Overview of Water Resources Modelling

Progress and Challenges

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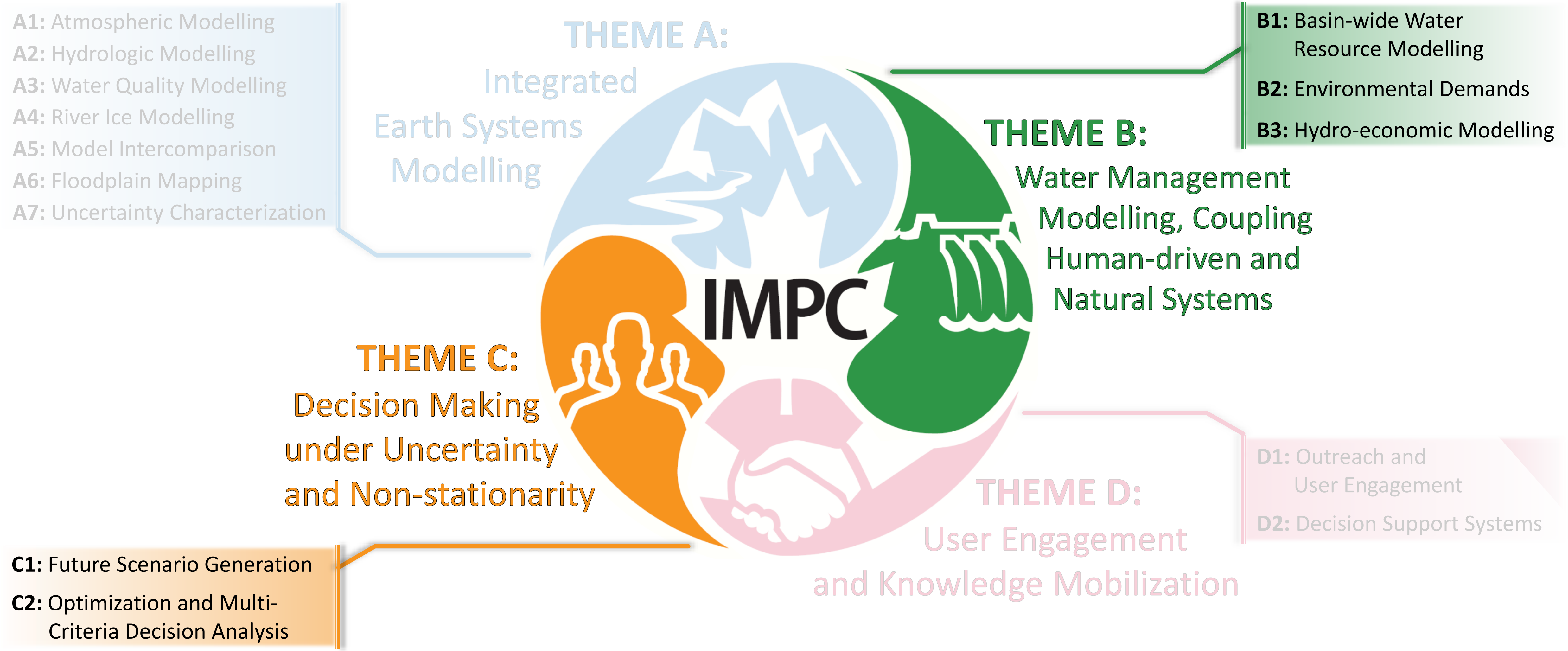
Global Institute for Water Security
USASK.CA/WATER

