How to represent human-water processes in land-surface models: Current state and ways forward

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Including water Management in large-scale models

Gif-Sur-Yvette, 28-30 September 2016

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Human as a key hydrological driver during the "Anthropocene"

Pokhrel et al. (WIREs Water, 2016)

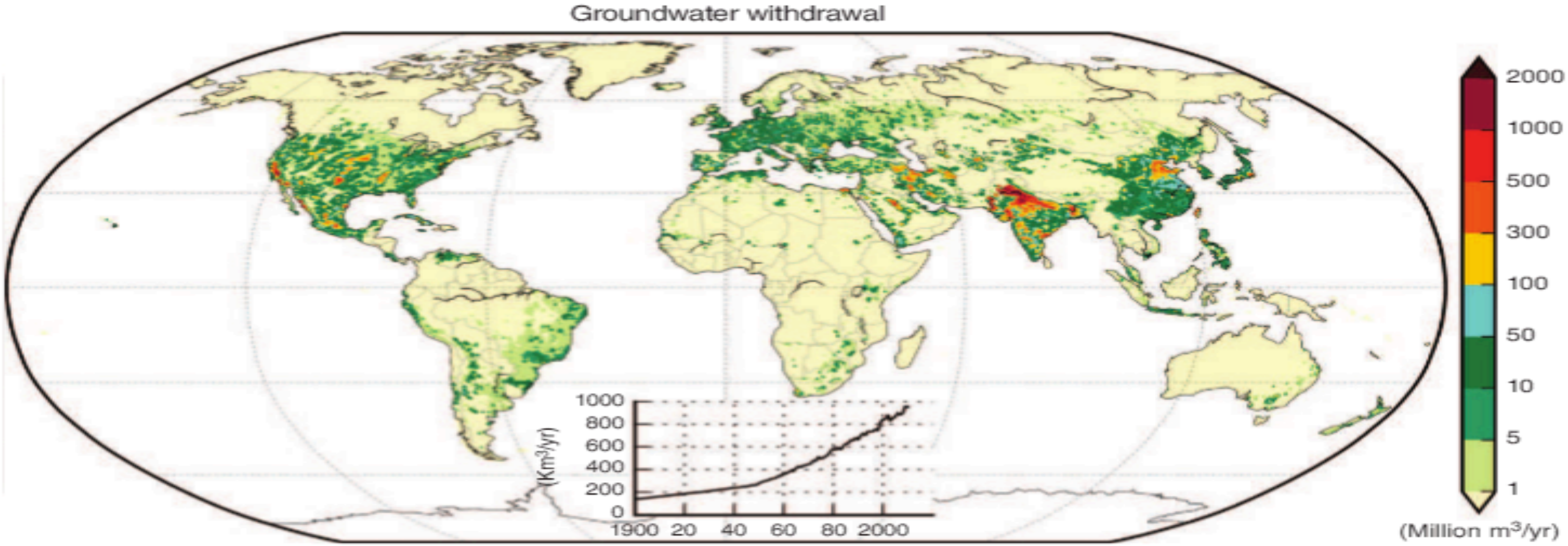


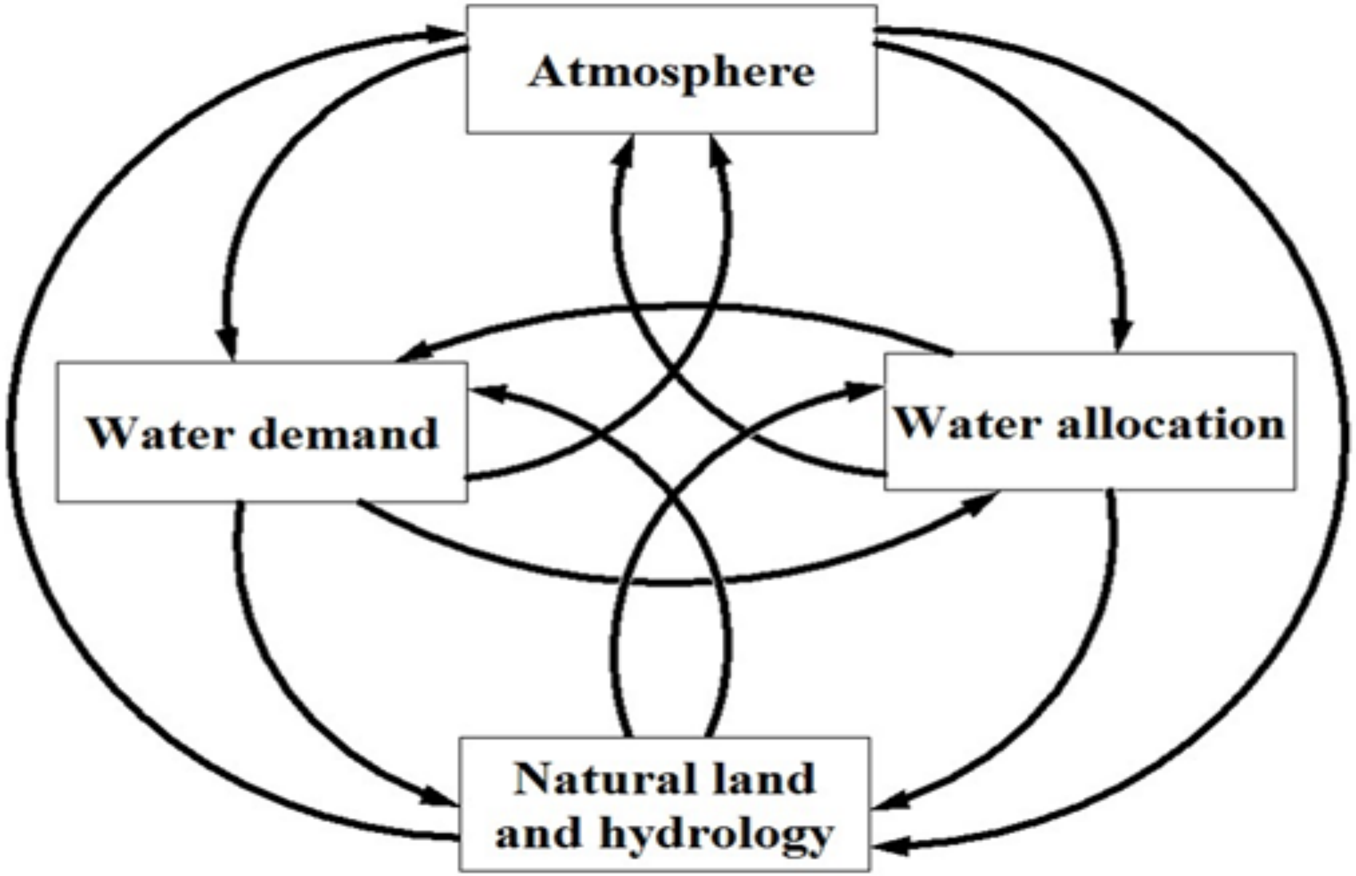
FIGURE 5 | Groundwater withdrawals per 0.5 degree grid cell for circa 2000, compiled by Wada et al.[13] based on the groundwater database of the International Groundwater Resources Assessment Centre (IGRAC). The inset depicts the time series of global total withdrawals from 1900 to 2010.

Key challenges in including human-water processes in large-scale models

1. Including human-water processes requires extending the scope of large-scale modeling.
2. There is a mismatch between the scales in which human-water processes take place and the scale of large-scale models.
3. Including human-water processes in large-scale models requires new process representations.
4. A wide spectrum of natural and anthropogenic drivers can influence the interrelation between man and water.
5. Data support is limited.

Water resource management as an emerging element of terrestrial water cycle

- Human-water processes are largely manifested by water resource management.
- Water resource management can be considered as the combinations of activities around anthropogenic water use, water supply and water allocation.



Taxonomy of current representations of water resource management in large-scale models

- **<u>Type of element</u>**
  e.g., water demand *vs.* water availability *vs.* water allocation
  Irrigation *vs.* industrial demand
  Groundwater vs. surface water
- **<u>Type of approach</u>**
  e.g., top-down *vs.* bottom-up approach
- **<u>Type of conceptualization</u>**
  e.g., irrigation demand as a function of soil moisture content *vs.* evapo(transpi)ration
- **<u>Type of simulation</u>**
  e.g., historical simulation *vs.* future projections
  Regional *vs.* global simulation
- **<u>Type of host models</u>**
  e.g., GHMs *vs.* LSMs
- **<u>Type of inclusion</u>**
  e.g., online *vs.* offline

Part I. Water demand
Type of demand: Irrigation
Modeling approaches

• Top-down estimation of irrigation demand

Information at coarse spatial and temporal scales

Census data
(e.g., FAO-AQUASTAT)

Models' outputs
(e.g., GCAM)

Included in offline and online modes. Simulated under historical and future scenarios regionally and globally.

