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Floridan Aquifer Collaborative Engagement for Sustainability

Simulating Nitrate Transport to the Devil's Springs Complex Using SWAT-MODFLOW and MODPATH

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USDA United States Department of Agriculture National Institute of Food and Agriculture

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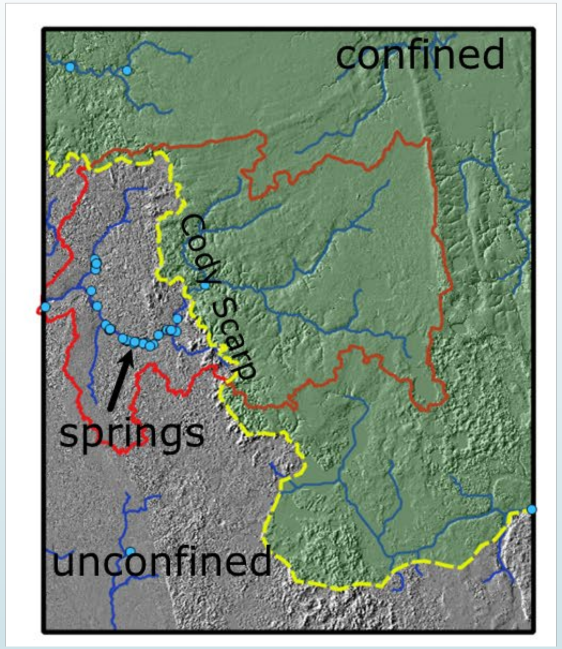
Background (1)

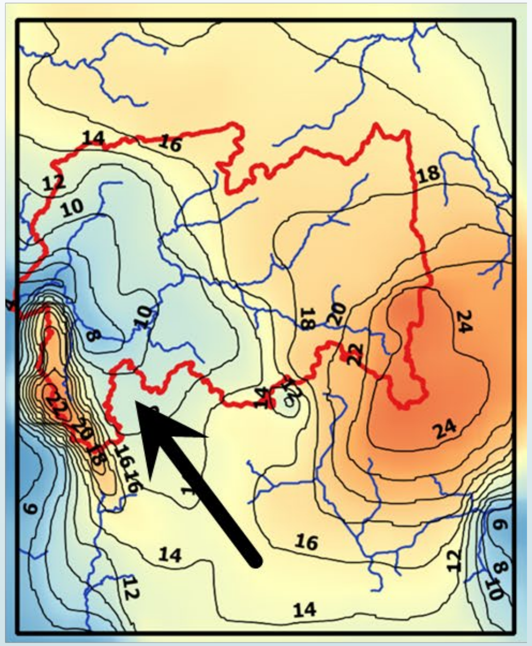
Within the framework of the **FACETS** Project, we built a **SWAT-MODFLOW** model for the **Santa Fe River Basin** (This is our biophysical model)

Santa Fe River Basin

Hydro-geomorphic Characteristics



Aquifer levels in UFA



We plan to extend this to a **SWAT-MODFLOW-RT3D** model

Background (2)

