IMPC THEME B: Water Management Modelling, and Coupling Human-driven and Natural Systems

Saman Razavi, September 15, 2017

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Research Themes

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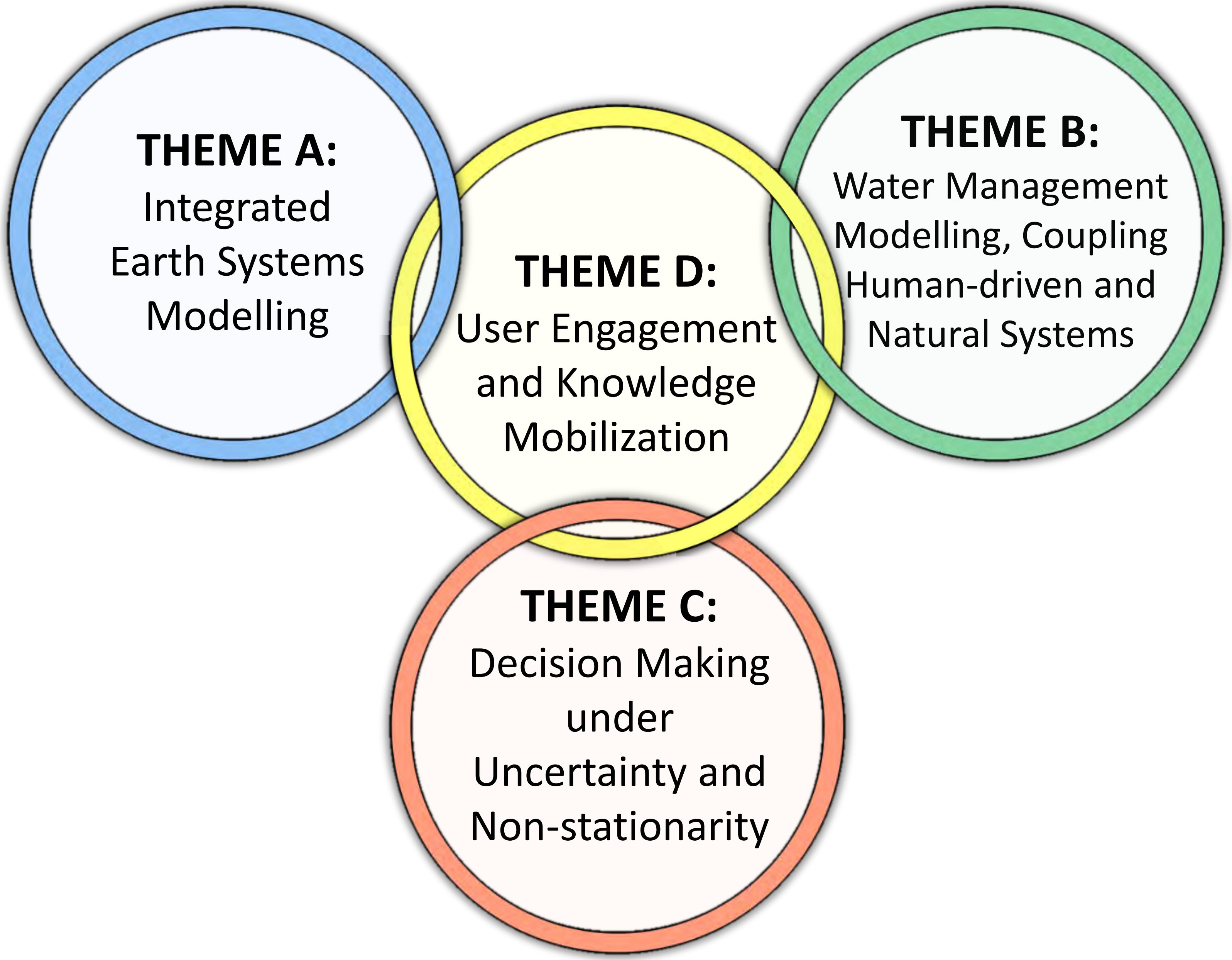

Theme B Overarching Research Questions

I) how can models of natural and human-driven components of the Earth system be integrated to represent their interactions and feedbacks, including human activities and values?

II) how can we develop and unite socio-economic and hydro-ecologic performance models for integrated water resources management?

Theme B Objective

This theme aims to develop a modelling platform for integrated water resources management that fully couples anthropogenic factors with natural systems models, including ecosystem constraints.

Specific objectives are to:

I) simulate watershed systems with existing water infrastructure under the current and alternative future hydro-climatic conditions and operational strategies for the 21st century,

I) evaluate potential infrastructure and policy developments, and

III) analyse trade-offs between objectives, e.g. economic development, ecosystem protection, under different hydro-climatic conditions.

Theme B Work Packages:

B1: Developing a water resources model to simulate different operational policies of existing and future water infrastructure

B2: Developing a performance model for aquatic ecosystems based on hydro-ecologic metrics and environmental demands

B3: Developing an integrated hydro-economic model to assess the direct and indirect impacts of policy decisions based on socio-economic water valuation studies