Land-use, technologic, socio-economic and climatic proxies

Irrigation water demand at the grid scale

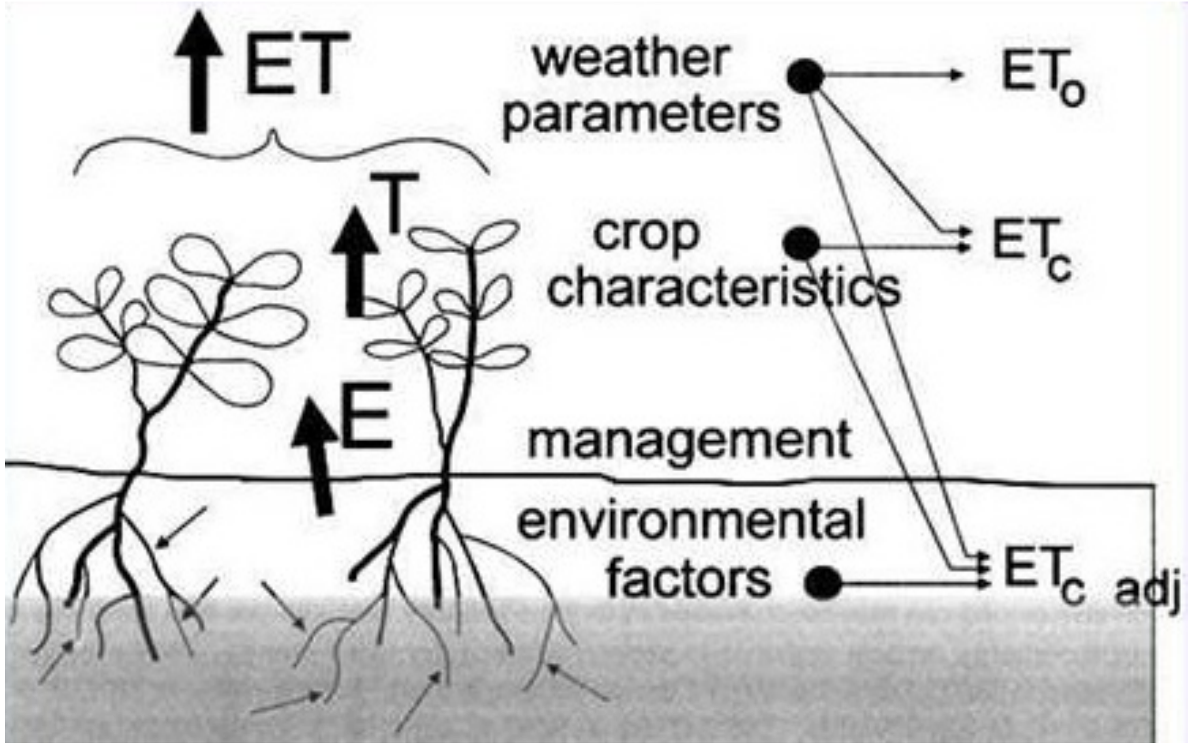
Gridded irrigation demand

Pros and cons

- **Simplicity and easy implementation**
- **Quality of large-scale irrigation data**
- **Uncertainty in socio-economic models**
- **Natural variability in irrigation demand in time and space**

Part I. Water demand
Type of demand: Irrigation
Modeling approaches

- Bottom-up estimation of irrigation demand



- **Centered around evapo(transpi)ration**
- **Wide range of conceptualizations**
- **Implementation (and to some extent conceptualization) depend on the data availability and the level of complexity supported by the host model**

