

Climate Warming & California's Water Future

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<http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/>

Real work done by

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Overview

**Climate
Changes**

Droughts

**Other
Changes**

Floods



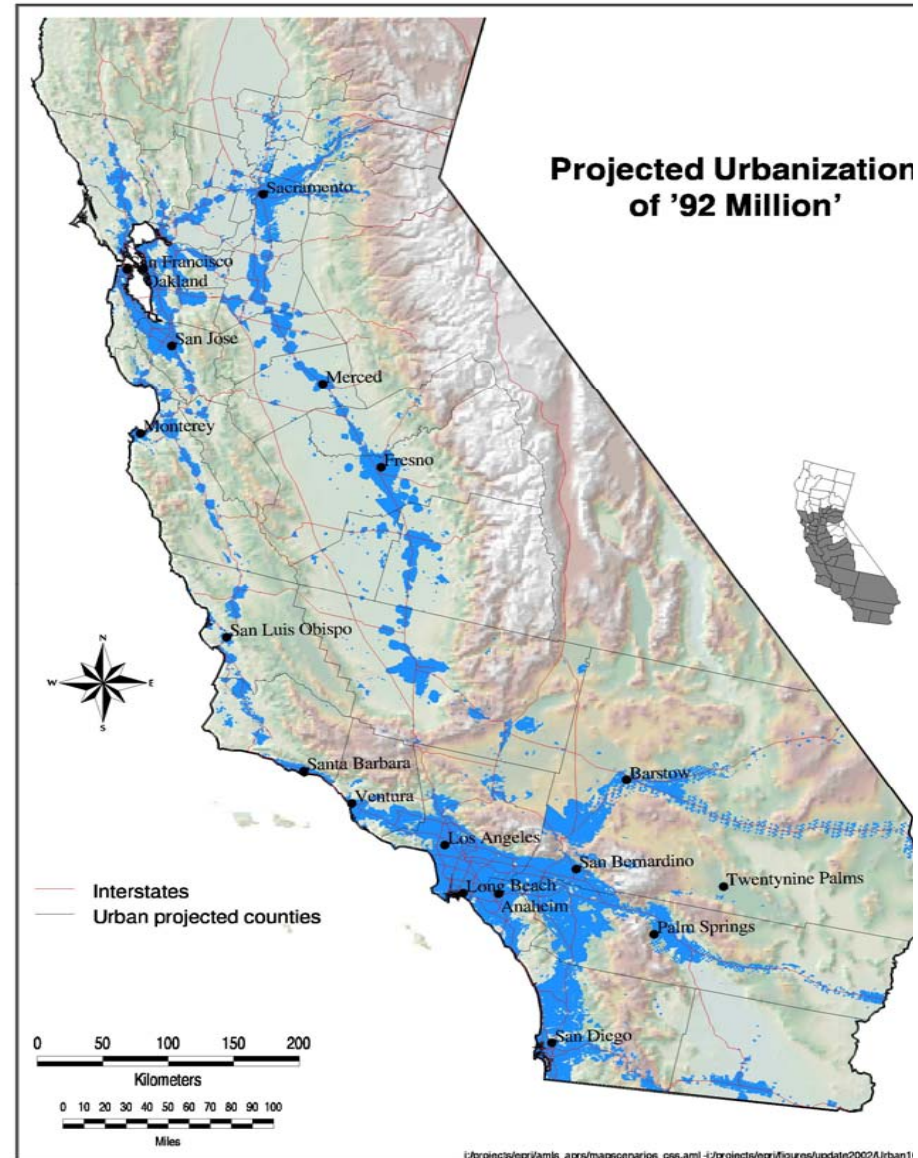
Adaptations

Forms of Climate Change

1. Sea level rise
2. Climate warming
3. Climate oscillations
4. Multi-decade droughts
5. Other forms of change?

Other Big Changes

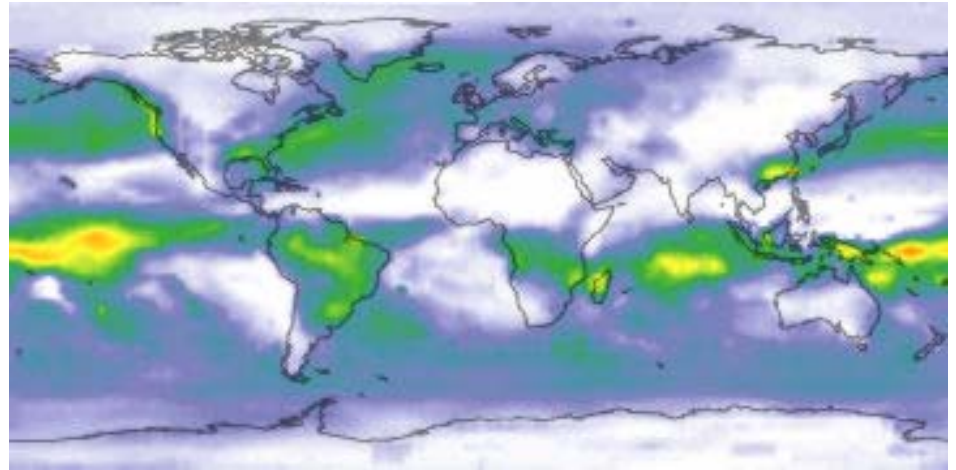
1. Population growth
2. Land use
3. Social values
4. Economic well-being
5. Crop prices, yields, etc.
6. Others?