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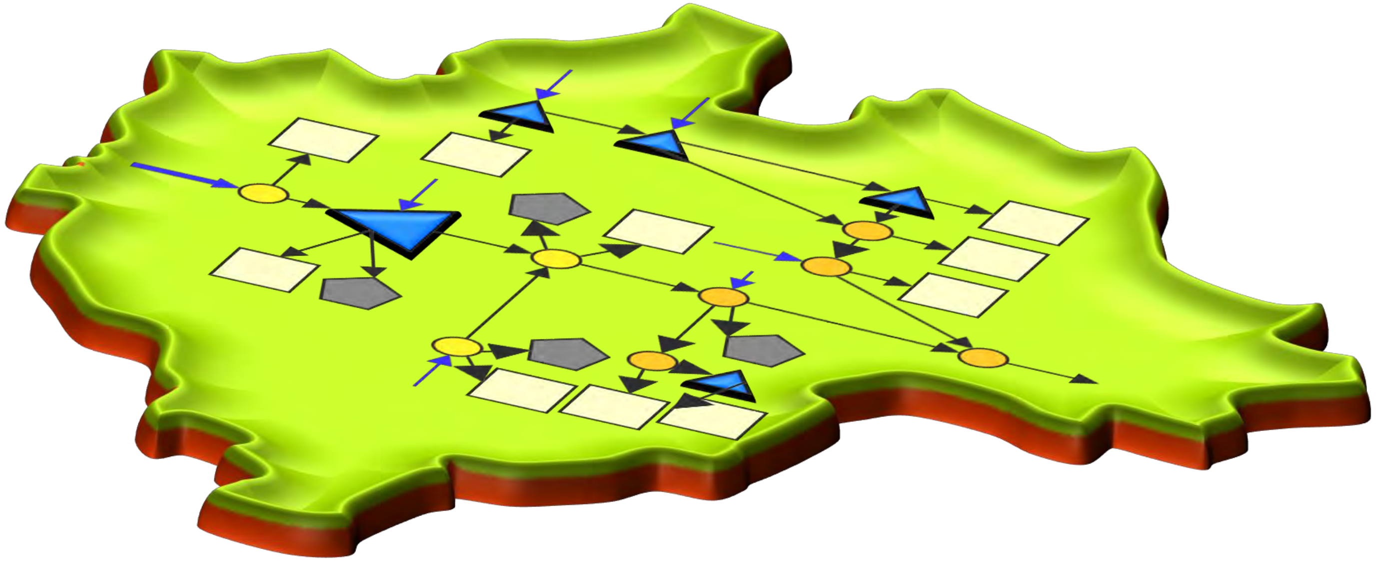
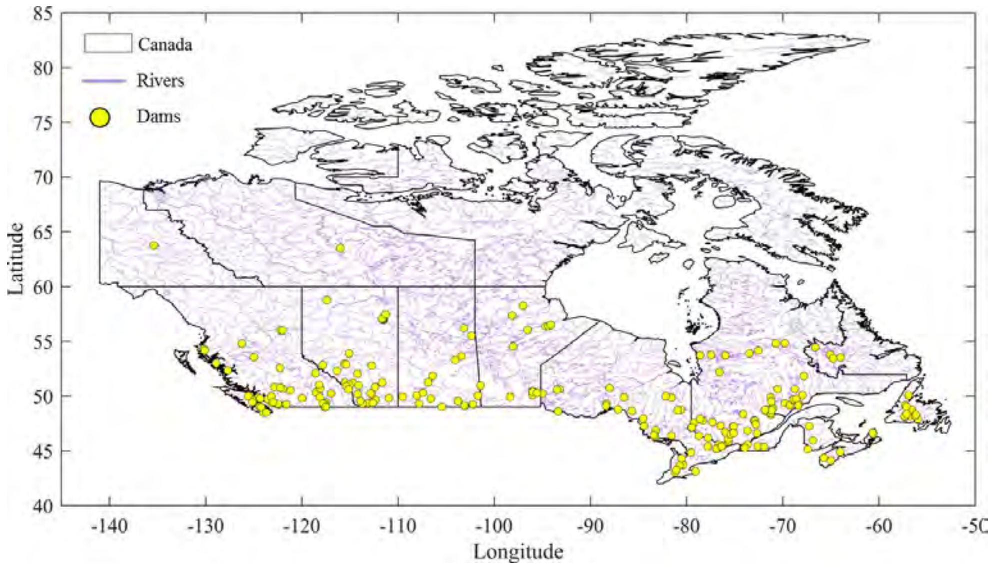
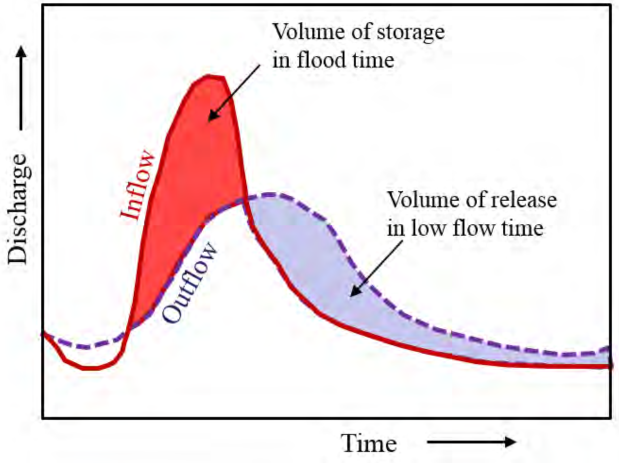
IMPC SUB-THEME B1:
Developing a water resources model to simulate different operational policies of existing and future water infrastructure

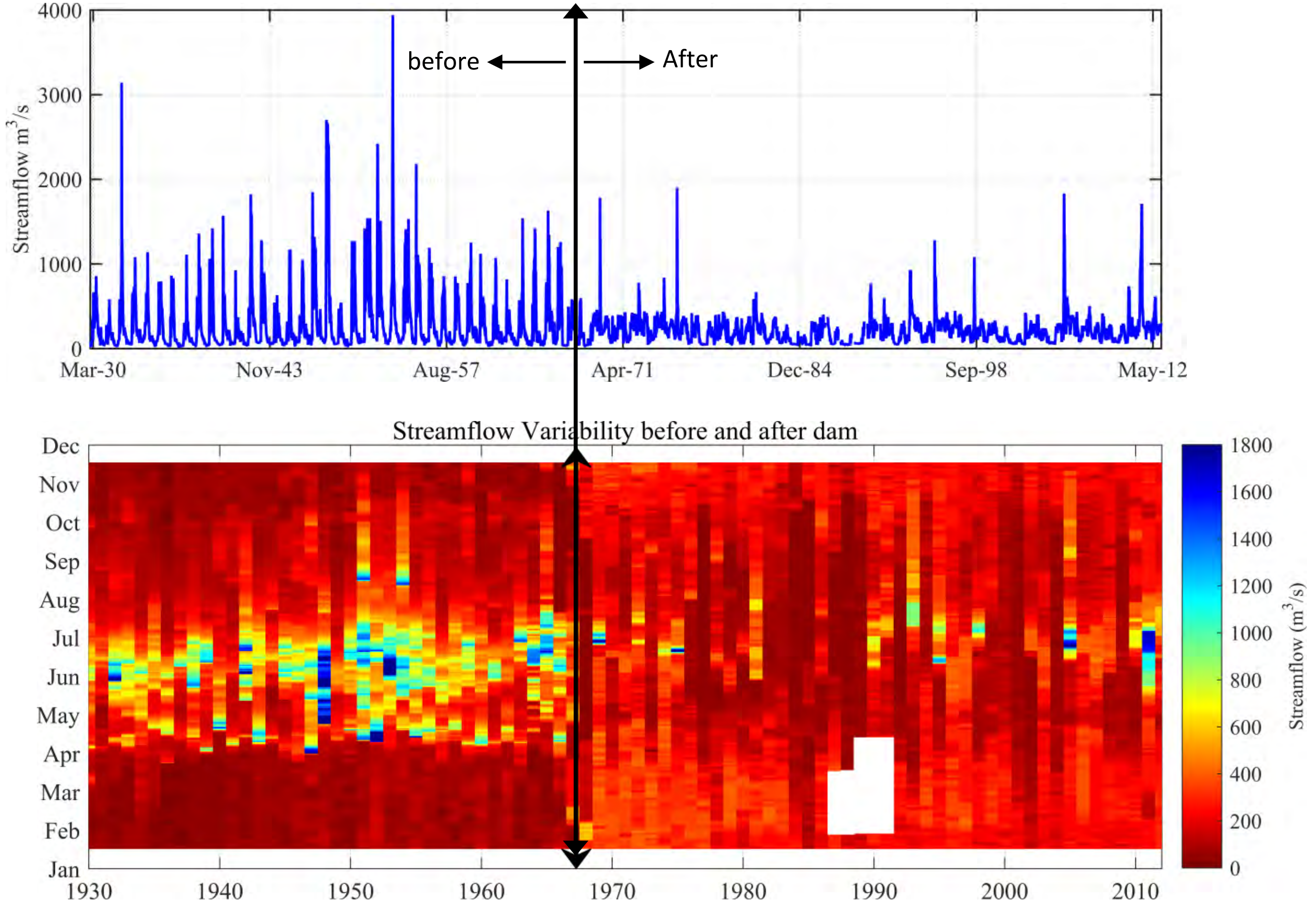


Our watersheds are heavily regulated…





Lake Diefenbaker



Challenges

- Institutional Fragmentation: the lack of coordination across federal, provincial and local level of governments. The direction of the fragmentation is both ‘vertical’ and ‘horizontal’ (Renzetti and Dupont, 2017).

- Poor linkage between advanced hydrologic modelling, water systems modelling, and decision making processes.

- Economics have played relatively limited role in Canadian water resources management in the past (Renzetti and Dupont, 2017).

- The complexity of water resources systems, especially due to uncertainty in human behaviour and political processes.

