The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

SEI STOCKHOLM ENVIRONMENT INSTITUTE

SIGILLUM UNIVERSITATIS TUFTENSIS 1852 PAX ET LUX

Integrating Water Supply And Ecological Flow Requirements

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Collaborative Research:

Richard Vogel – Tufts University
Stacey Archfield – Tufts University
Mark Smith – The Nature Conservancy
Colin Apse – The Nature Conservancy
Jack Sieber – The Stockholm Environment Institute
Brian Joyce – The Stockholm Environment Institute

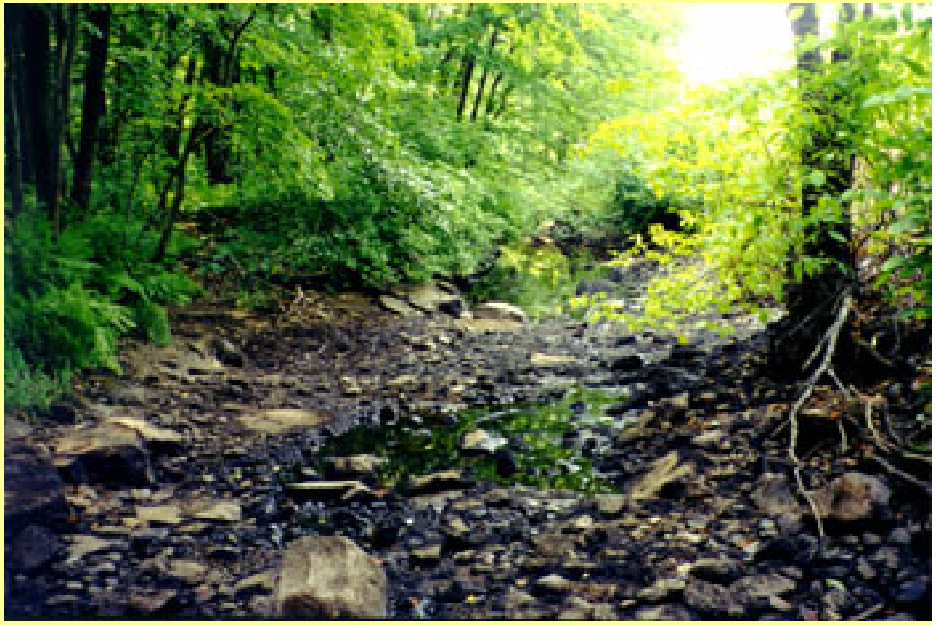
Outline of Talk

- ☞Historical Perspective on the Problem of Ecological Flow Protection
- ☞Introduction to the Ecodeficit
- ☞Optimal Balance of Water For Humans and Ecosystems
- ☞Relationships Between Reservoir Storage, Yield and Instream Flow

Low Flow Conditions in Water Rich Massachusetts

Tufts University

Fish Brook, Boxford



Sudbury River, Hopkinton

Photos from MA Riverways Program website

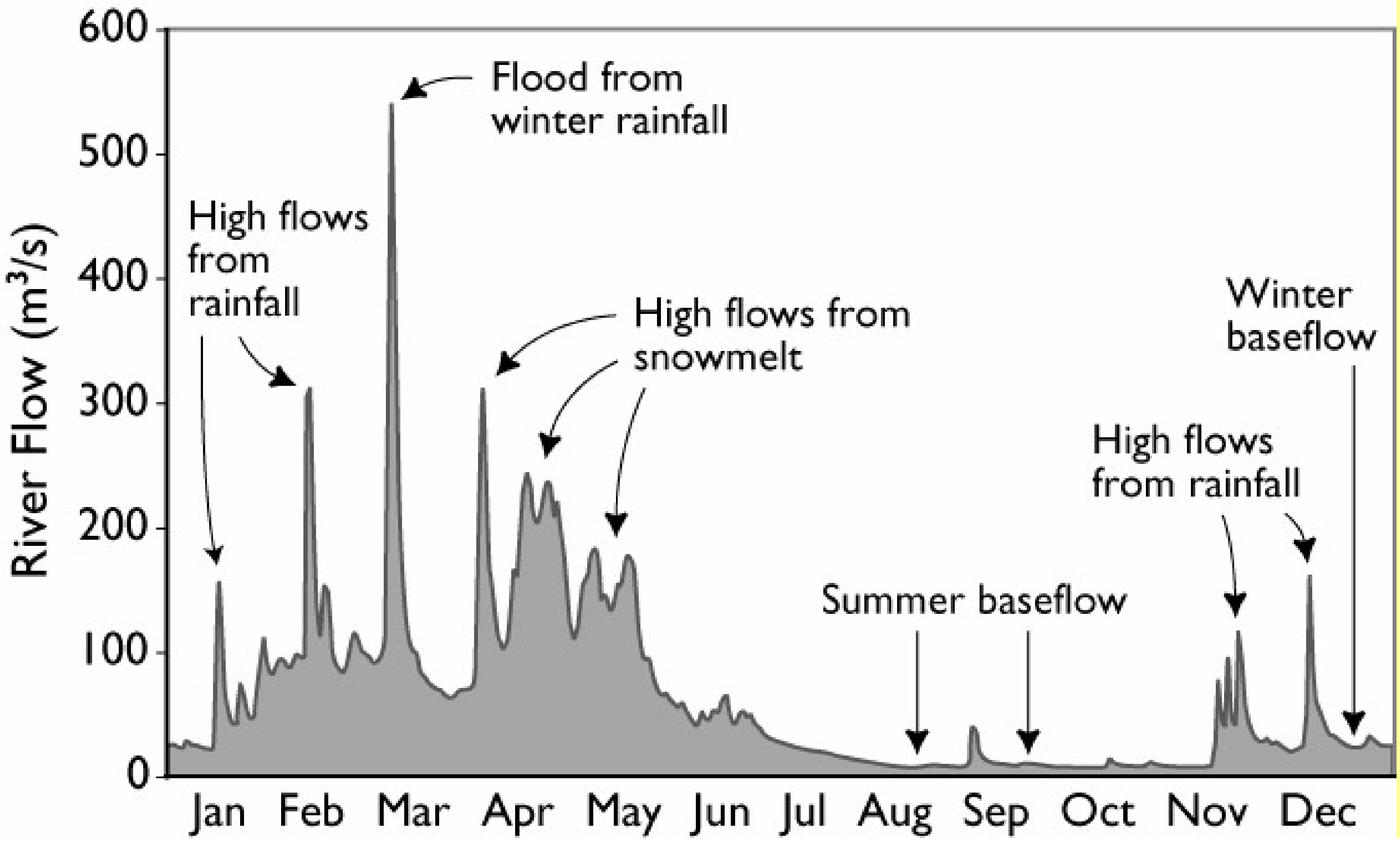
Low Flows In Rivers Due to Human and Natural Causes Lead to Water Supply Deficits

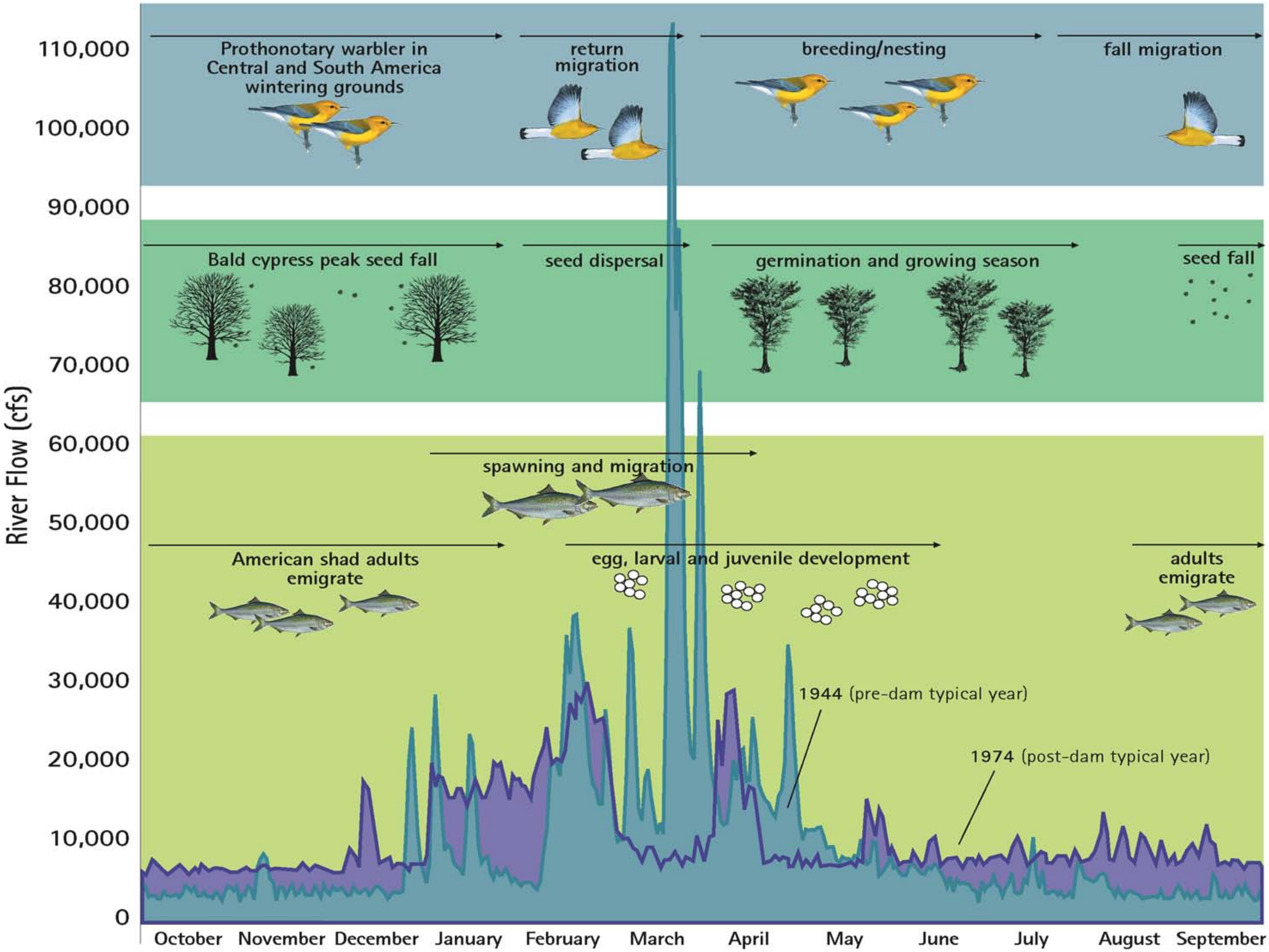
Tufts University

Middleton Pond,
Massachusetts

Wenham Lake
Massachusetts

Ecosystem Depends Upon Natural Variability

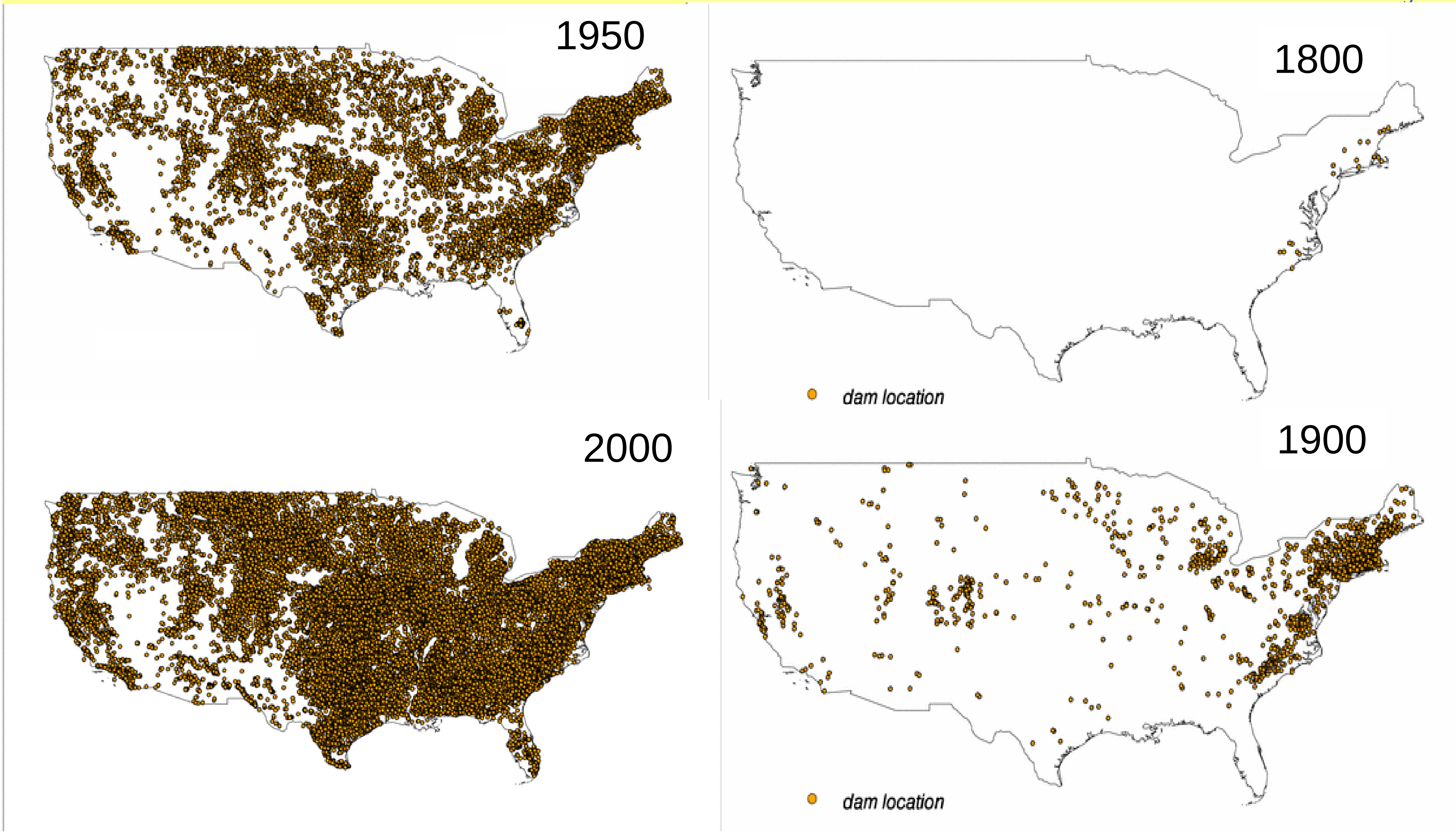




110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
River Flow (cfs)
Prothonotary warbler in Central and South America wintering grounds
return migration
breeding/nesting
fall migration
Bald cypress peak seed fall
seed dispersal
germination and growing season
seed fall
spawning and migration
American shad adults emigrate
egg, larval and juvenile development
adults emigrate
1944 (pre-dam typical year)
1974 (post-dam typical year)
October
November
December
January
February
March
April
May
June
July
August
September

