Groundwater Modeling Advisory Panel: Selected Current Practices in Groundwater Modeling

Groundwater Week/Summit
Nashville, TN
Tuesday, December 5, 2017: 10:40 a.m.-12:00 p.m.
GMAP Group Co-Leads (Field Complexity, Step-Wise/AE Modeling, Model Uncertainty, Model Applications and GW/SW Interaction) with Charles Job, Moderator

Background

- USGS anticipates increase in modeling demands
  - multi-disciplinary factors
  - applied to landscape-level science
  - more complex scientific questions & resource issues
- GW modeling field – evolving with rapid change & interconnecting with other technical disciplines
- 60 NGWA members collaborated to improve GW modeling & application.

Background

- April 2016, nearly 40 prominent groundwater modelers formed Groundwater Modeling Advisory Panel (GMAP)
- Mission: Provide collective understanding of selected subjects & observations for professional practice improvement
- Goal: Advance GW modeling through information exchange & outreach to groundwater professionals
- Objectives: Research technical questions & identify alternative/ best techniques & responses

Background

- Identified 33 GW modeling topics & categorized into 5 groups
  1. Field Complexity
  2. Stepwise/Analytical Element Modeling
  3. Uncertainty in Modeling
  4. Model Applications
  5. Integrated Groundwater/Surface Water Modeling
- Completed practice papers & peer review June 2016 to June 2017
- Not developing modeling standards but share perspectives and experiences for other modelers' benefit

Background

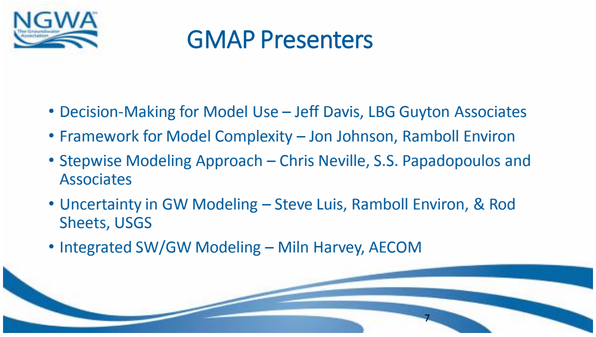
Papers address questions of:

- How should decision-makers consider groundwater modeling in project development and solution?
- How should the complexity of the subsurface be considered in developing groundwater models?
- What considerations should be made in moving from simple to more complex model development?
- How can uncertainty be included in modeling to inform decisions for groundwater supply and remediation?
- What approaches can be followed to address interaction of groundwater and surface water in decisions?

Looking Ahead

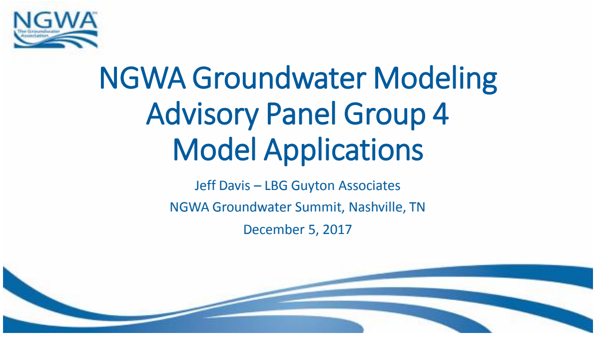
- Bring other questions forward for consideration & development
- Planning future discussions and papers

- Now – on to the GMAP report-out
  - Access Papers online at: http://www.ngwa.org/pubs/Pages/white-papers.aspx
  - 5 presentations
  - Approximately 10 minutes each
  - Followed by question-answer session



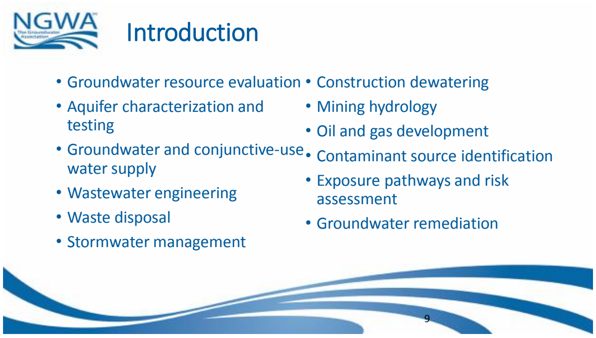
GMAP Presenters

- Decision-Making for Model Use – Jeff Davis, LBG Guyton Associates
- Framework for Model Complexity – Jon Johnson, Ramboll Environ
- Stepwise Modeling Approach – Chris Neville, S.S. Papadopoulos and Associates
- Uncertainty in GW Modeling – Steve Luis, Ramboll Environ, & Rod Sheets, USGS
- Integrated SW/GW Modeling – Miln Harvey, AECOM



