International Conference: "Global and Regional Climate Changes"
Kyiv, Ukraine
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Decisionmaking for Climate Adaptation in the Water Sector

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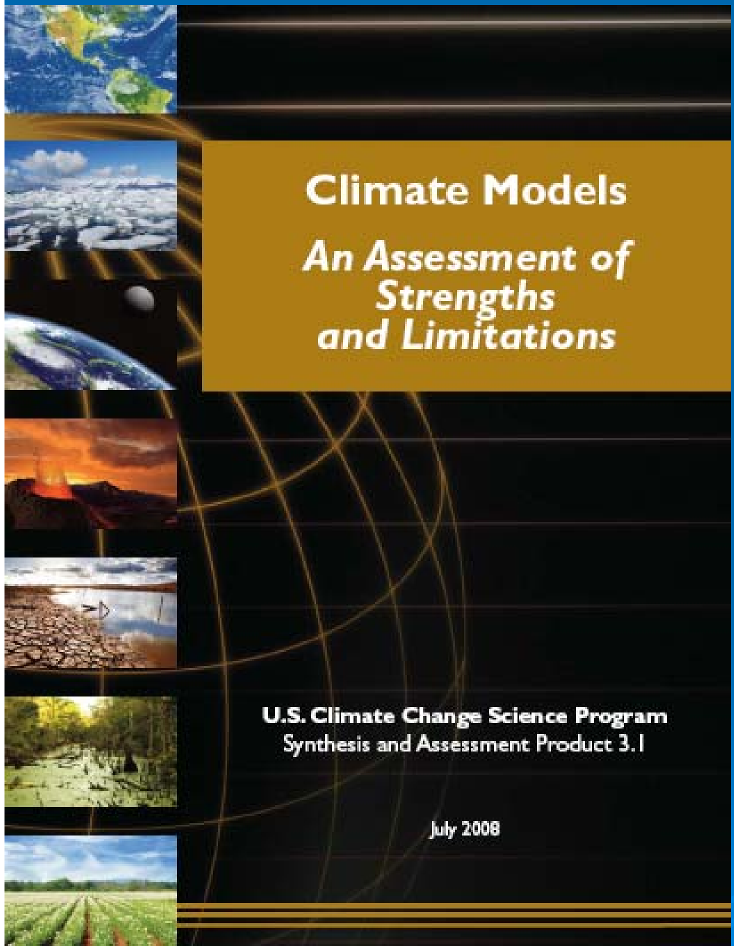
Transitioning to *Adaptation* under Climate Uncertainty

- **How to deal with risk, uncertainty and ‘unknowns’ in decision making?**
- We’re in a **20-year transition period** before good information and reliable models become available.
- How to deal with non- stationary climate?
- Role of GCMs in evaluation of water resources management options
- Are the current methods (i.e. stochastic hydrology) ‘good enough’ to deal with uncertainty?
- Are there practical engineering design methods to deal with ‘robustness’, ‘resiliency’ and ‘reliability’ ?

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

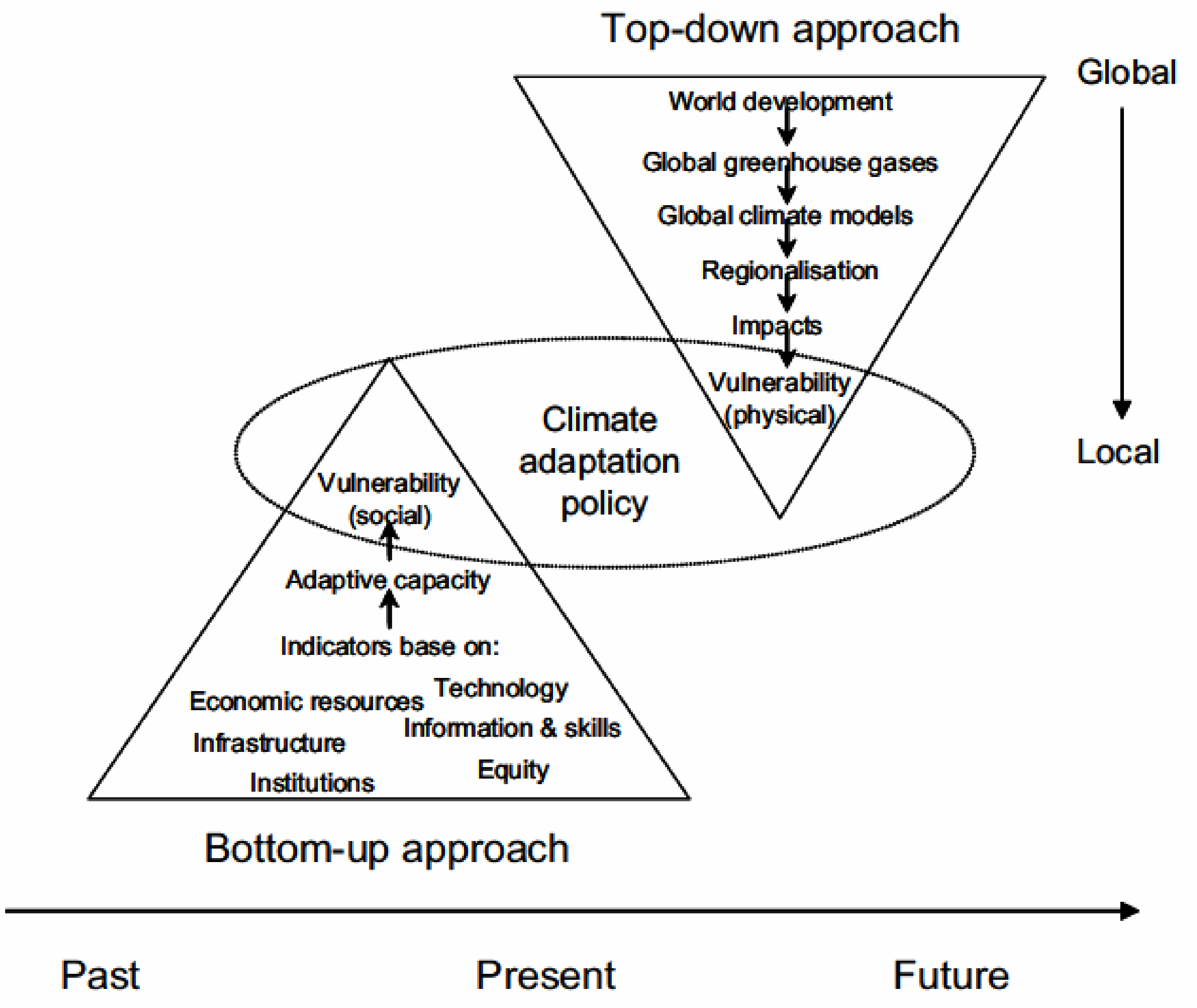
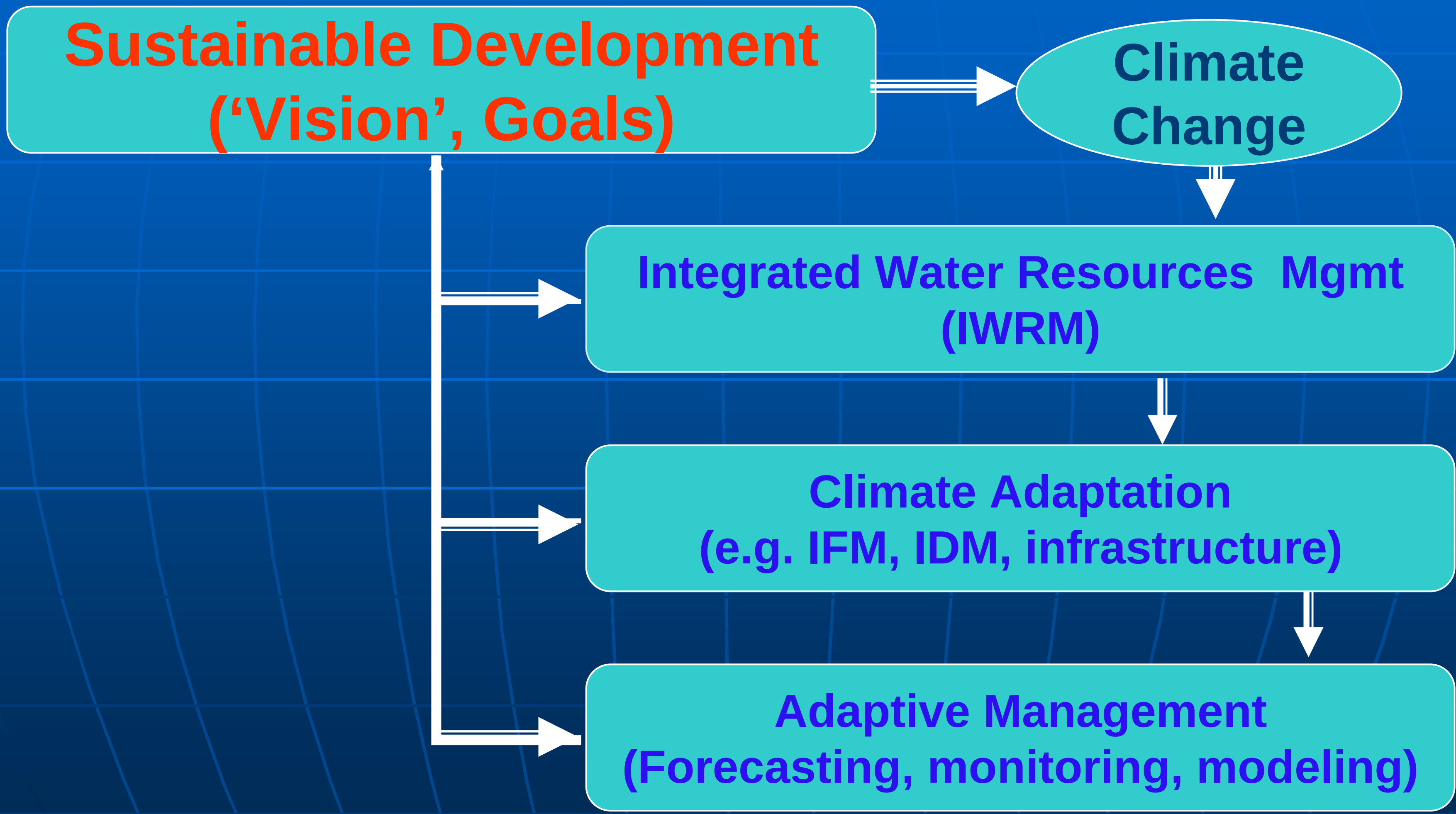
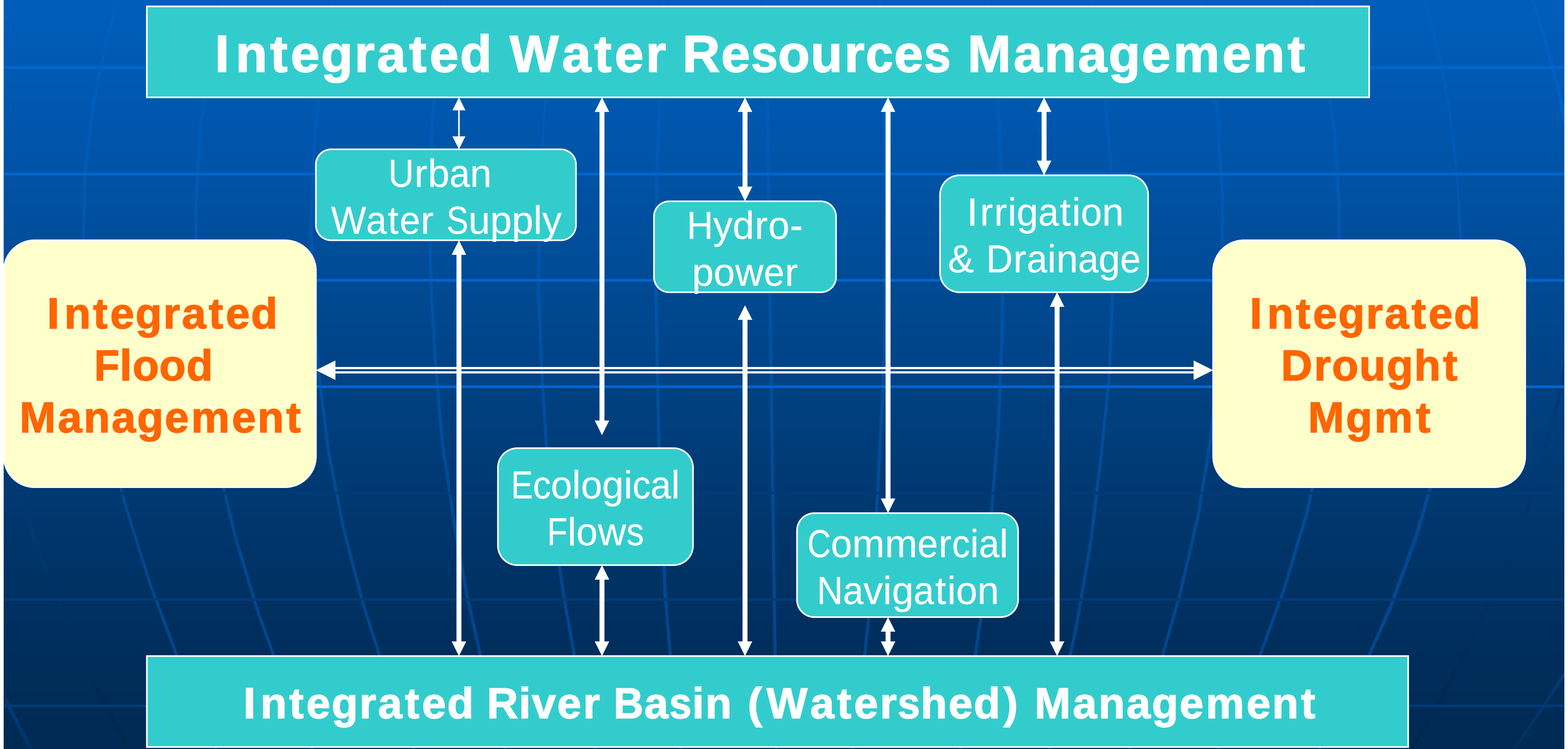


Figure 3.1. "Top-down" and "bottom-up" approaches used to inform adaptation to climate change (from Dessai and Hulme 2004).

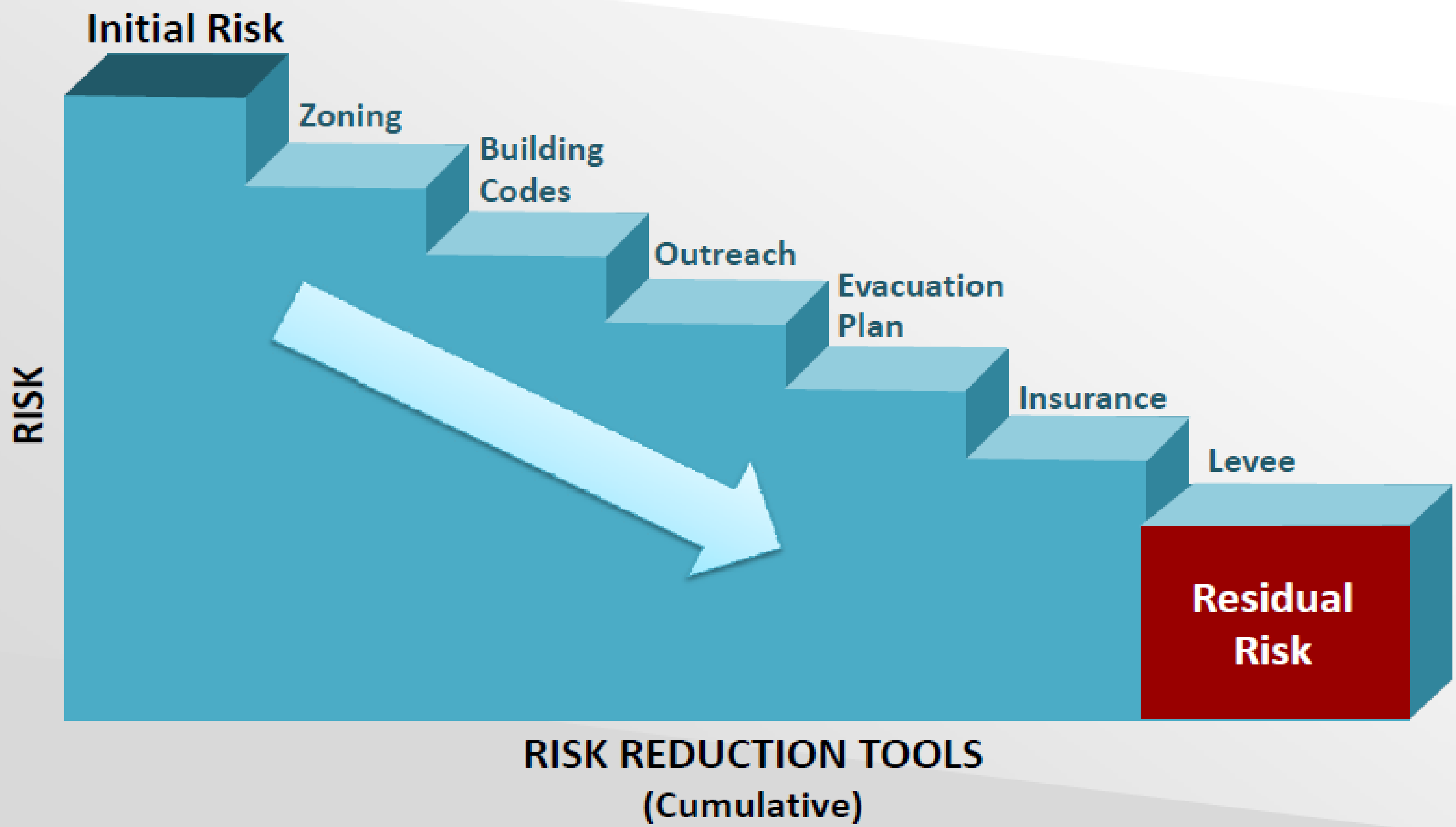
Context for Climate Change and Sustainable Development: Levels of Analysis for a Conventional Risk Mgmt Framework



IWR**Management**
of Water Sectors



Shared Flood Risk Management: Buying Down Risk



All Stakeholders Contribute to Reducing Risk!

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.

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').

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

Corps Reservoir Operations: Revising/Updating Regulations

National Dam Safety Program

Corps' Dam Safety **Portfolio Risk Management Process**

Risk Informed Priorities for Permanent Risk Reduction

Tolerable Risk Guidelines

Interim Risk Reduction Measures

Issue Evaluation Studies

Dam Safety Modification Reports

Periodic Inspections/Periodic
Assessments/Asset Management

National Levee Safety Program

Mission: Assess integrity and viability of levees, recommend actions to assure levee systems do not present unacceptable risks to public, property, environment.

Increasing Rigor

Routine Inspections:
Verifies O&M, More Rigorous Standards, Improved Communication, System-based, Every Year

Periodic Inspections:
Verifies O&M, Evaluates Structure Stability, Compares Constructed Criteria to Current Criteria, Every 5 Years

Levee Screening:
Begin to categorizing.

