Center for Watershed Sciences

University of California Davis

Multi-benefit Flood Bypass Capacity Optimization

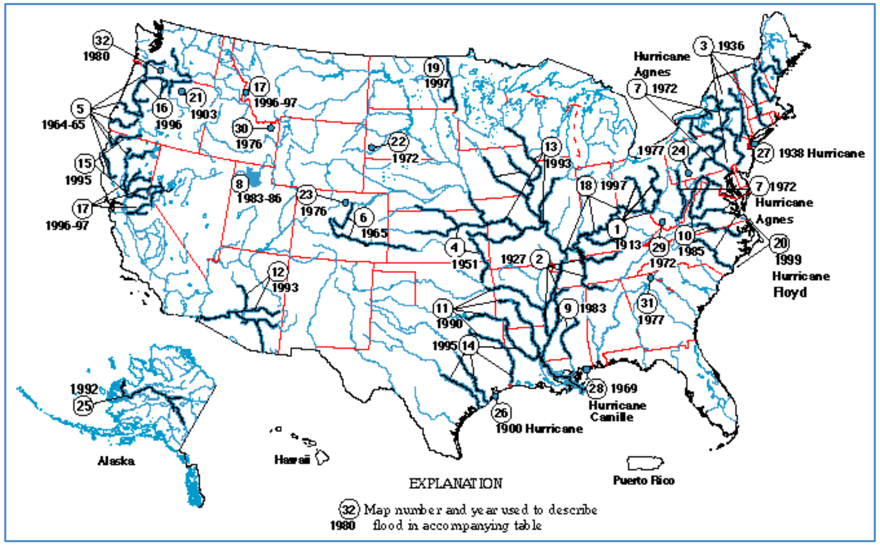
Alessia Siclari, Dr. Rui Hui, Prof. Jay Lund

Outline

- Natural flood control
- Flood bypasses
- Ecological function of flood bypasses
- LP model to calculate optimal bypass capacity
- Bypassing floods on the Sacramento River
- Results and Insights

Prevent floods or reintroduce them?

