Water Resource Engineering Modeling Applications Overview

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Getting The Water Right

Q: How do we know if we can get the water “right”?

A: Models!
Why Use Models?

- Integration of data (visualization and use)
- More complete understanding of study area and sensitive parameters
- Guide future data collection
- Simulate specified scenarios (design/prediction)
  - Hydrologic/hydraulic stresses (rainfall, GW pumping, etc)
  - Effects of land use changes etc.
  - Project alternative comparisons
- Presentation of outputs and associated evaluations
Why Use Models?

• Provides best estimate of represented system given data limitations

• Model results are only as reliable as the accuracy and completeness of the field data, i.e. the ability of the data to represent the hydrologic and hydraulic system being modeled

• Simply stated – the outputs (results) are only as good as the worst piece of input (data)!!!!!!!!!!!!!
The Rainfall Runoff Process

- Precipitation
- Surface runoff
- Infiltration
- Groundwater flow
- Water table
- Lake
- River
- Spring
- Evaporation
- Condensation
- Transpiration
- Ocean
- Groundwater
Orographic Effects on Rainfall

- Topography of foothills/mountains causing air mass to rise, drop in temperature, exceed dew point, and precipitate.
- Orographic effects are observed on many Caribbean Islands—with prevailing moist, easterly winds and central mountain ridges.
- Maximum rainfall tends to occur on windward (north and east) side and near peak of mountains.
- Rainfall is lower on the landward (south and west) side of the mountains due to rainshadow effect.
Orographic Effects on Puerto Rico Rainfall

- Majority of Puerto Rico’s rainfall is orographic in nature.
- Cordillera Central mountains run east-west over the island.
- Due to pronounced orographic effect of these mountains, rainfall is distributed rather unevenly over the island.
- Annual rainfall ranges from 55-67” in northern coastal plains, 157-197” in northeast tropical rainforest, to less than 39” in the southwest.

Figure 69. Average annual rainfall in Puerto Rico (1951-80) is greatest in the mountains where it is locally greater than 200 inches. Rainfall is least, less than 40 inches, in lowland areas along the south coast.
HEC-HMS
GeoHMS – Hydrologic Parameters

Define modeling methods

Parameterize model using GIS data

Develop a distributed model
Input files generated by HEC-GeoHMS include the basin model file, which contains the physical description of the study area and parameter data estimated using GIS datasets, and background maps.
Streamflow Hydrograph
Digital Terrain Model

HEC-GeoRAS can utilize both a TIN or GRID representation of the ground surface for data extraction and inundation mapping.
Floodplain Mapping

- Floodplain boundary follows edge of grid cells
- Smooth Floodplain Delineation option
- Important along linear features
HEC-ResSim
Reservoir System Simulation

- Geo-referenced System Schematic
  - Reservoirs
  - Routing Reaches
  - Control Points

- Rules represent the goals and constraints on reservoir releases
  - Flood Control Constraints
  - Conservation Goals
  - Hydropower & Pump-back Storage
  - Tandem & Parallel System Operation
  - Credit Storage
The Watershed Analysis Tool (HEC-WAT)

Hydrology

Reservoir

Flood Damage

Hydraulics
A Differing Perspective

• Surface water models typically focus on short-term storm events with very simplified representation of groundwater and between storm conditions.
• Groundwater models typically view surface water processes as a boundary condition.
• The continuous (i.e. during and between storm events) simulation of the land-based phase of the hydrologic cycle is required for more complete understanding of hydrologic processes.
The U.S. Geological Survey Finite-Difference Modular Flow Model (MODFLOW)

- Most widely used/validated groundwater flow model.
- Public Domain
- Cell-Centered, 3D, finite difference model
- Steady state or transient saturated flow
- Various “packages” can be added to simulate specific applications (i.e. simple streamflow, reservoirs, recharge from precipitation etc.)
USGS MODFLOW

\[
\frac{\partial}{\partial x} \left( K_{x} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{y} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{z} \frac{\partial h}{\partial z} \right) - W = S_{x} \frac{\partial h}{\partial x}
\]
“Coupling” Approaches

- “Loose Coupling” - each model is run independently and information is exchanged following completion of model runs.