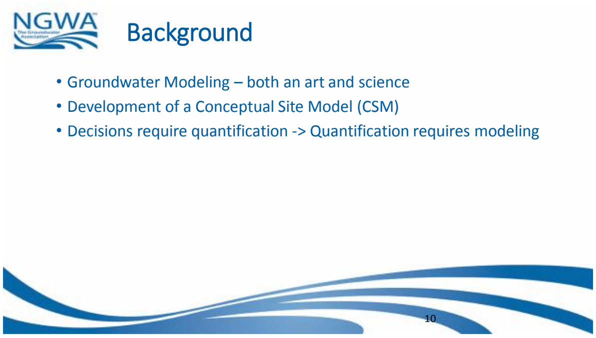
NGWA Groundwater Modeling Advisory Panel Group 4 Model Applications

Jeff Davis – LBG Guyton Associates
NGWA Groundwater Summit, Nashville, TN
December 5, 2017



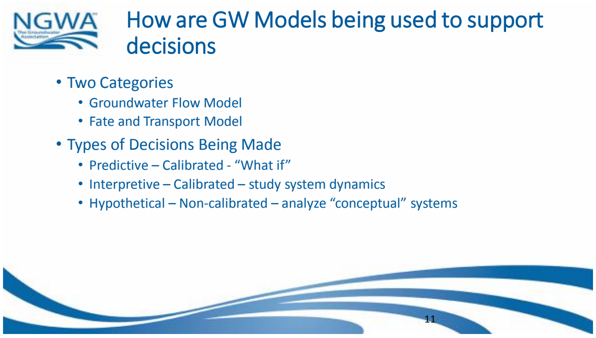
Introduction

- Groundwater resource evaluation
- Aquifer characterization and testing
- Groundwater and conjunctive-use water supply
- Wastewater engineering
- Waste disposal
- Stormwater management
- Construction dewatering
- Mining hydrology
- Oil and gas development
- Contaminant source identification
- Exposure pathways and risk assessment
- Groundwater remediation



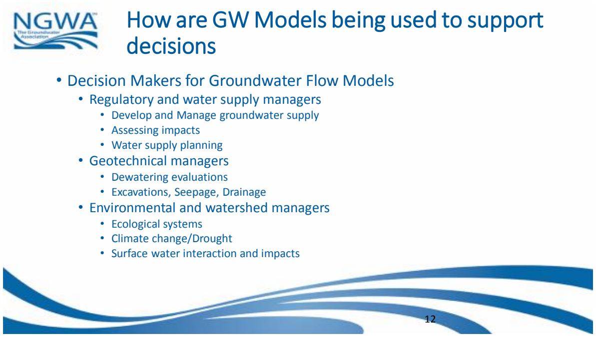
Background

- Groundwater Modeling – both an art and science
- Development of a Conceptual Site Model (CSM)
- Decisions require quantification -> Quantification requires modeling



How are GW Models being used to support decisions

- Two Categories
  - Groundwater Flow Model
  - Fate and Transport Model
- Types of Decisions Being Made
  - Predictive – Calibrated - “What if”
  - Interpretive – Calibrated – study system dynamics
  - Hypothetical – Non-calibrated – analyze “conceptual” systems



How are GW Models being used to support decisions

- Decision Makers for Groundwater Flow Models
  - Regulatory and water supply managers
    - Develop and Manage groundwater supply
    - Assessing impacts
    - Water supply planning
  - Geotechnical managers
    - Dewatering evaluations
    - Excavations, Seepage, Drainage
  - Environmental and watershed managers
    - Ecological systems
    - Climate change/Drought
    - Surface water interaction and impacts

How are GW Models being used to support decisions

- Decision Makers for Fate and Transport Models
  - Regulatory and water supply managers
    - Remediation strategies
    - Assessing potential impacts
    - Source identification
  - Environmental and watershed managers
    - Saltwater intrusion
    - Hydrogeochemistry
    - Surface water interaction and impacts

