Model Objectives?

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USGS
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Goal of this talk

Asking you to help choose modeling objectives

That are specific enough to guide model design

We'll try to explain why they are important and why earlier is better

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Contents

The role of objectives in model development

Possibilities for Big Lost

Discussion / Brainstorm

The Role of Objectives in Model Development

Why these things matter and why we should set them early

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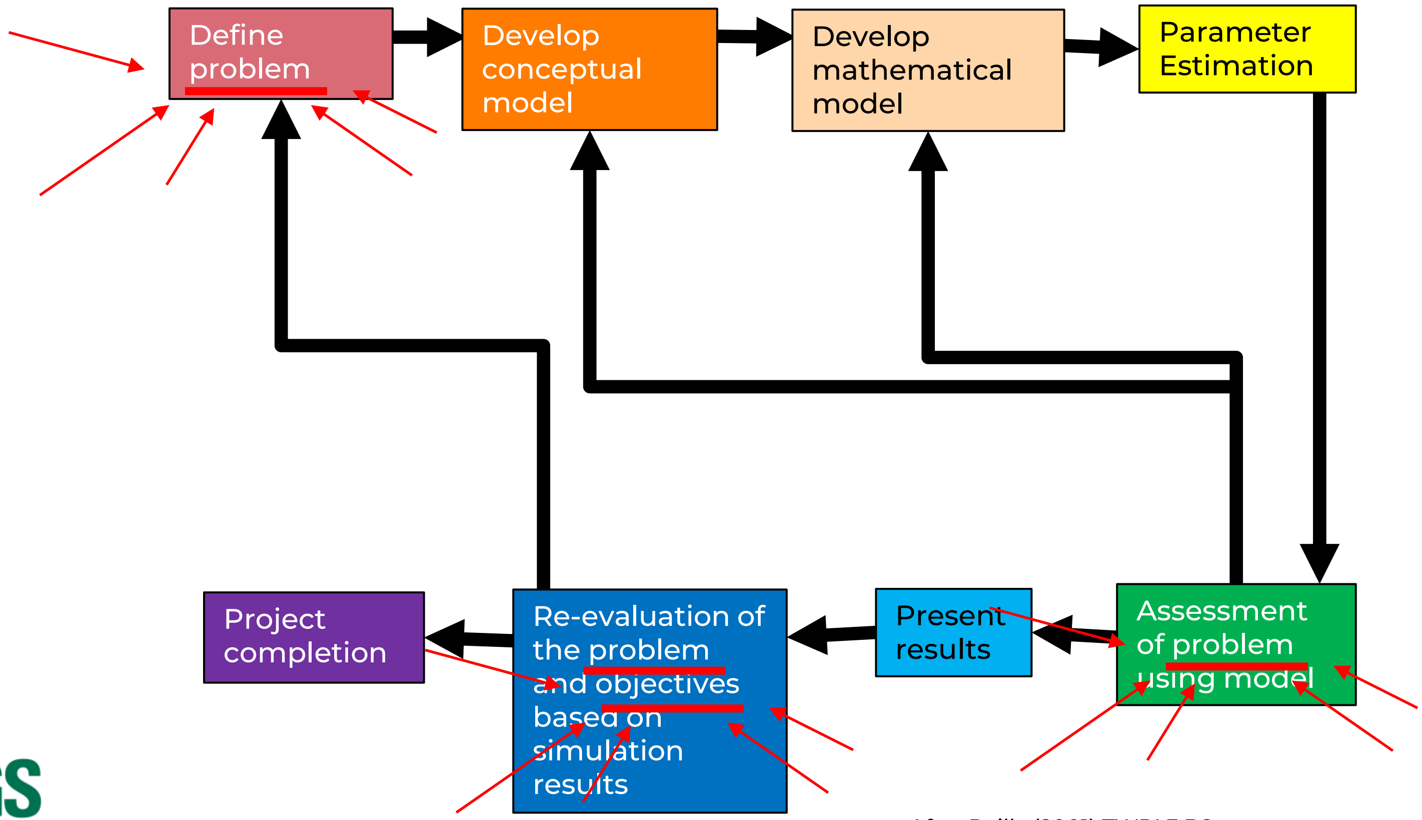
Objectives are key to a focused modeling effort



After Reilly (2001) TWRI 3,B8

Let’s try to be specific

“A model that can help us understand groundwater resources and serve as a tool for water resource planning and management. “

What aspect of the resource do you want to understand?
Groundwater levels?
Changes in streamflow?
Are you afraid that doing *some thing* will impact these?
Where?
When?
…

General vs. Specific

General

Model's can have long lives with unexpected applications. We should ensure the model is adaptable.

- Can simulate SW/GW interactions
- Can simulate impact of new wells
- Won't be too hard to adapt for contaminant transport

Specific

Specific objectives will require the model to include certain features. $$$ is being spent to build this model now. Why?

- If we add a large new production well next to the Big Lost River, how will it impact streamflow? What is the timing of the impacts?
- A new municipal well is proposed at X,Y and will pump at a rate of X. What is the maximum drawdown at this other well? In what month does it occur? What if the well were located elsewhere?