Periodic Assessments:
Periodic Inspection + Potential Failure Mode and Consequences Analysis, Every 5 Years

Risk Assessments:
Data Intensive, Determine Likelihood and Consequences of Failure, Every 10 Years

Continuous Feedback

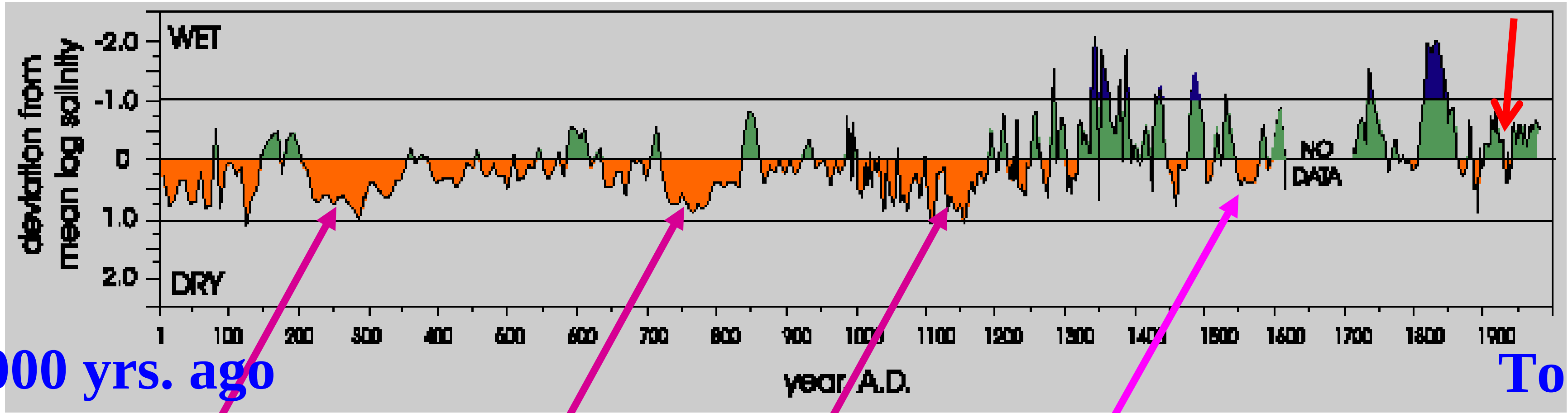
Federal Interagency Floodplain Management Task Force

- 11 Water Oriented Agencies
- Meet quarterly to align and unify federal floodplain and risk management programs and issues
- Re-instituted September 2009
- Developing five-year work plan
- Conducting public listening sessions
- Drafting updated Executive Order governing floodplain management

2000-year Climate history of central U.S.

The US Breadbasket: The Mid-West

Dust Bowl



2000 yrs. ago

Today

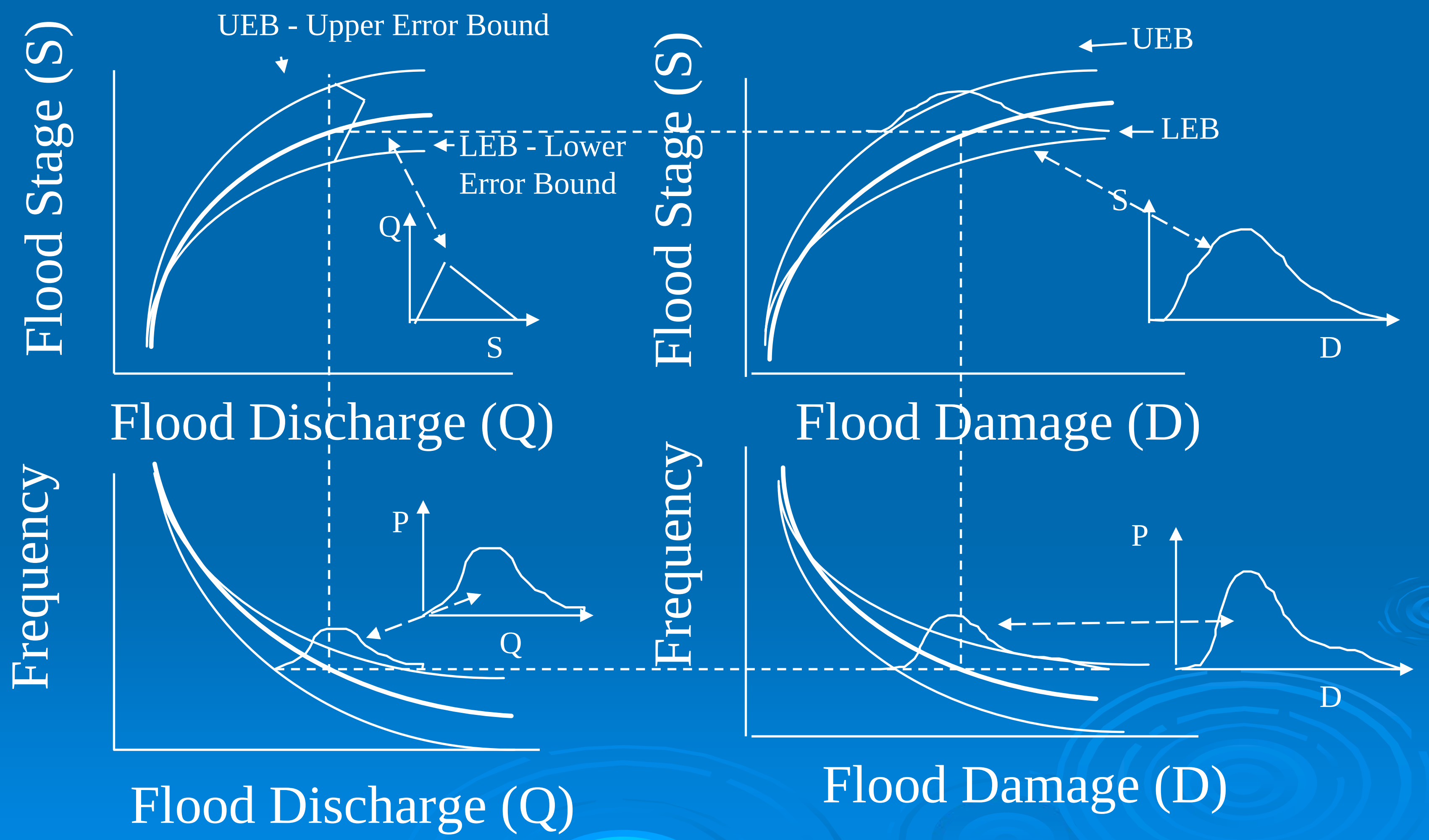
16th century "megadrought"

- 100 year "megadroughts"

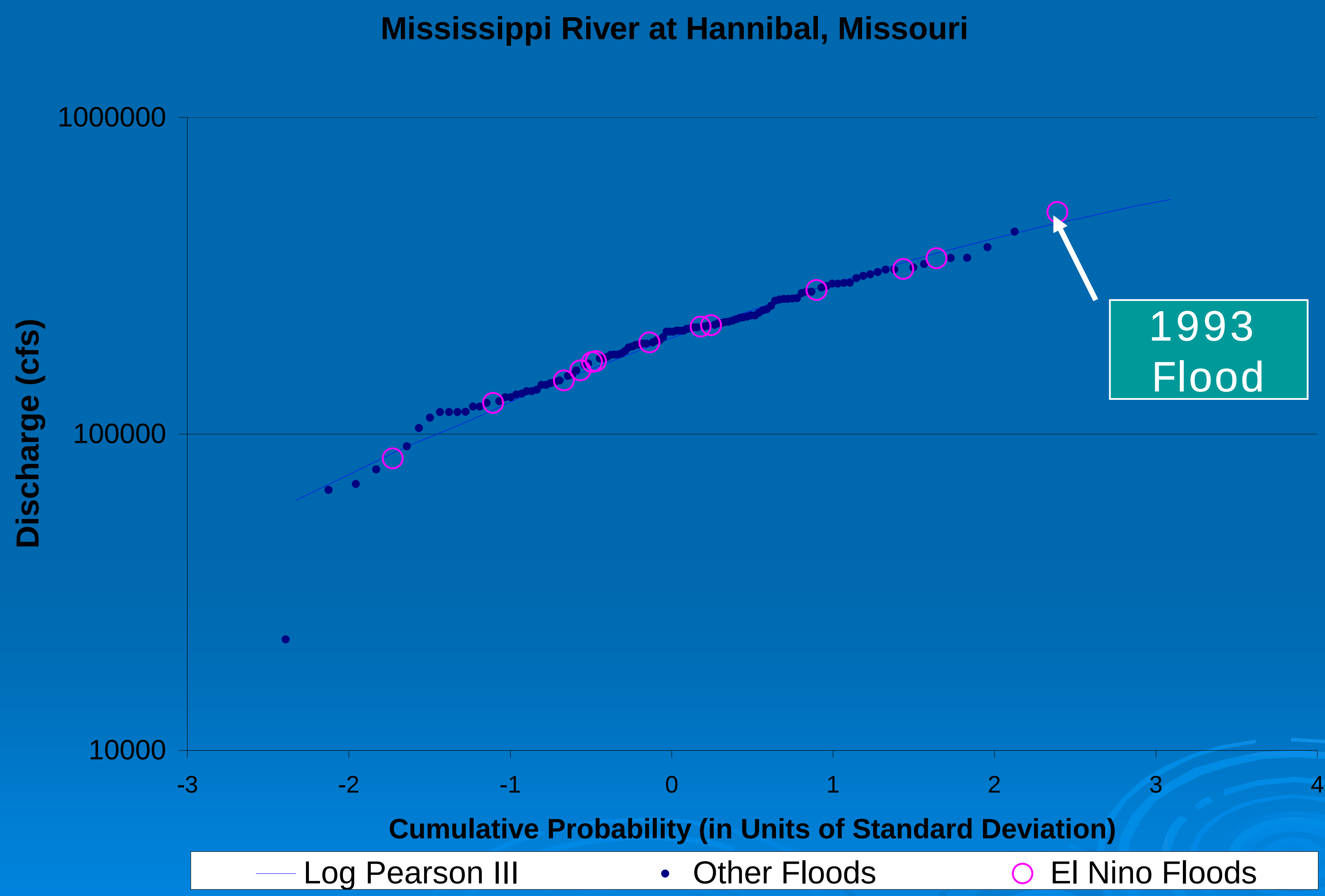
Source: Overpeck 2004

Uncertainty and Flood Damage Calculation

(Corps of Engineers Procedures - HEC-FDA;1992)



ENSO Floods: LP3 distribution



R&U Flood Damages Analysis

Plan	Expected Annual Damage ($'000)			Probability EAD Reduced Exceeds Indicated Amount ($'000)				
	Without Plan	With Plan	Damage Reduced	0.95	0.75	0.50	0.25	0.05
20 foot levee	575.0	220.0	355.0	290.0	325.0	350.0	380.0	450.0
25 foot levee	575.0	75.0	500.0	370.0	435.0	490.0	550.0	690.0
30 foot levee	575.0	0.0	575.0	410.0	495.0	560.0	630.0	815.0
Channel	575.0	200.0	375.0	300.0	325.0	360.0	400.0	600.0
Detention Basin	575.0	250.0	325.0	200.0	260.0	300.0	330.0	450.0
Relocation	575.0	300.0	275.0	150.0	200.0	260.0	300.0	450.0

Discounted Avg Annual Net Benefits (Benefits – Costs)

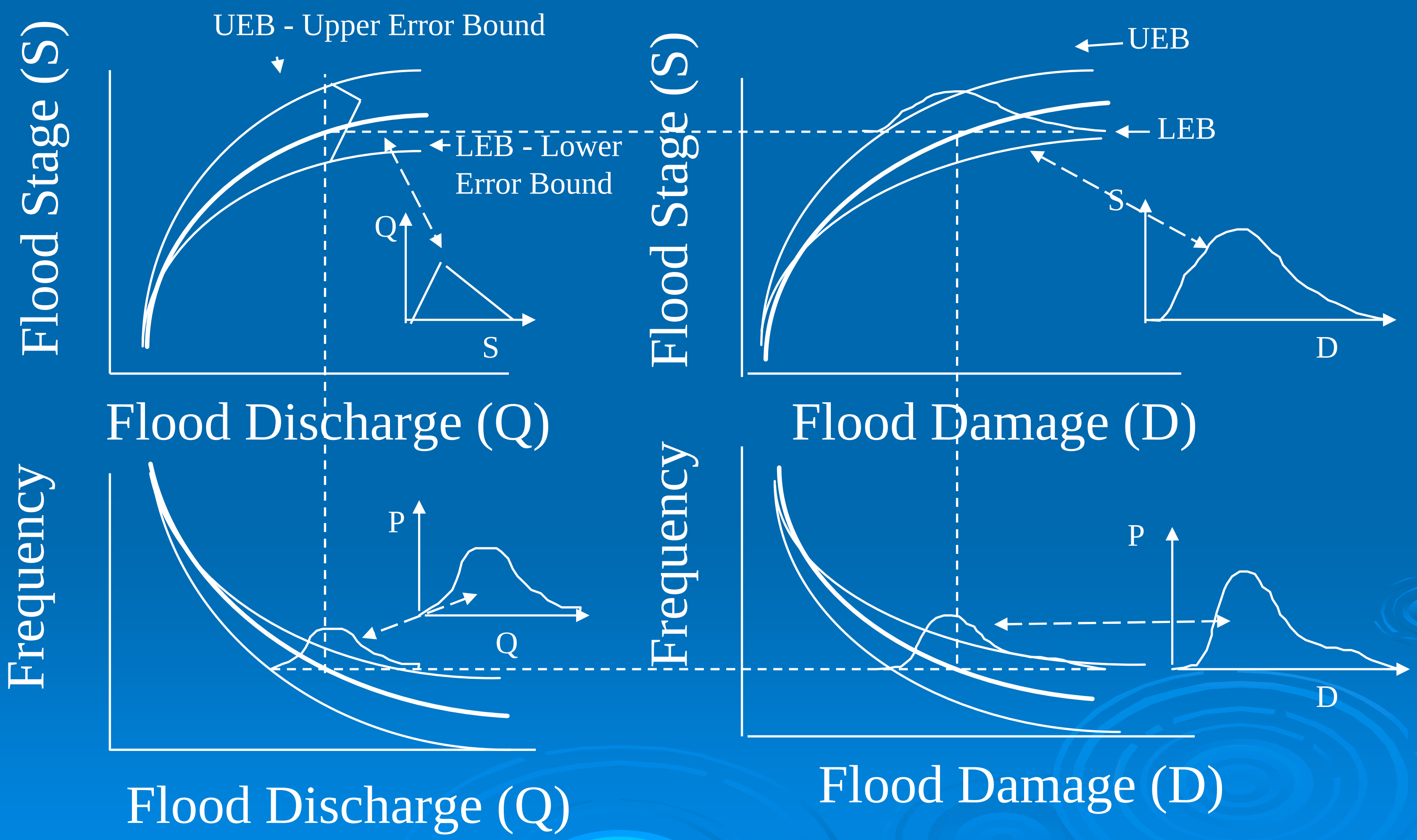
Plan	Expected Annual NED Benefit and NED Cost ($'000)			Probability Net Benefit Exceeds Indicated Amount ($'000)				
	Benefits	Cost	Net Benefits	0.95	0.75	0.50	0.25	0.05
20 foot levee	355.0	300.0	55.0	(25.0)	20.0	53.0	88.0	148.0
25 foot levee	500.0	400.0	100.0	(40.0)	35.0	91.0	152.0	280.0
30 foot levee	575.0	550.0	25.0	(155.0)	(60.0)	12.0	88.0	261.0
Channel	375.0	300.0	75.0	(30.0)	15.0	70.0	120.0	205.0
Detention Basin	325.0	275.0	50.0	(20.0)	18.0	50.0	75.0	150.0
Relocation	275.0	475.0	(200.0)	(300.0)	(250.0)	(210.0)	(170.0)	(50.0)

Long-term Risk of Failure

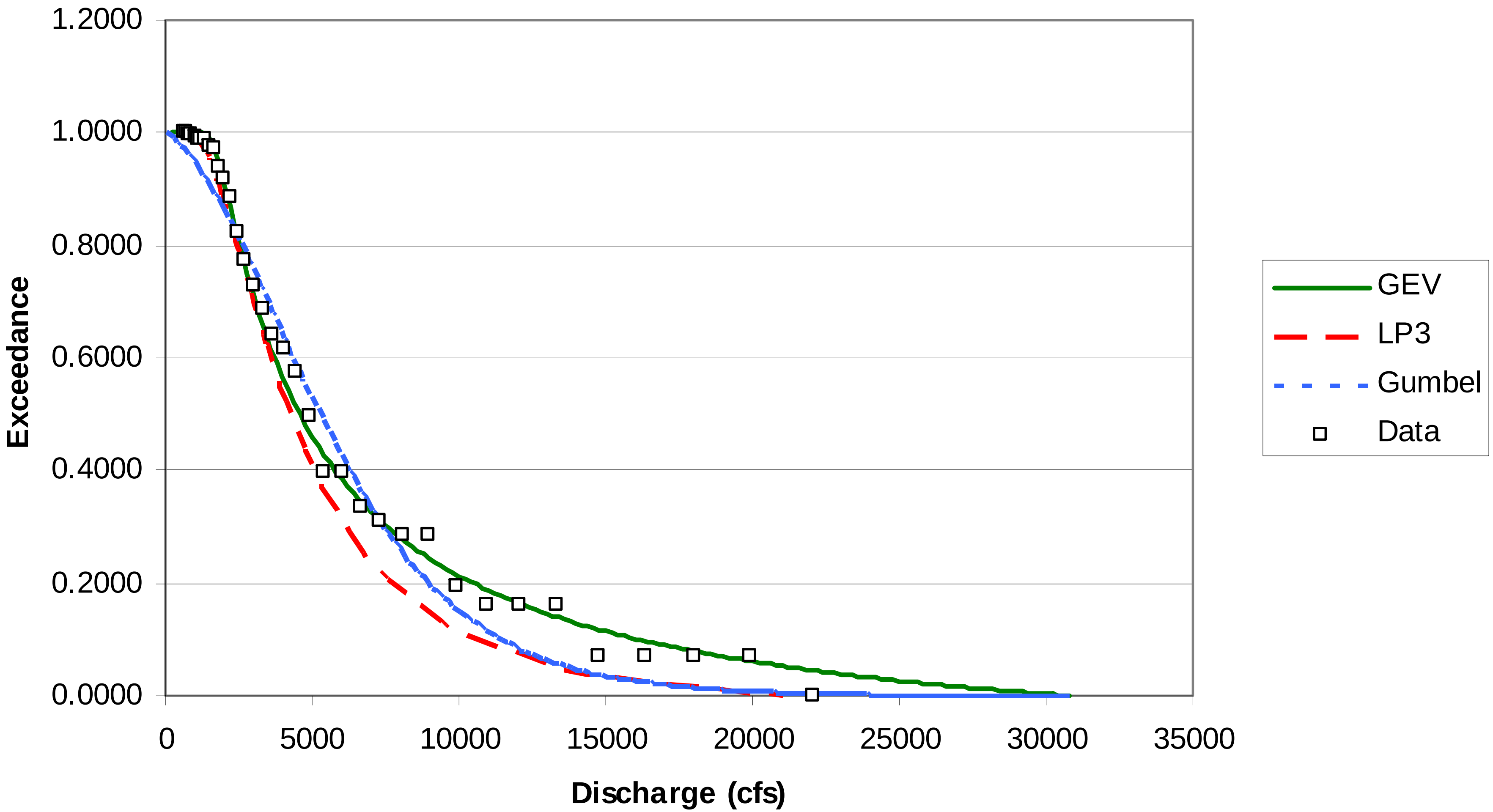
Plan	Annual Performance (Expected Annual Probability of Design Being Exceeded)	Equivalent Long-term Risk (Probability of Exceedance Over the Indicated Time Period)		
		10 Years	20 Years	50 Years
W/O Project	0.250	0.944	0.997	1.000
20 foot Levee	0.020	0.183	0.332	0.636
25 foot Levee	0.010	0.096	0.182	0.395
30 foot Levee	0.001	0.010	0.020	0.049
Channel	0.025	0.224	0.397	0.718
Detention Basin	0.030	0.263	0.456	0.782
Relocation	0.100	0.651	0.878	0.995