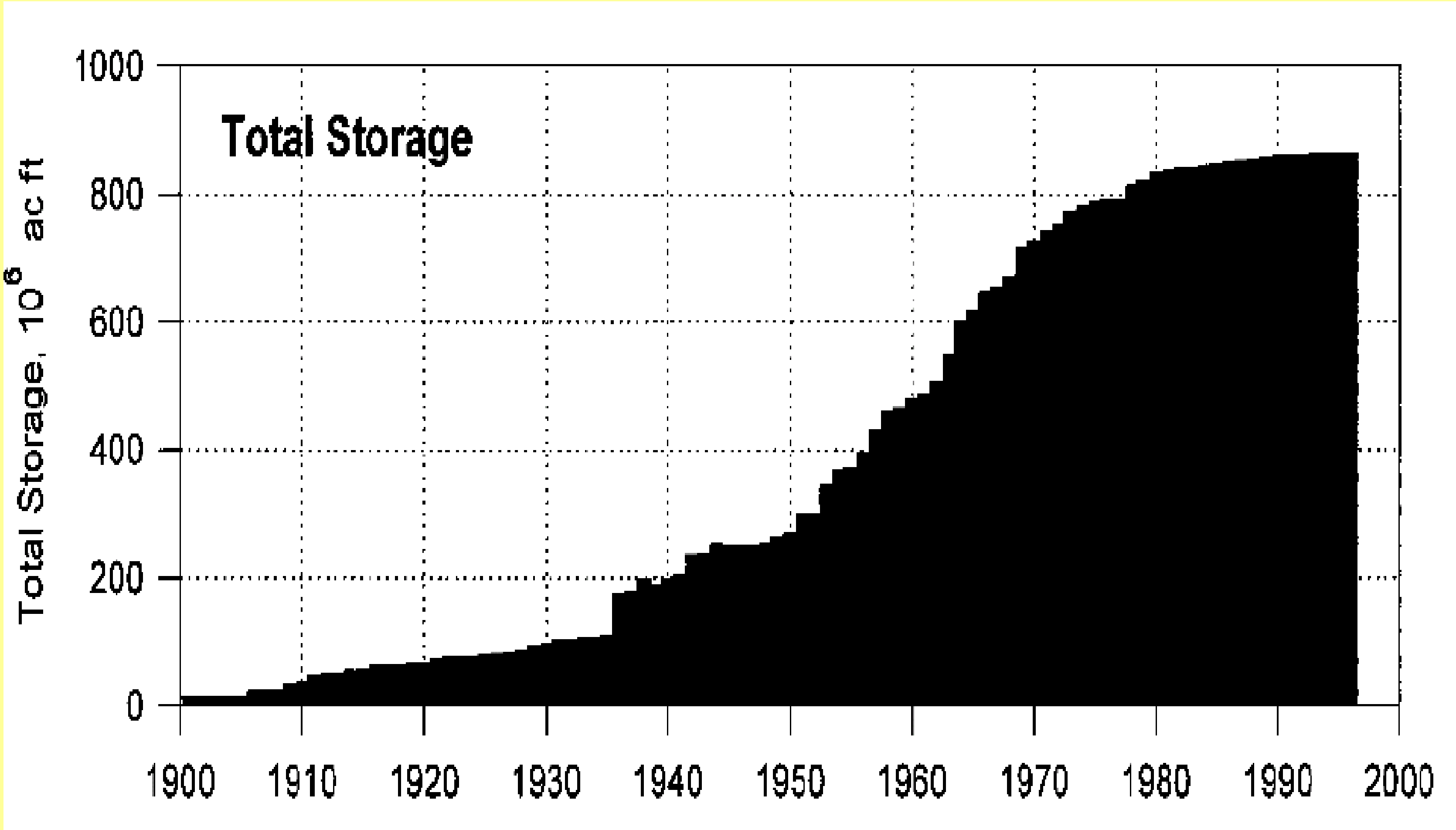
There are now over 75,000 dams Occurring on average every 70km On over 5.2 million km of river miles

Tufts University

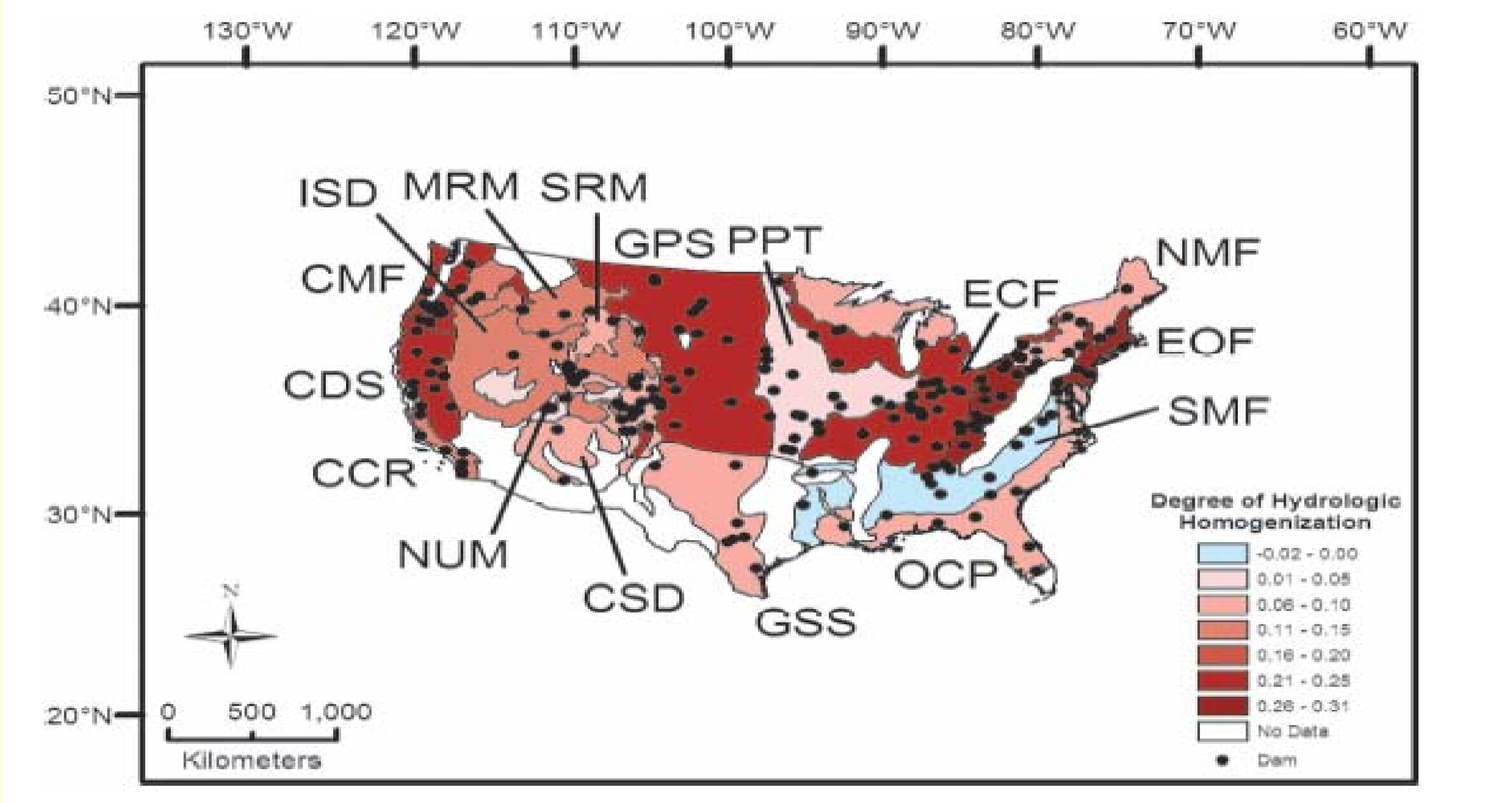


History of increasing total reservoir storage for the continental U.S.

(from U.S. Army Corps of Engineers, 1996)

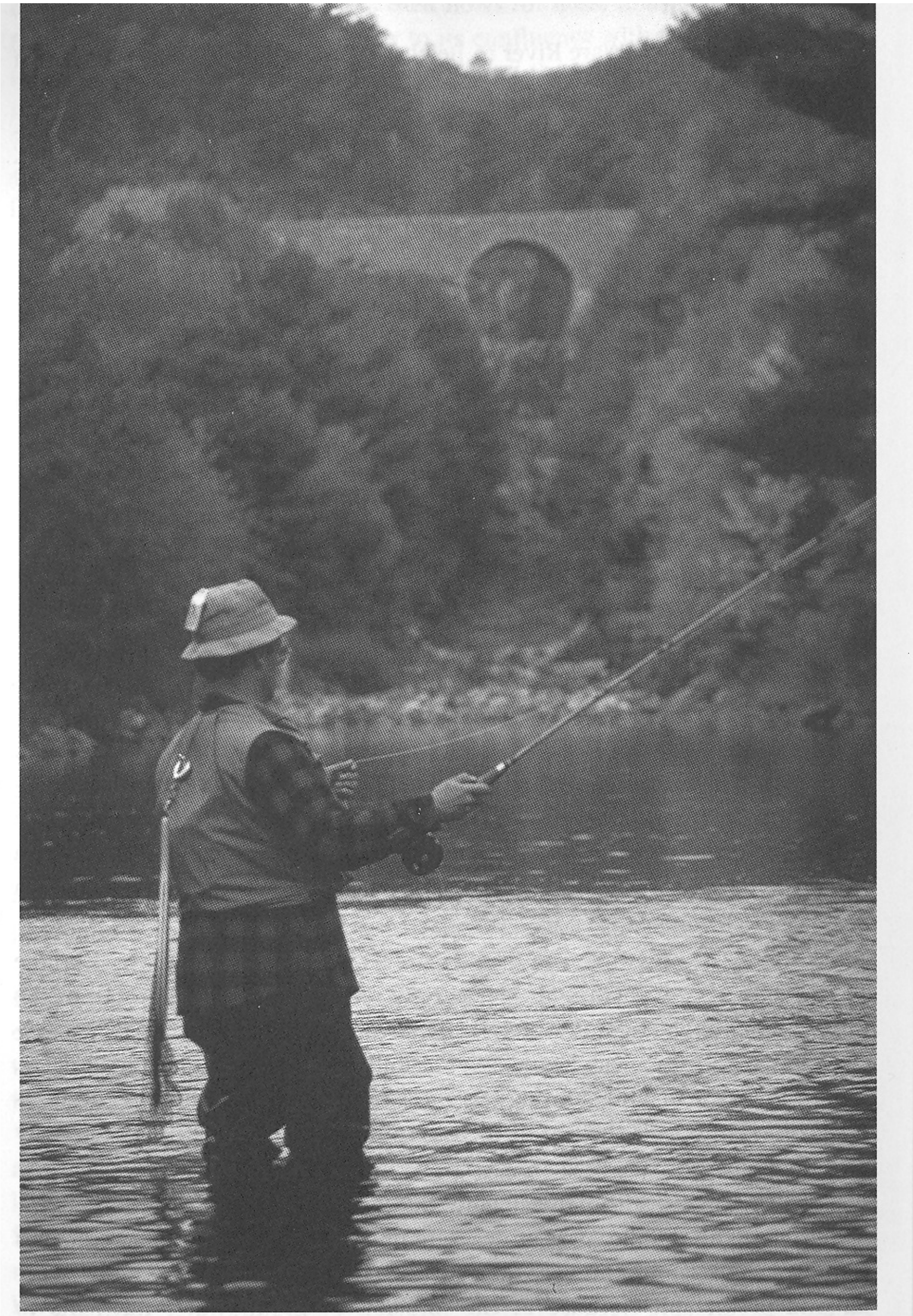


Dams 'flatten' the downstream flow regime



Shading denotes degree of homogenization in flow regimes due to dams

(from Poff et al. 2007, PNAS)



Its Not So Simple!