How are GW Models being used to support decisions

- Hindcast VS Forecast
  - Hindcast (Historical)
    - Changes to a calibrated model
    - Answer “what if” questions – minimize uncertainty
    - Litigation, risk, allocation, site stewardship
  - Forecast (Future)
    - Hypothetical future
    - Base case and alternative scenarios
    - More common than hindcast models

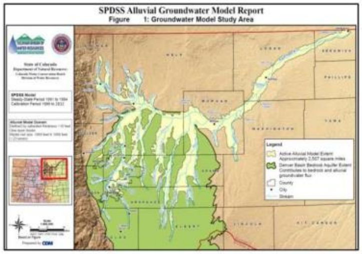
How to select the appropriate model

- **Factors to consider** when developing a model for decision-making purposes **are directly linked** to the decision being made.
- Purpose and Scale
- For more detail in model selection, see the GMAP Group 1 paper: “A Decision Framework for Minimum Levels of Model Complexity

Case Studies

- Background
- Model Selection and Development
- Decision-Making Requirements
- Results and Lessons Learned

Case Study 1 – South Platte Decision System (SPDSS) Groundwater Flow Model

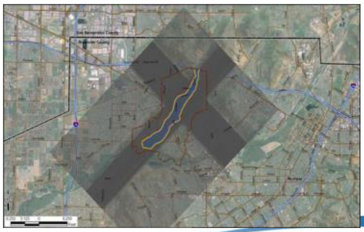


Case Study 1 – SPDSS Model

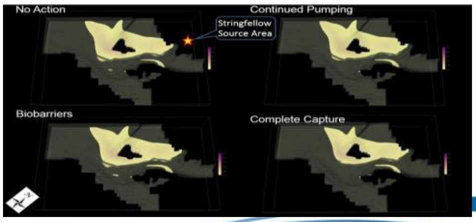
- Decision-Making Requirements
  - Develop friendly databases
  - Provide data, tools, and models
  - Promote information sharing
- Results and Lessons Learned
  - Significant benefits for having data organized and online
  - Transparent organization of data
  - Future integration with surface water/rights models

Case Study 2 – Stringfellow Superfund Site

Case Study 2 – Stringfellow Superfund Site



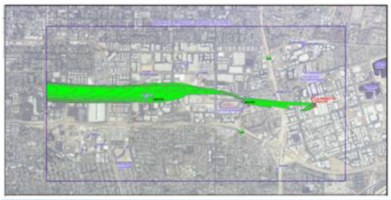
Case Study 2 - Stringfellow Superfund Site



Case Study 2 – Stringfellow Superfund Site

- Decision-Making Requirements
  - Evaluate impact on nearby extraction wells
  - Evaluate response of potential remedial alternatives
- Results and Lessons Learned
  - Simulated alternatives gave similar results
  - Finite difference grids yielded computation inefficiencies
  - Finite element or MODFLOW-USG would improve efficiency

Case Study 3 – Use of a groundwater flow and transport model to assess feasibility of aquifer storage and recovery in a contaminated setting



PCE Distribution in Response to Groundwater Recharge

Case Study 3 – ASR feasibility

- Decision-Making Requirements
  - Evaluate feasibility of ASR candidate site
  - Water management alternatives and cost allocation
  - Remedial design optimization
- Results and Lessons Learned
  - No adverse effect on PCE plume
  - An expanded monitoring network was created
  - Facilitated regulatory approval of project

Group 4 - Model Applications

Authors
- Jeff Davis – LBG Guyton
- Sean Kosinski – Integral Consulting
- Jim Finegan – Kleinfelder, Inc.
- Mary Halstead – CO Div of Water
- Jill Van Dyke – MI DEQ
- David Bean – Amec Foster Wheeler
- Mohsen Mehran – Rubicon Eng. Corp.

Reviewers
- Eve Kuniansky – USGS
- Jaco Nel – Univ of Western Cape
- Charlie McLane – McLane Environmental
- Jack Hermance – Brown Univ.

What's next?