IMPC
Integrated Modelling Program for Canada
Global Water Futures


A1: Atmospheric Modelling
A2: Hydrologic Modelling
A3: Water Quality Modelling
A4: River Ice Modelling
A5: Model Intercomparison
A6: Floodplain Mapping
A7: Uncertainty Characterization
THEME A:
Integrated Earth Systems Modelling
B1: Basin-wide Water Resource Modelling
B2: Environmental Demands
B3: Hydro-economic Modelling
THEME B:
Water Management Modelling, Coupling Human-driven and Natural Systems
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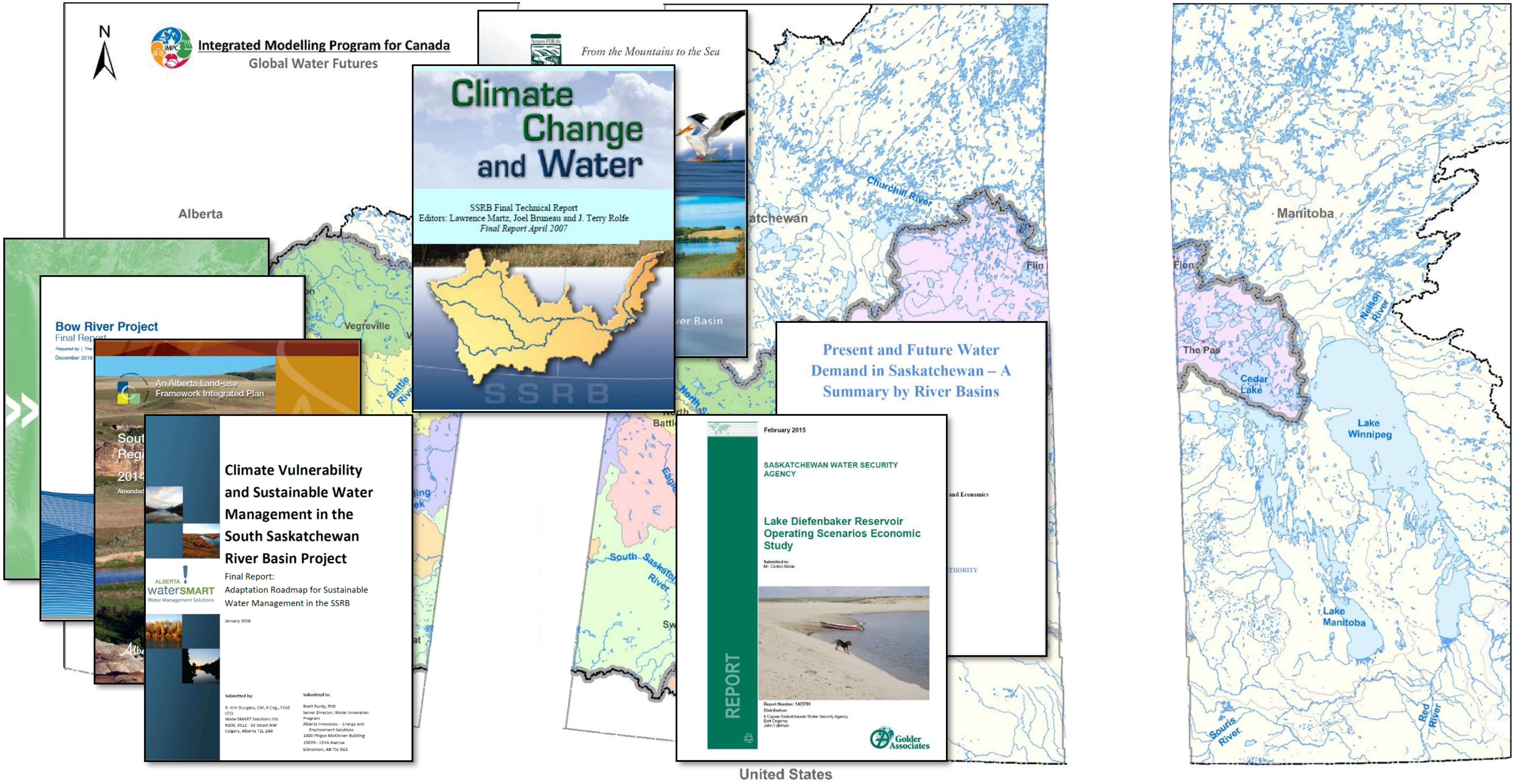
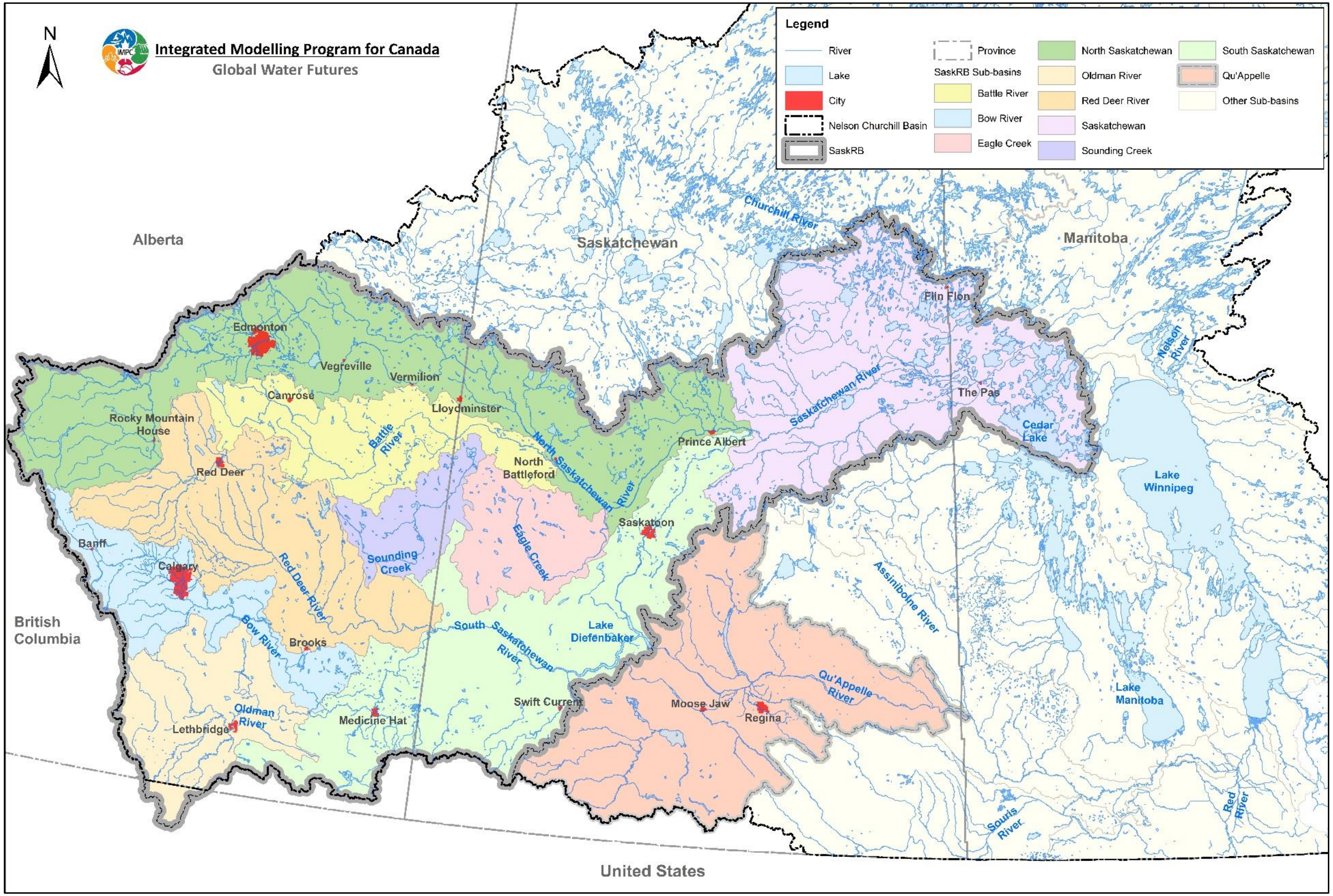
THEME C:
Decision Making under Uncertainty and Non-stationarity
C1: Future Scenario Generation
C2: Optimization and Multi-Criteria Decision Analysis
D1: Outreach and User Engagement
D2: Decision Support Systems
THEME D:
User Engagement and Knowledge Mobilization