Uncertainty and Flood Damage Calculation

(Corps of Engineers Procedures - HEC-FDA;1992)

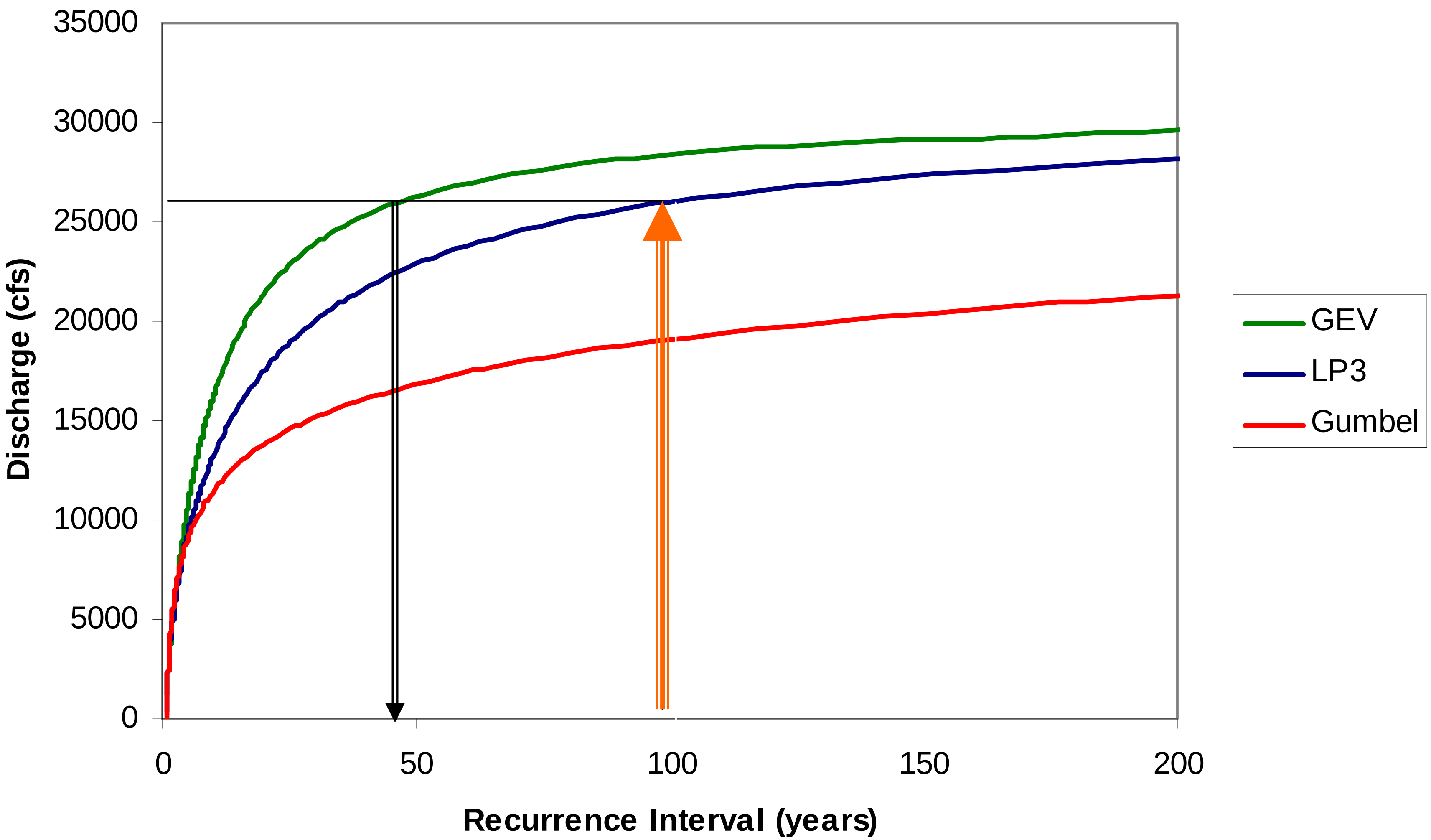


Hydrologic Excedance graph



Discharge Recurrence Intervals for Different Frequency Distributions:

100-year event GEV distribution = 225-year event on LP3



CONCLUSIONS

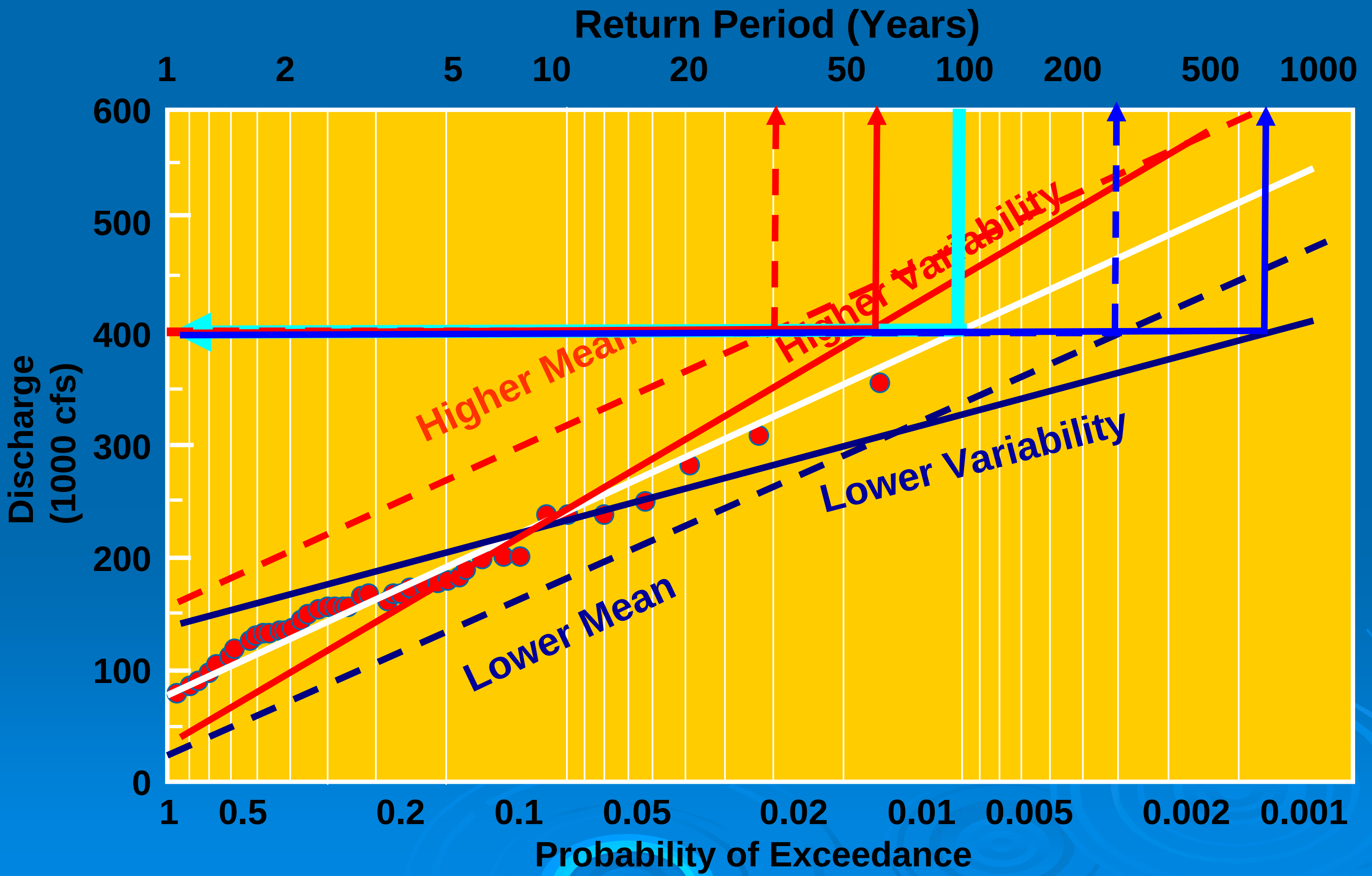
- Flood and Drought Management are the 'leading edge' of any pragmatic adaptation strategy – both for 'managed' and rainfed systems.
- Stochastic hydrology is still a useful way of dealing with climate uncertainty
- The best way to deal with uncertainty is to use proven engineering design methods to upgrade **resiliency, robustness and reliability,**
- IWRM is the accepted paradigm/context for dealing with climate adaptation and adaptive management
- Transitional pragmatic economic evaluation and engineering design tools needed in absence of good information from GCMs and forecasting models
- Expansion and improvement of current hydromet monitoring systems is essential to effective climate adaptation – esp adaptive management
- Economic decision criteria dominate any adaptation responses – need to be revised


Finis-Merci

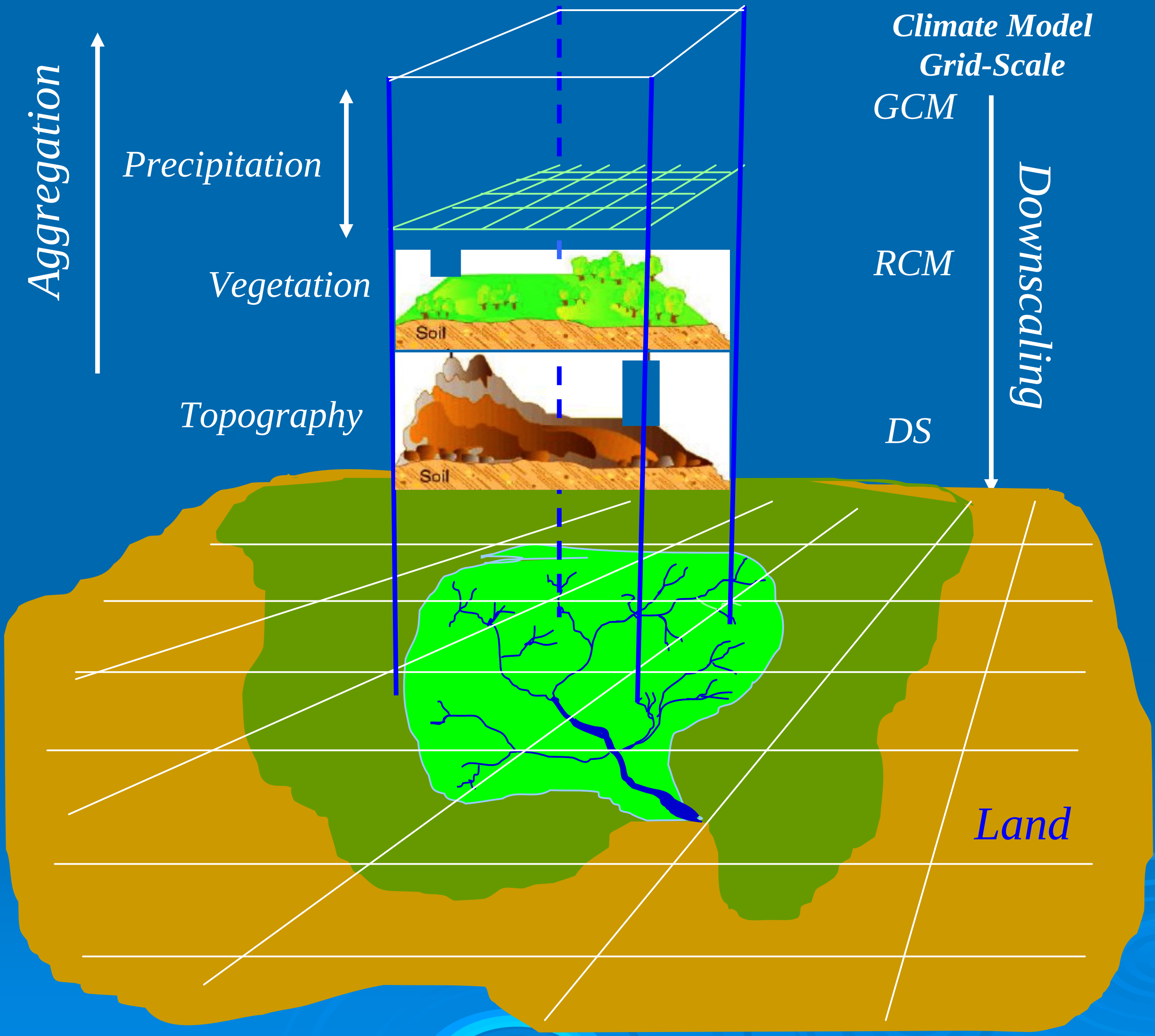
Potential Hydrologic Scenarios

1. Precipitation and Runoff Trends
   (e.g. increase/decrease)

2. Hydrologic Variability
   (e.g. magnitude/severity/duration)



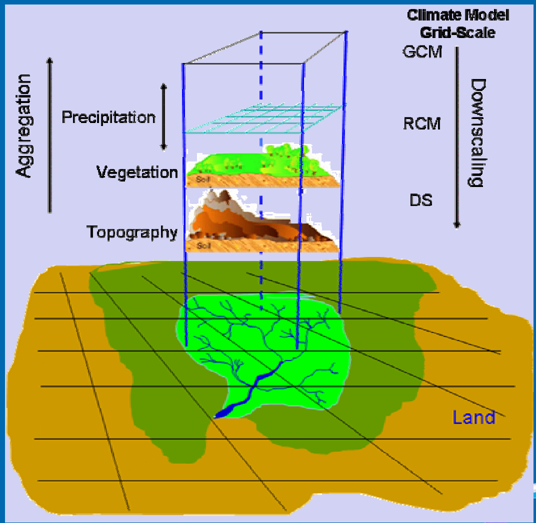
Climate Model Downscaling to watershed Scale

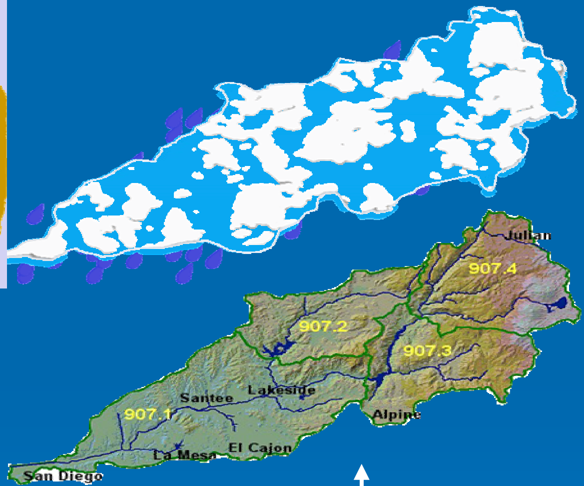


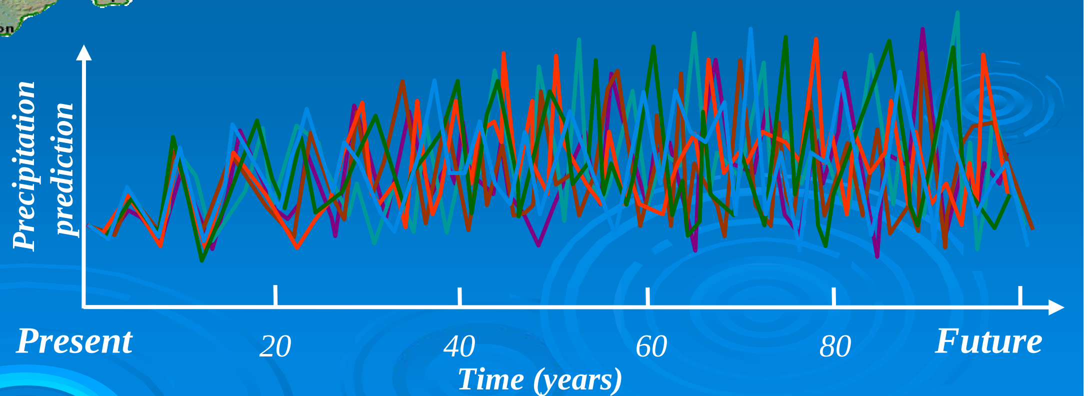
Climate Model Downscaling to Regional/Watershed Scales

Generation of Future Precipitation Scenarios:

Single Model – Multiple Realization

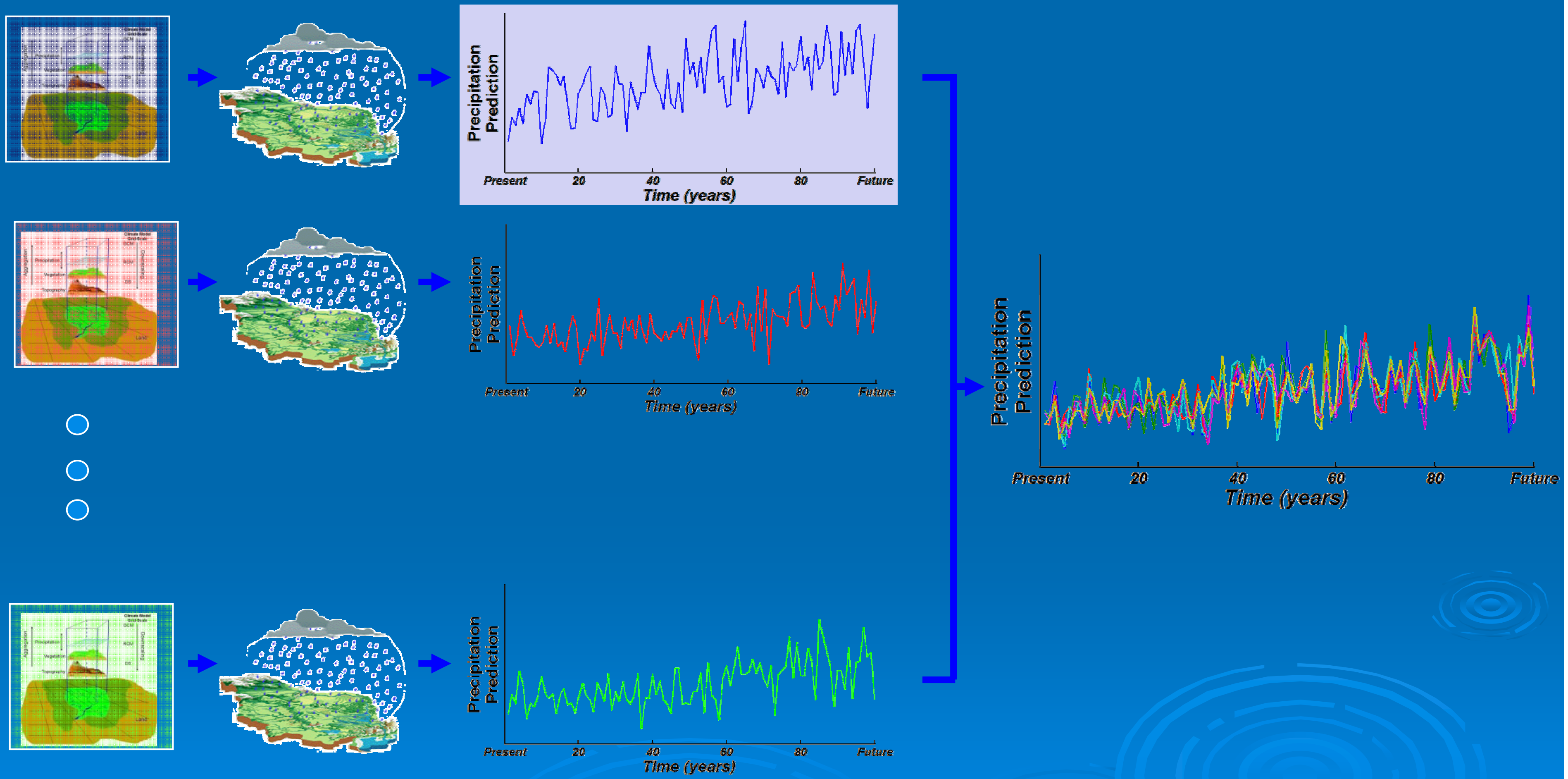






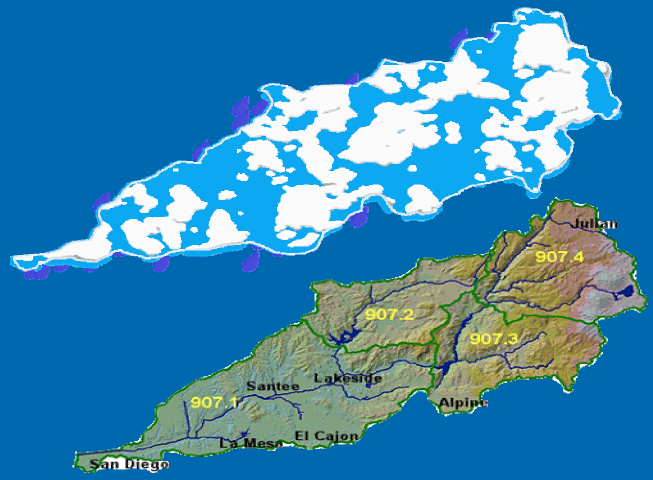
Multi-Model Ensemble Approach

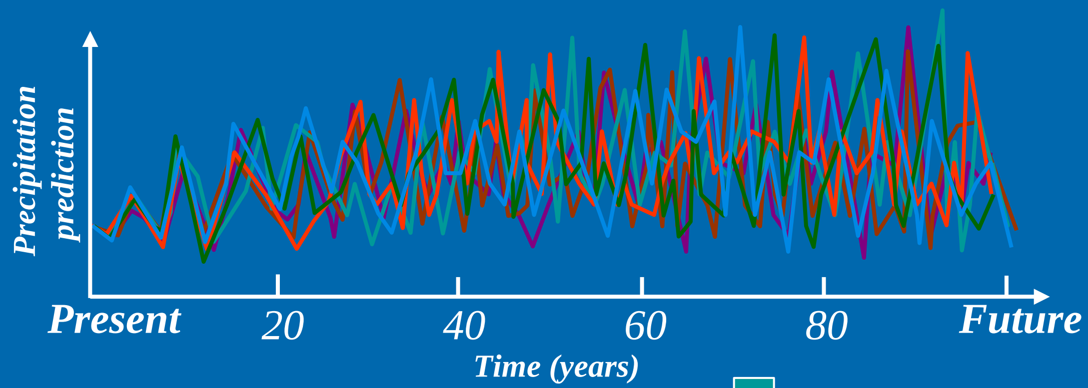
Generation of Future Precipitation Scenarios