- Climate change and approaches to changing hydrologic conditions; how to model it, and how to assess its impact on groundwater resources

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NGWA Groundwater Modeling Advisory Panel Group 1 Field Complexity

Jonathan Johnson – Ramboll Environ
NGWA Groundwater Summit, Nashville, TN
December 5, 2017

FIELD COMPLEXITY
GROUNDWATER MODELING ADVISORY PANEL

Jonathan Johnson, PhD

A DECISION FRAMEWORK FOR MINIMUM LEVELS OF MODEL COMPLEXITY

Authors	Additional Group 1 members
Bruce Hensel	Jon Johnson
Vikas Tandon	Kelton Barr
David Bean	Mike Gefell
Jim Finegan	Steve Luis
Melissa Hill	Paul Nickles
Jill Van Dyke	
Michael Alfieri	

TENSION

Decisions are based on:
- ✓ Model objective
- ✓ Hydrogeologic system features
- ✓ Chemical transport system features

Data - assumes data needs have already been addressed
Stakeholders - communication tool

TABLE A

General considerations

- Degree of detail based on model use

TABLE B

Hydrologic drivers

- Flow models
- Hydrologic features
- Type of model
  - Analytical and analytic element up to 3D cell by cell properties

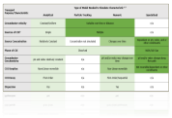
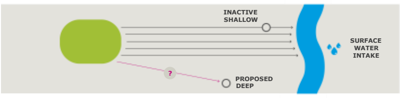


TABLE C

Fate and transport drivers

- Purpose of transport model
- Type of model
  - Analytical up to numeric reactive geochemical

EXAMPLE SITE:
SHALLOW AQUIFER, DOWNGRADIENT STREAM



1. Contamination in shallow upgradient area
2. Conceptual model: transport entirely in the shallow
3. 10 yrs consistent water level data
4. Detections in original supply well lead to shutdown and reliance on surface water extraction for water supply
5. Now elevated concentrations in surface water causes them to seek additional water source
6. Potential extraction well location in deeper zone but towards the source area

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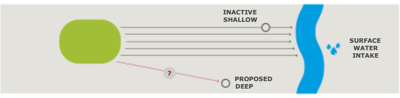
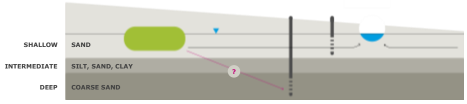
IS IT POSSIBLE FOR THE CONSTITUENTS FROM THE SOURCE TO REACH THE PROPOSED EXTRACTION WELL?





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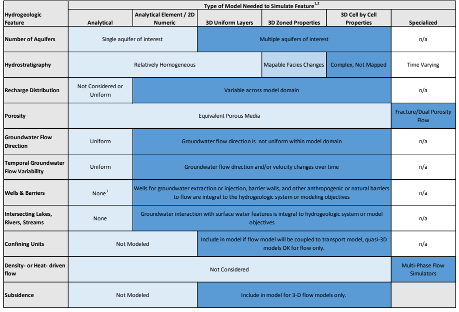
1. Model complexity increases from left to right, and with darker shading greater complexity.
2. Determine type of model needed to capture hydrogeologic complexity by using the left-most model type that fits hydrogeologic features to be modeled.
3. For non-transport applications, there are analytical models that solve for radial flow to a well

Model Complexity, Table B. Hydrogeologic Drivers



Hydrogeologic Feature	Type of Model Needed to Simulate Feature[1,2]					
	Analytical	Analytical Element / 2D Numeric	3D Uniform Layers	3D Zoned Properties	3D Cell by Cell Properties	Specialized
Number of Aquifers	Single aquifer of interest		Multiple aquifers of interest			n/a
Hydrostratigraphy	Relatively Homogeneous			Mapable Facies Changes	Complex, Not Mapped	Time Varying
Recharge Distribution	Not Considered or Uniform	Variable across model domain				n/a
Porosity	Equivalent Porous Media					Fracture/Dual Porosity Flow
Groundwater Flow Direction	Uniform	Groundwater flow direction is not uniform within model domain				n/a
Temporal Groundwater Flow Variability	Uniform	Groundwater flow direction and/or velocity changes over time				n/a
Wells & Barriers	None[3]	Wells for groundwater extraction or injection, barrier walls, and other anthropogenic or natural barriers to flow are integral to the hydrogeologic system or modeling objectives				n/a
Intersecting Lakes, Rivers, Streams	None	Groundwater interaction with surface water features is integral to hydrogeologic system or model objectives				n/a
Confining Units	Not Modeled		Include in model if flow model will be coupled to transport model, quasi-3D models OK for flow only.			n/a
Density- or Heat- driven flow	Not Considered					Multi-Phase Flow Simulators
Subsidence	Not Modeled		Include in model for 3-D flow models only.			

