Advancing Saltwater Intrusion Modeling in Miami-Dade County

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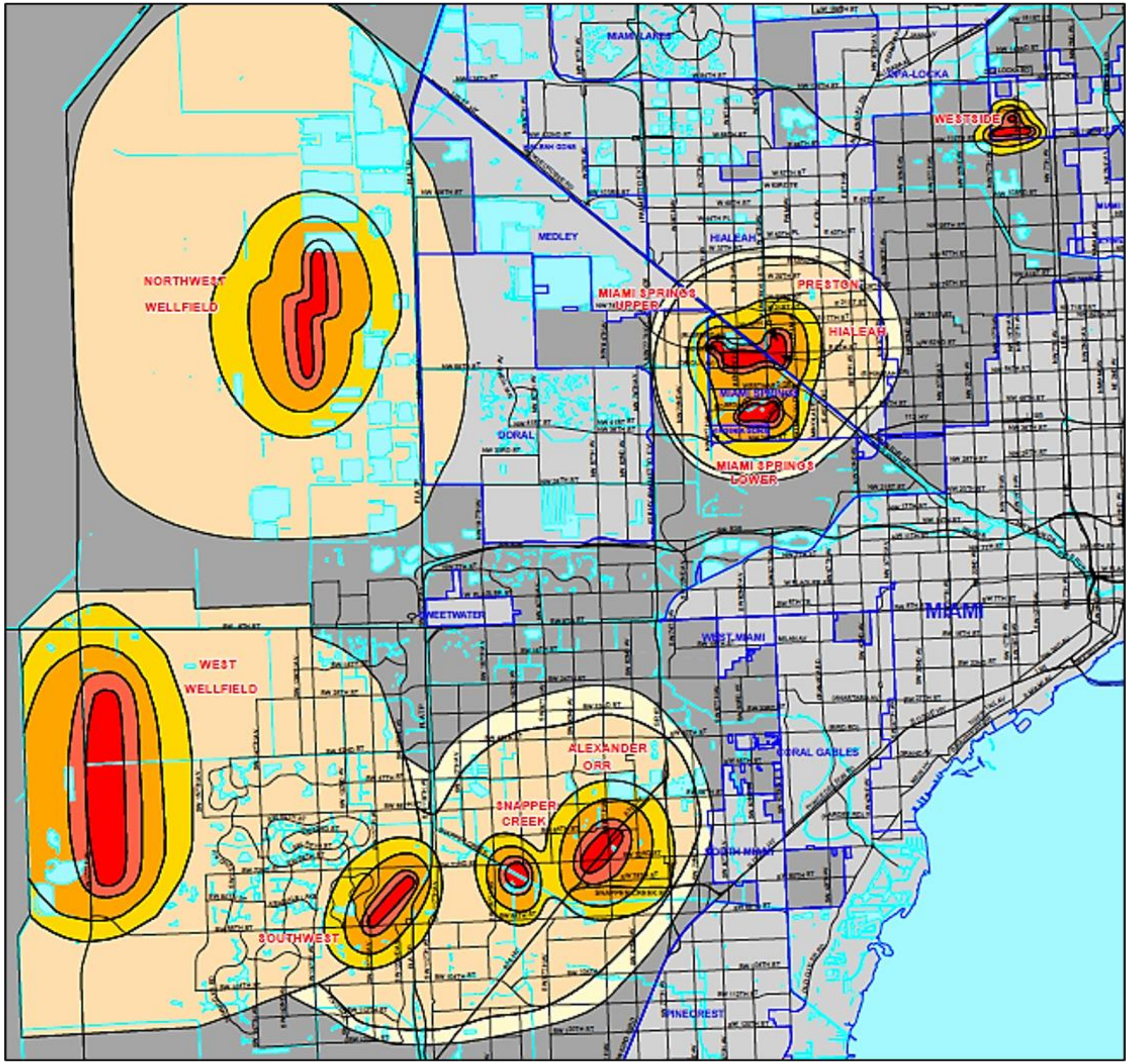
miami-dade water

MIAMI-DADE COUNTY

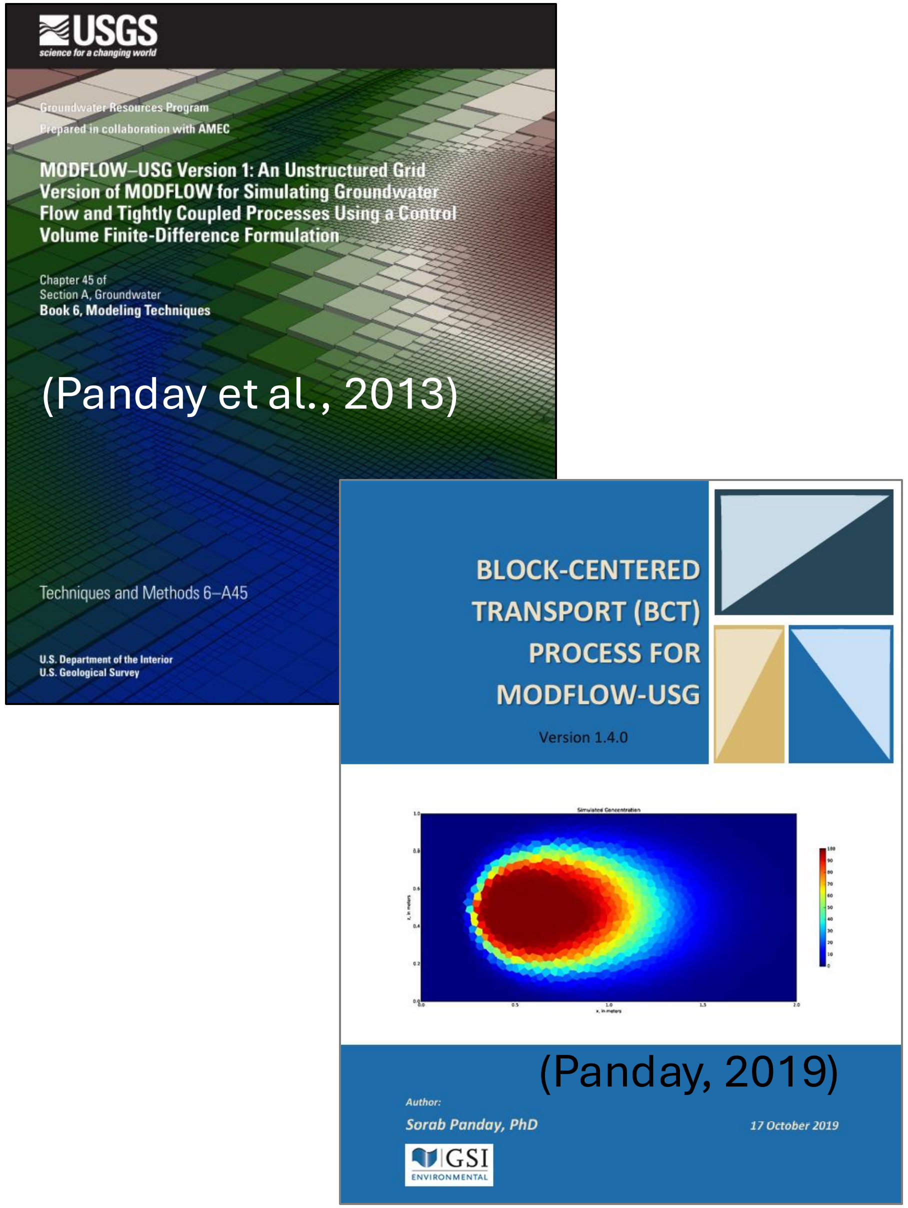
Model Purpose and Motivation

- Sea level rise is reducing the effectiveness of salinity gravity control structures, allowing saltwater to move farther inland raising the risk of saltwater intrusion into Miami-Dade's wellfields
- This poses a serious risk to our water supply and could require expensive solutions like relocating wellfields or investing in desalination.



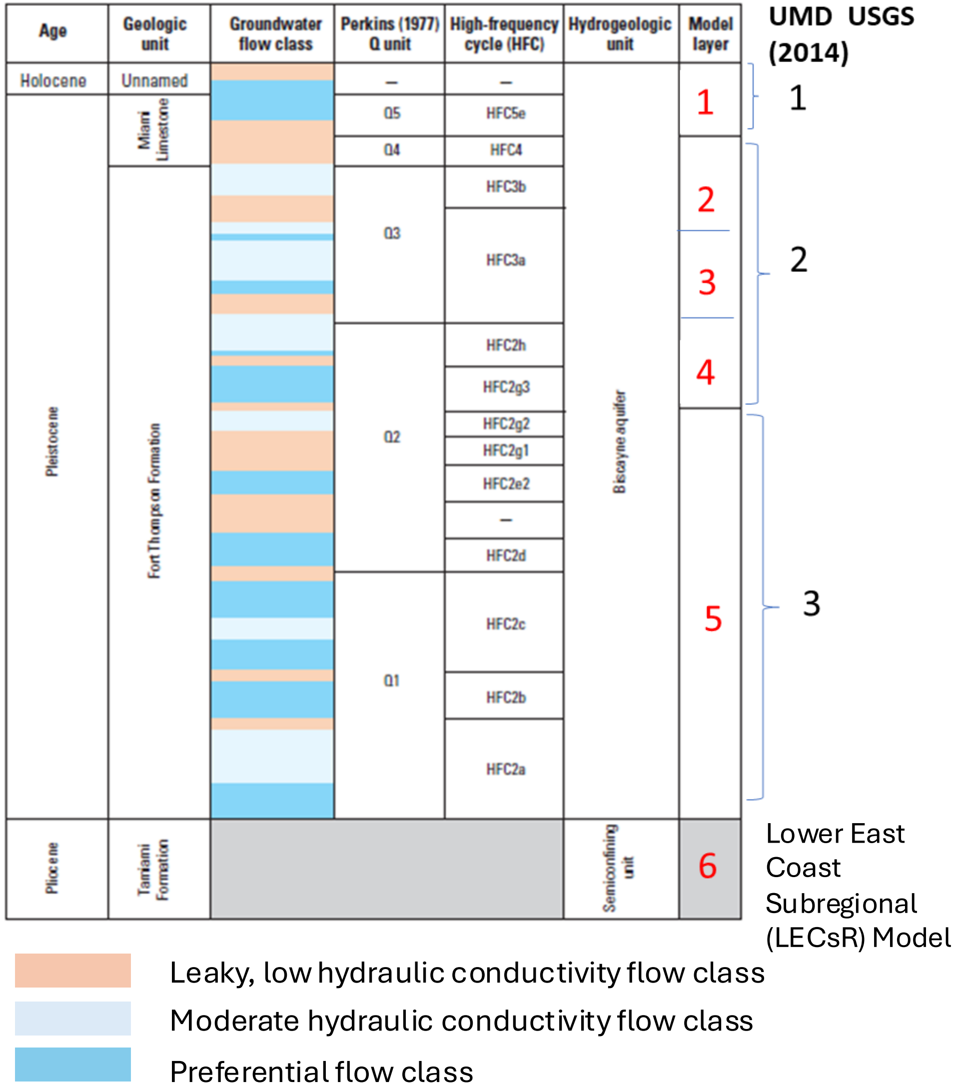
Selection of Source Code

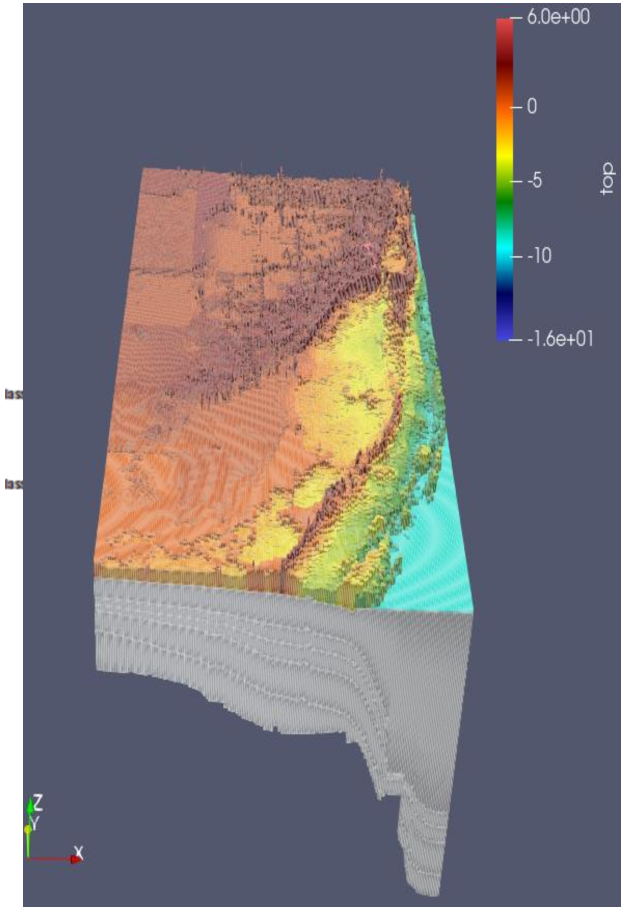
- MODFLOW Unstructured Grid Transport, **MODFLOW-USGT**
  - **Unstructured Grid** Capability
    - Handles complex connections between cells
    - Allow for finer resolution in areas of interest
    - Layers do not need to be uniformly structured
  - **Integrated Flow and Transport Framework**