John Landis, UCB, estimates 2002

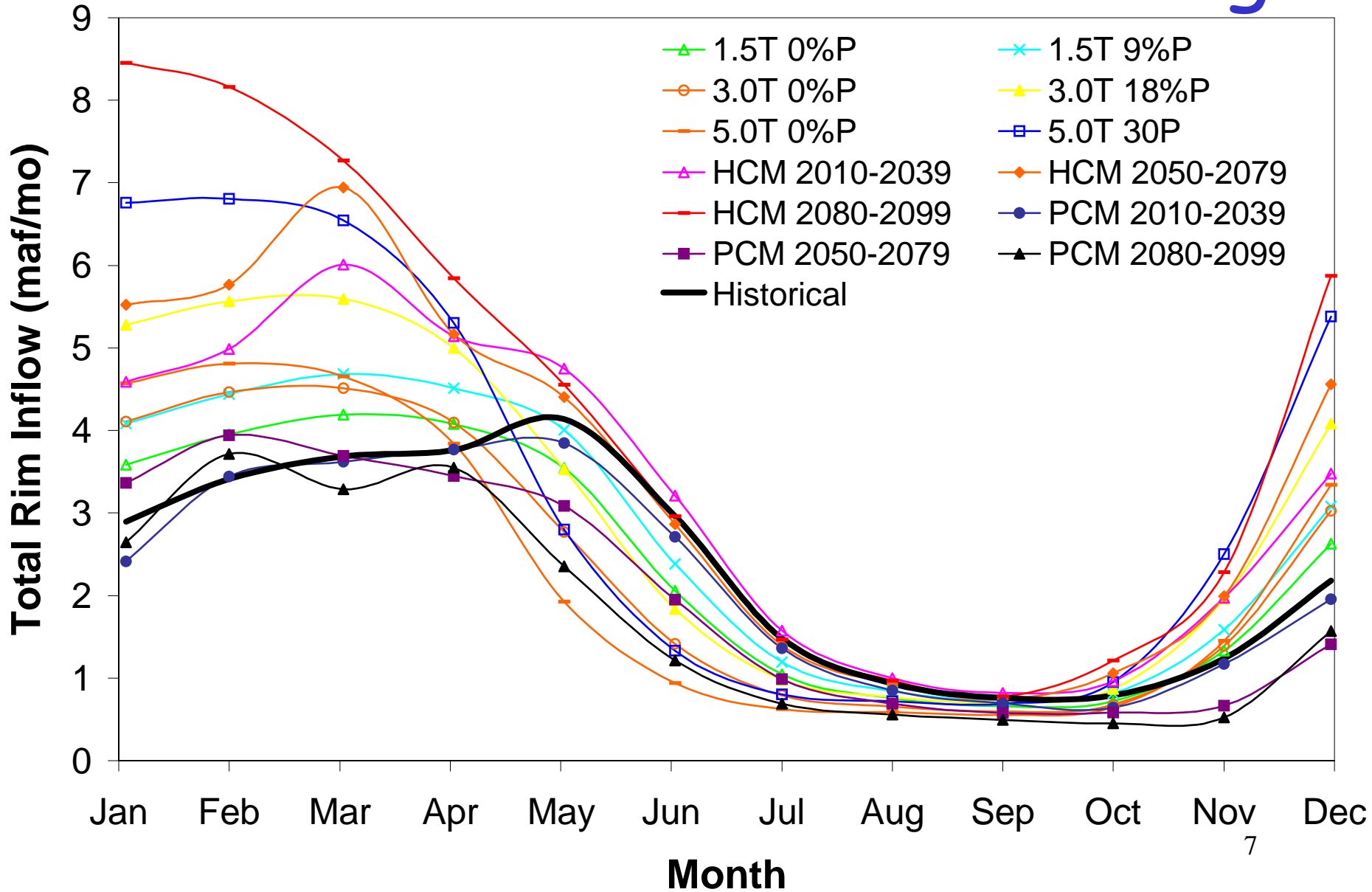
Long-Term Water Concerns

1. Water Supply
2. Flood Control
3. Ecosystems

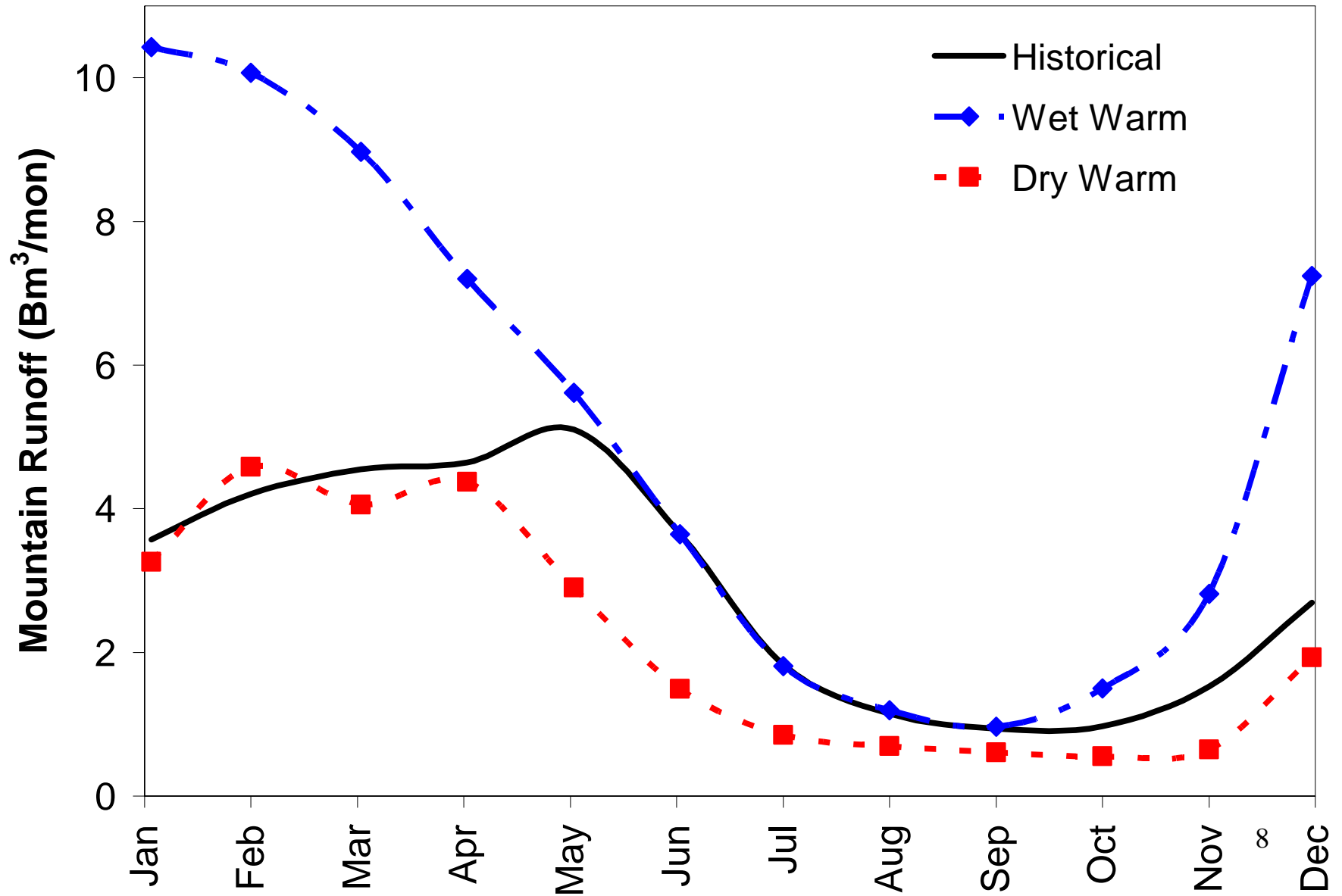


Images: NASA

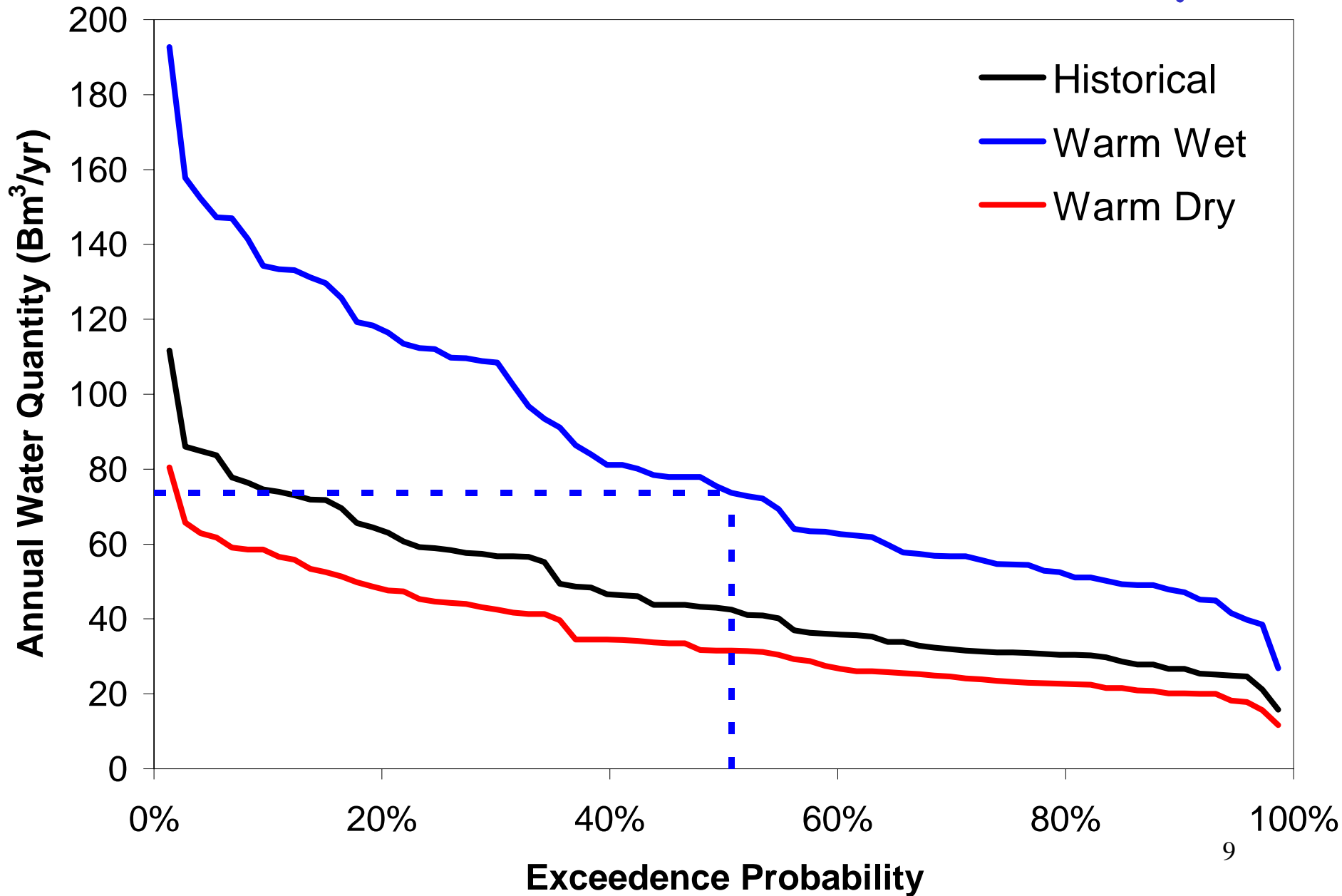
Inflows with Climate Warming



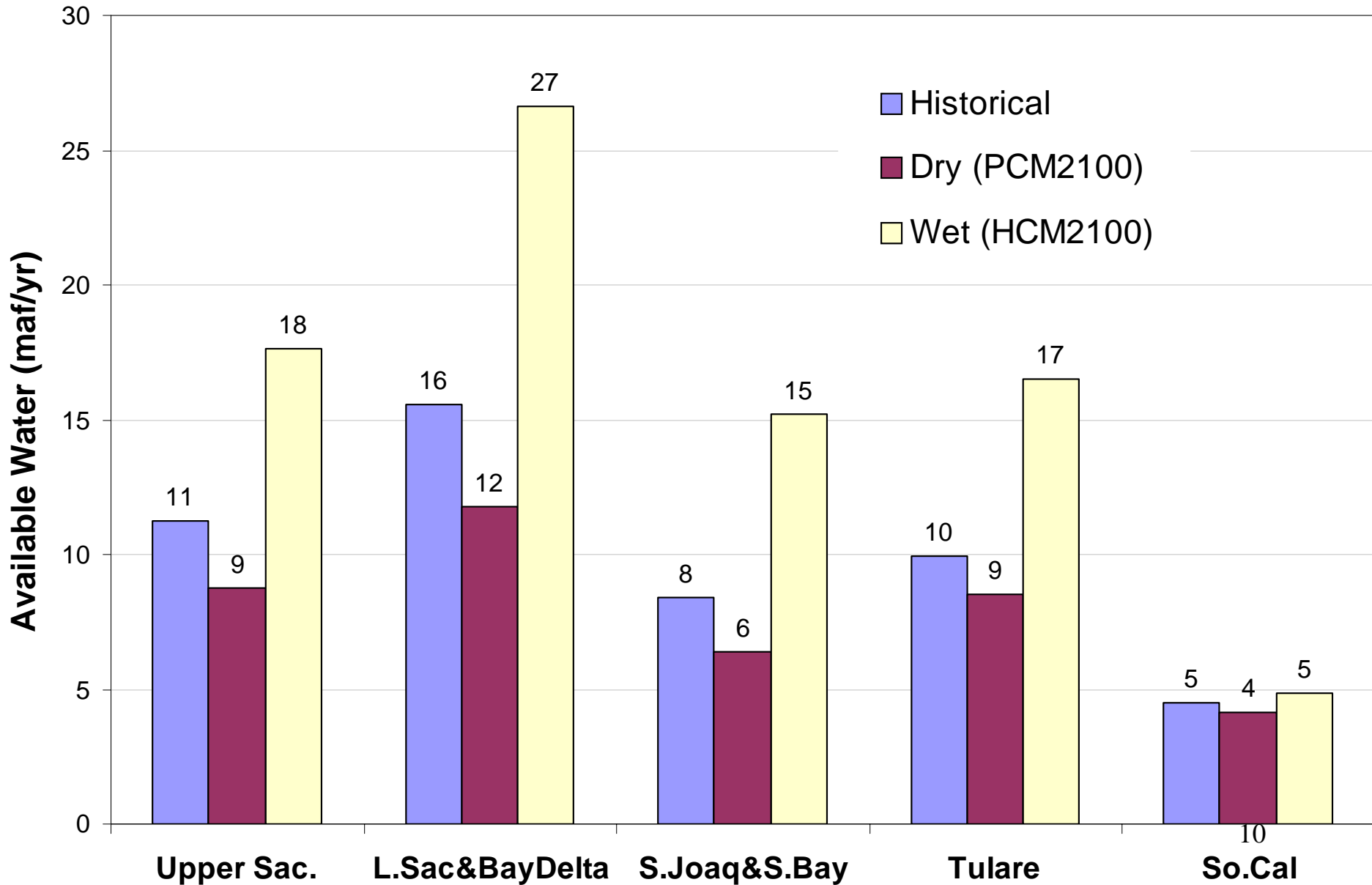
2100 Average Monthly Total Rim Runoff



2100 Annual Exceedence Probability



Climate Scenarios by Region



Climate Warming & Water Supply

- 2100 water availability, population, land use, and water demands
- Water management adaptation to climate warming extremes

2100 Water Availability Extremes (maf/yr)

Scenario	Average Availability	Change
Historical	37.8	0
Dry Warming (PCM)	28.5	-9.4
Wet Warming (HCM)	42.4	4.6

Estimated Raw Water Supply Availabilities and Changes

Climate Scenario	Overall Water Quantity (Bm ³ /yr)	Change (%)	Raw Water Availability (Bm ³ /yr)	Change (%)
Historical	46.7	0	46.7	0
Warm Wet (+3.3 T; +62% P)	83.5	79	52.3	12
Warm Dry (+2.3 T; -26% P)	35.1	-25	35.2	-25

