HYDROPREDICT 2012
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Overview of Issues Related to

Pragmatic Approaches for Water Management Under Climate Change Uncertainty

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Issues to Consider when addressing Climate Change

- **Climate impact assessment methods**, vulnerability assessments that are sector specific as well as project and site specific
- **Climate change science** – how useful are the GCM modeling experiments in deriving realistic estimates of changes in the frequency, duration and intensity of natural hazards (tornados, hurricanes, droughts, floods, rainfall, monsoons, etc.)
- **Engineering design standards** – how can the GCM data effectively be used for revising design standards?
- **Regulatory criteria** for public and private sector building codes, hazard zones and exclusion zones
- **Planning and evaluation techniques**, including economic decision criteria and benefit-cost analysis
- **Methods for uncertainty analysis**, and transforming uncertainties into robust designs (related to the cascading uncertainties associated with vulnerability assessments and climate change science).

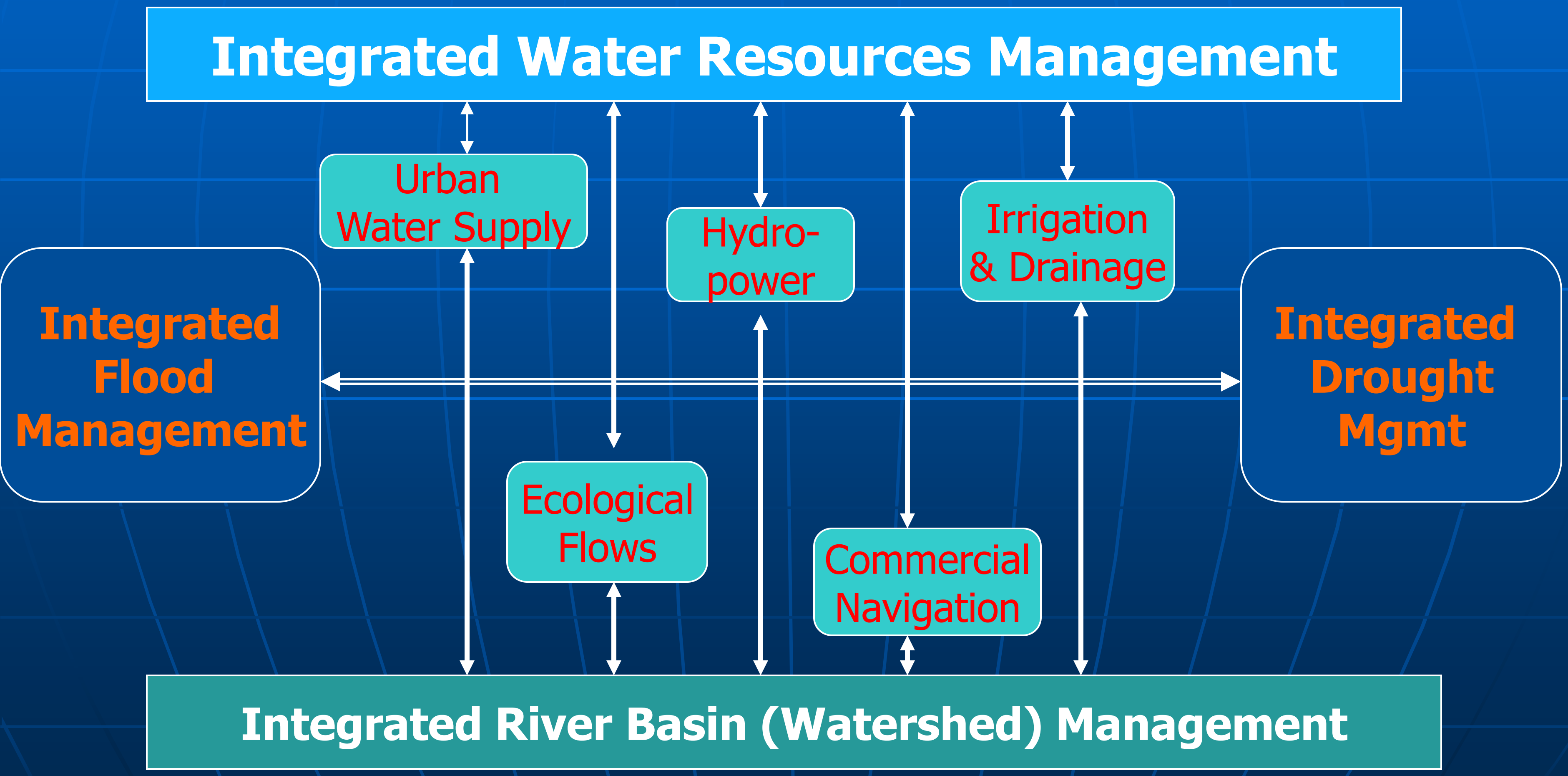
Functions/Elements of Water Resources Management
Conventional Mechanisms for Adapting to Climate Uncertainties

- Planning **new investments**, or for capacity expansion (reservoirs, irrigation systems, levees, water supply, wastewater treatment)
- Maintenance and **major rehabilitation** of existing systems (e.g. dams, barrages, irrigation systems, canals, pumps, etc.)

Adaptive Management Measures

- **Operation & regulation** of existing systems: accommodating new uses or conditions (e.g. ecology, climate change, population growth)
- Modifications in **processes and demands** (water conservation, pricing, regulation, legislation)
- Introduce new **efficient technologies** (desalting, biotechnology, drip irrigation, wastewater reuse, recycling, solar energy)

IWR**Management**
of Water Sectors



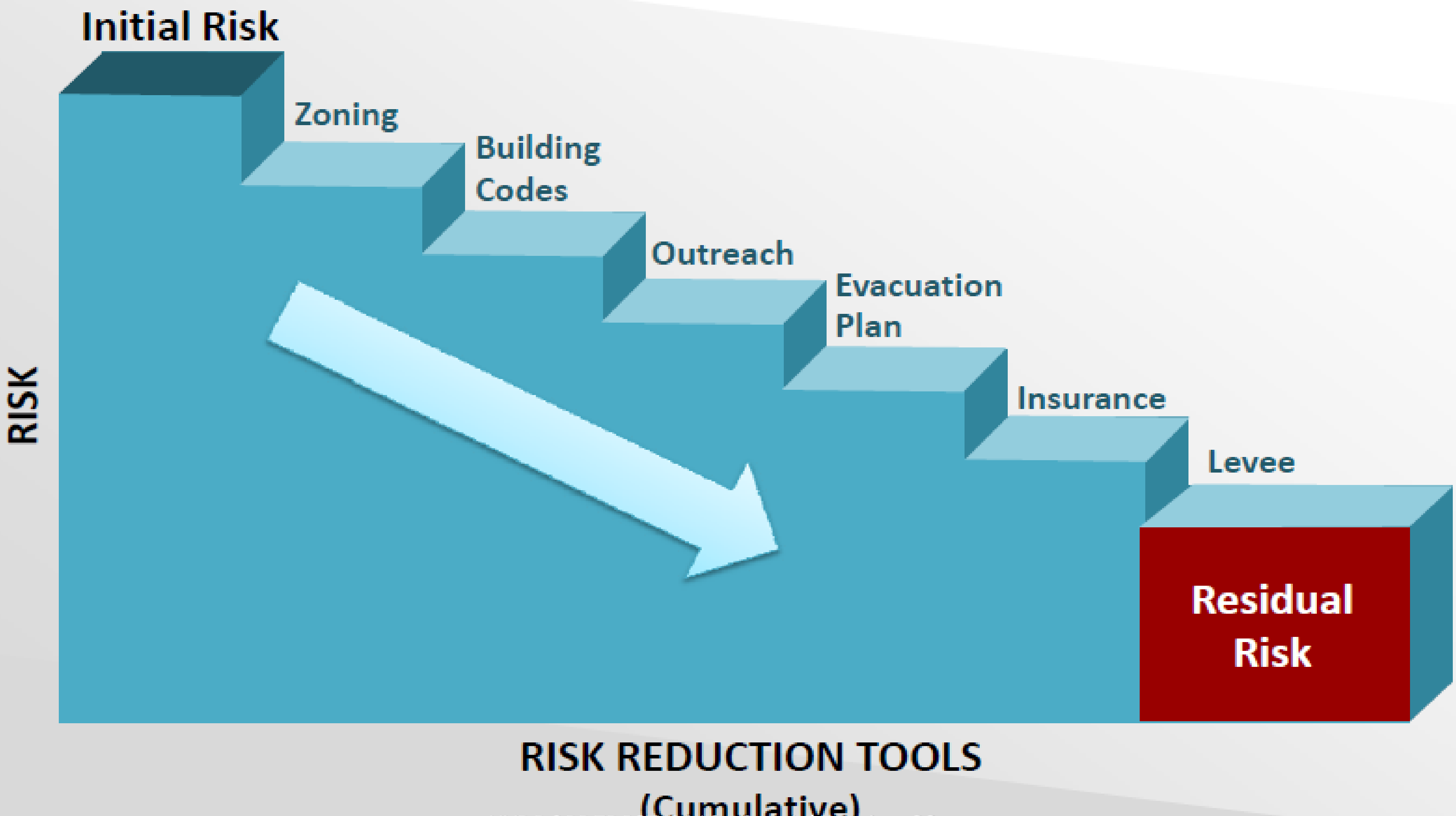
Water Sector Focus is on **Risk Management** for ***Climate Variability*** (which is foundation for CC)

Design, operations, rehabilitation require project evaluation & design criteria: combination of standards & risk analysis

- Dam safety (convert PMP/PMF to risk-based designs)
- Levee design criteria (SPF to risk-based designs)
- Shore erosion, coastal protection (PMH)
- Reservoir operating criteria, improved forecasting
- Reservoir/system water allocation changes
- Delineation of 100-year floodplains/NFIP
- Drought & Flood Contingency Mgmt (reservoir, urban)
- Emergency Operations/Advanced Measures (seasonally anticipated snowmelt flooding, hurricanes, etc.)

In **transition period,** need new/extended methods for flood/drought frequency analysis under non-stationary climate, with trends.

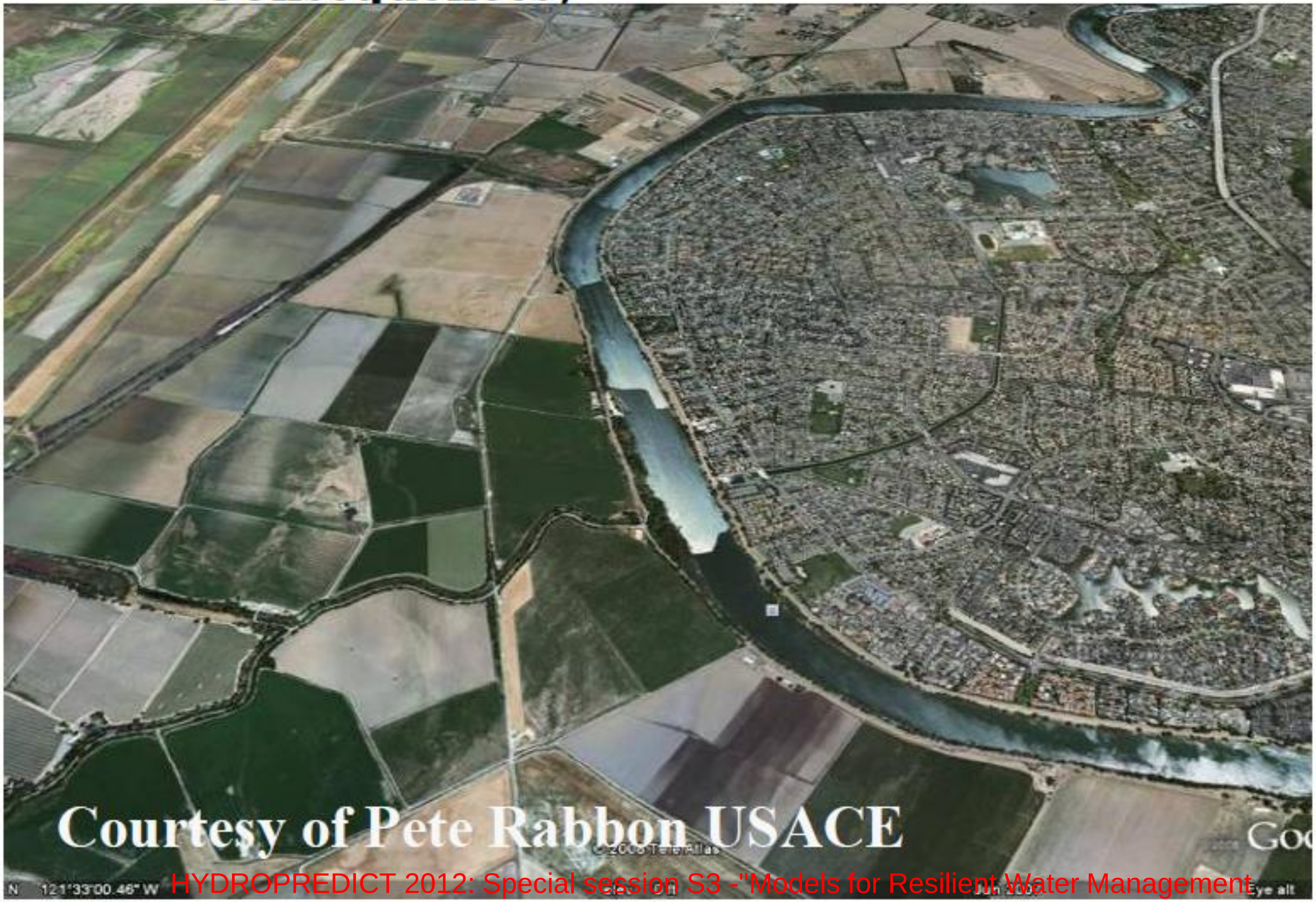
Shared Flood Risk Management: Buying Down Risk



All Stakeholders Contribute to Reducing Risk!

Baker

Flood Risk = P (Probability of flood) X Consequences)



Climate Adaptation: Top Down or Bottom up?