Vertical, Spatial and Temporal Discretization

- Vertical Discretization
  - **6 layers** (the most productive is layer 5)
  - Updated topography (SFWMD, 2023)
  - Added Tamiami Formation (layer 6)
- Grid Discretization
  - **250×250 m** (820×820 ft)
  - 378 rows × 202 columns
- Temporal Discretization
  - **Daily** time steps
  - Calibration period: Jan 1, 2018 – Dec 31, 2022

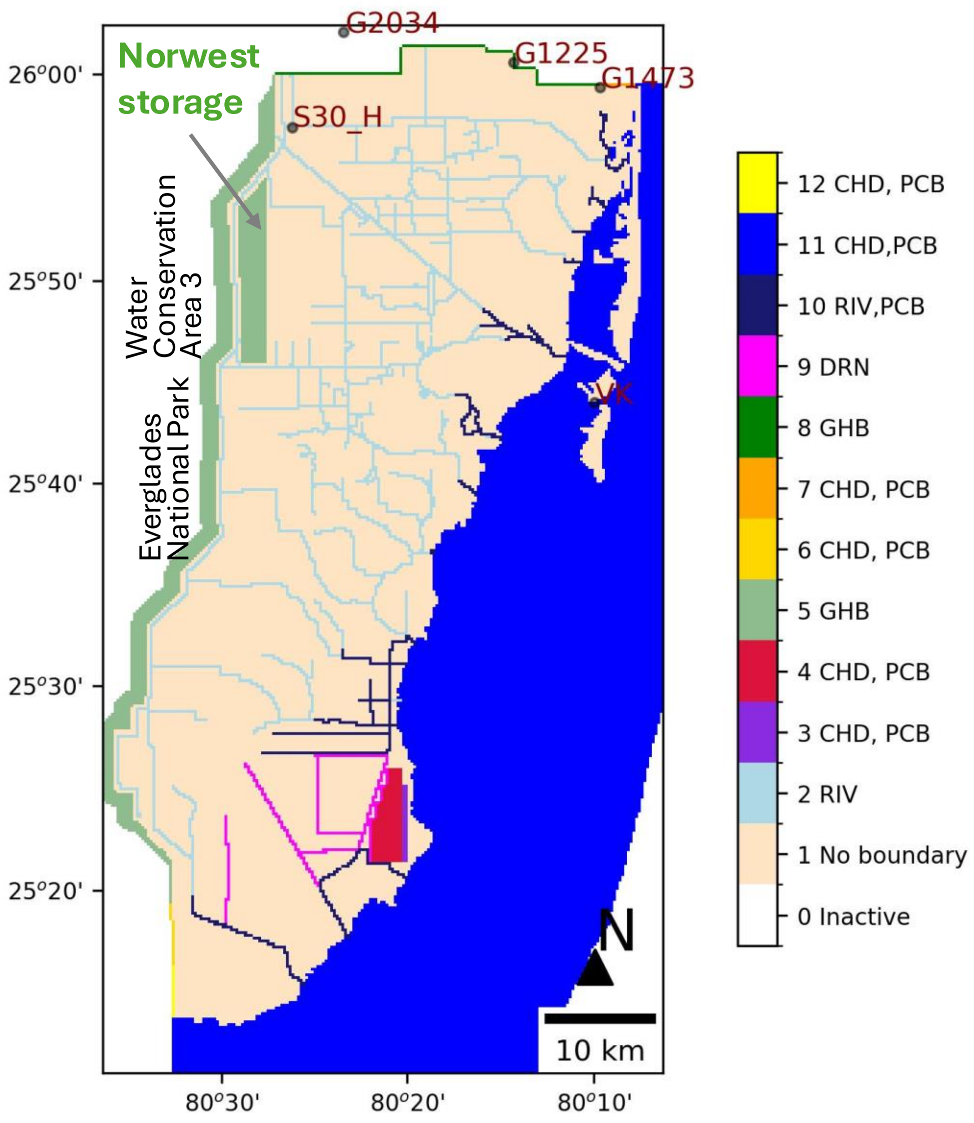




Source:
Fish & Stewart, 1991
Hughes & White, 2016

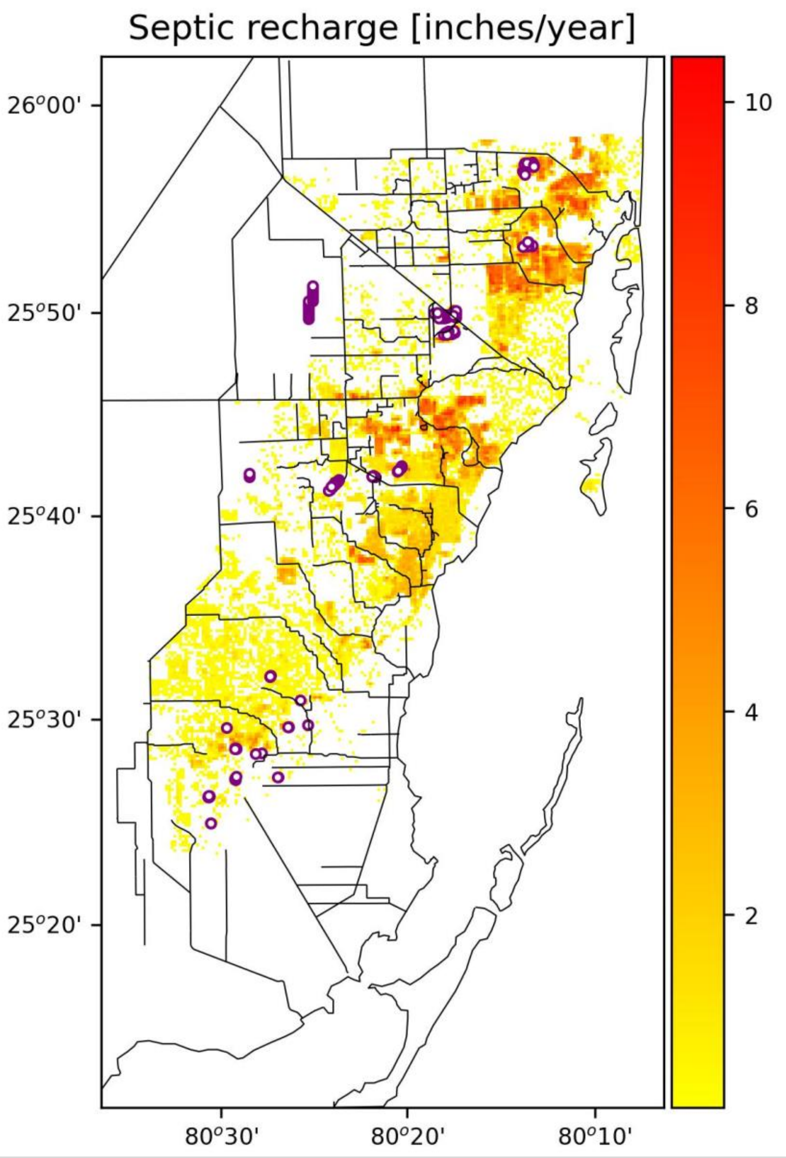
Model Boundaries

- **WCA-3B/ENP**
- **Northwest storage**
- **Northern Boundary**
- **East Tidal Ocean**
- **Cooling Canals and Interceptor at Turkey point**



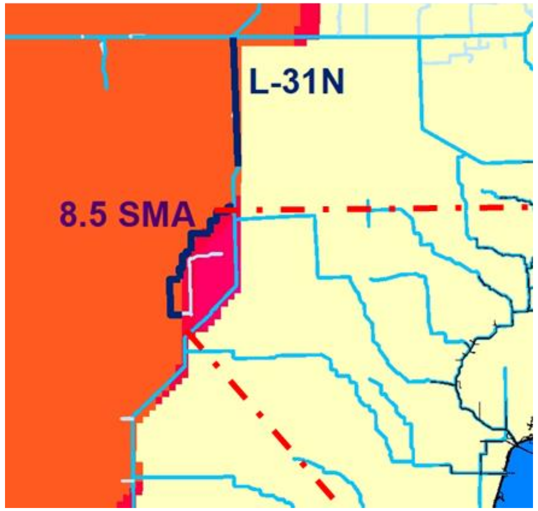
Additional Components in the Model (1/3)

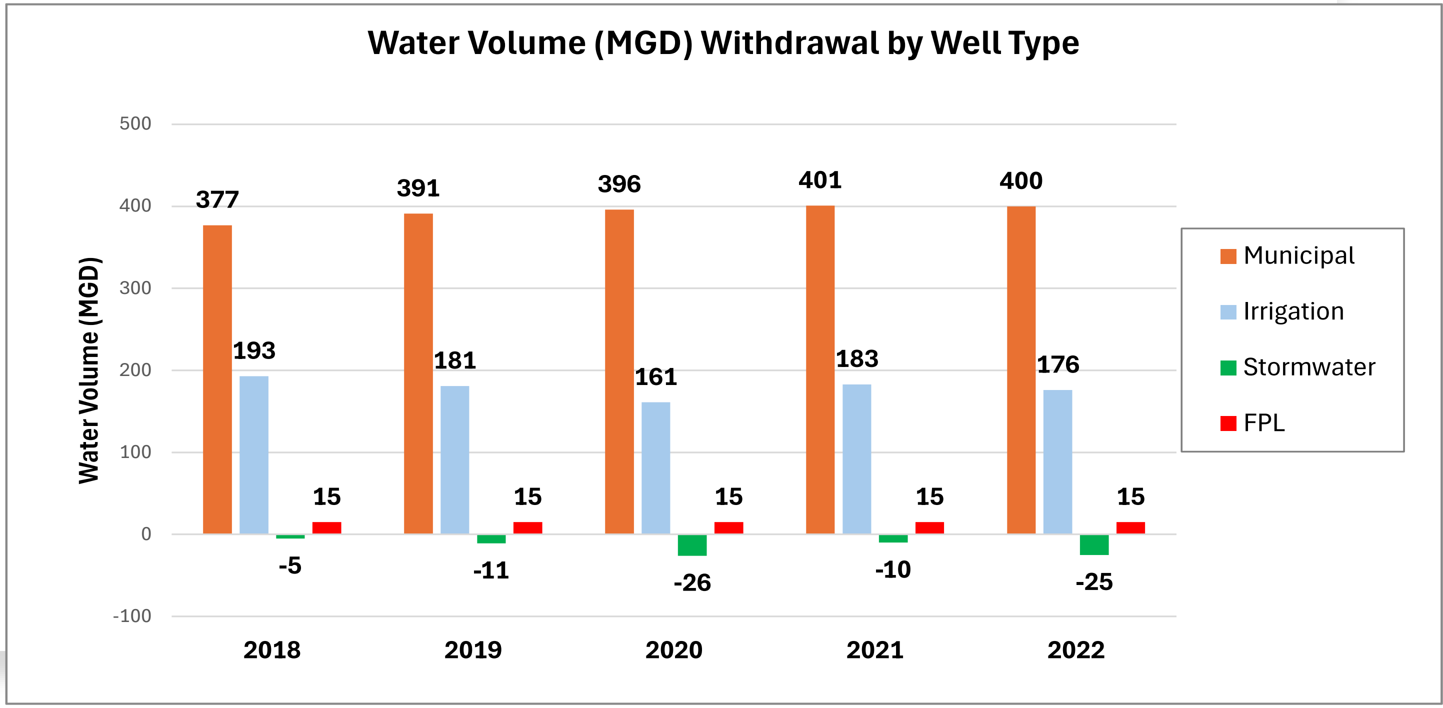
- Simulating Septic Systems
  - Data from **MDWASD** research on **septic system locations**
  - Assumptions:
    - **~55 gallons/person/day**
    - **~2.2 persons/system → ~120 gallons/day per system**
    - **Constant**