The Status Quo:
Fragmentation in Modelling and Management



Objective:
Integrated Modelling for Basin-Wide Decision Support



A Survey of Modelling Platforms

#	1	2	3	4	5	6	7	8	9	10	11	12
Program Name	**WEAP**	**MIKE HYDRO Basin**	**Colorado DSS**	**WRMM**	**RiverWare**	**HEC-ResSim**	**FreeWAT**	**SWAM**	**REALM**	**CaWAT**	**OASIS**	**WRISM (CalSIM)**
Price	$250 - $1000 US Dollars / 2yrs	$380 CAD + applicable charges (shipping, etc)	FREE	Not available for public use	$2360 - $4160 US Dollars / yr	FREE	FREE	Not available for public use	FREE	N/A	Not Free	Free and open source
Allocation Algorithm	Prioritized (lp-solve)	Prioritized, Fract. of flow (1. p.68)	Prioritized, MDSA algorithm (1.p.10)	Prioritized, Out-of-Kilter algorithm (p.1-2)	Flexible Rule-based allocation, CPLEX (p. 5)	Only Release Allocation, (2.p.11-82)	Surface/Ground- water rights (3.p.13,3.p.18)	Colorado DSS MDSA algorithm (p. 3-1)	Penalty func., RELAX Algorithm (1.p.23)	N/A	Linear solver XA, developed by Sunset Software Technology	open source CBC and commercial XA
Time step	1 – 365 days	Seconds (1.p.3)	Daily & monthly (1.p.5)	1-365 days (p.1-7)	Hourly to yearly (p. 3)	TBD	TBD	Monthly (p. 1-1)	Hourly, Daily, Weekly, Monthly, etc (1.p.26)	Monthly, Monthly (2.p.5)	Anything between 5 min to 1 year	1 day or 1 month
Demand Sites	Agriculture, Urban, Industry, etc.	Agriculture, Urban, Industry, etc (1. p.101)	Agriculture, Urban, Industry, etc	Agriculture, Urban, Industry, etc (p.1-5)	General water users (p. 1460)	N/A	Irrigation	Agriculture, Urban, Industry (p.2-5, p.2-10)	Agriculture, Urban, Industry, etc	N/A	Irrigation, withdrawals, hydropower, environmental flows etc.	Irrigation, withdrawals, hydropower, environmental flows etc.
GUI	YES	YES	YES	YES	YES	YES	YES based on QGIS	YES basen on MS Excel	YES	MS Excel Env (1.p. 4)	Yes	Yes
API	YES	YES (3)	N/A	N/A	RCL (p. 1)	YES (only internal)	N/A	N/A	N/A	N/A	Yes	Yes
Scenario Analysis	YES	YES (2. p.7)	YES (2.p.7)	N/A	YES (p. 1)	YES (2.p.13-i)	N/A (1.p.13)	N/A	YES (1. .p. 132)	N/A	Yes	Yes
Rainfall-Runoff Modeling	Simp. FAO, MABIA, PGM, SMM	NAM, UHM (1. p.49)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Link to SWAT (1.p. 4)	No – link to other model	No – link to other model
Irrigation Demand	Based on FAO56	FAO 56 (1. p.109)	ASCE Pen-Mont (2.p.3)	Jensen-Haise eq. (p. c-2)	N/A	N/A	[probably] FAO 56 (1.p.56)	Blaney Criddle eq. (p. 2-10)	FAO 56 (4.p.4)	Link to AquaCrop (1.p.4)	No	No
Water Quality Modeling	DO, BOD, Temp. Link to Qual2k	BOD, DO, NH4, NO3, P, user defined, (1. p165)	N/A	N/A	DO, TDS, TDG, Temperature (p. 1)	N/A	N/A	N/A	Salinity, Turbidity, Temp, etc (1.p.31)	N/A	Yes – up to three conservative constituents	No – link to other model
Groundwater Modeling	Link to MODFLOW Link to MODPATH	Linear reservoir (1&2 aquifer) (1.p.50)	Link to MODFLOW (3.p.33)	N/A	N/A (p. 117)	N/A	MODFLOW* (1.p.iii)	N/A	N/A	N/A	No	No
Reservoir Operation	YES	YES (1. p.132)	YES (1.p.254)	YES (p.1-5)	YES (p. 1)	YES	N/A	YES (p. 2-3)	YES (1.p.48)	N/A	Yes	Yes
Financial Analysis	Simple Cost - Benefit	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	No
Internal Scripting Interface	VBS, PHP, Ruby, Python, Perl, JS	N/A	Self-developed commands (3.p.227)	N/A	RiverWare Policy Language (p. 1)	Jython (2.p.14-49)	N/A	N/A	YES, REALM macro language (3.p.2)	N/A	Yes OCL (Operations Control Language)	Yes WRESL (Water Resources Simulation Language)
Hydropower Modeling	YES	YES (1. p.147)	N/A	YES (p.1-5)	YES	YES (2.p.11-44)	N/A	N/A	N/A	N/A	Yes	Yes
Calibration Algorithm	PEST Algorithm	SCE, PSE (2. p. 24)	TBD	N/A	N/A	YES but Unknown (2.p.14-39)	UCODE_2014 (6.p.21)	N/A	N/A	N/A	No	No
Input Data	Manual Time series, [illegible]	.dfs0 and shapefiles	[illegible]	[illegible]	[illegible]	HEC-DSS time series	ASCII, istSOS, .sqlite,	[illegible]	[illegible]	[illegible]	Microsoft Access and	HEC DDS and text file