The Quabbin Reservoir Tailwater Region, Just Below the Spillway Attracts Fly Fisherman from All over the Region!

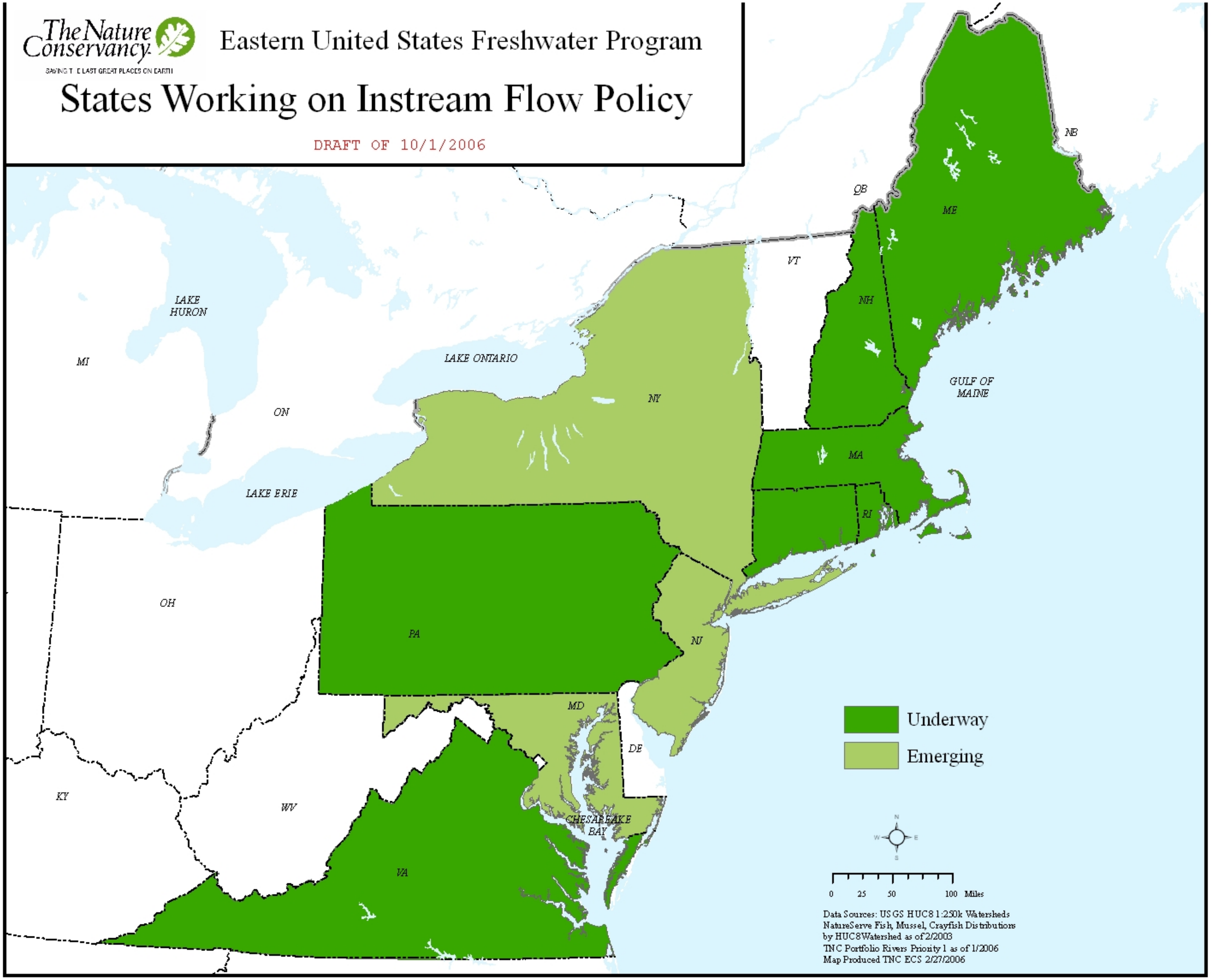
Dams Provide Many Benefits Including:

- Water Supply
- Hydropower
- Irrigation
- Recreation
- Cooling Water
- And …

Dams Also Provide Flood Protection

The Setting and Problem

- The need to balance human and ecological flows results from our historical lack of attention given to ecological flows (instream flow) in water resource management
- There are dozens of texts and tens of thousands of articles on the management of reservoirs for human needs
- Until very recently, they only assign a minimum flow requirement for instream flows



The Nature Conservancy
Eastern United States Freshwater Program
States Working on Instream Flow Policy
DRAFT OF 10/1/2006
LAKE HURON
MI
ON
LAKE ONTARIO
LAKE ERIE
OH
PA
NY
VT
NH
ME
QB
NB
MA
RI
NJ
MD
DE
CHESAPEAKE BAY
WV
KY
VA
GULF OF MAINE
Underway
Emerging
N
W
E
S
0
25
50
100
Miles
Data Sources: USGS HUC8 1:250k Watersheds
NatureServe Fish, Mussel, Crayfish Distributions
by HUC8Watershed as of 2/2003
TNC Portfolio Rivers Priority 1 as of 1/2006
Map Produced TNC ECS 2/27/2006

The Setting and Problem

There is a sizable literature addressing each of the following problems:

- ☞ Instream Flow Needs
- ☞ Optimal Reservoir Management (for human uses)
- ☞ Water Resource Policy and Negotiations

However, there is very little literature integrating these three areas.

The Setting and Problem

Tufts University

- What causes ecological flow stress?
  - ☞ Increased human withdrawals (ground and surface)
  - ☞ Natural climatic variability
  - ☞ Climatic change
  - ☞ Land use changes (impact water quality and flow regimes)

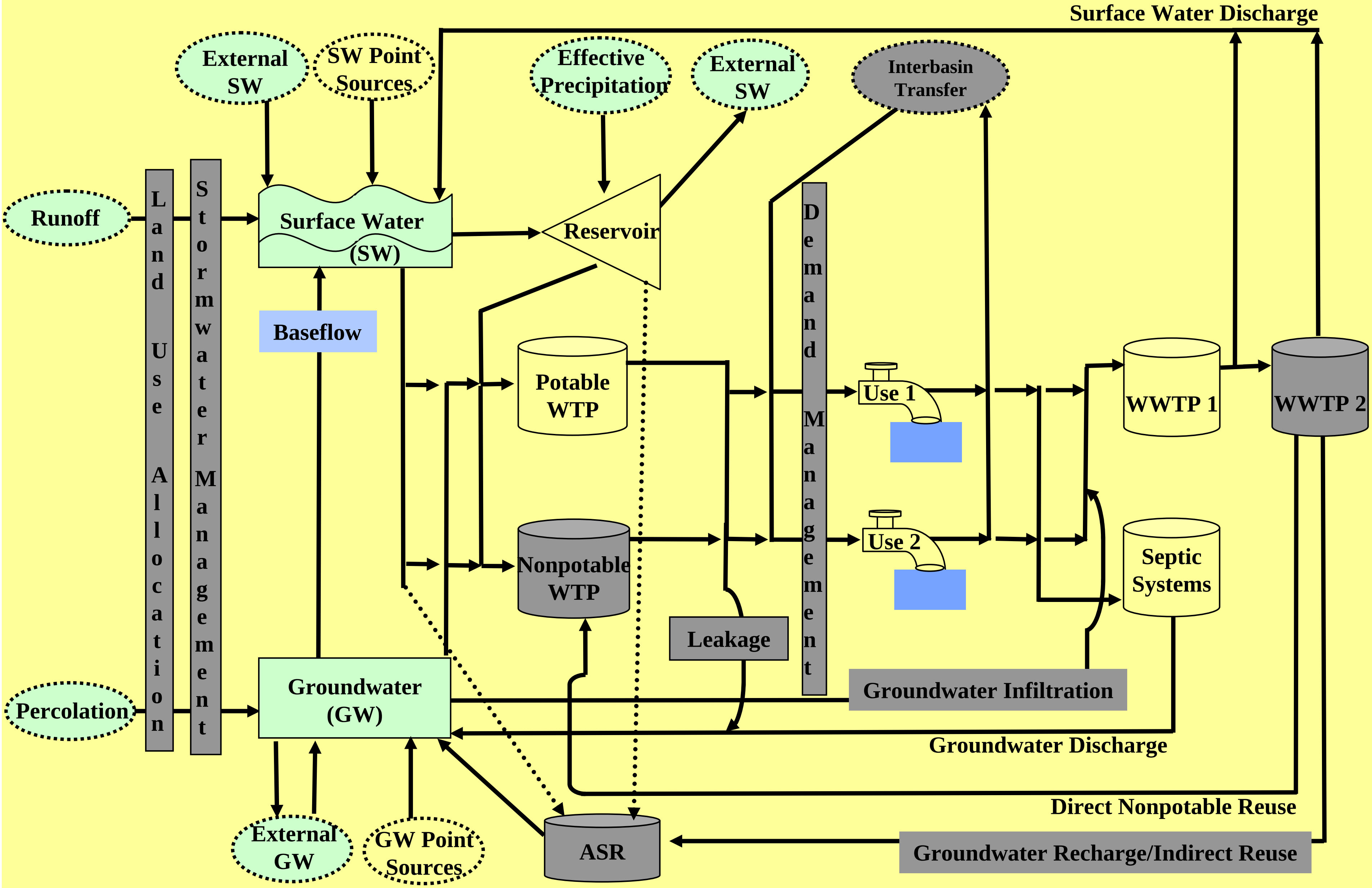
The Setting and Problem

- How do we reduce ecological flow stresses?
  - ☞ Decrease human withdrawals (demand management, reuse, leak detection, …)
  - ☞ Stormwater recharge/management
  - ☞ Land-use management
  - ☞ Groundwater banking
  - ☞ **Improve environmental releases**

(topic of this talk)

A Watershed Systems Optimization Model Could be Used

From Zoltay, Vogel and Kirshen (2007)



Watershed Systems Approach: Management Options

Tufts University

Table 6. Management Recommendations with Increasing Management Options.

Management Options	Units	Current Allocation	Optimal Allocation	Near Term Optimization	Long Term Optimization with WW Export	Long Term Optimization without WW Export
Consumer's Rate Change	%	NA	NA	**10% (Max)**	**50% (Max)**	**50% (Max)**
DWTP Infrastructure Repair	% of Leaks	NA	NA	**100%**	**100%**	**100%**
WWTP Infrastructure Repair	% of Infiltration	NA	NA	NA	0	**100%**
Stormwater BMPs	# units	NA	NA	0	0	0
Land Conservation	Ha	NA	NA	NA	0	0
Nonpotable Distribution System	% of Consumers	NA	NA	NA	0	0
Additional Surface Water Storage	MG	NA	NA	NA	0	0
Additional Capacity:						
Surface Water Pumping	MGD	NA	NA	NA	**5.4**	**5.4**
Groundwater Pumping	MGD	NA	NA	NA	0	0
Drinking Water Treatment	MGD	NA	NA	NA	0	0
Wastewater Treatment	MGD	NA	NA	NA	0	**1.6**
Aquifer Storage & Recovery	MGD	NA	NA	NA	0	0

Watershed Systems Approach
Ipswich River Example,
From Zoltay, Vogel and Kirshen (2007)

Table 8. Management Recommendations with Increasing Instream Flow Requirement.