Additional Components in the Model (2/2)

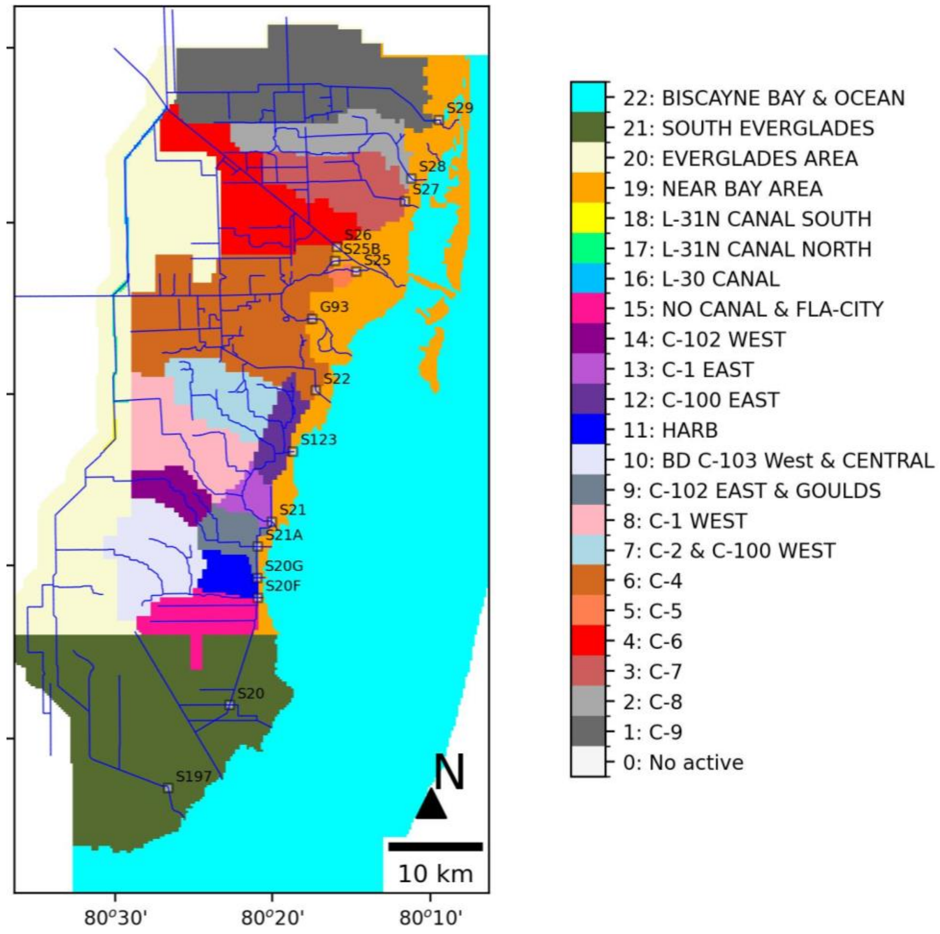
- Wall Barriers
  - **L-31N**
    - To reduce groundwater flow from Everglades National Park to the L31-N canal
    - In 2016 five miles seepage barrier
    - Depth: approx. 10.6 m (35 ft)
- Model Stresses – Wells
  - Historical **municipal** production wells
  - Estimated **private self-supply irrigation** demand wells (agricultural, golf course, residential, and recreation)
  - **Stormwater** injection wells in the Biscayne
  - FPL Extraction Wells in layer 5 for a total 15 MGD



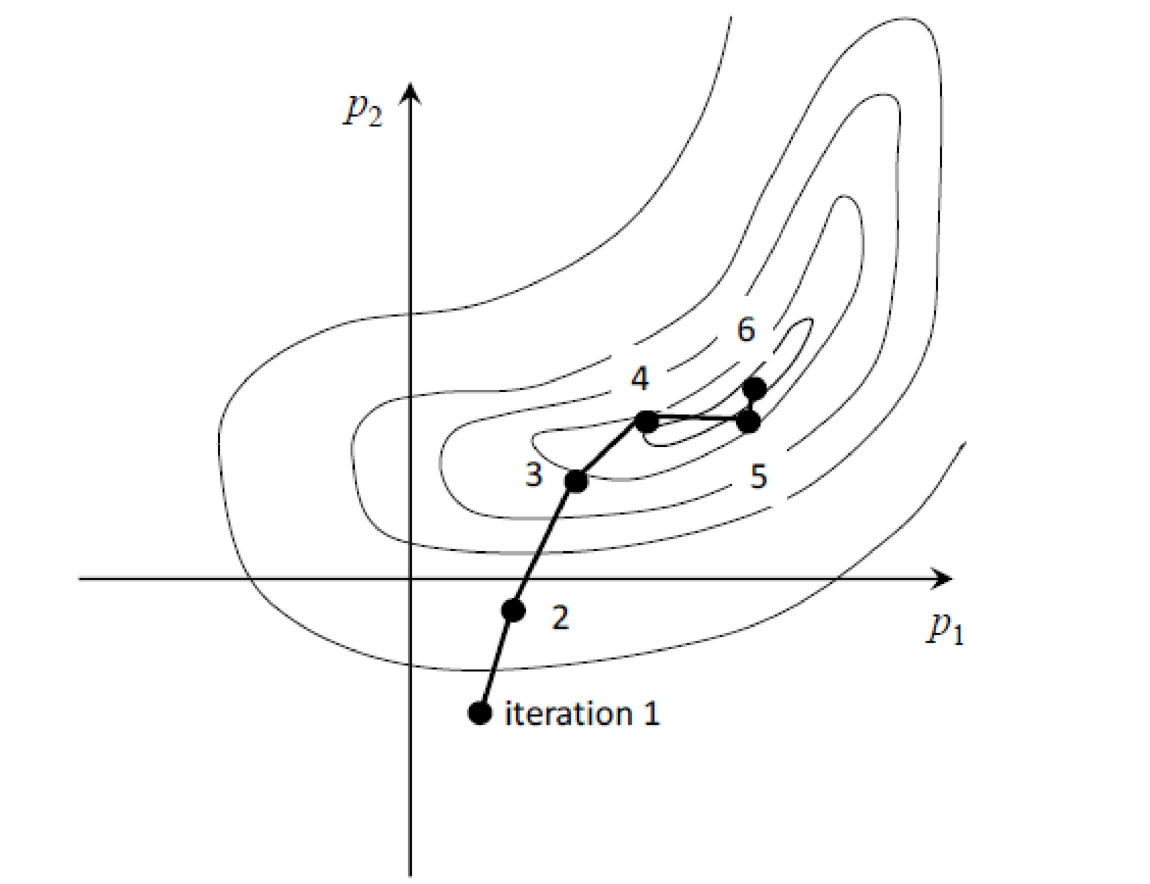


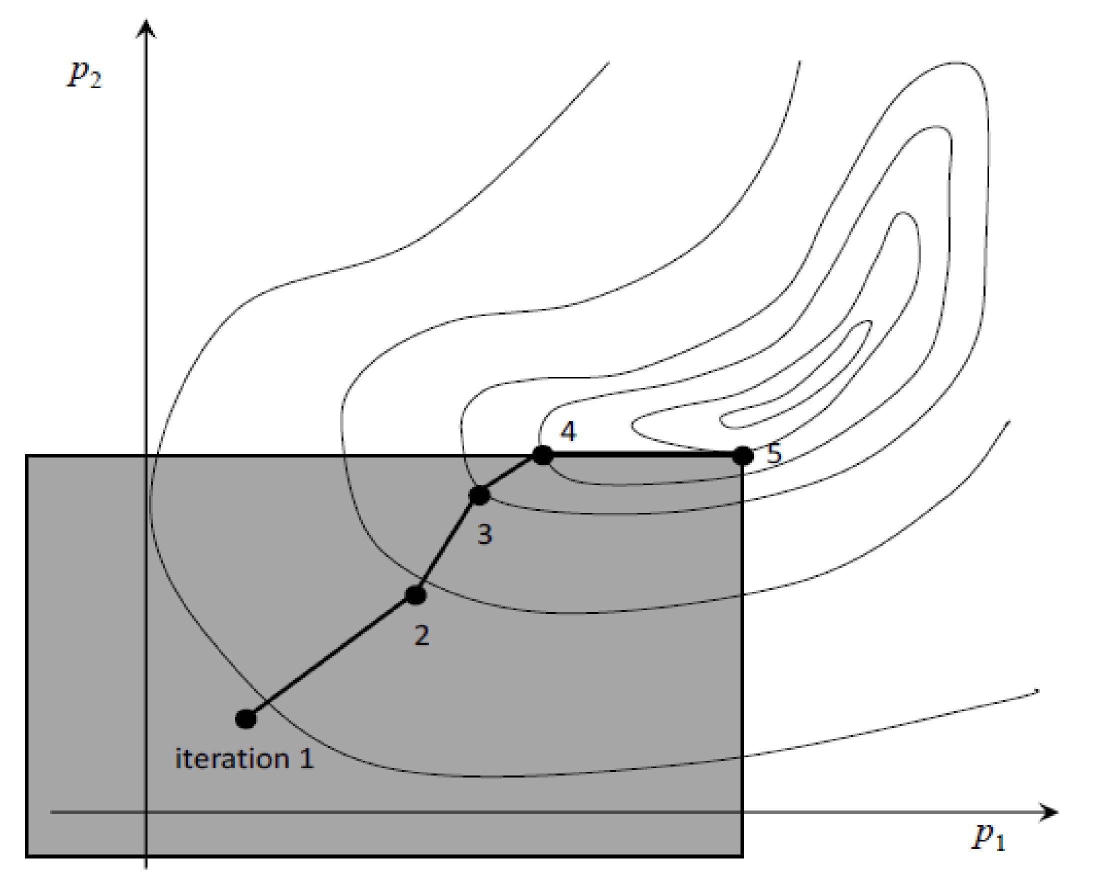
Flow Budget

- Structure inflows/outflows (bi-monthly calibration using historical data)
- Structures (out – in) = Canal/Aquifer Flows + Runoff



Calibration MDWASD Groundwater Model Using PEST (Parameter Estimation)





(From John Doherty)

Objective of PEST

- Reduce mismatch between simulations and observations.
- More accurate models for nonlinear systems.

Goal

Minimize the objective function (weighted least-squares).