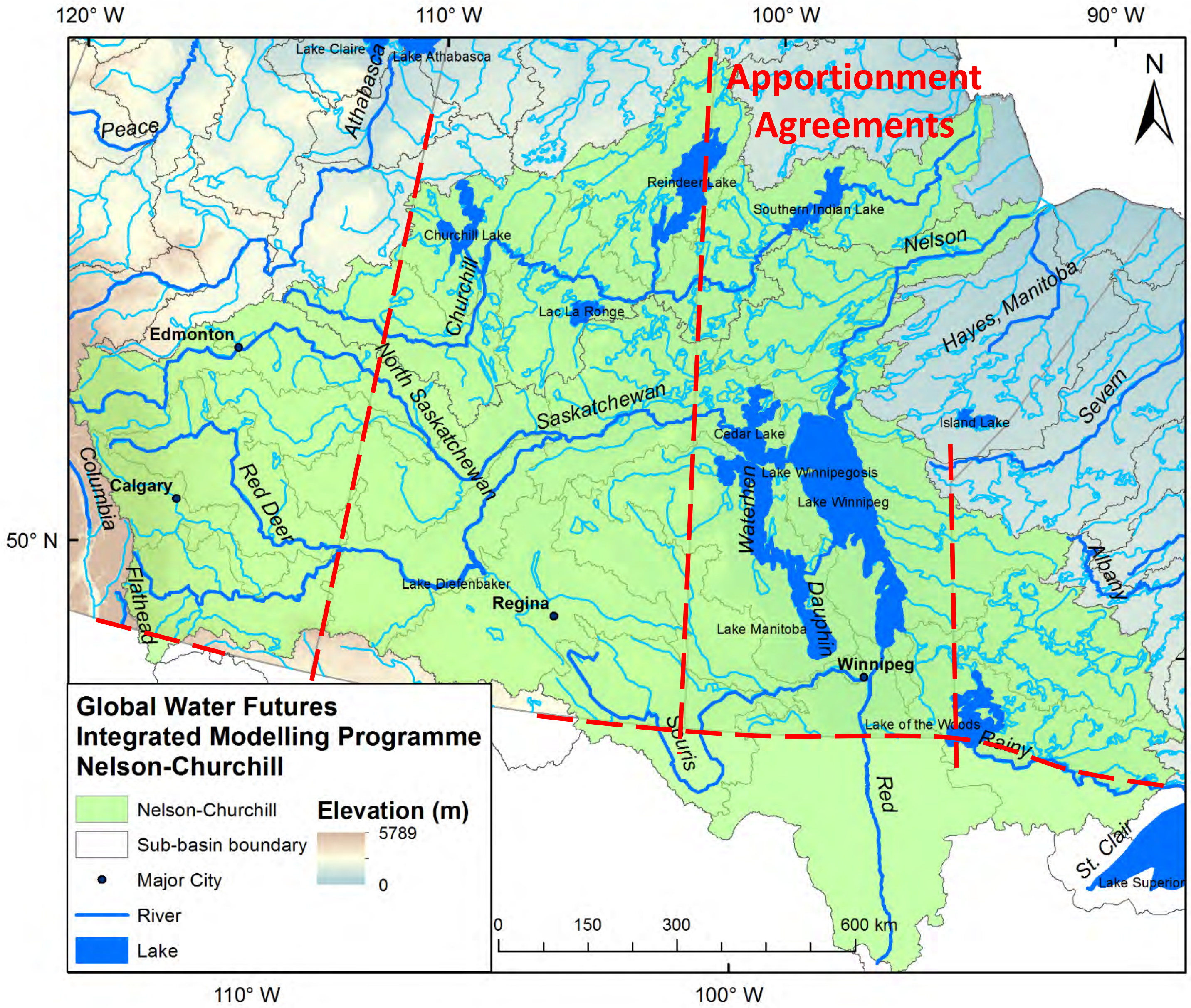
Objectives

- Develop a high-fidelity water system/management model to simulate basin-wide system performance across Sask-Nelson River Basin under (1) various hydro-climatic conditions and (2) current and alternative futures of water policies and infrastructure.
  - ✓ This model will simulate alternative human behaviours in operations and governance (different policy options), and interventions into the hydrologic system (new inter- and intra-basin transfers, reservoirs, irrigation, etc.).

- Couple the water resource system model with the state-of-the-art land surface-hydrology and water quality models.

- conduct “participatory modelling” where stakeholders are engaged in and contribute to the co-development of the model from beginning to end to ensure the transparency of the underlying assumptions, strengths and limitations, and intended uses (linked to Theme C).

Bringing the pieces together …



Water Management Issues:

- Transboundary water issues,
- “Localized” approach to water management,
- Indigenous water needs,
- Over-allocation and competing demands,
- Environmental flows, etc.

Hydrologic Prediction Issues:

- Complex hydrology (Rockies, prairies, boreal forest),
- Floods and drought,
- River ice,
- Lakes and wetlands,
- Heavily regulated catchments,
- Land cover change & atmospheric feedback loops, etc.

Water Quality Issues:

- Eutrophication and nutrient transport,
- Algal blooms,
- Manure and fertilizer application,
- Contamination due to oil and gas extraction, etc.

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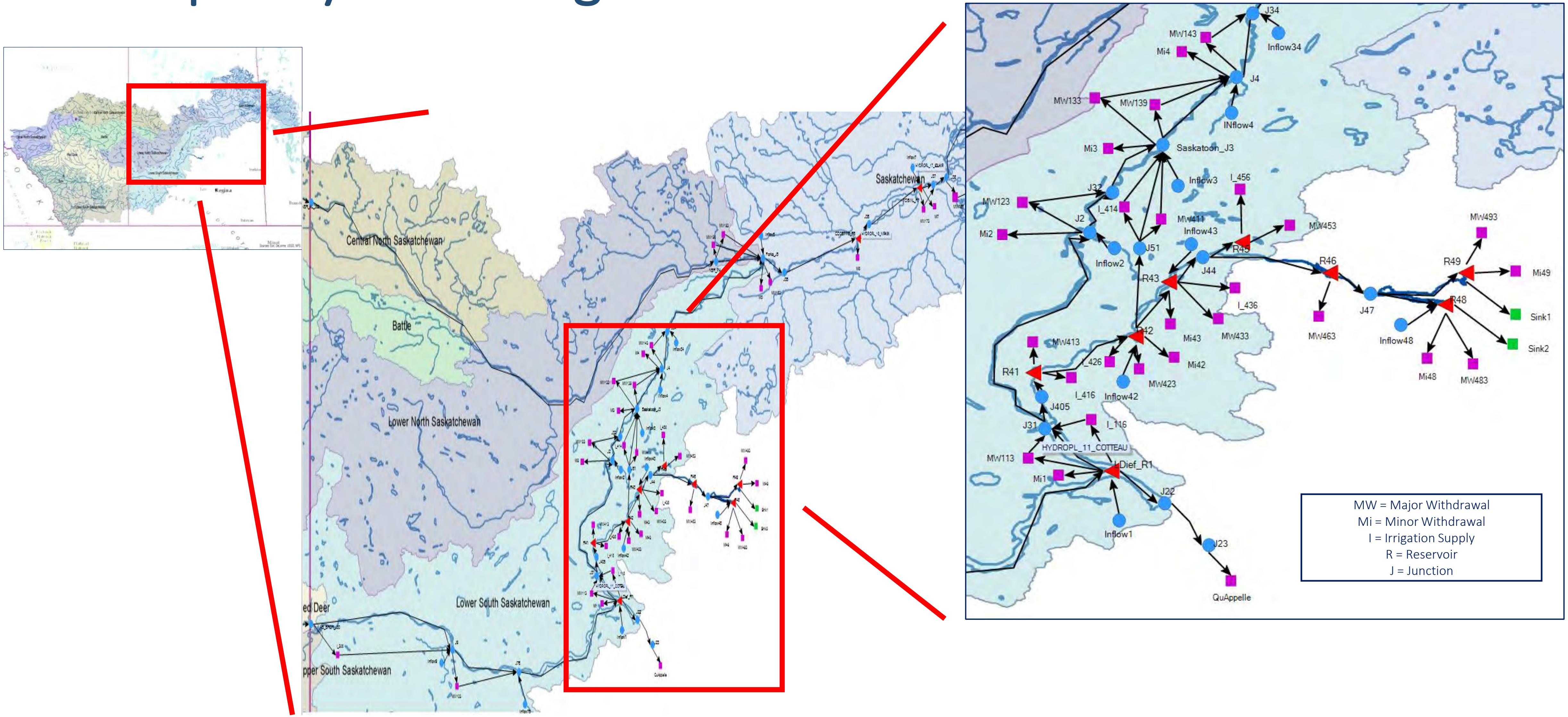
Preliminary Modelling Started to be Brought in Participatory Modelling …