Management Options	Units	¼ ISF	½ ISF	Full ISF
Consumer's Rate Change	%	**50%**	**50%**	**50%**
DWTP Infrastructure Repair	% of Leaks	**100%**	**100%**	**100%**
WWTP Infrastructure Repair	% of Infiltration	**100%**	**100%**	**100%**
Stormwater BMPs	# units	0	0	**120**
Land Conservation	ha	0	0	0
Nonpotable Distribution System	% of Consumers	0	0	0
Additional Surface Water Storage	MG	0	0	0
Additional Capacity:				
Surface Water Pumping	MGD	**5.4**	**5.4**	**5.0**
Groundwater Pumping	MGD	0	0	0
Drinking Water Treatment	MGD	0	0	0
Wastewater Treatment	MGD	**1.6**	**1.6**	**1.6**
Aquifer Storage & Recovery	MGD	0	0	**18**
Water Reuse Facility	MGD	0	0	0
Net Benefit		**$3,084,187**	**$3,066,407**	**($9,530,879)**

ISF=Instream Flow; the fraction of instream flow met in scenario

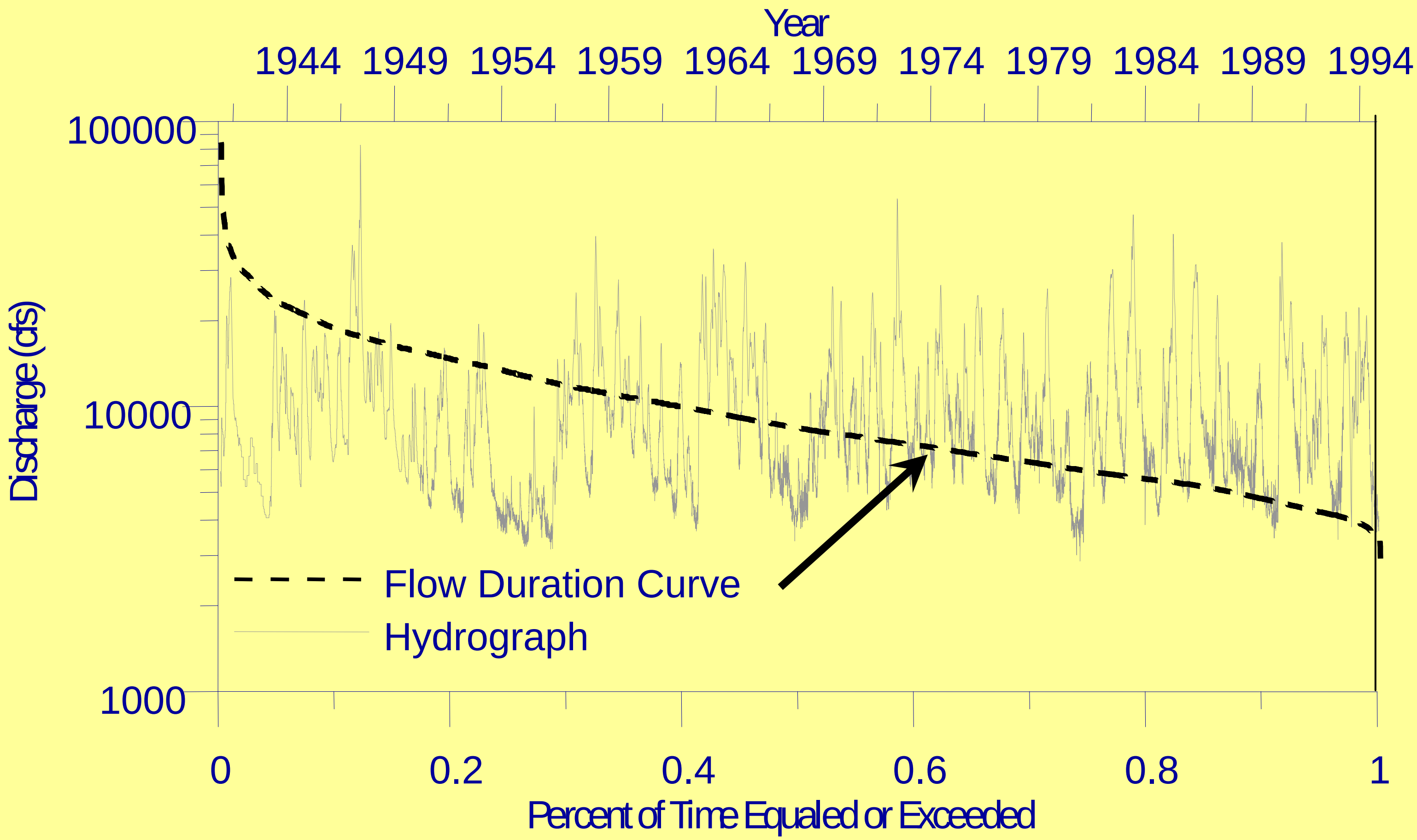
Historical Perspectives

- *When the systems were designed the question was:*
- How much water can we reliably withdraw from the river?

- *Today's question is:*
- How much water do we need to leave in the river?

Flow Duration Curves (FDC's) are Useful Tools for Ecological Flow Assessments

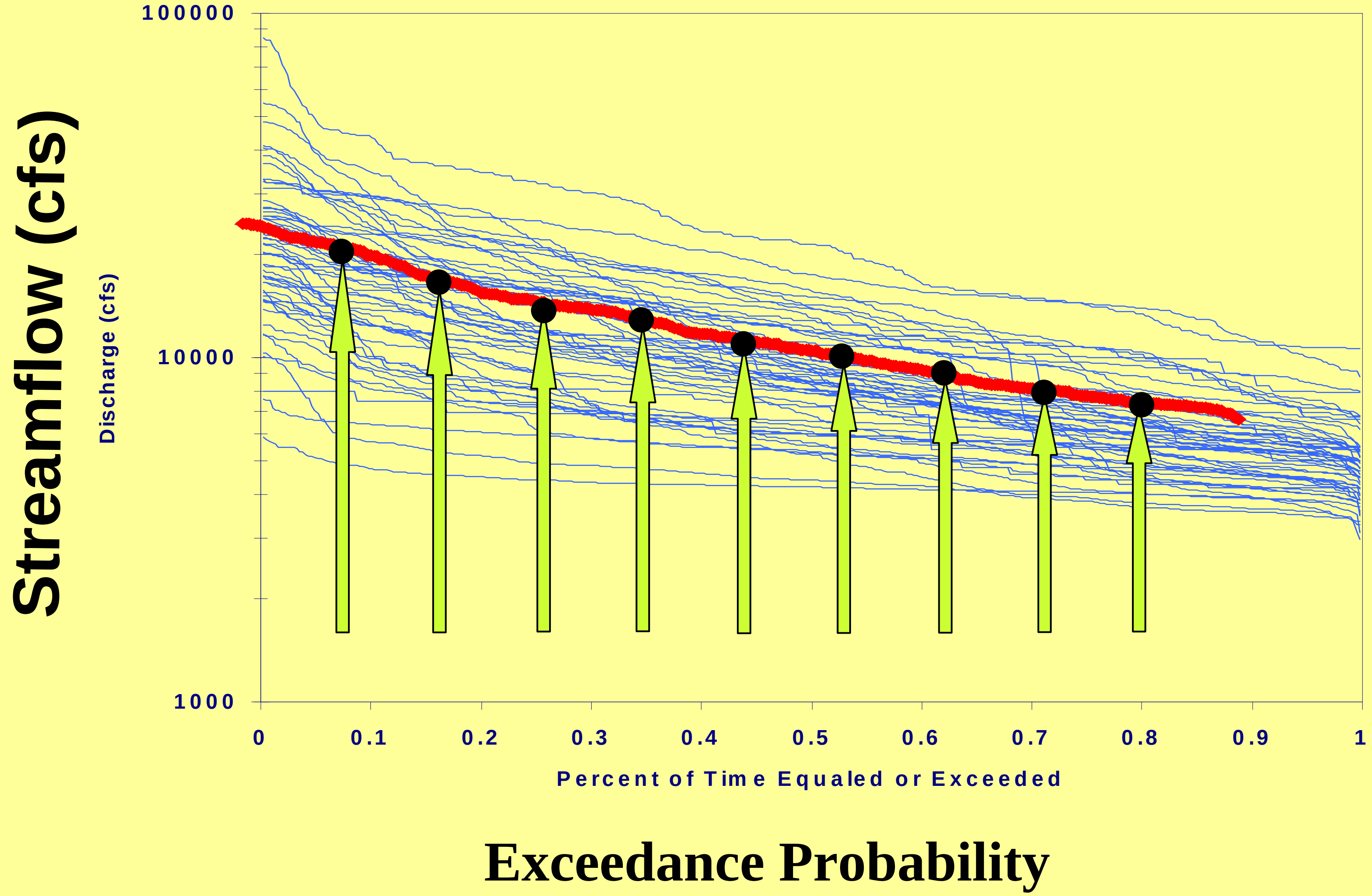
Tufts University



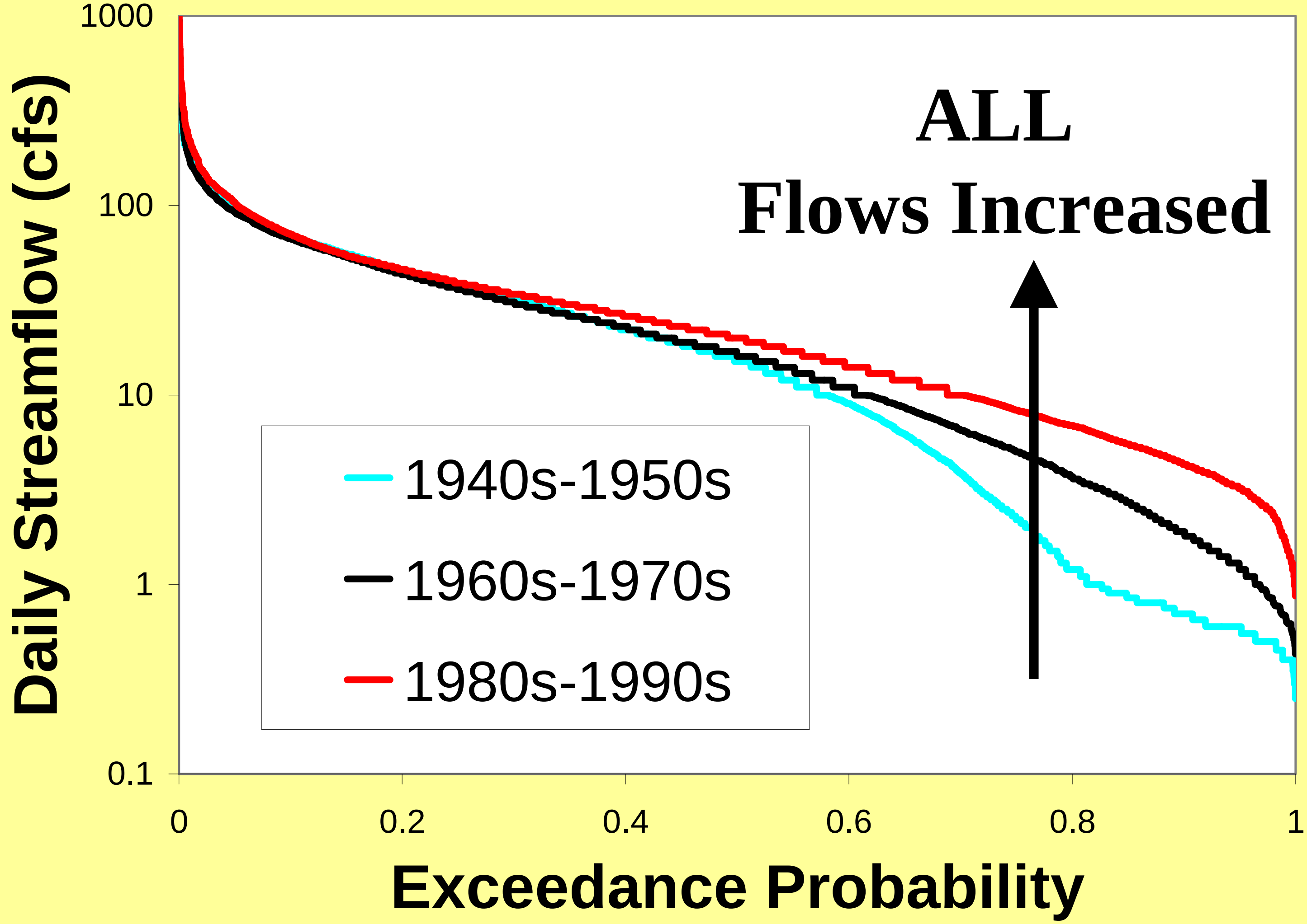
Suwannee River, Near Wilcox, FL

Annual FDC's and the Median Annual FDC

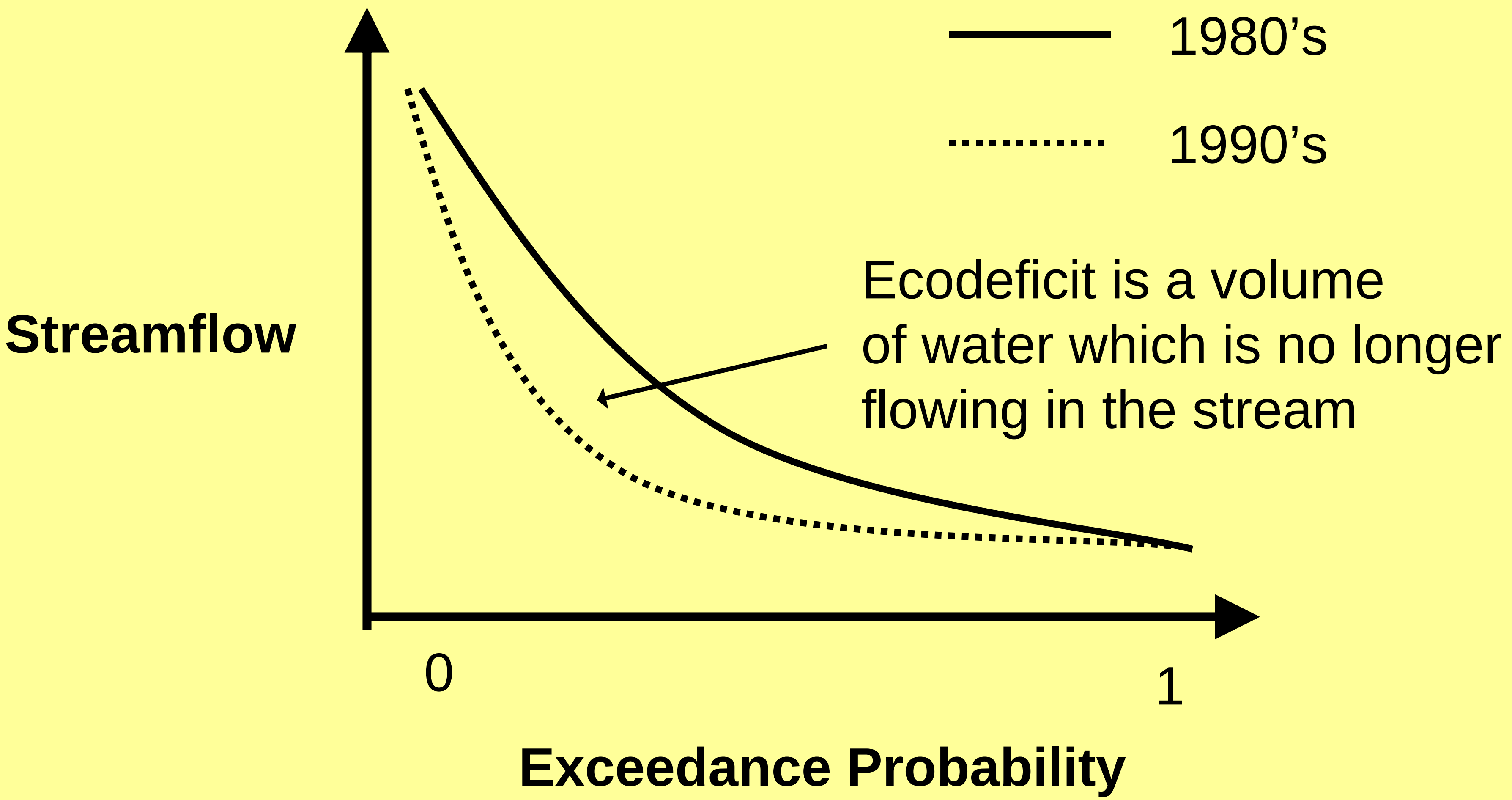
Tufts University



An Example of Use of FDC's for documenting hydrologic change – Aberjona River, MA