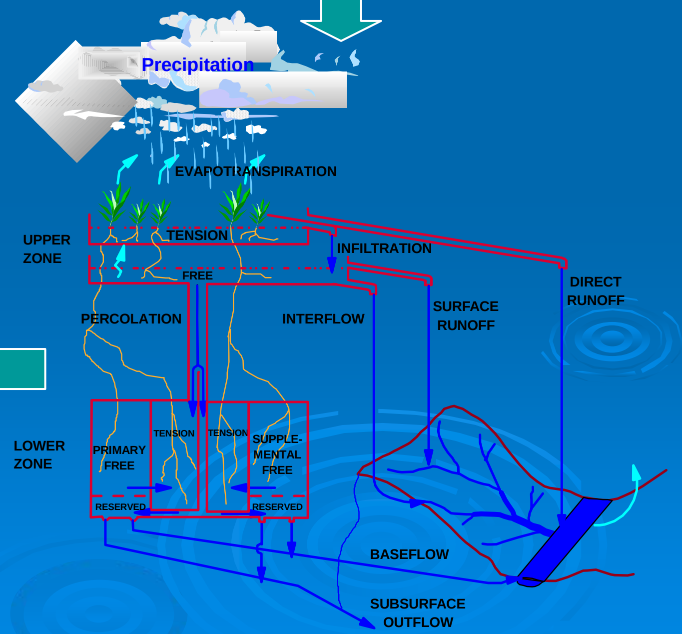


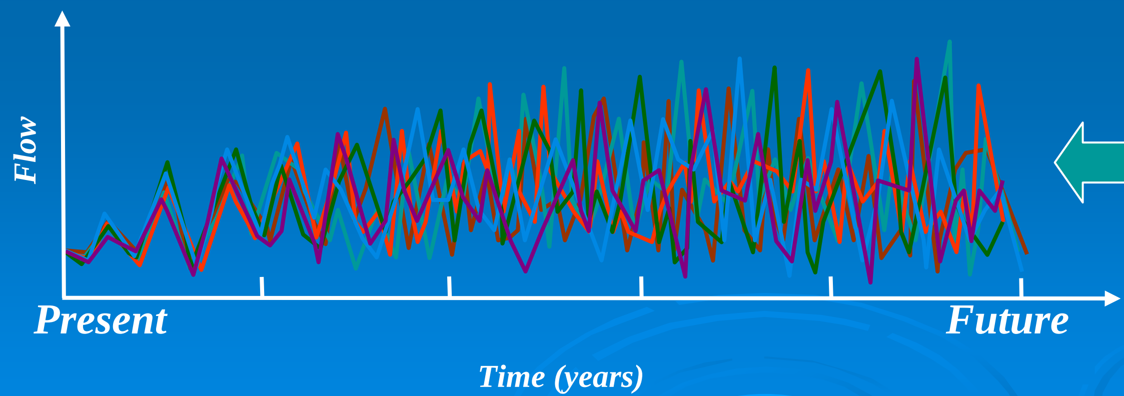
Downscaled Precipitation to Runoff Generation

Generation of Future Runoff Scenarios

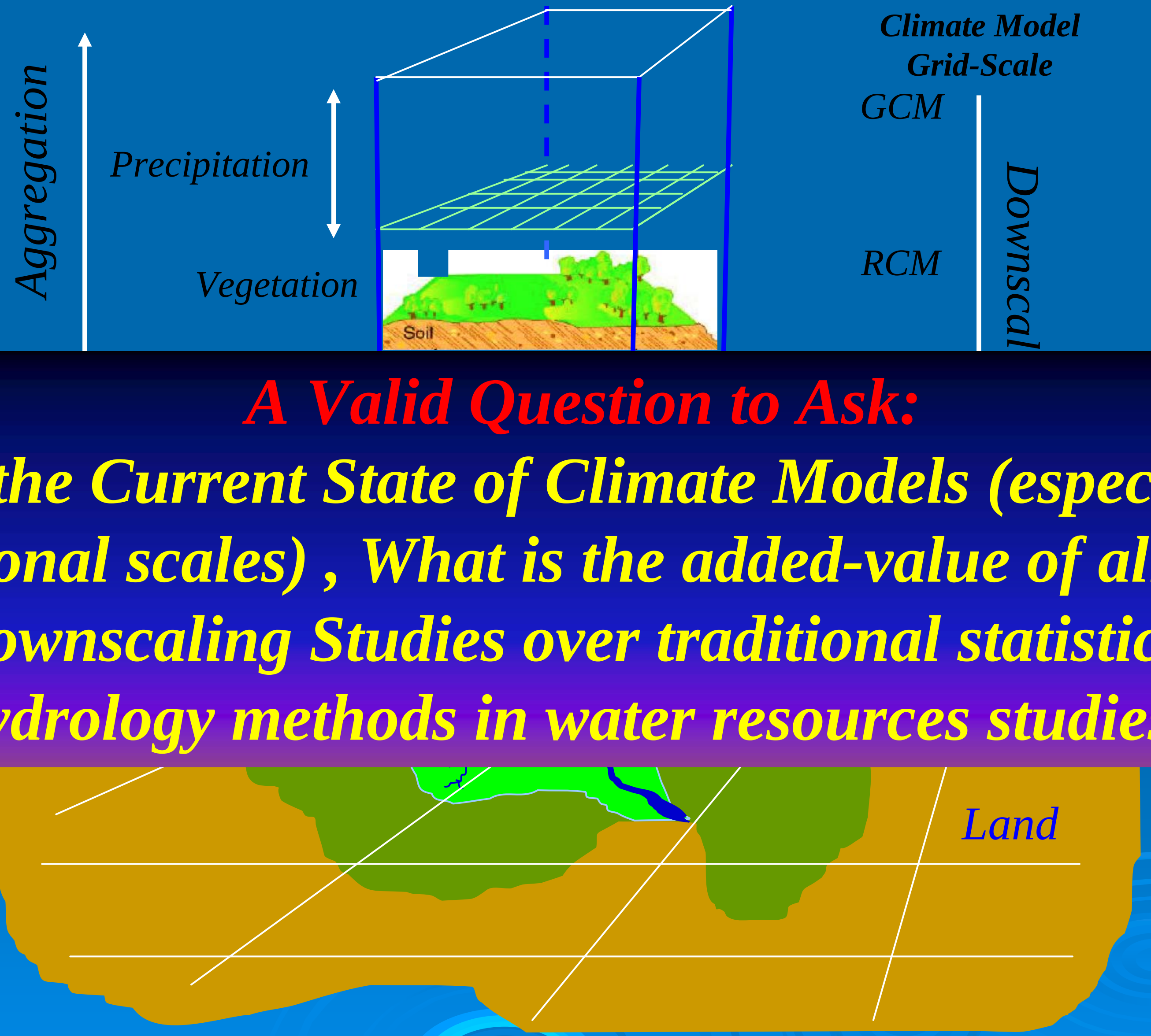








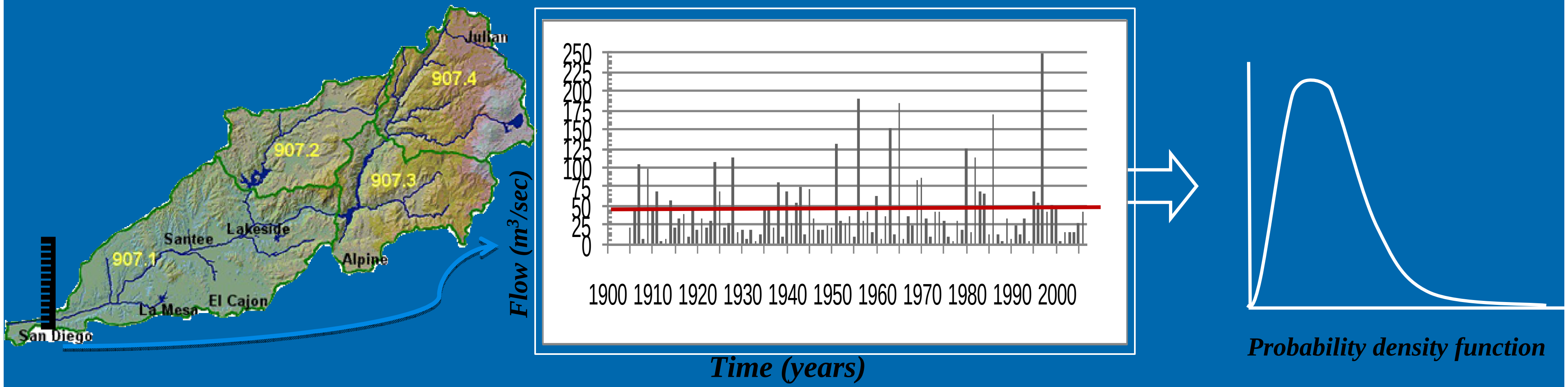
Climate Model Downscaling to regional/watershed Scale

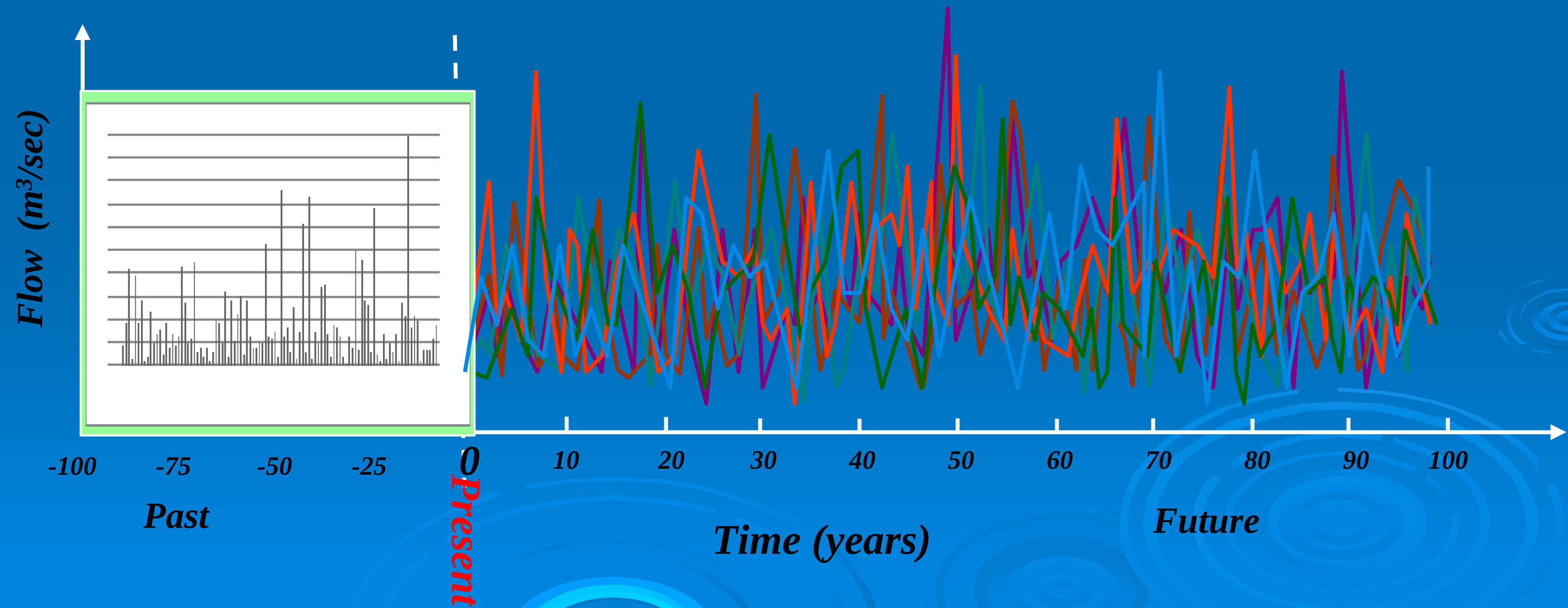


A Valid Question to Ask:

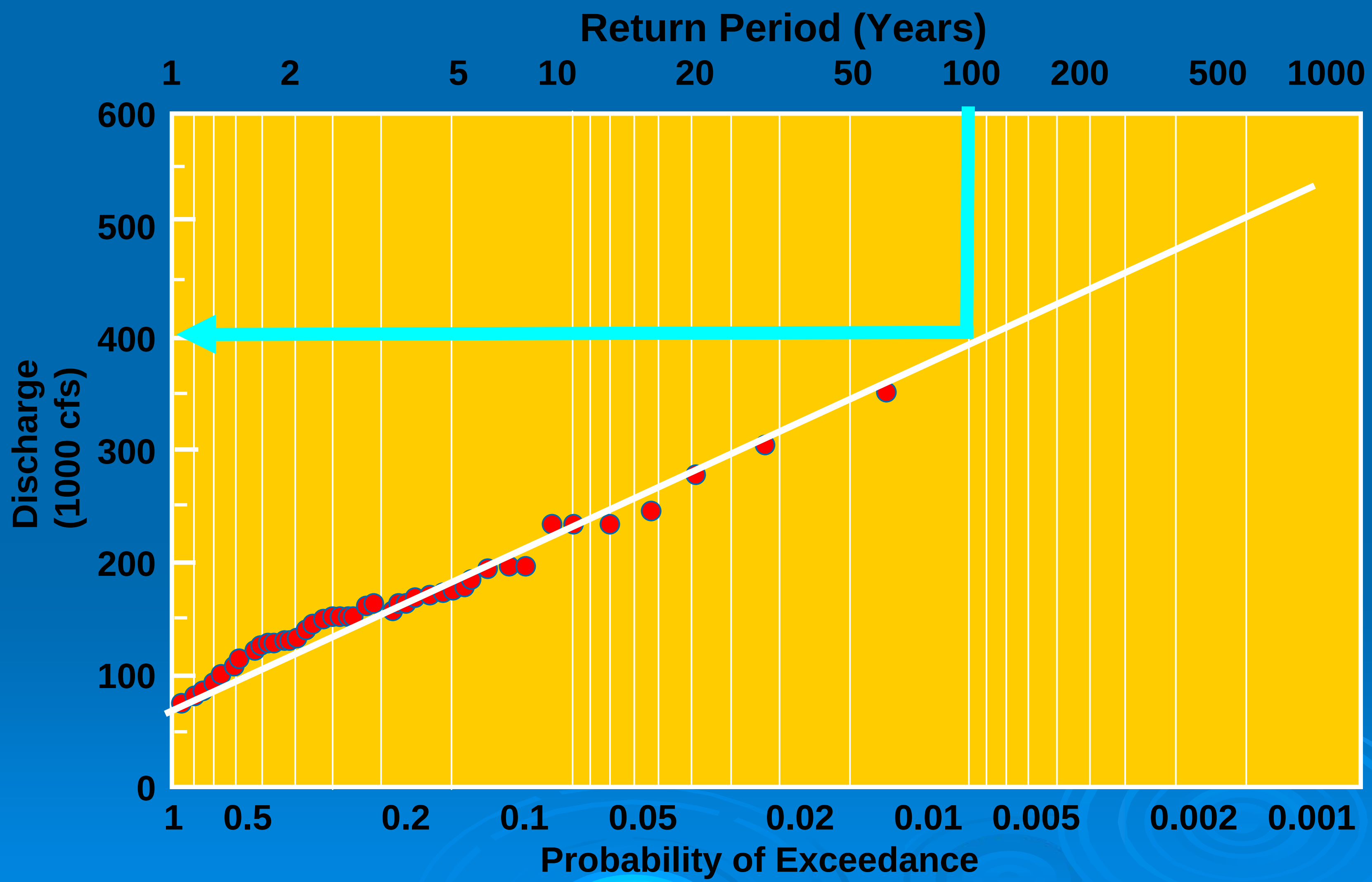
Given the Current State of Climate Models (especially at regional scales) , What is the added-value of all the Downscaling Studies over traditional statistical hydrology methods in water resources studies?