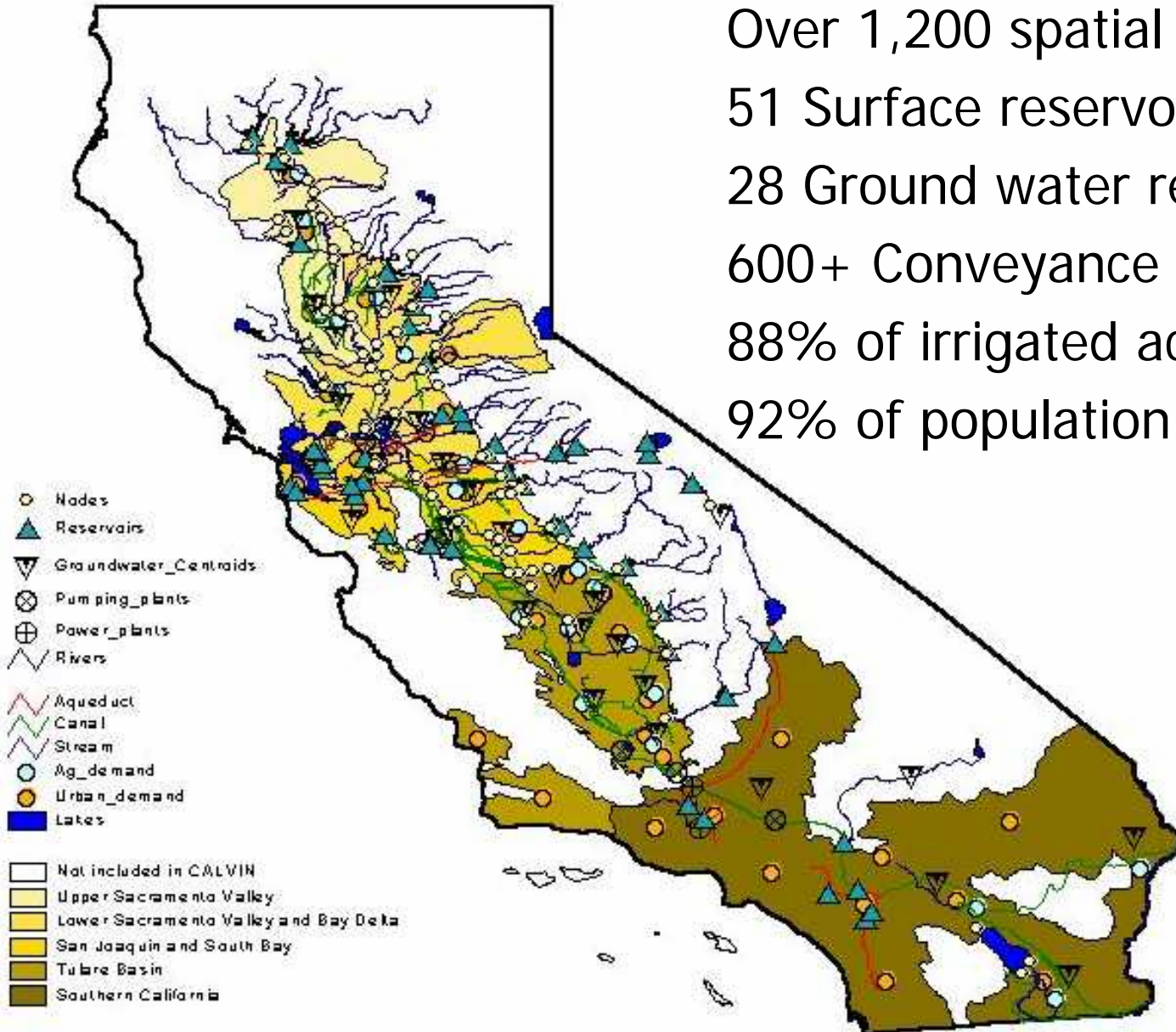
- Rainfall changes do not translate directly to runoff changes or usable water supply.
- Increases in water demands (+5.6 Bm³/yr) might pose greater challenges than climate warming

What can we do? - Adaptation

- Coordinated facility operations
- Joint surface & groundwater operations
- Water allocation and markets
- Urban conservation/use efficiencies
- Agricultural use efficiencies and fallowing
- Environmental water use efficiencies
- New technologies
 - Wastewater reuse
 - Seawater desalination

CALVIN Model Coverage

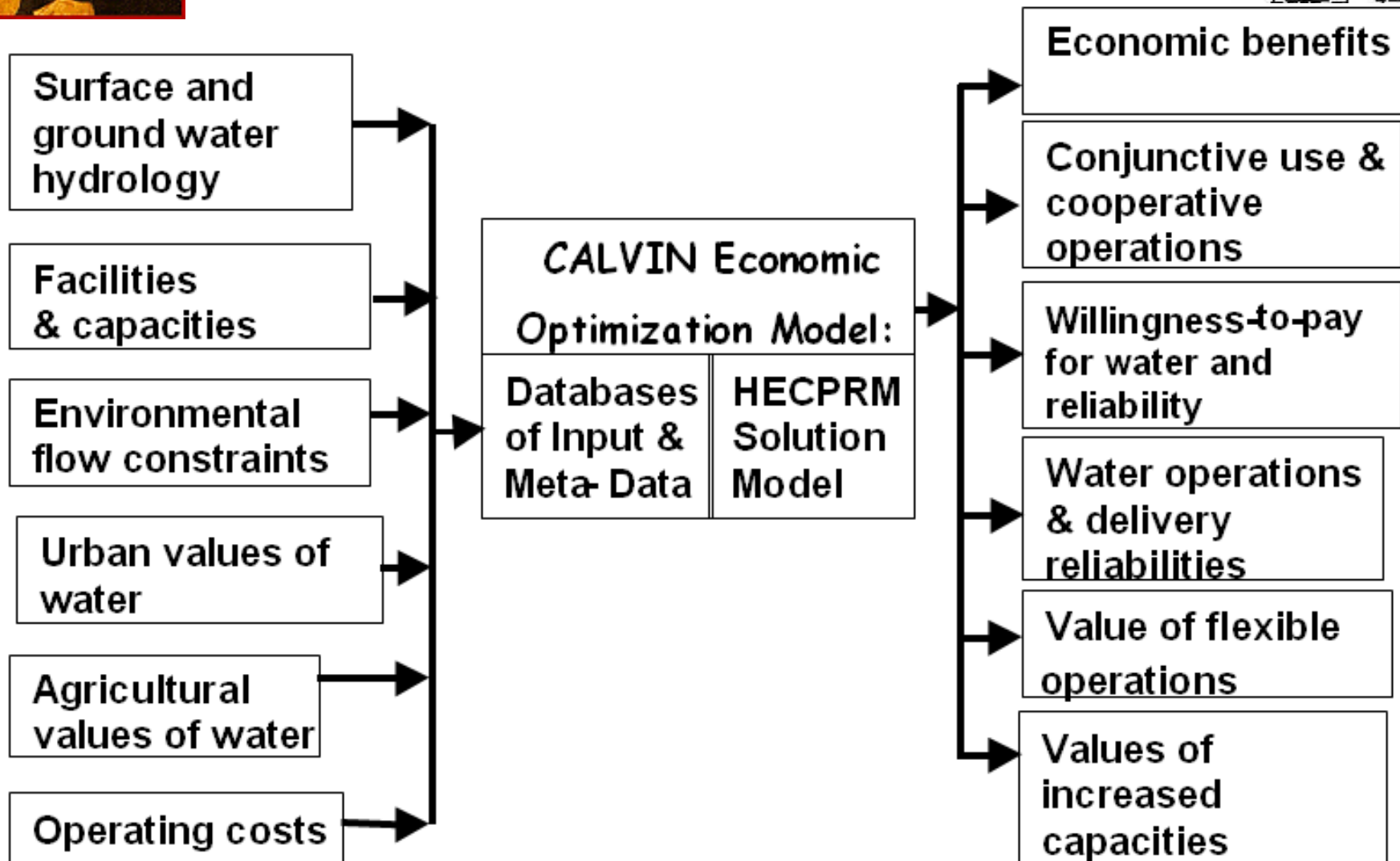
Over 1,200 spatial elements
51 Surface reservoirs
28 Ground water reservoirs
600+ Conveyance links
88% of irrigated acreage
92% of population





Data Flow for CALVIN

NOBODY LIKES US
"BIG PICTURE"
PEOPLE.



Integrated Adaptation Options

- Water allocation and markets
- Joint surface & groundwater operations
- Coordinated facility operations
- Urban conservation/use efficiencies
- Cropping changes and fallowing
- Agricultural water use efficiencies
- New technologies
 - Wastewater reuse
 - Seawater desalination