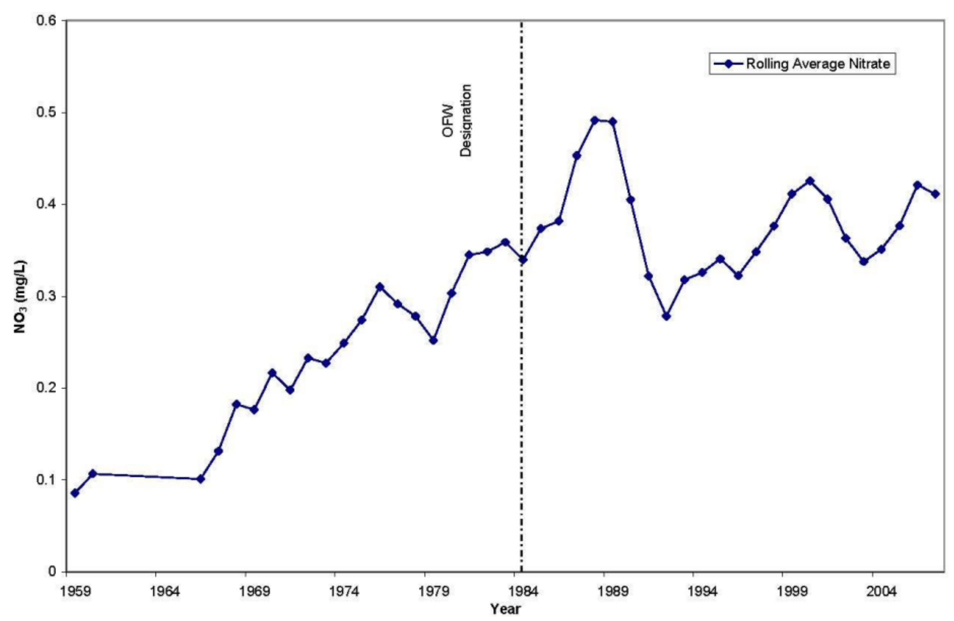


FIGURE 5. HISTORICAL NITRATE DATA FOR THE SANTA FE RIVER, 1959–2004

From: Santa Fe River Basin Management Action Plan – March 2012

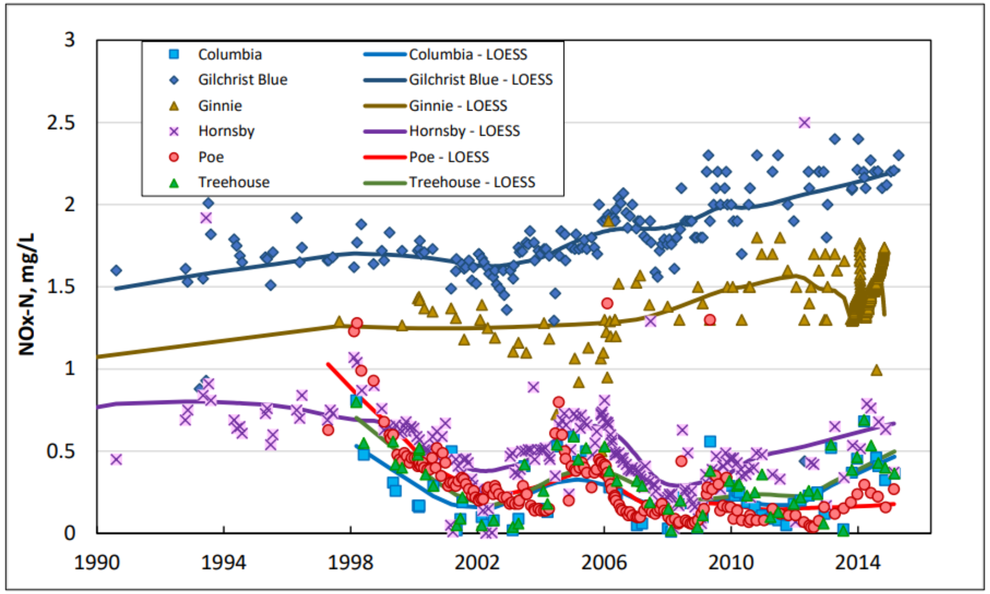


Figure 19. Nitrate concentrations at selected Santa Fe River springs in the study area (SRWMD May 2020)

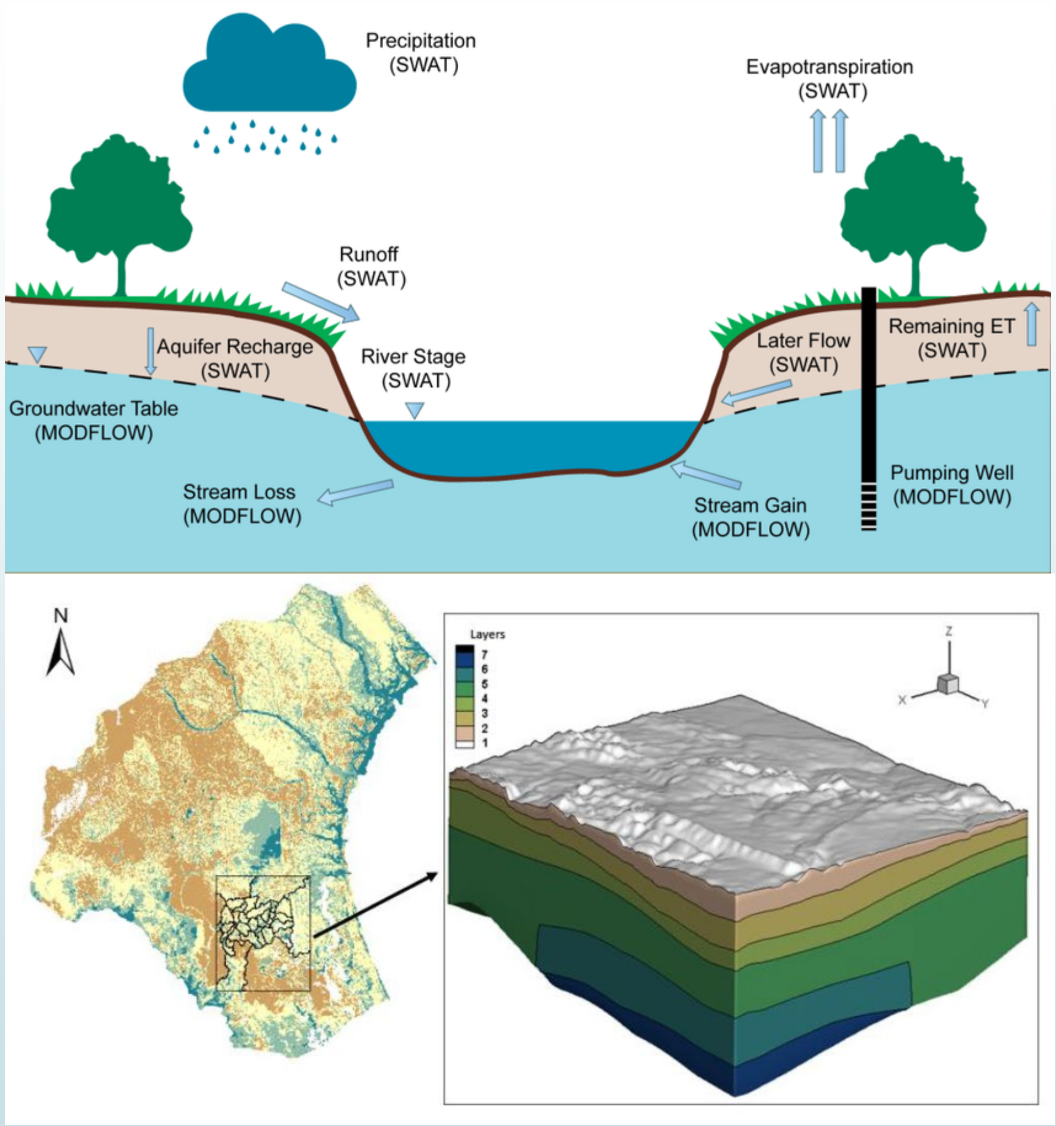
From:
Minimum Flows and Minimum Water Levels Re-evaluation for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs – January 2021