- “Tight Coupling” – models are run independently, information is exchanged within the model runs; such as during each time step, or the larger of the time steps in the 2 models. (e.g., MIKESHE)

- “Fully Integrated” – All flow equations are solved simultaneously. (e.g., WASH123D)

- Lots of “hybrid approaches”
What is MODBRANCH?

- MODBRANCH is a hydrologic model that results from coupling the USGS Groundwater model MODFLOW and the USGS Stream/River model BRANCH
- Simulates hydrology and water management of sub-regions
- Highly refined and variable grid spacing
- Simulates 3D groundwater and canal flow
- Used for short term simulations (~1 year)
- Developed by USGS and USACE-Jacksonville
- Uses SFWMM2x2 results for boundary conditions
Conceptual model development – Initial Plans

- Processes to be included
  - Hydrologic
  - Hydraulic
  - Control structures
  - Hydro-stratigraphic
  - Hydro-geologic
  - Operations
MODHMS Concept

- Fully Integrated Hydrologic and Water Quality Numerical Modeling System developed by HydroGeologics, Inc.
- MODFLOW-Based
  - Surface water hydrology & water quality
  - Density dependent flow & transport
  - Unsaturated zone flow & transport
- Rigorous Coupling and Mathematical Formulation and Efficient Numerical Solutions Schemes
RAS-HMS-MODFLOW

- Coupling of HEC-RAS with MODFLOW began by USACE-HEC in mid 2000’s
- Pilot Application to Highly Urbanized C-4 Basin in Miami-Dade County
- Now Incorporating HEC-HMS Rainfall/Runoff Module
- Hydraulic Canal Routing/Control Structures/Operating Rules Ideal for Flood Event Simulations
- Beta Version in CY 2012
- Anticipated wide use by USACE and public

(Heimlich, FAU, 2009)
Both HEC-RAS and MODFLOW are considered to be the standards of the profession.

The coupling of these two models, in conjunction with a practical, user-friendly interface, will provide a much-needed, state-of-the-art, non-proprietary tool.

Field Applications
- where changes in channel stage have direct impacts on groundwater
- where stresses (such as groundwater pumping) affect flow in adjacent stream and channels
- where hydraulic design influences adjacent groundwater
- backwater effects
- low-flow simulations.
MIKE SHE - Integrated Modelling

- MIKE SHE is an integrated but physically distributed hydrological model developed by Danish Hydraulic Institute (DHI)
- Encompasses all major components of hydrologic cycle: overland flow, unsaturated flow, recharge, groundwater flow, etc.
- Can be run in an interactive/integrated fashion with DHI’s channel network MIKE 11 model
Tidal Caloosahatchee

Real Cross Sections and Weir Elevations

Inter-basin Transfer

Gate Openings

Inter-basin Transfer
WASH123D: Overview

- Developed by George Yeh (University of Central Florida) and his colleagues
- A Finite Element Model for Flow and Transport
- Represents Variably Saturated Variable-Density Water Flow (i.e., can address saltwater intrusion)
- Simulates Sediment and Reactive Chemical Transport
- Represents Watershed System as a Combination of 1D River/Stream network, 2D Overland, and 3D subsurface sub-domains
TABS Numerical Models

- **RMA 2**
  - A 2-D depth-averaged hydrodynamic model originally developed by the USACE in 1973

- **SED2D**
  - A 2-D numerical model for depth-averaged transport of cohesive or non-cohesive sediments

- **RMA 4**
  - A 1-D/2-D numerical model for depth-averaged transport of one to six constituents

- **TABS-MDS (RMA 10)**
  - A 3-D hydrodynamic numerical model - includes flow, constituent transport and sediment transport
Curvilinear-grid Hydrodynamic model in 3-D (CH3D)

- A 3-D finite difference model developed jointly by USACE Engineering Research and Development Center and Iowa Institute of Hydraulic Research

- Can simulate hydrodynamics, salinity, sediment, eutrophication (DO, N, P, phytoplankton, and zooplankton), etc.