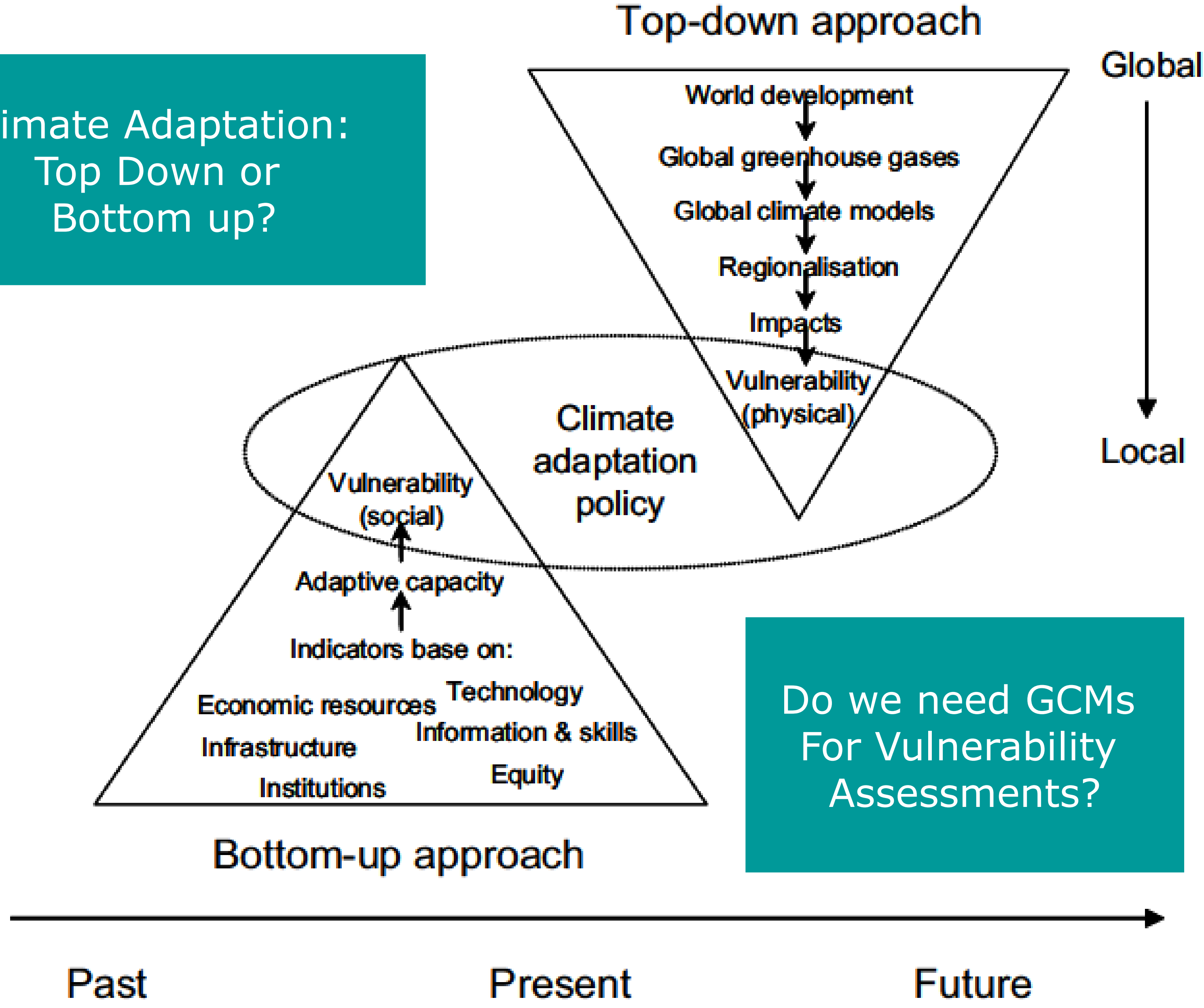
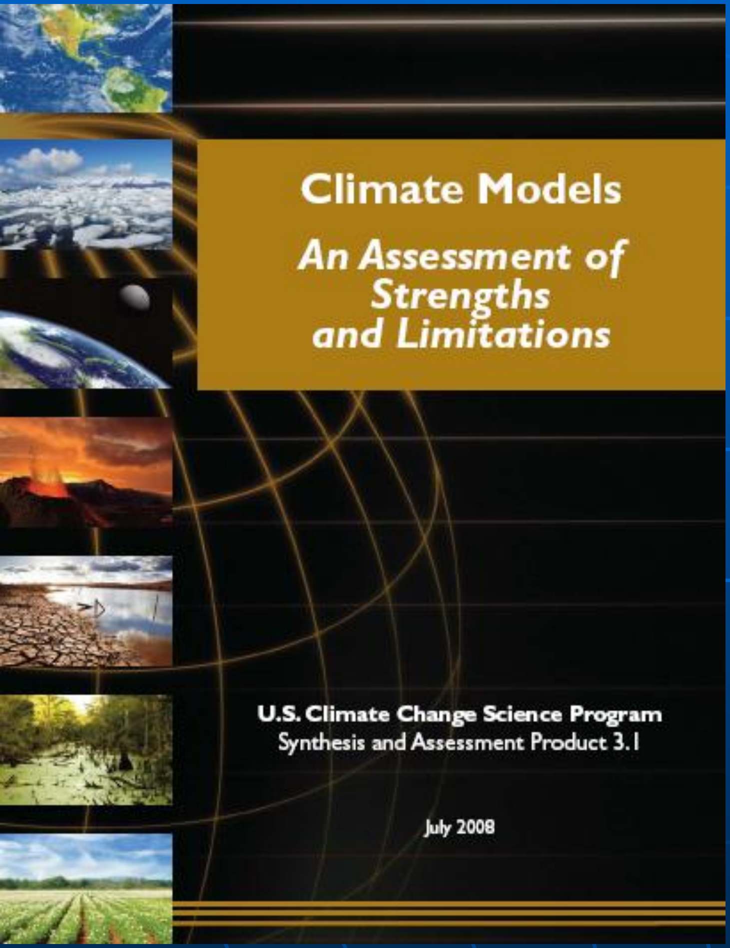


Figure 3.1. "Top-down" and "bottom-up" approaches used to inform adaptation to climate change (from Dessai and Hulme 2004).

Do we need GCMs For Vulnerability Assessments?

Recent Assessment of Climate Models

How Accurate Are Global Climate Models?



- Regional trends in extreme events are not always captured by current models

- It is difficult to assess the significance of these discrepancies and to distinguish between model deficiencies and natural variability

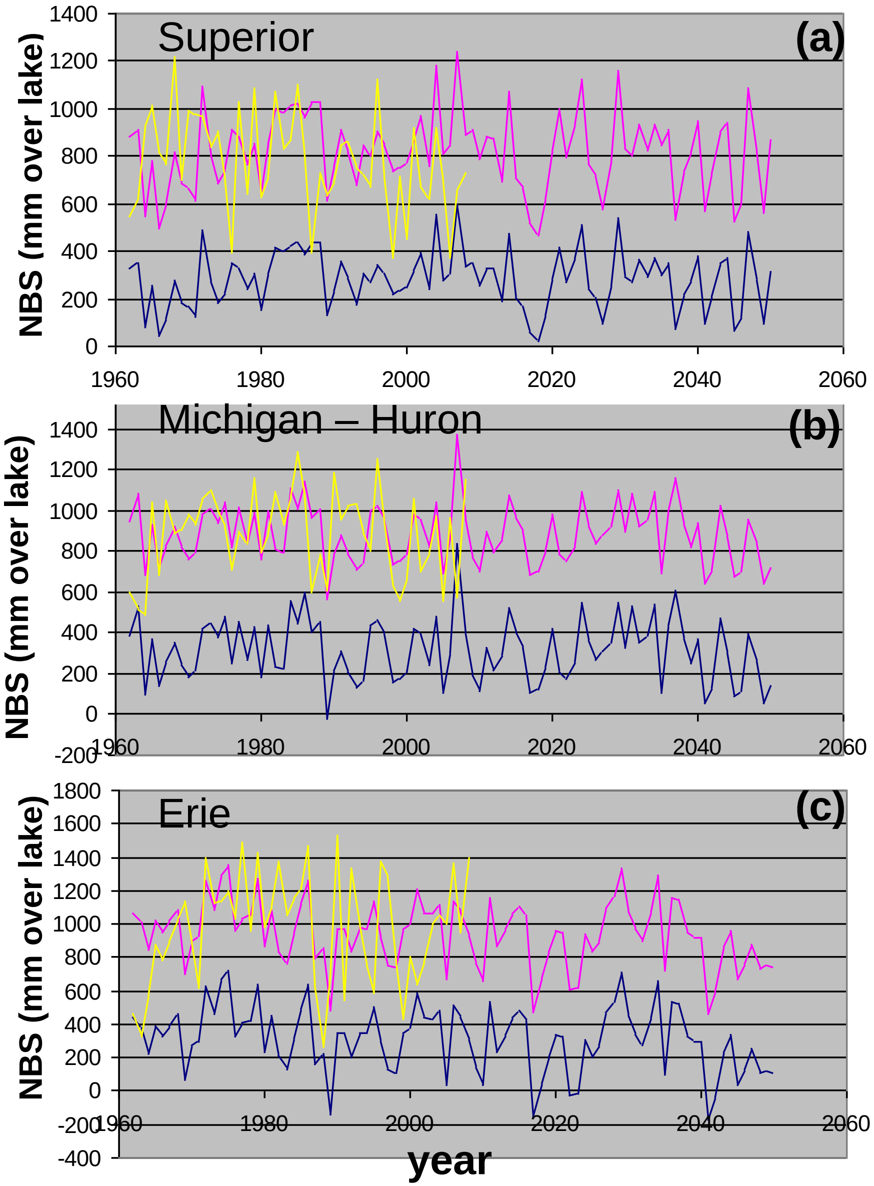


Fig. 3 Annual NBS for: (a) Lake Superior; (b) Lake Michigan – Huron; (c) Lake Erie. Yellow – observed (EC residual method); blue – GLRCM simulation; pink – GLRCM simulation with bias correction.

"Bias Corrections"

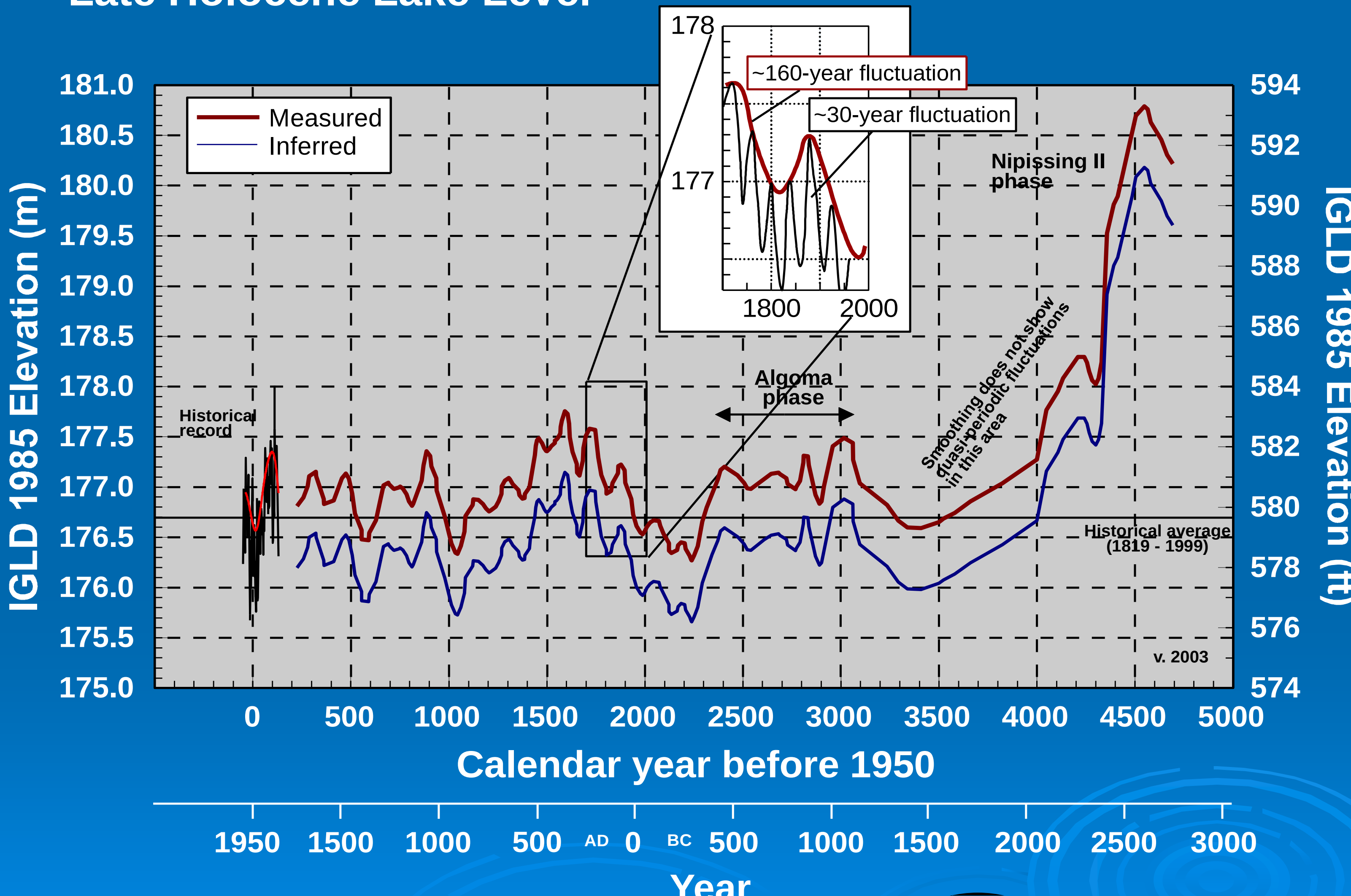
Blue – Original model results

Yellow – Observed (historical)