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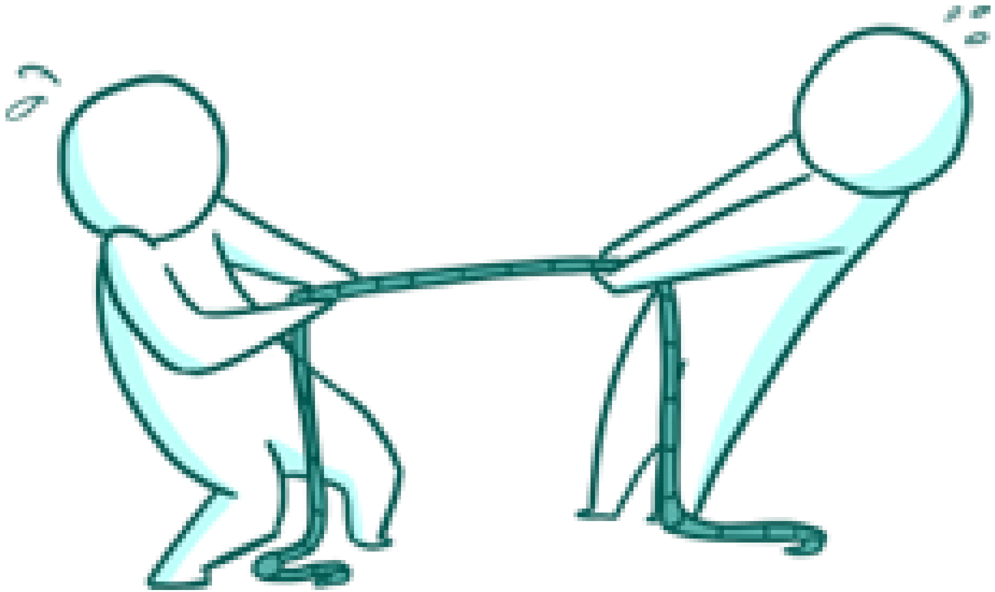
Model Design Tradeoffs

Complexity can be necessary to accurately simulate aspects of the physical system, but it comes at a **cost**. Let’s only add



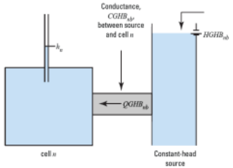
Level of Complexity Chosen to Meet Objectives

Don't add complexity for the sake of realism. Add only as needed to enable model to meet objectives.

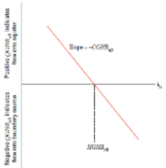
Specified Head

Specified Flux

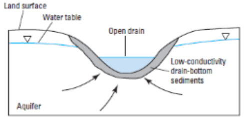
General Head



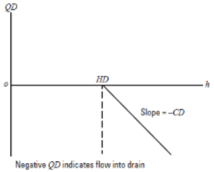
$$QGHB_{nb} = CGHB_{nb}\left(HGHB_{nb} - h_n\right)$$



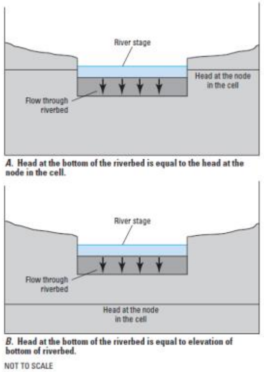
Drain



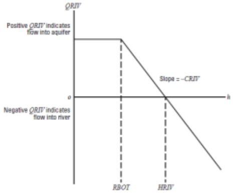
$$QDRN_{nb} = CDRN_{nb}\left(HDRN_{nb} - h_n\right), \quad h_n > HDRN_{nb}$$
$$QDRN_{nb} = 0, \quad h_n \le HDRN_{nb}.$$



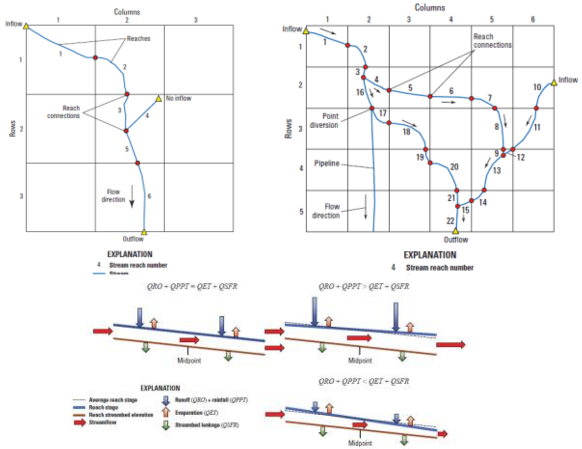
River



$$QRIV_{nb} = CRIV_{nb}\left(HRIV_{nb} - h_n\right), \quad h_n > RBOT_{nb}$$
$$QRIV_{nb} = CRIV_{nb}\left(HRIV_{nb} - RBOT_{nb}\right), \quad h_n \le RBOT_{nb}.$$