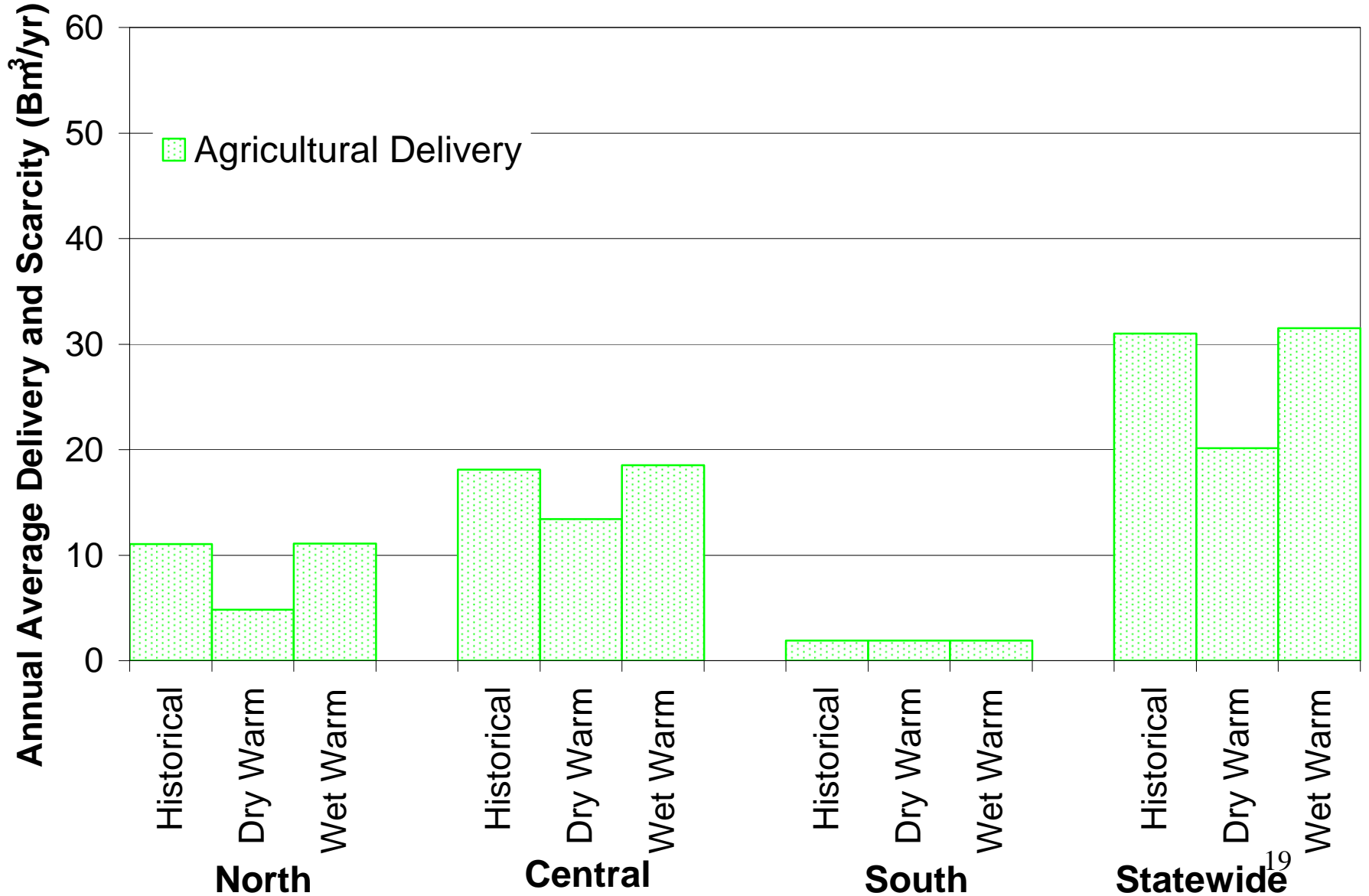
Water Management Objectives

Environmental flows - first priority

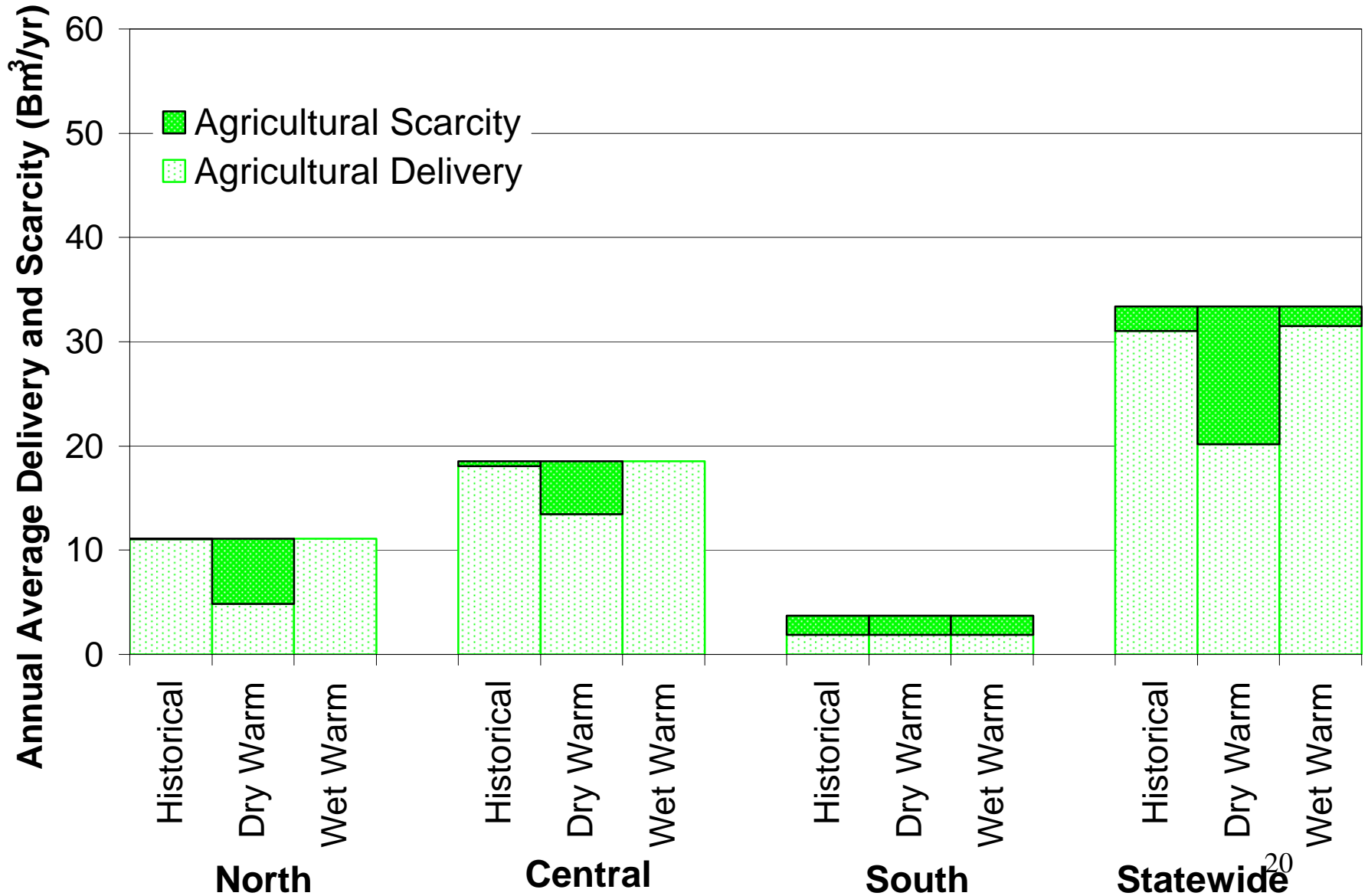
Economic Water Uses:

- Agricultural economic values
- Urban economic demands (residential, industrial, and commercial)
- Hydropower benefits
- Operating Costs