Definition of an Ecodeficit



Ecodeficit can be defined in terms of streamflow or habitat

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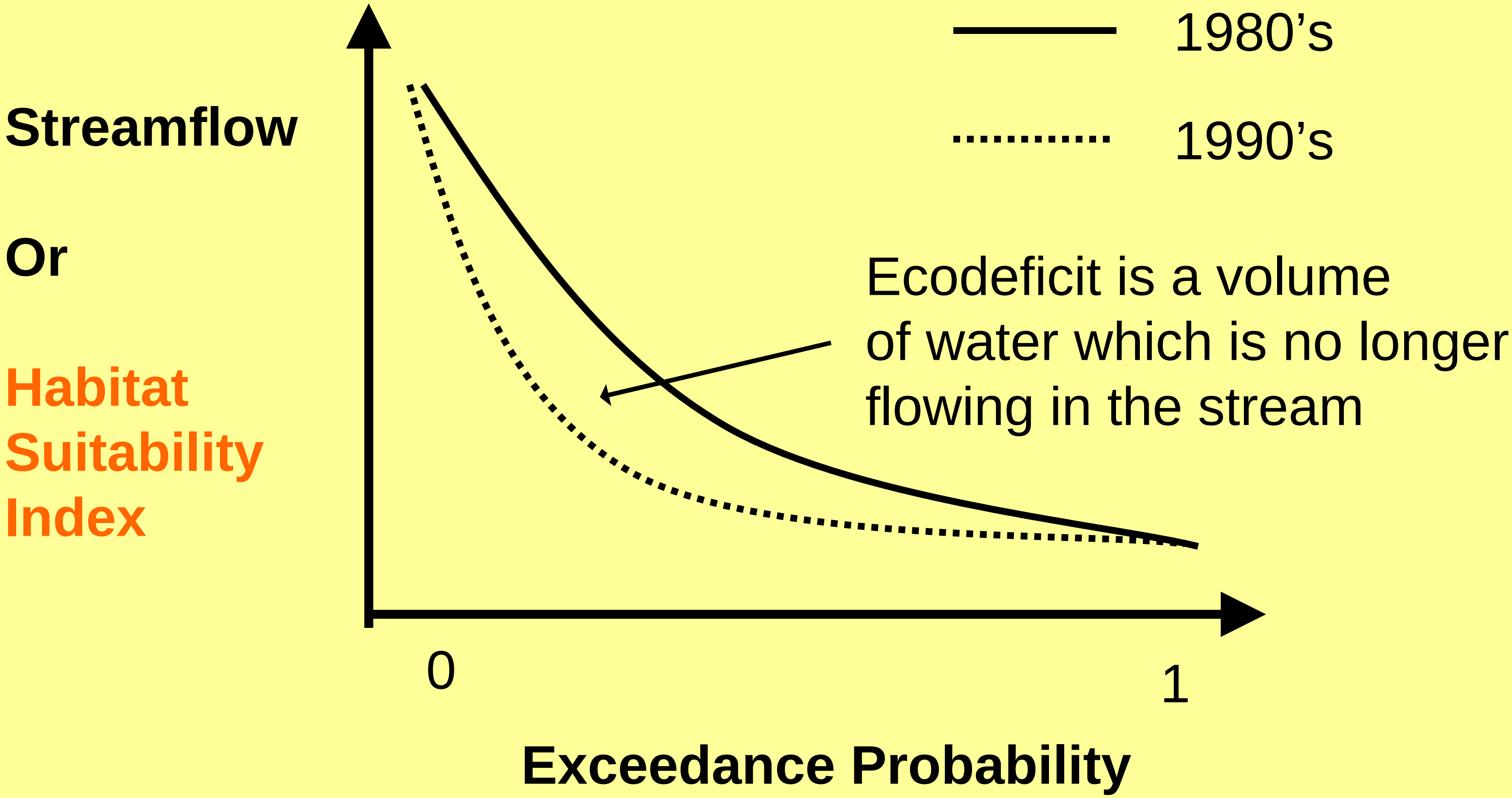
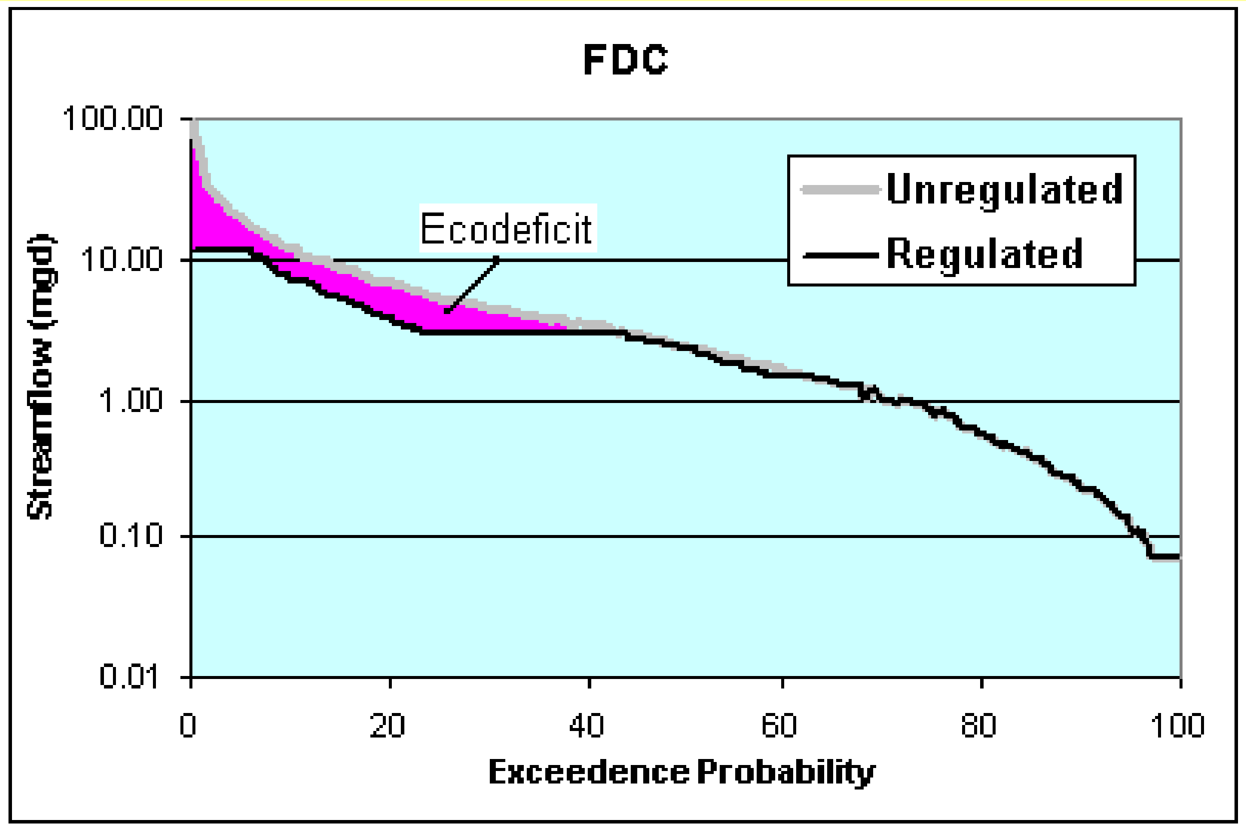


The Ecodeficit – An Example



Here ecodeficit represents reduction in streamflow after river is regulated by withdrawals from a reservoir.

An Ecodeficit and Ecosurplus are Both Possible

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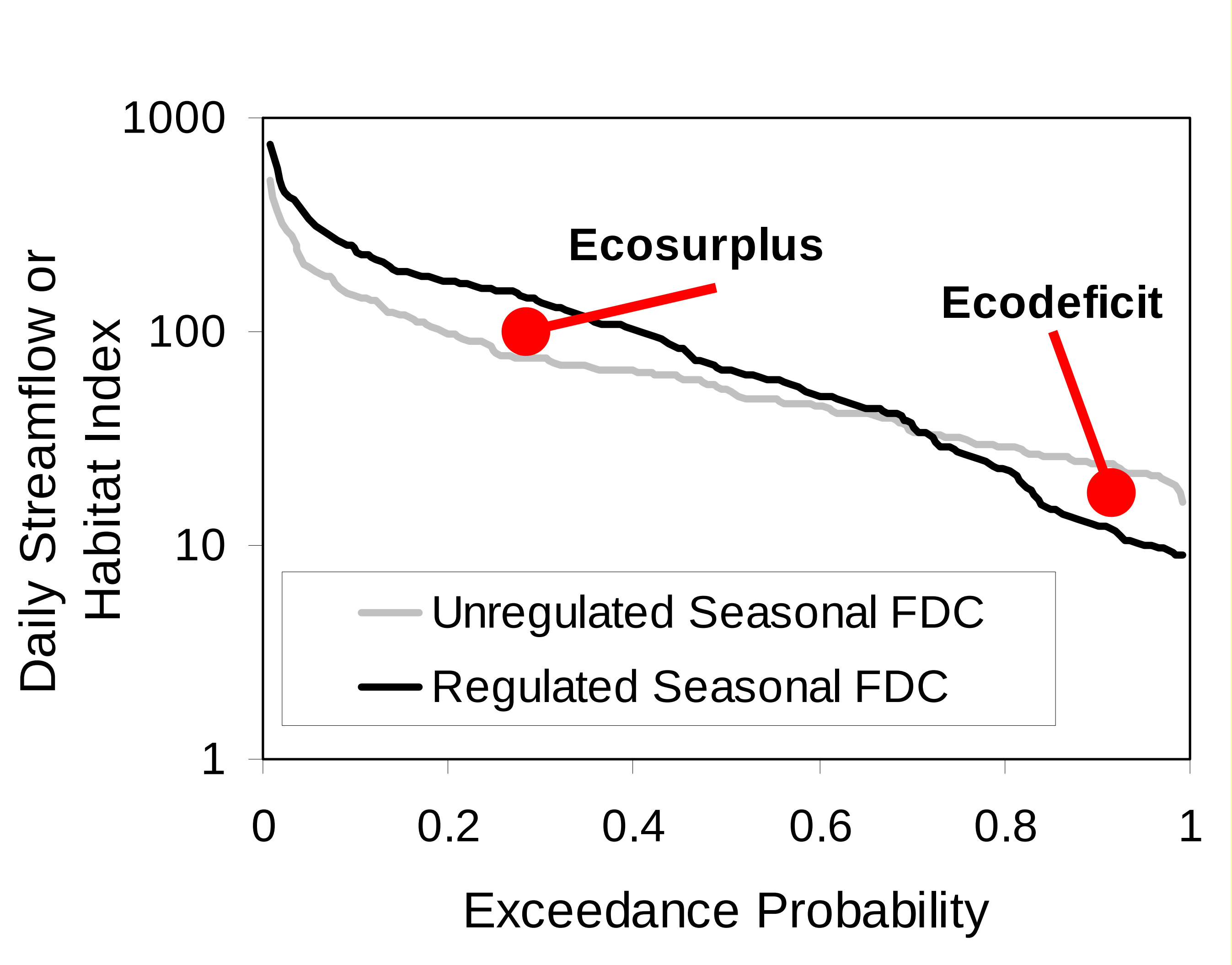