Stream Flow Routing



$$QSFR_{nb} = S^{*}_{SFR,nb}\frac{K_{nb}L_{nb}W_{nb}}{b_{nb}}\left(HSFR_{nb} - h_n\right)$$

$$Q_{mdpt_{nb}} = QSRI_{nb} + QTRB_{nb} + QMVR_{nb} + 0.5\left(QRO_{nb} + QPPT_{nb} - QET_{nb} - QSFR_{nb}\right)$$

$$D_{nb} = \left[\frac{Q_{nb}n_{nb}}{C_u W_{nb} S_{0_{nb}}^{1/2}}\right]^{3/5}$$

$$QSFR_{nb} = QSRC_{nb} \quad \text{if } QSFR_{nb} \ge QSRC_{nb}$$
$$QSFR_{nb} = S^{*}_{SFR,nb}CSFR_{nb}\left(HSFR_{nb} - SBOT_{nb}\right) \quad \text{if } QSFR_{nb} < QSRC_{nb},$$

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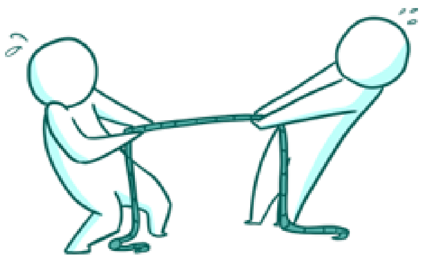
Model Design Tradeoffs

Model objectives tell us how to navigate these tradeoffs.

Detail
Greater complexity to get closer behavior of the natural system

Accuracy
Does complexity yield more accuracy OR does it hobble parameter estimation and degrade accuracy?



Usability
How easy/hard to understand and to use for different scenarios

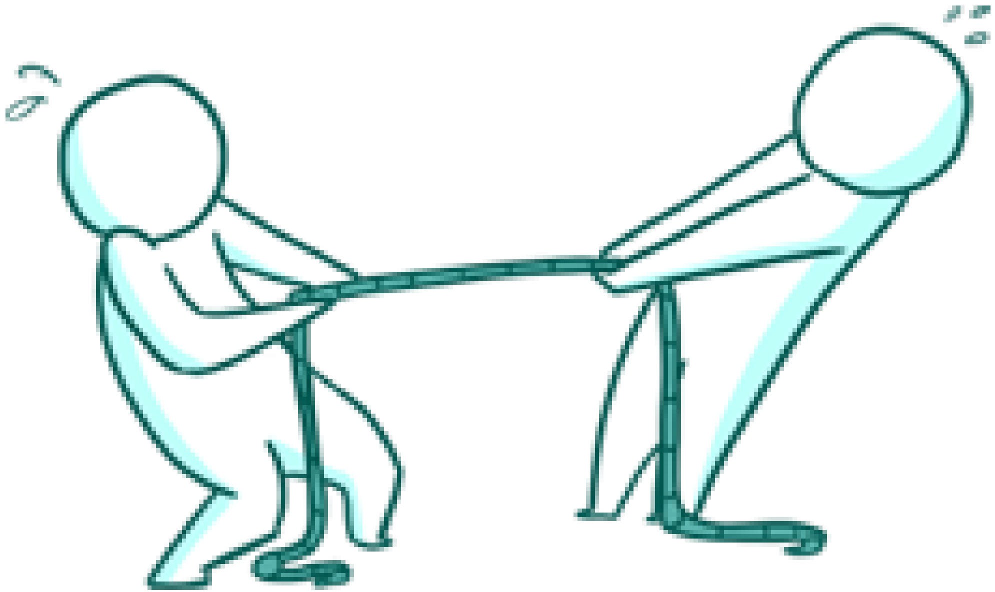
Runtime
Can we properly estimate parameters?
Uncertainty?
Test different designs?

Effort
Time / money to build and update
Will it prevent further use?

Stability
How robust is the solver for this problem?
Is it fragile? Will changes cause non-convergence?

Model Design Tradeoffs

Models are simplifications, in which errors are inevitable. **Improving one aspect of the model may harm another**. Model objectives tell us how to navigate these tradeoffs.



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Jake's turn...

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Role of objectives in model development

We didn’t come to these conclusions on our own.

ground water

Guest Editorial/

Modeling: Picture Perfect or Abstract Art?

by John Doherty[1,2]

In a landmark paper, Freeze et al. (1990: Freeze, R.A., J. Massmann, L. Smith, T. Sperling, and B. James. Hydrogeological decision analysis: 1 A framework. *Ground Water* 28, no. 5:738–766) discussed the role of models in environmental decision-making. A decision must address the fact that something bad may happen. We may be willing to pay a price to reduce the likelihood of its occurrence. How much we are prepared to pay depends on the cost of its occurrence, and on the amount by which its likelihood can be reduced through preemptive management.

The role of modeling in this process is to assess likelihood. This must not be confused with predicting the future. Modeling should constitute a scientific expression of our ignorance rather than a claim to knowledge that we do not possess. When it makes a prediction, a model cannot promise the right answer. However, if properly constructed, a model can promise that the right answer lies within the uncertainty limits which are its responsibility to construct. Obviously these limits should be as narrow as possible, given local expert knowledge and the information content of site-specific data. Extraction of maximum information from that data during the history-matching process through which uncertainty limits are constrained through replication of historical system behavior is therefore an integral part of the modeling process.