Pink – what you get after bias correction

Lake Michigan

Late Holocene Lake Level



USGS

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Great Lakes Regulation

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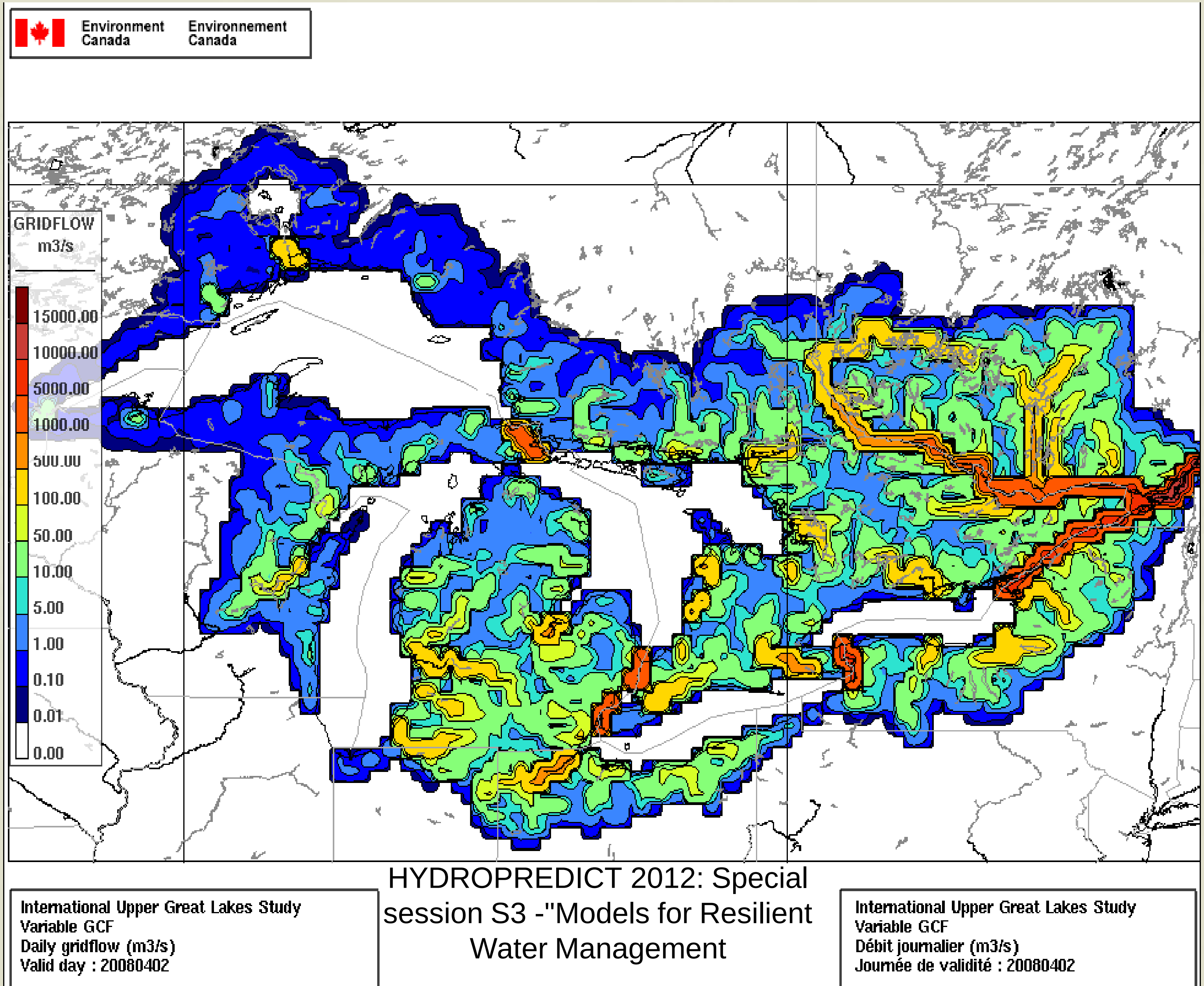
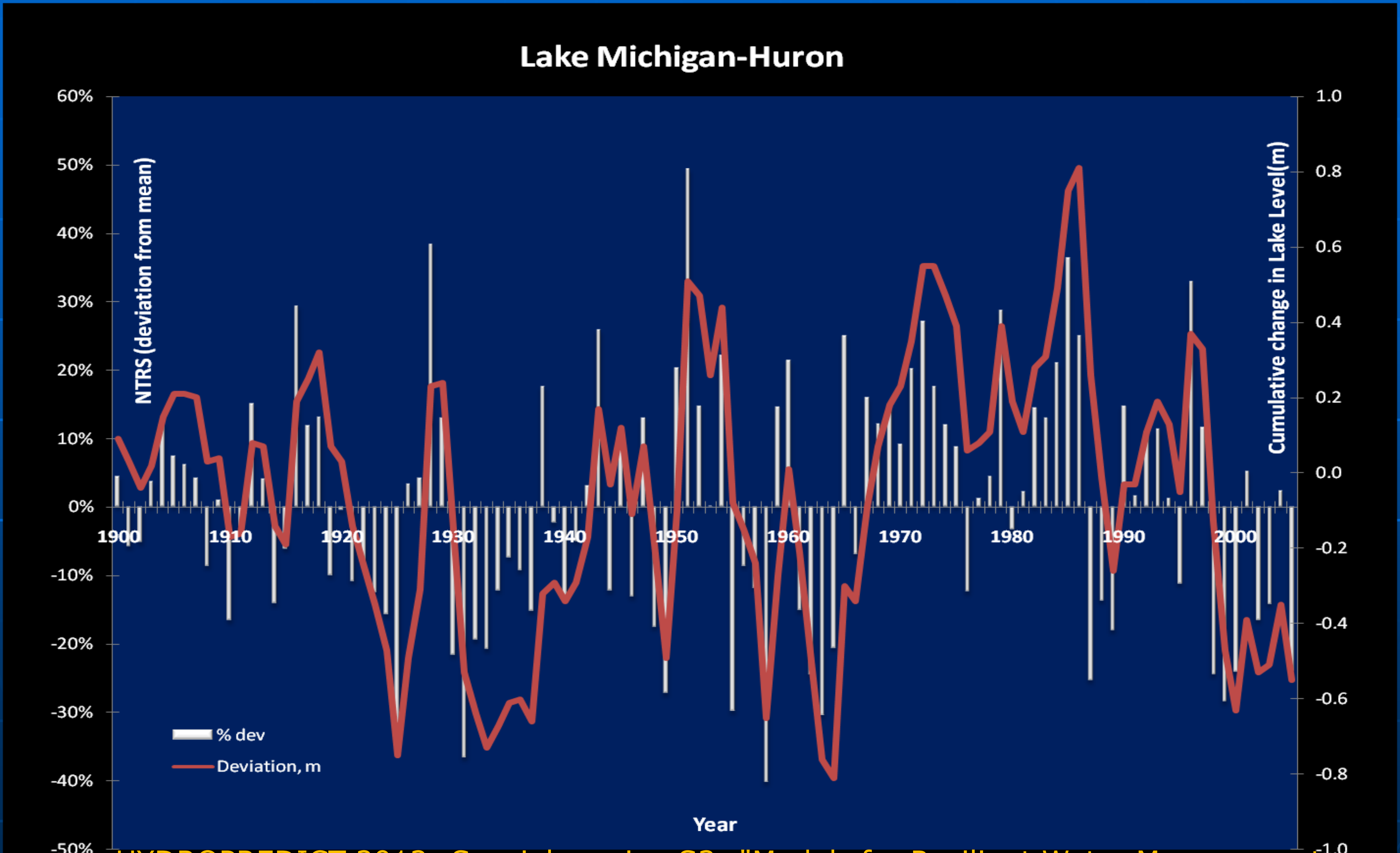
Public Involvement

Public concerns about water levels in the upper Great Lakes differ strongly depending on geographical location.

Water Balance Model



NTS Deficit & Lake Levels



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LOSLR/IUGLS Study Guidelines

- Contribute to **Ecological Integrity**
- **Maximize economic and ecological net benefits**
- No **disproportionate loss (Equity)**
- Flexible in recognition of **unusual or unexpected** conditions
- Adaptable to **climate change** and **climate variability**.
- Decision-making will be **transparent and representative**
- **Adapt** to future advances in knowledge, science and technology.

IJC International Lake Ontario – St. Lawrence River Study (1999-2005)

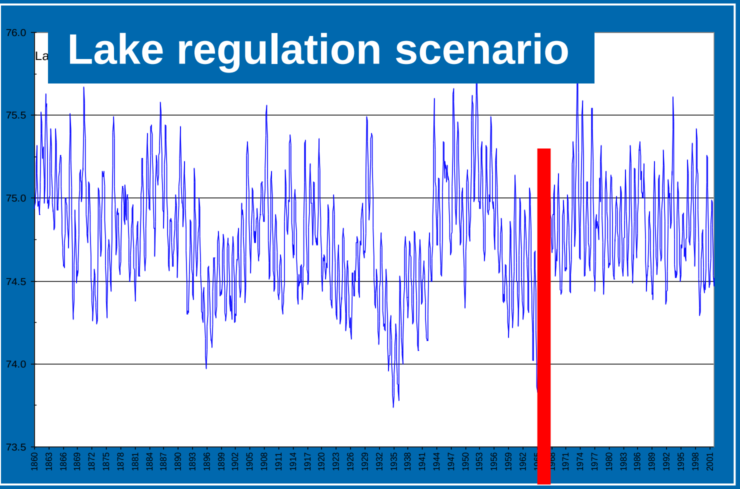
Candidate Plans:
- A: Balanced Economics
- B: Balanced Environmental
- D: Blended Benefits

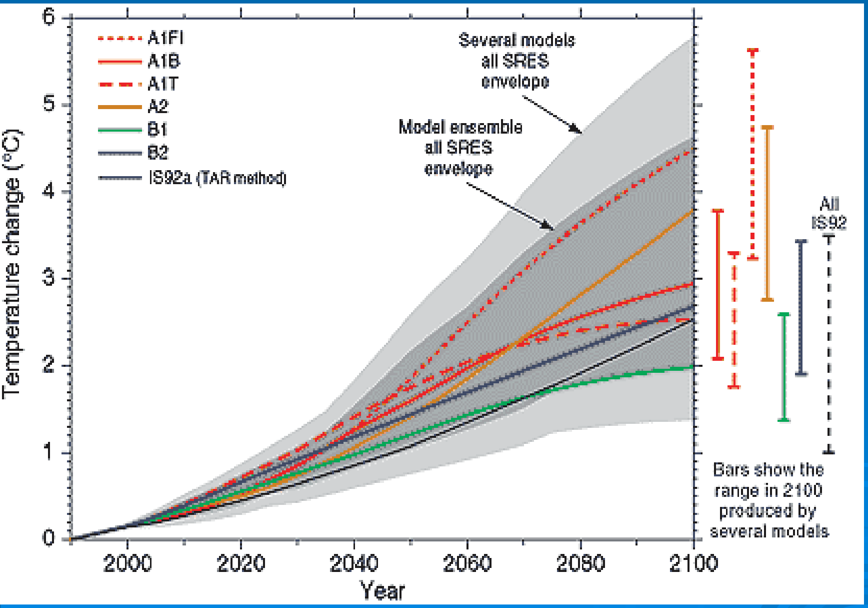
Natural Flow Plan
- E: Natural Flow

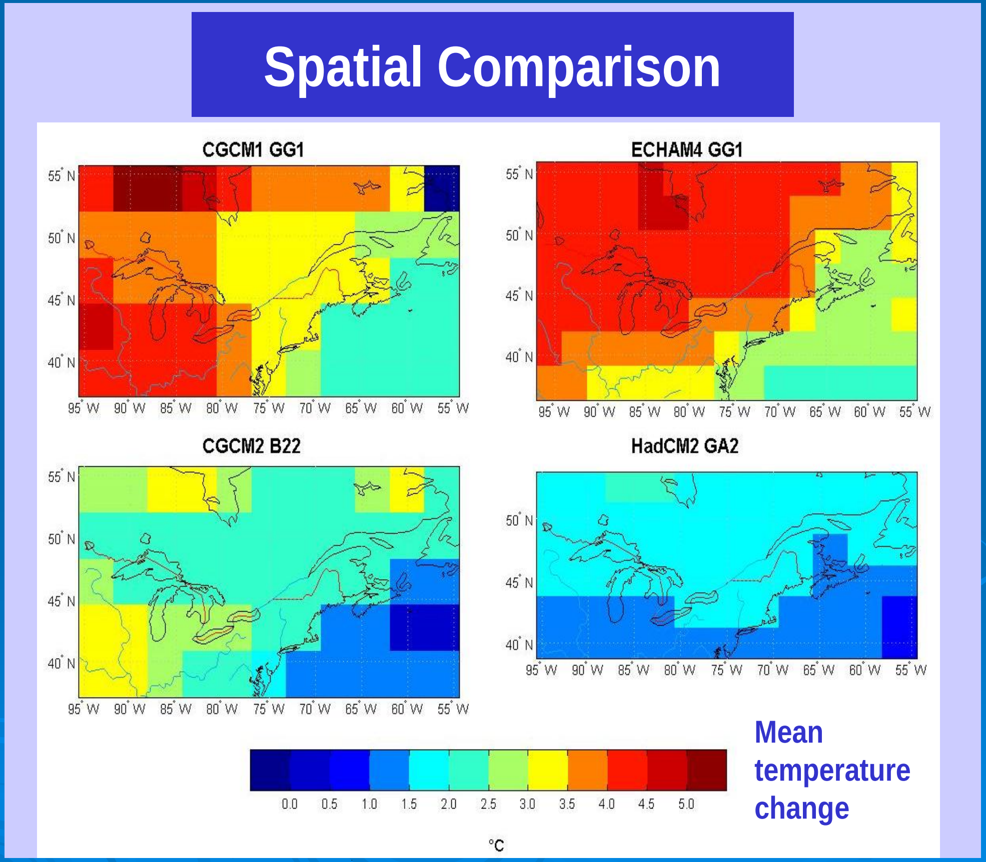
Interest Specific:
- Ontario Riparian Plan
- Recreational Boating Plan

Reference Plans:
- Plan 1998
- Plan 1958DD
- Plan 1958D

IJC Lake Ontario Study: Hydrologic Scenarios Including Climate Change







Net Economic/Ecologic Benefits of Alternative Plans: Historical Record (1900-2000)