Advantages of Ecodeficit/Ecosurplus

Can handle changes in seasonal, annual and decadal flow regimes

Summarizes entire flow regime from droughts to floods

Provides both graphical and quantitative summary

FDC's are already widely used in hydrology and habitat assessment

FDC's can be defined in terms of flow or habitat

Confidence intervals are easily obtained, leading to hypothesis tests

Competition for Water

- When there's plenty of water, competition among flow needs is irrelevant
- Some standards exist for instream flow
  - Existing standards may not protect habitat
  - Existing standards are rarely adaptive
- Usually there are **NO** standards for water supply reliability

Tradeoff or Competition is a Multi-objective Optimization Problem

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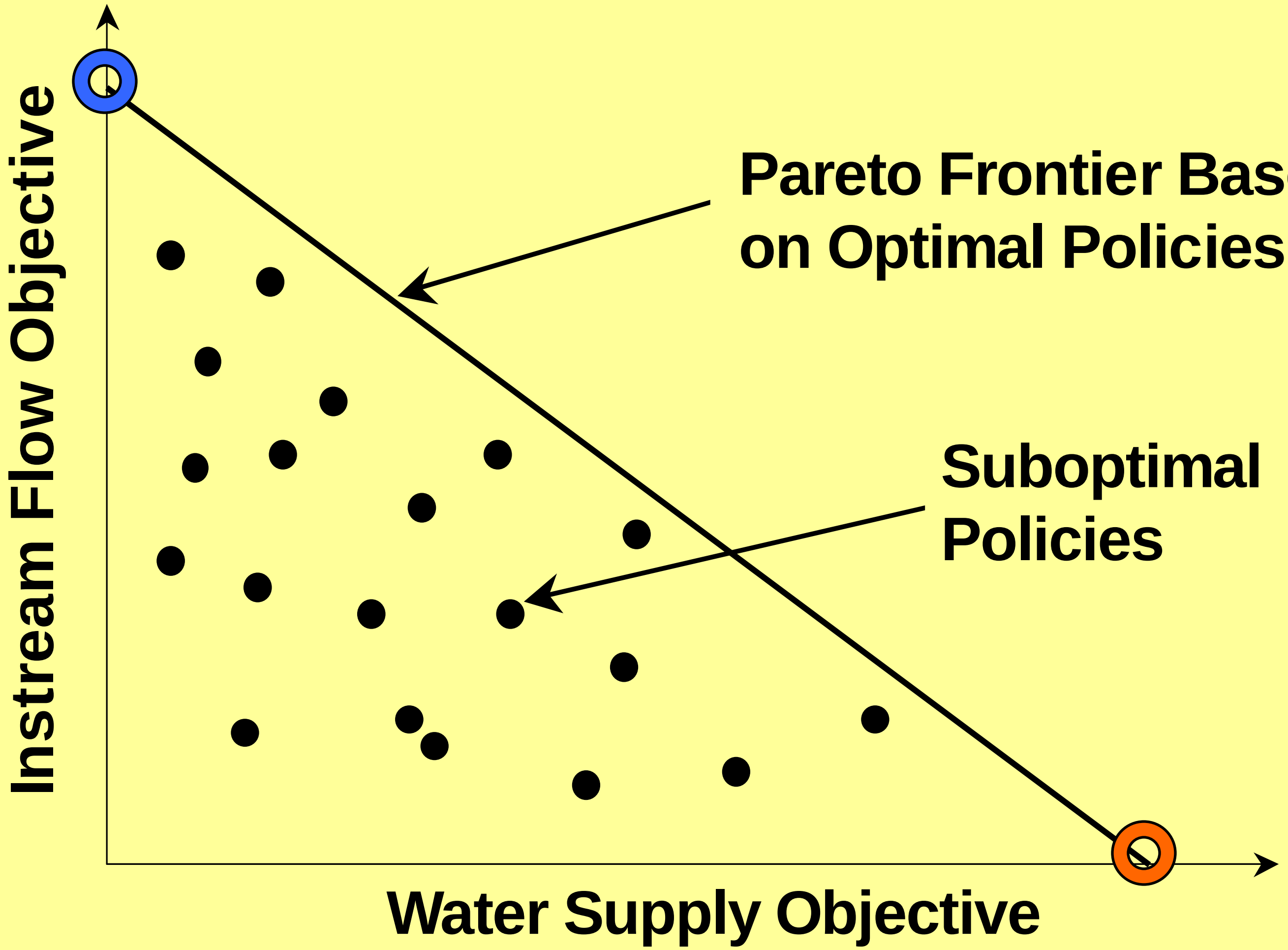
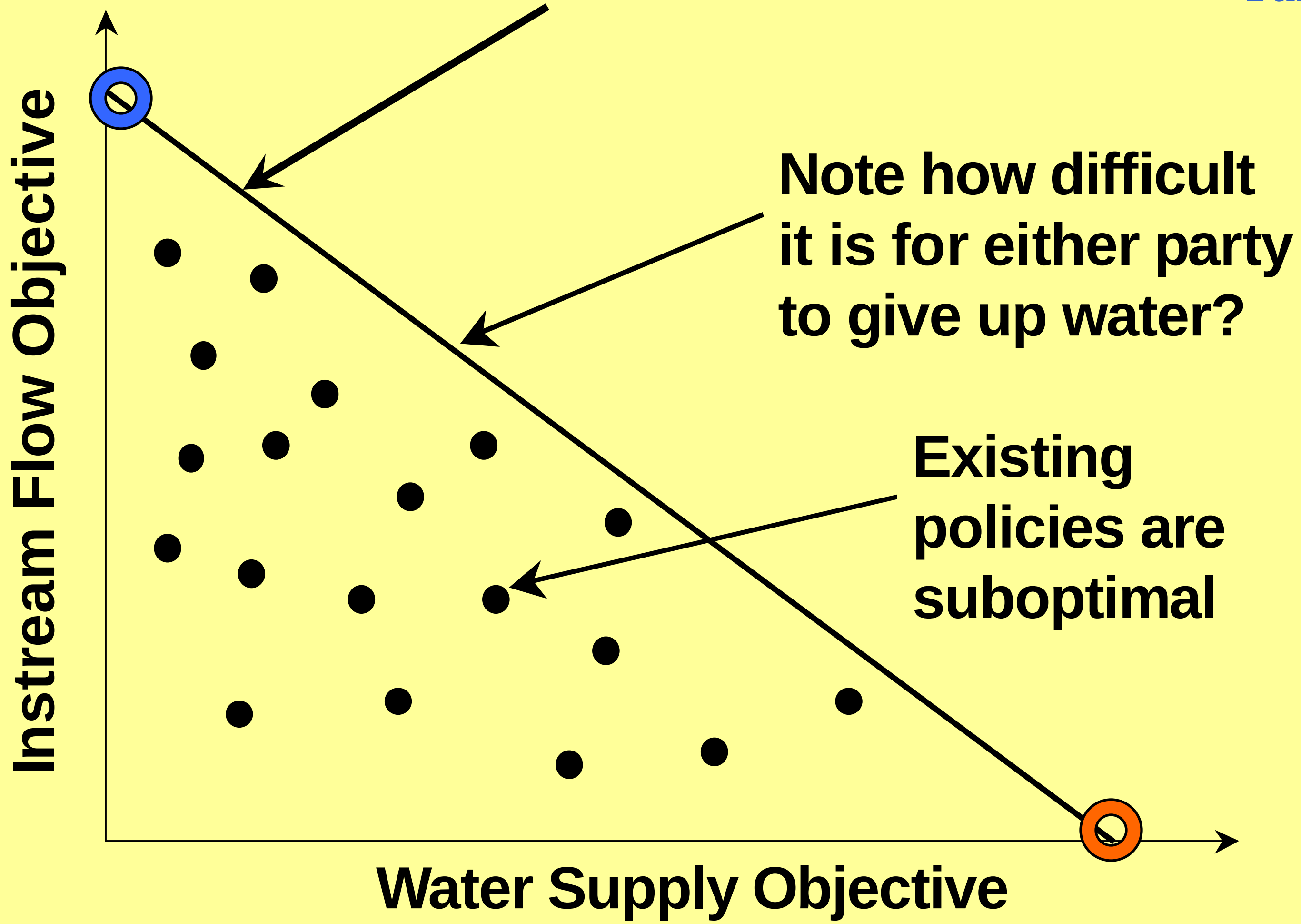
Tradeoff or Competition is a Multi-objective Optimization Problem

The biota now has a place at the negotiating "table"

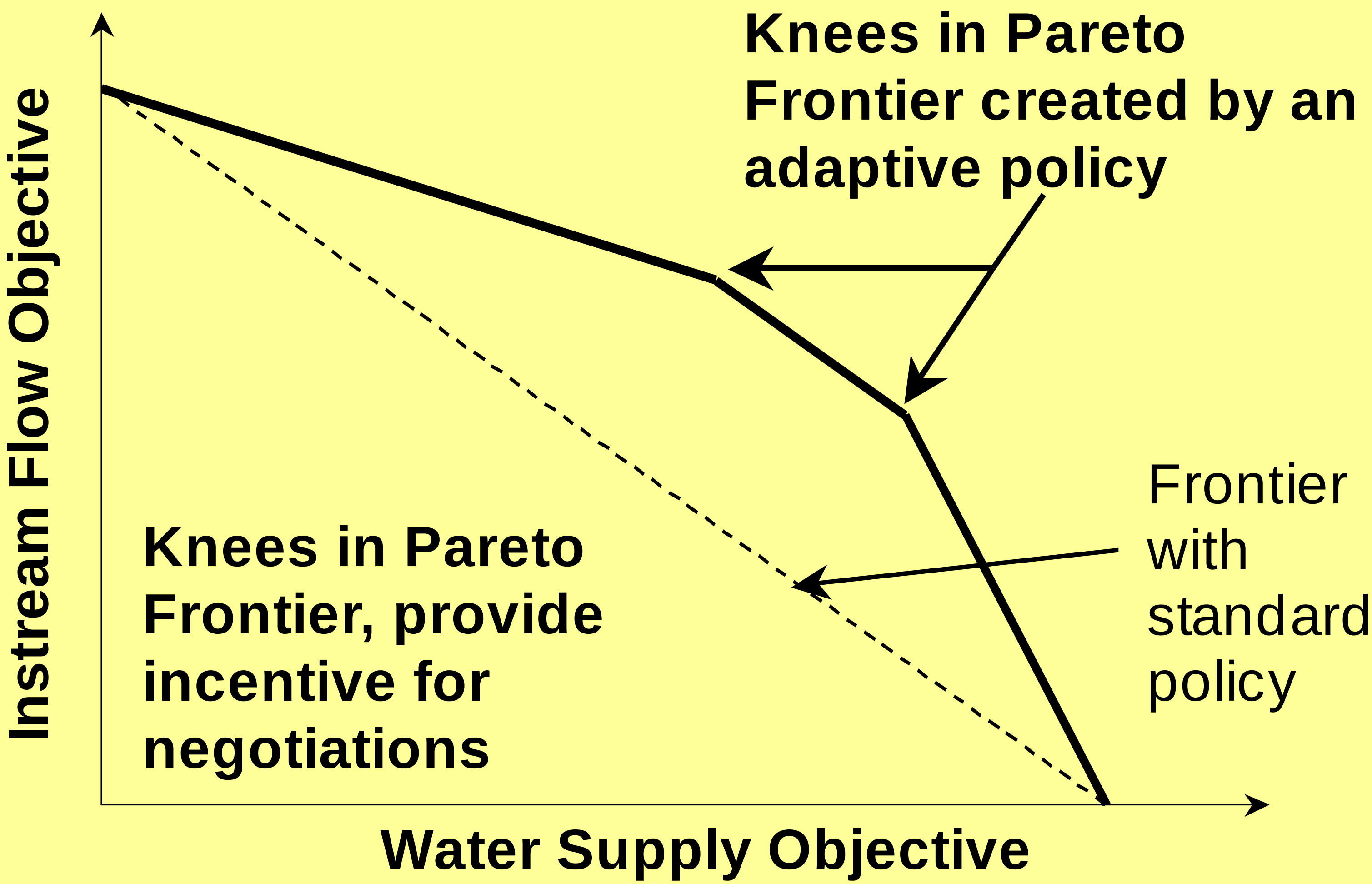
Tradeoff or Competition is a Multi-objective Optimization Problem