From these considerations it is at once apparent that if a model is to attain its decision-support potential it cannot be used on its own. Instead it must “dance” with equally sophisticated software which facilitates parameter estimation and uncertainty analysis. Together these two packages must strive to endow the modeling process with the ability to encapsulate that which can be known of a system while quantifying that which cannot. Together they should therefore create a context in which cooperative decision-making can take place, with risks of unwanted eventualities neither over-estimated nor given insufficient recognition.

So why do we not embrace models as tools for encapsulating our knowledge and quantifying our ignorance? One reason is that human beings have always wanted to “see” the future as if the veil of time were lifted. In pursuing this time-honored endeavor, complex models are the current prophetic tool of choice. However, complex models are cumbersome; they take too long to run; they teeter on the brink of numerical instability; and their outputs are contaminated by numerical noise. Hence they make poor dancing partners for parameter estimation and uncertainty analysis software. Nevertheless they do make good receptacles for expert knowledge, for they are built of pieces that are recognizable. Simple models, on the other hand, are fast and stable—and they can dance. With proper tuning, their outputs may fit field data well. Hence they are capable of extracting information from that data. But the receptacles into which that information flows are often unclear; receptacles for expert knowledge may be vague or nonexistent.

It is obvious that there is a tension here. It follows that a site-specific compromise between model simplicity and complexity must always be found if the modeling process is to provide the optimal basis for decision support at a particular location, in relation to a particular issue. However, all too often complexity wins the day—often for no other reason than to preemptively circumvent criticism that the model does not “look like” what we imagine reality to look like.

Learning how to define and locate the optimal compromise between simplicity and complexity is one of the biggest problems facing current modeling practice. Unfortunately our industry fosters a culture that makes it too easy to discredit a model that does not resemble a picture from a geological textbook, and too hard to accept one that entails incisive abstraction, notwithstanding the latter’s demonstrable superiority in extracting information from (often expensively acquired) site data. However, a model deserves criticism only when it fails to achieve the only thing that it has a right to claim—quantification of uncertainty and maximum reduction of uncertainty through optimal processing of environmental data. “Picture perfect” rarely equates to optimality in either respect.

Editor’s Note: Opinions expressed are the author’s and not necessarily those of the National Ground Water Association.

[1]National Centre for Groundwater Research and Training, Flinders University, Australia; johndoherty@ozemail.com.au
[2]Watermark Numerical Computing, Brisbane, Australia.

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Groundwater

Technical Commentary/

Forecast First: An Argument for Groundwater Modeling in Reverse

by Jeremy T. White

Introduction

Numerical groundwater models are important components of groundwater analyses that are used for making critical decisions related to the management of groundwater resources. In this support role, models are often constructed to serve a specific purpose that is to provide insights, through simulation, related to a specific function of a complex aquifer system that cannot be observed directly (Anderson et al. 2015).

For any given modeling analysis, several model input datasets must be prepared. Herein, the datasets required to simulate the historical conditions are referred to as the calibration model, and the datasets required to simulate the model’s purpose are referred to as the forecast model. Future groundwater conditions or other unobserved aspects of the groundwater system may be simulated by the forecast model—the outputs of interest from the forecast model represent the purpose of the modeling analysis. Unfortunately, the forecast model, needed to simulate the purpose of the modeling analysis, is seemingly an afterthought—calibration is where the majority of time and effort are expended and calibration is usually completed before the forecast model is even constructed. Herein, I am proposing a new groundwater modeling workflow, referred to as the “forecast first” workflow, where the forecast model is constructed at an earlier stage in the modeling analysis and the outputs of interest from the forecast model are evaluated during subsequent tasks in the workflow.

The Traditional Workflow for Groundwater Modeling Analysis

Groundwater modeling analyses typically follow, with little deviation, the progression shown in Figure 1A. This groundwater modeling workflow focuses on history matching—that is, reproducing what is already known—but affords many opportunities to overlook elements important to the model’s purpose. For example, during conceptual model development, practitioners may need to decide how to conceptualize surface water features. Is a simple head-dependent flux boundary condition sufficient? Or should a more rigorous representation be used? Although others have demonstrated the importance of surface water system representation in certain modeling analyses (e.g., Mitchell-Bruker and Haitjema 1996), here I am concerned with how the surface water system representation may affect the purpose of the model. In the traditional modeling analysis workflow, this decision is made during construction of the calibration model datasets and may be revisited during model calibration; several factors may influence the choice of how to conceptualize surface water features. For example, the surface water system representation may be chosen on the basis of model run time. A novice practitioner may choose to represent the surface water system by speculating how it may affect the calibration process. An experienced practitioner may choose to represent the surface water system by speculating how the surface water system may affect the model’s purpose. Unfortunately, even the experienced practitioner must rely on expert judgment; it is not possible to directly evaluate how the surface system representation may affect the simulated forecast(s) because in the traditional workflow, the forecast model has not yet been constructed (Figure 1A).