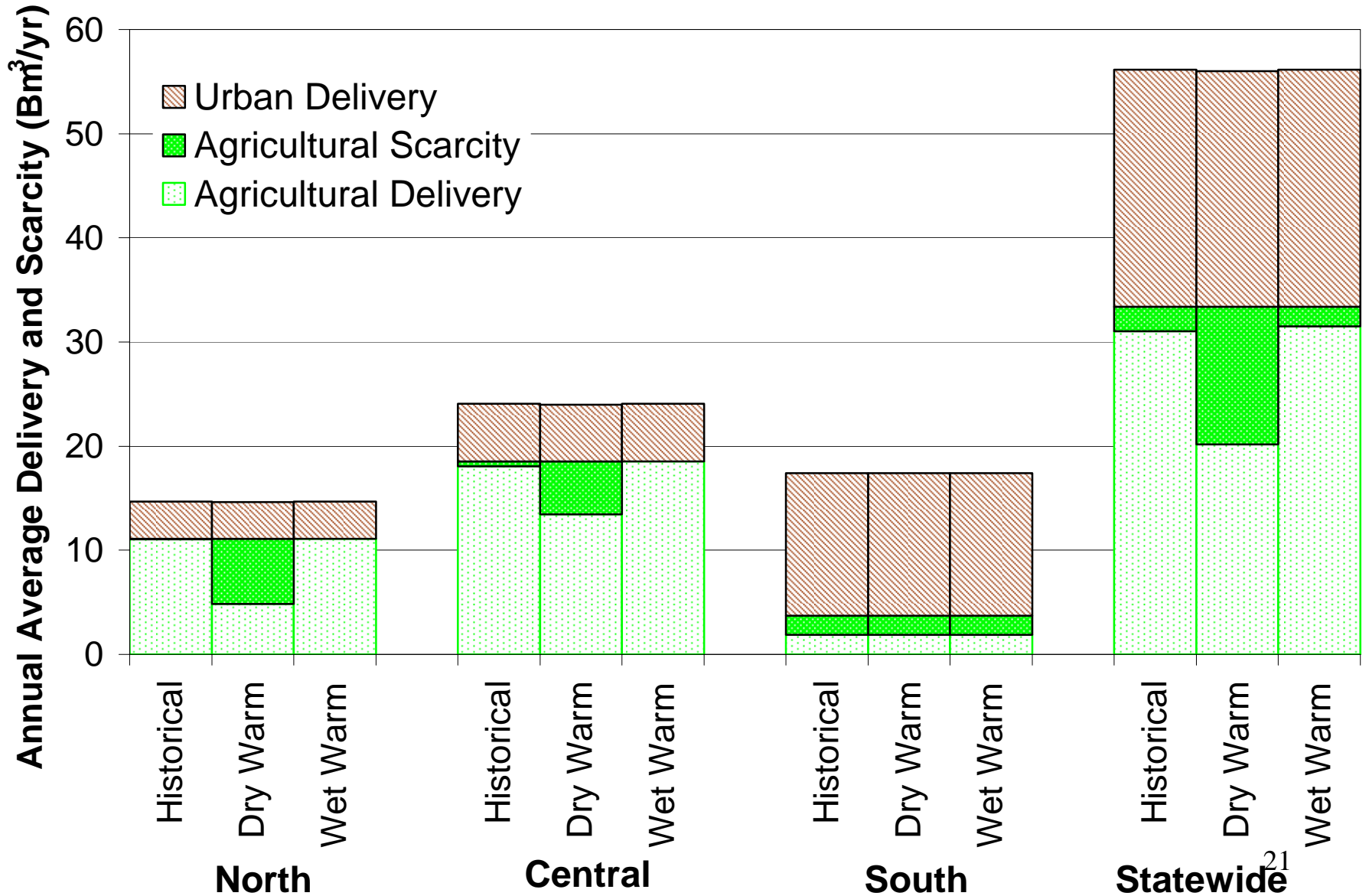
2100 Water Deliveries and Scarcities



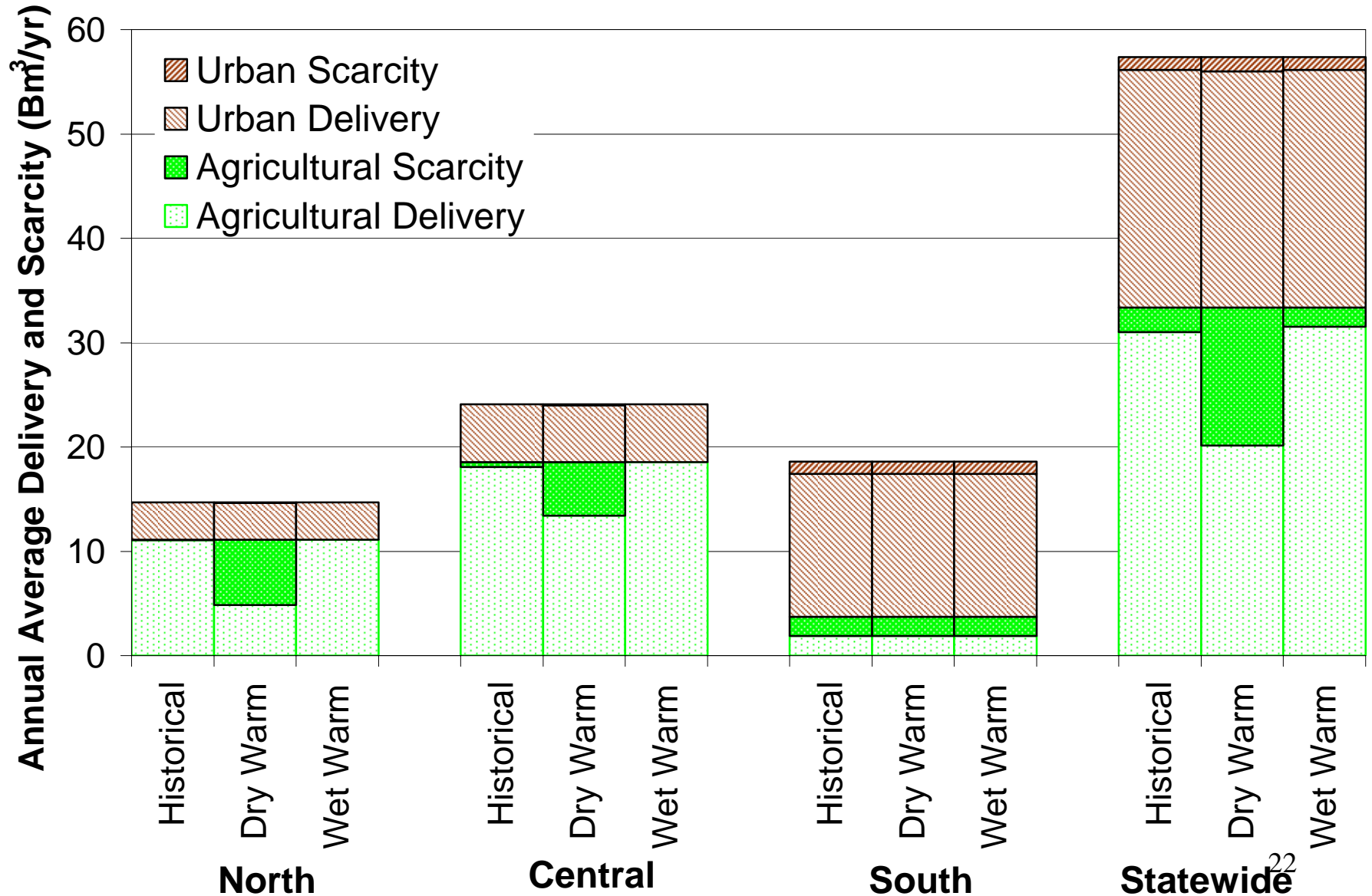
2100 Water Deliveries and Scarcities



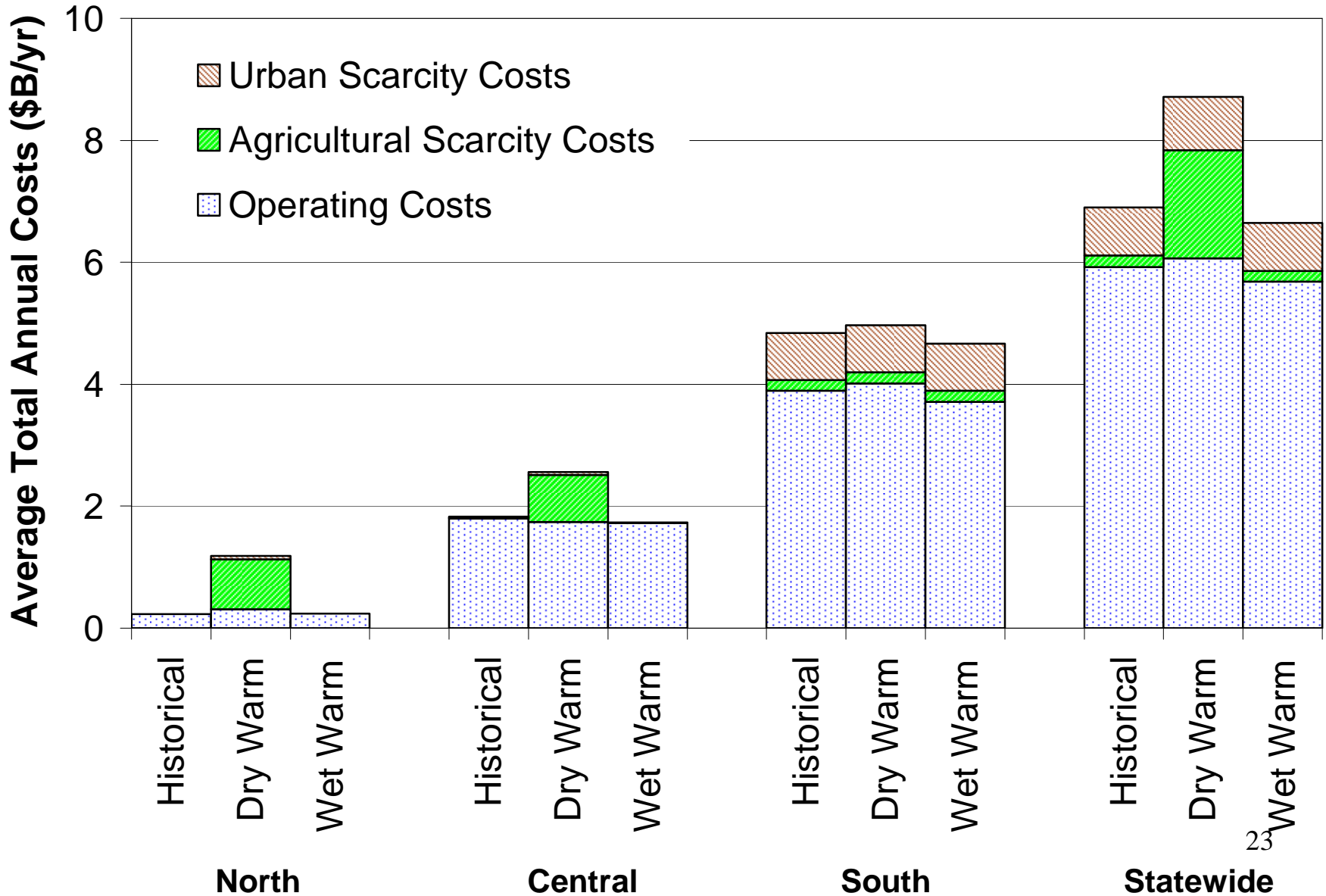
2100 Water Deliveries and Scarcities



2100 Water Deliveries and Scarcities



2100 Total Scarcity & Operating Costs

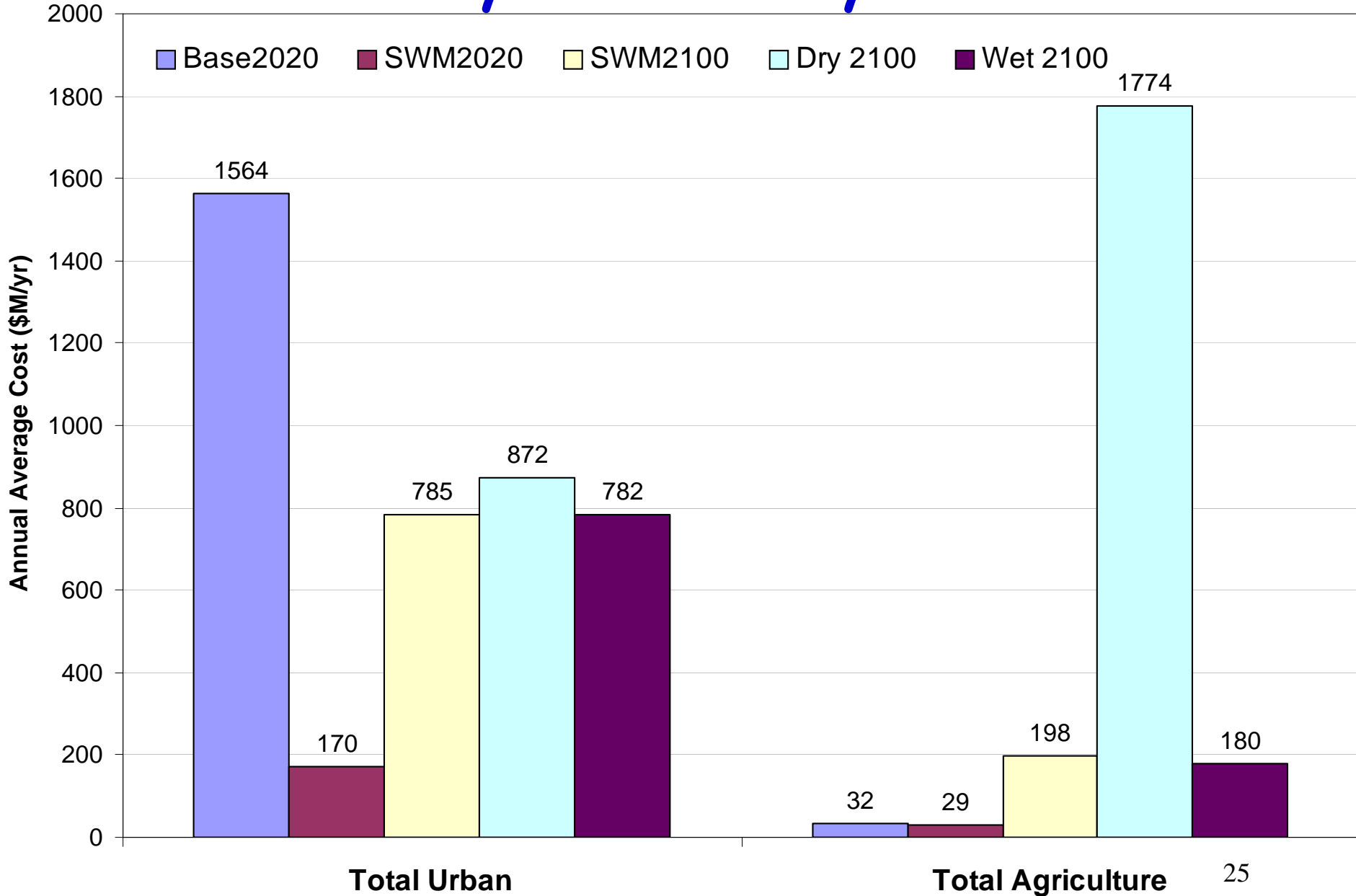


Statewide Economic Costs

(\$ million/yr)

Cost	Base 2020	SWM 2020	SWM 2100	Dry 2100	Wet 2100
Urban Scarcity	1,564	170	785	872	782
Agric. Scarcity	32	29	198	1,774	180
Operating	2,581	2,580	5,918	6,065	5,681
Total Costs	4,176	2,780	6,902	8,711	6,643

Scarcity Costs by Sector



Adaptive Responses

- Groundwater reservoir use
- Water transfers
 - Agricultural to urban
 - Colorado River
 - Central Valley
 - Water quality exchanges
 - Flexibility trading
- New technologies
 - Wastewater reuse
 - Sea water desalination
- Urban water conservation/use efficiencies

The mix of responses is important.