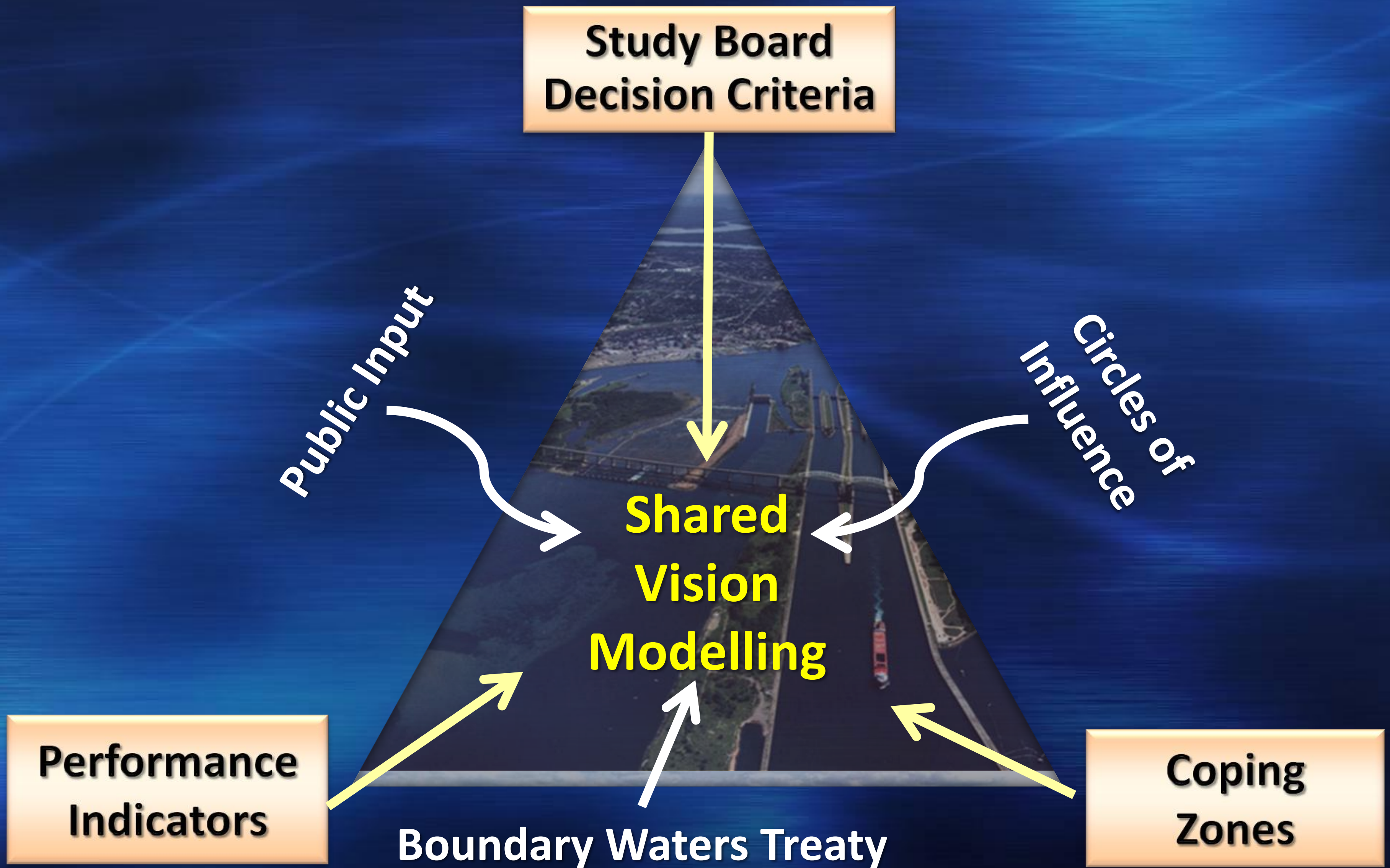
Avg. annual net benefits ($US million)	Plan 58DD	Plan A	Plan B	Plan D	Plan E
Net Benefits	**0.00**	**7.52**	**6.48**	**6.52**	**-12.30**
Shoreline Damages	0.00	**-0.62**	**-1.11**	**0.32**	**-25.96**
Navigation	0.00	0.41	2.20	2.31	4.13
Recreation Boating	0.00	4.23	-0.58	2.04	**-4.64**
Hydroelectric	0.00	3.50	5.97	1.82	14.16
Municipal Water	0.00	0.00	0.00	0.00	0.00
Environmental Index	**1.00**	**1.06**	**1.35**	**1.10**	**4.04**
Wetlands Index	**1.00**	**1.02**	**1.44**	**1.17**	**1.56**

GCM Scenarios: Economic Robustness of Plans
IJC Lake Ontario-St. Lawrence Regulation
w.r.t Climate Change Scenarios

Avg. ann. net benefits ($US million)	Plan 1958DD	Plan A	Plan B	Plan D	Plan E
		Econ Efficiency	*Environ* Quality	*Combo* Benefits	*Natural* Flows
Plan 1958DD (current plan)	0	7.52	6.48	6.52	-12.30
C1- Hot/Dry	-115.65	34.89	-1.42	20.09	-4.91
C2 - Warm/Dry	-49.52	9.85	4.89	5.25	-34.03
C3 - Hot/Wet	-81.69	21.53	2.61	17.77	-2.46
C4 - Warm/Wet	13.98	8.33	11.78	9.65	-21.38

St. Marys River at Sault Ste. Marie

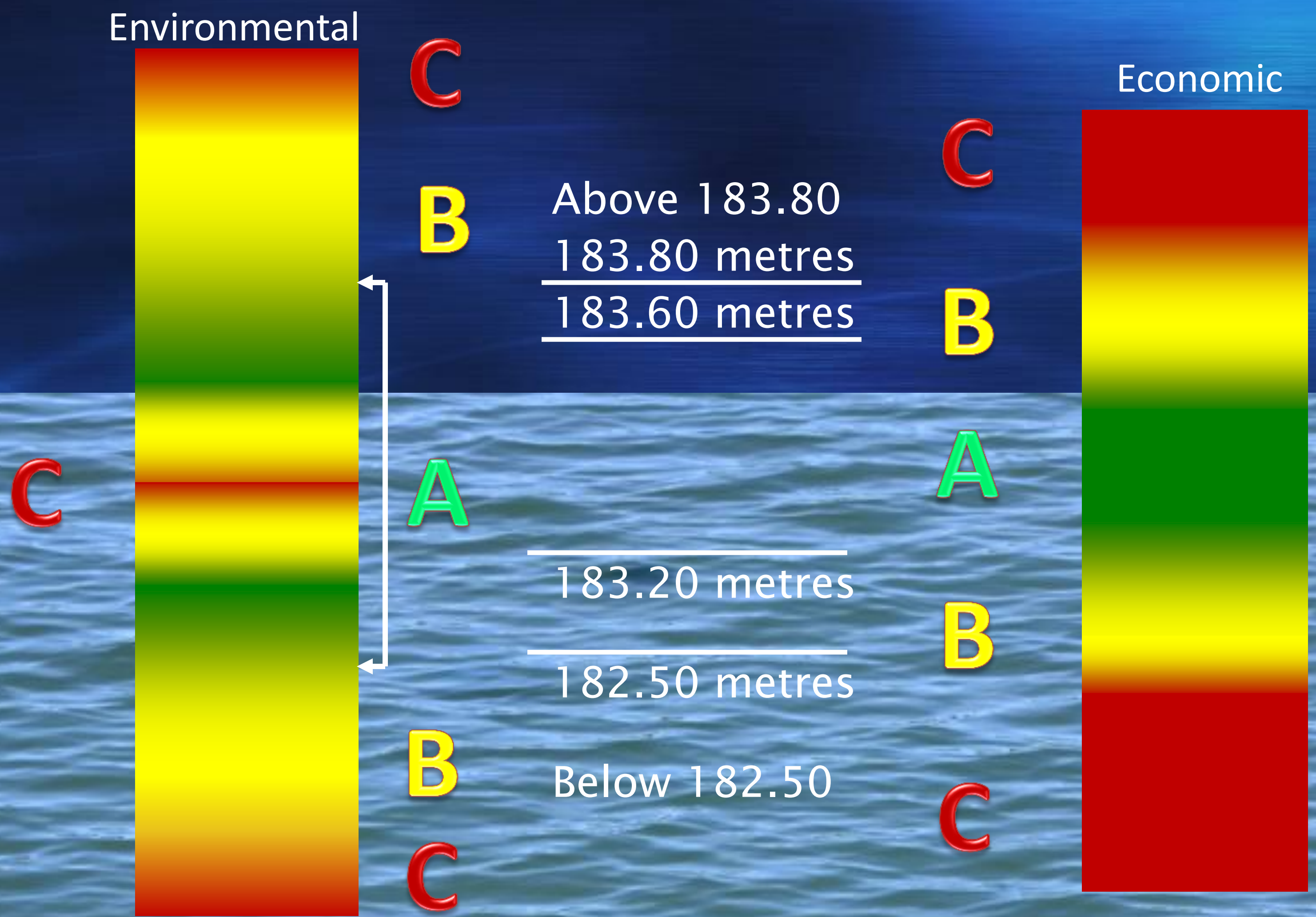
Elements of Plan Formulation & Evaluation



Performance Indicators

- ✓ **Municipal, Industrial and Domestic Water Uses:**
  - ✓ Inventory of water intakes and outfalls
- ✓ **Commercial Navigation:**
  - ✓ Transportation costs
- ✓ **Hydropower :**
  - ✓ Power generation & economic benefits
- ✓ **Ecosystems:**
  - ✓ Integrated Ecological Response Model based on data from selected Great Lakes sites
- ✓ **Coastal Processes:**
  - ✓ Erosion, flooding, low water and shore protection
- ✓ **Recreational Boating:**
  - ✓ Boat ramps and marinas

Example - Lake Superior Coping Zones

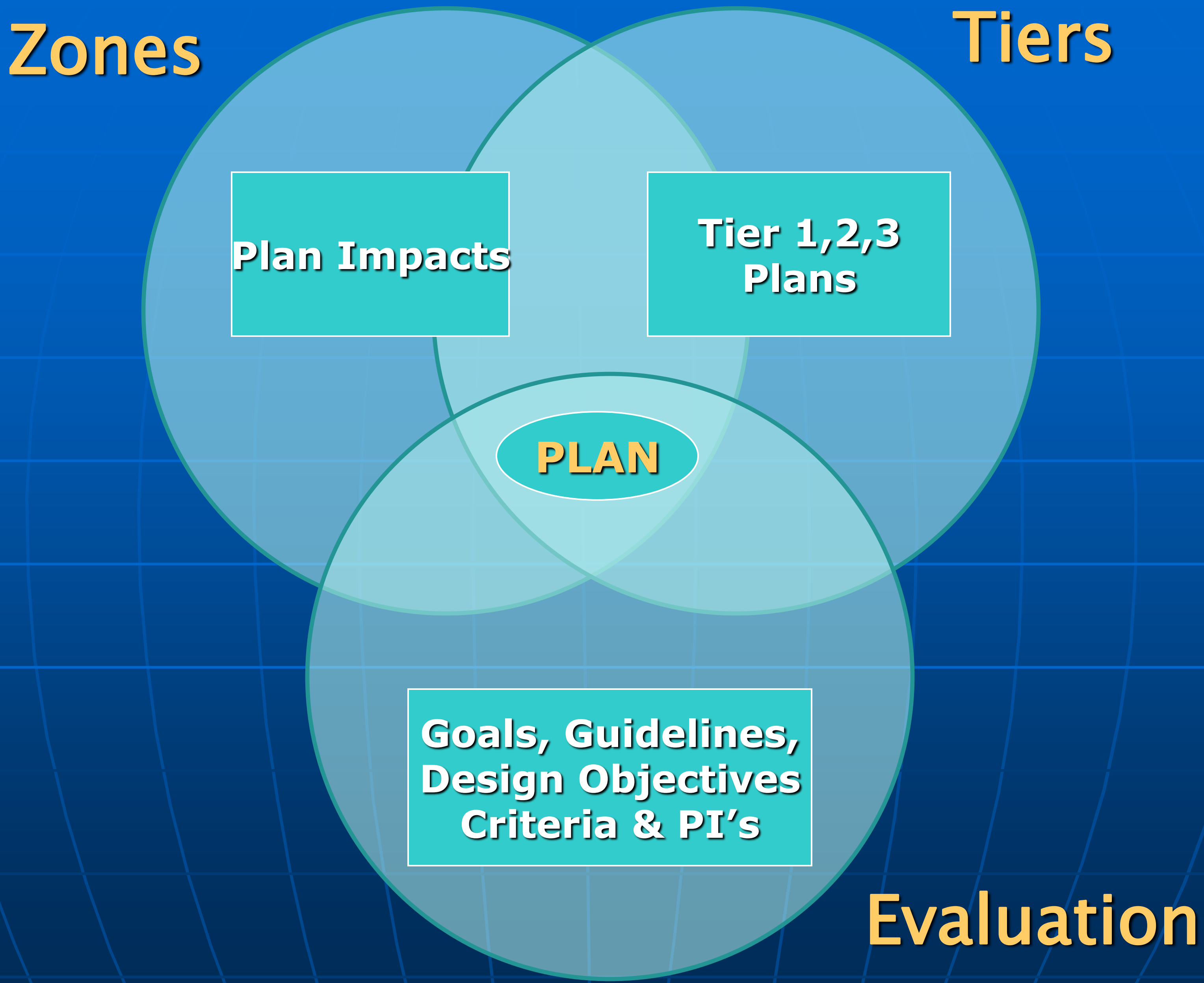


Possible Triggers (examples only):

- **High: 183.8 m – High frequency of extreme flooding damage –infrastructure failing. Use PIs to monitor impacts**
- **Low: 182.5 m - Shipping routes permanently shift out of Duluth and Thunder Bay after two years low C**
- **Low: 181.8 m - Ecosystem function severely threatened – fish species unable to spawn when cut off from tributaries**

Zones A, B, and C

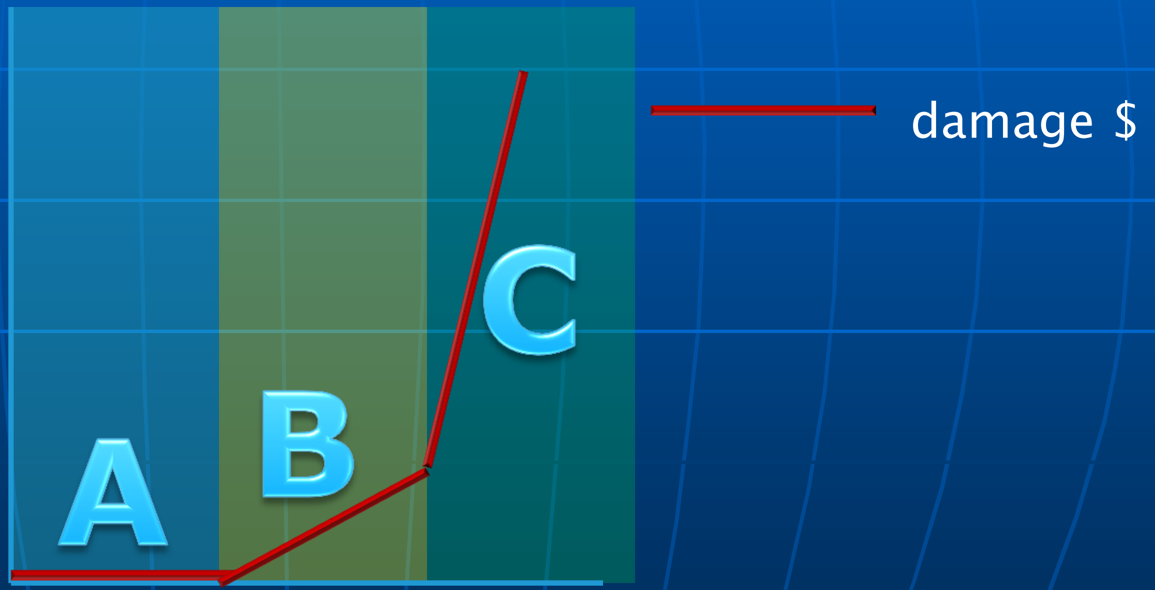
- Zone A – acceptable water level conditions, typically closer to average levels and flows
- Zone B – damaging but survivable conditions, typically near historic high and low levels
- Zone C – catastrophic or unsustainable damages, typically at levels well above record highs or well below record lows.
- “Water level conditions” means a combination of duration, severity and timing