Following construction of the calibration model datasets, some form of calibration is undertaken, a process where model inputs are adjusted until the model outputs acceptably match historical system conditions. Most modern modeling analyses will employee some form of formal parameter estimation. At the start of the parameter estimation process, model inputs must be “parameterized,” that is, identified as uncertain and, therefore, selected for adjustment. Furthermore, an objective function, representing how the model should reproduce the past, must be formed (Anderson et al. 2015). The tasks of parameterization and objective function formulation

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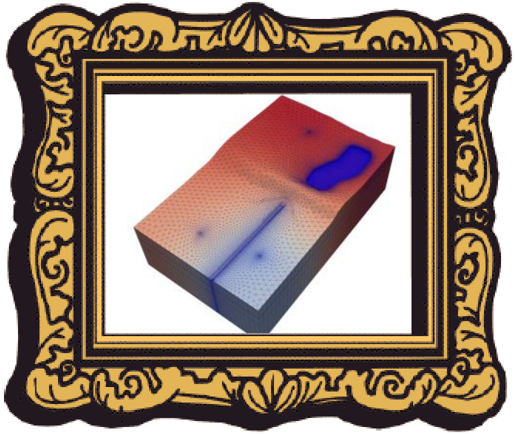

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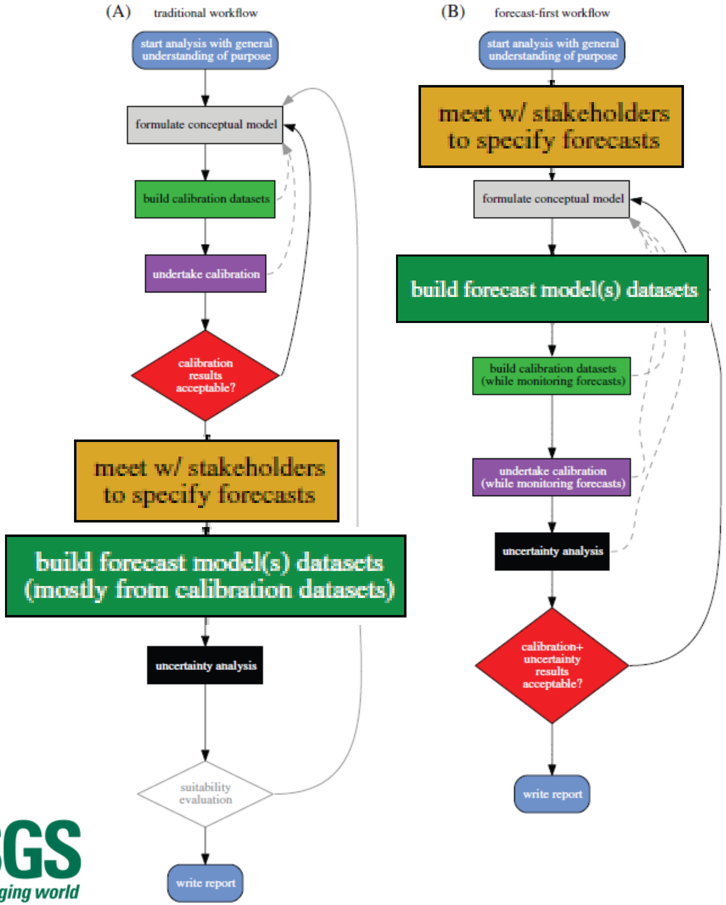
Role of objectives in model development



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… back to Stephen

Example Big Lost Model Objectives

And scenarios

Project Basics

Timeline
Now – July 2025

Products
Groundwater flow model
Details to be decided and discussed with MTAC

Two Scenarios
Details to be decided and discussed with MTAC

Model Report
USGS Scientific Investigation Report (SIR)

Data Release
USGS *ScienceBase* web page (*www.sciencebase.gov*)
Model
Scenarios
Input data
Scripts and tools for pre and post processing
Software tools for running scripts and other tools