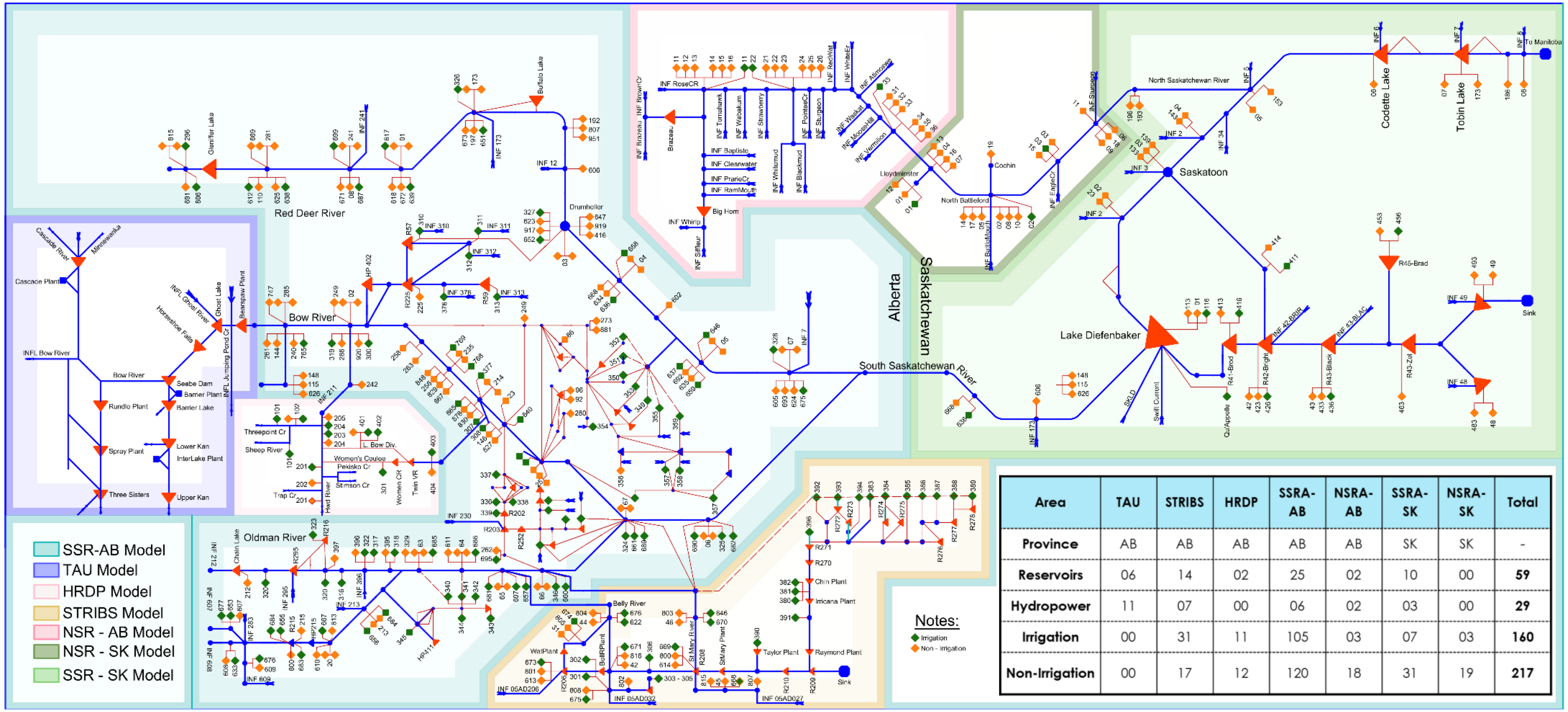
Short-Listed Models

	WRMM	WEAP	MODSIM	WRIMS
Freeware	Not available for public use	\$250–\$1 000 for 2 year single license	Free	Free
Open source	No	No	No	Yes
Time step	1–365 days	1–365 days	15 minutes– 1 month	1 day or 1 month
GIS interface	No	Yes	Yes	No
Additional functionality	No	Rainfall-runoff, water quality, financial analysis	Link to external models	Linked to external DLLs- water quality, flow routing
Previously linked to other models	No	SWAT	SWAT, MESH, QUAL2K, GA, PSO, ANN	IWFM, CalLite, PRISM, APSIDE, DSM2-SJR
Automation	Yes	Yes	Yes	Yes

Important Criteria:

- Open Source
- Free for Public Use
- Flexibility in representing operating policies
- potential for extension
- Technical Support

Integrated Saskatchewan River Basin Model (MODSIM)



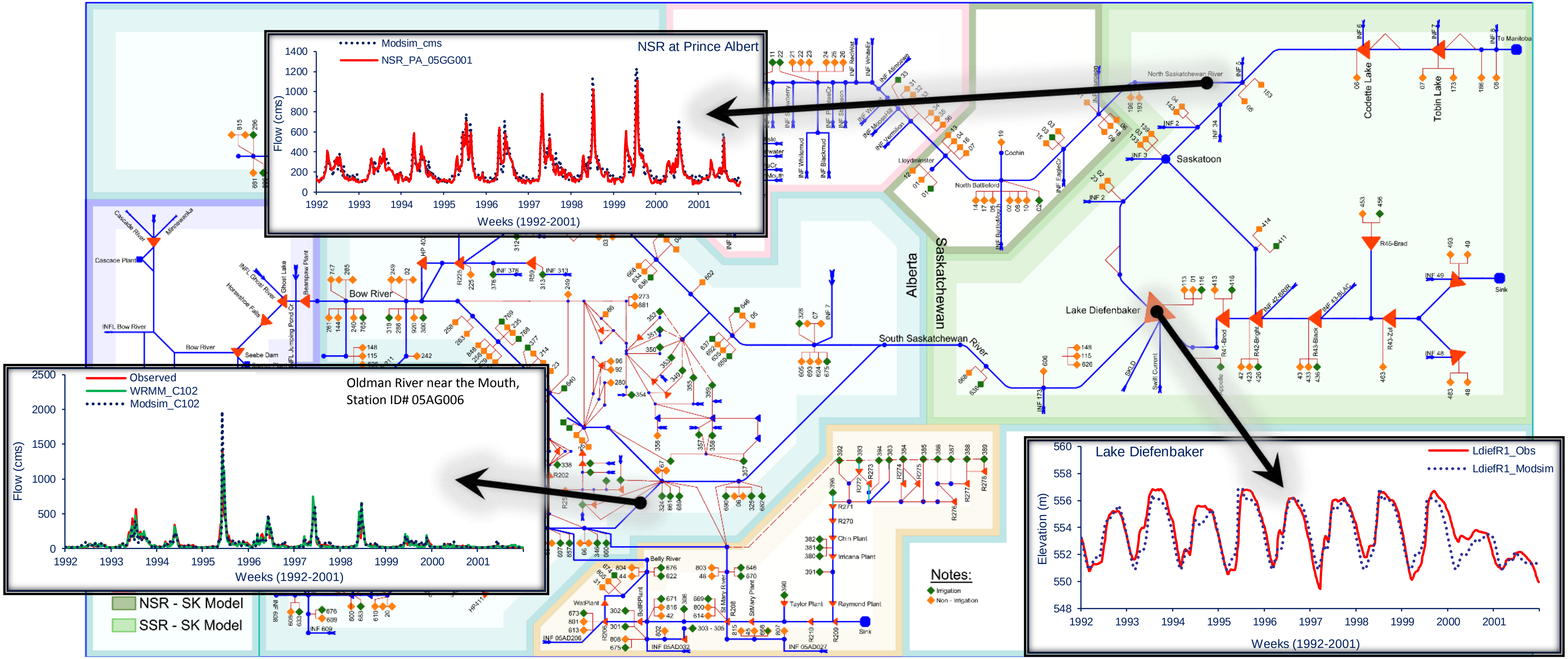
Area	TAU	STRIBS	HRDP	SSRA-AB	NSRA-AB	SSRA-SK	NSRA-SK	Total
Province	AB	AB	AB	AB	AB	SK	SK	-
Reservoirs	06	14	02	25	02	10	00	**59**
Hydropower	11	07	00	06	02	03	00	**29**
Irrigation	00	31	11	105	03	07	03	**160**
Non-Irrigation	00	17	12	120	18	31	19	**217**