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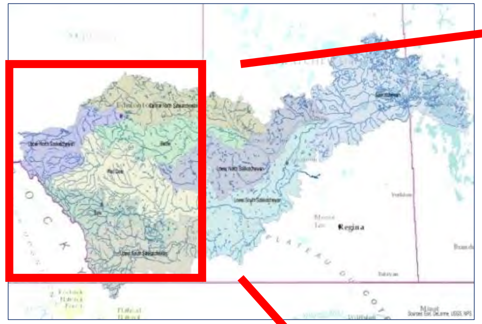
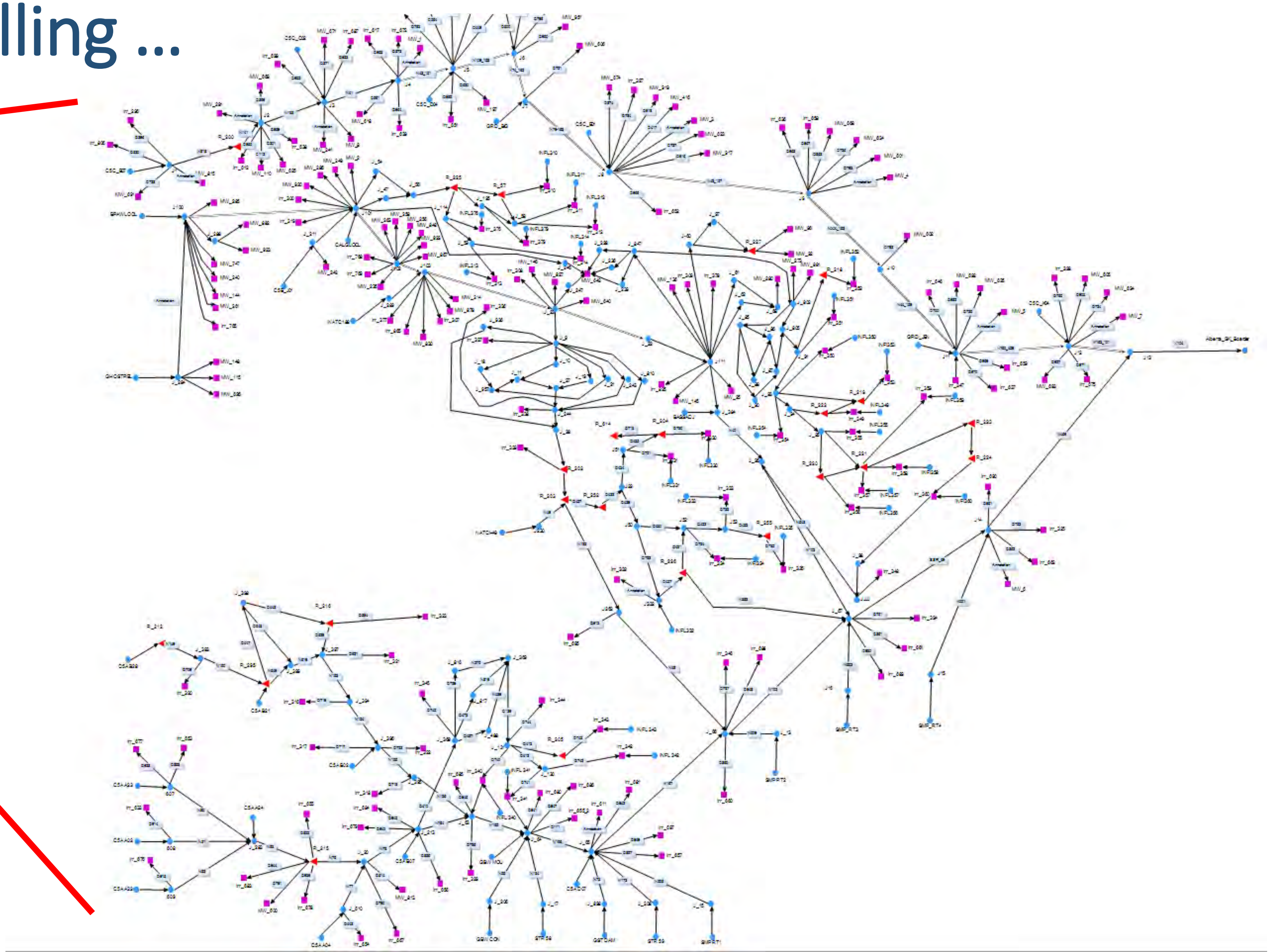


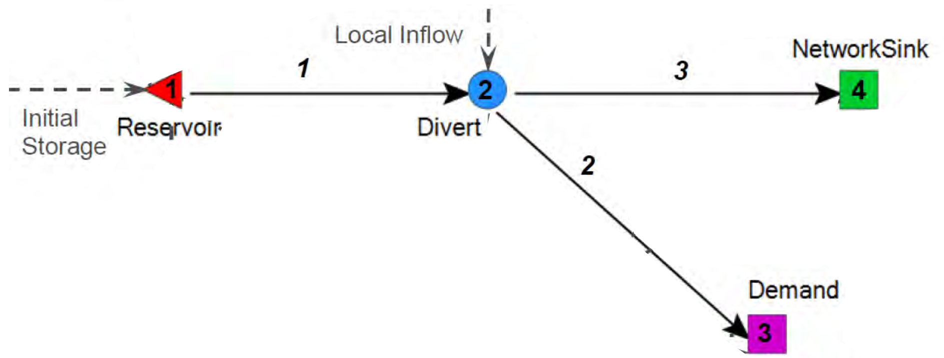


MODSIM-DSS and WEAP:
River Basin Management Decision Support Systems

- Based on Network Flow Algorithms.

- Modellers are only responsible for defining the physical flow network.

- All artificial nodes and links are added automatically by the model.