Formula

$$\sum w_i^2 (z_i - o_i)^2$$

z_i Observed data
o_i Model output
w_i Observation weight

<u>Model output "o_i" is function:</u>

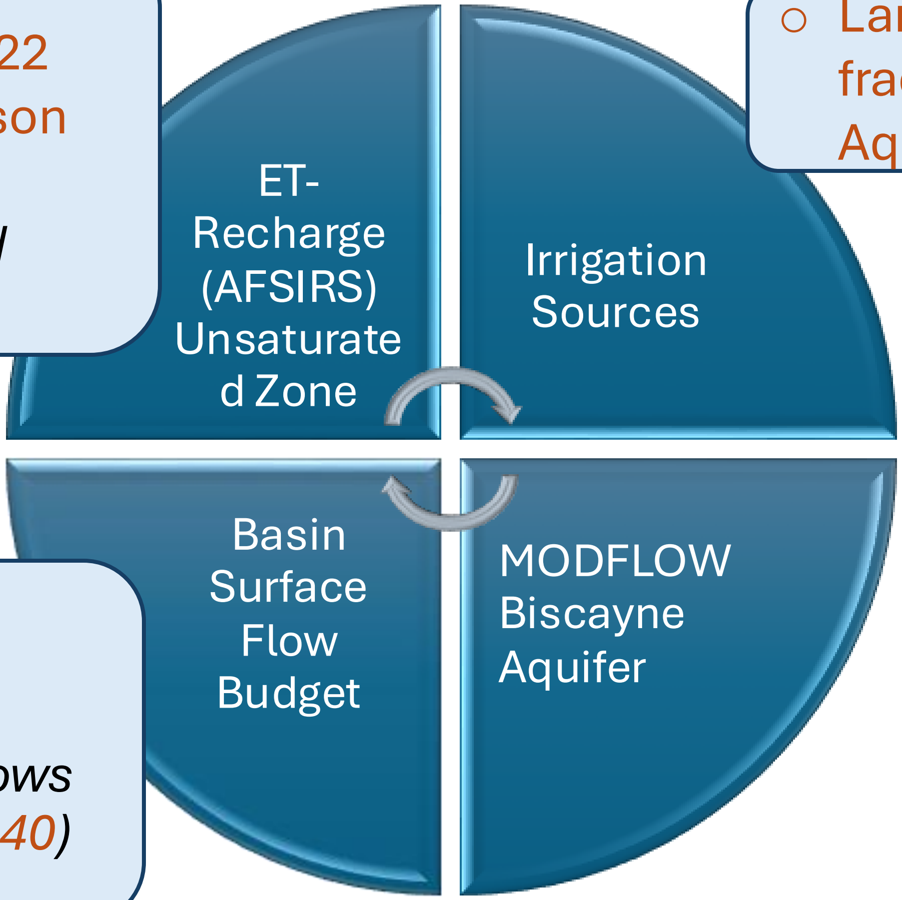
- Model formulation
- Parameter values
- Parameter bounds
- Weights

Calibration Parameters/*Targets* Coupling Models

Total parameters: 1139 QSS; 1188 TR Including QSS

- Excess water fraction Runoff/Percolation for 22 zones and wet/dry season
- *ET/Rainfall and crop coefficients by trial and error*

- Landscaping irrigation fraction to define source from Aquifer or PWS



- Canal leakance for 76 zones
- *Structure bi-monthly flows for 18 sub-basins (18, 540)*

- Horizontal Hydraulic Conductivity 973 pilot points
- Vertical Hydraulic Conductivity fractions (two zones per layer)
- Porosity/Specific Yield, 46 pilot points each
- Global dispersivity value
- *Groundwater levels (130, 200K) ; salt-front (285, 370)*

WASD Computer Power used for Model Calibration

- Model Calibration Performance Summary
  - Stress periods: Up to **16,000**
  - Calibration parameters: up to **1,188**
  - Average model run time**: ~7 hours**
  - Parallel executions: Up to **152** simultaneous runs
- Computing Resources Used:
  - **4 Virtual Servers: 18 parallel runs each**
  - **2 Supercomputers: 35 parallel runs each**

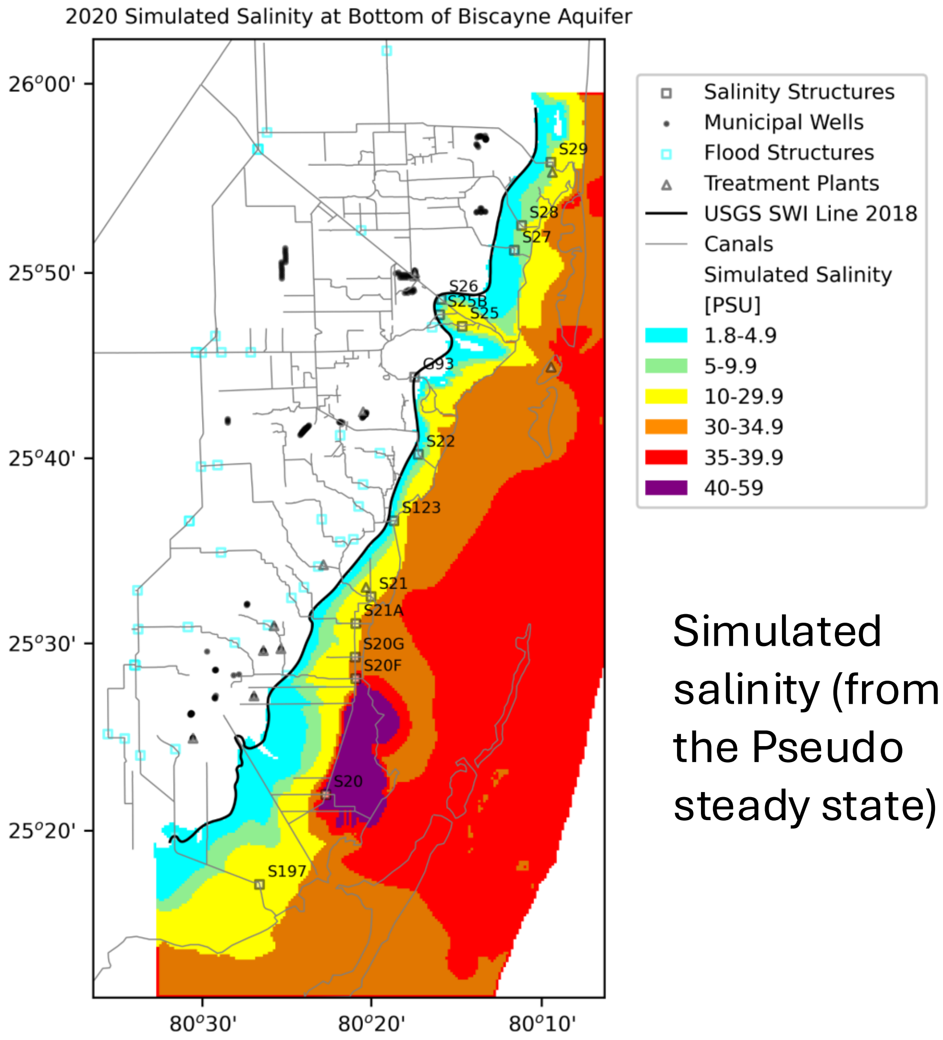
Using python/pyemu (Jeremy White) for interfacing with PEST(++)

Methodology of PEST MODFLOW Calibration

	1 STEP: Pseudo Steady state MODEL	2 STEP: Transient MODEL
Purpose	**Provides a stable starting point to predict future scenarios only due to sea-level rise**	**Reflects system dynamics to predict future management scenarios**
Stress Periods	16,000 daily/44 years	1,876 daily /5 years
Why it's important	○ Calibrate parameters to match USGS 2018 saltwater intrusion line intrusion, and average water table elevation ○ **Mass conservation equilibrium** ○ **Initial concentration condition during the transient run**	○ Match simulated heads, canal flows and salinity given by 2018 to 2022 saltwater intrusion line ○ Generate wellhead protection areas under different scenarios ○ **Optimize the well system to find new locations to replace wellfields with issues**

Approximate Inland Extent of the Saltwater Intrusion at the Base of the Biscayne Aquifer (USGS)

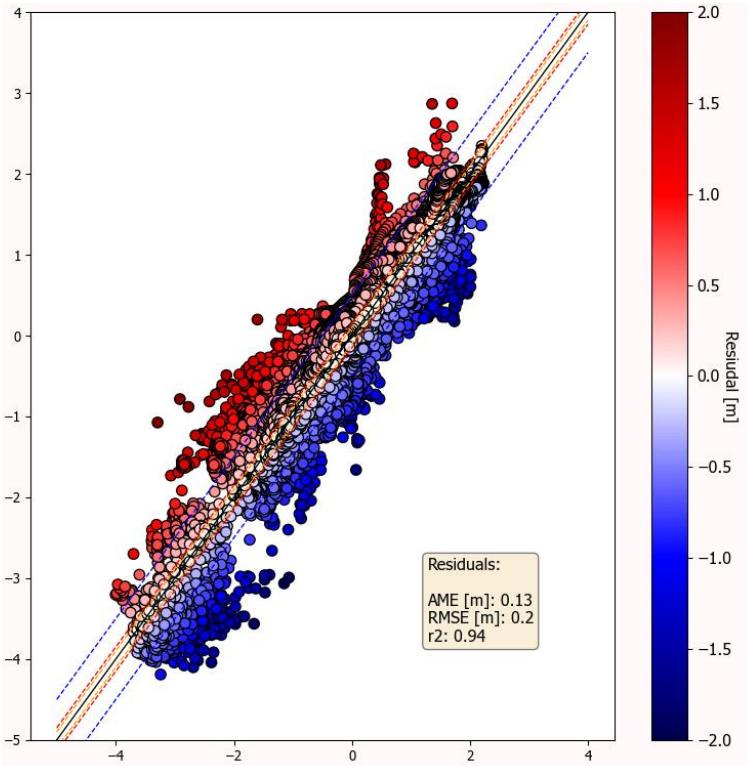
- Saltwater Intrusion Line defined at 1,000 mg/L chloride
- 285 pseudo-targets were assigned along each saltwater intrusion line for calibration purposes

