Acknowledgement
Integrated model simulation results from:

Ross, M., and Trout, K. (2017).“Assessment of the Integrated Northern Tampa Bay Model no groundwater pumping scenarios.” Center for Modeling Hydrologic and Aquatic Systems, Department of Civil and Environmental Engineering, U. of South Florida, Tampa, FL. Prepared for Tampa Bay Water, Clearwater, FL
Outline

• Fully-integrated hydrologic model?
  – What is it?
  – When is it used or needed?
• Integrated Hydrologic Model (IHM) simulation engine
• Integrated Northern Tampa Bay Model, application of the IHM
• Case Study: Hydrologic responses to well pumping reduction
• Summary
Fully-Integrated Hydrologic Model
What is this simulation technology?

- Completely simulate hydrologic system & water table (WT) feedback
  - Uplands, water bodies, & GW
  - WT feedback: runoff, ET, recharge
- Interfacial boundary conditions (BC) for single-regime models replaced with dynamic simulation
  - Surface hydrology
    - Depth-to-water table(t)
    - Baseflow(t)
  - Groundwater hydrology
    - Recharge rate(t)
    - Maximum evapotranspiration rate(t)
    - Water-body stage(t)
    - Specific yield(t)
Fully-Integrated Hydrologic Model Simulates All Processes and WT Feedback
Relative Change in Flux Magnitude
Deep vs Shallow Depth-To-Water Table

DEEP Depth to Water Table

Rainfall → Evapotranspiration

SWET → GWET → Runoff

Depth to Water Table (DWT)

Vadose Zone Storage

Saturated Groundwater Storage

Recharge

SHALLOW Depth to Water Table

Rainfall → Evapotranspiration

SWET → GWET → Runoff

Water Table Feedback Zone (Root Zone + Capillary Zone)

Vadose Zone Storage

Saturated Groundwater Storage

Recharge

DWT
• Hydrologic, hydrogeologic, climate, & anthropogenic attributes
  – Near-surface water table causes dynamic feedback among processes
    • Uplands, water bodies, & groundwater
  – Changes to anthropogenic stresses or climate
    • Dynamically alter WT feedback & interfacial BC (e.g., depth - to - water table, recharge)

• Strategic decision support needs
  – Increase simulation accuracy, capability, & flexibility (e.g., dry & wet, MFL)
  – Quantitatively partition causes of changes for flows & levels
    • Climate, well pumping, surface - water diversions, landuse
Integrated Hydrologic Model (IHM) and Integrated Northern Tampa Bay (INTB) Model

• 4,000 sq miles North & East of Tampa Bay
• 50% near-surface water table
• 25% water & wetlands
• 500 million gallons per day well pumping
• Surficial & upper Floridan aquifers connected by a leaky semi-confining unit
• Floridan aquifer well pumping influences:
  – Surficial aquifer levels (water table)
  – Lake & wetland levels
  – Streamflow

Decision support needs

IntegratedHydrologicModel.org
Integrated Northern Tampa Bay (INTB) Model Pumping Scenarios Within CWC Florida GW Basin

- **Compare two scenarios**
  - Historical well pumping (200 MGD)
  - No well pumping

- **Compare scenario responses**
  - Depth-to-water table & recharge
  - Streamflow, surface runoff, baseflow, & runoff fraction of streamflow
  - Upland ET & water-body ET
  - Groundwater above land
  - Water-body stage
GW Pumping Reduction: DWT & Recharge Change

- **Water Table Elevation Change**
  - WT Elevation
    - *Increase*
  - Depth to WT
    - *Decrease*
    - *Transition DEEP to SHALLOW*
  - Recharge
    - *Decrease*
  - Δ Related to Pumping Rate

Credit: Ross and Trout 2017

Areas with increase in recharge is outcome of a basin that includes shallow and deep depth-to-water table; occurs over deep DWT.
GW Pumping Reduction: Streamflow Change

Streamflow
*Increase by Factor 1.05 to 20

Streamflow = Runoff + Baseflow
*Increase both components
*ΔRunoff causes up to 42% of Δstreamflow

Runoff Fraction
*Decrease

Δ Related to Pumping Rate
GW Pumping Reduction: ET Change

Uplands ET
* Decrease vadose
* Increase GW
* Net increase

Water-Body ET
* Increase

ΔET Related to Pumping Rate

Legend:
F = Forested; G/P = Grass/Pasture
A/I = Agric/Irrigated, U = Urban
M/O = Mining/Other
Benefits of Fully-Integrated Hydrologic Models

• Simulate all processes, WT feedback, & interfacial BC

• Strategic application conditions
  – Near-surface depth -to- water table with dynamic WT feedback
  – Change to anthropogenic stress or climate alters dynamic WT feedback & interfacial BC
  – Natural systems or water supplies currently or anticipated to be stressed

• Decision support requires more accuracy, capability, or flexibility
• Quantitatively partition causes of changes in flows & levels
• One model to assess changes to all flows & levels
Questions

IHM website: IntegratedHydrologicModel.org
GW Pumping Reduction Water Above Land

- Integrated model has increase in days where water is above land
  - Locations coincide with water bodies
  - Dynamic conversion of recharge to runoff and ET minimizes water above land in upland areas
- Very difficult for groundwater models to avoid water above land in upland areas
  - Water above land in upland areas can cause overestimate of change to baseflow, springflow, and heads for a pumping reduction
GW Pumping Reduction
Water-Body Stage Change

- Integrated model shows increase in water-body stage caused by net effects of:
  - Increase in runoff and baseflow
  - Increase or decrease in water-body leakage
  - Increase in water-body ET

- Very difficult for groundwater model to simulate changes to water-body stage
  - Without change in water-body stage, baseflow change can be overestimated for a pumping reduction
Surface-Groundwater Flow Exchange
Water Table Influence Through Capillary Forces

(a) Deep Water Table
No WT Interaction with Surface

(b) Shallow Water Table
WT Interaction with Root Zone

(c) Very Shallow Water Table
WT Interaction with Land Surface

Land Surface

- Gravity Zone
- Intermediate Capillary Zone
- Capillary Fringe Zone

Soil Moisture, $\theta$

Drier $\rightarrow$ Wetter

Wetter $\rightarrow$ Drier
Areas With Near-Surface Depth-To-Water Table Assessment Advantages Using Integrated Models

Near-Surface Water Table
Surface Soil Moisture: Capillary Fringe

Deep Water Table
Surface Soil Moisture: Gravity Zone

Move WT

LS

ξ_{RZ}

ξ_{GZ}

ξ_{CZ}

Z_{WTo}

ξ_{GZ}

ξ_{CZ}

Z_{WTo}