Statistical Hydrology: "synthetic" stream flow Generation

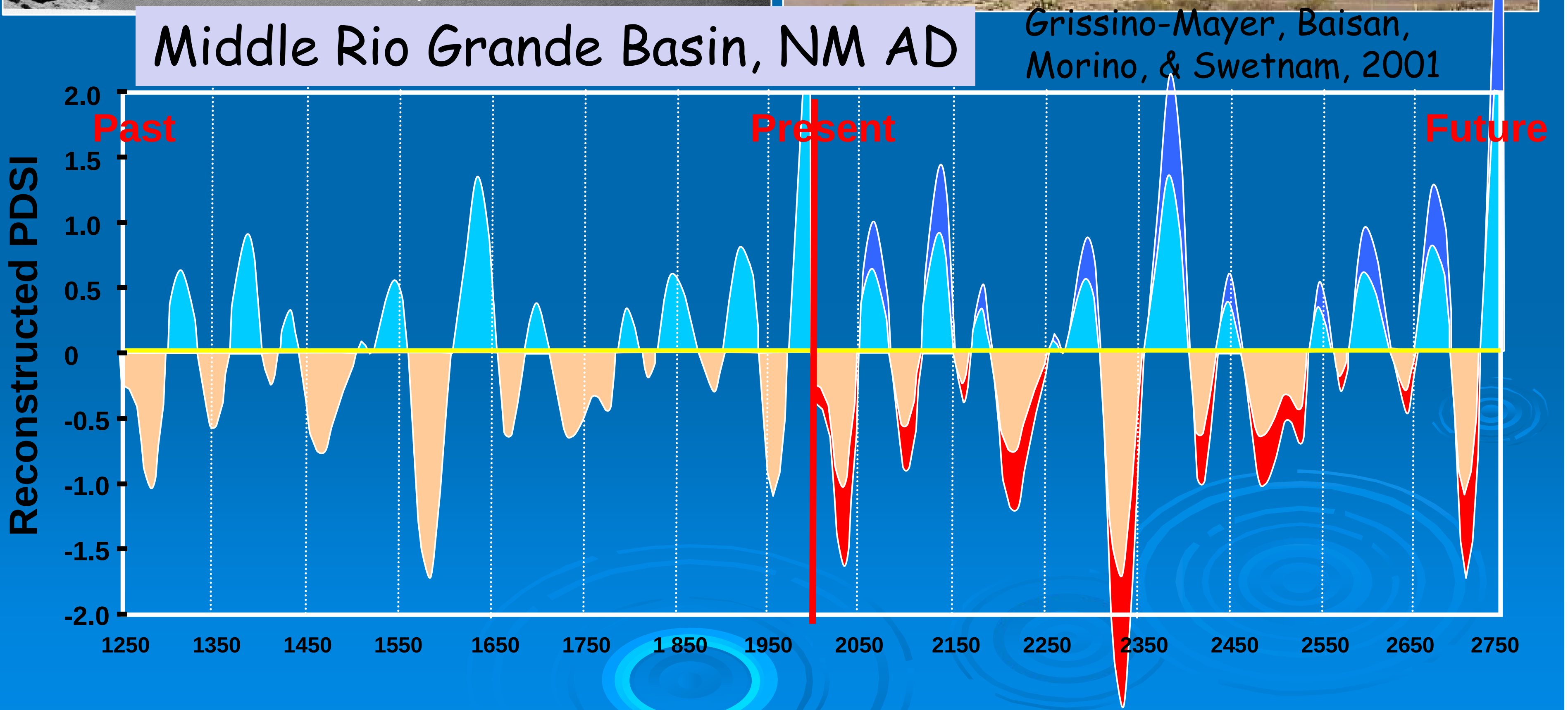




Potential Hydrologic Scenario: Stationarity!



Statistical Hydrology Developed Based on Stationarity Assumption



Wide-Range of Impacts on Infrastructure Design

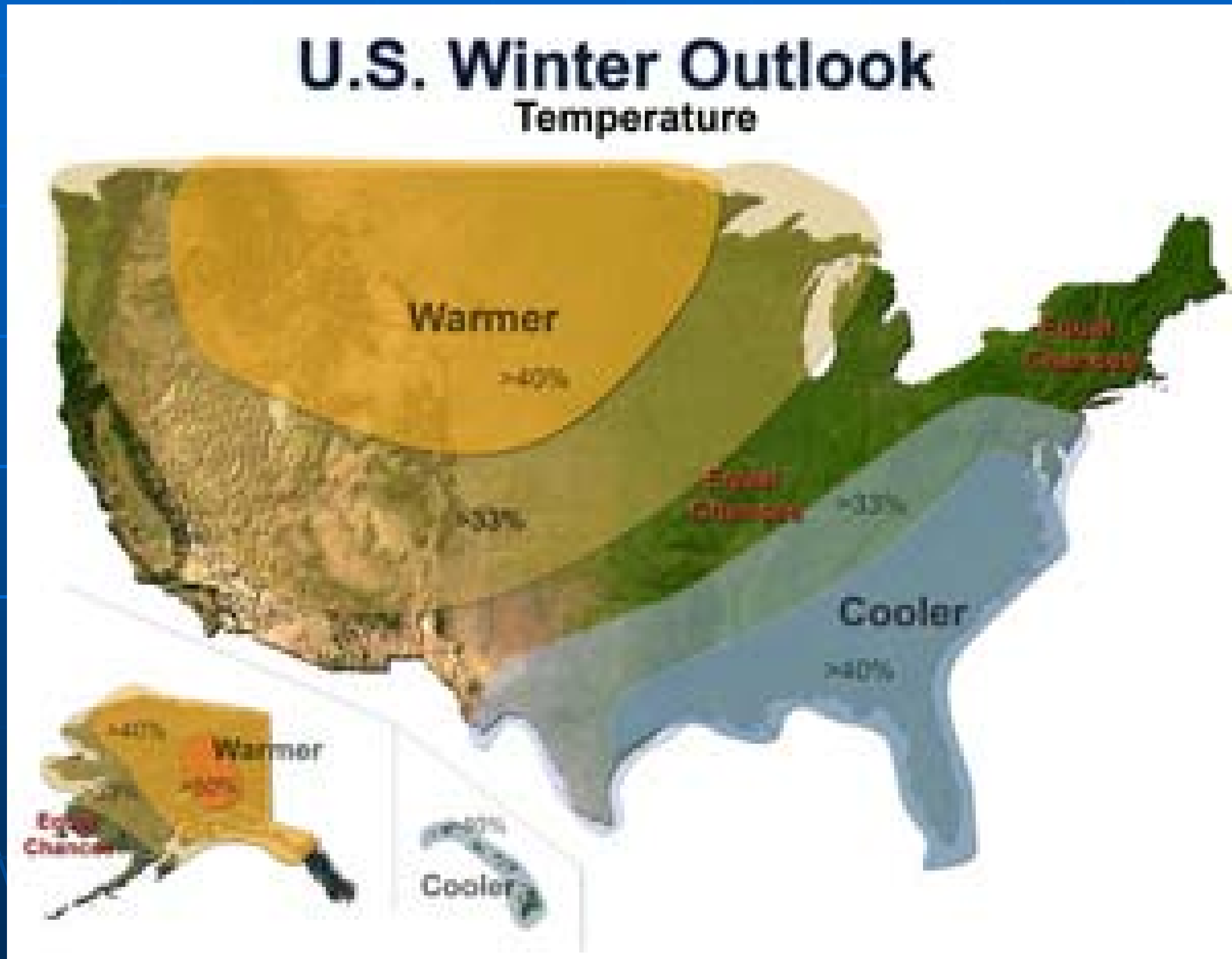
Concluding points

- Presently, the accuracy of regional-scale climate model fall short of meeting the requirements of water resources planning.

- The value of Traditional stochastic hydrology methods should not be underestimated. Research is required to advance their capability to address Hydroclimate decision making needs.

Factoring in Resiliency in water resources systems design and planning is still the safest approach!

NOAA: El Niño to Help Steer U.S. Winter Weather (October 15, 2009)



NOAA Highlights of the U.S. Winter Outlook (December through February) include:

Warmer-than-average temperatures are favored across much of the western and central U.S., especially in the north-central states from Montana to Wisconsin. Though temperatures may average warmer than usual, periodic outbreaks of cold air are still possible.

Below-average temperatures are expected across the Southeast and mid-Atlantic from southern and eastern Texas to southern Pennsylvania and south through Florida.

Above-average precipitation is expected in the southern border states, especially Texas and Florida. Recent rainfall and the prospects of more should improve current drought conditions in central and southern Texas. However, tornado records suggest that there will also be an increased chance of organized tornado activity for the Gulf Coast region this winter.

Drier-than-average conditions are expected in the Pacific Northwest and the Ohio and Tennessee River Valleys.

Northeast: Equal chances for above-, near-, or below-normal temperatures and precipitation. Winter weather in this region is often driven not by El Niño but by weather patterns over the northern Atlantic Ocean and Arctic, such as the North Atlantic Oscillation. These patterns are often more short-term, and are generally predictable only a week or so in advance.

California: A slight tilt in the odds toward wetter-than-average conditions over the entire state.

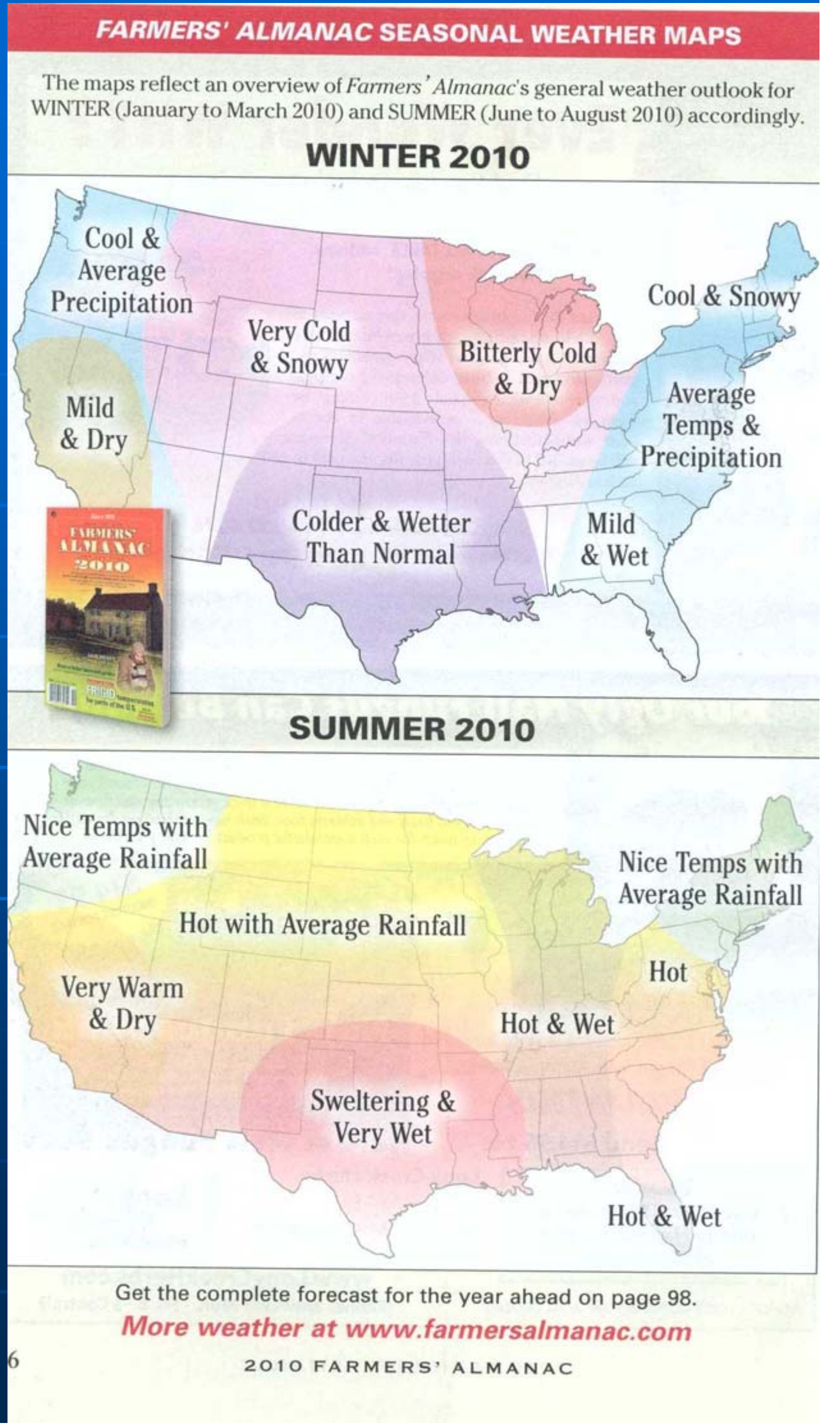
Alaska: Milder-than-average temperatures except along the western coast. Equal chances for above-, near-, or below-median precipitation for most areas except above median for the northwest.

Hawaii: Below-average temperatures and precipitation are favored for the entire state..

This seasonal outlook does not predict where and when snowstorms may hit or total seasonal snowfall accumulations. Snow forecasts are dependent upon winter storms, which are generally not predictable more than several days in advance.

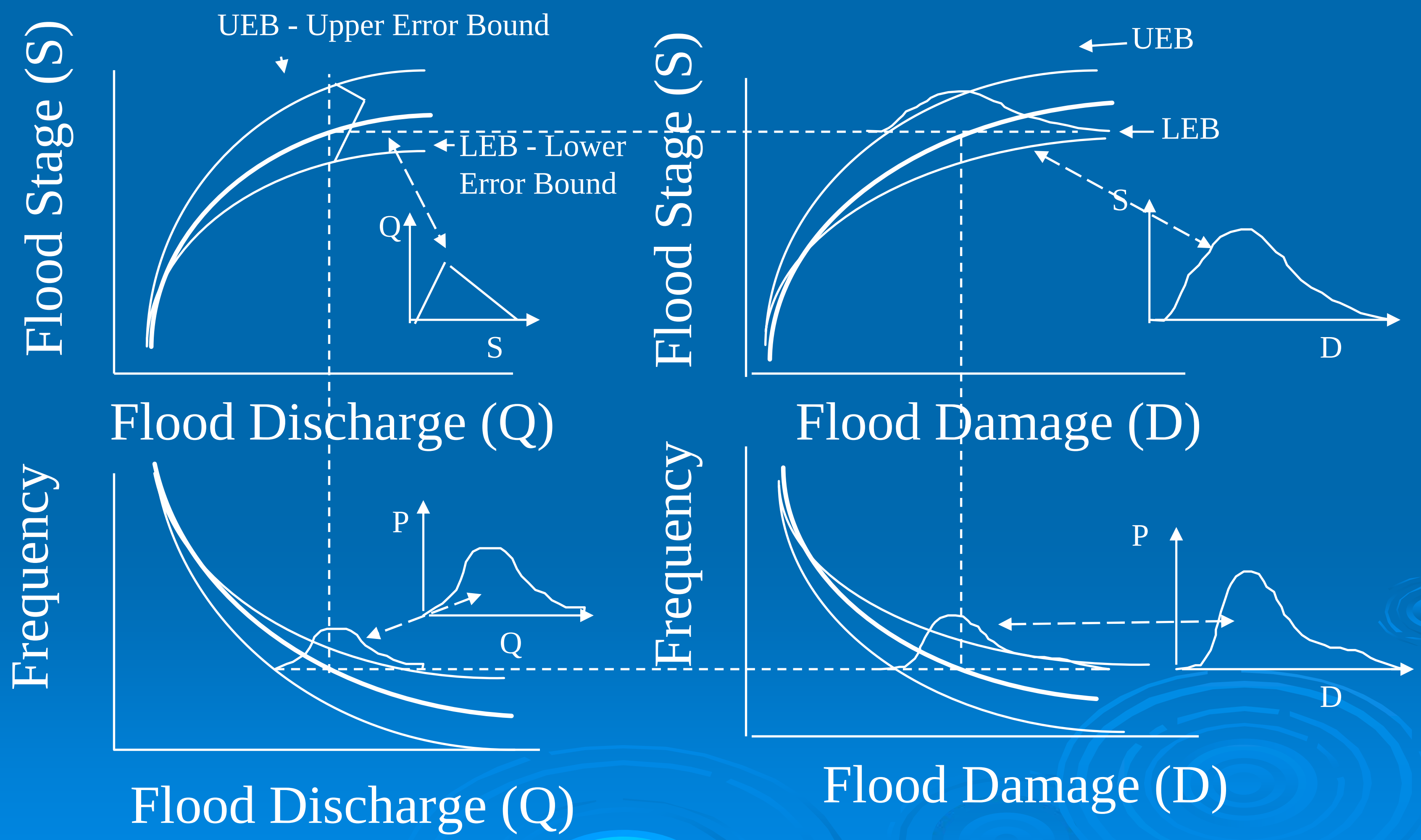
- If you can't make sense of the GCM scenarios...
- If you can't rely on seasonal forecasts...
- If your predictions of hurricane activity have failed, then try....

2010 Farmers' Almanac Predictions for the U.S.



Uncertainty and Flood Damage Calculation

(Corps of Engineers Procedures - HEC-FDA;1992)



How to translate Global Warming GCM Info into real decisions?

- **Top down approach** (advocated by climate modeling community)**:** translating GCM outputs into design criteria and decisions, assuming that information is useful and certain
- **Bottom Up:** (advocated by the practitioners) develop incremental adaptive coping strategies based on engrg practice and experience with risk, uncertainty and build in resiliency, robustness and reliability (just as we've always done from the times of the Pharaohs

Hurricanes & Global Warming?

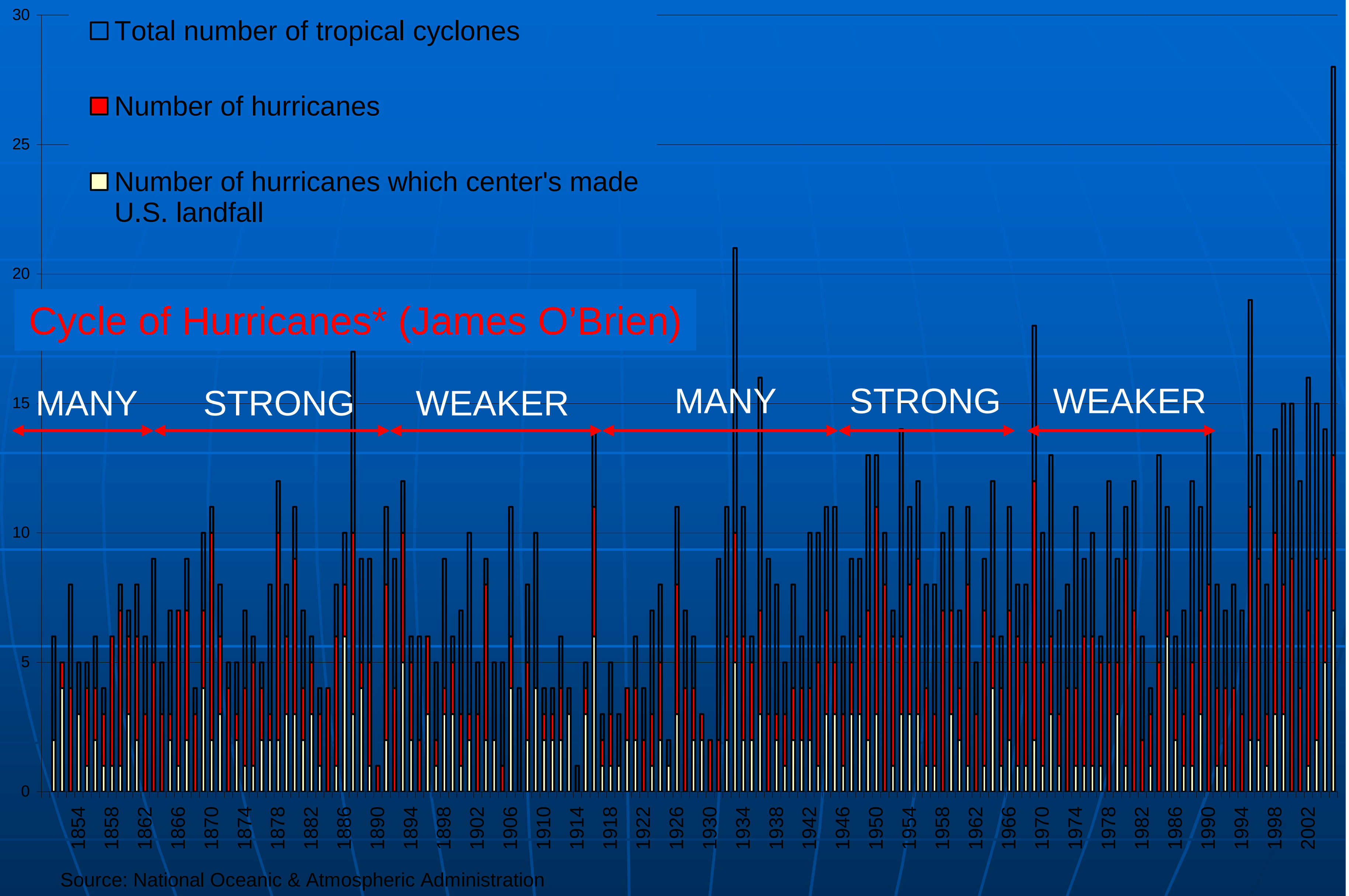
- 2004, 2005 Atlantic hurricane seasons broke many records
- 2006 predicted to have 15 named storms; 10 hurricane strength; 4-5 major making landfall in US

  2006 A BUST !!! Not much happened (FEMA, Corps and other agencies spent $millions anticipating) 2007, 2008, 2009 as well.
- **Debate among US meteorologists:**

A. 25-40 yr cycle ? (e.g. Landsea & Gray) or

B. part of global warming cycle ? (e.g. Emmanuel)

Herein lies the problem for water engineers- how to translate vague climate scenarios, scientific disputes and flawed predictions into design criteria for reliable structures and response systems?