Elevated nitrate levels in springs (> 0.35 mg/l)

SWAT-MODFLOW can provide some insights into the problem of nitrate transport to the river and the springs!

SWAT-MODFLOW

Inputs:
- Topography
- Soils
- Weather
- Land use
- Water use
- Land management
- Hydrostratigraphy (clipped from NFSEG)



Outputs:
- Crop yields
- Stream stage/flow
- Groundwater levels/fluxes
- Nitrate leaching

For nitrate concentration in the subsurface we could use SWAT-MODFLOW-RT3D

Idea: Use MODPATH with SWAT-MODFLOW instead of SWAT-MODFLOW-RT3D

MODPATH: Particle-tracking code for MODFLOW

What is particle-tracking? What are particles?

In the real world we can release a dye tracer to see how contaminants would be transported.
In a numerical groundwater flow model we can use the same principle:
Instead of a dye we use particles that are advected by the simulated flow field!
While they move, they store travel paths and travel times

What can we do with particle-tracking:

- Source areas (where does the water come from)
- Travel times (how long does it take for the water arrive)
- Contaminant transport

Since it's a model, we can reverse the flow field and track particles back-wards!

Approach

Use the SWAT-MODFLOW model to establish boundary conditions for a **stand-alone MODFLOW model** that uses larger time steps (or steady-state).
This is done by averaging percolation, evapotranspiration and river stages)
(Otherwise, we need to store many flow fields…)

↓

Define the **initial positions of the particles** to be back-tracked.
(Place them in discharge areas of interest such that **each particle corresponds to a certain volume of water**)