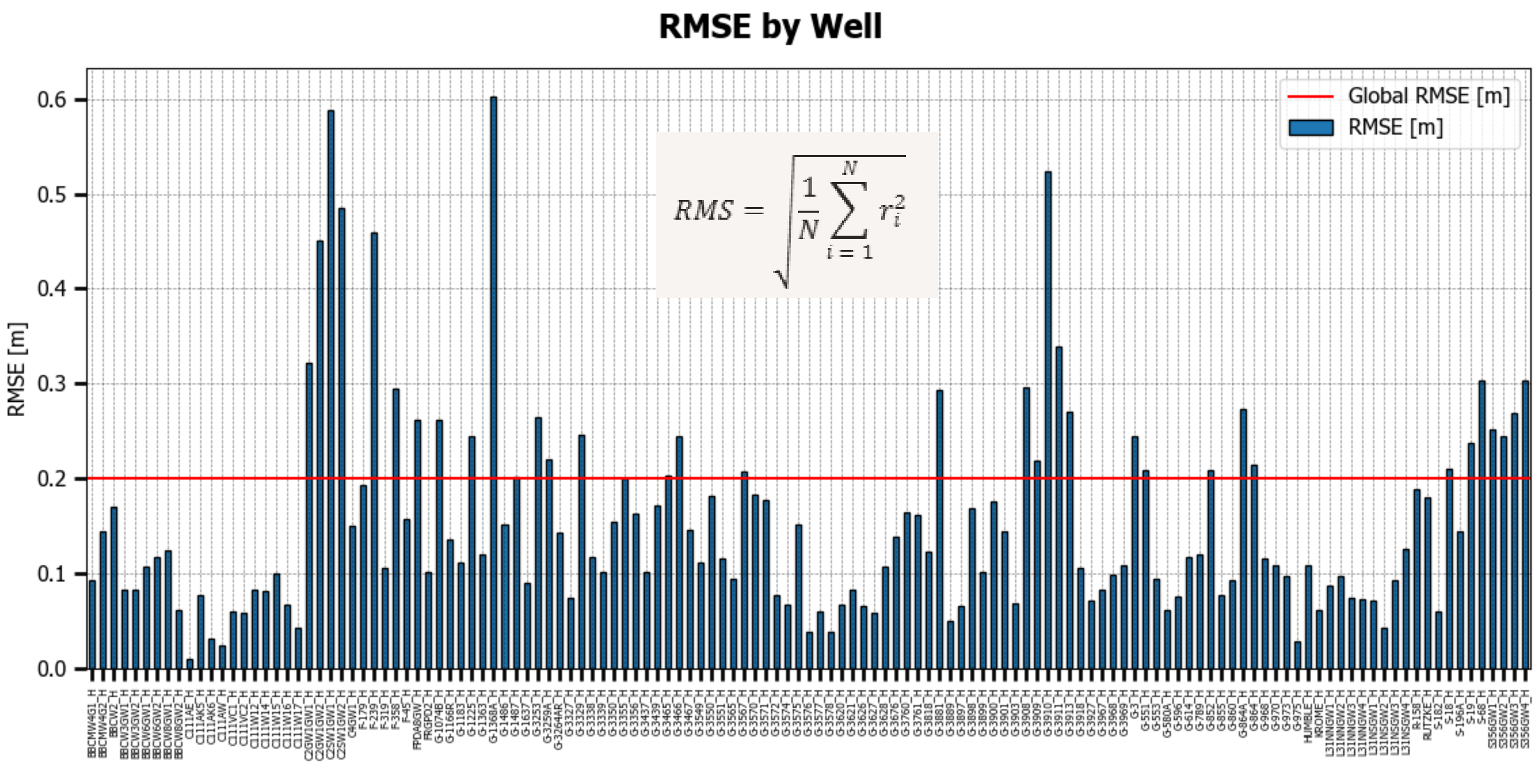


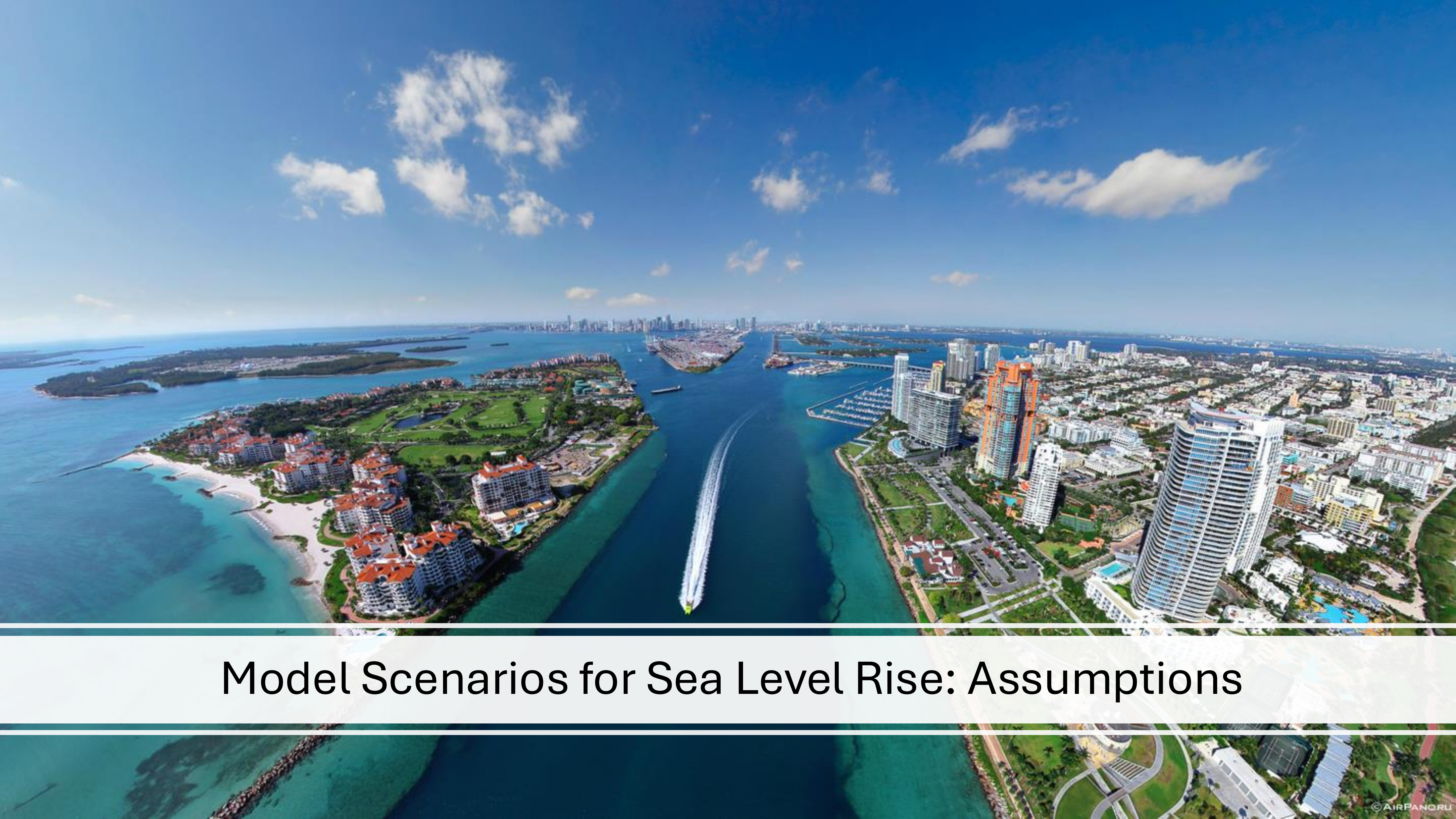
Simulated salinity (from the Pseudo steady state)

Calibrated Heads (2018-2022)

Scatter Plot



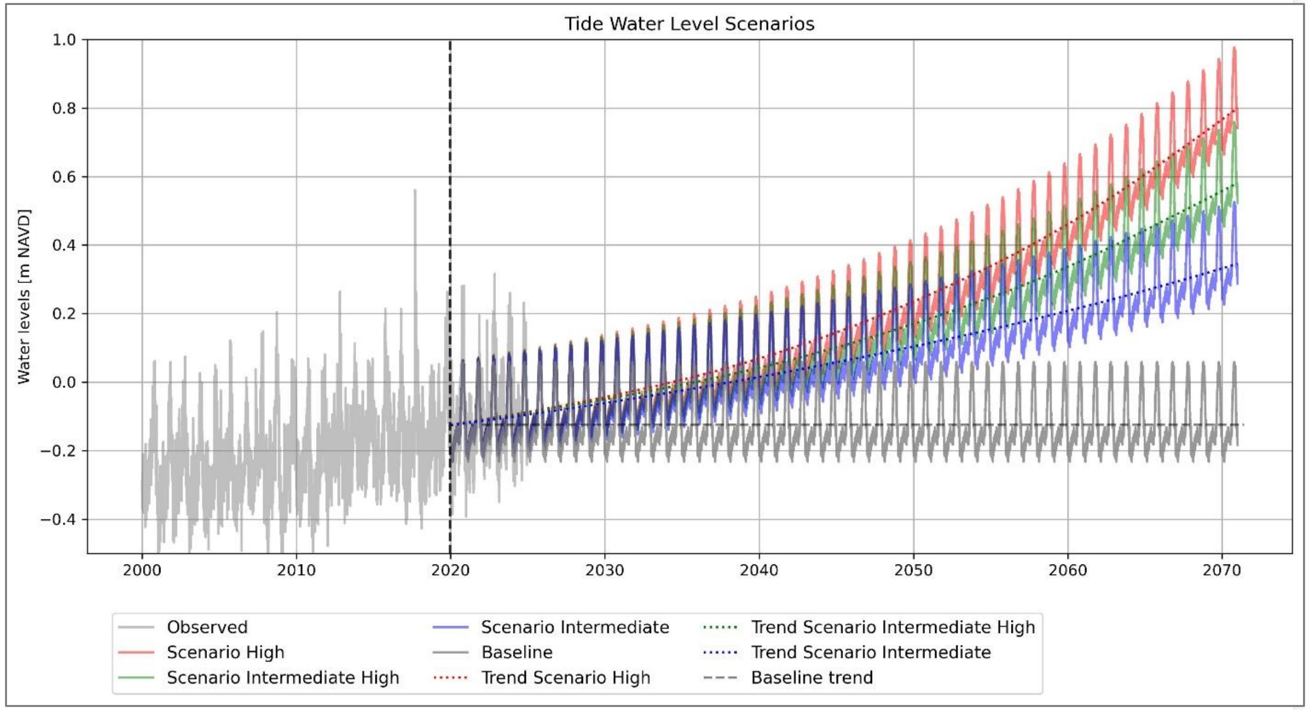




Model Scenarios for Sea Level Rise: Assumptions

Simulation of Groundwater Flow and Transport to 2070 Under Sea Level Rise

- Goal: Predict how sea level rise (SLR) will affect saltwater intrusion through 2070.
- Model assumptions:
    - 2020 Baseline condition
    - Assumes average constant daily conditions (rainfall and ET) over 50 years (2021–2070)



SLR projections are based on the Southeast Florida Regional Climate Change Compact, 2024:

- Intermediate (rise of 0.465 m or 1.5 ft rise by 2070)
- **Intermediate-High (rise of 0.695 m or 2.3 ft rise by 2070)**
- High (rise of 0.908 m or 3.0 ft rise by 2070)

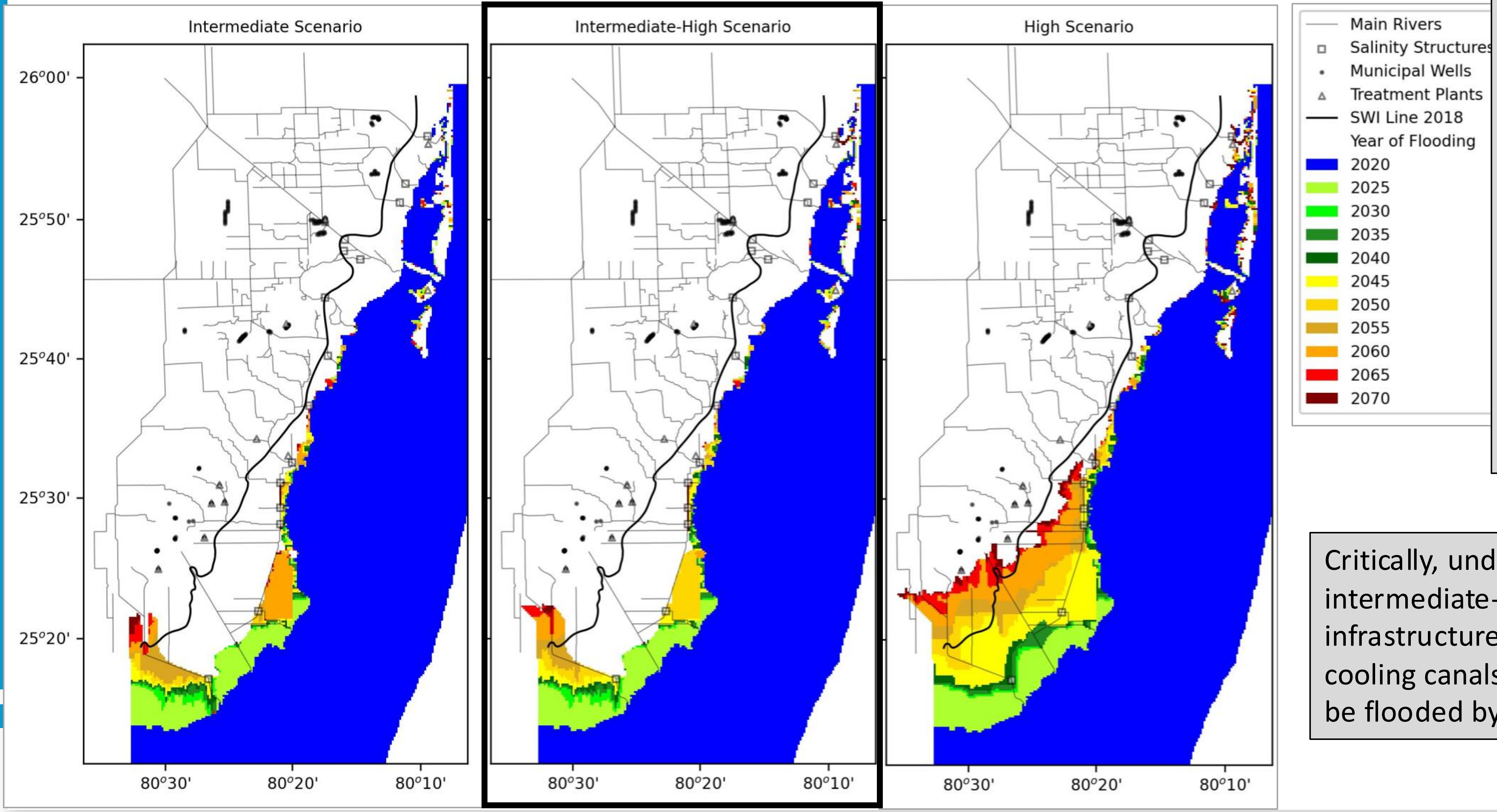
Pump-infrastructure Scenarios for managing canal systems