Network Flow Algorithm

MODSIM simulates water allocation mechanisms in a river basin through sequential solution of a network flow optimization problem for each time period $t = 1,\ldots,T$:

link cost　　link flow

$$\text{minimize} \quad \sum_{k \in A} c_k \, q_k$$

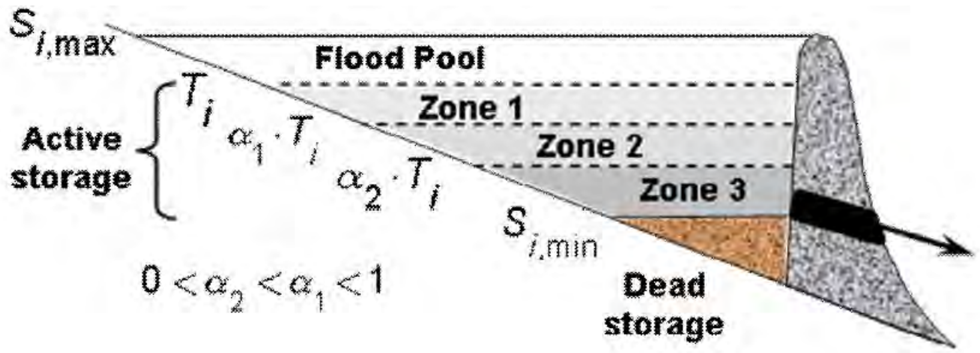
subject to:

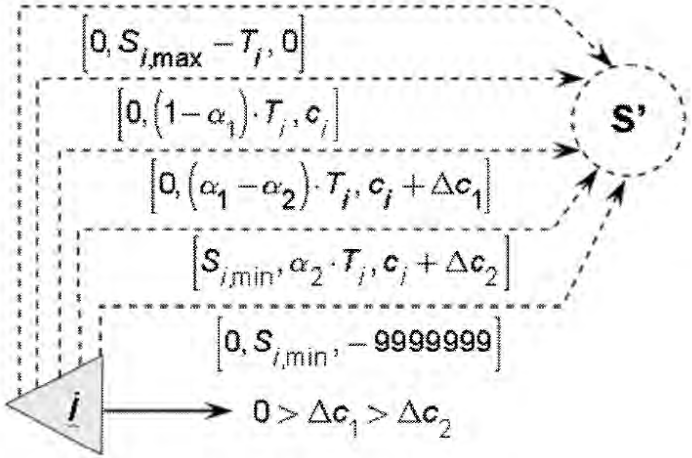
$$\sum_{k \in O_i} q_k - \sum_{j \in I_i} q_j = b_{it}(\mathbf{q}) \quad \text{for all nodes } i \in N$$

$$l_{kt}(\mathbf{q}) \le q_k \le u_{kt}(\mathbf{q}) \quad \text{for all links } k \in A$$

Optimization is primarily conducted as a means of accurately *simulating* the allocation of water resources in accordance with operational priorities based on system objectives, operational experience, water rights, and other ranking mechanisms, including economic factors.

Reservoir Information and Priorities





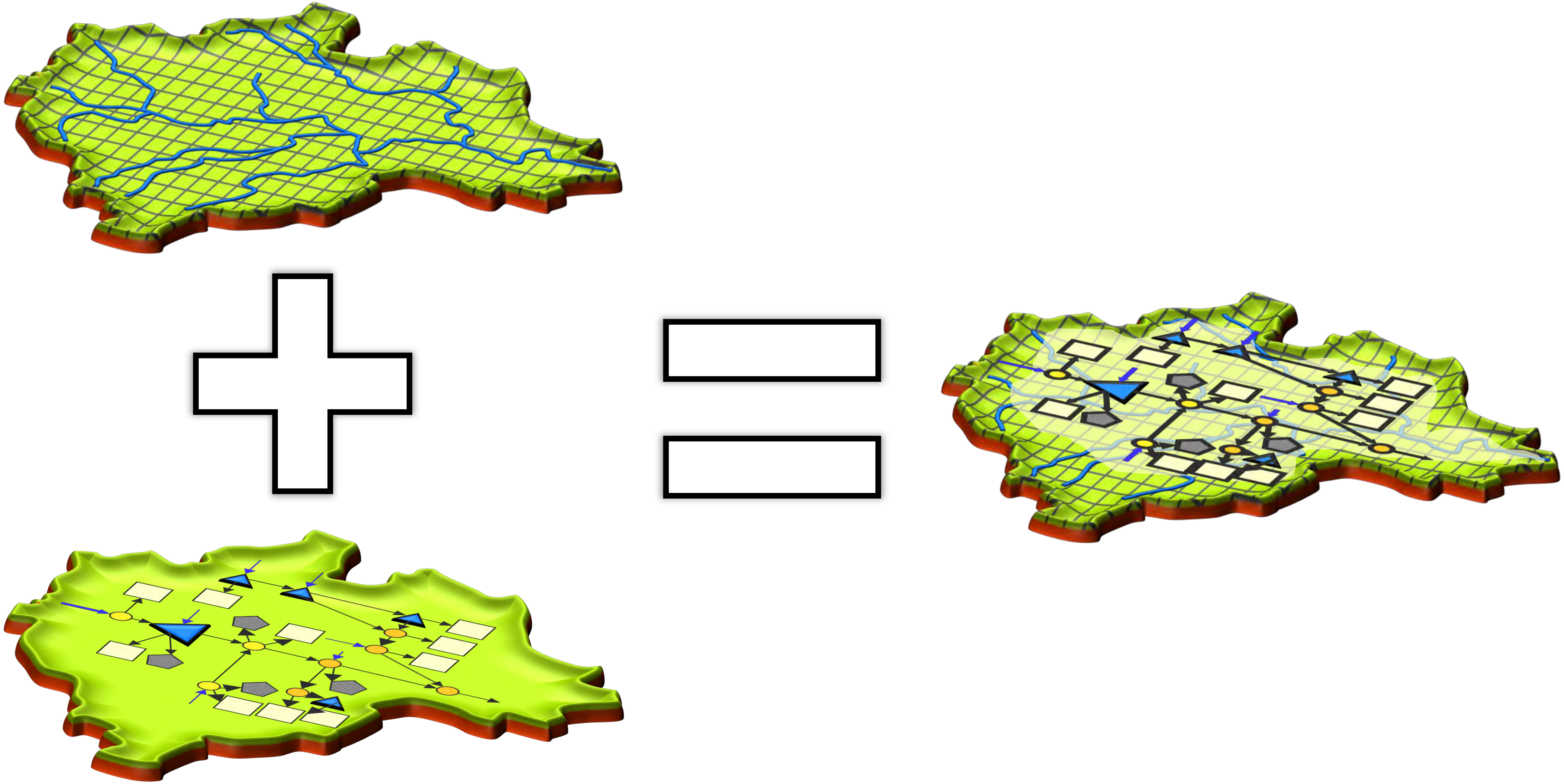
Cost $c_i = -(50000 - 10 \cdot OPRP_i)$

Priority Number

where *OPRPi is* an integer priority ranking from 1 to 5000, with lower numbers indicating a higher ranking, resulting in a negative cost.

This priority (penalty function) concept applies to different (consumptive/non-consumptive) demands.

Coupling Hydrology and Water Management



Two General Approaches

- Point-based Operation
  - Focused to address and satisfy local issues and needs
  - Minimal consideration about other elements in a watershed
  - Easy to implement and efficient to include in watershed models
  - Effective to reproduce the historical patterns of operation
  - Future operations?
- System-based Operation
  - From a systems perspective, tries to operate all the elements in a "system" together such that the benefits across the system is maximized.
  - More work and data to implement. Some previous attempts to include them in watershed models (difficult).
  - Is expected to better simulate what might happen in the future operations.
  - Powerful and commonly used tools for decision making and support.