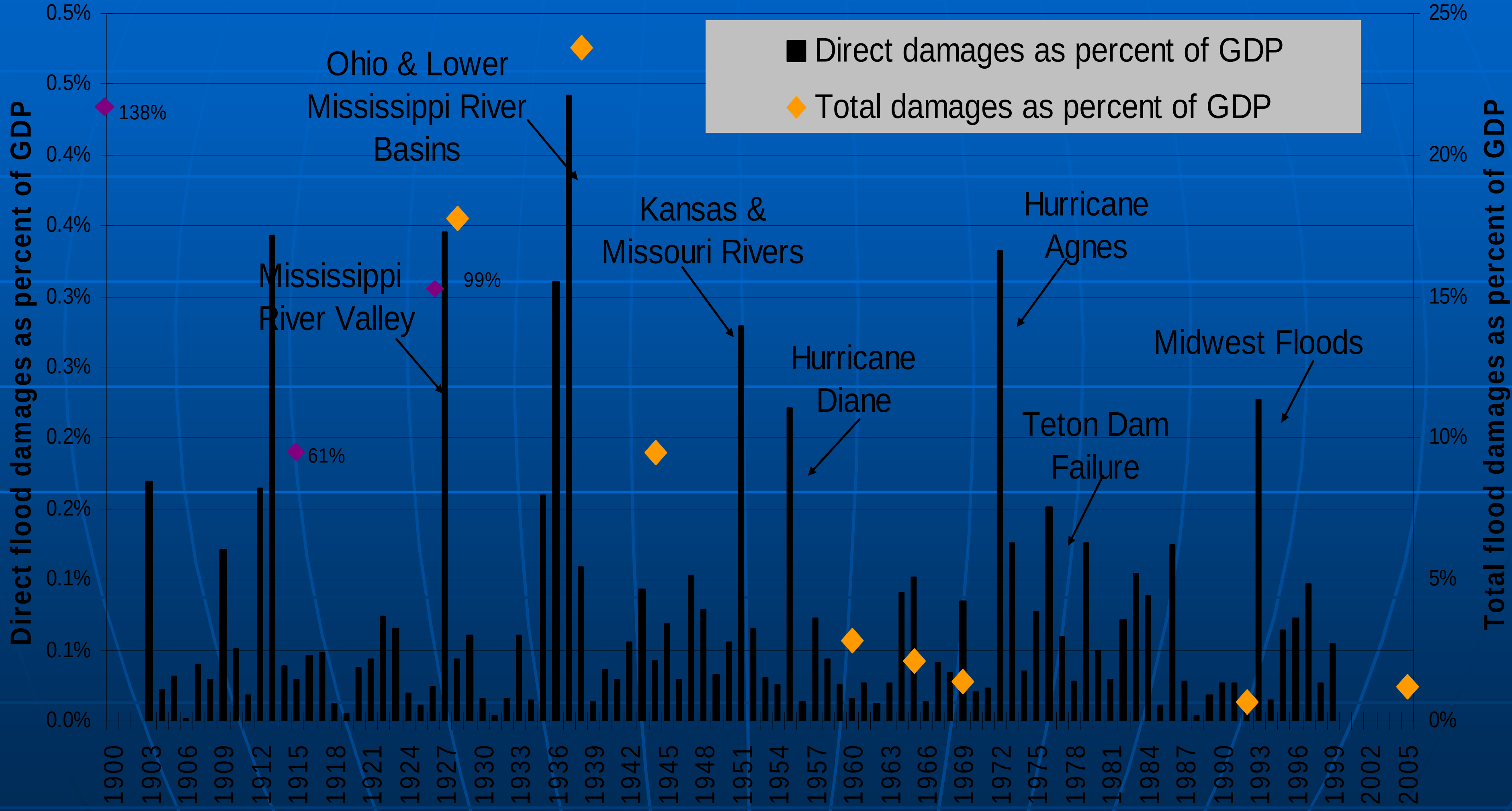
Note: Prior to 1970, tropical cyclones were not monitored by satellites; meaning that those cyclones that did not hit the land of the United States were not systematically recorded.

Most Damaging Hurricanes

	Year	Cat	Damages
Katrina (FL, LA, MS)	2005	3+	$ 100.0 B +
Andrew (FL, LA)	1992	5	43.6 B
Charley (FL)	2004	4	15.0 B
Ivan (AL, FL)	2004	3	14.2 B
Hugo (SC)	1989	4	12.2 B
Agnes (FL, GA, SC, PA)	1972	2	11.3 B

Flood Damages as Percent of GDP

(Based on damages and GDP data in 2000 dollars)



Floods in a changing climate

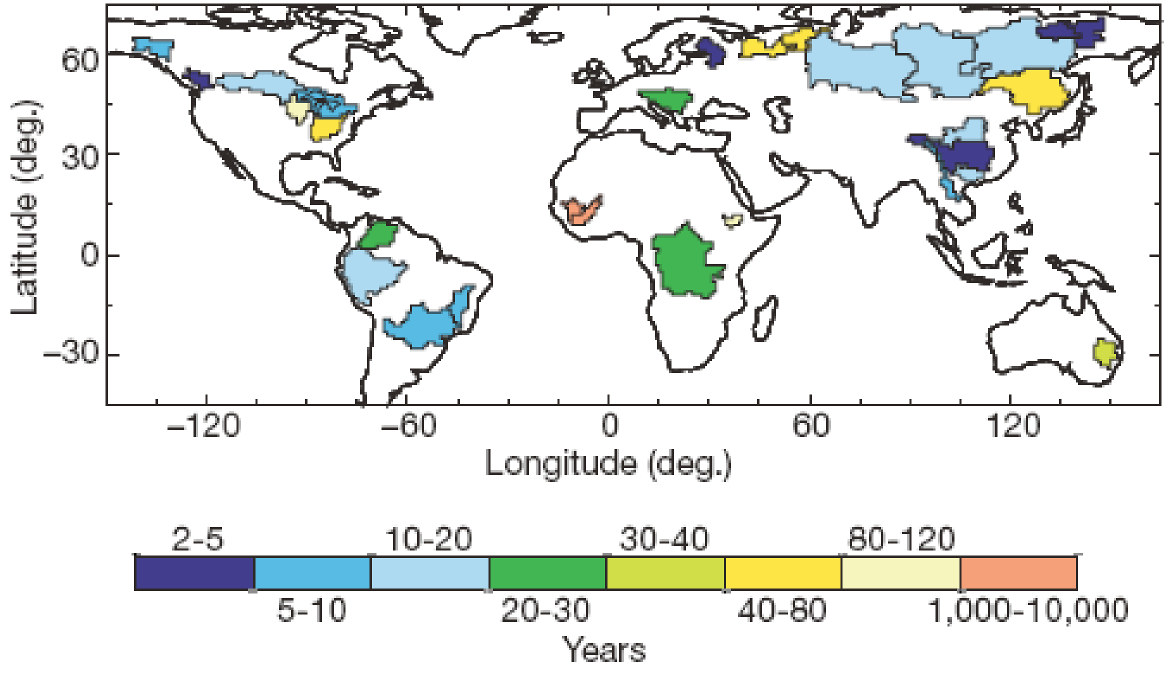


Figure 2 Map showing the gauged drainage areas and flood-risk sensitivities of the 29 river basins in this study. Colour indicates the modelled return period, under idealized quadrupling of atmospheric CO_2 concentrations, of the flood magnitude associated with a 100-yr return period in the control experiment. Although results for low-latitude basins are provided, the poor performance of the model in low latitudes should be kept in mind.

Nature, 2002

Increasing risk of great floods in a changing climate

P. C. D. Milly*, R. T. Wetherald†, K. A. Dunne* & T. L. Delworth†

Or Not …

Kundzewicz et al., 2005

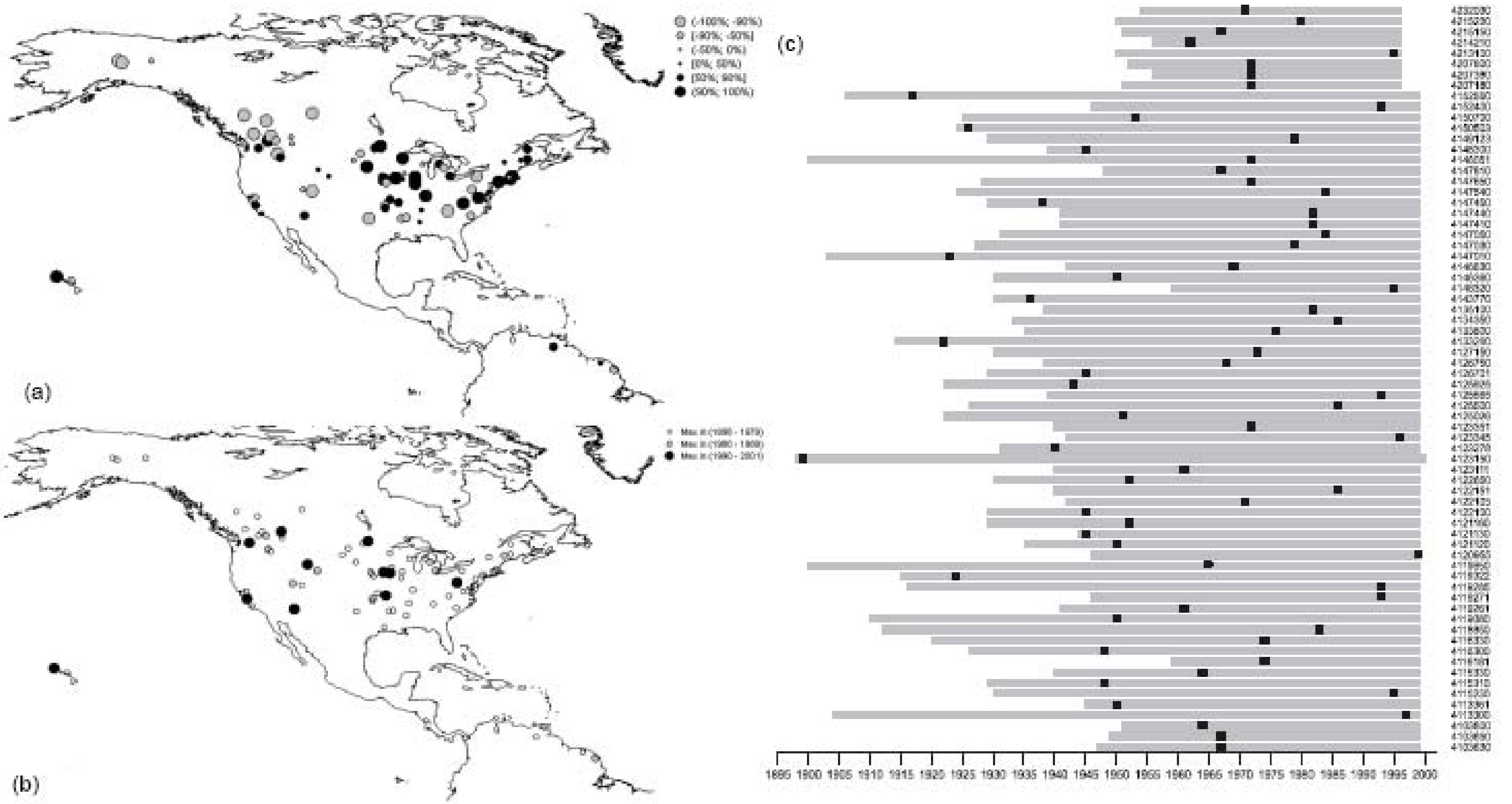
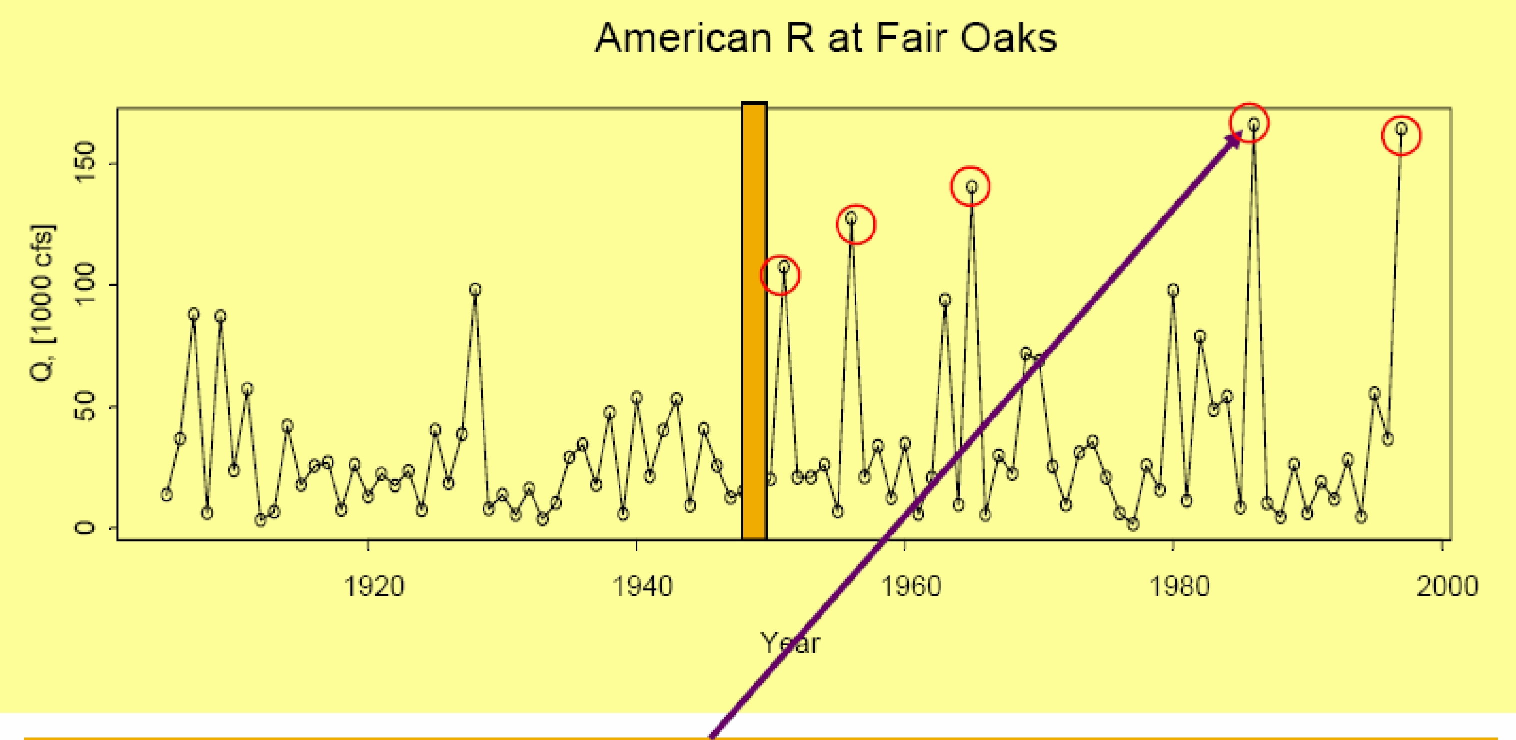


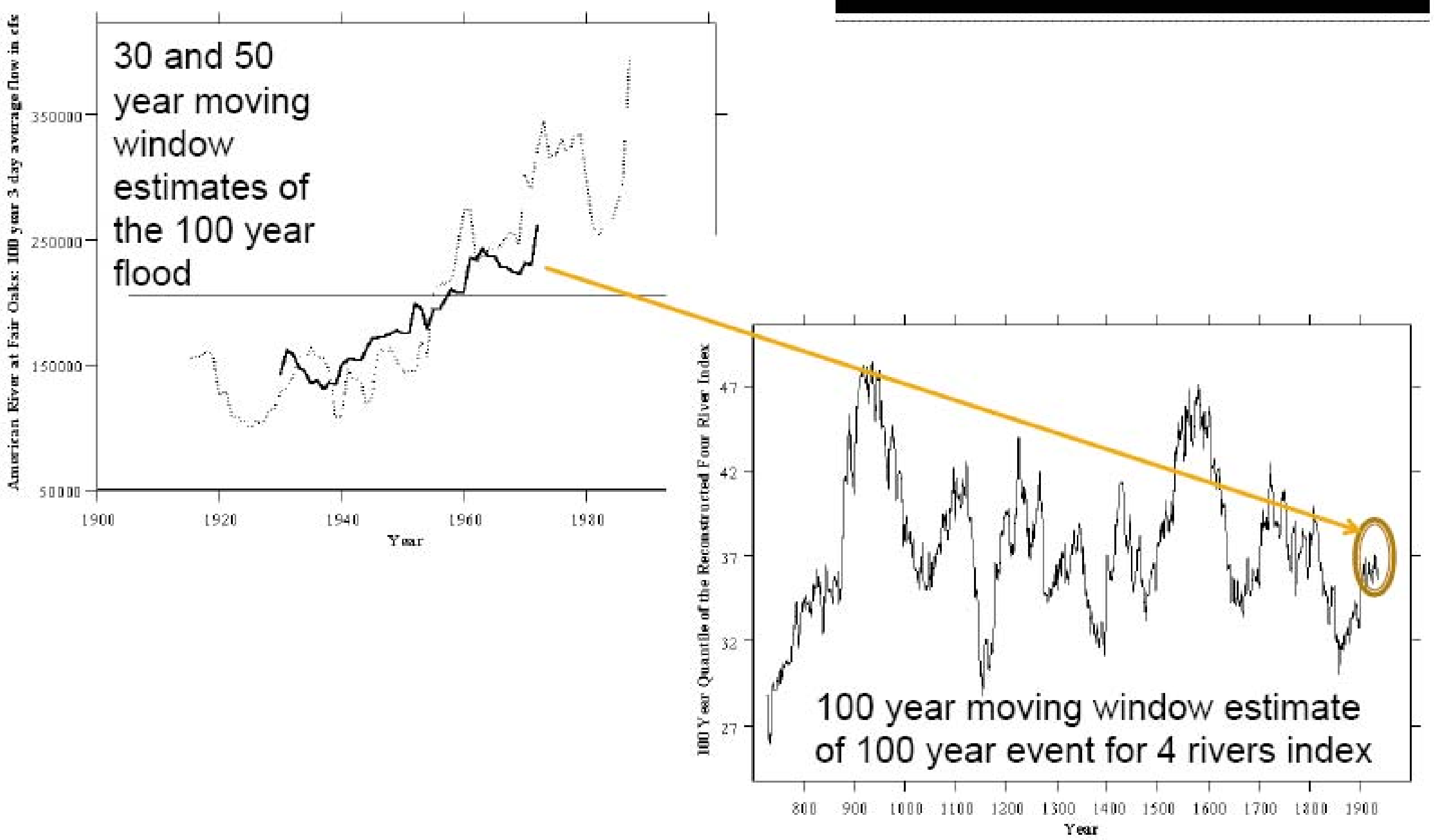
Fig. 1 Significant changes in annual maximum flow of North American rivers: (a) trend index; (b) decade of occurrence of the highest maximum flow within the available data; and (c) duration of the series and the year of occurrence of the maximum flow.