1. "No action" Scenario:
   - SFWMD don't do any action with respect to pumping infrastructure
   - As a result, the headwater levels at salinity control structures increase due to structure failure caused by sea level rise higher than maintenance elevation
2. "SFWMD Action" Scenario:
   - Pumps are installed at failing salinity control gravity structures
   - Maintain the headwater levels at their optimal (**historical 2020**) conditions

Salinity structure	**Elevation Headwater (m NAVD)**	SLR projections		
		Inter	**Inter-High**	High
S29_H	0.17	2060	2050	2050
S28_H	0.10	2050	2045	2045
S27_H	0.06	2045	2045	2040
S26_H	0.19	2060	2055	2050
S25B_H	0.23	2065	2055	2050
S25_H	0.17	2060	2050	2050
G93_H	0.27	2070	2060	2055
S22_H	0.31	2070	2060	2055
S123_H	0.29	2070	2060	2055
S21_H	0.12	2055	2050	2045
S21A_H	-0.01	2040	2035	2035
S20G_H	0.05	2045	2045	2040
S20F_H	-0.01	2040	2035	2035
S20_H	0.04	2045	2040	2040
S197_H	0.19	2060	2055	2050

Projected year when the salinity gravity structure may become obsolete (canal failure): **mean average** tidal elevations at Virginia Key surpass inland canal water levels

Projected **Flooding Year** timeline for when **mean average** tidal elevations at Virginia Key are expected to exceed the land's elevation, triggering permanent flooding and salinization

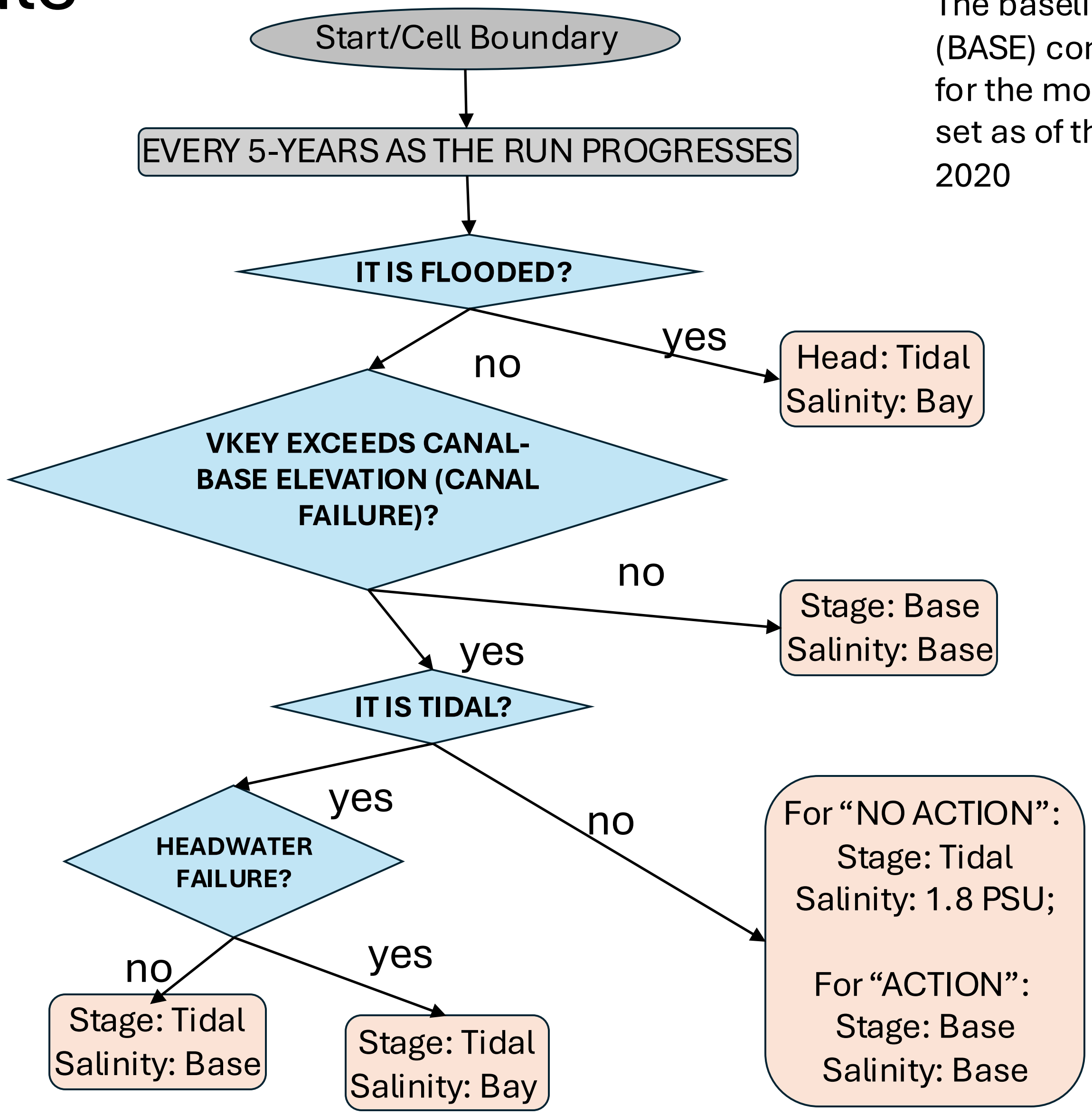


Timeline accelerates under higher sea level rise projections. What begins as a concern in the southern coastal zones around 2040 becomes a widespread by 2060 in the High Scenario. Portions of the barrier islands projected to be flooded

Critically, under the intermediate-high scenario, key infrastructure such as the FPL cooling canals is projected to be flooded by the year 2050.

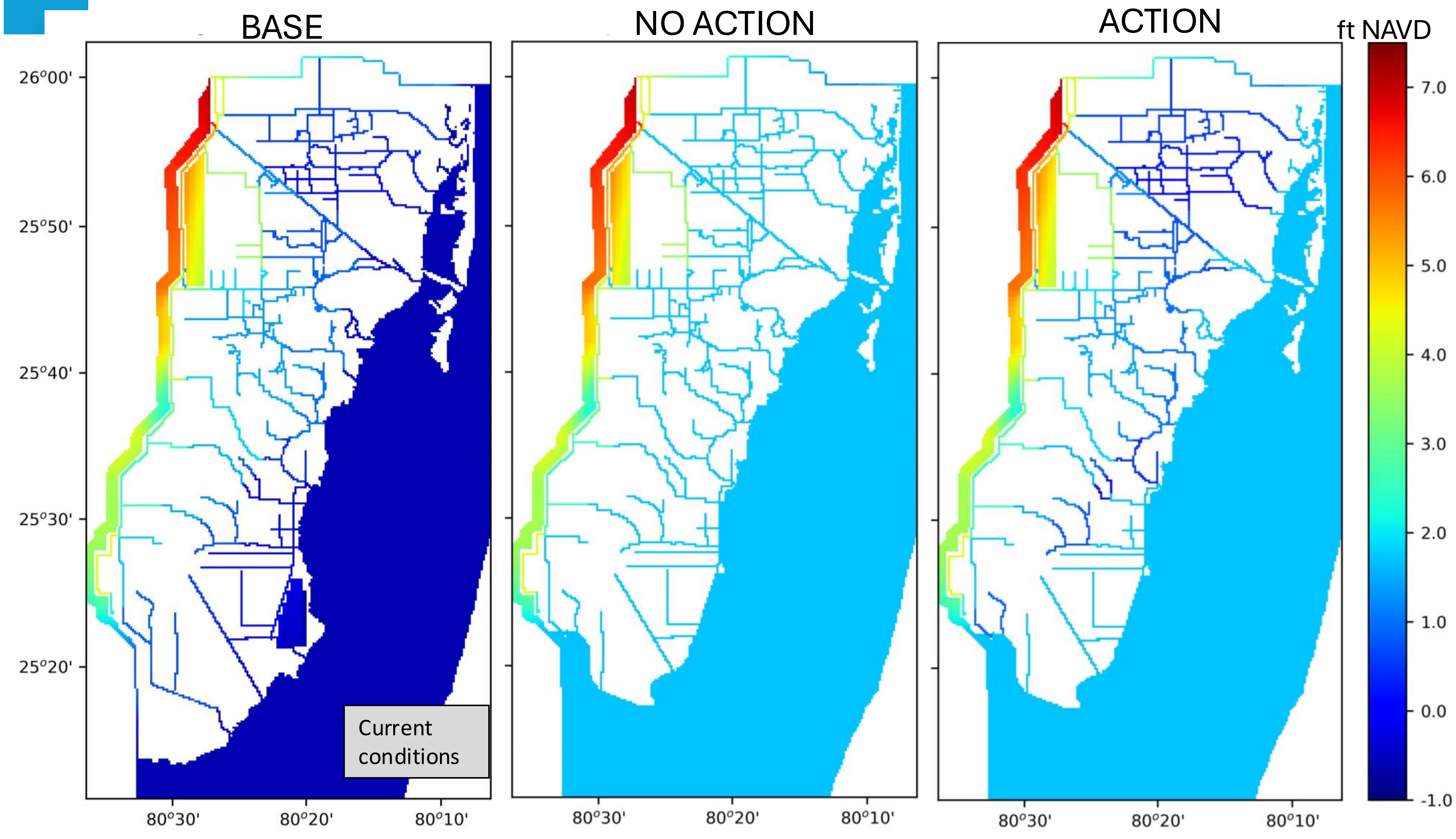
Boundary Conditions Handle in Model Over Time

- Updated every 5 years from 2021 to 2070 based on mean average sea level rise for the years: 2025, 2030, 2035, 2040, 2045, 2050, 2055, 2060, 2065, and 2070
- Model tidal levels are dynamic (updated daily)
- Salinity levels are assumed constant within each 5-year interval
- Water Conservation Areas and Everglades National Park levels remain constant
- Condition applies at each canal boundary based on two key thresholds:
  - **Flooding Year**
  - **Canal Failure Year**



The baseline (BASE) condition for the model is set as of the year 2020

Stage Boundaries Defined for the Year 2070 (under Inter-High Scenario)