Coupling Hydrology and Water Management

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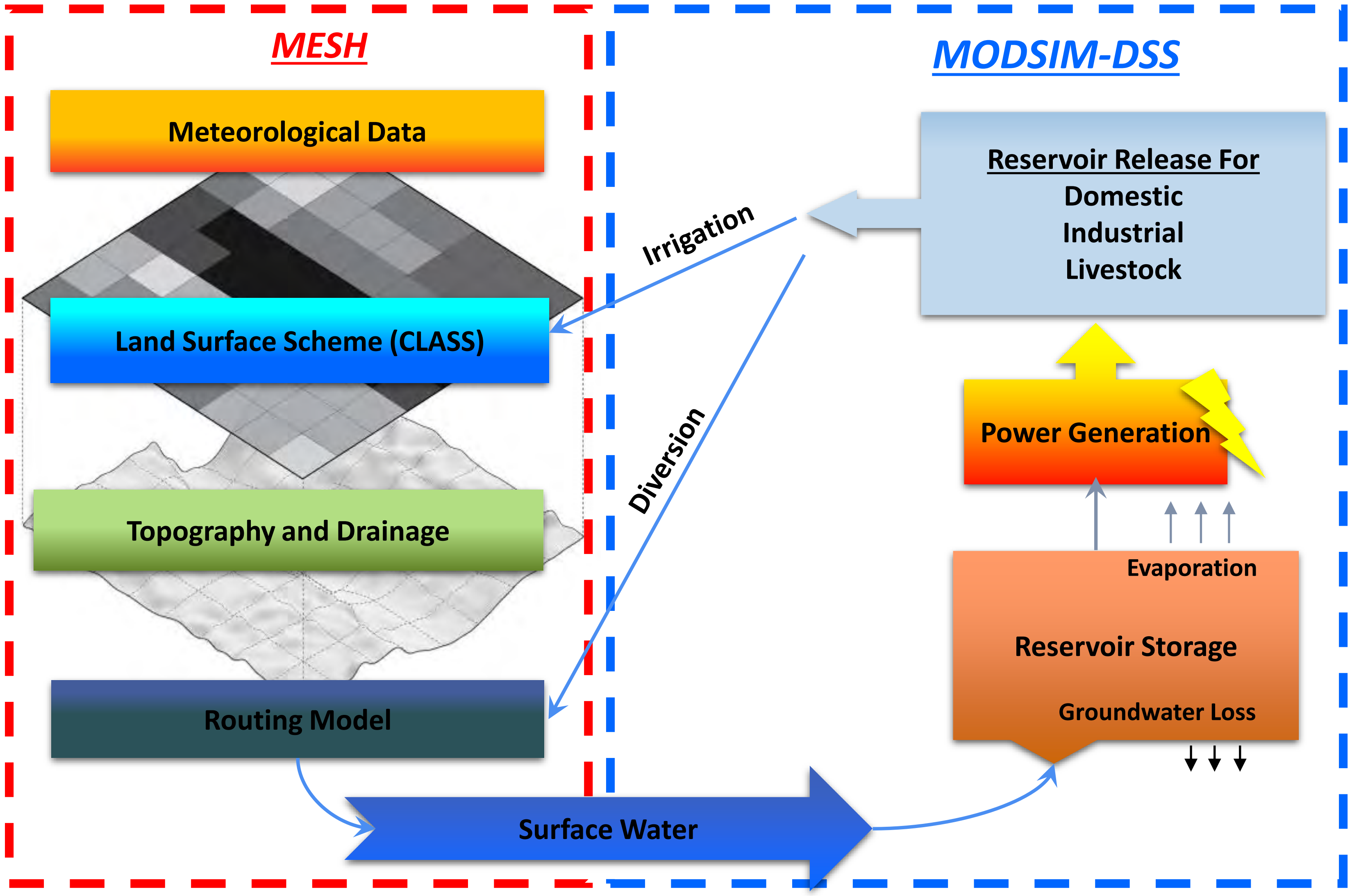
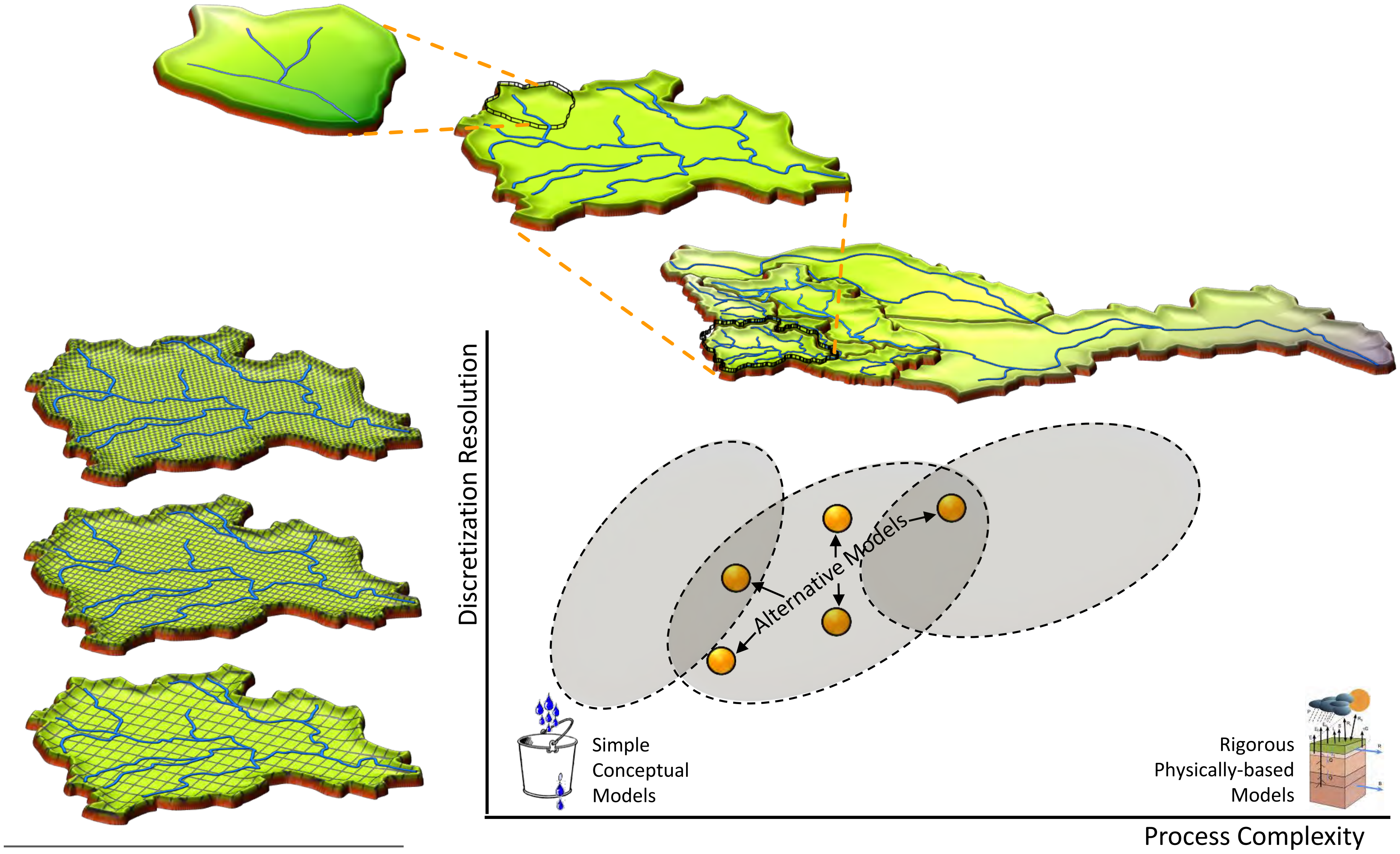


