued

6) Monitoring strategies must therefore recognize and account for the existence of these features as the lowest “head” conditions in Local flow systems, recognize springs as important sampling locations

and encompass transient natural and anthropogenic events such as

heavy rainfall or extensive ground water withdrawal respectively.

7) Specifically-designed methods can be employed to aid in the accurate monitoring and characterization of karstic watersheds, including dye or natural isotopes tracing, to quantify the interaction between the surface and ground water components of the system.

8) While the development of numerical predictive models of such systems is rather challenging and in need of additional research and model calibration with field-data; it is never-the-less a doable endeavor that should be relied upon as a valuable, scientifically-based tool to help in making water and land use decisions and policies at all levels of government.



Recommendations to the Florida Monitoring Council

- 1) The Florida Council should make the effort to educate the National Monitoring Council about the unique nature of karstic watersheds and the specific approaches, methodologies and policies that must be implemented in order to monitor, characterize, model, conserve, sustain, protect and manage such watersheds.
- 2) The Florida Council should seek to form a “***karstic Regions Consortium***” (KRC) with other states with similar hydrogeological settings (Kentucky, Texas etc, see map) in order to have a one voice in affecting real changes at the federal level.
- 3) One suggested approach is to draft a joint resolution or “white paper” in collaboration with these states and present it to these states’ Congressional delegations and to the EPA, USGS, NOAA, Corp of Engineers and other federal agencies that have a role in water resource conservation and environmental protection.
- 4) Enclose with the resolution a list of research topics, surveys, maps and other scientific data needed to underpin any suggested changes by the KRC. The KRC should then seek funding from these agencies for proposals and projects designed to realize and meet these needs.



Selected Reading on the topic of Surface Water interaction with Ground water

Nathan, R.J., McMahon, T.A., 1990. Evaluation of automated techniques for base flow and recession analysis. *Water Resources Research* 26 (7), 1465–1473.

Harlow, J.R.B., and Coupe, R.H., 2011. Ground water and Surface Water Exchange and resulting nitrate dynamics in the Boque Phalia Basin in Northwestern Mississippi : *Journal of Environmental Quality*, Posted on line 9 Nov. 2011. doi:10.2134/jeq2011-0087

Arnold, J.G., Allen, P.M., Muttiah, R., Bernhardt, G., 1995. Automated base flow separation and recession analysis techniques. *Ground Water* 33, 1010–1018.

Delin, G.N., Healy, R.W., Lorenz, D.L., Nimmo, J.R., 2007. Comparison of local to regional scale estimates of ground water recharge in Minnesota, USA. *Journal of Hydrology* 334, 231–249.

Mau, D.P., Winter, T.C., 1997. Estimating ground water recharge from streamflow hydrographs for a small mountain watershed in temperature humid climate, New Hampshire, USA. *Ground Water* 35 (2), 291–304.

Mazvimavi, D., Meijerink, A.M.J., Stein, A., 2004. Prediction of base flows from basin characteristics: a case study from Zimbabwe. *Hydrological Sciences* 49 (4), 703–715.

McCuen, R.H., 1989. *Hydrologic Analysis and Design*. Prentice Hall, pp. 355–360. (book)

Olmsted, F.H., Hely, A.G., 1962. Relation between ground water and surface water in Brandywine Creek Basin, Pennsylvania. *US Geological Survey Professional Paper* 417-A.16



This USGS reference was received only yesterday

Barlow, J.R.B., and Coupe, R.H., 2011, Groundwater and Surface-Water Exchange and Resulting Nitrate

Dynamics in the Bogue Phalia Basin in Northwestern Mississippi: Journal of Environmental Quality, posted online 9 Nov. 2011.

doi:10.2134/jeq2011.0087

Monitoring the exchange between the Mississippi River and the underlying alluvial plain Sand & Gravel aquifer in North Western Mississippi and using a 2-D GW/SW interaction model showed that heavy concentrations (39.8 mmol/L) of nitrates in surface water was not matched by any detection (zero) of nitrate in the ground water as measured in shallow monitoring wells adjacent to the river or in in-stream piezometers. These findings indicated to the authors that nitrates were effectively denitrified through the stream bed. This work supports the need for monitoring surface and ground water as one entity.