32 MOST SIGNIFICANT FOODS IN THE US IN THE 20TH CENTURY



THE YOLO BYPASS BIRDS STOPOVER

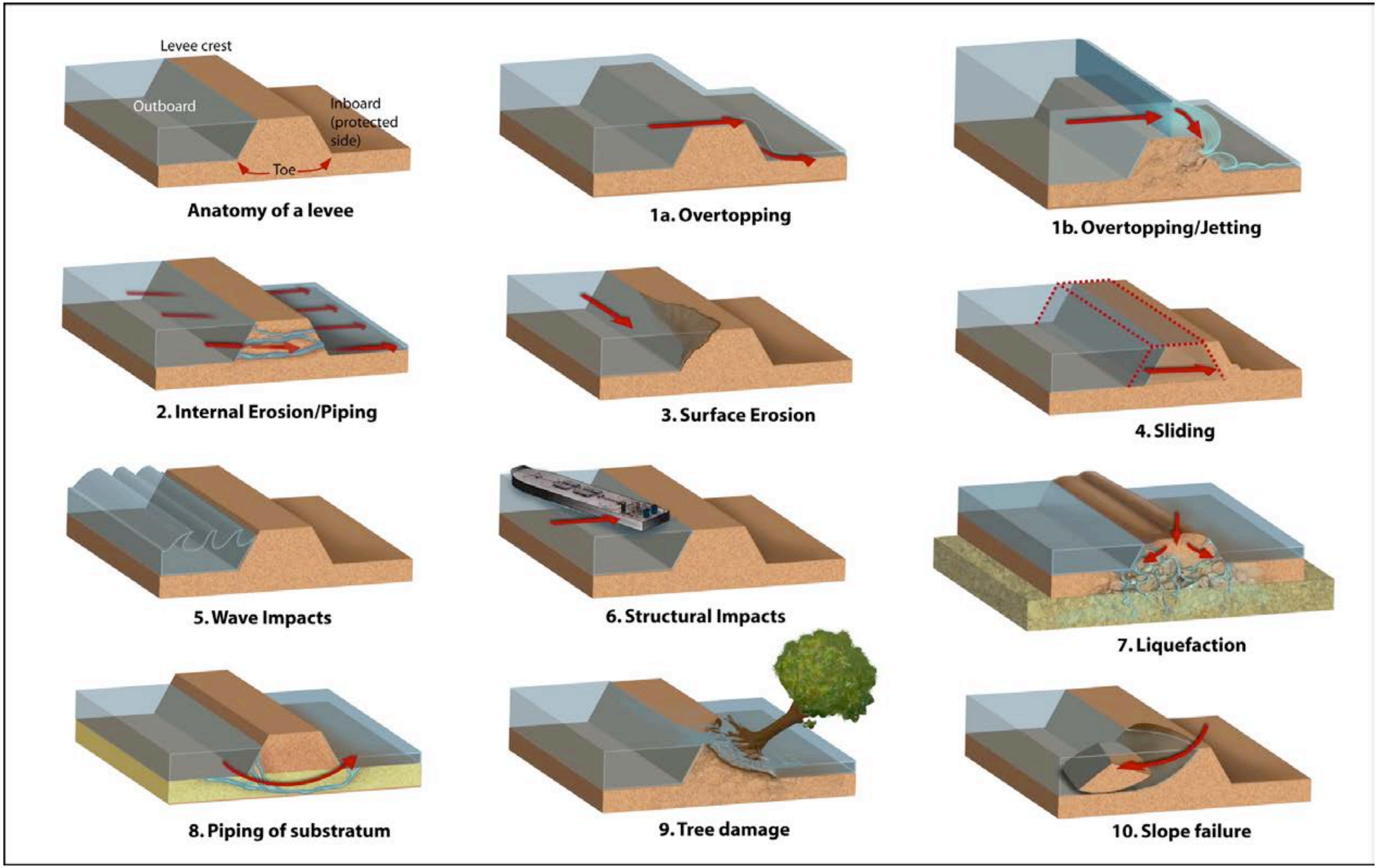

Photo credit: Dave Feliz

1993 FLOOD IN THE MISSISSIPPI RIVER ($20 BILLION DAMAGES)


Photo credit: USGS.com

FISHES GROW IN RIVER AND IN FLOOD BYPASS

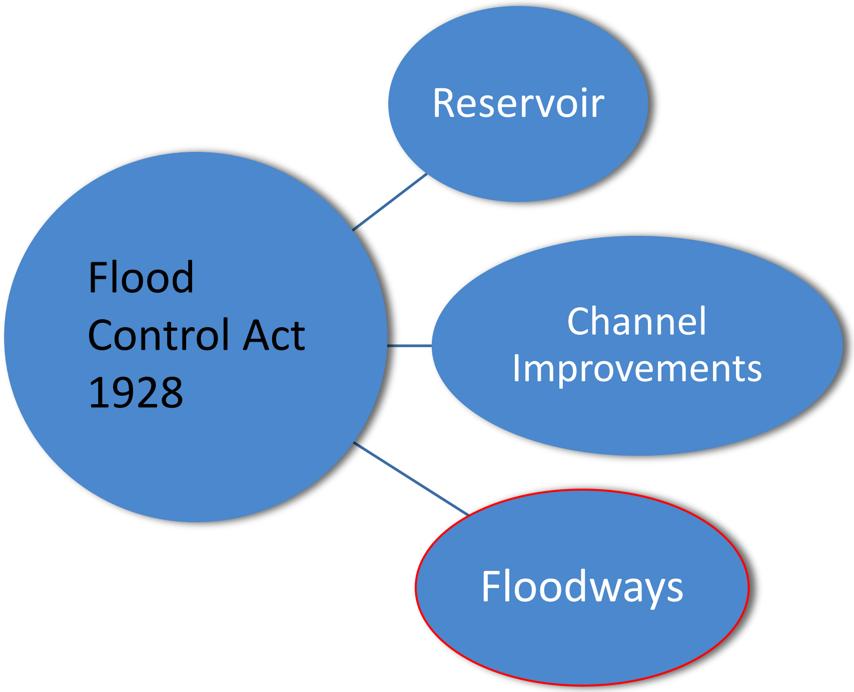
Failure of "conventional" flood protection systems