Model Complexity Considerations …



Model Complexity Considerations …

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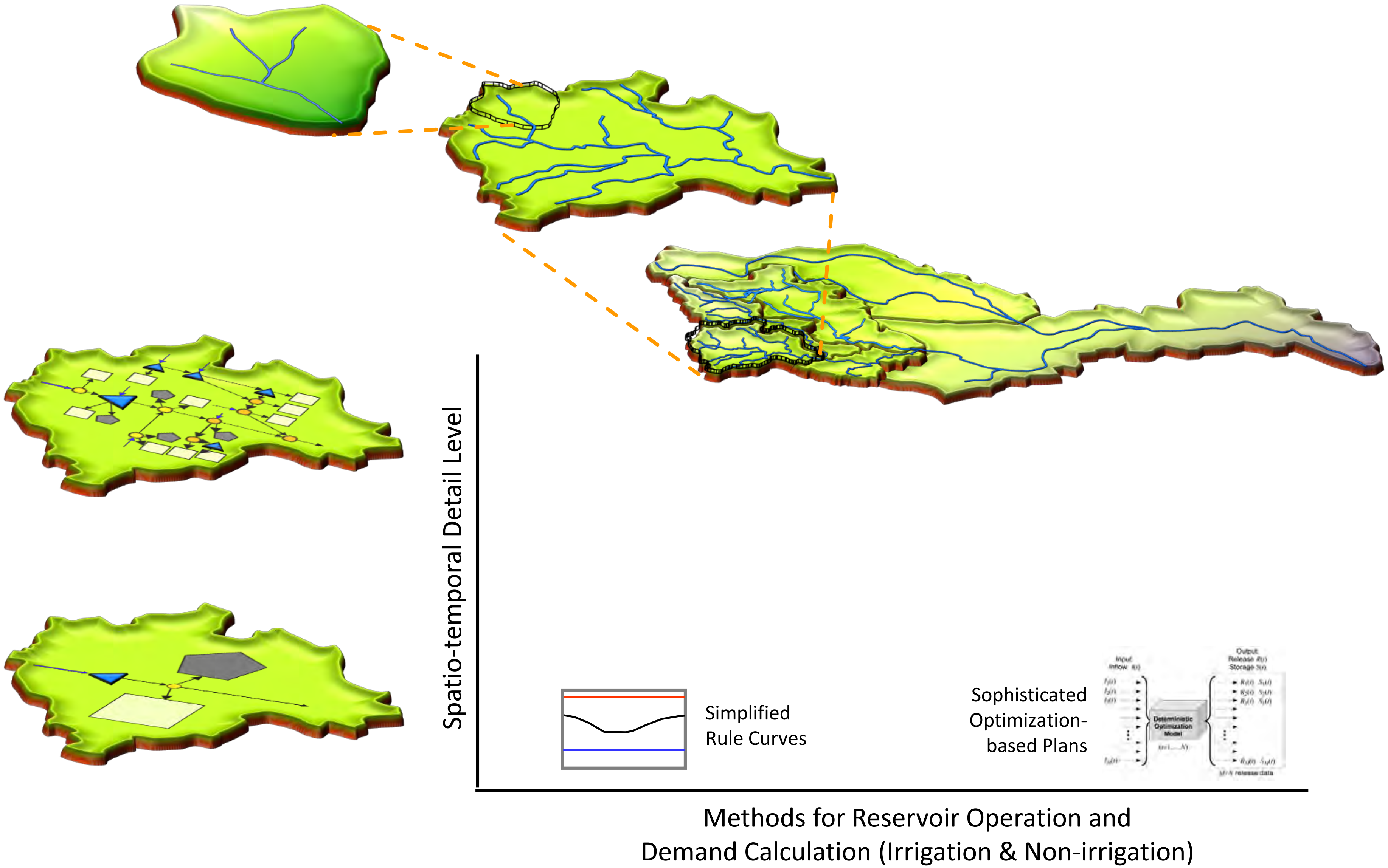

Inclusion of Groundwater in Water Management?

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- ✓ More than 90% of rural Albertan use groundwater for water supply (domestic, agricultural, municipal, industrial, etc.).

- ✓ 3% of water supply in Alberta (excluding domestic use) is from groundwater (Government of Alberta, 2010).

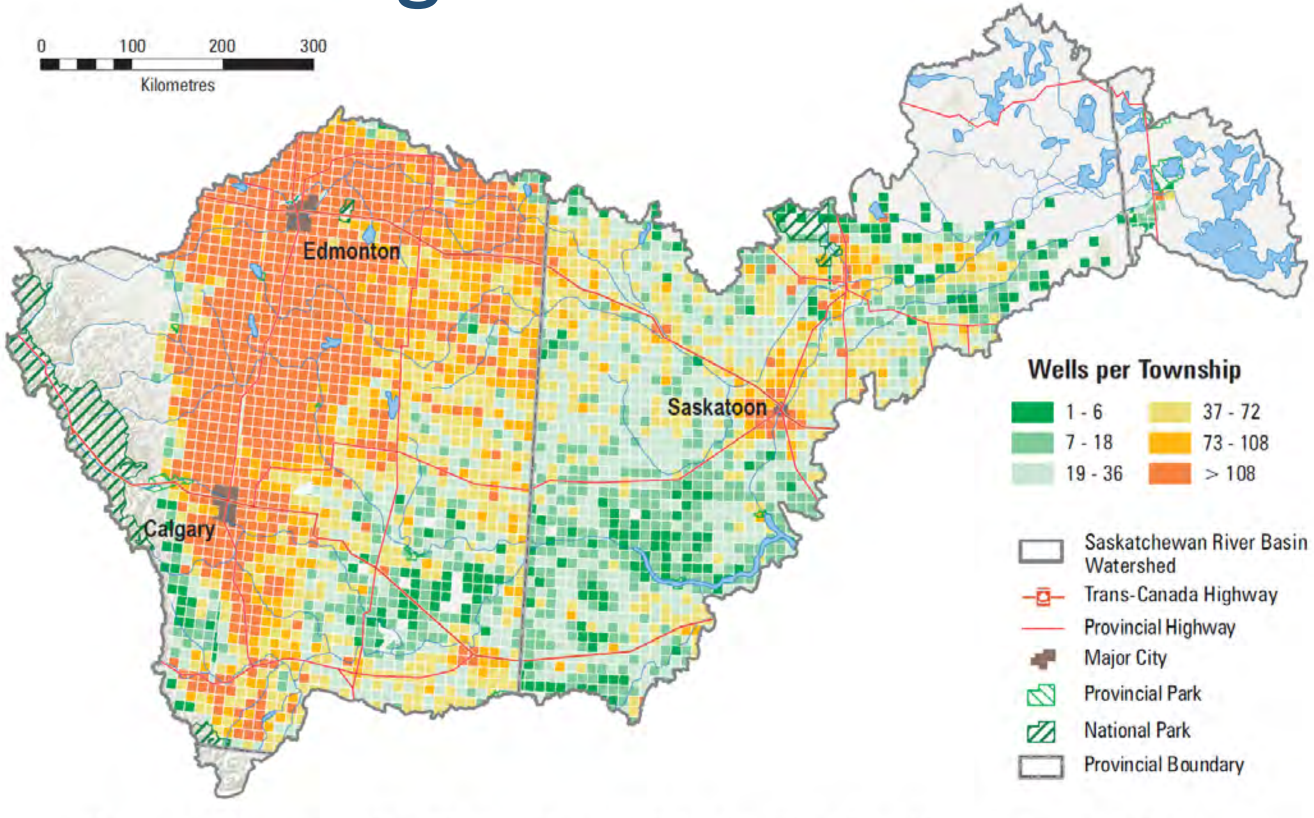


Figure 2.6. Distribution of Potable Groundwater Wells by Township (adapted from data courtesy of PFRA).