Economic Value of Facility Changes

(\$/unit-yr)

Reservoir (taf)	SWM2100	Dry	Wet
Turlock	69	202	56
Pardee	68	202	56
Pine Flat	66	198	56
New Bullards Bar	65	196	56
Los Vaqueros	64	186	53
Canal (taf/mo)			
Putah S. Canal	7378	7611	6528
Mokelumne Aqued.	7180	7609	6301
Coachella Canal	3804	3487	3618
Friant Kern Canal	1733	1960	3585
Colorado Aqueduct	1063	970	759
California Aqueduct	669	1823	452

Environmental Flow Costs

Average Cost (\$/af)

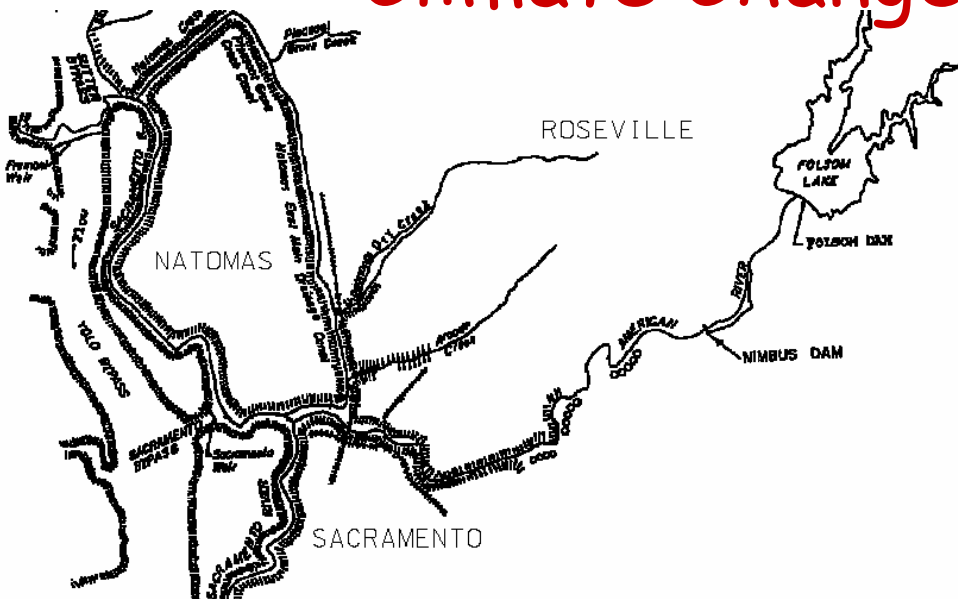
Minimum Flows	SWM2100	Dry 2100	Wet 2100
Trinity River	45	1011	29
Sac. R. at Keswick	4	665	3
Mokelumne River	21	332	0
Yuba River	0	2	1
Merced River	17	70	1
Mono Lake Inflows	1254	1301	64
Owens Dust Mitigation	1019	1046	3
Refuges			
Sac West Refuge	11	23	0
Volta Refuges	38	311	21
SJ/Mendota Refuges	33	250	11
Kern	57	377	36
Delta Outflow	10	229	0

Conclusions: Statewide Water Supply

- 1) Climate warming can be wetter or drier overall, with seasonal flow shifts.
- 2) Optimization needed for large complex systems, given dynamic interdependencies at multiple scales.
- 3) Agricultural water users in the Central Valley are the most vulnerable to climate warming.
- 4) California's water system can adapt to the fairly severe population growth and climate warming.
- 5) Water markets drive adaptation. Without water market, it would be much more costly.

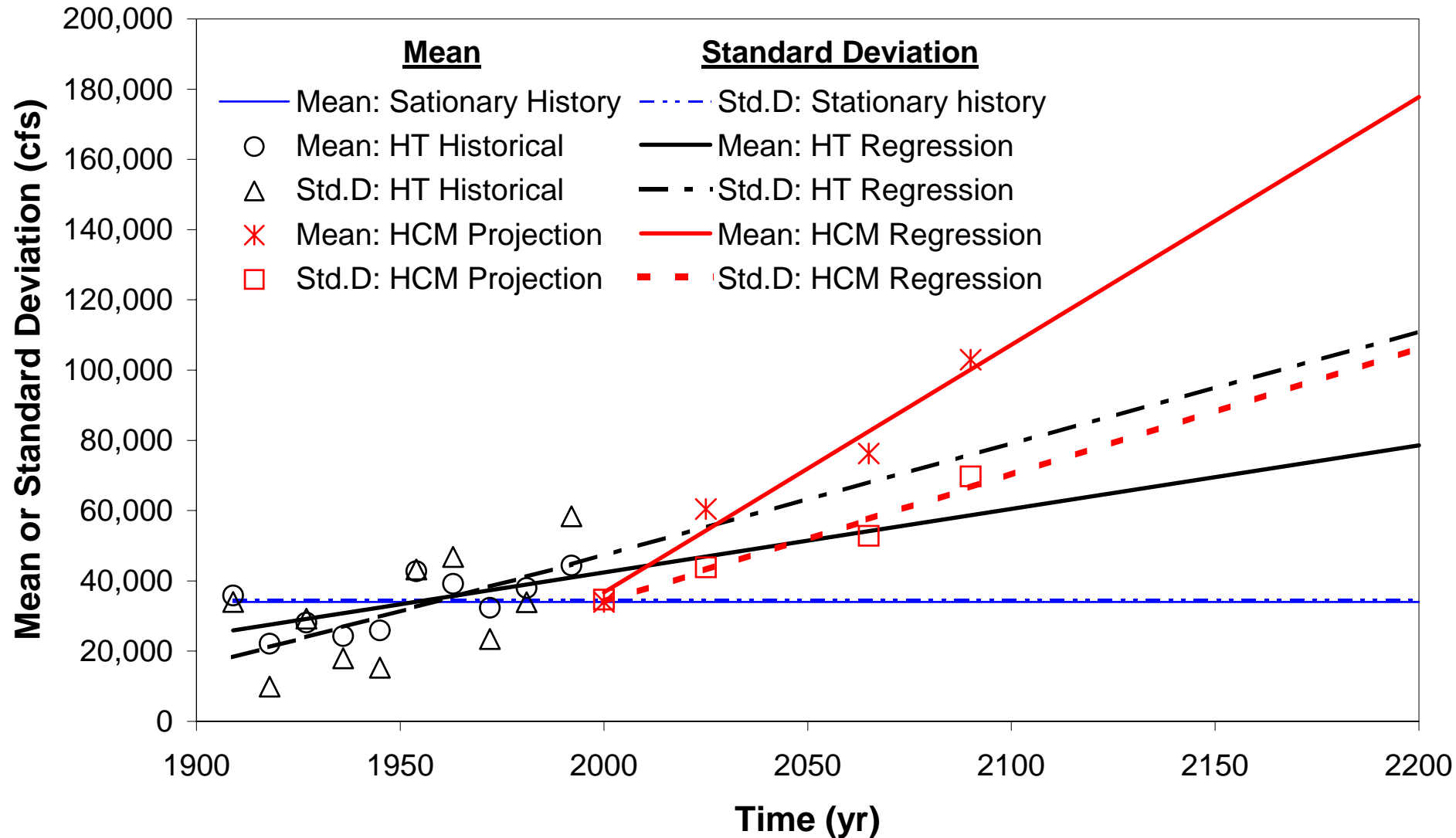
Flooding on the Lower American River

Climate Change and Urbanization

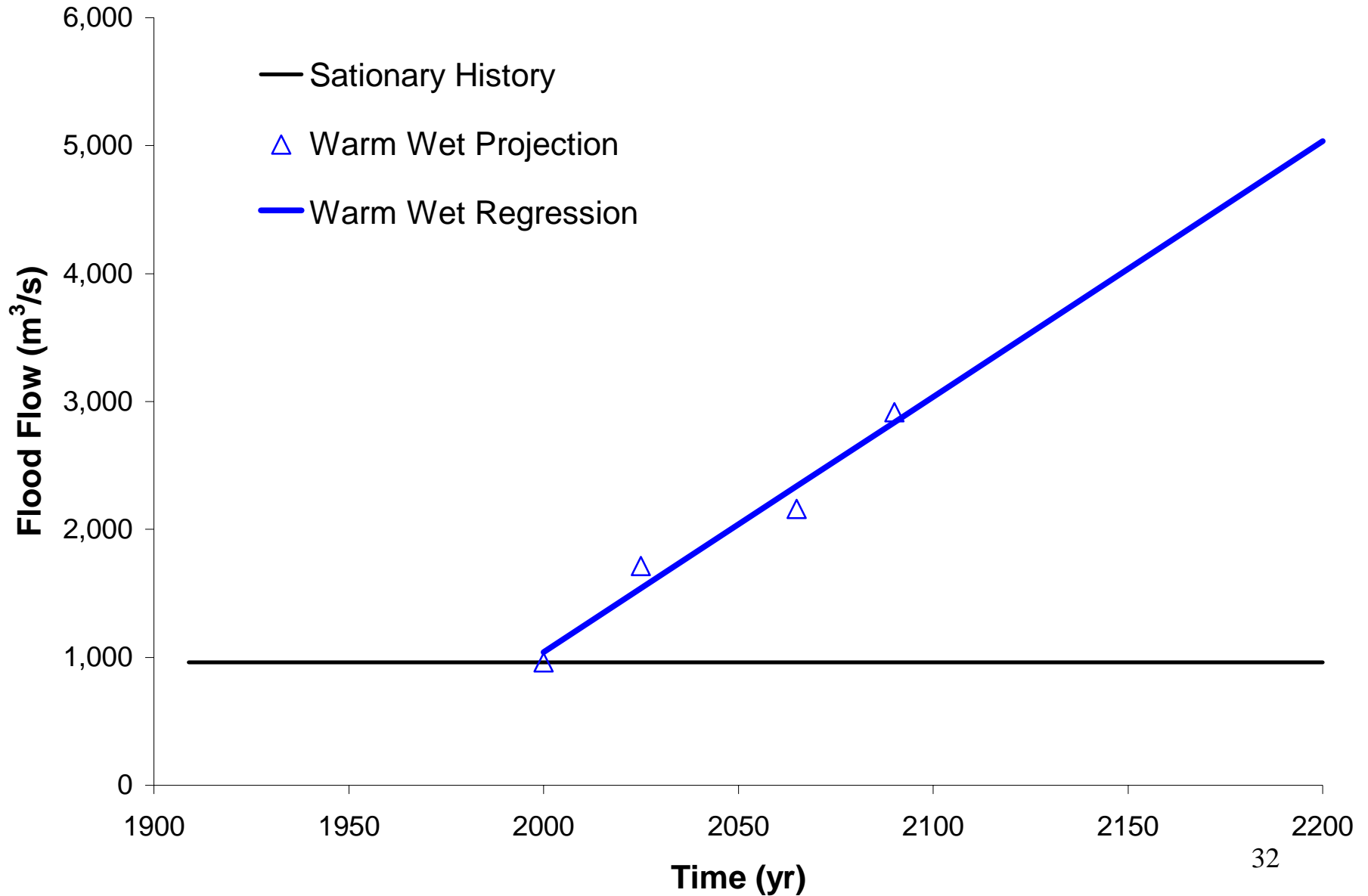


What are long-term optimal levee heights and levee setbacks, given different climate change scenarios and increasing urban values for floodplain land?