- Model can be used to investigate sedimentation, dredging, and channel evolution
An Array of Applications
Comprehensive Everglades Restoration Plan (CERP)

- Surface Water Storage: Reservoirs – 180,000 acres
- Aquifer Storage & Recovery: 330 wells
- Stormwater Treatment Areas (STAs): 36,000 acres
- Reuse Wastewater: 2 Regional plants
- Seepage Management
- Operational Changes: (USACE, 2010)
- Removing Barriers to Sheetflow: 240 miles
Global Climate Change Quartet

Figure 1. Anticipated Water Management Impacts of Climate Change.

(SFWMD, 2011)
Variation in South FL Rainfall

THUNDERSTORMS

HURRICANES

DROUGHT

Figure 14 - Large thunderstorms frequently develop over the Everglades in the summer. This photo shows a typical super cell over the sugarcane fields of west Palm Beach County in August. (Photo: B. Heimlich)

Figure 17 - Hurricane Jeanne, 2004 (NHC)

Figure 45 - Lake Okeechobee experienced record low levels in 2008 after several consecutive years of drought.

(Heimlich, FAU, 2009)
Sea Level Rise

- **USACE 2009 Method**
- **Low SLR Rate Based on Historic Key West rate, 9.3 inches by 2100**
- **Modified NRC I and III Curves consider IPCC**
- **Adopted as unified SE Florida projection**
- **Subject to 2012 revision (IPCC)**

(SFWMD, 2011)
SLR Impacts

- **Direct Impacts** (storm surge)
- **Flood Protection** (urban flooding)
- **Water Supply** (saltwater intrusion)
- **Natural System** (coastal ecosystems)

(Ocean Avenue, A1A)

(SFWMD, 2011)
(FAU, 2008)
SLR IMPACTS

DIRECT IMPACTS

INUNDATION OF BARRIER ISLANDS AND COASTAL INFRASTRUCTURE

COASTAL FLOODING & ECOSYSTEM CHANGES

BEACH EROSION

(FAU, 2008)
(SAHA, FIU, 2011)
SLR Impacts

FLOOD PROTECTION
reduced discharge
from coastal structures

(Heimlich, FAU, 2009)
(SFWMD, 2011)
Modeling Methodology

- Wind Field – Wind Stresses
  - PBL TC96

Surge Model
- Surge model: ADCIRC

Wave Models
- Offcoast Waves: WAM
- Nearshore Waves: STWAVE

Unified Grid
- Coupling
Hurricane Storm Parameters & Storm Tracks

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<th>Radius of Max Winds nm</th>
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</table>

Storms produced approximately 100-yr water levels in southeastern Louisiana (LACPR & FEMA studies)
Maximum Surge Envelope

Storm 17
Cp = 900 mb, Rmax = 14.9 nm, Vf = 11 kts

Base
SLR0.5
SLR1.0
Jacksonville Harbor Deepening Project
Navigation Concerns

Insufficient Channel Depths and Widths

Difficult Currents

Not Enough Turning Basins

IWW Perpendicular Ebb Current

St. Johns River Ebb Current
Environmental Considerations
Evaluate Potential Project Impacts

Threatened/Endangered Species
Wetlands
Wildlife Resources
Water Quality

Upstream Salinity Impacts - Potential Water Withdrawals - Salt Marshes
Expansion of Off-Shore Disposal Areas - Mile Point Widener - Trout River Cut Widener
Field Measurements and Modeling

**PHYSICAL CHARACTERISTICS**
- **Water Levels**
- **Velocities and Flows**
- **Salinity**
- **Channel Shoaling**
- **Ship Wakes**
- **Coastal Shoreline Impacts**