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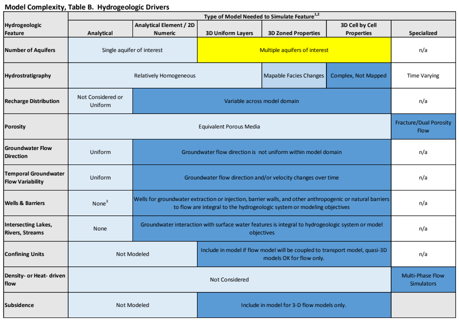

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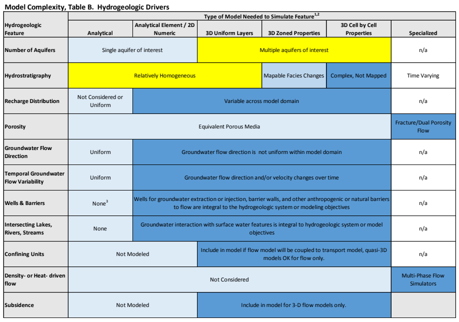

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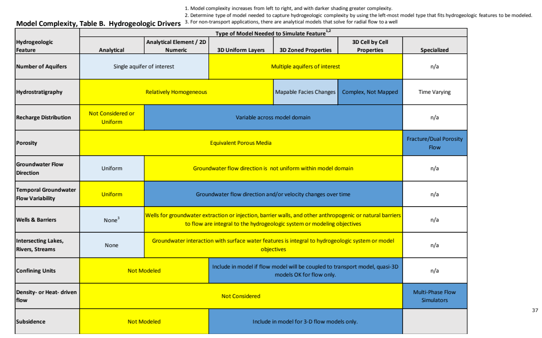

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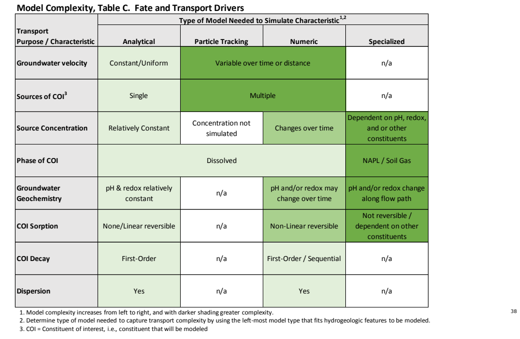

Model Complexity, Table C. Fate and Transport Drivers

Transport Purpose / Characteristic	Type of Model Needed to Simulate Characteristic[1,2]			
	Analytical	Particle Tracking	Numeric	Specialized
Groundwater velocity	Constant/Uniform	Variable over time or distance		n/a
Sources of COI[3]	Single	Multiple		n/a
Source Concentration	Relatively Constant	Concentration not simulated	Changes over time	Dependent on pH, redox, and or other constituents
Phase of COI	Dissolved			NAPL / Soil Gas
Groundwater Geochemistry	pH & redox relatively constant	n/a	pH and/or redox may change over time	pH and/or redox change along flow path
COI Sorption	None/Linear reversible	n/a	Non-Linear reversible	Not reversible / dependent on other constituents
COI Decay	First-Order	n/a	First-Order / Sequential	n/a
Dispersion	Yes	n/a	Yes	n/a

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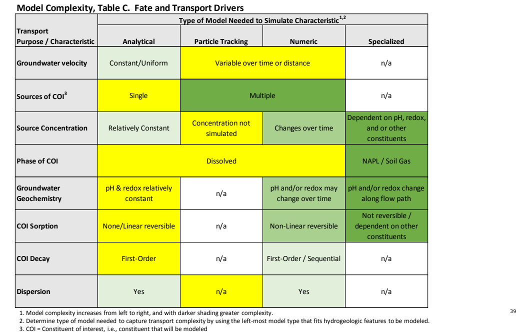
3. COI = Constituent of interest, i.e., constituent that will be modeled



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THANK YOU
QUESTIONS?