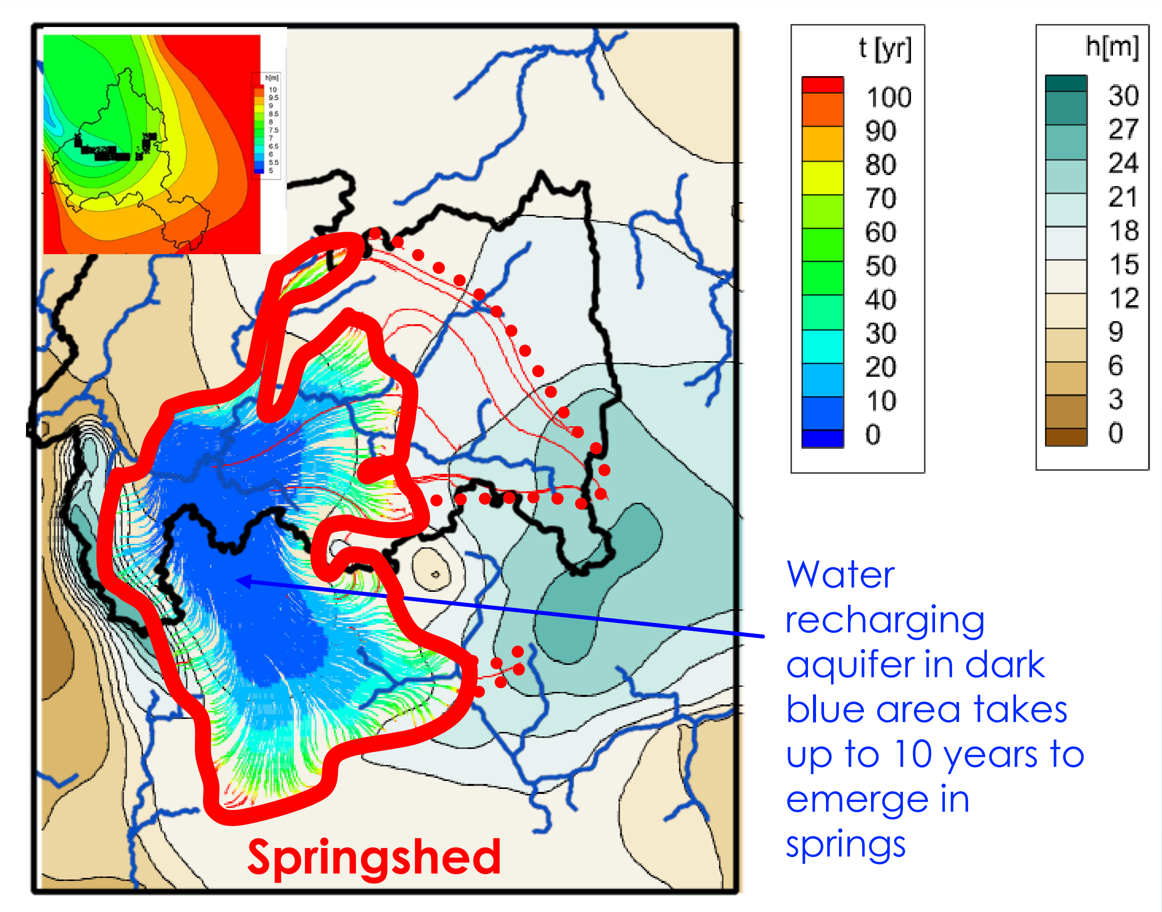
↓

Run MODPATH in backward mode

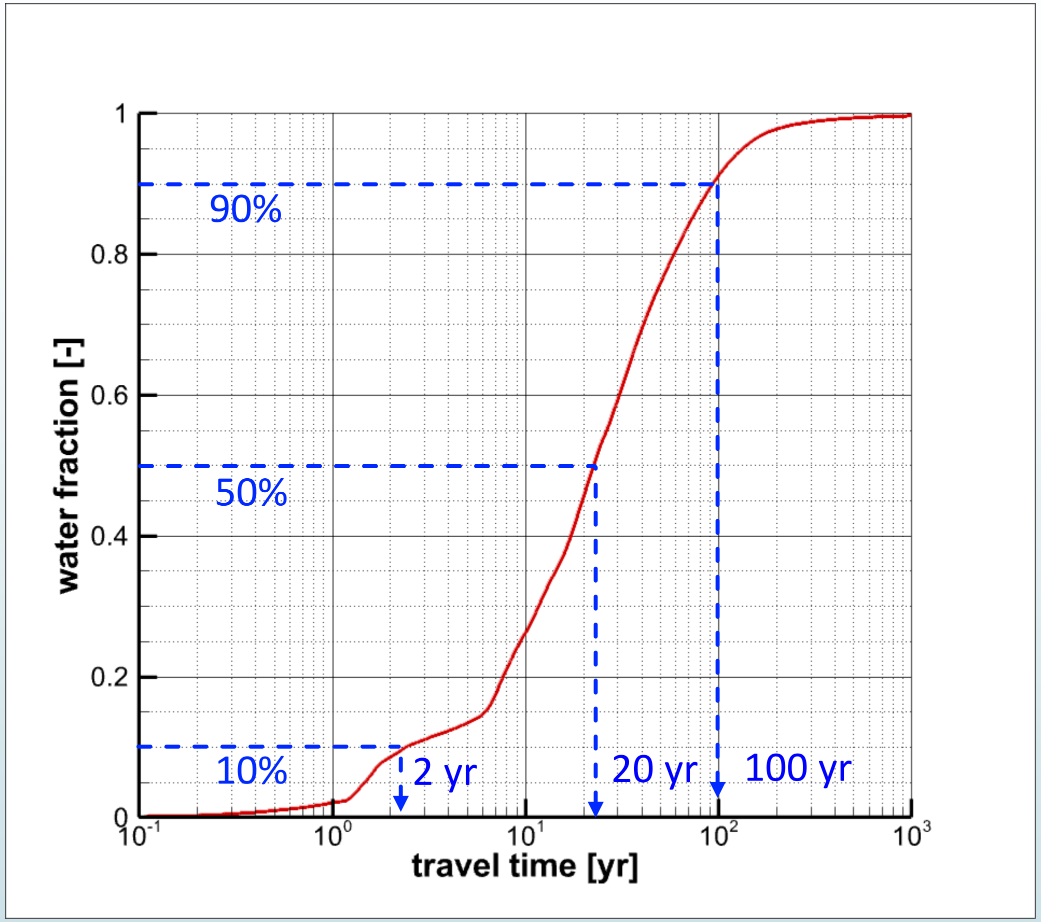
↓

Post-processing of travel times

Application to Devil's Spring Complex (1)



Groundwater Contributing Area to Devil's Spring Complex & Poe Springs)