Zones
Tiers
Plan Impacts
Tier 1,2,3
Plans
PLAN
Goals, Guidelines,
Design Objectives
Criteria & PI's
Evaluation

Zones and PIs

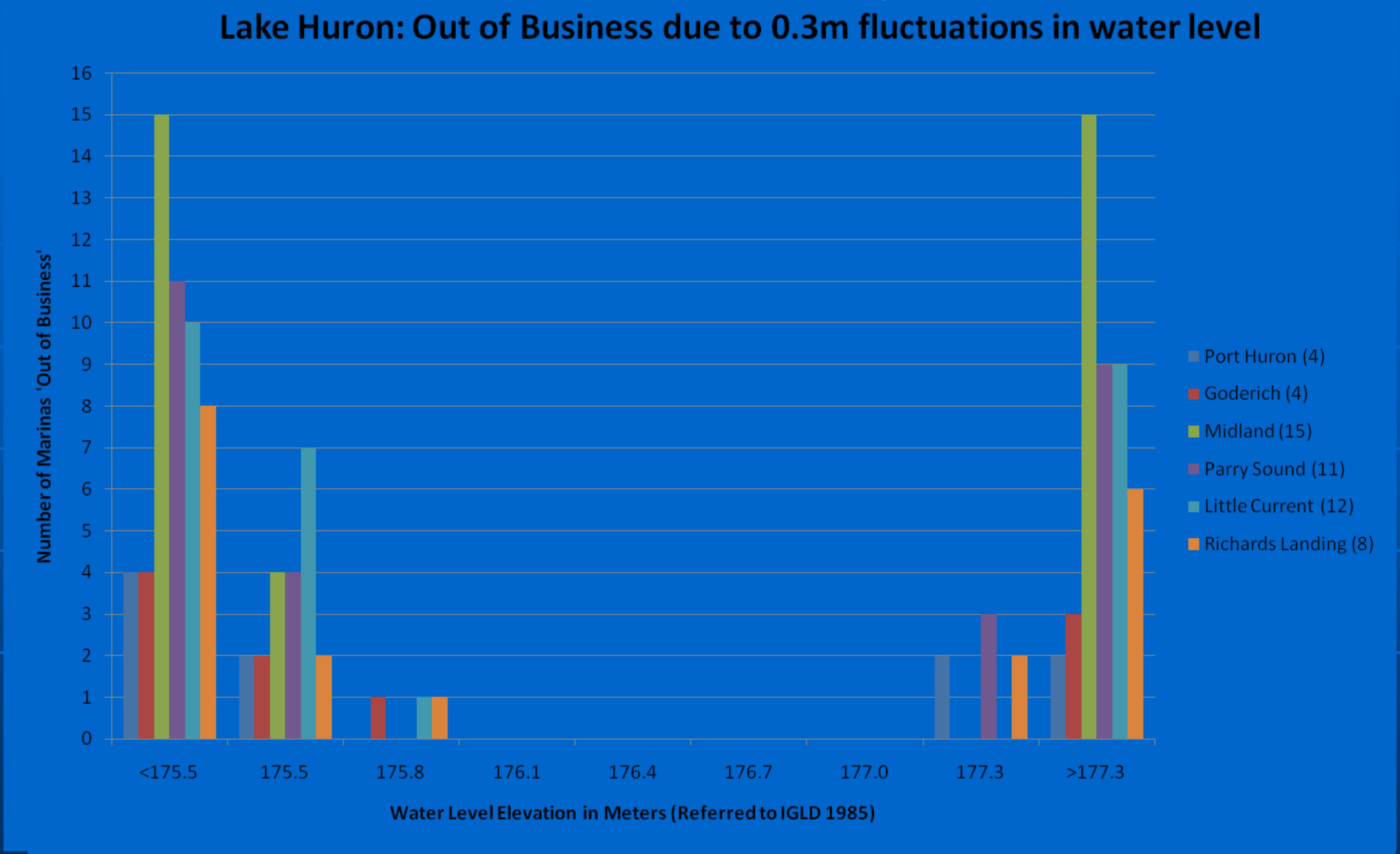
- There is a firmer conceptual connection between Zones and PIs, for example

PI: Flood damage $



Lake level (higher →

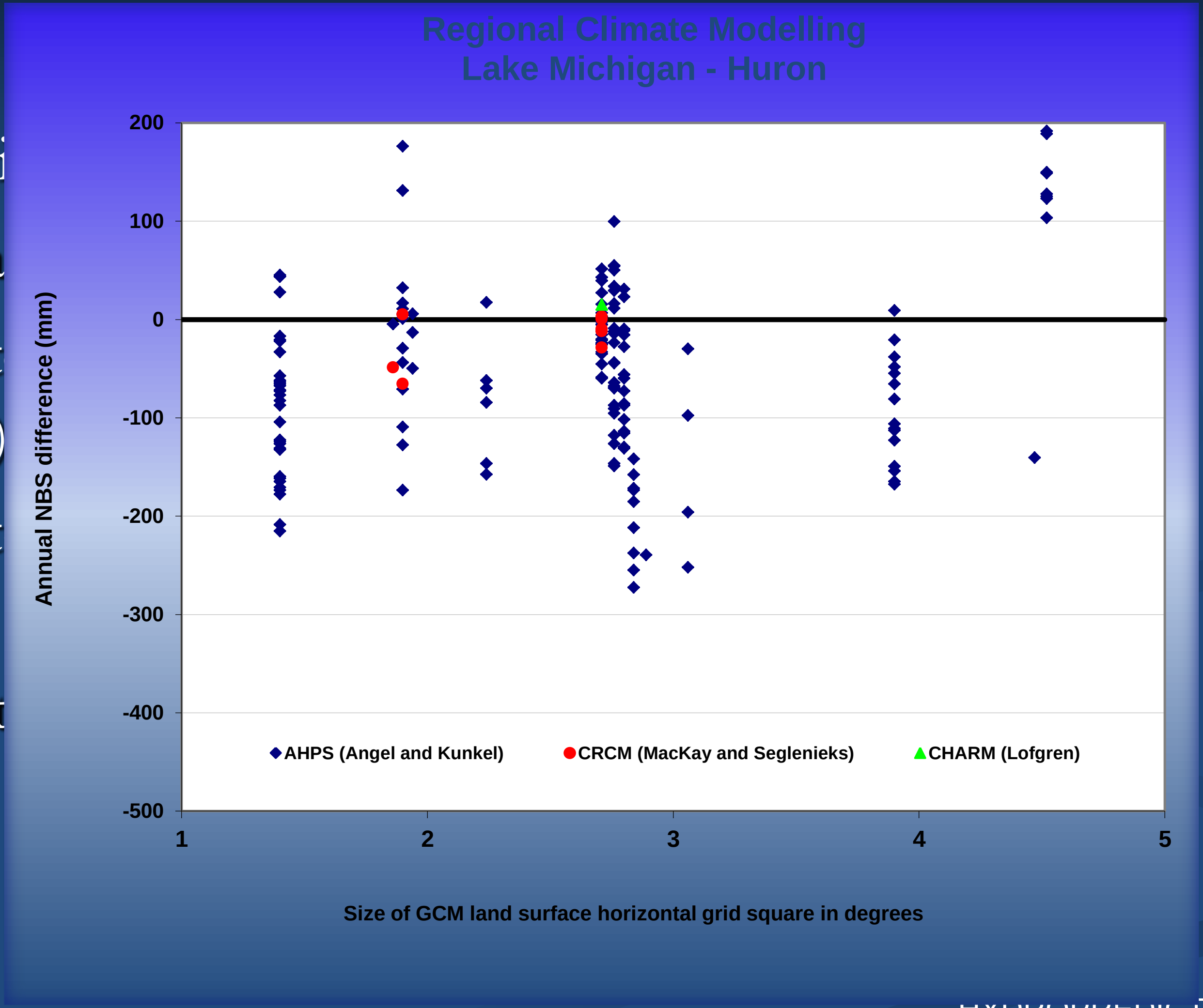
Recreational Boating



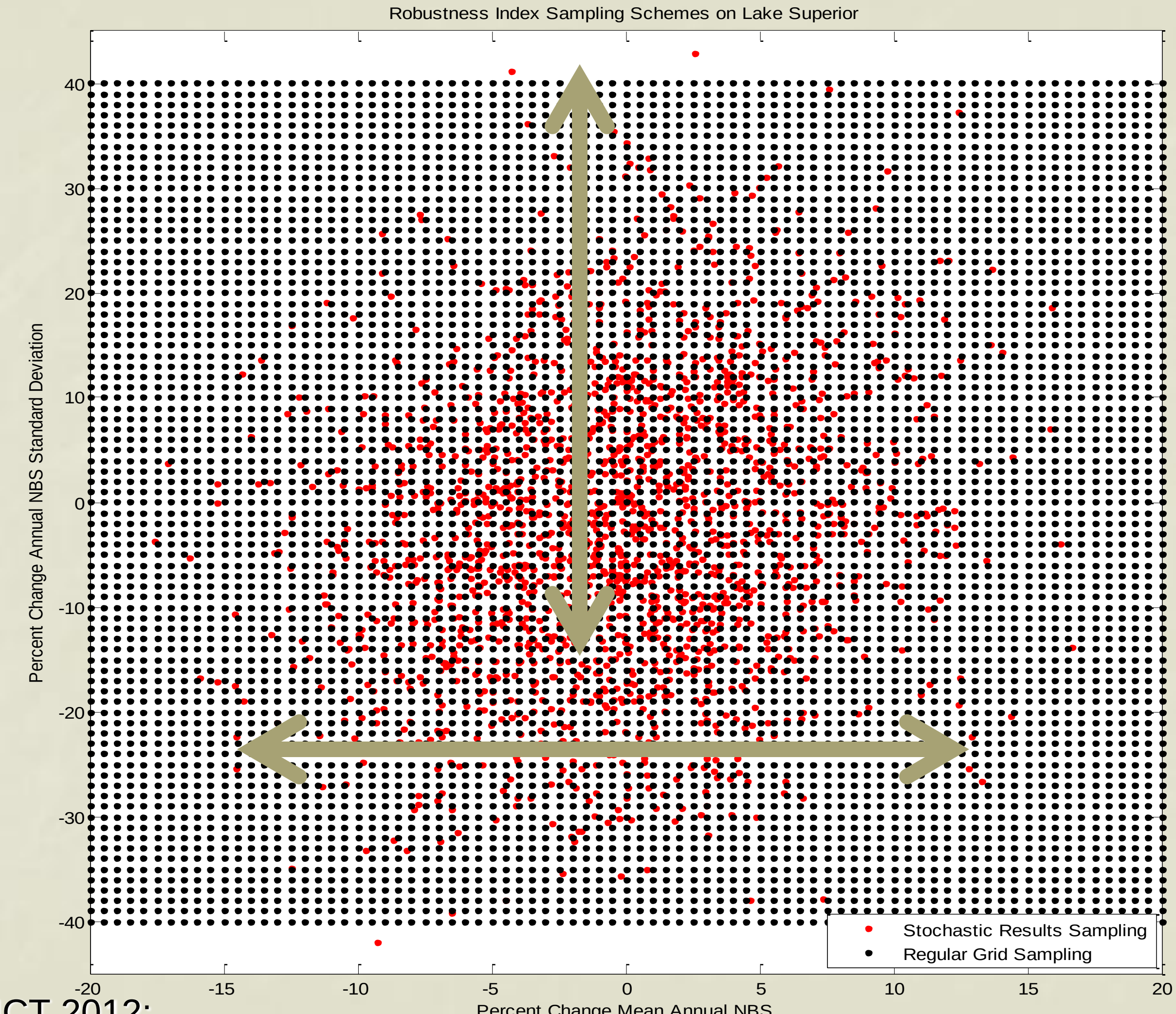
•On Lake Huron, at least half of the marinas in the Little Current, Port Huron, and Goderich AOS would go out of business if the water level were to drop by three feet (0.9m) from the average elevation for May through August, 2009 (176.4m).

Selecting the NBS Sequences: testing for Robustness and Resilience

- Histori
- Stocha
- Climat (RCM)
- Climat model
- Recent



Resilient = Wider Range of acceptable performance in Variance NBS change



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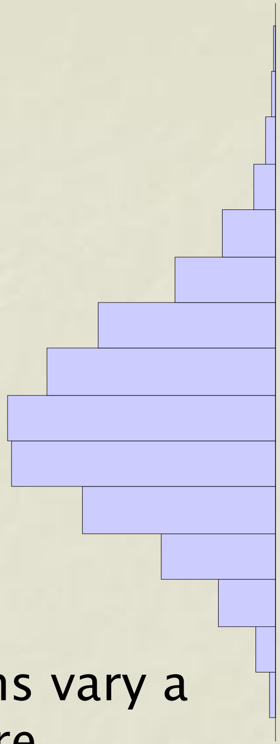
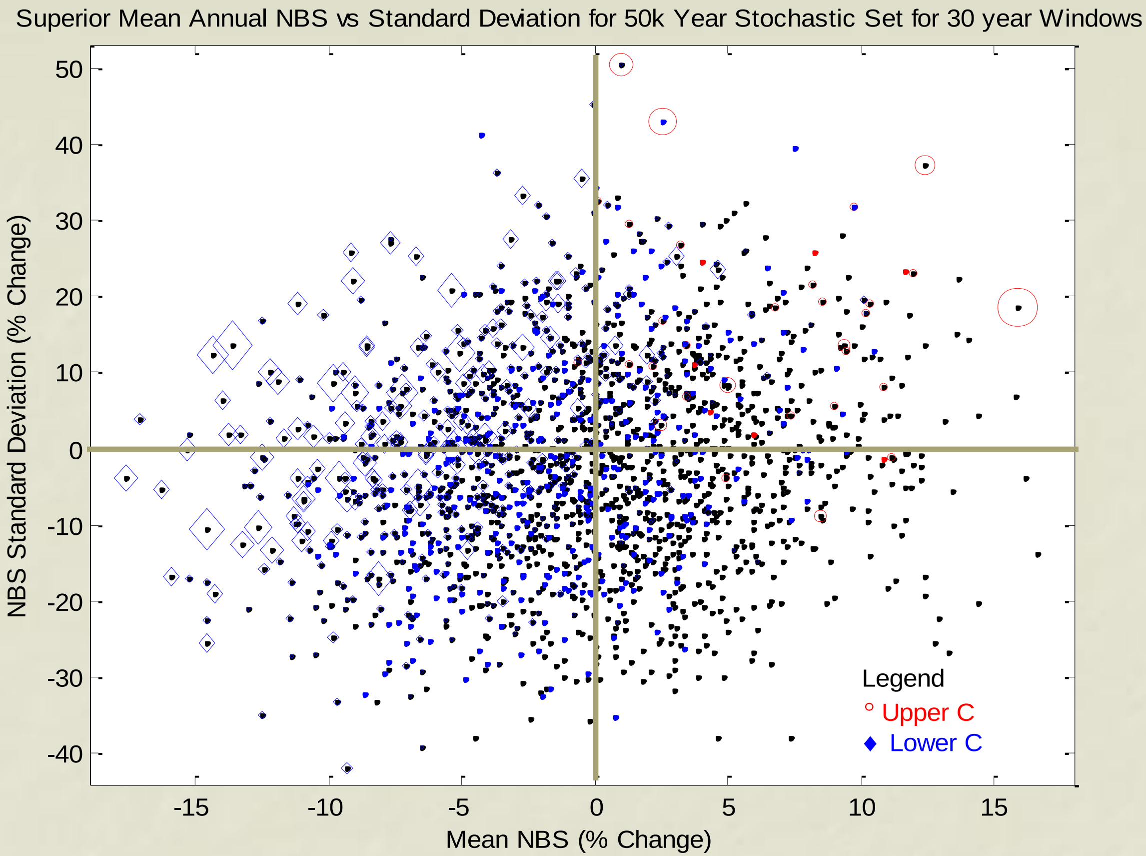
Robust = Wider Range of acceptable performance in mean NBS change

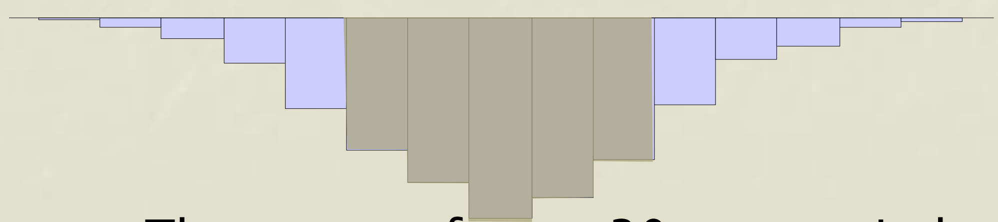
Range of the Stochastic NBS climate changes (L. Superior)





Standard deviations vary a little more.