Conceptualization

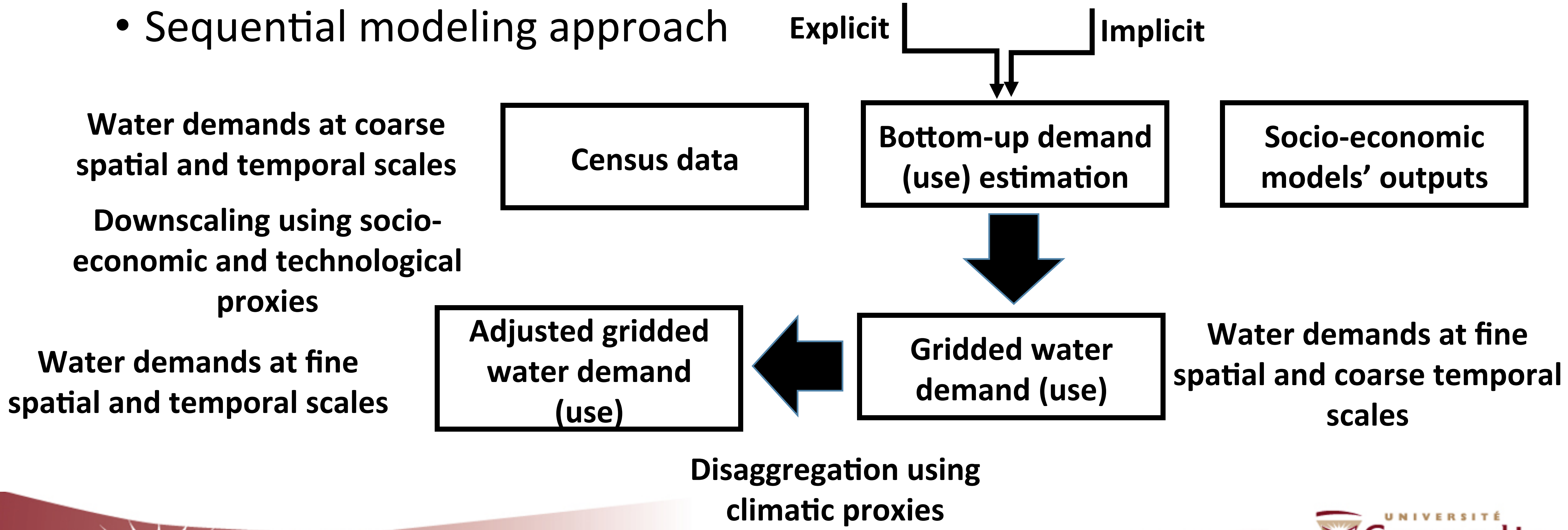
- **Soil moisture content in the root zone**
  - ❑ **Saturated soil moisture**
  - ❑ **Soil moisture at field capacity**

Part I. Water demand
Type of demand: Irrigation
Conceptualizations

- Crop water requirement
  1. Evapotranspiration-based (FAO-CROPWAT)
     - ❑ Easily implementable
     - ❑ Known limitations
  2. Transpiration-based
     - ❑ More physically-based
     - ❑ Requires a detailed vegetation scheme
     - ❑ Carbon cycle should be included

Part I. Water demand
Type of demand: Municipal, industrial, energy
Modeling approaches

- Include both consumptive and non-consumptive uses
- Sequential modeling approach



Part I. Water demand
Outstanding challenges

- Online simulations
- Modeling resolution
- Data support
- Demand estimation algorithms
  - ❑ Water demand *vs.* water withdrawal *vs.* actual water use
  - ❑ Uncertainty
  - ❑ Water availability constraint
- Limitation in host models

Part II. Water supply
Type of supply: Lake and reservoirs
Modeling procedure

- Location, purpose, physical characteristics
- In-grid reservoirs *vs.* main channel reservoirs
- Reservoir operation algorithms
  - ❑ Lake models
  - ❑ I/O models
  - ❑ Simulation-based algorithms (after Hansaski *et al.*, 2006)
  - ❑ Optimization-based algorithms (after Haddeland *et al.*, 2006)
  - ❑ Modified algorithms

There is still no recognition of changes in vertical fluxes

Part II. Water supply
Type of supply: Diversion and water reuse
Modeling procedure

- Streamflow diversion
  - ❑ In-basin diversion: Instantaneous abstraction
  - ❑ Inter-basin diversion: Routing

- Desalination and water reuse
  - ❑ Bottom-up estimations
  - ❑ Top-down downscaling

Data support is limited

Part II. Water supply
Type of supply: Groundwater
Modeling procedure

Groundwater availability

- Unlimited availability: Non-renewable and Nonlocal Blue Water (NNBW)
- Groundwater availability as a function of baseflow: linear reservoirs
- Dynamic representation of groundwater availability