TTD. Median travel time for groundwater emerging from springs ~20 years

Results represent work in progress and are not yet peer reviewed

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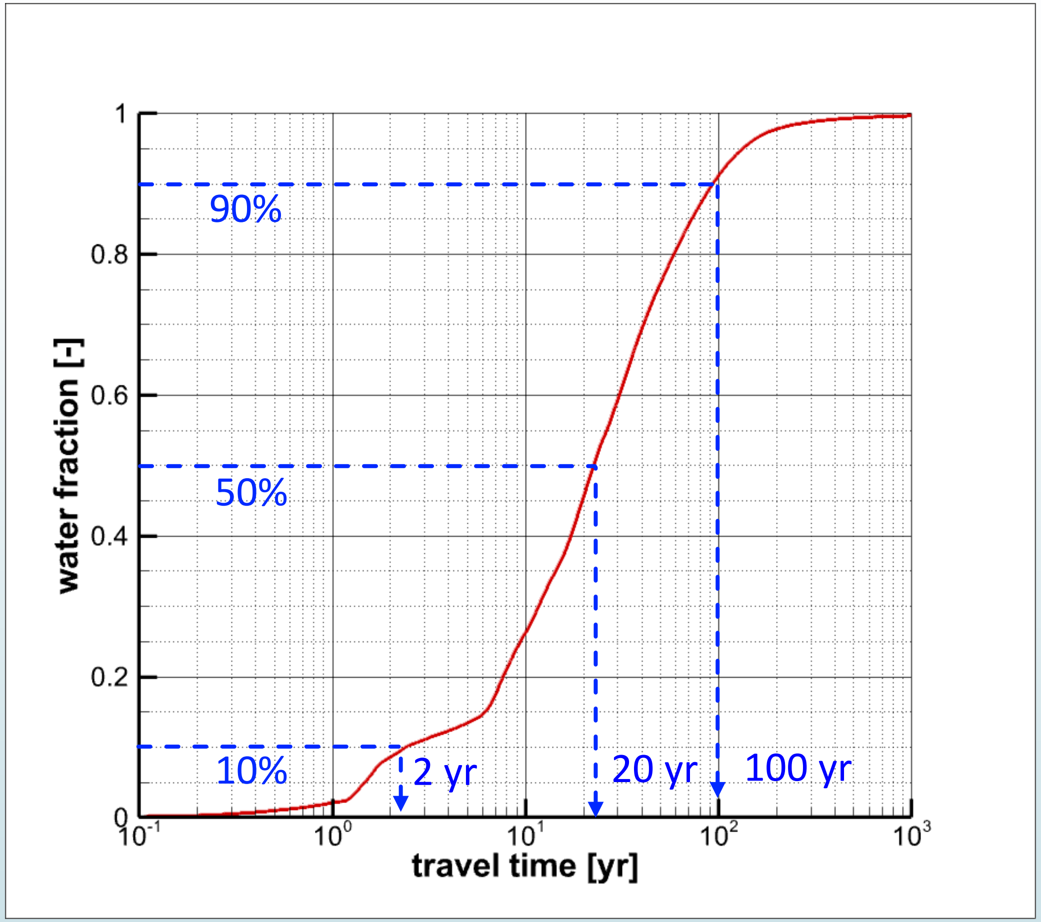
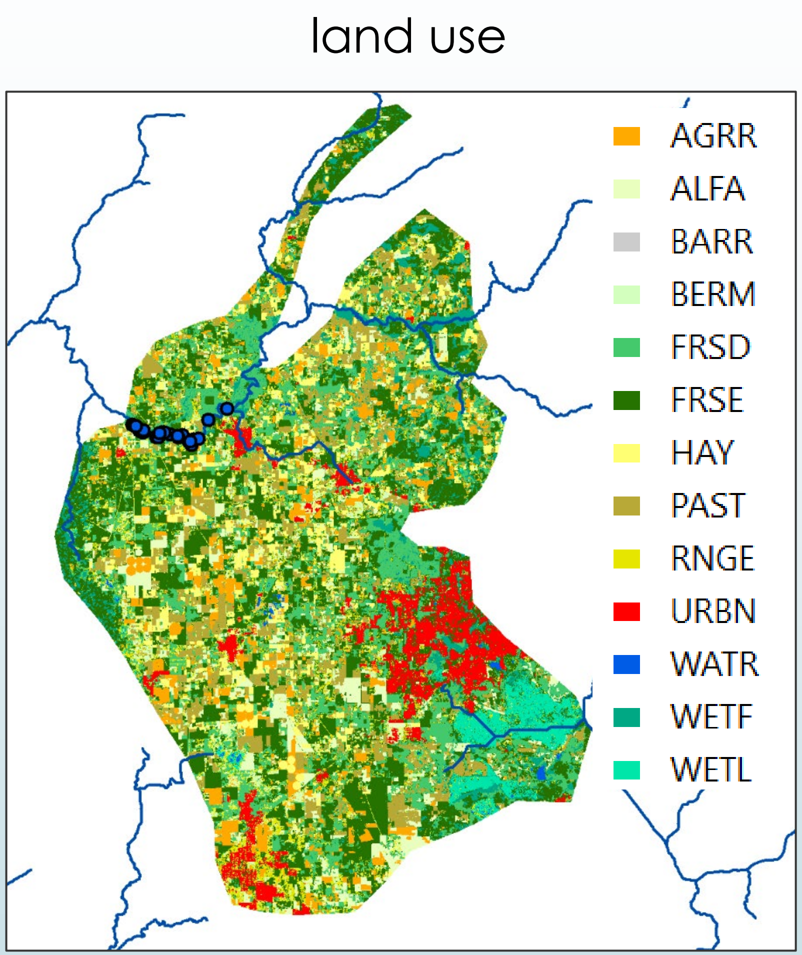
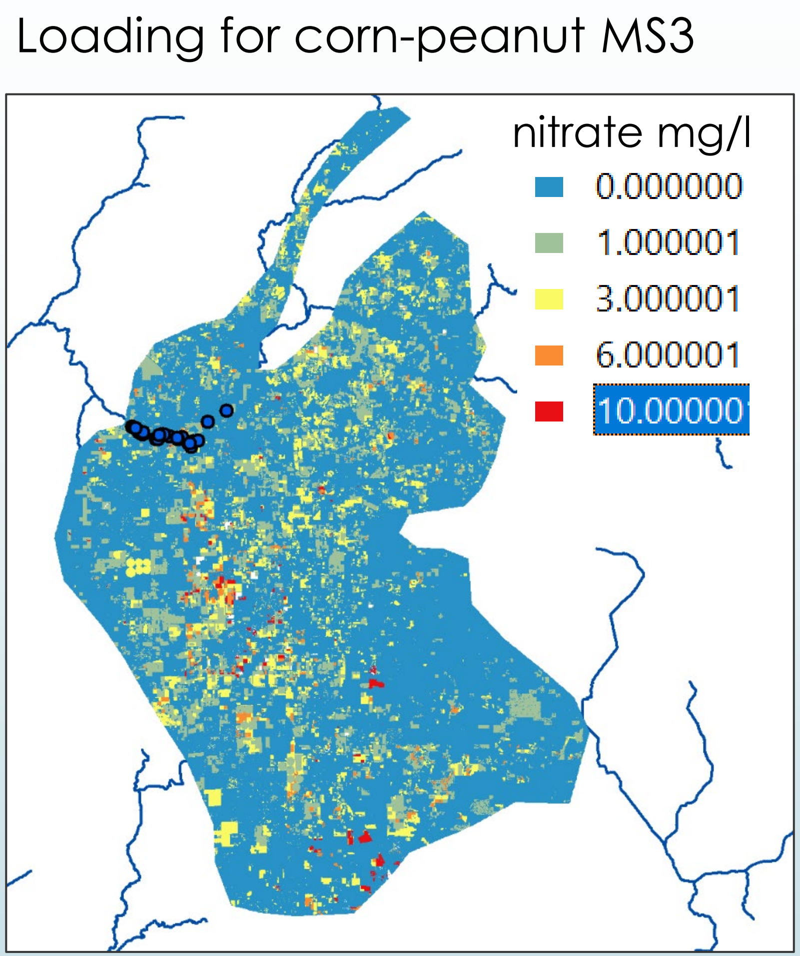
Application to Devil's Spring Complex (2)