- An extremely complex system
- Simulates the operation of the existing water infrastructure, updated to 2018
- Can simulate a range of *what-if scenarios*, including any change in water supply, allocation policy, demand development, infrastructure development, etc.
- Has the potential to fully couple with the hydrologic model, economic model, social model, etc.

Model Validation

Against observations and sub-basin scale models where available

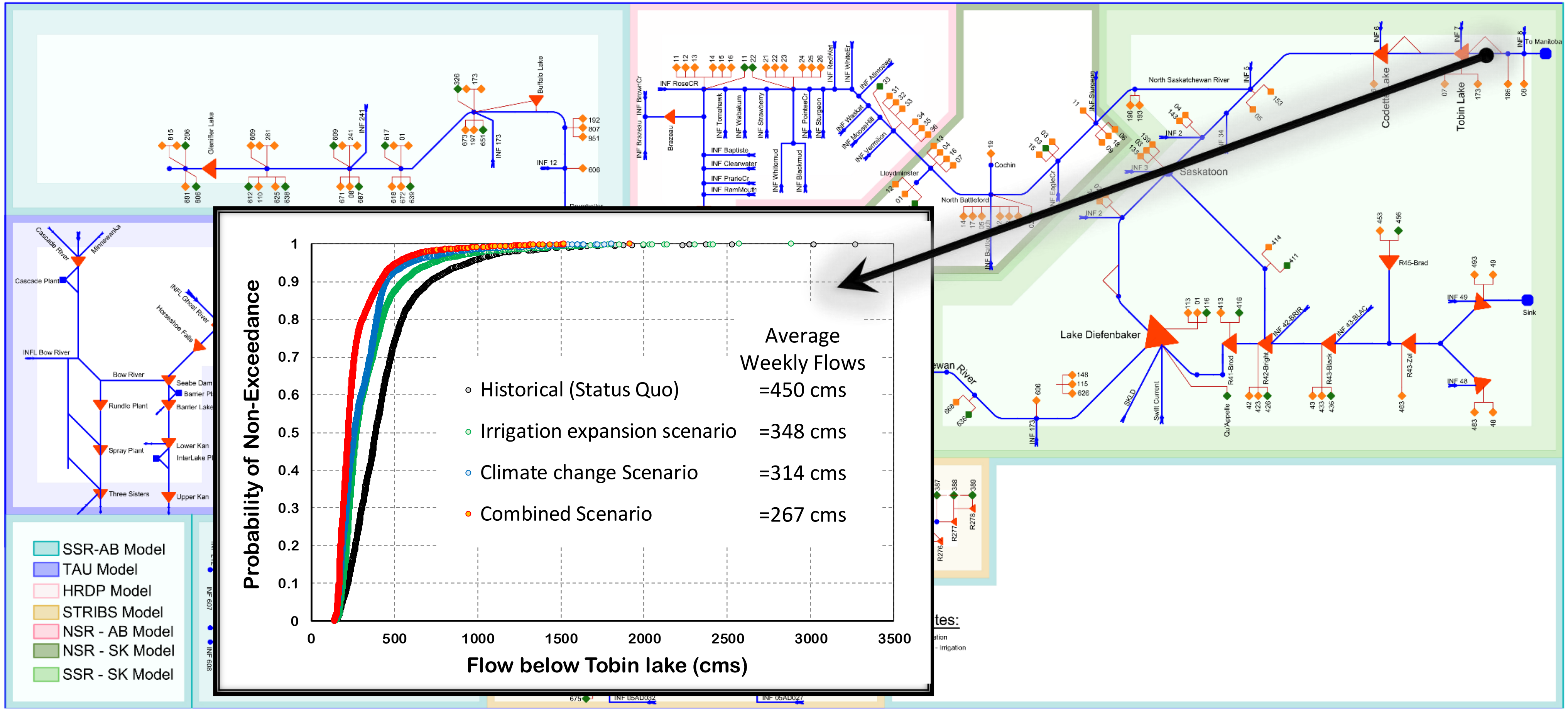


Model Validation by Stress Testing