Groundwater recharge

- Heuristic approach
- Leaky buckets
- Physically-based Richards' equation

Part III. Water allocation
Type of allocation: Surface water
Modeling procedure

- Conditioning the demand to the available supply
  - ❑ Heuristic approaches
- Priorities
  - ❑ Static assumptions
  - ❑ Dynamic assumptions
- Estimate allocation
  - ❑ Handling water deficit
  - ❑ Abstract from supply sources

Part III. Water allocation
Type of allocation: Groundwater
Modeling procedure

- In-grid allocation
  - ❑ Lateral groundwater movement is largely ignored
- Renewable *vs.* non-renewable allocation
  - ❑ Recharge *vs.* abstraction
- Groundwater withdrawal
  - ❑ Bottom-up approach

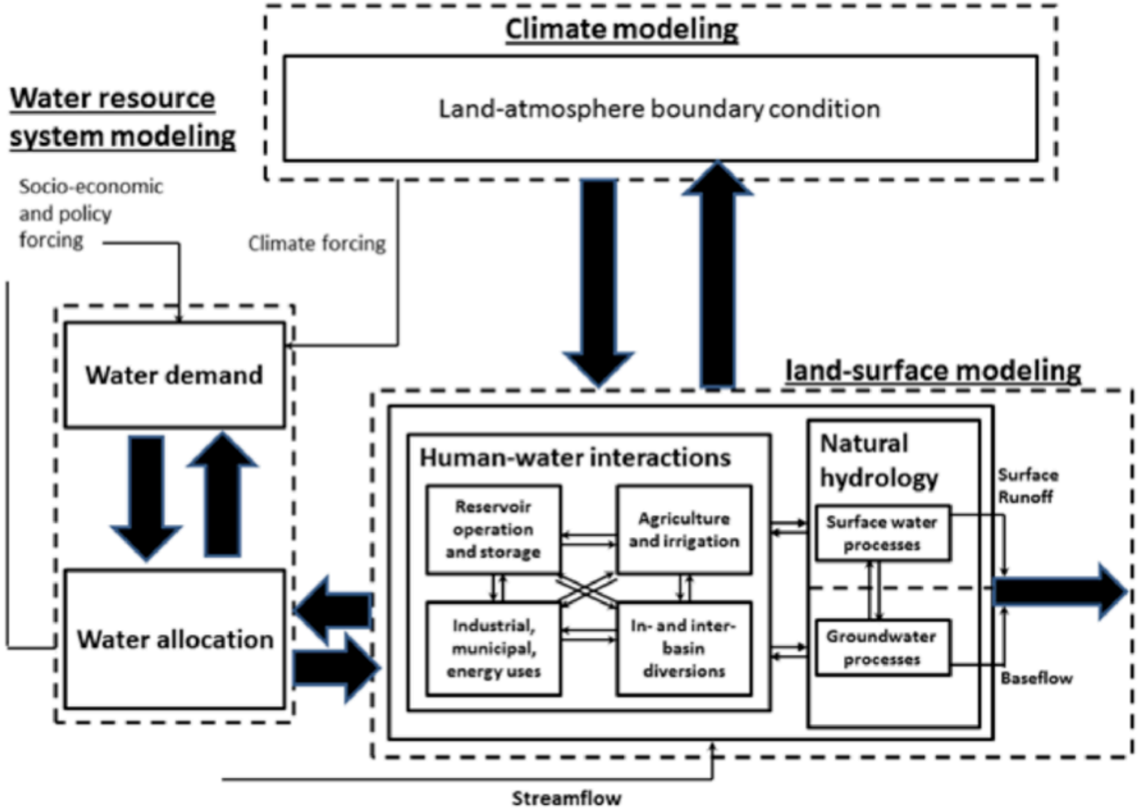
    Depend on how the groundwater availability is considered
  - ❑ Top-down approach