Three-Day Peak Inflows at Folsom Lake



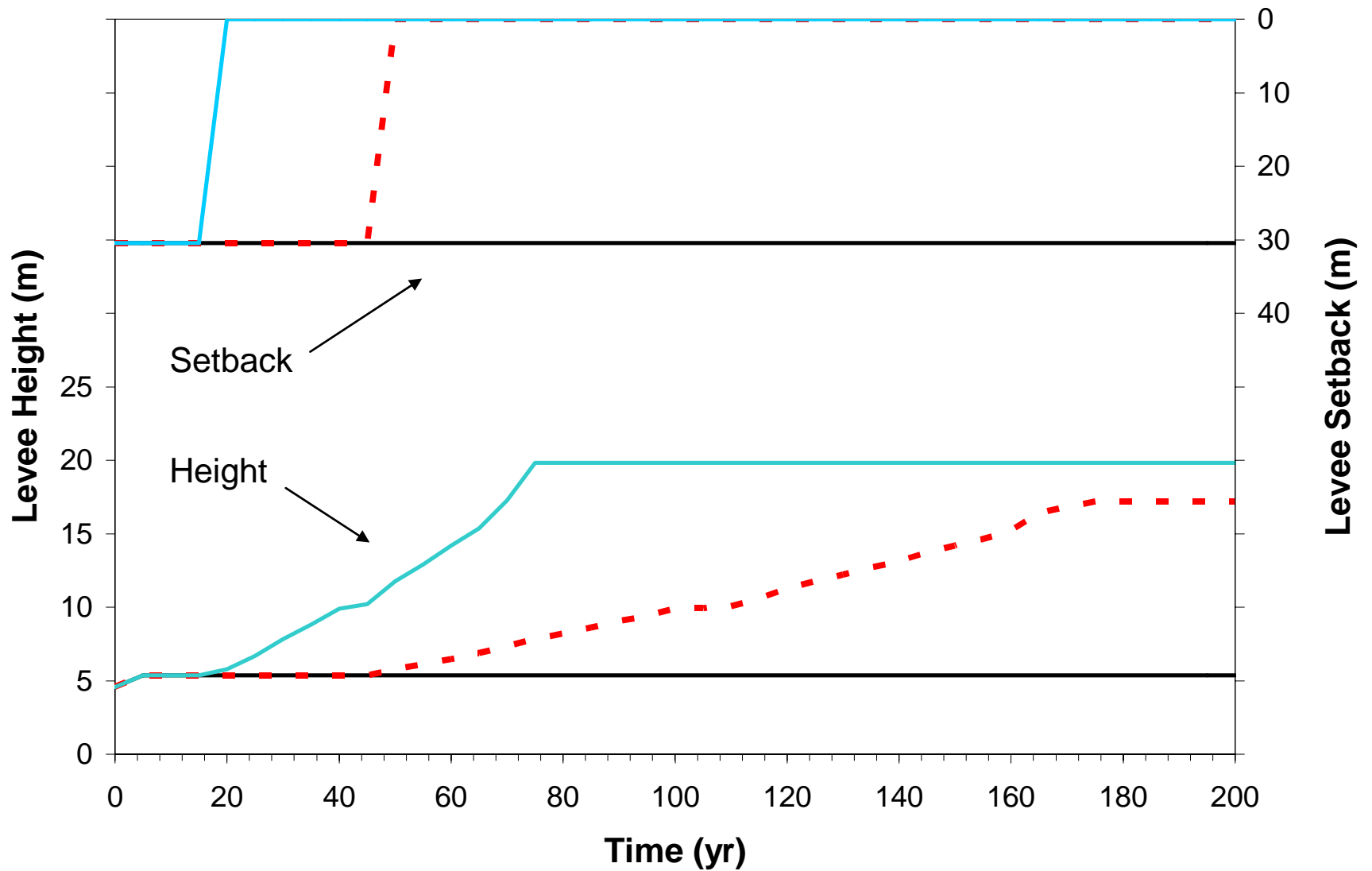
Mean Flood Flows at Folsom Lake



Method

- Find least-cost levee heights and setbacks - optimization model
- Changing flood probabilities
- Changing urban land and flood damage values – 200 year time frame.