Climate change scenario: Inflows reduced by 20%

Irrigation expansion scenario: Demand increased by 400% in SK and 20% elsewhere

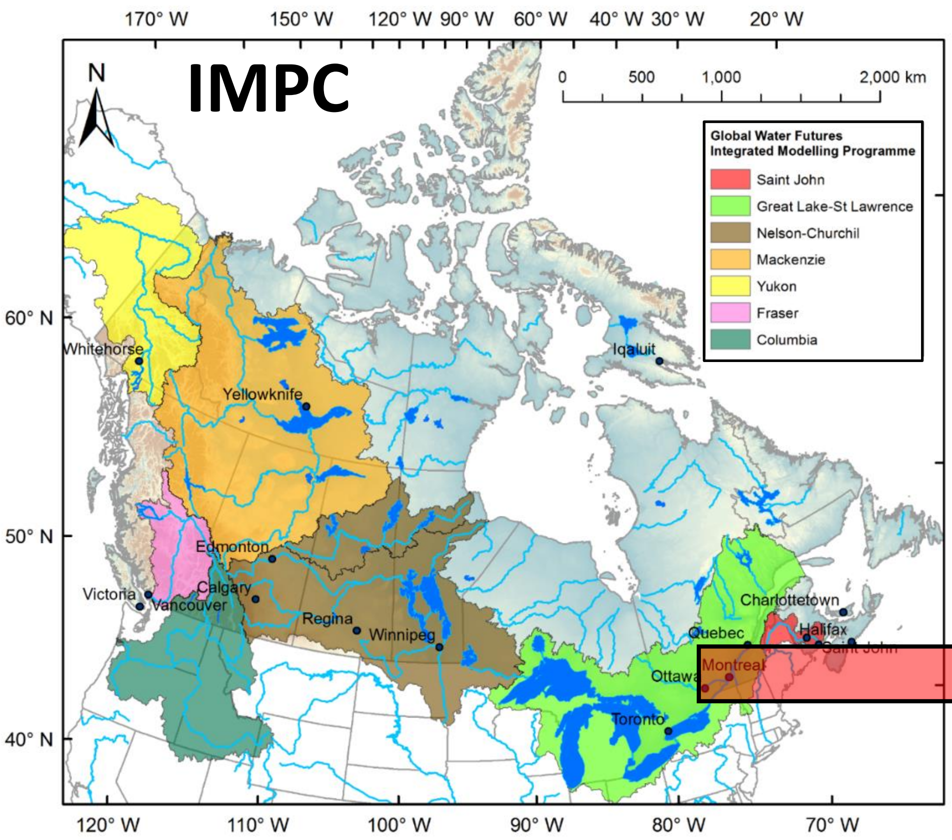
Combined scenario: the combination of the above



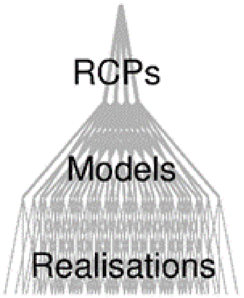
Challenges

- Actual demands (and Ag-Water Model)?
- Actual Non-irrigation demands (domestic, industrial, etc.)?
- Development plans?
- Actual reservoir operating policies?
- …

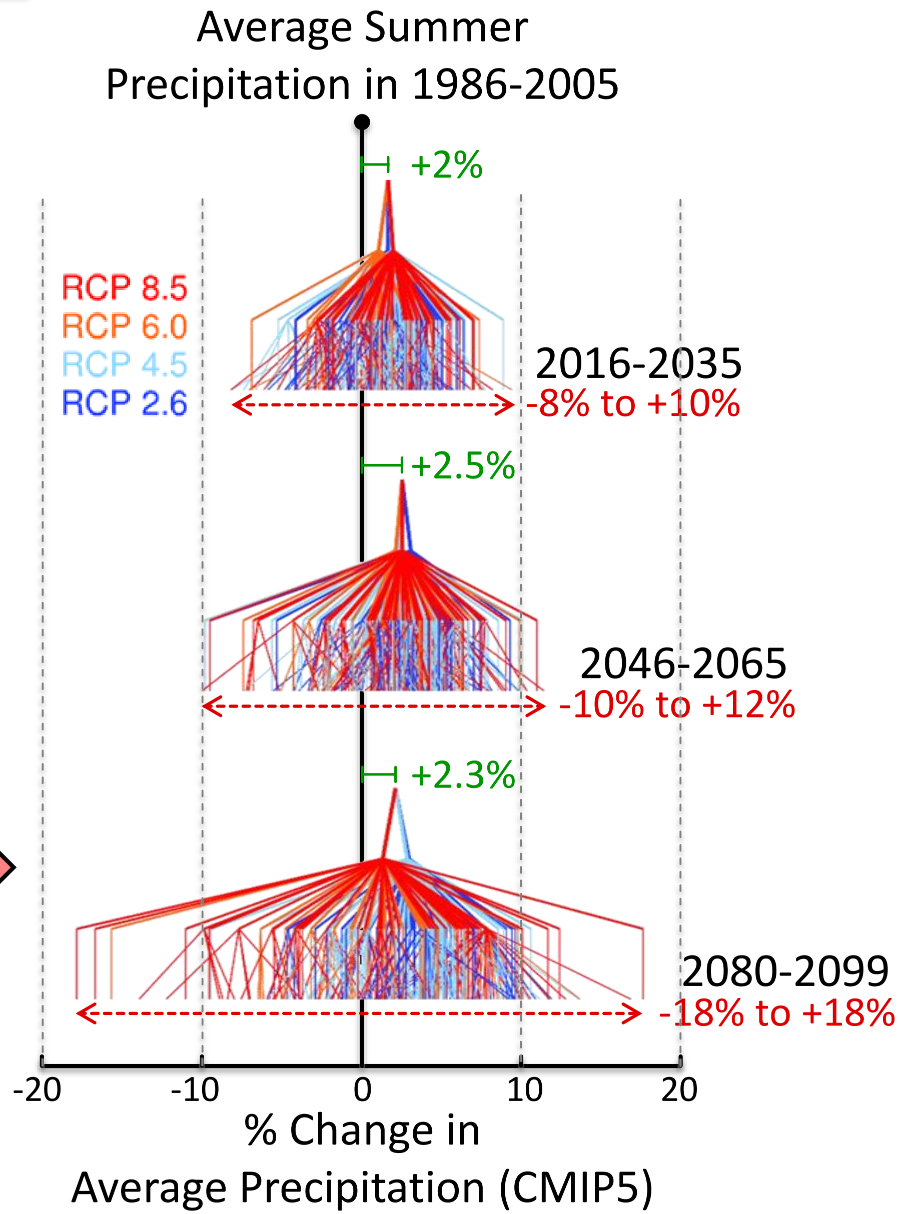
Looking Into The Future
Scenario Discovery