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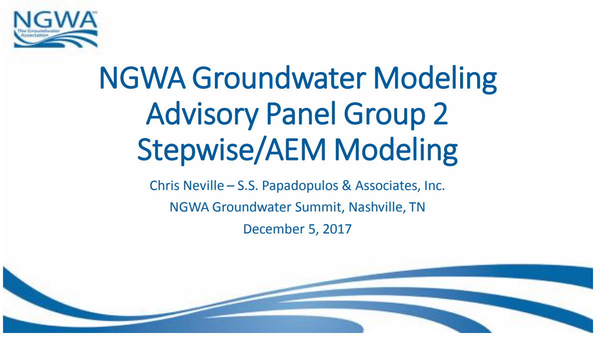
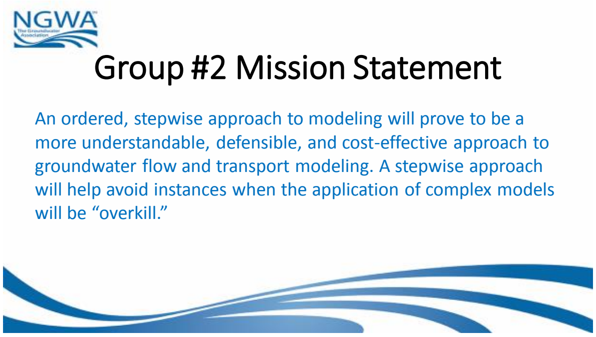
RAMBOLL ENVIRON



NGWA Groundwater Modeling Advisory Panel Group 2 Stepwise/AEM Modeling

Chris Neville – S.S. Papadopulos & Associates, Inc.
NGWA Groundwater Summit, Nashville, TN
December 5, 2017



Group #2 Mission Statement

An ordered, stepwise approach to modeling will prove to be a more understandable, defensible, and cost-effective approach to groundwater flow and transport modeling. A stepwise approach will help avoid instances when the application of complex models will be “overkill.”

Group #2

The team:

David Bean
Charlie McLane
Jack Hermance
Jill Van Dyke
Chris Neville

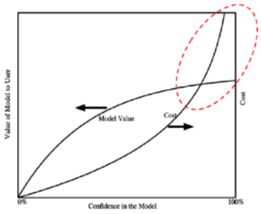
The coaches:

Chuck Job
Henk Haitjema
Randy Hunt
Bob Schreiber

Groundwater Modeling-Paper 2.pdf: A Stepwise Approach to Groundwater Modeling

- Motivation: The value of a model
- Putting our modeling tools in perspective
- The key questions modelers must ask themselves
- Progression of modeling steps
- A suggested stepwise groundwater modeling process
- Benefits of a stepwise approach to groundwater modeling
- What else in the Group #2 White Paper

The Value of a Model, and when to Stop

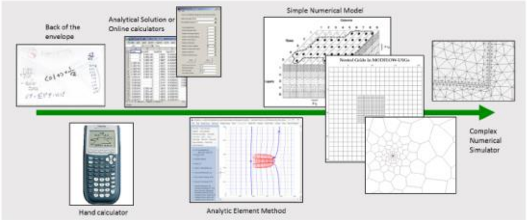


Unnecessary expenditure zone

In incorporating more complexity, striving for a better answer, and reducing uncertainty, it is possible to go too far. This represents an unnecessary expenditure of resources, and marginalizes the value of the modeling exercise.

Source: Hassan (2003)

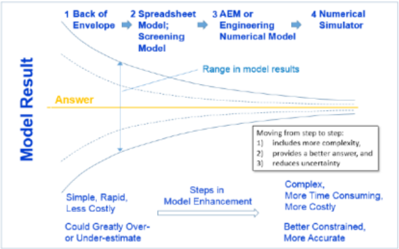
Spectrum of Modeling Tools



Key questions modelers must ask themselves

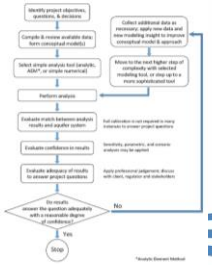
1. Why is the modeling being conducted?
2. What degree of model complexity is required for this model application?
3. Are sufficient data available to support the required degree of complexity?
4. Are the costs of acquiring new data warranted?
5. Will the additional insight that may be gained from more data and a more complex analysis prove cost-effective in terms of the objectives of the model application?

Progression on Modeling Steps



Moving from step to step:
1) includes more complexity,
2) provides a better answer, and
3) reduces uncertainty

Stepwise Groundwater Modeling Process



Selected Benefits of a Stepwise Approach (1)

1. Stepwise incorporation of model complexity allows the modeler to test the effects of individual features on the model response, added one at a time.
2. Starting simply can provide answers to the rest of the team while there is still enough budget to do something with, or about, the modeling results.
3. Stepwise modeling that begins with a simple analytic or analytic element model can "cover a lot of ground," incorporating far field hydrologic features without the necessity of gridding or meshing all of that model space (e.g., Haitjema 1992).