What is the 100 year flood on the American River, at Sacramento, CA?



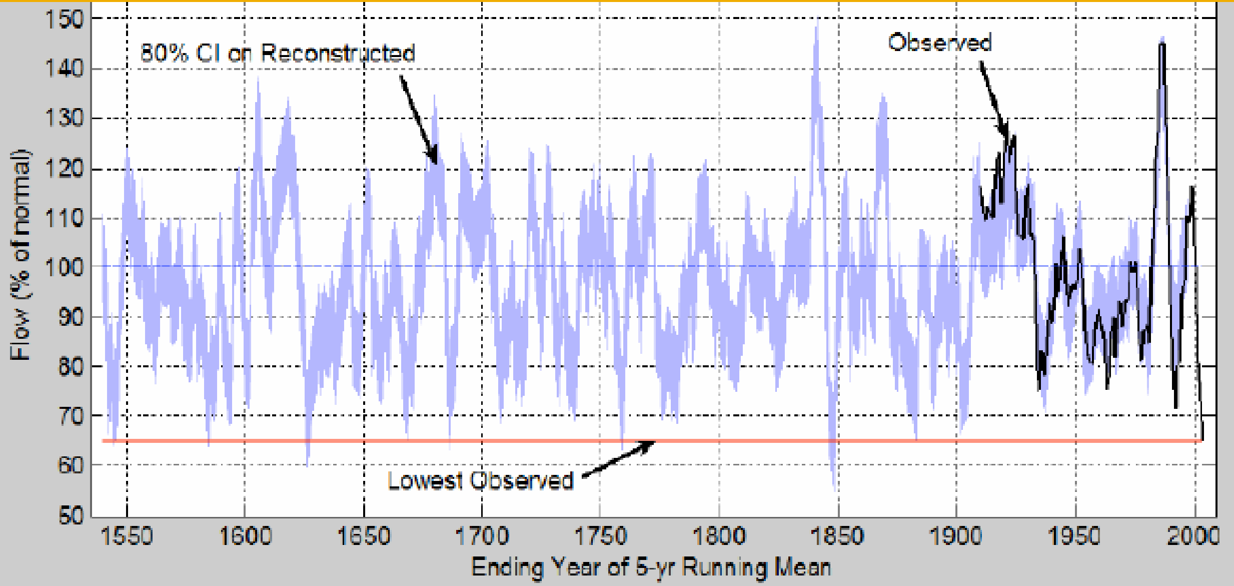
Projected Single event damage from overtopping >$40 billion - SAFCA,2000

Nonstationarity of the 100 year flood at Sacramento



Hydrologic/Climatic Variability

How should these long periods of climatic departures be managed?
How adequate are the reservoirs (Storage capacity = 5+ years of mean annual flow?

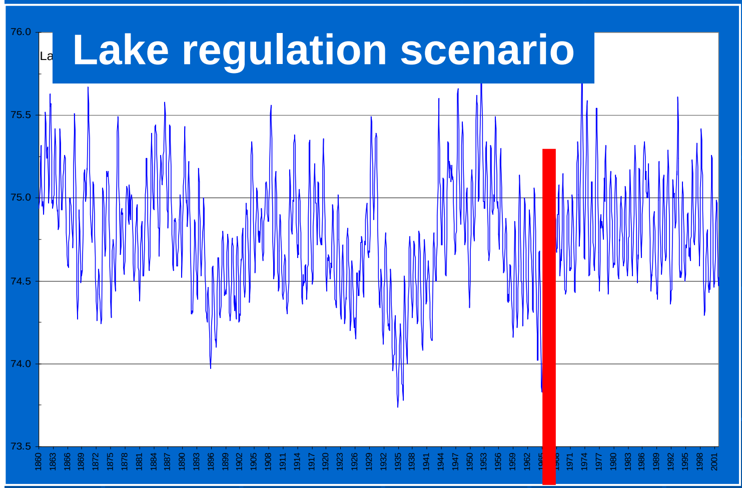


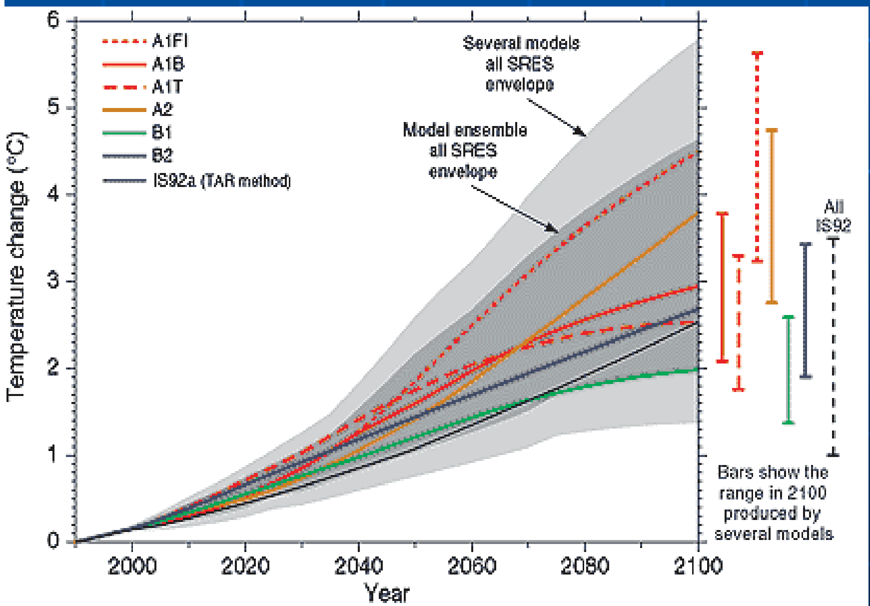
Data analysis courtesy of Dave Meko

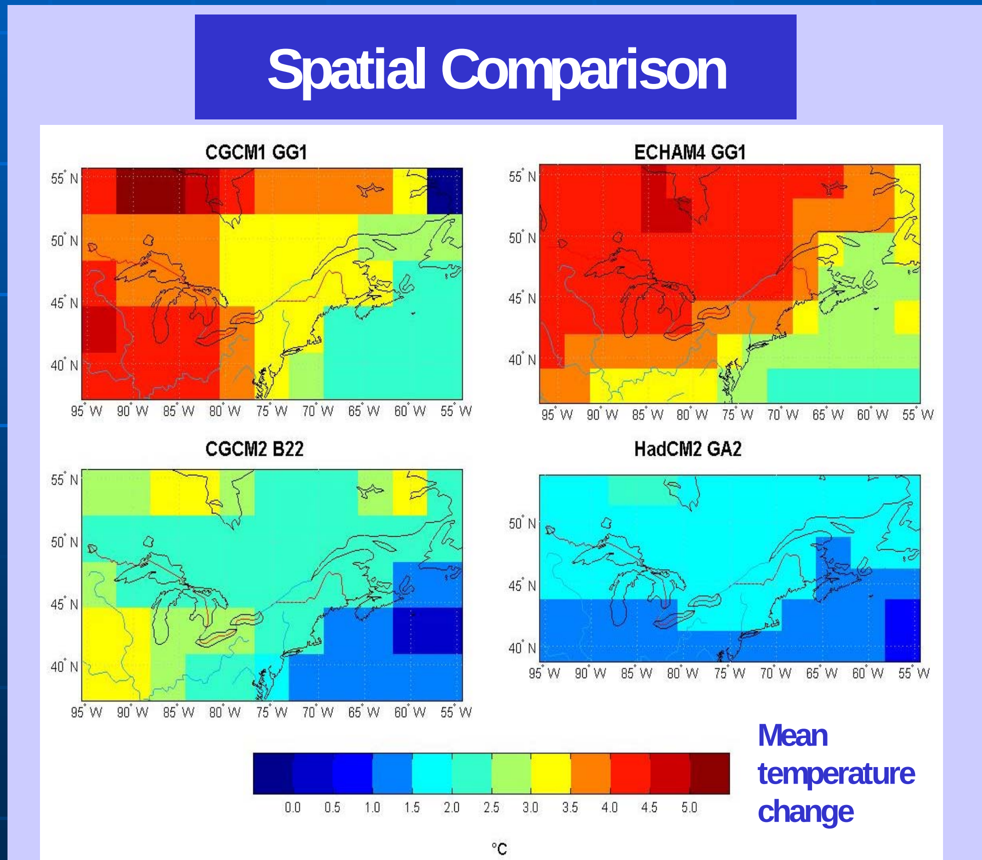
1900 to 2004

From Eric Kuhn, 2005

IJC Lake Ontario Study: Hydrologic Scenarios Including Climate Change







IJC International Lake Ontario – St. Lawrence River Study

Candidate Plans:

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

Natural Flow Plan

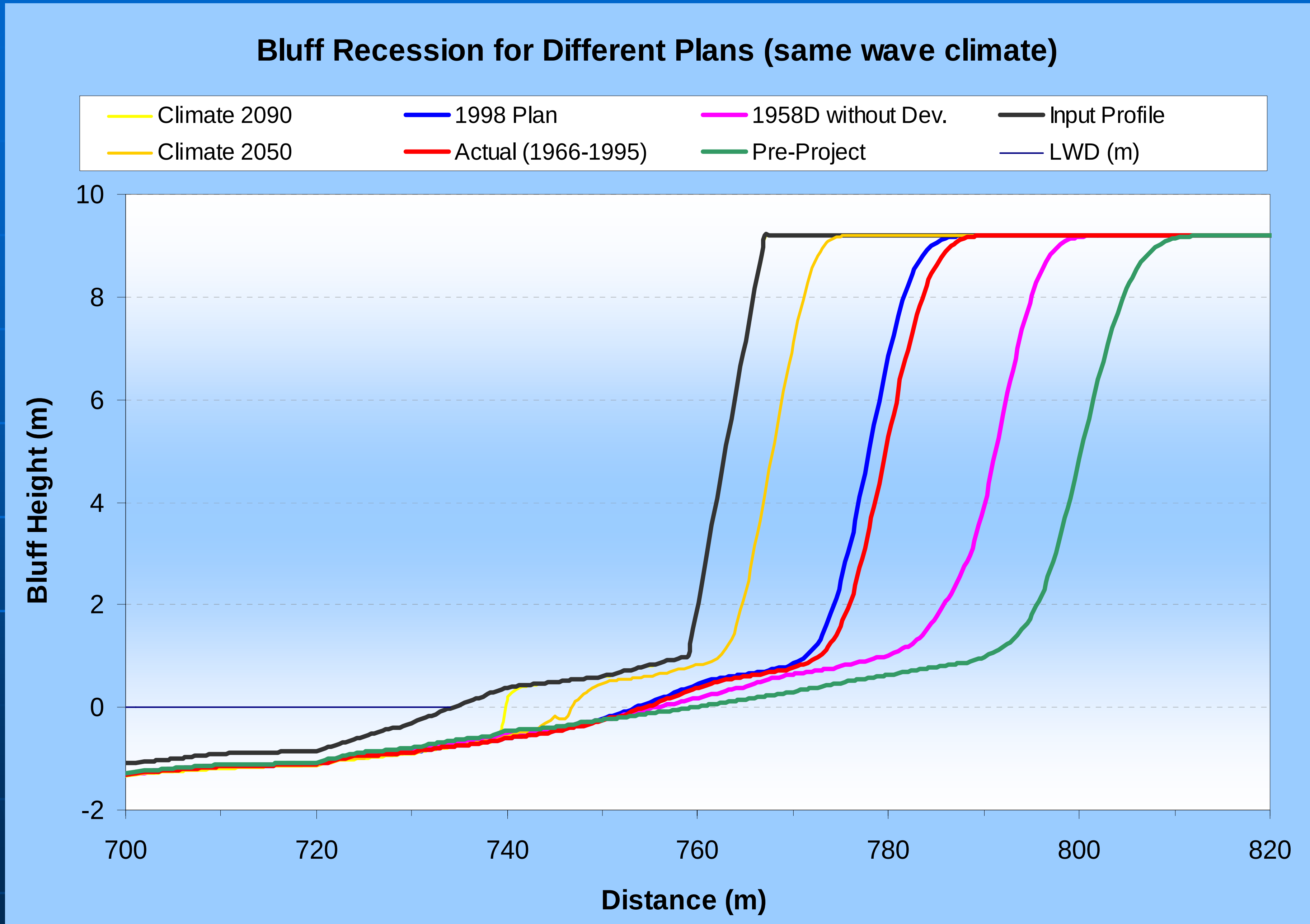
- E: Natural Flow

Interest Specific:

- Ontario Riparian Plan
- Recreational Boating Plan

Reference Plans:

- Plan 1998
- Plan 1958DD
- Plan 1958D


Bluff Recession for Different Plans (same wave climate)
Climate 2090
Climate 2050
1998 Plan
Actual (1966-1995)
1958D without Dev.
Pre-Project
Input Profile
LWD (m)
Bluff Height (m)
Distance (m)
10
8
6
4
2
0
-2
700
720
740
760
780
800
820

Net Economic/Ecologic Benefits of Alternative Plans

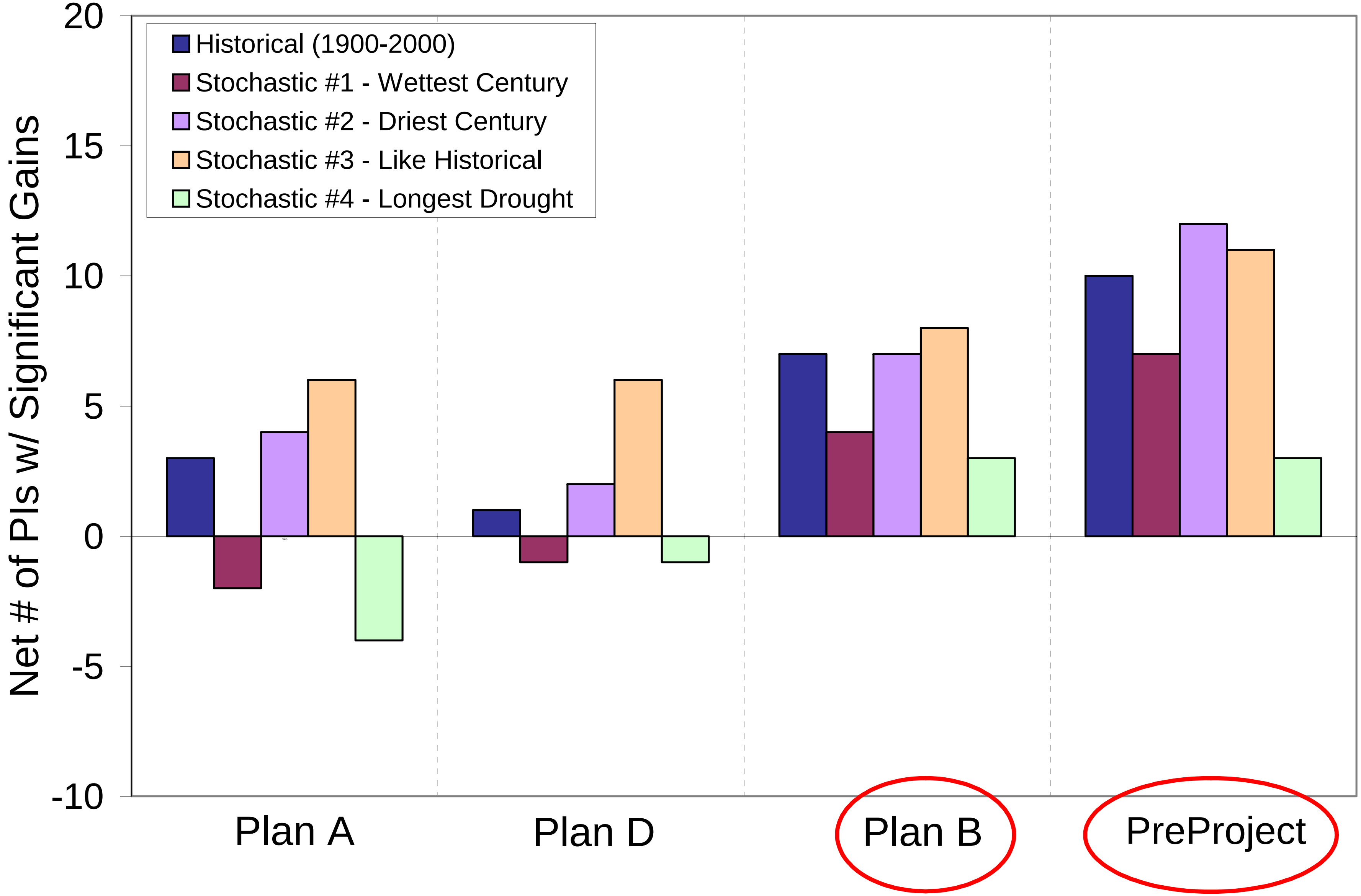
Avg. annual net benefits ($US million)	Plan 58DD	Plan A	Plan B	Plan D	Plan E
Net Benefits	0.00	7.52	6.48	6.52	-12.30
Shoreline Damages	0.00	-0.62	-1.11	0.32	-25.96
Navigation	0.00	0.41	2.20	2.31	4.13
Recreation Boating	0.00	4.23	-0.58	2.04	-4.64
Hydroelectric	0.00	3.50	5.97	1.82	14.16
Municipal Water	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

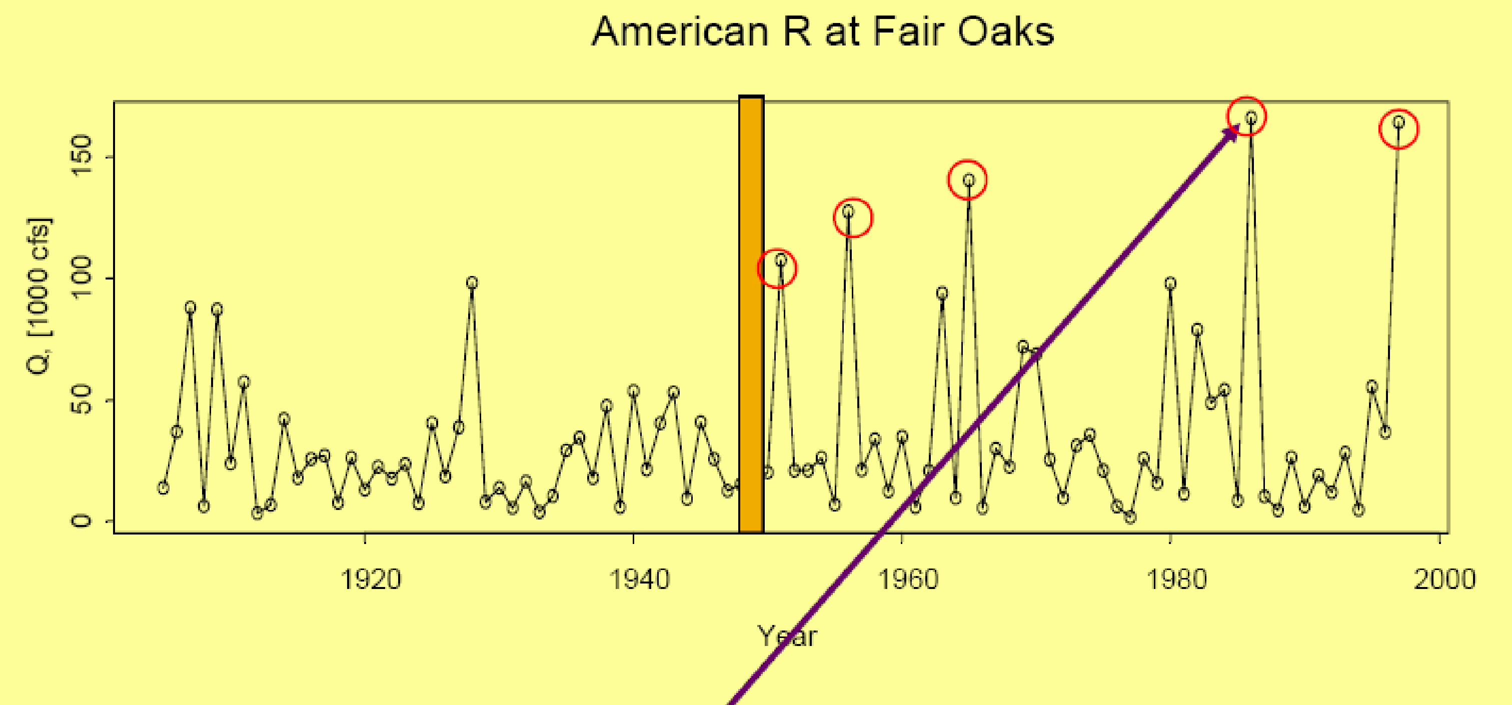
Ecological Robustness/Resiliency- **Stochastic Scenarios**