Cascade of Uncertainty (CMIP5)

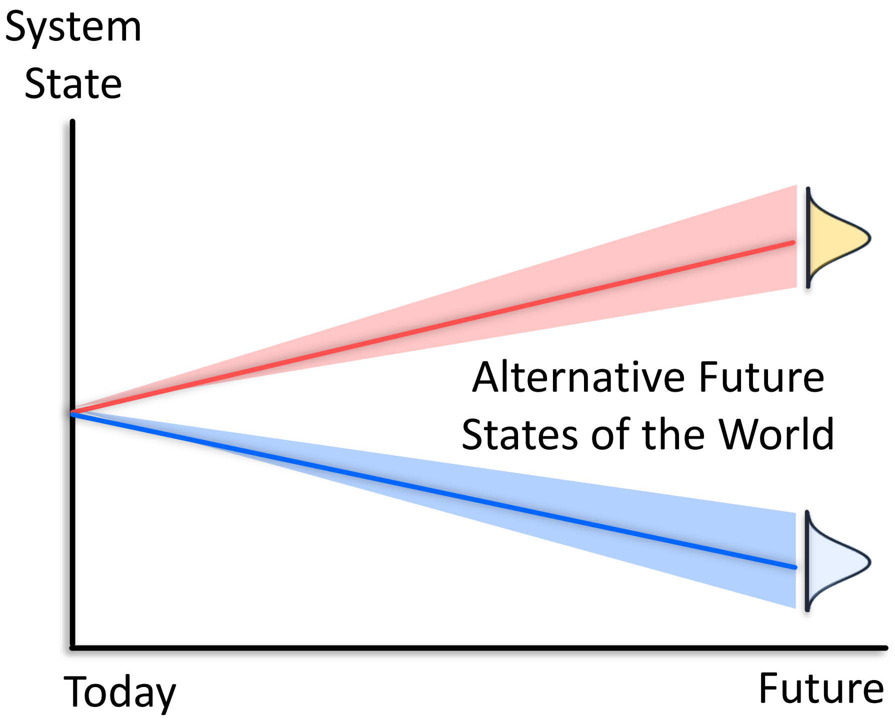


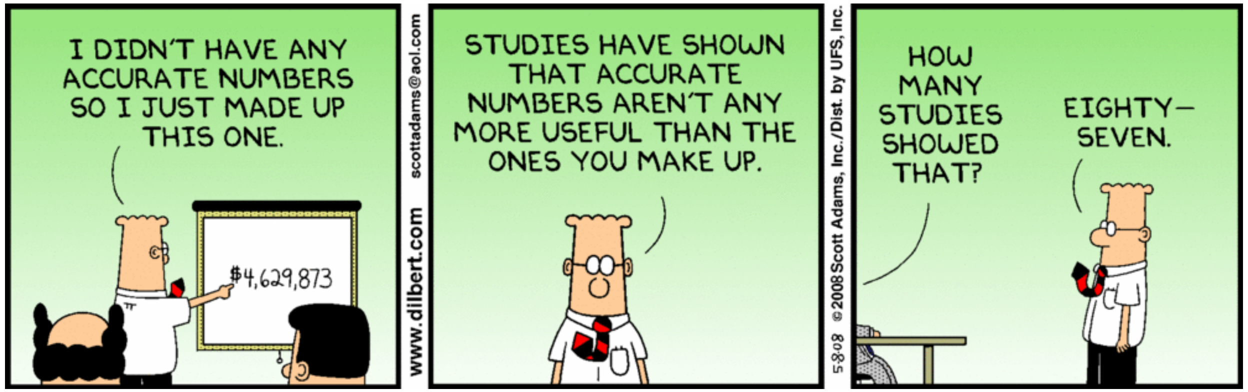
Great-Lakes Basin



Asong Z. E., Hawkins, E., Razavi, S., et al. Climate change projections for scenario-led hydrological impacts assessment: Rethinking how we interpret the cascade of uncertainty for effective adaptation. In Prep.

Living With "DEEP" Uncertainty?





- Is the *"predict-then-plan"* paradigm obsolete? (Top-Down Decision Making)
- How can we minimize vulnerability when the future deviates from our assumptions about it?
  (Bottom-Up, "Robust" Decision Making: "Scenario Discovery" and "Building Resilience")