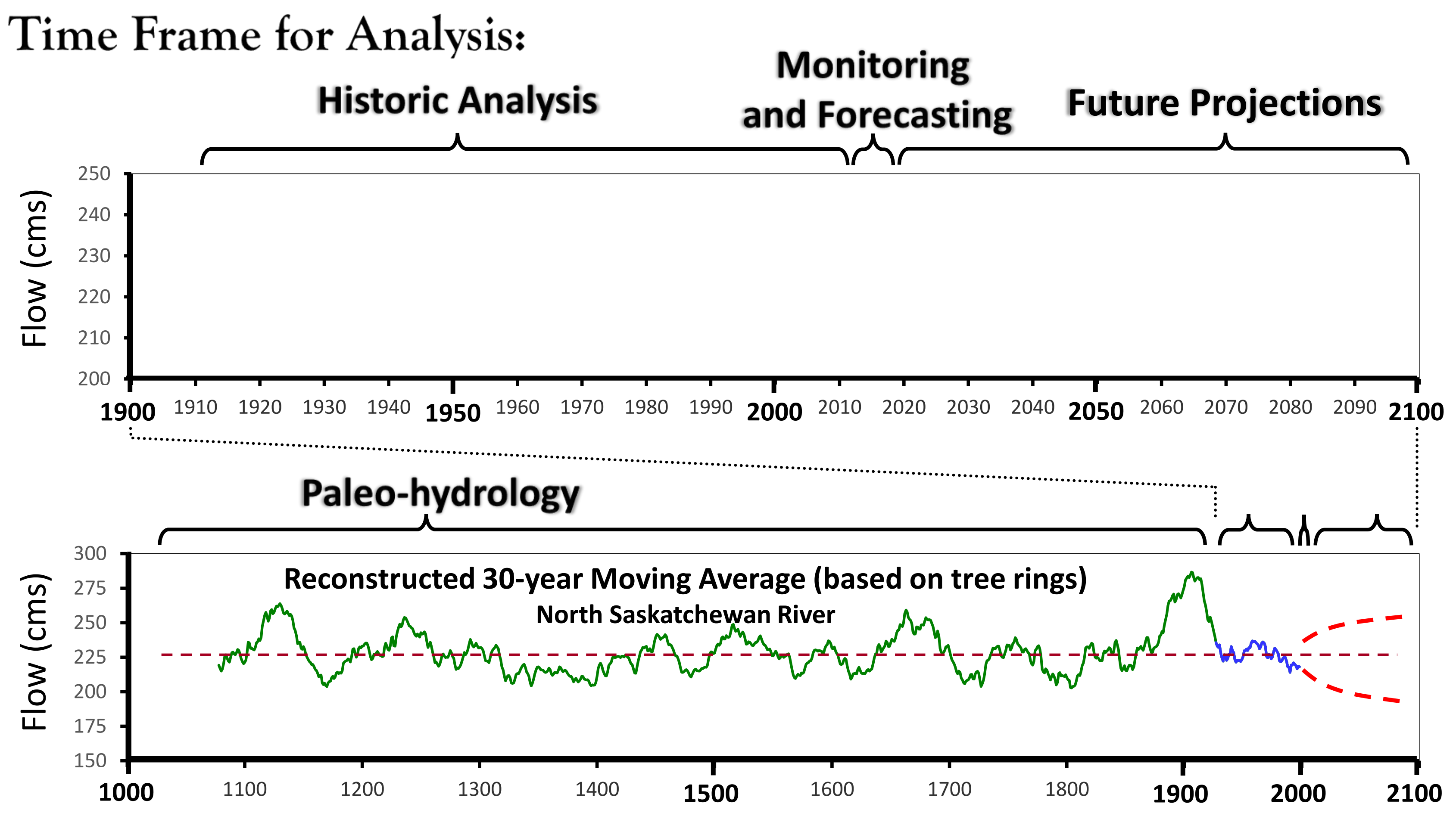
Partners FOR the Saskatchewan River Basin. (2009)

- ✓ 215,000 active wells (4,000 added each year) in Alberta – many from shallow aquifers that are connected with river flows, wetlands, and lakes (Government of Alberta, 2010).

Water means the WORLD to Us...

UNIVERSITY OF SASKATCHEWAN
Global Institute for Water Security
USASK.CA/WATER

Lessons from Paleo-Hydrology …



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MODSIM objects:

summary of their functionality and data requirements

Icon	Functionality	Data Requirements
Reservoir [Operations]	▪ Main-stem and offstream reservoir operations ▪ Flood control, conservation pools; dead storage ▪ Zones for storage balancing in multi-reservoir systems	▪ Elevation-area-capacity tables ▪ Maximum, minimum, initial storage ▪ Reservoir storage guidecurves ▪ Reservoir balance tables ▪ Hydraulic outlet capacity tables ▪ Net evaporation loss; seepage ▪ Inflow forecasts (if available)
Reservoir [Hydropower]	▪ High-head hydropower ▪ Run-of-river hydropower [0 storage] ▪ On-peak, secondary and firm energy ▪ Pumped storage	▪ Nonlinear efficiency tables as functions of head and discharge ▪ Tailwater-discharge tables ▪ Powerplant capacity ▪ Load factors for pumped storage
StorageRight Reservoir	▪ Storage right accounts ▪ Storage ownership maintenance ▪ Water banking and service contracts	▪ Storage right users ▪ Group ownerships
NonStorage	▪ Watershed runoff ▪ Tributary inflow ▪ Flow confluence and diversion ▪ Groundwater return flows ▪ Stream depletion from pumping	▪ Imported inflow time series data ▪ Execution of external rainfall-runoff models through custom code
Demand	▪ Consumptive demand ▪ Groundwater pumping ▪ Stream-aquifer modeling with Glover model or USGS stream depletion factor (sdf) method	▪ Import of demand time series data ▪ External consumptive use models ▪ Demands/priorities conditioned on hydrologic state ▪ Water use efficiency (time variable) ▪ Aquifer parameters; pumping capacity
Flowthru	▪ Instream flow requirements environmental, ecological or navigation purposes ▪ Nonconsumptive demands ▪ Gaging station for model calibration	▪ Time series of instream flow requirements ▪ Flow-through demands and priorities vary with hydrologic conditions ▪ Measured flow data for calibration
NetworkSink	▪ River basin outlet (multiple outlets for several basins allowed)	
Link	▪ Channel losses ▪ Maximum and Minimum Flow	▪ Time series of maximum capacities ▪ Link costs and benefits
MultiLink	▪ Represent nonlinear discharge-channel loss functions ▪ Nonlinear cost-discharge functions ▪ Multiple water sources and rights	▪ Time series of maximum capacities ▪ Link costs and benefits
Routing Link	▪ Streamflow and channel routing	▪ Muskingum method coefficients ▪ User defined lag coefficients

Case Study 1: Saskatchewan River Basin

Area of 400,000 km^2

With ~50 reservoirs

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