Selected Benefits of a Stepwise Approach (2)

When you implement a stepwise approach, one of two things may happen:

1. You will reach an acceptable answer after a few steps (of increasing complexity), and you will thus save time and money for your project and your client.
2. You will continue a phased approach until you have developed a complex model.

This outcome may cause some to question the wisdom of following the stepwise approach—but in taking this path you will have gained much more insight along the way, have made all the right decisions in developing and executing the model, and will understand the results on a deeper level.

What else is in Group #2 White Paper?

1. Capsule summaries of case studies
2. Extensive references and suggestions for further reading
3. Details on the spectrum of modeling tools and the progression of modeling steps
4. A discussion of when to stop
5. Lots more benefits of a stepwise approach

NGWA Groundwater Modeling Advisory Panel Group 3 Model Uncertainty

Steve Luis – Ramboll Environ
Rod Sheets – US Geological Survey
NGWA Groundwater Summit, Nashville, TN
December 5, 2017

Motivating Questions

1. Why do we need uncertainty analysis?
2. What are the approaches for managing uncertainty?
3. What are the benefits of uncertainty analysis?
4. How do we communicate with stakeholders about uncertainty?

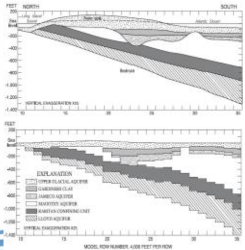
Why Do We Need Uncertainty Analysis?

Origins of uncertainty

- Gap between model and reality
- Limited subsurface observations

Uncertainty analysis helps

- Identify data needs
- Identify parameters to refine
- Plan next steps in model development
- Provide basis for more formal decision analysis
- Manage expectations of stakeholders – typically *not* modelers



Reilly and Harbaugh, 2004

What Are the Approaches for Managing Uncertainty?

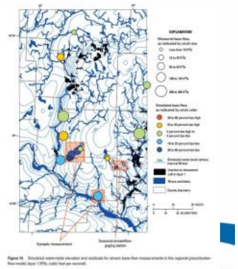
- Methods
  - Sensitivity Analysis
  - Parameter Sensitivity Analysis
  - Scenario Sensitivity Analysis
- Tools
  - Basic Scenario Analysis
  - Monte Carlo Methods
  - Generalized Likelihood Uncertainty Evaluation (GLUE)
  - Bayesian Uncertainty Analysis

What Are the Benefits of Uncertainty Analysis?

Uncertainty analysis helps us understand

- Strengths and weaknesses of the model
- Reliability of model predictions
- Connection between data availability and model reliability
- Quantification of model limitations

Uncertainty analysis provides more information than calibration alone



How Do We Communicate with Stakeholders About Uncertainty?

- Employ everyday language easy for non-modelers to understand
- Be relevant to the decision at hand
- Discuss potential consequences of results being incorrect
- Use language that reflects the practitioner's assessment of uncertainty and confidence in the reliability of the analysis
- Graphics!

Table 1. Likelihood Scale

Term*	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

USGS

Prepared in cooperation with the San Antonio Water System

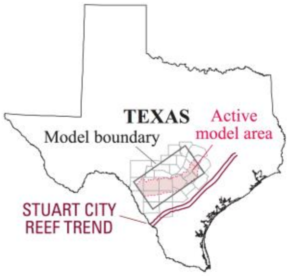
New Insights into the Edwards Aquifer—Brackish-Water Simulation, Drought, and the Role of Uncertainty Analysis

Key Findings

What was the focus of the model?

USGS FAC

2016-3



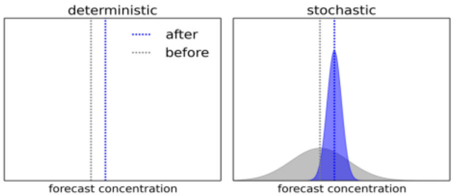
4,000+ Parameters and >8000 observations

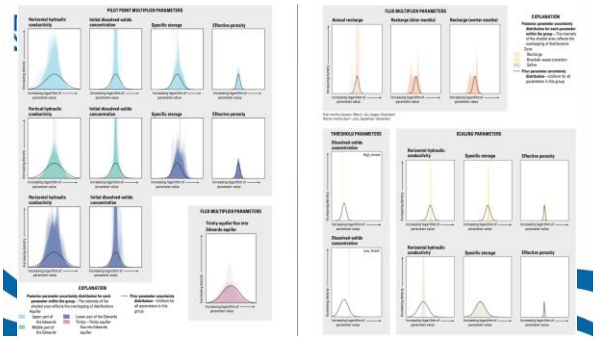
- Pilot point multiplier parameters for Kh, Kv, storage, effective porosity, and initial concentrations
- Trinity influx, recharge, karstic alteration and spring parameters
- Water levels and spring discharge

Parameter Uncertainty

History matching **does not eliminate** parameter uncertainty...