- The median age corresponds well with estimates based on isotopes / cfk's (Katz et al.)
- Original hydraulic conductivities in NFSEG gave median age of 100 yr. Most particles reached the LFA. We increased the hydraulic conductivity of the UFA at the expense of MCU and LFA to obtain the median age of 20 years (keeping the effective horizontal hydraulic conductivity the same).
- **It will decades to see the full impacts of a change in land use / land management.**



Land use and nitrate loadings in the springshed





We can simulate these loadings for a variety of land uses and management systems!

(Note: no urban loadings yet)

Application to Devil's Spring Complex (3)

Using:

τ: travel time

$c_L(x_i, y_i, t)$: nitrate loading from SWAT to MODFLOW domain

κ: half-life of nitrate

$$c(t) = 1/n \sum_{i=1}^{n} c_L(x_i, y_i, t - \tau_i) e^{-\kappa \tau_i}$$

We can change the loading and see how the concentrations in the springs will change!

NOTE:

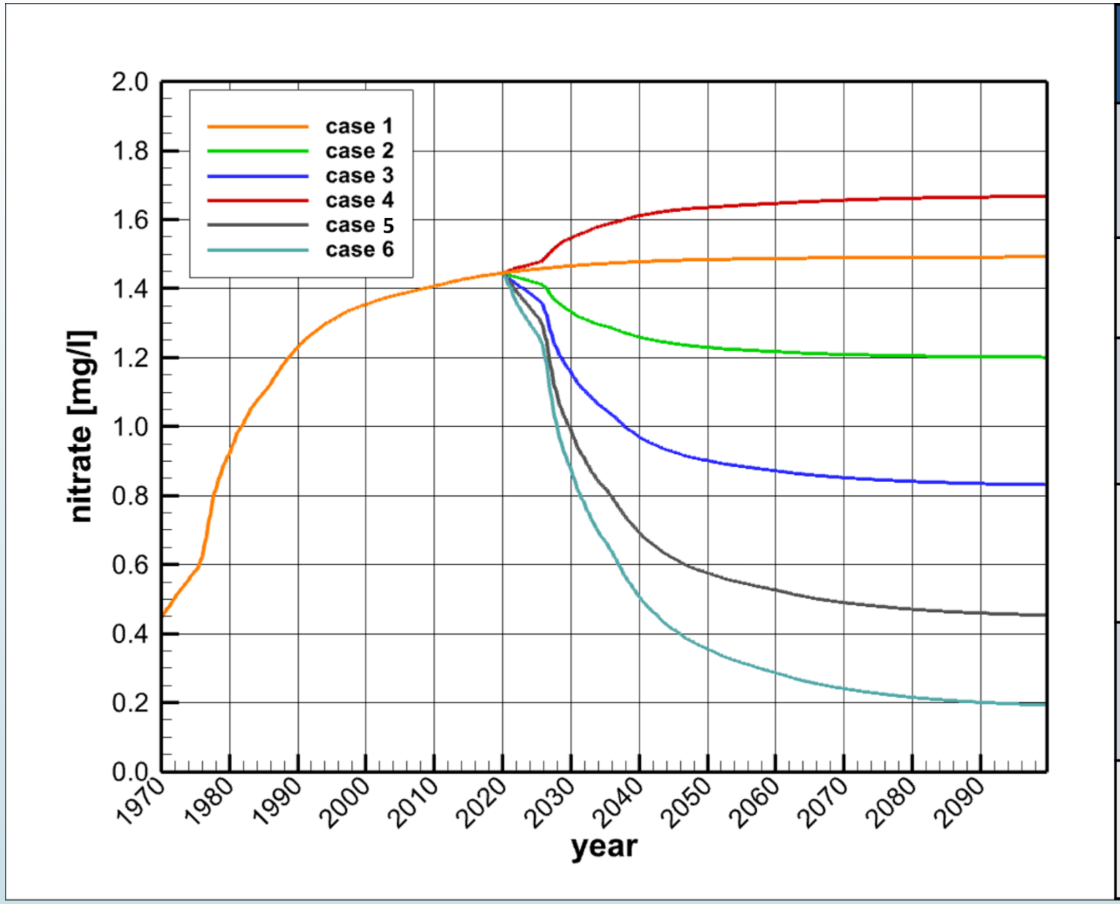
- Flow remains the same (and steady-state). We use the same TTD throughout.
- Our changes in loading are purely hypothetical

What we want:

Understand the time, direction and magnitude of changes in nitrate concentrations.

(i.e. the reality, past and future, is different, but our scenarios do provide insights into what would happen if the nitrate loading is changed.

Application to Devil's Spring Complex (4)



scenarios	Load ranking
Case 1 (base case): Conventional, corn-peanut CP-MS3	2
Case 2: Improved, corn-peanut CP-MS2	3
Case 3: Economically Feasible, corn-peanut CP-MS1	4
Case 4: Convert Ag to Slash Pine MS1	5
Case 5: Conventional, corn-carrot-peanut CCP-MS1	1
Case 6: Convert all land uses to natural longleaf	6

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Implications

- It may take a long time before we see the full impacts of BMAP's. Those BMAP's may include those that have already been implemented. **Legacy nitrate: Lagged delivery of nitrate.**

- We may need a lot of **patience** to see the desired improvements in nitrate concentrations.

- If we do not see immediate significant improvements that does not prove that the old management practices did not affect the nitrate levels in the spring.

- If we do not see immediate significant improvements that does not prove that stricter BMAP's are needed.

- Some areas with short travel times to the springs may yield quicker impacts at the springs when targeted for a change in land use. But in the long terms, this may not be the best strategy.

- SWAT-MODFLOW-MODPATH could be a **useful tool to monitor the progress in nitrate reduction** during any period before the full impacts are observed.

Some useful features of SWAT-MODFLOW-MODPATH

- We can obtain **additional information** from a SWAT-MODFLOW model in terms of **TTD's, source areas and pathlines** (and do this relatively **cheap**).
- If additional data are available (like measured median ages), then we have **extra calibration / validation targets**. We can improve the underlying flow model!
- SWAT simulates the nitrate loadings while accounting for many biophysical processes near the land surface (plant growth, denitrification, etc.). It can also account for septic tanks, pastures, etc.. In other words, **SWAT enables as a very versatile boundary condition for nitrate loading**.
- The TTD can indicate how to long we need to run a SWAT-MODFLOW-RT3D model.
- MODPATH is not affected by numerical dispersion