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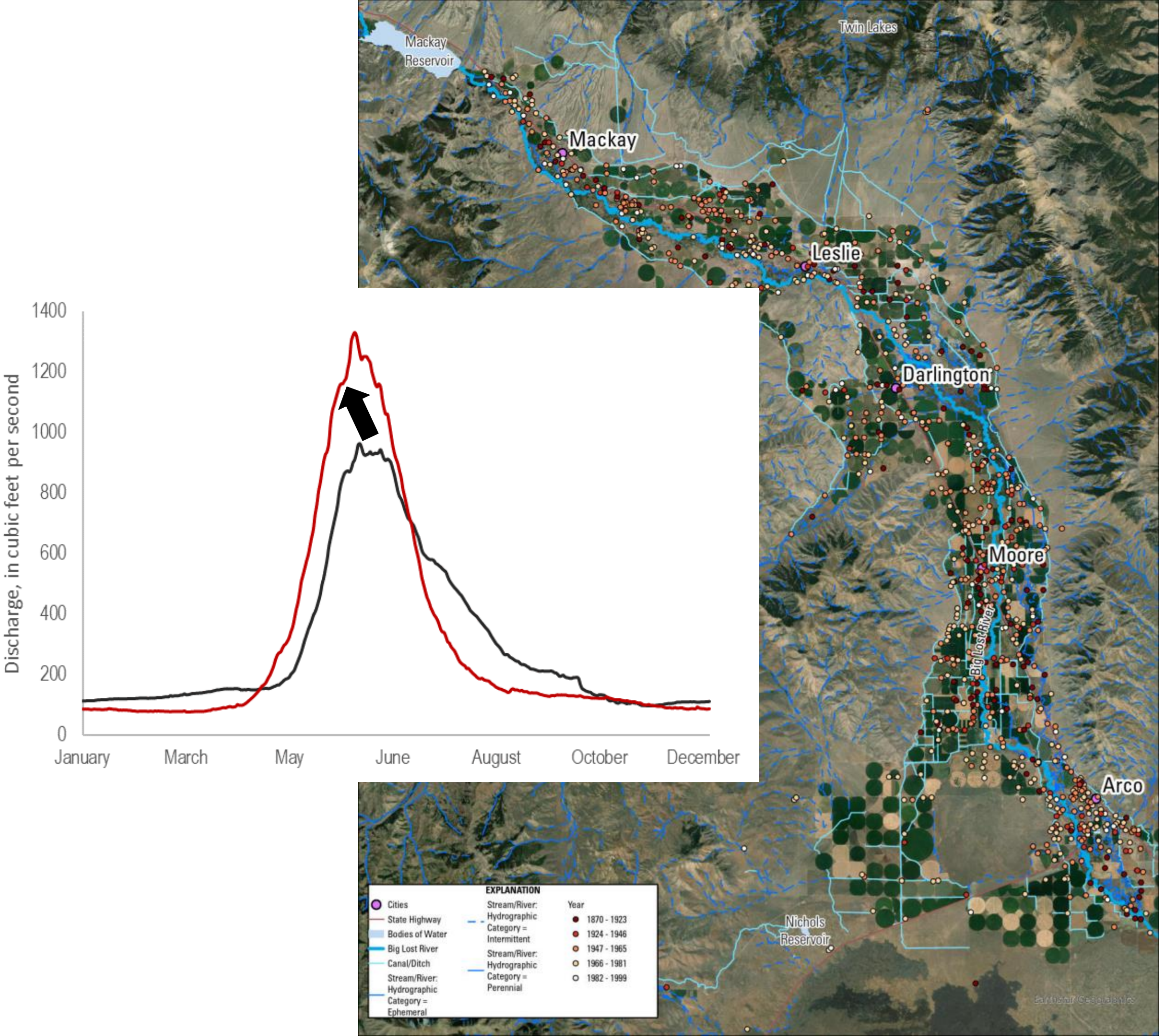
Disclaimer

We have not decided anything yet. These are presented only as examples. Our aim is to get the conversation started by providing some specific ideas that may garner feedback.

Reduced Mackay Storage Capacity

Reservoir storage loss due to infill; impact on surface water and groundwater flows

- Estimate rate of decrease in reservoir storage capacity
- Calculate timing and magnitude of future delivery reductions
- Assign reductions based on water rights priority
- Simulate supplementary pumping as needed and as allowed