How much do we know about all of these parameters?





Groundwater Modeling Advisory Panel – Uncertainty Subgroup

- Steve Luis – Ramboll Environ
- Peter Schulmeyer – Collier Consulting
- Rod Sheets – US Geological Survey
- Paul Martin – Matrix Solutions
- Michael LeFrancois – Arcadis
- David Bean – Amec Foster Wheeler
- Dan Puddephatt – GHD
- Connor Newman – Nevada Division of Environmental Protection

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NGWA Groundwater Modeling Advisory Panel Group 5 Integrated SW/GW Modeling

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Peter Mock – Peter Mock Groundwater Consulting, Inc.
NGWA Groundwater Summit, Nashville, TN
December 5, 2017

Integrated SW/GW Modeling

- integrated SW/GW models are tools that provide us an opportunity to better simulate the hydrologic cycle as part of groundwater analysis
- but, they require a lot more data
- the decision to use an integrated SW/GW model should consider:
  - the physical hydrologic processes that affect the site
  - the role of landscapes and hydroclimate in parameterizing the system
  - the computer modeling codes that are available
  - how these codes represent the hydrologic processes in simulating the flow of water through the site

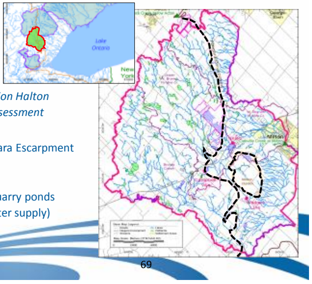
Integrated SW/GW Modeling

- there are 3 commonly used methods for integrating SW/GW models:
  1. manually-linked models (e.g. SWMM/MODFLOW, SWAT/MODFLOW, …)
     - separate surface water and groundwater models are set-up & simulated independently and calibrated to common observation data
  2. coupled models (e.g. GSFLOW – which combines PRMS/MODFLOW)
     - the hydrologic and hydrogeologic systems are integrated through boundary condition links, which is solved using iterative matrix solution methods
  3. fully-integrated models (e.g. HydroGeoSphere, ParFlow, CATHY, …)
     - simultaneously solves the governing equations for SW flow (rainfall-runoff) and GW flow (infiltration-groundwater flow-discharge)

Integrated SW/GW Modeling

- this paper provides a simple discussion of:
  - the conceptual model of surface water-groundwater interaction
  - the various data that are required to describe it
  - the numerical models that are available to represent it
- next steps:
  - find test case models from industry which use the aforementioned software
  - present the data that was used to develop the numerical models
  - discuss the model development process
  - discuss the simulation results

Integrated SW/GW Modeling

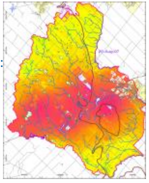


- Model 1: Milton GSFLOW Model
  - 50 km east of Toronto, ON
    - developed by EarthFX for *Conservation Halton*
    - to aid in *Source Water Protection Assessment*
  - model study area includes:
    - 3 watersheds that transect the Niagara Escarpment
    - 475 km of streams
    - 275 lakes and wetlands
    - 2 managed reservoirs and several quarry ponds
    - 2 major wellfields (for municipal water supply)

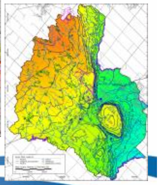
Integrated SW/GW Modeling

- GSFLOW model comprised of:
  - PRMS sub-model (fully-distributed):
    - climate data
    - soil properties
    - land cover
    - topography
  - MODFLOW-NWT sub-model:
    - variable grid
    - hydrostratigraphic unit interfaces
    - lakes and wetlands for PRMS runoff
    - groundwater recharge and discharge

PRMS Infiltration



MODFLOW Heads



Integrated SW/GW Modeling

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http://www.ngwa.org/pubs/Pages/white-papers.aspx