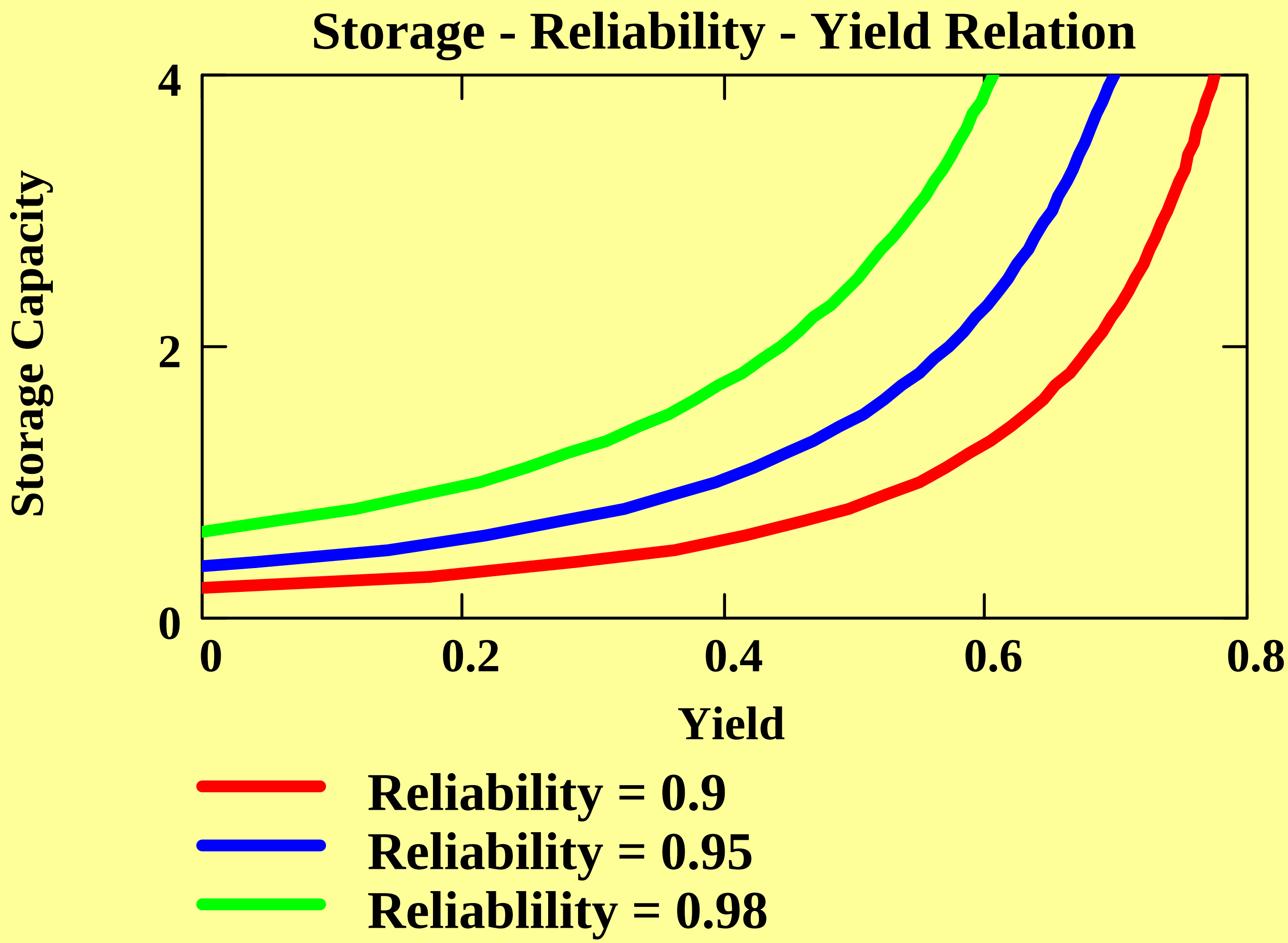
Most uniform instream flow policies lead to a zero-sum game



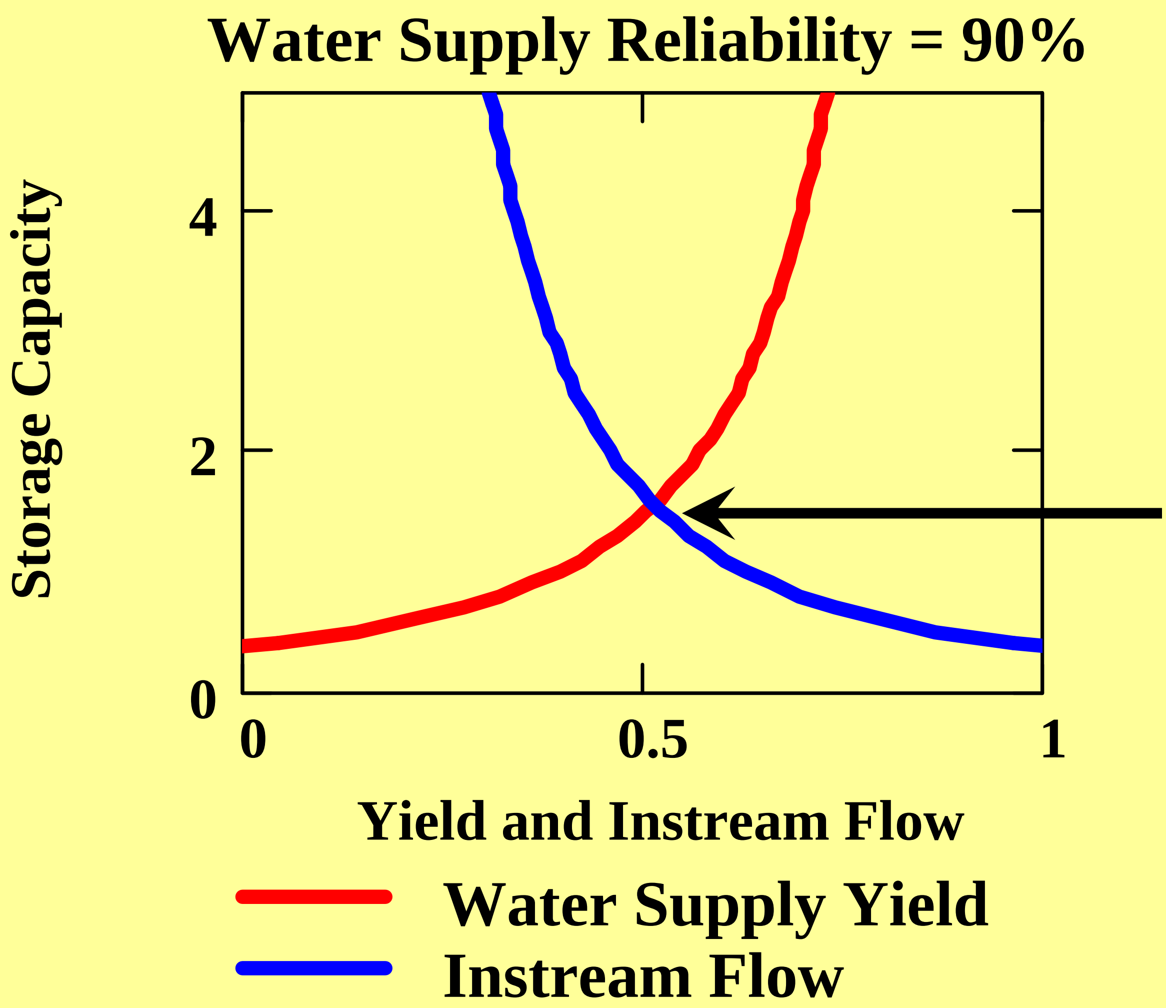
Research goal is to improve our ability to negotiate the Pareto Frontier



The Traditional Water Supply Storage – Reliability – Yield Relationship



Little Attention Is Given to Properties of Instream Flow



Large Storage favors water supply Yield

Smaller Storage favors instream flow

Exploring the Storage - Yield – Instream Flow Relationship

Goal

Examine the impact of a range of release polices on the reservoir storage capacity S, water supply yield Y, and instream flow I.

Experimental Design:

- Daily streamflows for Green river in Massachusetts (46 sq. mi)
- Storage ratios, S/μ range from 0-3, where
  - S=reservoir storage capacity
  - μ=mean annual inflow to reservoir

Typical Storage Ratios Across the United States

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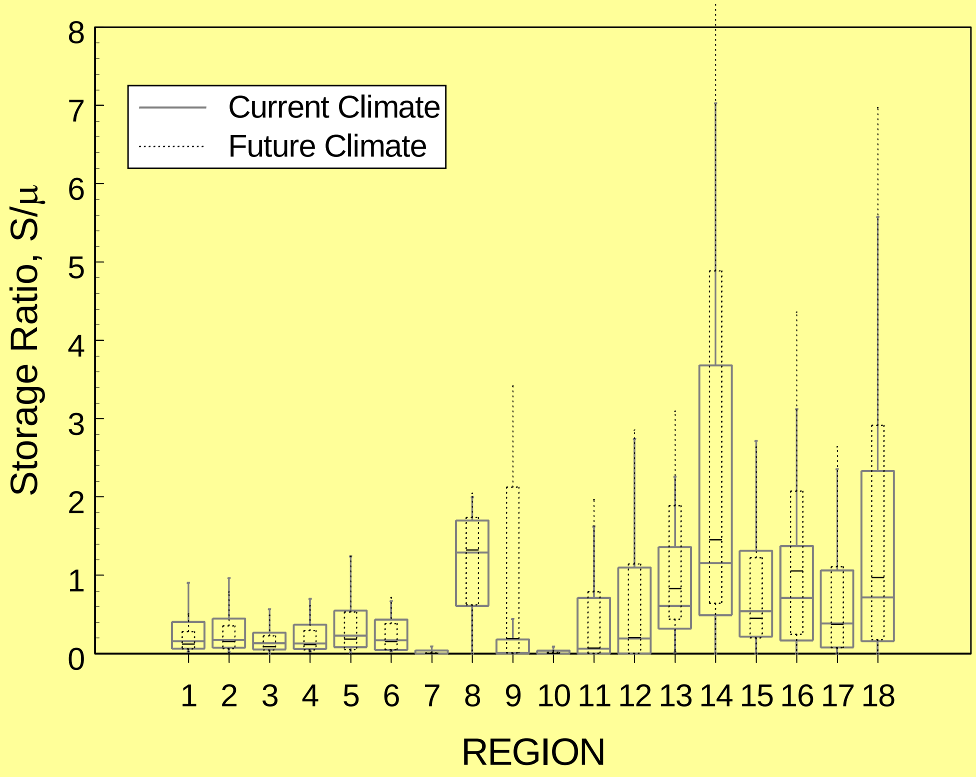

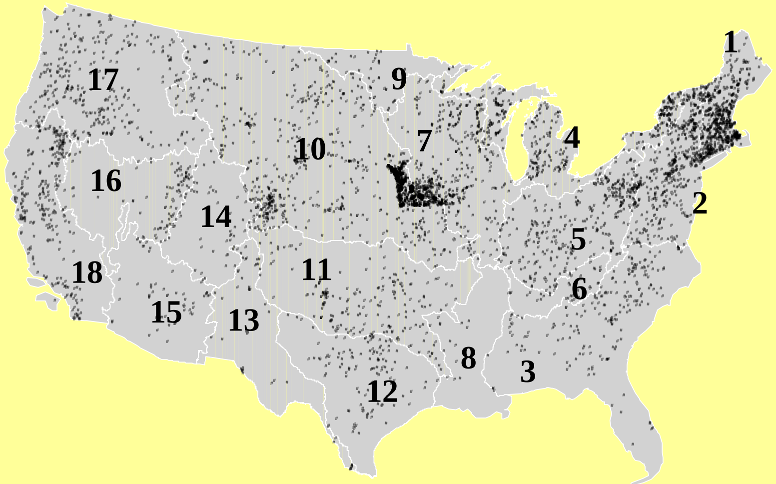

Storage Ratio is Number of Years of Water In Storage (From Vogel et al. 1999)

Reservoir Release Policies Considered

- No instream flow release
- FOI - Release fraction of inflow to reservoir
- Fixed Minimum Release
- Flow components – releases to enhance floods and low flows
- FOI with demand (drought) management