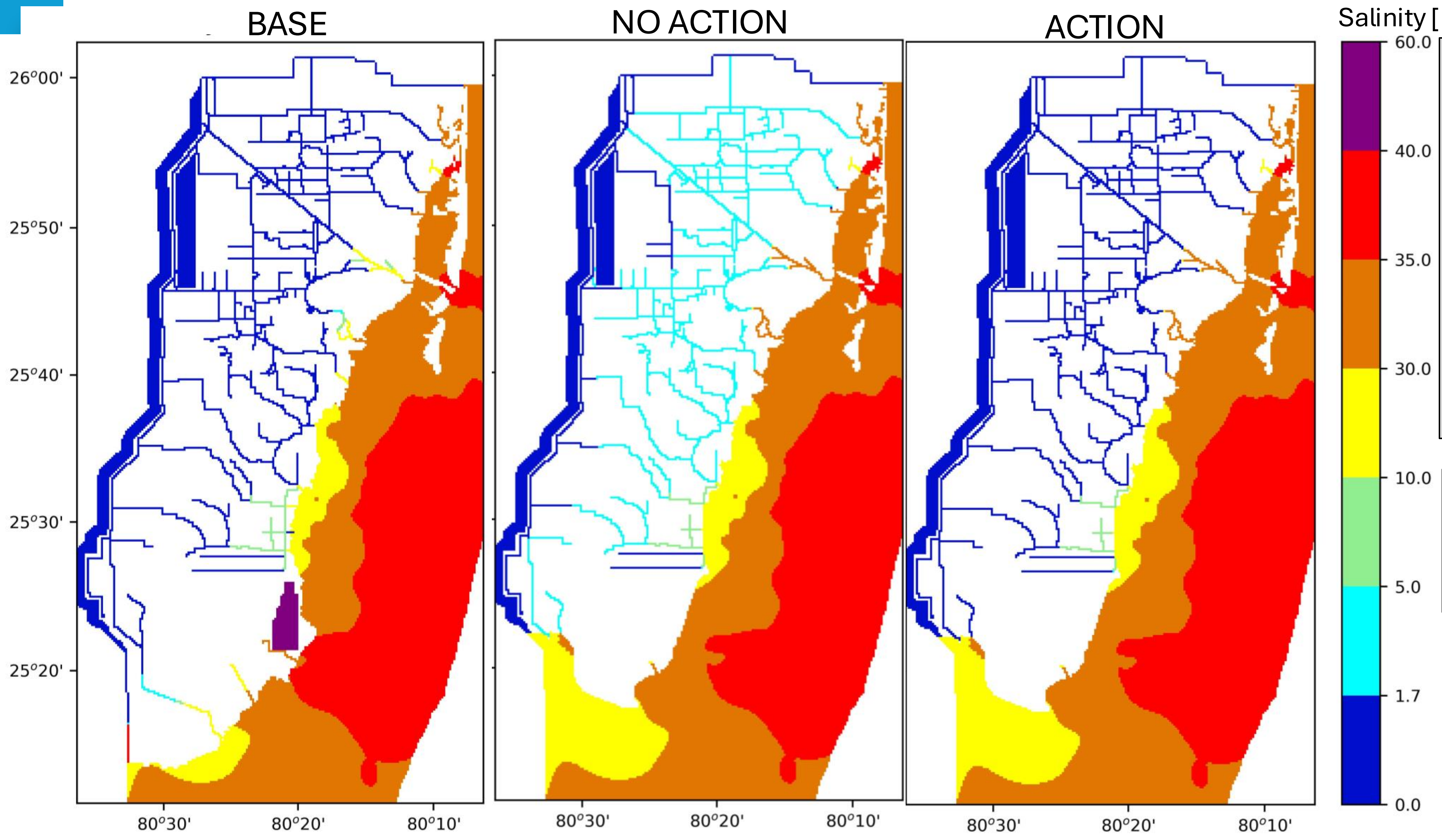


'No Action' scenario—canal headwaters are allowed to rise (by 2.3 ft) with Virginia Key's tidal elevation—inland shift of high-water zones, which could lead to increased flooding and saltwater intrusion.

In contrast, in the 'Action', headwaters are maintained at Base levels through pumps.

In our modeling assumptions, water levels in the Everglades are held constant except in south.

Salinity Boundaries Defined for the Year 2070 (under Inter-High Scenario)



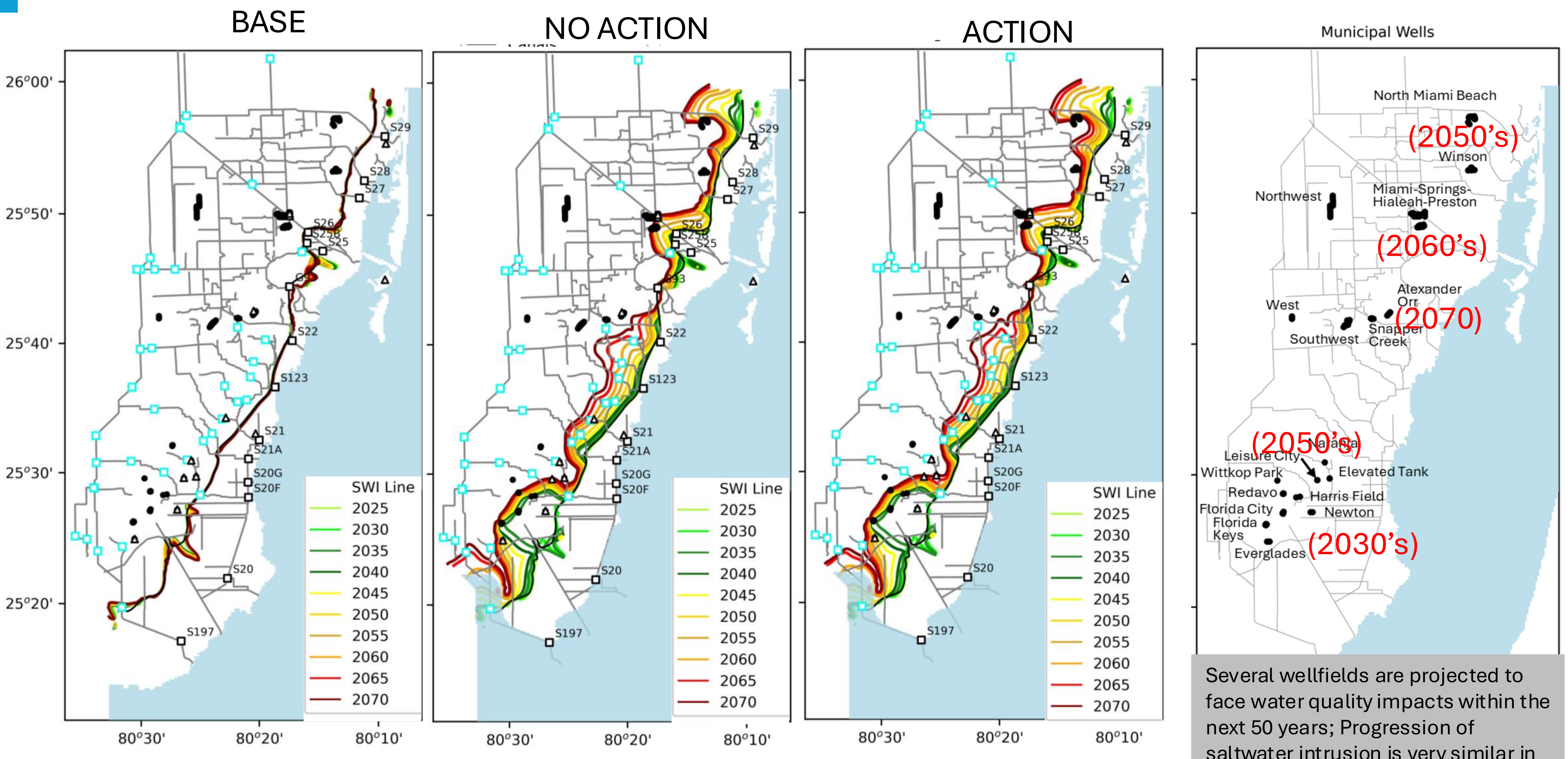
The Bay salinity boundary expands further inland, consistent with the areas projected to be flooded. Salinity in tidal canals also increases to match Bay salinity levels.

NO ACTION: Inland river salinity is set to 1.8 PSU, which results in saltier conditions throughout the canal network.

ACTION: Maintain base salinity levels in the inland system through pumps

Model Scenarios for Sea Level Rise (Intermediate-High): Results

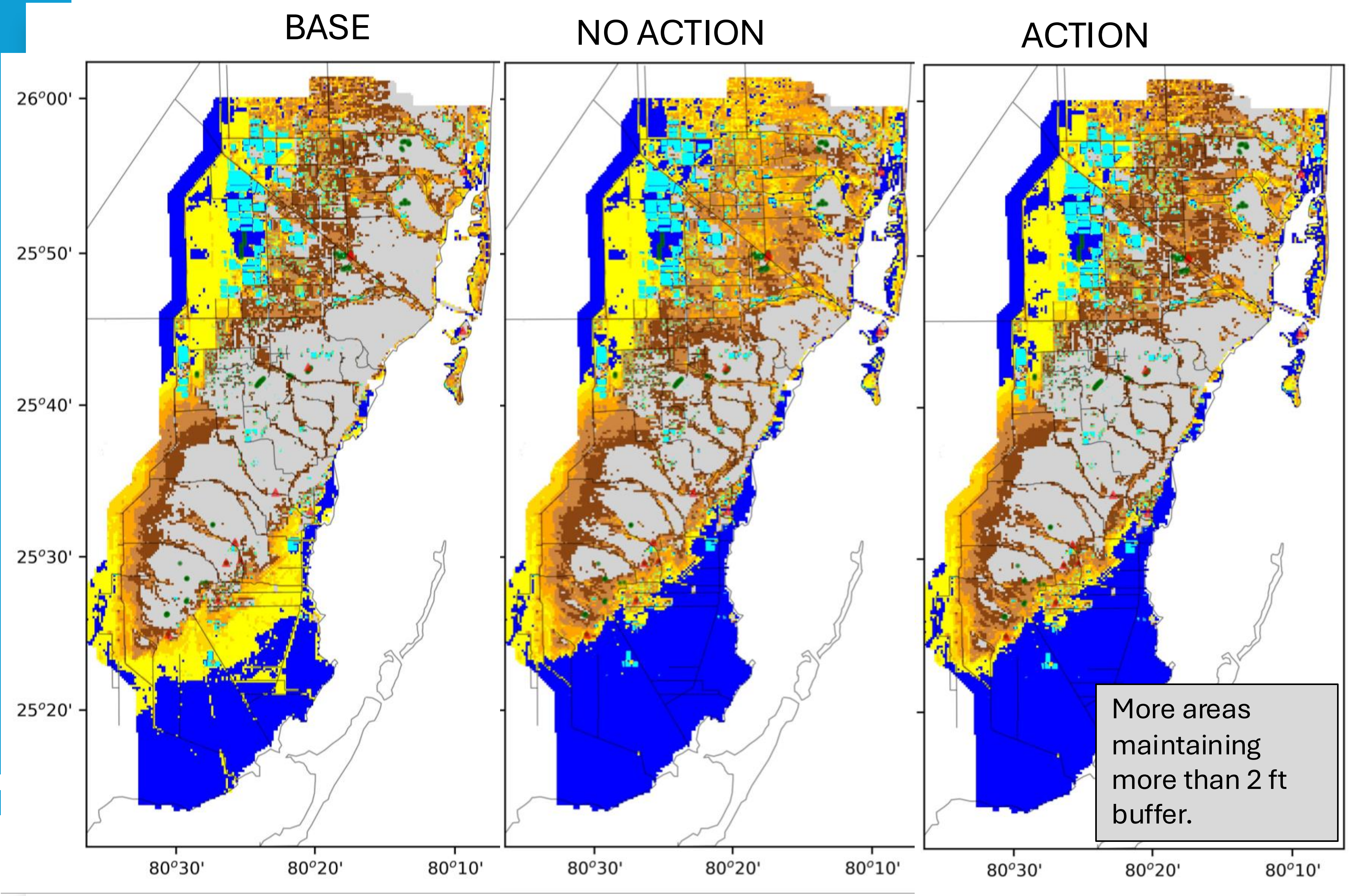
Simulated Saltwater Intrusion Line at the Base of the Biscayne Aquifer

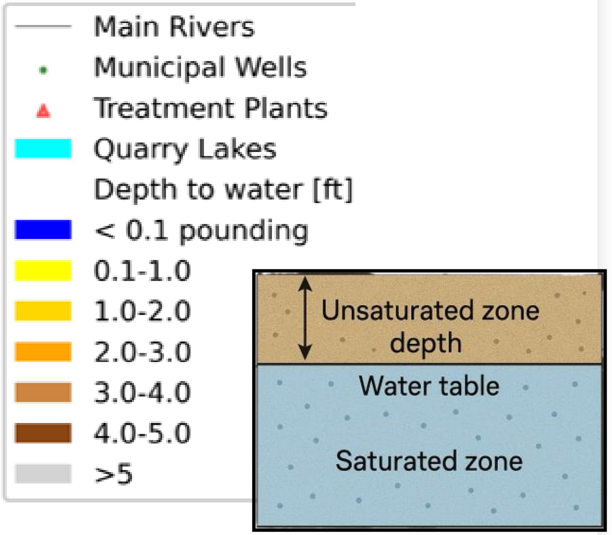


Several wellfields are projected to face water quality impacts within the next 50 years; Progression of saltwater intrusion is very similar in both scenarios.