**MEASUREMENTS**
- **Bathymetric Survey**
- **Water Level Gages**
- **Salinity and Suspended Sediment Sensors**
- **Acoustic Doppler Velocity and Flow Meters**
- **Measurement Plan**
- **Wave Gages**

**Modeling**
- **Forcing**
- **Hydro-Modeling**
- **Ship Sim**

**Design**
- **Design**
- **Salinity**

**Impacts**
- **Shoaling**
- **Coastal**
Modeling

Advanced Circulation (ADCIRC) Models
Coastal water levels and velocities

Adaptive Hydraulics Modeling (ADH)
2-d and 3-d currents (velocities and flows) for the 20 mile project area

Field Measurements → Forcing → Hydro-Modeling → Ship Sim → Design → Salinity → Shoaling → Coastal

Design → Impacts
Local Model Applications - Regional ADCIRC Boundary Conditions

Tidal and Meteorologic

Modeling
- Field Measurements
- Forcing
- Hydro-Modeling

Design
- Ship Sim
- Design
- Salinity
- Shoaling
- Coastal

Impacts

Channel Design
Salinity
Coastal
Time Series Validated
(in terms of elevations and velocities at two stations)

Fernandina Beach
ODMDS ADCP

Jacksonville
ODMDS ADCP

Jacksonville ODMDS Elevations

Field Measurements → Forcing → Hydro-Modeling → Ship Sim → Design → Salinity → Shoaling → Coastal

Modeling → Design → Impacts
Channel Design

ADH

Field Measurements
Forcing
Hydro-Modeling
Ship Sim
Design

Existing Condition ↔ Validates

Alternative ↔ Refines

Ship Simulator

Modeling

Design

Impacts

Salinity
Shoaling
Coastal

BUILDING STRONG®

US ARMY CORPS OF ENGINEERS | Jacksonville District
Project Impacts

Environmental Fluid Dynamics Code (EFDC)
In coordination with SJRWMD; salinity levels along the Lower St. Johns River

Adaptive Hydraulics Modeling (ADH)
Sediment transport and shoaling along the Federal channel

Coastal Modeling System
Sediment budgets and sediment transport for coastal shoreline 10 miles south and north of the project area
Comparison of Model and Obs Salinities – Dry and Wet Calibration Period

**Dry Season**

- Dames Point (Surface)
- Dames Point (Bottom)
- Acosta Bridge (Surface)

**Wet Season**

- Dames Point (Surface)
- Dames Point (Bottom)
- Acosta Bridge (Surface)

**Field Measurements**

- Forcing
- Hydro-Modeling

**Modeling**

- Ship Sim

**Design**

- Design

**Impacts**

- Shoaling
- Coastal

**Salinity**
PROJECT OVERVIEWS
Coastal Work – Caribbean
Aguadilla Breakwater, PR
Designed and constructed by SAJ
El Morro Breakwater & Revetment
Designed and Constructed by SAJ
Protective Revetment along Veteran’s Drive, Charlotte Amalie, U.S.V.I.
Designed by SAJ, Construction underway by Local Government
Ft San Geronimo, PR
Riprap protection designed by SAJ; to be constructed by SAJ this FY.
Post-Hurricane Inspection of Dolosse Revetment along main airport runway, St Thomas, U.S.V.I., by SAJ personnel
PROJECT OVERVIEWS
Coastal Work – Florida
Dade County Beach Erosion Control Project (Miami Beach, FL)
Miami Beach Reef Ball Breakwater Project
Test lift of one breakwater module
Reef Balls in place in Caribbean, being used as an artificial reef structure
Tarpon Springs, FL
Existing Conditions
Tarpon Springs, FL
Proposed Revetment Design
Final Thought

A model is a tool to aid in our application of evolving science and founded engineering fundamentals. Any individual can generate a data set sufficient to “run” a model. Yet, understanding model strengths/limitations and the adequacy or appropriate range of sensitivities within modeling parameters is where the “engineer” plays the biggest role. Data is the driver in all modeling codes and modeling code applications. The biggest key point to understand is a model is only as good as its worst piece of data and must be properly applied.