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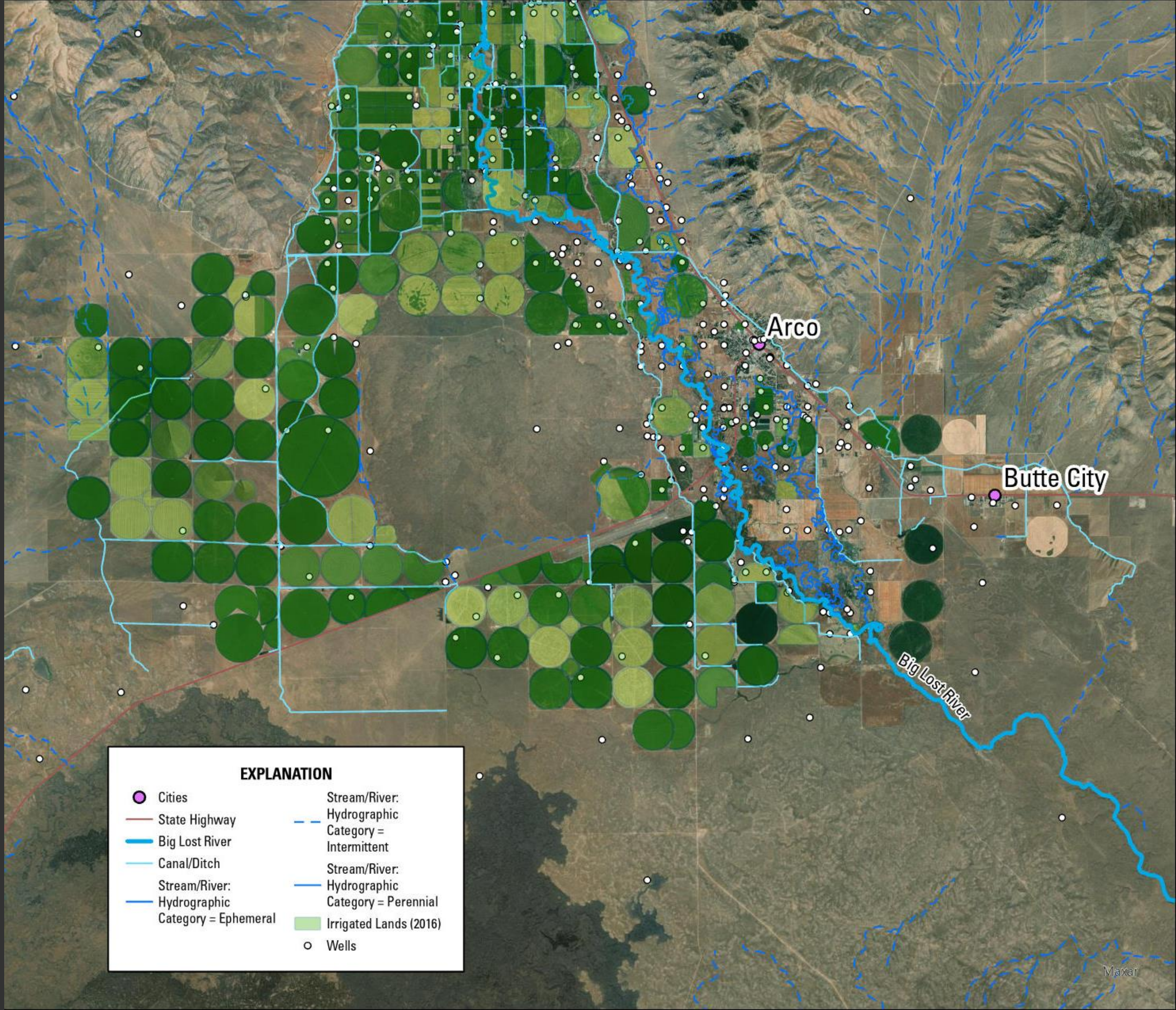
Climatic shift

Climatic shift from 'norm' to 'new norm'; impacts of surface water flows and gw levels

- Representing earlier runoff
- Lower soil moisture
- Increased ET



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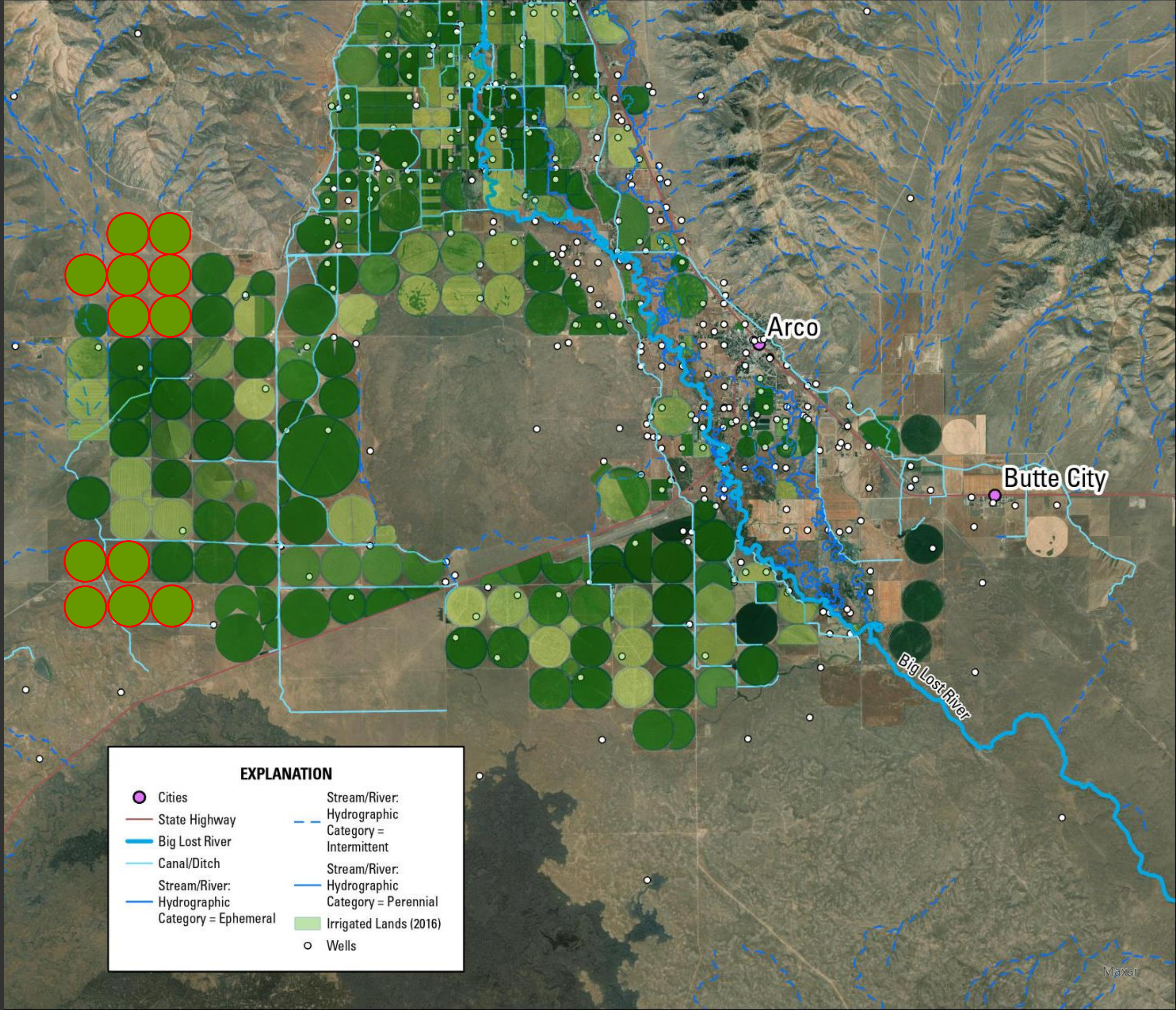
Shift of Agricultural Practices