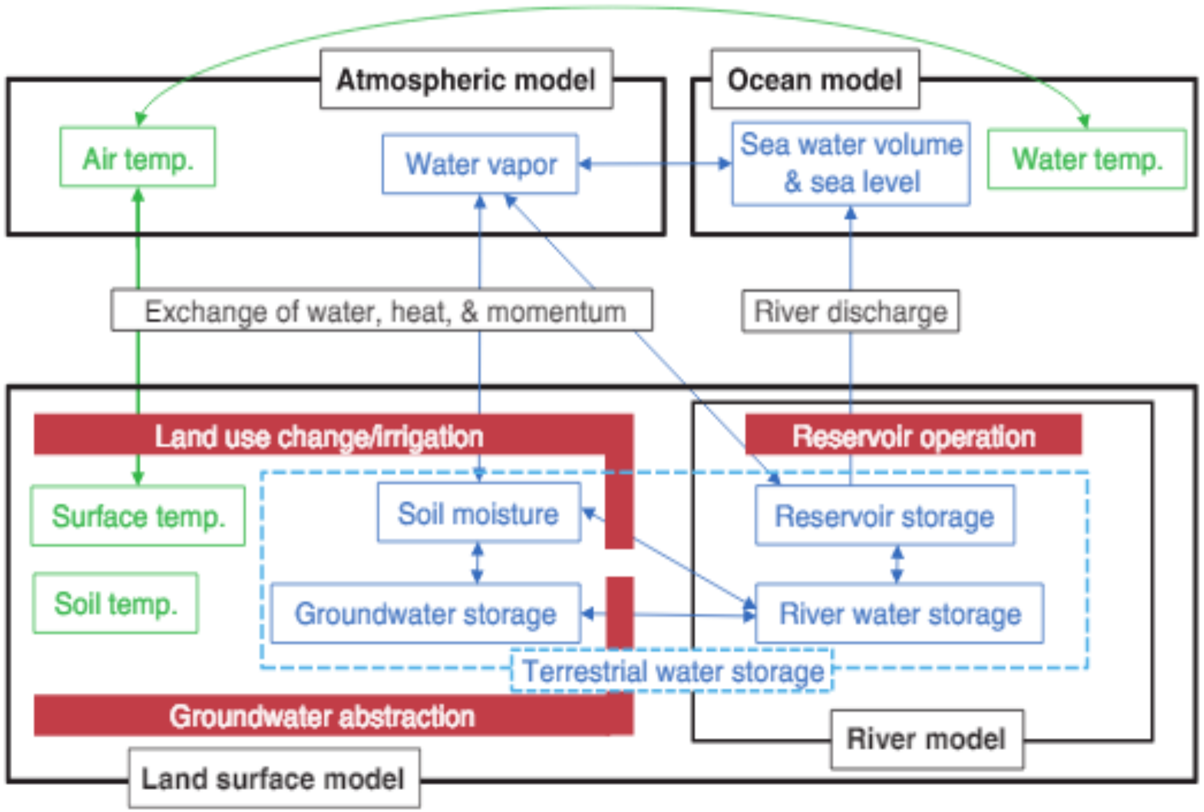
State-of-the-art

- There are limited offline applications that consider all the elements of water resource management within a unique model.
- There is a wide range of algorithms available that are not fully intercompared and benchmarked.
- There are significant errors in current modeling efforts.
- The capacity for online simulation is quite limited and there are gaps in process representation.
- Current efforts are bounded by the availability of data, computational barriers and the capability of host large-scale models.

An ideal representation

Pokhrel et al. (WIREs Water, 2016)