Some limitations of SWAT-MODFLOW-MODPATH

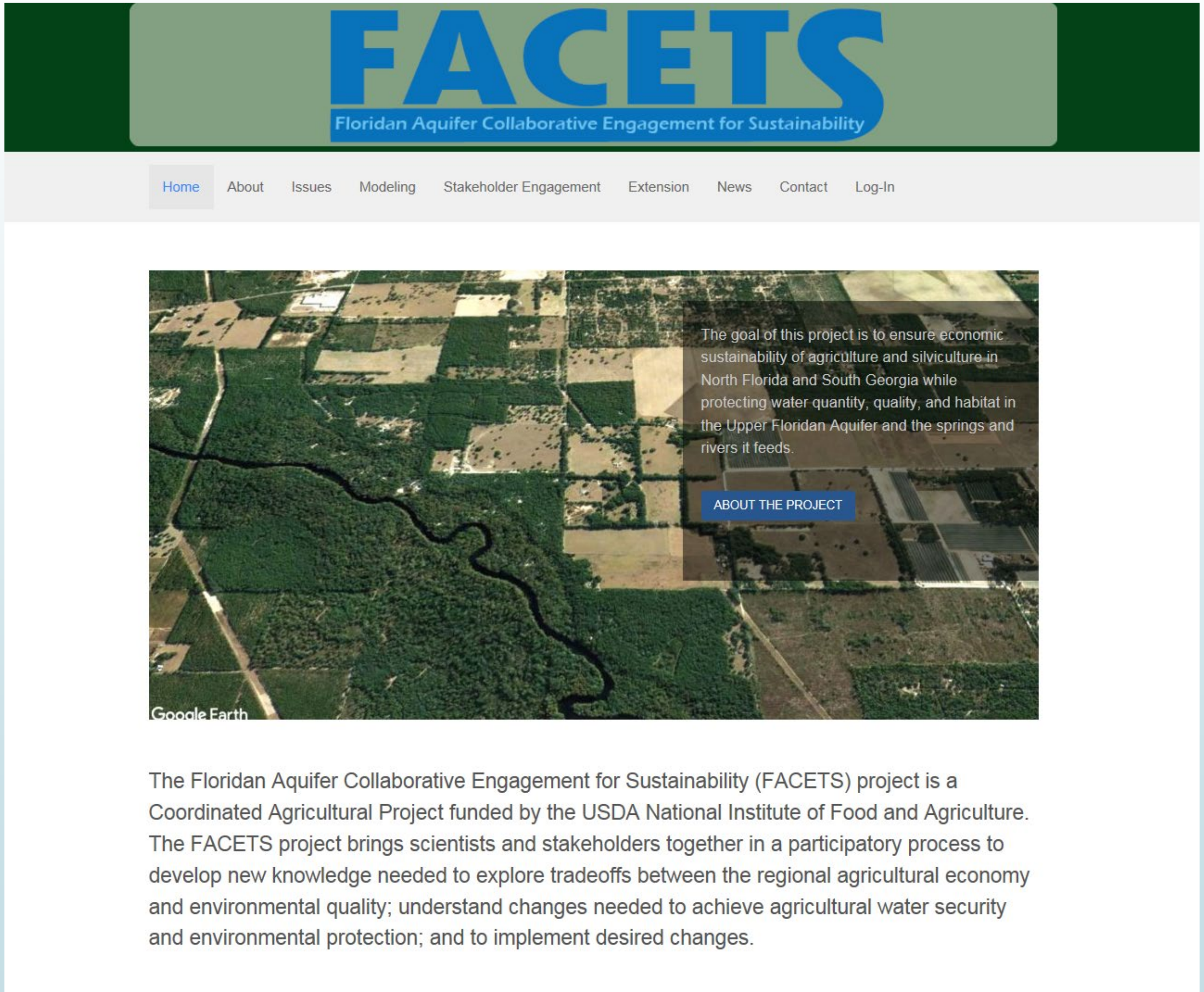
- Not efficient for simulating forward contaminant transport throughout the basin
- Becomes progressively more computationally demanding for transient flow fields with smaller time steps (Need to store and handle more flow fields)
- Can only analyze the travel times in the subsurface domain simulated by MODFLOW

Conclusions and future work

- MODPATH can extract additional information from a SWAT-MODFLOW model
- In our model it is used to extract a TTD, pathlines and source areas and to simulate the concentrations at the springs after hypothetical changes in land use and land management.
- The median travel time was used to improve the underlying flow model.
- Results indicate that it takes decades before we see the full impacts of such changes.

- Apply SWAT-MODFLOW-MODPATH to the Ichetucknee and Blue Hole Springs.
- Use SWAT-MODFLOW-MODPATH to designate those areas where BMAP's have the largest impact
- Build a full SWAT-MODFLOW-RT3D model

For more information: http://Floridanwater.org



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Backward particle-tracking

In a numerical model, it is possible **to reverse the flow field**.

You could then put particles in say a spring discharge area and **track the particles back to their source areas**. From the **travel times** of the particles one can compute a **travel time distribution** (TTD)

To get the TTD at a certain location and a certain time, the backward tracking approach is **most efficient!** (all particles contribute to TTD)

If we assume a steady-flow field, then from the travel times of *n* particles we can also compute the concentration of nitrate as a function of time provided a given nitrate loading c_L and denitrification rate k:

$$c(t) = 1/n \sum_{i=1}^{n} c_L(x_i, y_i, t - \tau_i) e^{-\kappa \tau_i}$$

If we only need the concentration at a certain discharge area in the model, then MODPATH is more efficient then RT3D