Release Policies have an enormous impact on storage – yield relation

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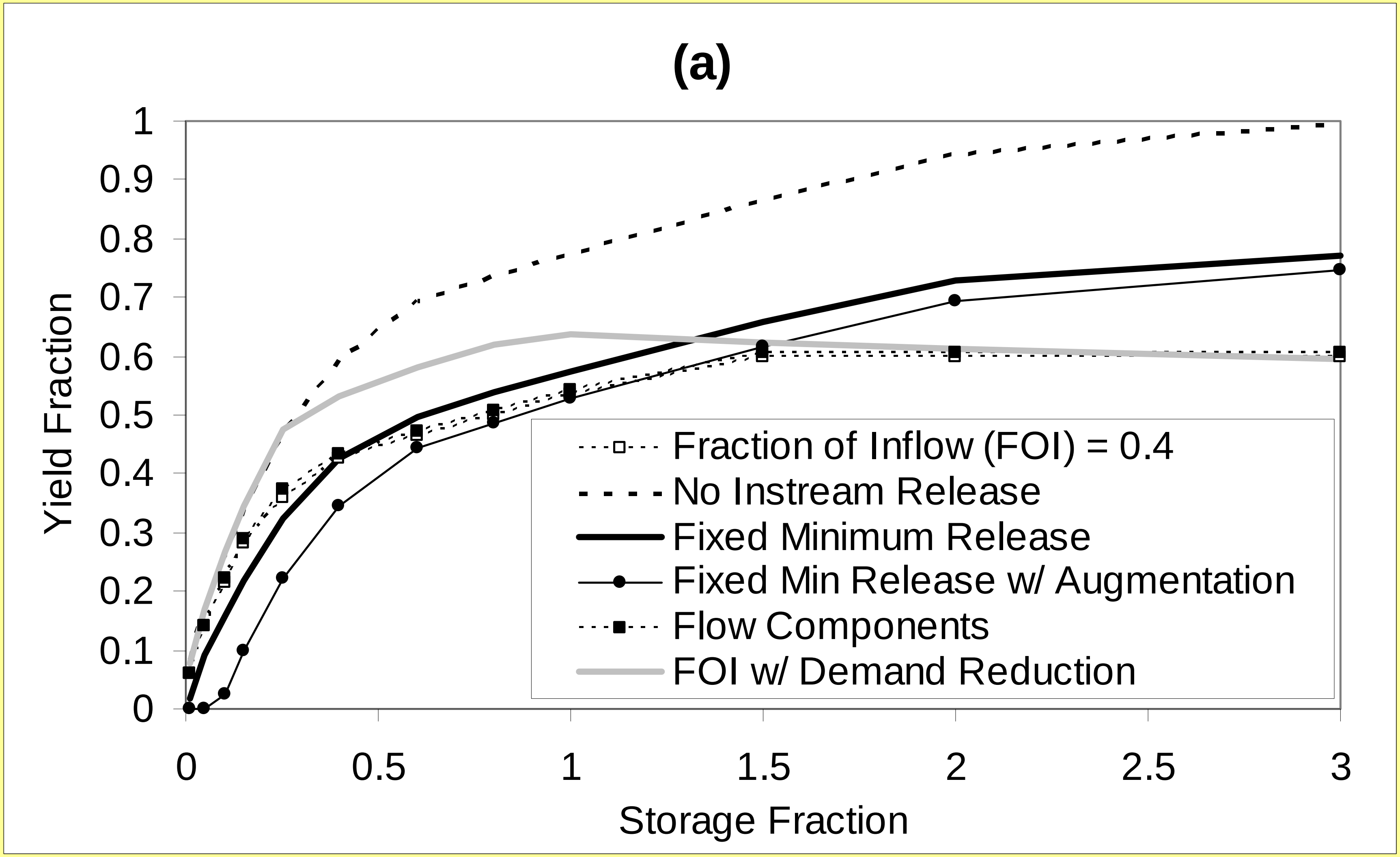
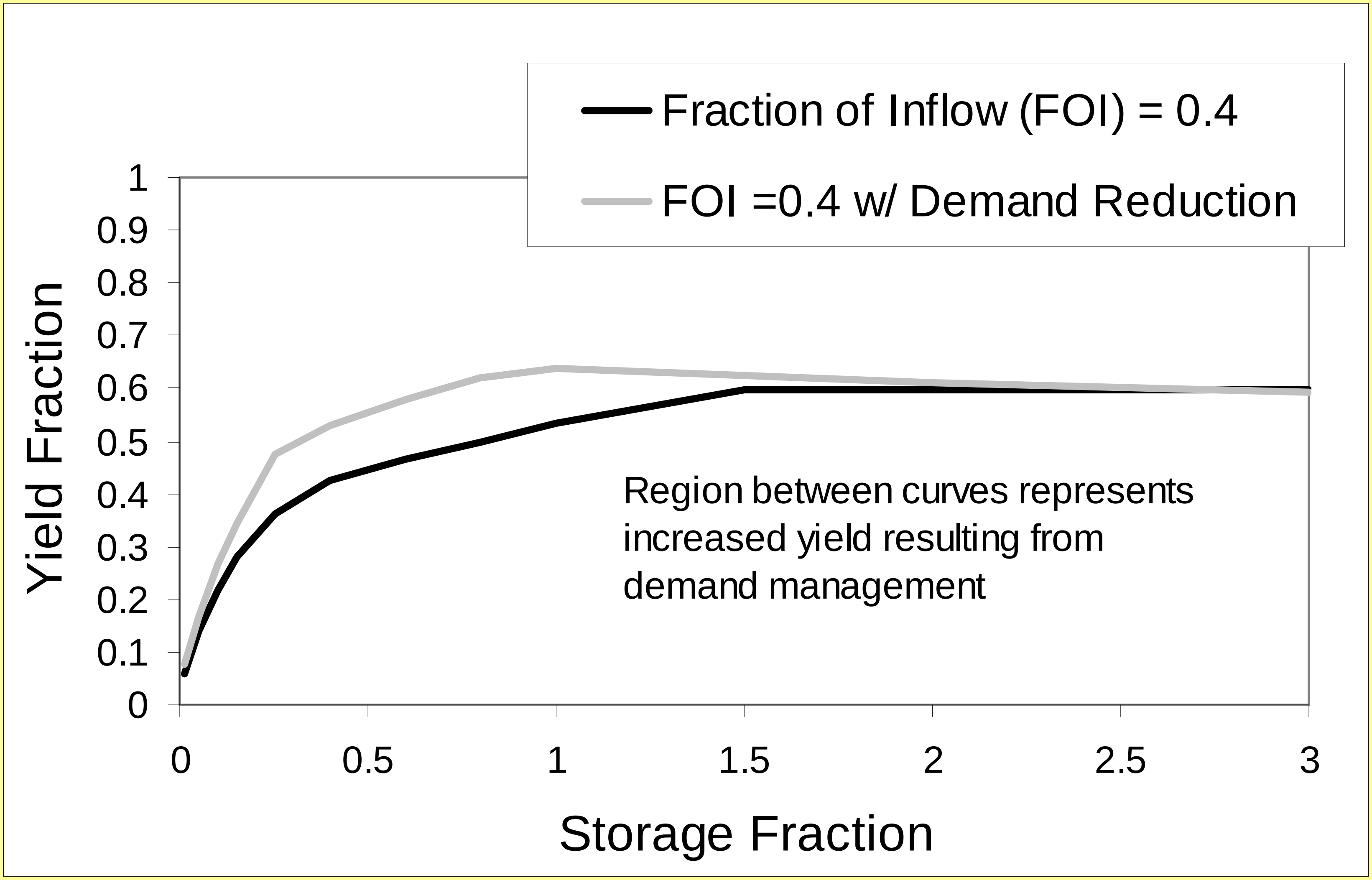


Demand reduction has enormous impact on storage yield curve



Fixed minimum release is good for small reservoirs but not large ones

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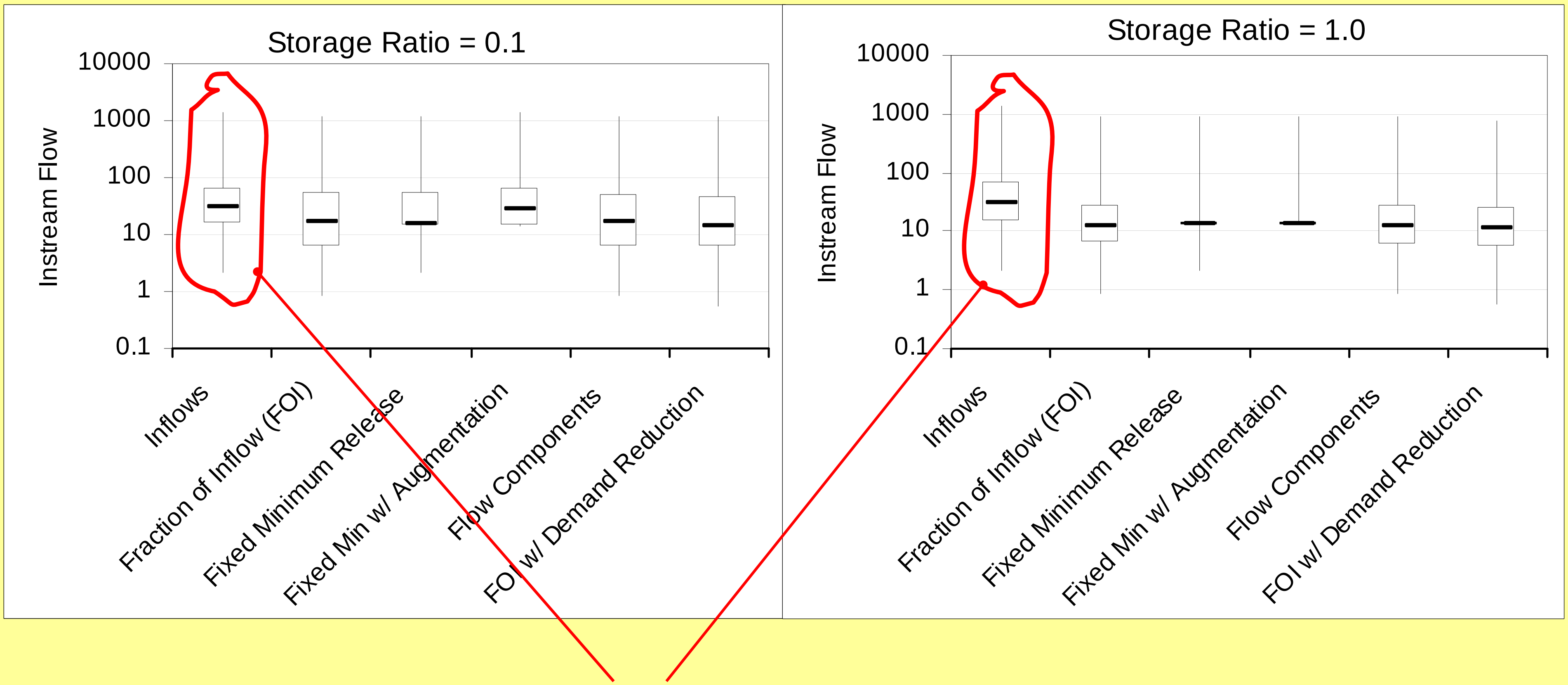
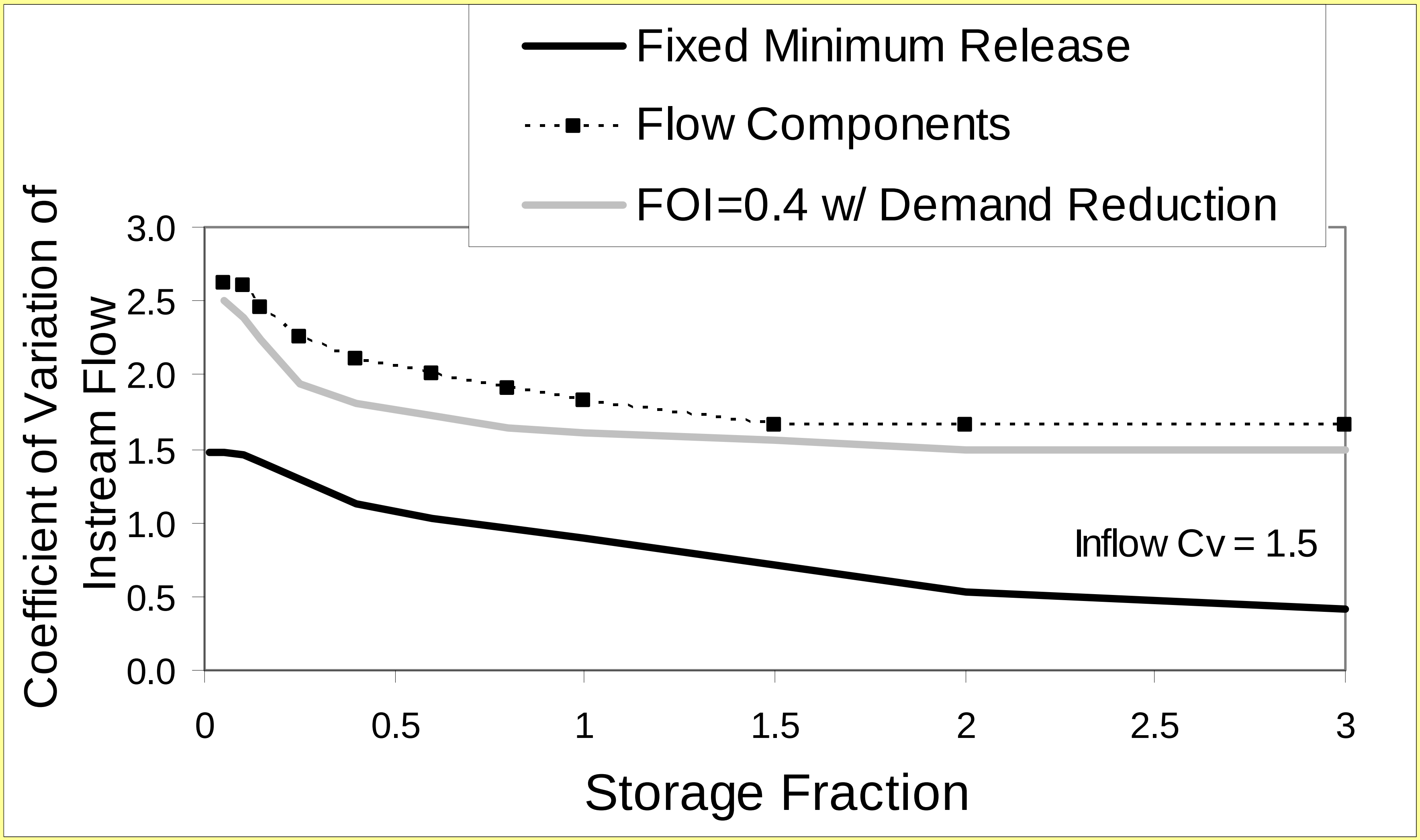


Inflows = Natural Flow Regime

Fixed minimum release is good for small reservoirs, but not large ones



Summary

Our Research Is:

- Quantifying trade-offs between competing water management objectives;
- Integrating a more precise definition of ecosystem flow needs into water supply management;
- Providing a tool for optimization of the timing and use of drought management, water conservation and other reservoir release strategies;
- Promoting a consensus-based decision-making approach to management of water resources.