Lake Superior



The means of most 30 year periods are within +/- 5% of long term average

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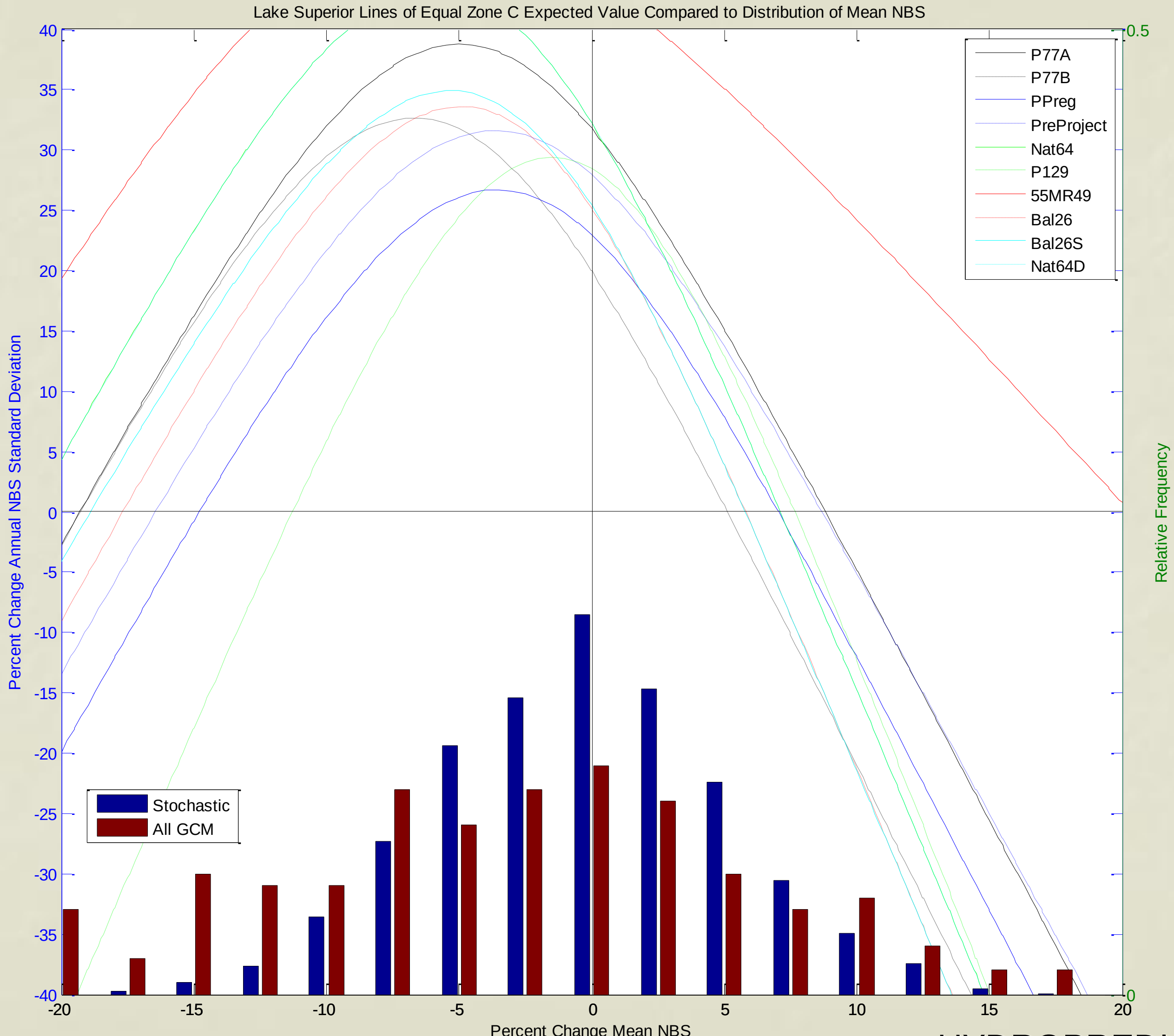
Lake Superior Regulation Plans



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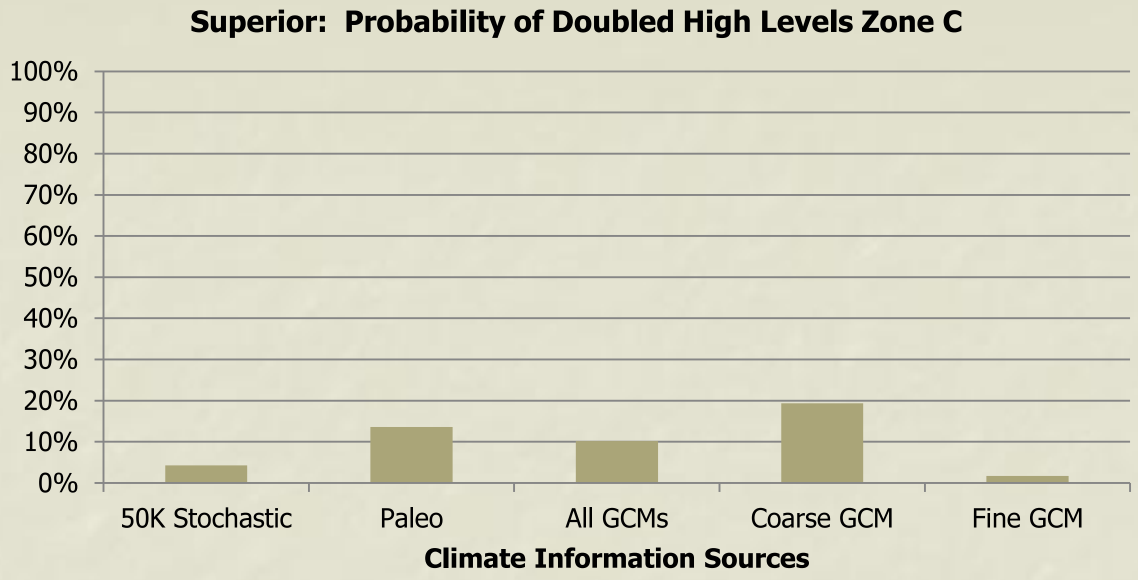
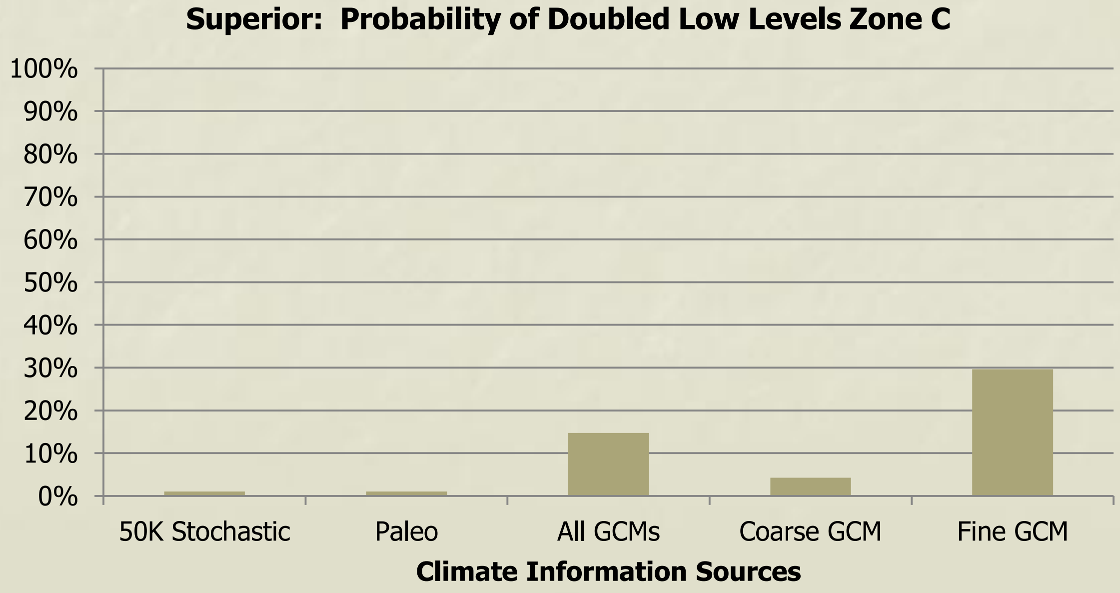
L. Superior: Plausibility of Double historical High Zone C's





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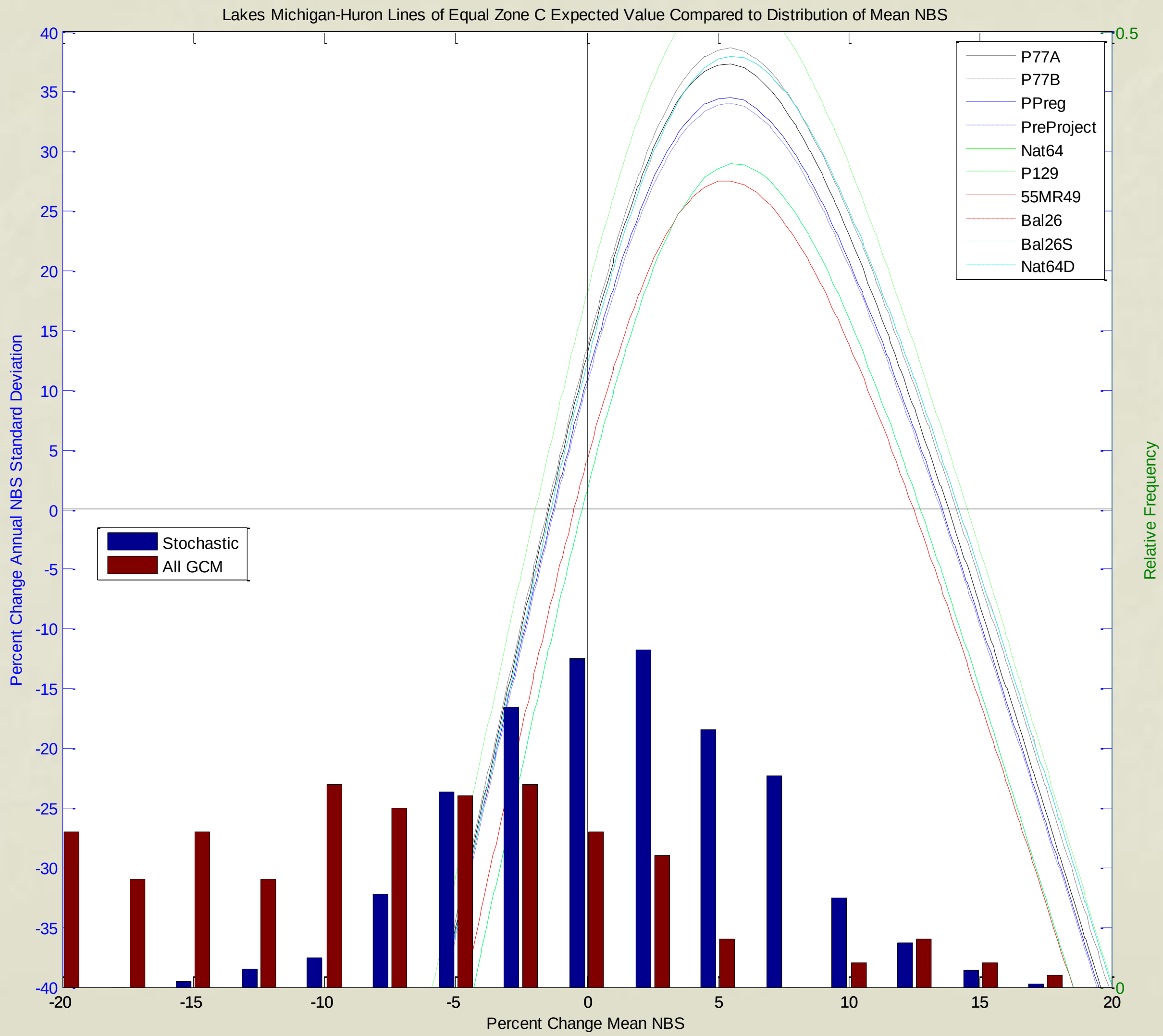
L. Michigan-Huron Regulation Plan Impacts