(# Ecological Performance Indicators's (of 32) with gains or losses)



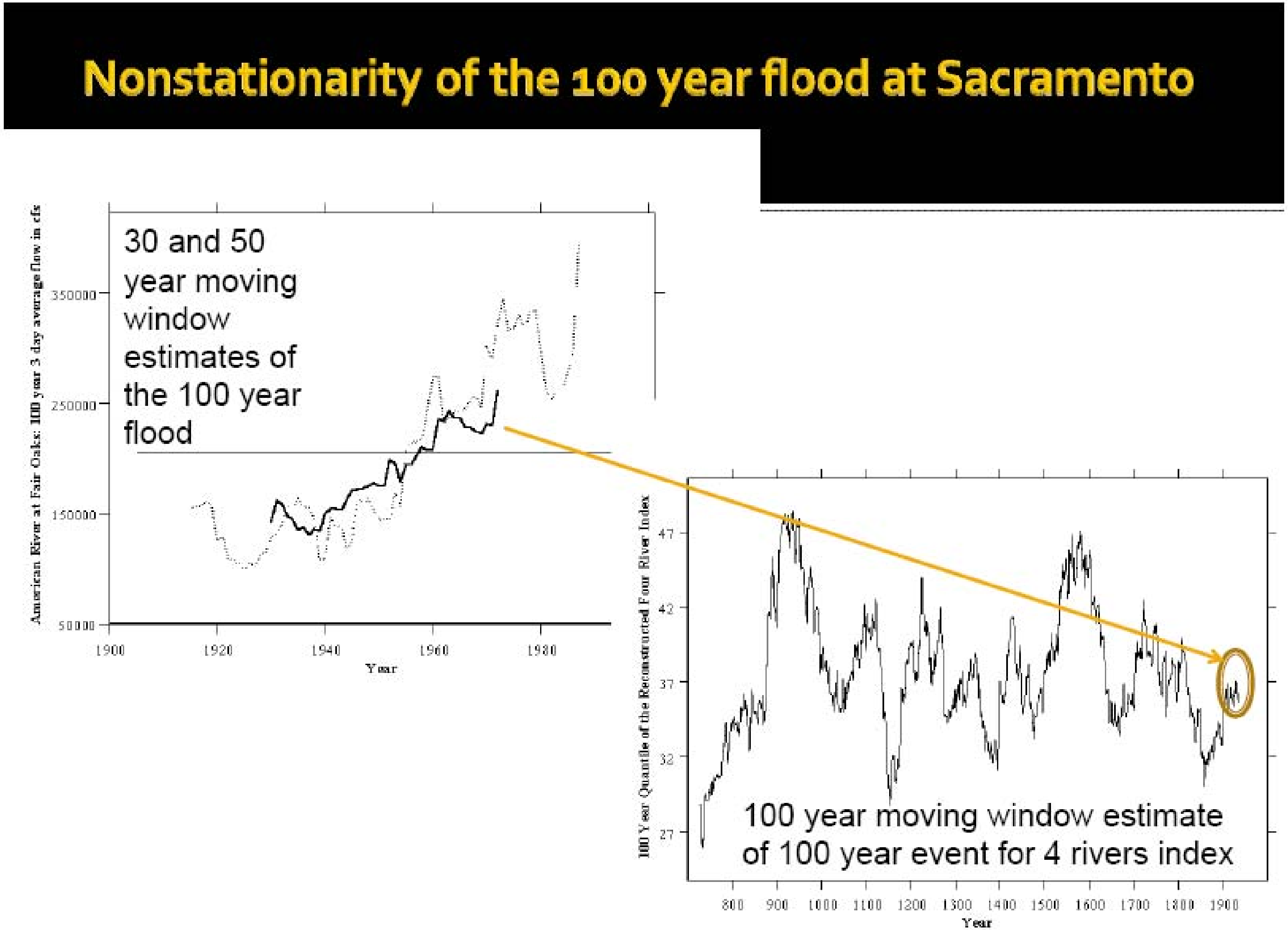
Hydro-Dendro-Climatology

What is the 100 year flood on the American River, at Sacramento, CA?



Projected Single event damage from overtopping >$40 billion - SAFCA,2000

Hindcasting the Flood Record with “Voodoo” Statistical Analysis

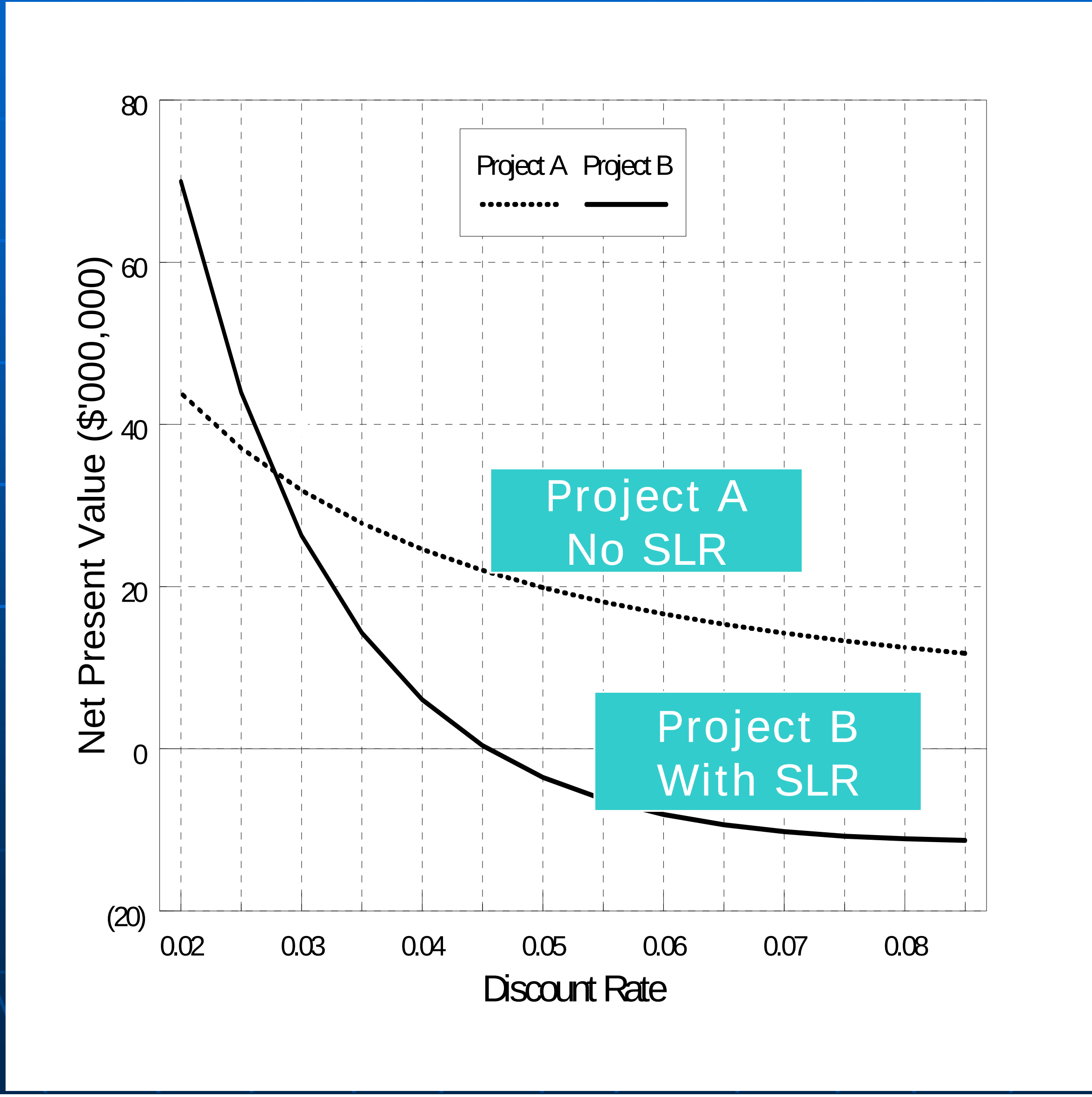


The ‘Double Discount’ Dilemma of Water Project Justification

In the classical expected-value approach, extreme events with low probability of occurrence are given the same proportional weight/importance (in the multiobjective commensuration process) regardless of their potential catastrophic or irreversible impact.

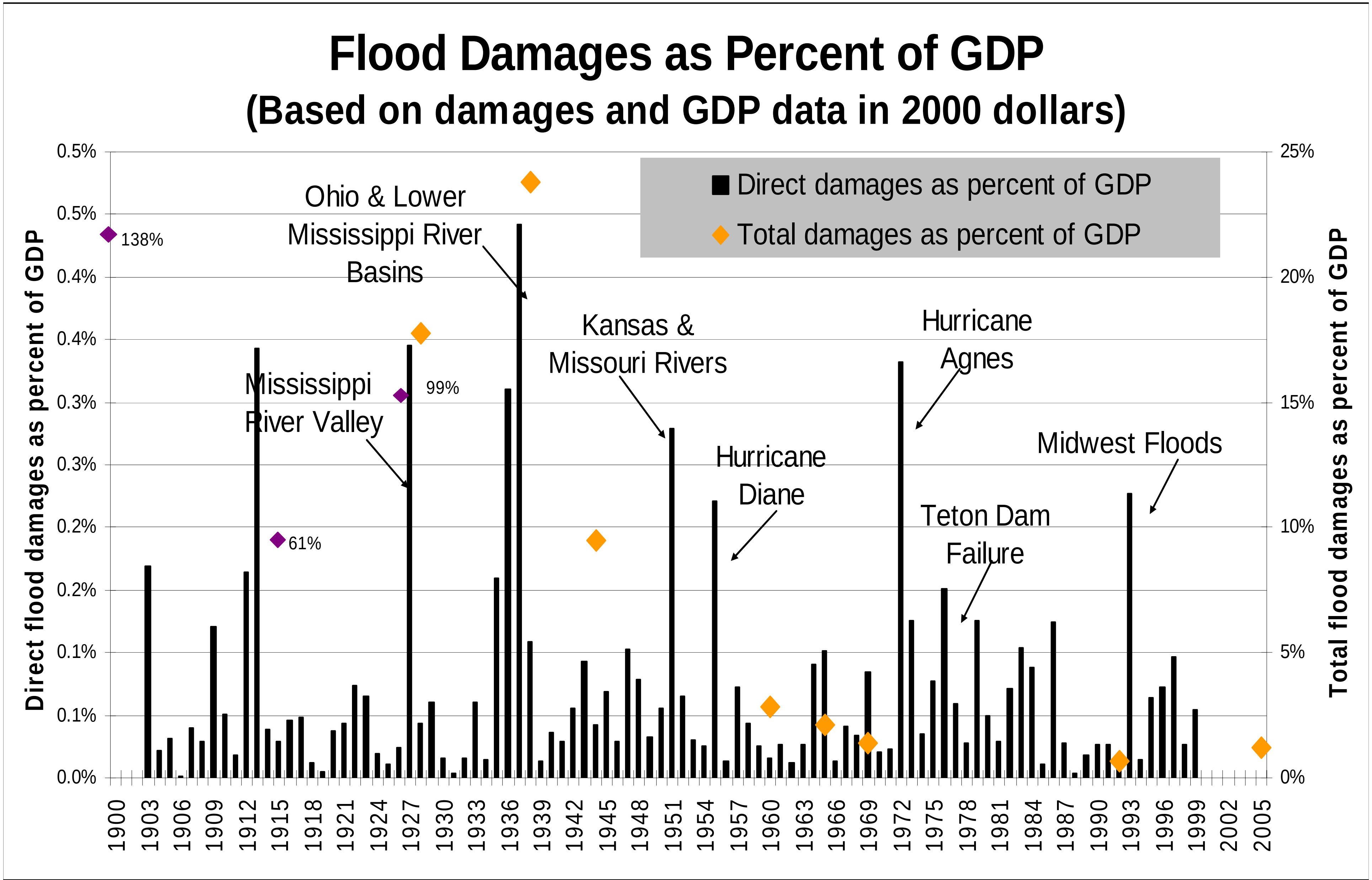
- Discounting for the **present value** of future benefits (r= discount rate of 2, 5, 7, 10 %)
- Discounting of low probability, high consequence events using flood/drought frequency analysis for **‘expected annual damages’**

Effect of Discount Rate on Choice of Option for Protection against Sea Level Rise



Most Damaging Hurricanes

	Year	Cat	Damages
Katrina (FL, LA, MS)	2005	3+	$ 100.0 B +
Andrew (FL, LA)	1992	5	43.6 B
Charley (FL)	2004	4	15.0 B
Ivan (AL, FL)	2004	3	14.2 B
Hugo (SC)	1989	4	12.2 B
Agnes (FL, GA, SC, PA)	1972	2	11.3 B
Betsy (FL, LA)	1965	3	10.8 B
Frances (FL)	2004	2	8.9 B
Camille (MS, LA, VA)	1969	5	8.9 B
Diane (East Coast)	1955	1	6.9 B
Jeanne (FL)	2004	3	6.9 B

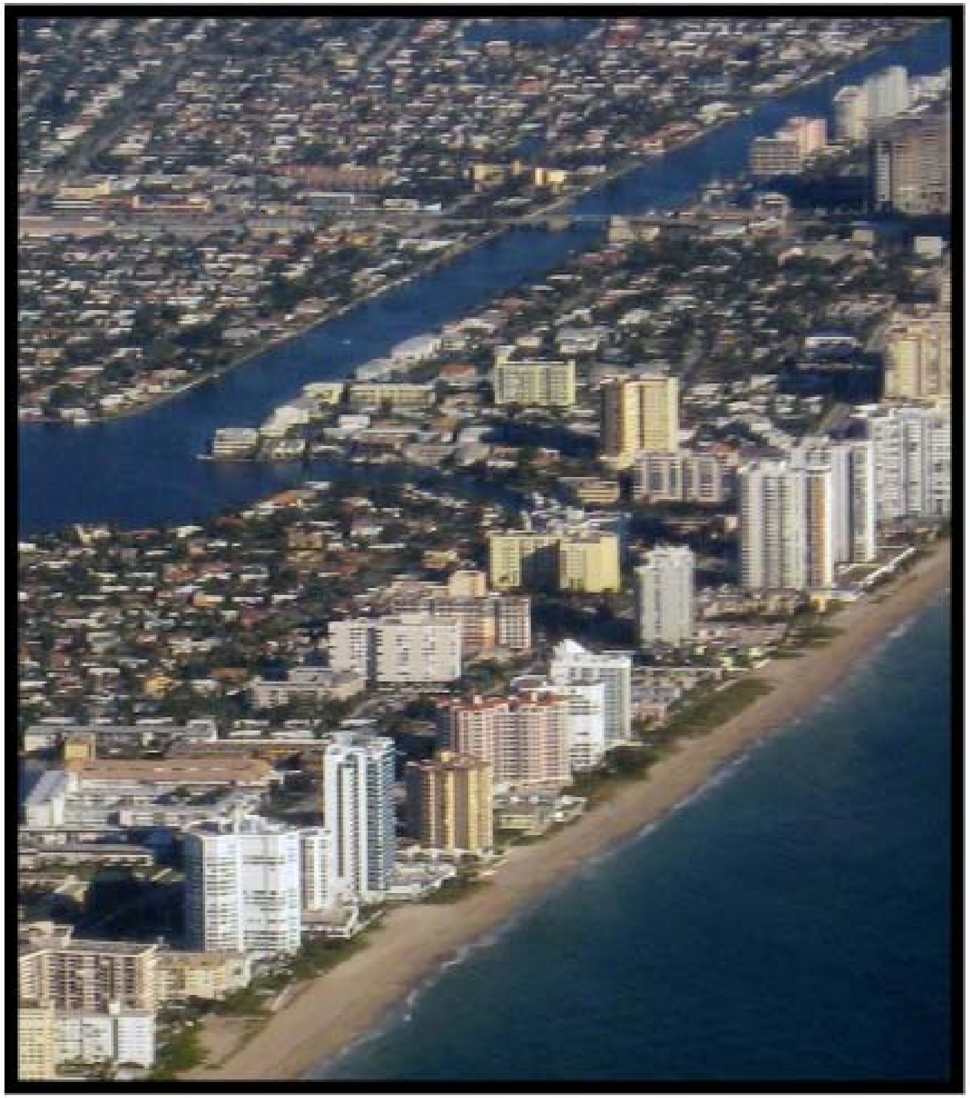

Flood Damages as Percent of GDP
(Based on damages and GDP data in 2000 dollars)
Direct damages as percent of GDP
Total damages as percent of GDP
Direct flood damages as percent of GDP
Total flood damages as percent of GDP
138%
99%
61%
Ohio & Lower Mississippi River Basins
Mississippi River Valley
Kansas & Missouri Rivers
Hurricane Diane
Hurricane Agnes
Teton Dam Failure
Midwest Floods
0.0%
0.1%
0.1%
0.2%
0.2%
0.3%
0.3%
0.4%
0.4%
0.5%
0.5%
0%
5%
10%
15%
20%
25%
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005

USA: Coastal Development

Miami Beach 1926

Wendler Collection

Miami Beach 2006



Joel Gratz © 2006

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

We're in a Transitional Period of Many Climate Uncertainties and Unknowns

Basic Messages:

- All drivers of hydrological cycle are affected by climate variability (CV) & global warming – climate change (CC)
- Water sector is the principal medium through which most people will experience CC
- Many tools, water resources management coping options designed for Climate Variability (CV), form the foundations for CC adaptation
- Socioeconomic factors, land uses, conflicts and population dynamics will dominate future conditions & and modes of adaptation - rather than CC
- Therefore, CC adaptation must be cast within a broader **IWRM framework**, & not viewed as an independently pursued analytical paradigm focusing only on CC
- Improving water governance and management is key to CC adaptation, more so than GCM modelling

Transitional period (Cont'd)

- **Keystone for adaptation** and adaptive management is a greatly expanded and improved hydromet system for monitoring, modeling and forecasting
- **Integrated Flood Management (IFM) and Integrated Drought Mgmt (IDM) are the 'leading edge'** and core of any climate adaptation strategy for the water sector, and will depend on short-term forecasting capabilities
- Climate information, GCMs and prediction services need to be **dramatically improved** before they are of value to water managers
- Huge upfront investments to avoid highly uncertain and largely unknown CC risks are problematic at this time – but there are sensible methods to accommodate most of these issues in a well-organized **risk management framework**