Change in practice or area of agriculture; impacts on surface water flows or gw levels

- Modification of farming techniques
- Expansion of irrigated area
- Change in crop types
- Modernization of equipment to prevent excess irrigation
- Reduction of incidental recharge, drain return flows



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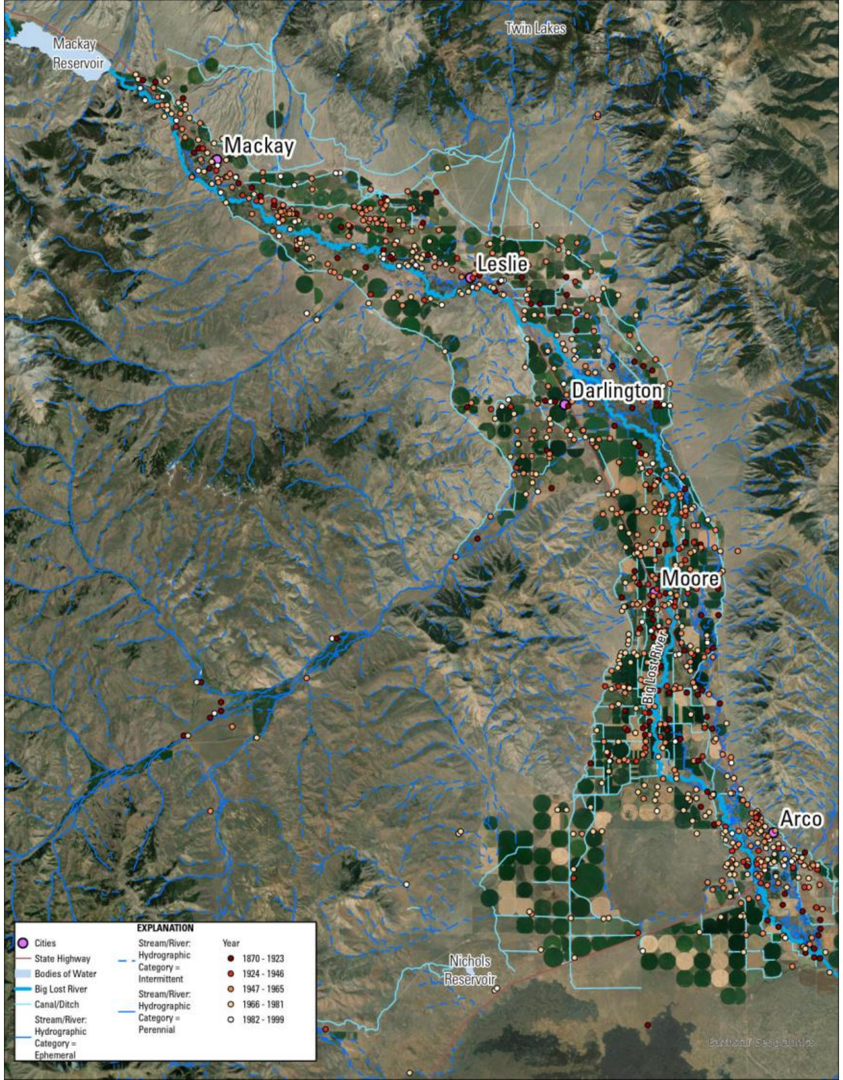
Water Call

Curtailment of junior gw rights; impacts on water availability to senior rights

- Hindcast and/or forecast streamflow capture calculation
- Run model with and without individual groups of wells to calculate discharging from wells being sourced from stream/canal seepage



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Discussion / Brainstorm

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Summary and Questions

Summary:
- A model can't do everything
- Objectives drive design decisions
- We should choose objectives early

What do you think?
- Any ideas of objectives or scenarios?
- Did you dislike any of the objectives or scenarios that we mentioned?

What do you want from us?
- More suggestions?
- Other examples?

Thanks!

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