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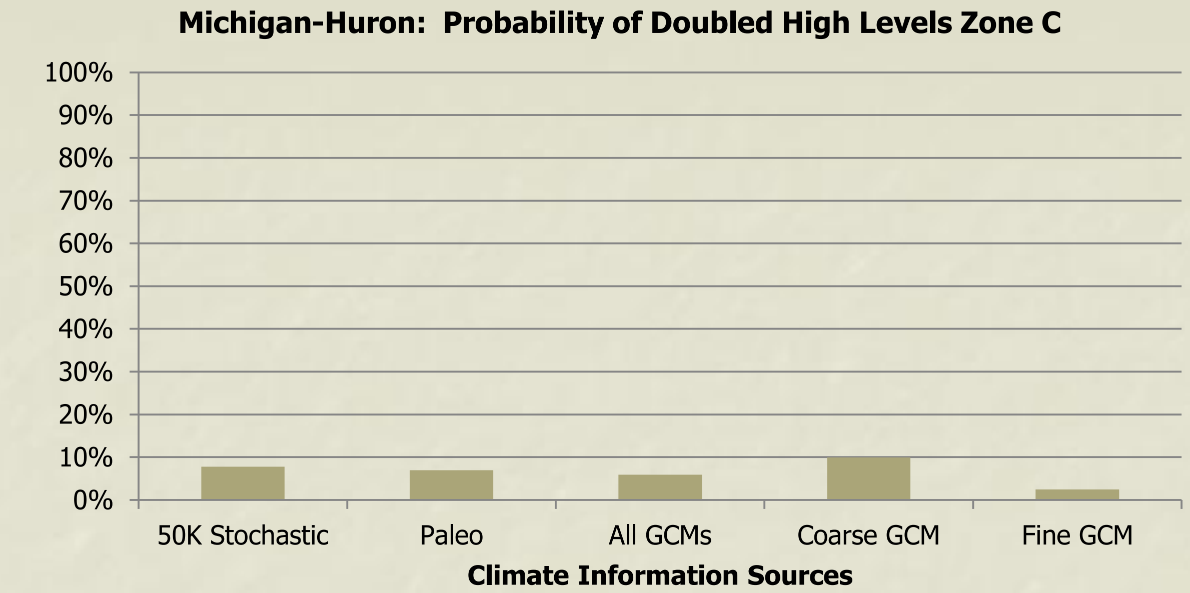
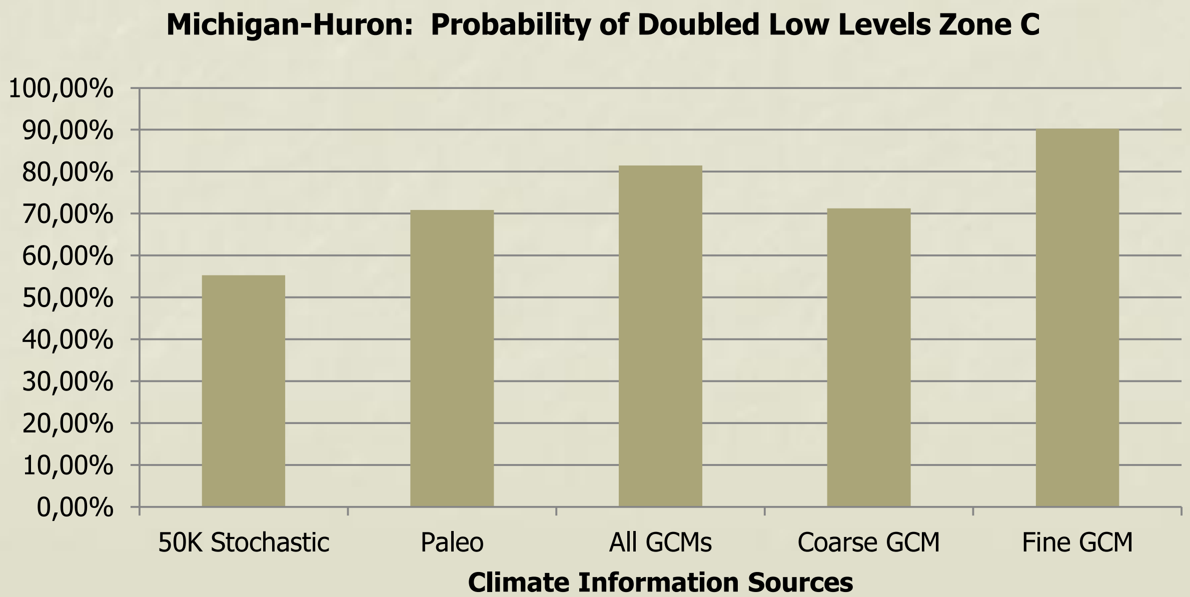
Michigan-Huron: Plausibility of Double historical Zone C's





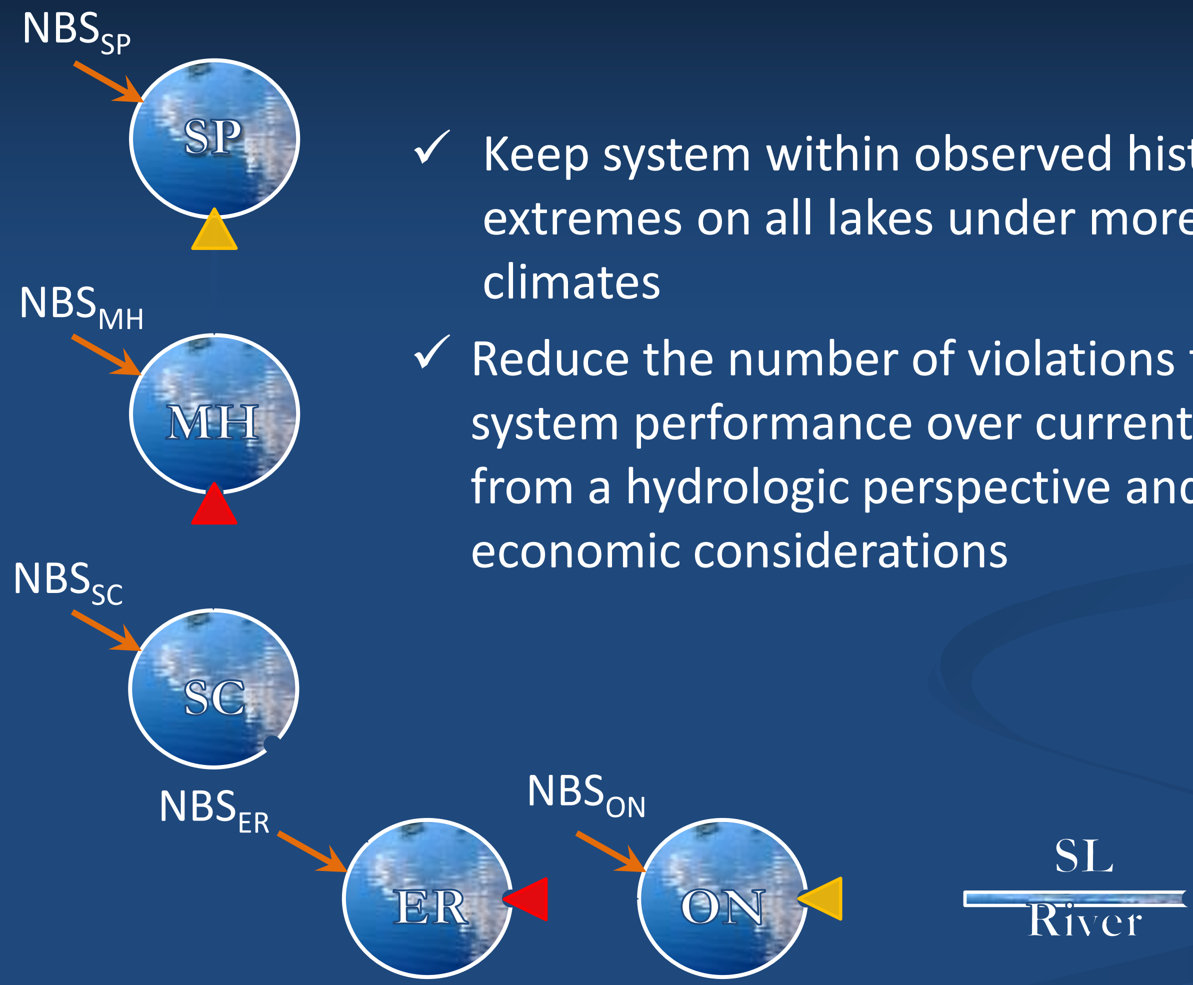
Candidate Regulation Plans After Screening . . .

Ranking	Hydrologic Attributes		Monetized External Effects			Non-monetized external effects		
	Superior	Michigan	Hydropower	Navigation	Shore Protection % overall/% helped	Sup 01 and Sup 02	Normalized St Marys	
77A	OK	OK	$0.00	$0.00		0.85	1	Keep
PP	OK	OK	$0.22	-$0.77	3%/23%	1.00	1.04	Reference
77B	OK	OK	$0.05	$0.16	-10%/46%	0.94	1.12	Improve SP
122	Fair	Fair	$0.01	-$0.38	6%/82%	0.86	1.22	Drop
122C	OK	OK	-$0.01	-$0.08	-1%/76%	0.88	0.86	Drop (too similar)
123	OK	OK	$0.01	-$0.42	6%/82%	0.89	1.36	Drop (hurts nav)
124	OK	OK	$0.01	-$1.83	6%/82%	0.90	1.24	Drop (hurts nav)
125	Fair	Fair	$0.00	-$3.54	6%/82%	0.90	1.22	Drop
126	Fair	Fair	$0.01	-$0.38	6%/82%	0.86	1.22	Drop
127	Fair	Fair	$0.01	-$0.38	6%/82%	0.86	1.22	Drop
128	OK	OK	$0.01	-$0.99	6%/82%	0.90	1.26	Drop (too similar)
129	OK	OK	-$0.02	-$0.29	6%/82%	0.87	1.36	Keep
130	OK	OK	-$0.05	-$0.28	3%/79%	0.87	1.16	Drop (too similar)
55M49	Best	Fair	-$0.14	-$1.37	-4%/26%	0.80	0	Drop (too biased)
Nat60	OK	OK	$0.04	$0.26	-1%/53%	0.89	1	Keep
Bal25	Mixed	Best	$0.00	$0.41	-19%/50%	0.94	1.34	Improve SP

Regulation Plan

Decision Criteria	Nat64D	NatOpt3	1977A
1. Maintain Lake Superior between 182.76 and 183.86 m	Pass	**Pass**	Pass
2. Balance water levels	Pass	**Pass**	Pass
3. Balance Lake Michigan-Huron water levels	Pass	**Pass**	Pass
4. Fewer Lake Superior levels below chart datum than preproject	Pass	**Pass**	Pass
5. Minimize environmental impacts	Pass	**Pass**	Pass
Number of fewer Zone C PI-Years	1	**1**	0
Number of greater Zone C PI-Years	0	**0**	0
SUP-01	0.39	**0.39**	0.36
SUP-02	0.40	**0.39**	0.34
6. Minimize disproportionate loss			0
Coastal (Δ SP Costs)	Pass	**Pass**	Pass
Boating slips	Pass	**Pass**	Pass
7. Reduce net shoreline protection costs (avg. annual reduction)	$0.15	**$0.06**	$0.00
8. Increase navigation benefits	$0.05	**$0.16**	$0.00
9. Increase hydropower benefits	$0.48	**$0.54**	$0.00
Increase average energy (kWh)	506	**572**	0

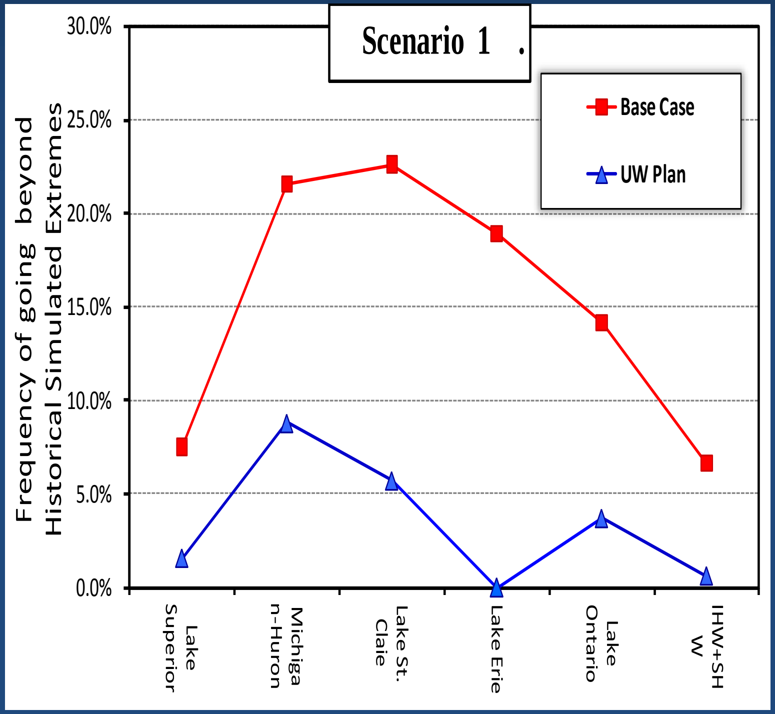
Multi-lake Regulation Objectives



- ✓ Keep system within observed historical extremes on all lakes under more extreme climates
- ✓ Reduce the number of violations to improve system performance over current operations from a hydrologic perspective and given economic considerations