Urban Growth Alone



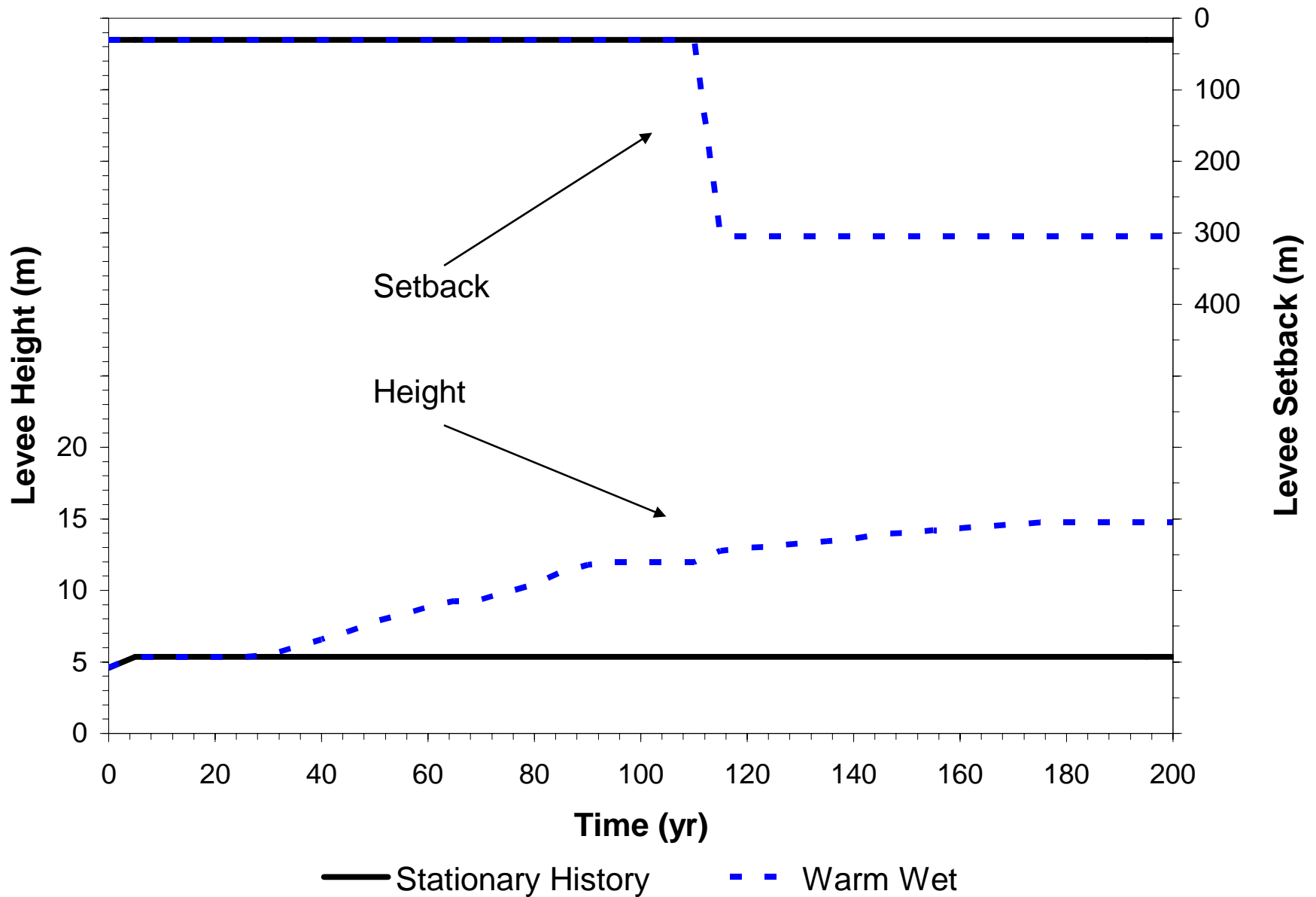
Annual urban land value increase

— 0%

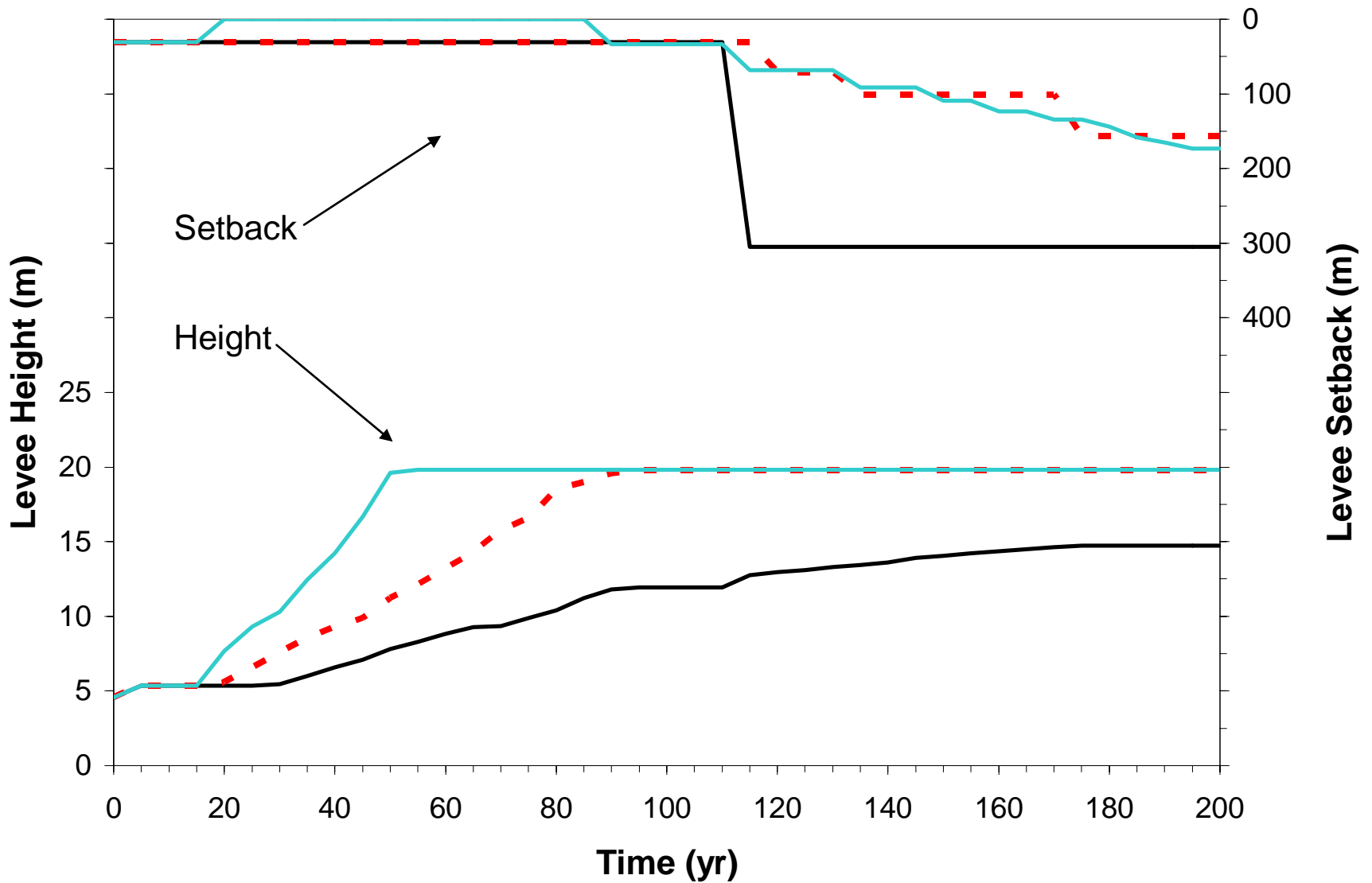
- - 2%

— 5%

Climate Change Alone Without Urban Growth

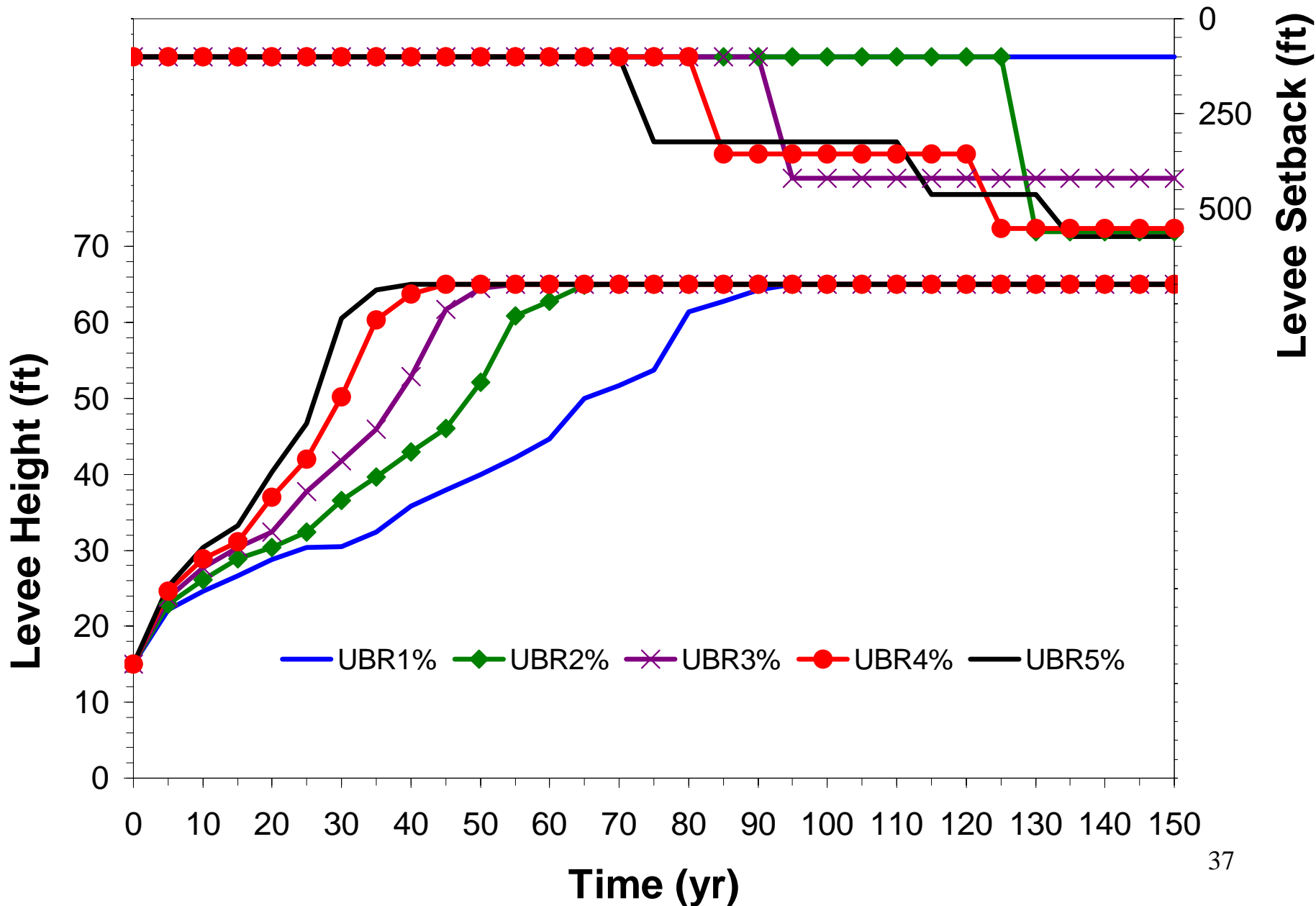


Combined Effects with Wet Warm Climate

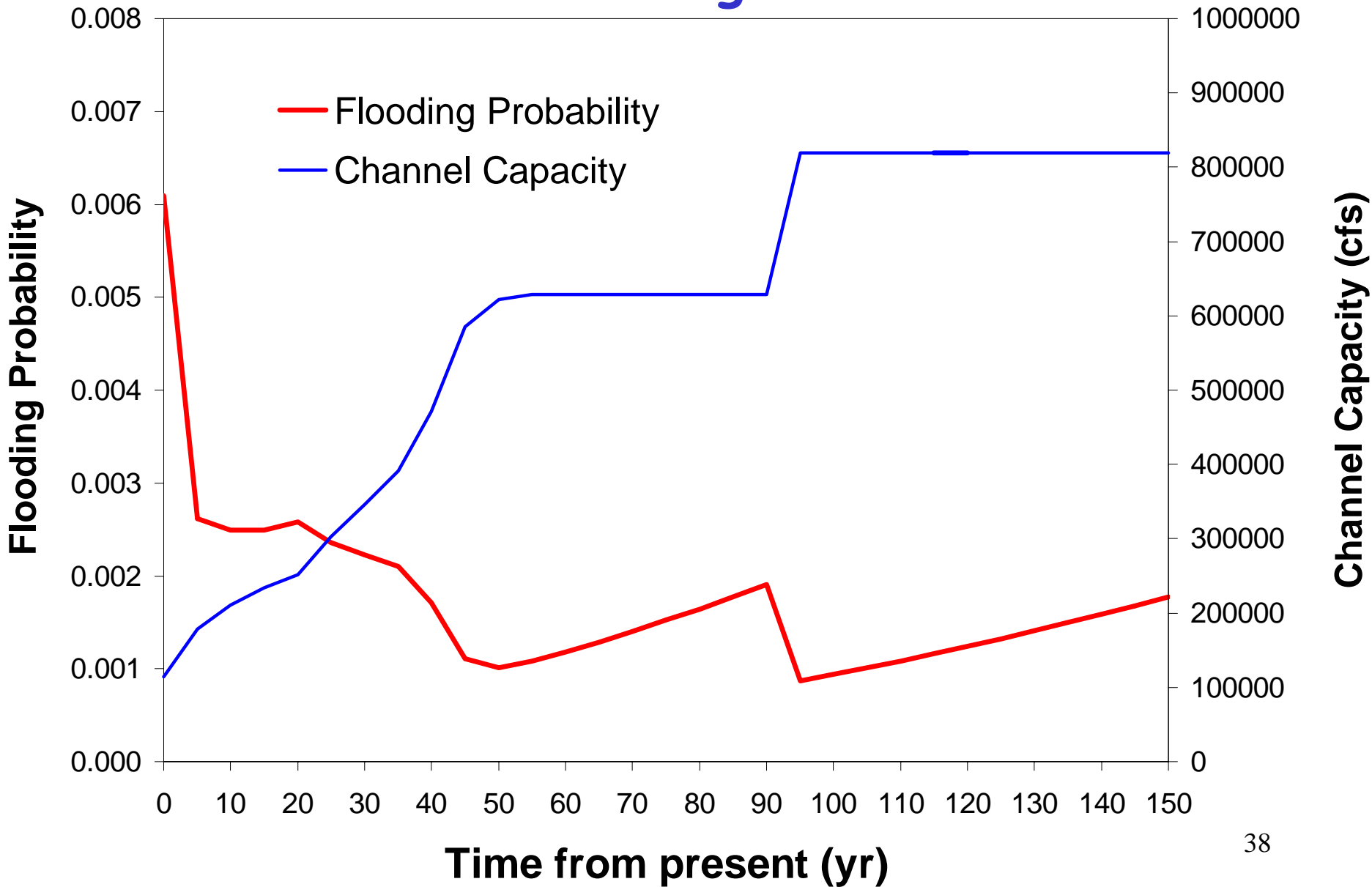


Annual urban land value increase rate: — 0% - - 2% — 5%

Combined Effects with Historical Trend in Floods



Flooding Probability and Channel Capacity 3% Urbanization - add damages and constr. costs?



Flood Control Conclusions

- Central Valley flooding could become dire
 - Continued urbanization
 - Wet climate warming
 - Continuation of recent flood trends
 - Other tributaries have similar problems
- Widening the lower American River floodplain and raising levee heights over the long periods is likely
- Floodplain planning should consider potential levee relocation

Overall Conclusions

- 1) Preliminary results
- 2) Climate warming could harm some Central Valley agriculture and environmental uses
- 3) Central Valley flood control is more dire
- 4) Adaptation, mix of options, and flexibility in climate and management studies
- 5) Enhance cooperation from local to statewide levels to gain from the richness and strengths of our water system

Overall Conclusions (con't)

- 6) Value of quantitative analysis
 - Precise understanding
 - Identifying important things we don't know
 - Exploring options and impacts
 - Making discussions more productive
- 7) Optimization can explore many options and identify promising combinations
- 8) We have only begun to understand water management in California, using numbers

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