Same lines will be produced for 250 mg/l

Estimated Unsaturated Zone Depth in 2070 (ft)

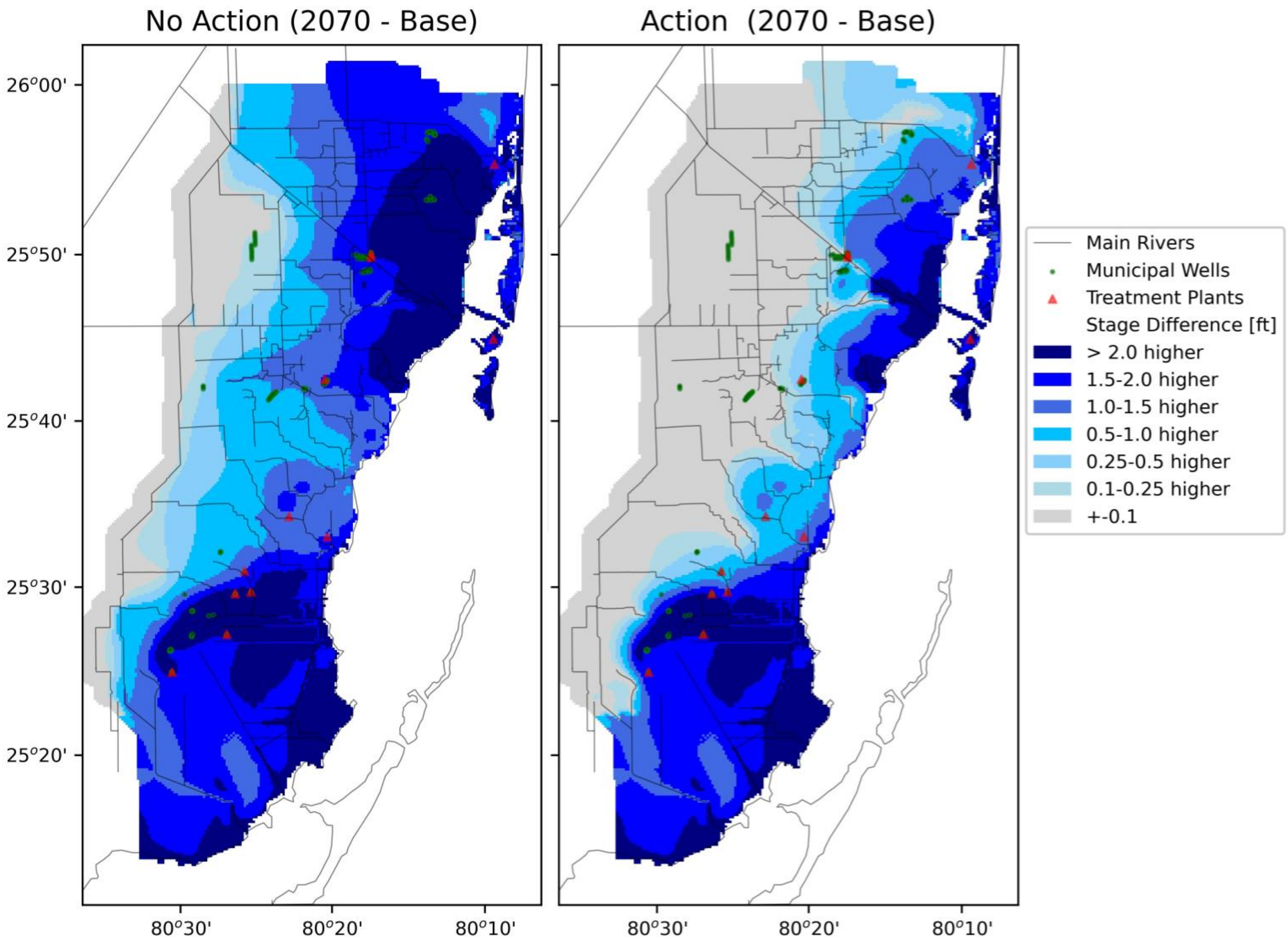




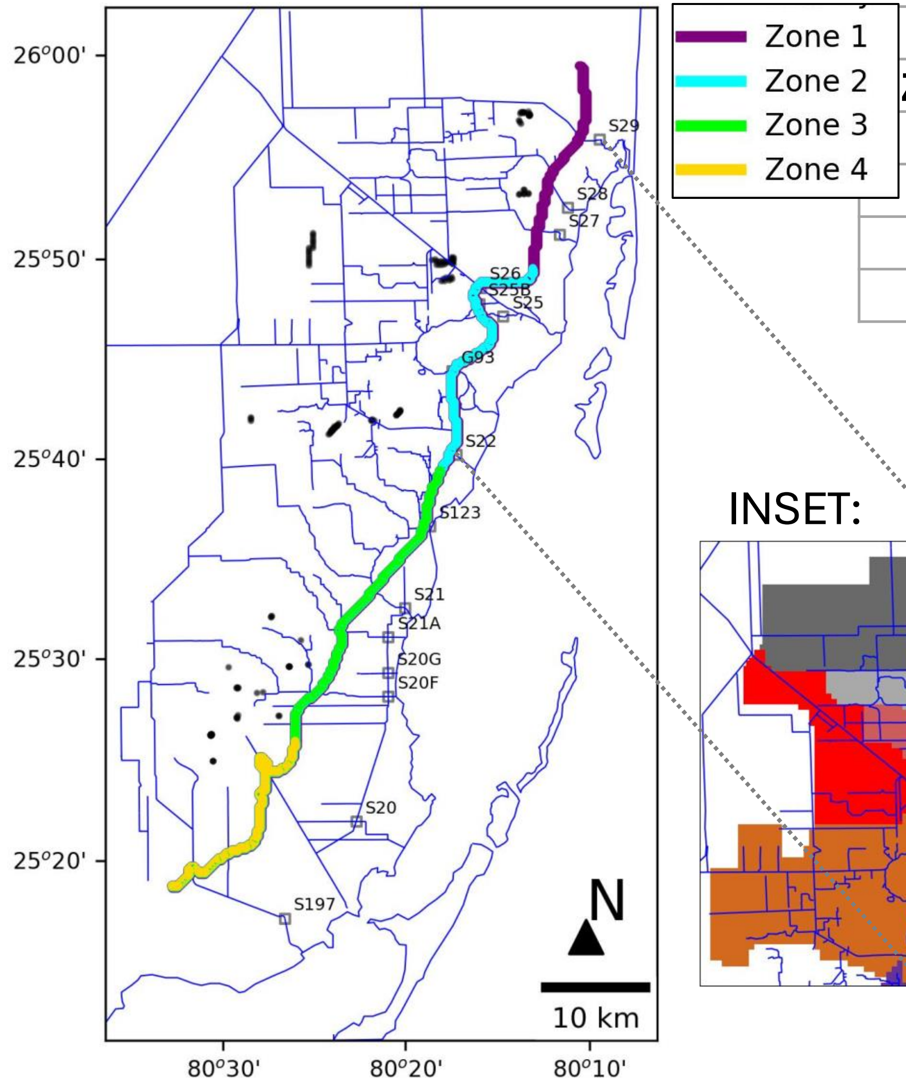
The blue areas (very shallow to ponding) expand, especially across the southern and coastal zones.

Predicted Water Table Difference by 2070 (ft) w.r.t BASE

- No Action Scenario
  - Much of the southern and coastal region experiences a 2 + ft rise in the water table (dark blue areas).
- Action Scenario
  - Water table rise is more moderated, with most areas experiencing a 0.5 to 2 ft increase instead.



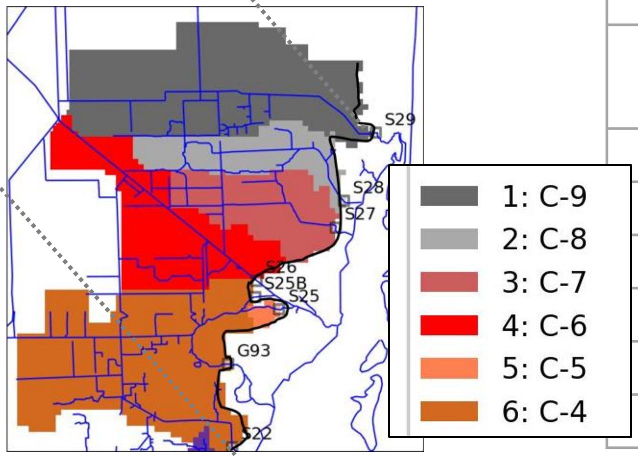
Net Transects Groundwater Flows in 2070 (cfs)



	+: to the west; - to the east			DIFFERENCE	
ZONE	**BASE**	**NO ACTION**	**ACTION**	NO ACTION	ACTION
1	27	28	77	1	50
2	-60	32	152	92	212
3	3	63	176	60	173
4	37	22	28	-15	-9

Groundwater flows flowing westward; significant changes from BASE; difference is the amount that pumping stations must make up in addition to runoff

INSET:



	+: to the west; - to the east			DIFFERENCE	
ZONE	**BASE**	**NO ACTION**	**ACTION**	NO ACTION	ACTION
1:C-9	6	12	39	6	33
2:C-8	0	5	20	5	19
3:C-7	5	17	27	12	22
4:C-6	-19	2	27	22	46
5:C-5	-20	17	67	37	87
6:C-4	-39	15	64	54	103

Conclusions

- Although the progression of saltwater intrusion is similar in both the "SFWMD Action" and "No-Action" scenarios, the "No-Action" approach leads to flooding and creates pathways for salinity to spread through the canals.
  - As a result, SFWMD intervention is crucial to ensure effective flood control and reduce associated risks.
- **Specific wellfields** are projected to experience water quality impacts over the next 50 years
  - Newton by 2030; Florida City and Florida Keys Aqueduct by 2035; Everglades Labor Camp and Norwood by 2045; Leisure City by 2055; Hialeah-Preston-Miami Springs by 2065; and Alexander-Orr by 2070.
- The primary **drivers of saltwater intrusion** are sea-level rise, tidal canal network, underperforming saline control structures and aquifer back-seepage
  - Localized impacts from nearby wellfields.

Expected Outcomes for Evaluating Sea Level Rise Risks

- Provide a foundation for future mitigation and adaptation strategies
- Assess **salinity changes in the Biscayne Aquifer**
  - Track inland migration of the saltwater interface as canal systems and coastal aquifers become increasingly saline
- Evaluate potential **impacts on water resources**, including wellfields, drinking water, agriculture, recreation, and the environment
- Analyze the **vulnerability of existing salinity control structures**
  - Estimate bay-to-inland back-seepage from sea level rise to guide the design of pumping stations
  - Determine total pumping needs for replacing obsolete salinity control structures
- Identify new **wellfields locations** in the Biscayne Aquifer to partially compensate for those that may be decommissioned due to saltwater intrusion, and it's released of regional flow