▲ Existing Regulating Structures   ▲ Potential Regulating Structures

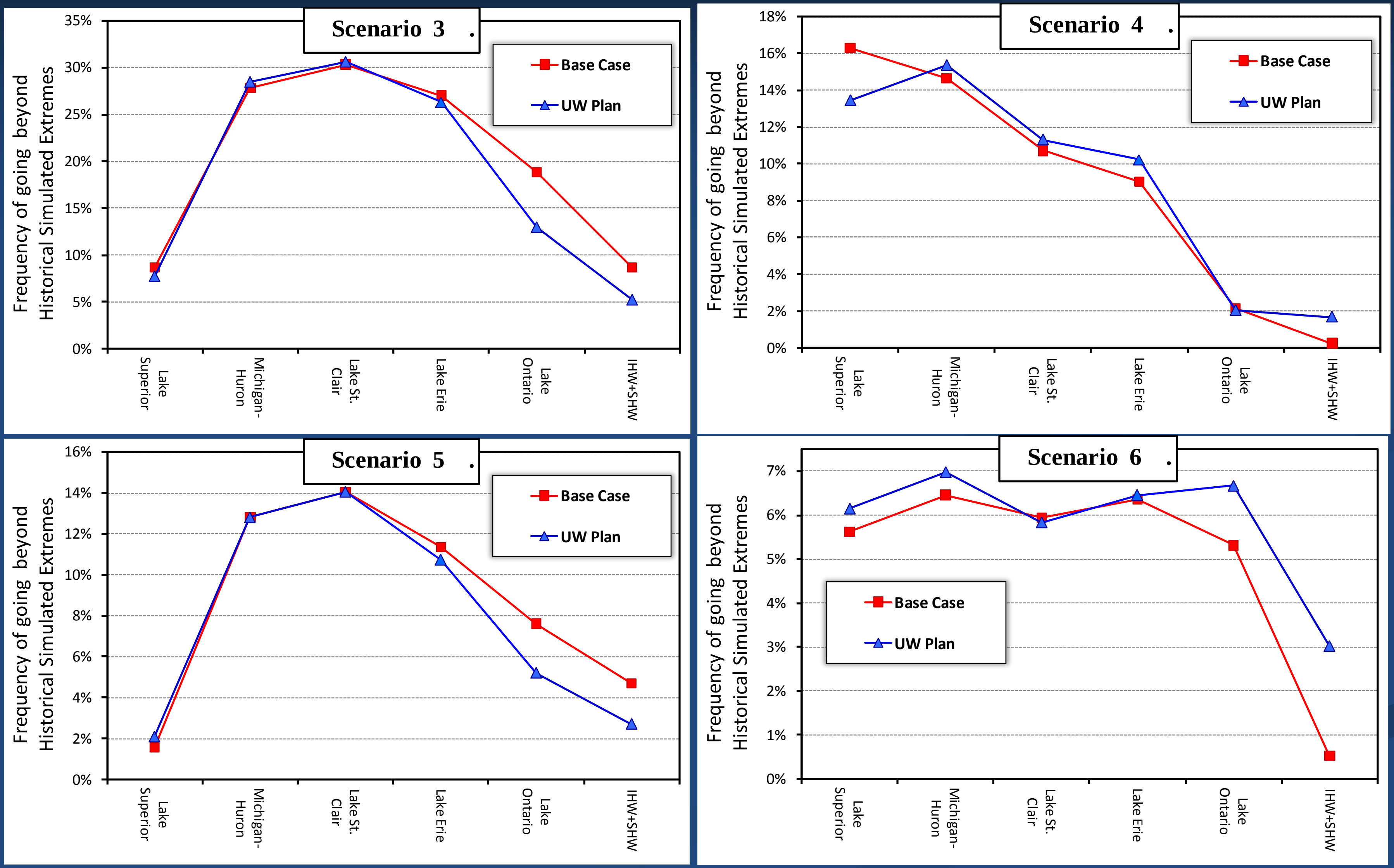
Findings



- ✓ Multi-lake regulation can accommodate restoration objectives;
- ✓ Although large improvements possible across the board for all scenarios and lakes these are estimated to cost more than 8 billion dollars ignoring structures on the St. Lawrence;
- ✓ Addressing Montreal and downstream requirements will cost several billion dollars more; and,
- ✓ Environmental issues are not considered nor the economic impacts

2. What mitigation is possible with revised release strategies at existing structures?

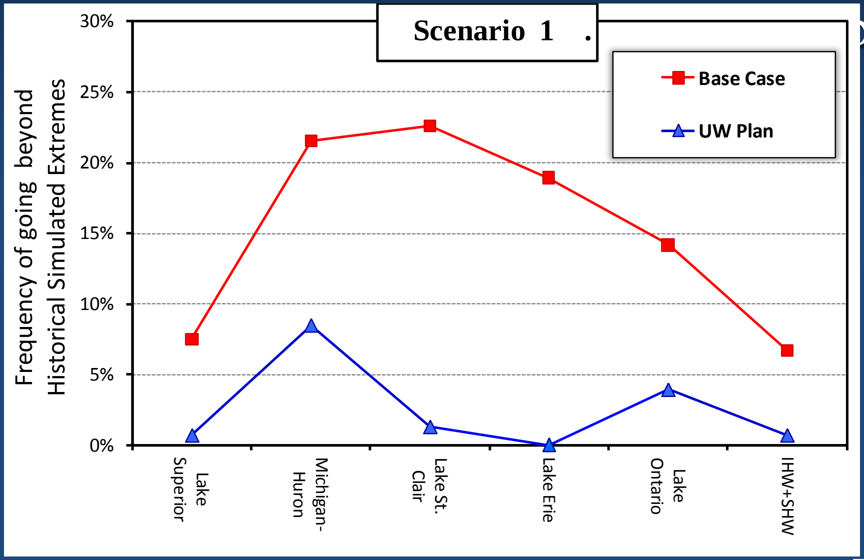
Q #2

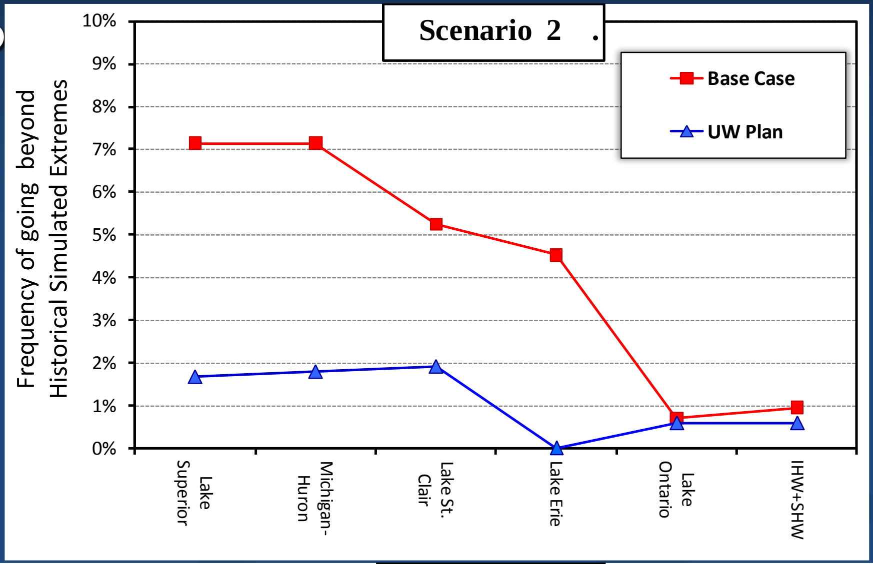


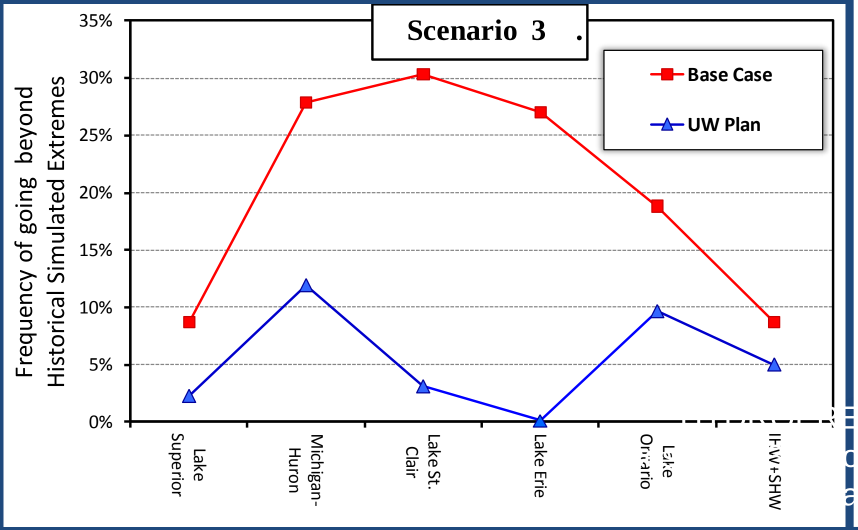
3. What mitigation is possible with 2 new structures on St. Clair and Niagara Rivers?

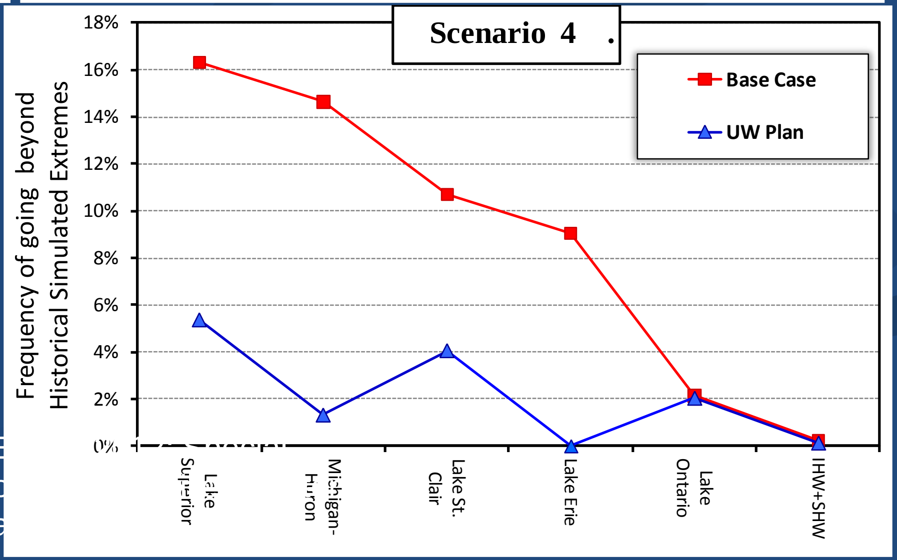
Q #3

- With unlimited budget, and thus additional structures downstream of









How long are we violating extremes (resilience)?

- Longest violation lengths (in Zone C)

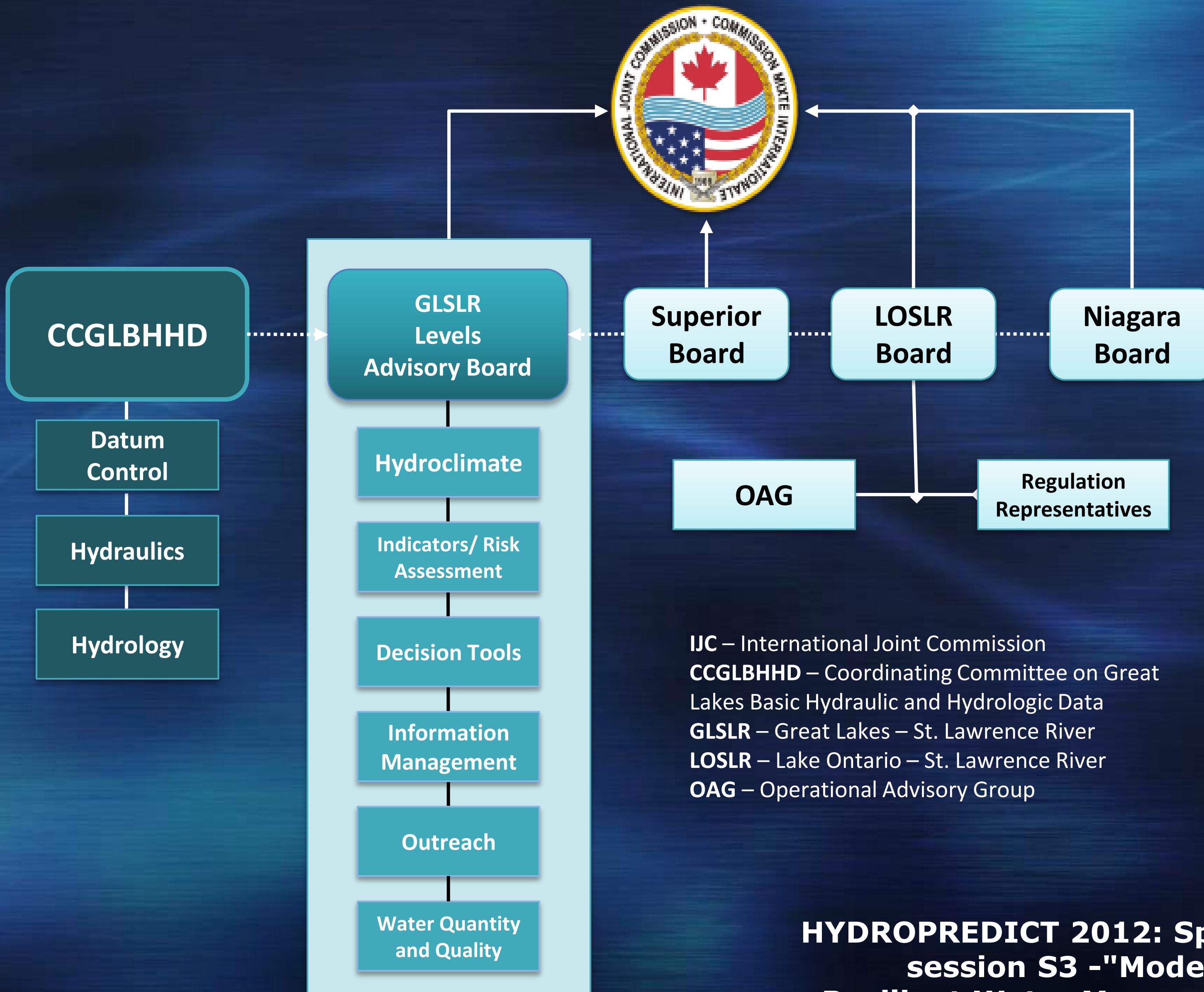
in 50,000 yr simulation:

	Extreme	SP	MH	SC	ER	ON	IHW	SHW	PCL	JET
		Consecutive Months								
Base Case	min	45	169	98	97	65	23	5	20	54
	max	109	63	20	21	19	7	0	5	6
$6.1 billion ignoring Montreal	min	8	67	44	4	60	49	11	11	12
	max	30	60	25	9	32	11	0	5	5

Adaptive Management

- ✓ Study identified six core elements of an effective adaptive management strategy
- ✓ Adaptive management has an important role to play in addressing the risks of future extremes in water levels in the upper Great Lakes.
- ✓ It requires leadership and strengthened coordination among institutions on both sides of the international border.

Water Level Advisory Board



IJC – International Joint Commission
CCGLBHHD – Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data
GLSLR – Great Lakes – St. Lawrence River
LOSLR – Lake Ontario – St. Lawrence River
OAG – Operational Advisory Group

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Different methods for incorporating Climate Information into Water Sector Project Planning/Design

- ☑ **GCM scenario analysis** (test plans for robustness, resiliency, reliability)
- ☑ Traditional **Stochastic analysis** of historic data
- ☑ **Hindcasting based on dendroclimatology** & statistical 'voodoo' to extend records
- ☑ Extending **existing statistical tools & models** (e.g. LP3 ⟹ 'fat-tailed' distrib-GEV)
- ☒ **GCM downscaling** and derived frequency analysis (not ready for 'prime time').

Key IUGLS Board Insights/Findings

- The Great Lakes are a complex system that we do not completely understand
- GCMs added much more uncertainty to the decision process, without clarifying future options
- We cannot rule out a “wetter” or a “dryer” future
  Exposed to “high” and “low” risks
- For a reasonable planning period (2010 – 2040), GCM-based projections offer no viable futures
- Stochastic approaches provide futures that are consistent with historical and Global/local context
- Uncertainty does impact how we manage risks beyond capability of regulation plan
- Adaptive management – dynamic regulation
- Assessing risk without making future predictions was the key climate-related analysis decision of IUGLS Board


Finis- Merci
Questions?
Discussion