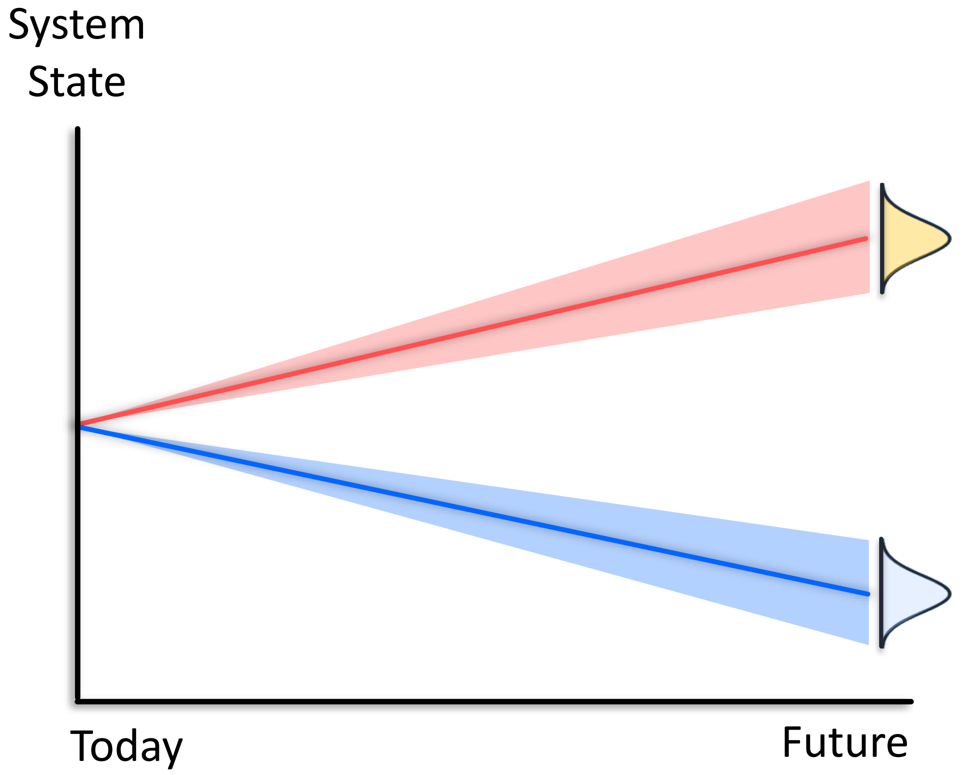
So What?!

Components of a Seamless Decision Support Framework

(1) Future States of the World (Scenario Discovery)

A future with deep uncertainty as a result of drivers such as climate, technological, socio-economic, and political change.

- Drivers out of control of the decision makers
- Need for a range of plausible future scenarios
- Include:
  - Supply/climate change scenarios (inflows, precipitation, temperature, etc.) – **Kasra Keshavarz and Andrew Slaughter)**.
  - Demand scenarios (population growth, irrigation expansion, etc.) – **Leila Eamen**.



Components of a Seamless Decision Support Framework

(1) Future States of the World

(2) Decision Alternatives

- Controllable by decision makers **(Leila Eamen, Hayley Carlson, Pat Gober)**:
  - They may be pre-specified by the decision makers
  - or be based on search via optimization or sampling (experimental designs)

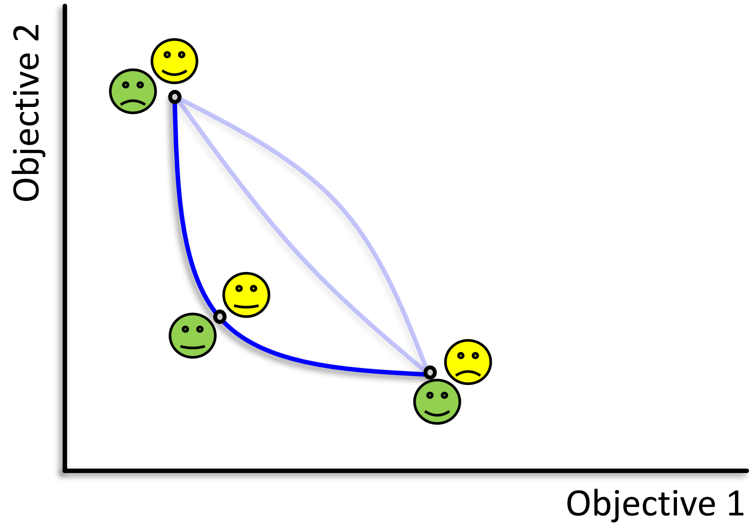
- Include development, management, or adaptation scenarios:
  - Non-structural/operating scenarios (alternative operating rules, license sharing, conservation strategies, reallocation strategies, etc.)
  - Structural scenarios (new reservoir, diversion, irrigation expansion, etc.)

Components of a Seamless Decision Support Framework

(1) Future States of the World
(2) Decision Alternatives
(3) Performance Metrics

How the system will perform with a *decision alternative* under a *given future state of the world*.

- Hydro-economic metrics **(Roy Brouwer, Leila Eamen)** and metrics for environmental and cultural flows **(Tim Jardine, Jennifer Lento, Graham Strickert, Azza Mohamadiazar)**
- Classic metrics such as reliability and vulnerability
- Trade-off Discovery **(Leila Eamen, Nhu Do)**
  - Conflicting interests across different stakeholders
  - identify trade-offs (facilitates negotiation)
  - Generate a common understanding for compromise solutions



Components of a Seamless Decision Support Framework

(1) Future States of the World

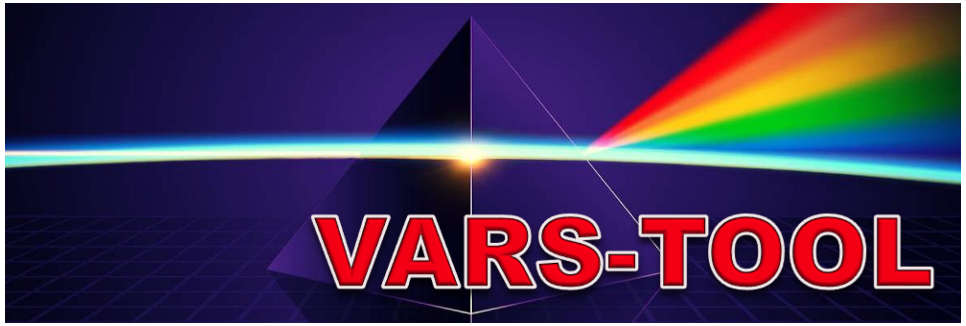
(2) Decision Alternatives

(3) Performance Metrics

(4) Robustness Metrics

How the system performance will be *insensitive to deviations* from the state(s) or assumptions the system was designed for (**Nhu Do, Leila Eamen, …**).

- Satisficing: *Not seeking optimal performance*, but meeting sufficient requirements.
- Regret-based: minimizing the cost or implications of incorrect decisions.



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