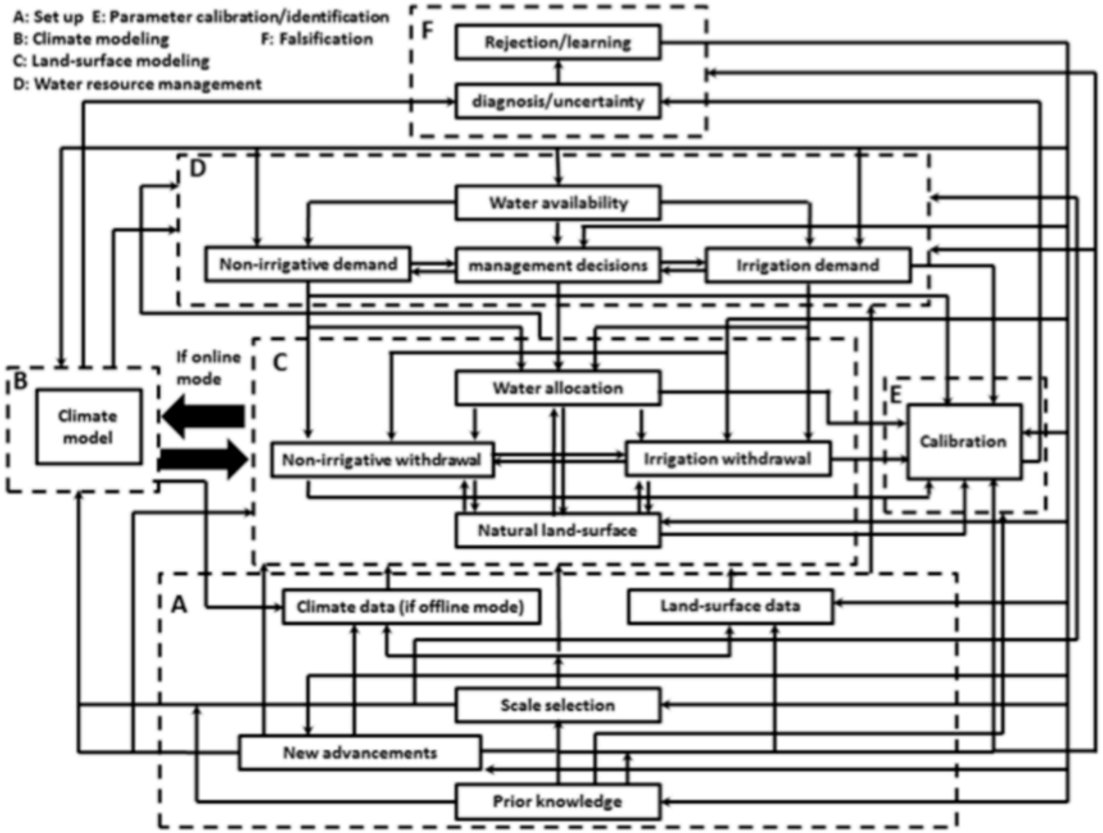


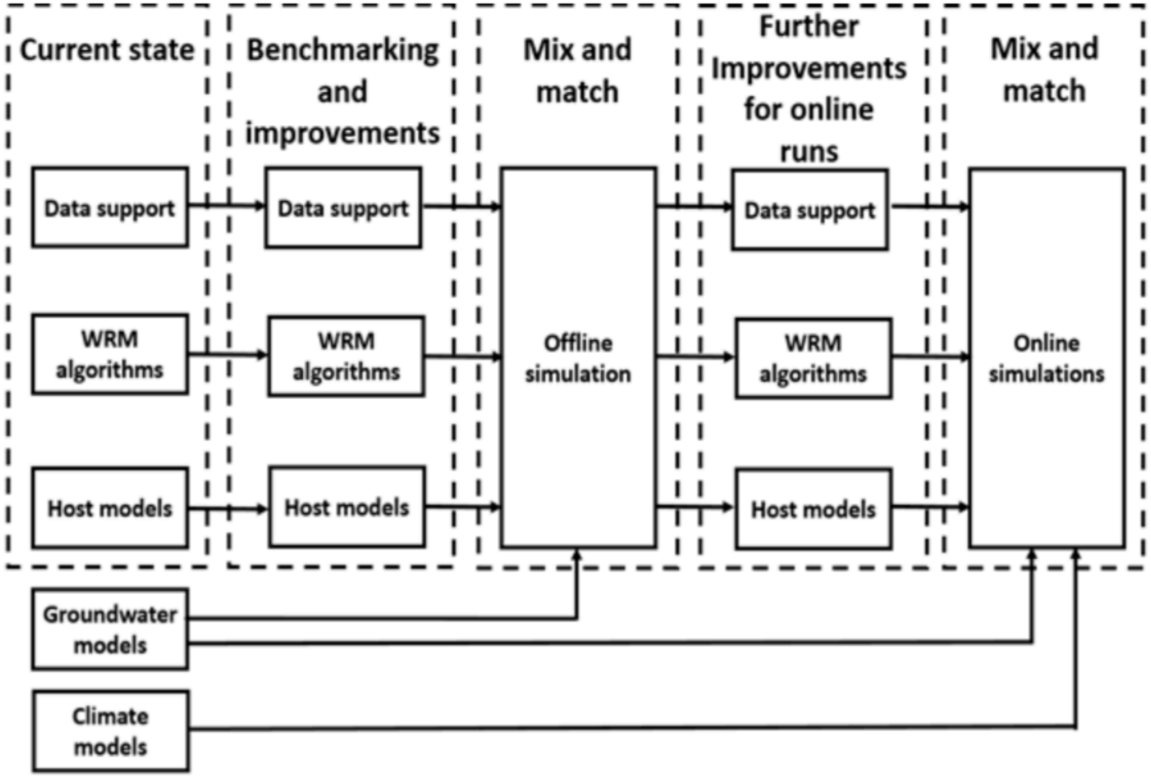


Opportunities to move forward

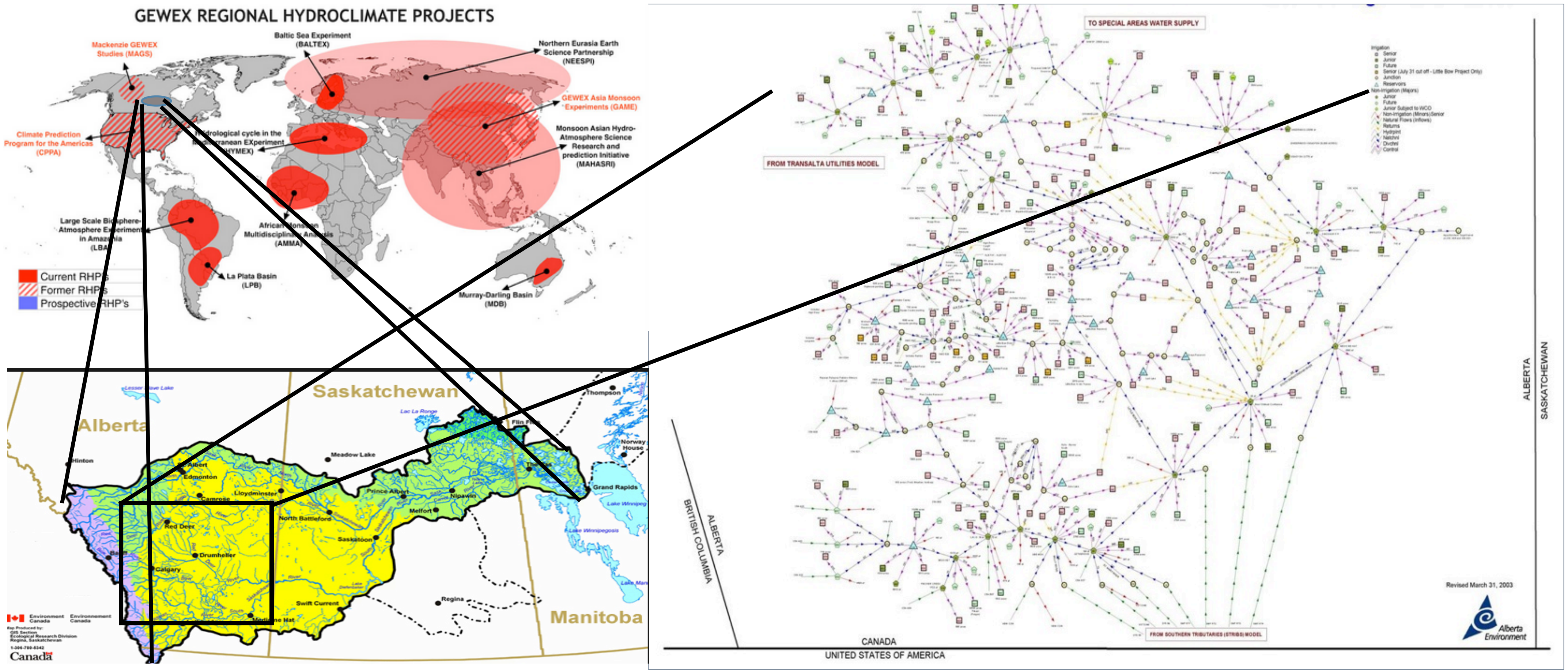
- Data support
  - ❑ Remote sensing technology
- Water resource management algorithms
  - ❑ Formal intercomparison, parameterization and uncertainty assessments
  - ❑ Enhanced algorithms
- Host models
  - ❑ Grid resolution
  - ❑ Sub-grid process representation
- Closing the water balance and online simulations
  - ❑ Advancement in couplers
  - ❑ Advancement in computations

A suggested approach for model development





We have almost everything we need!



Many thanks for your attention!

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