Source: Room for the River project

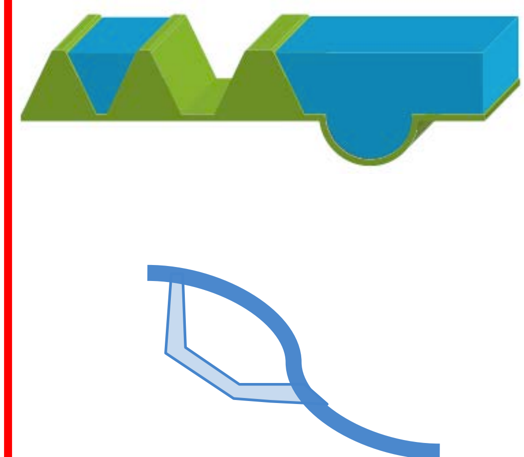
NO LEVEE HAS 0 PROBABILITY TO BE OVERTOPPED

Natural Flood Control: Floodways



A **flood bypass**, referred to as a floodway, permits excessive amount of water in a river or stream to be diverted in land which can tolerate flooding.

Flood Bypass

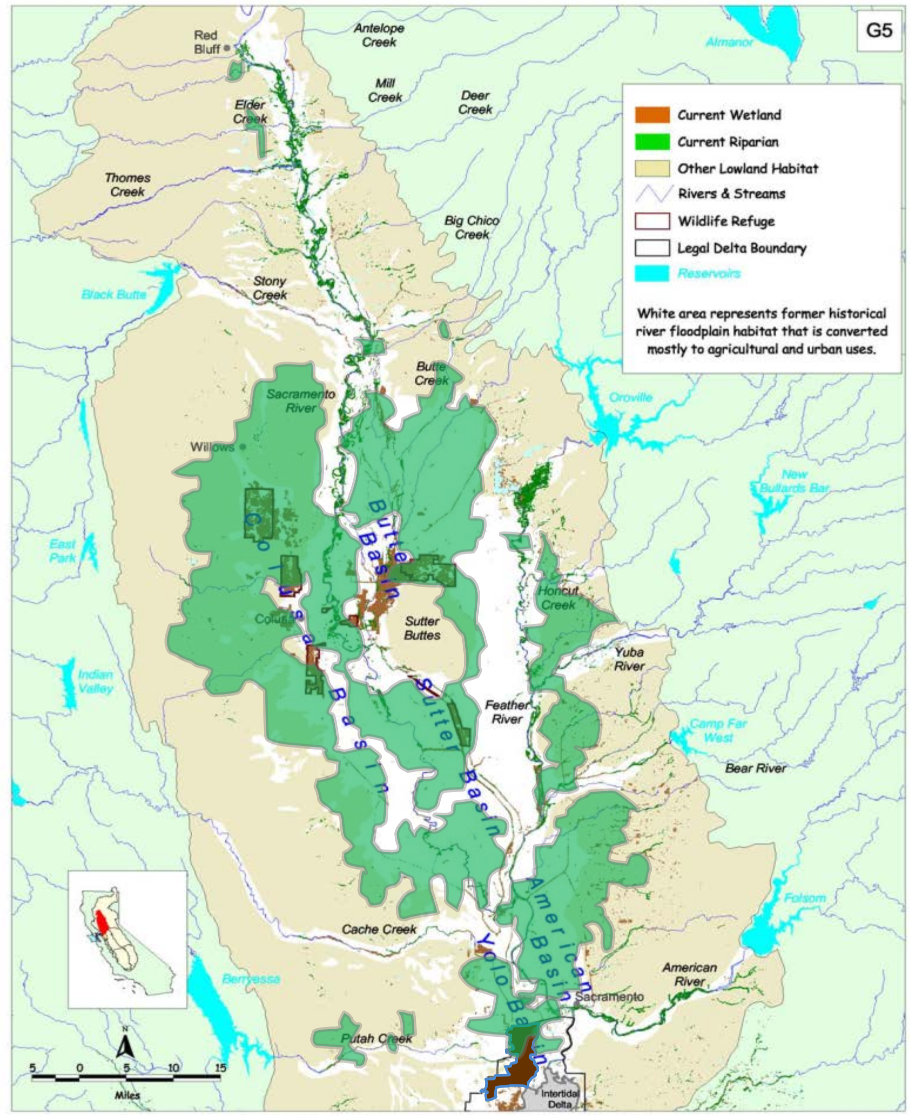


A high-water channel is designed to route overflow away from the river.

- Frequency and duration of inundation
- Ecological benefits
- Land use and land costs

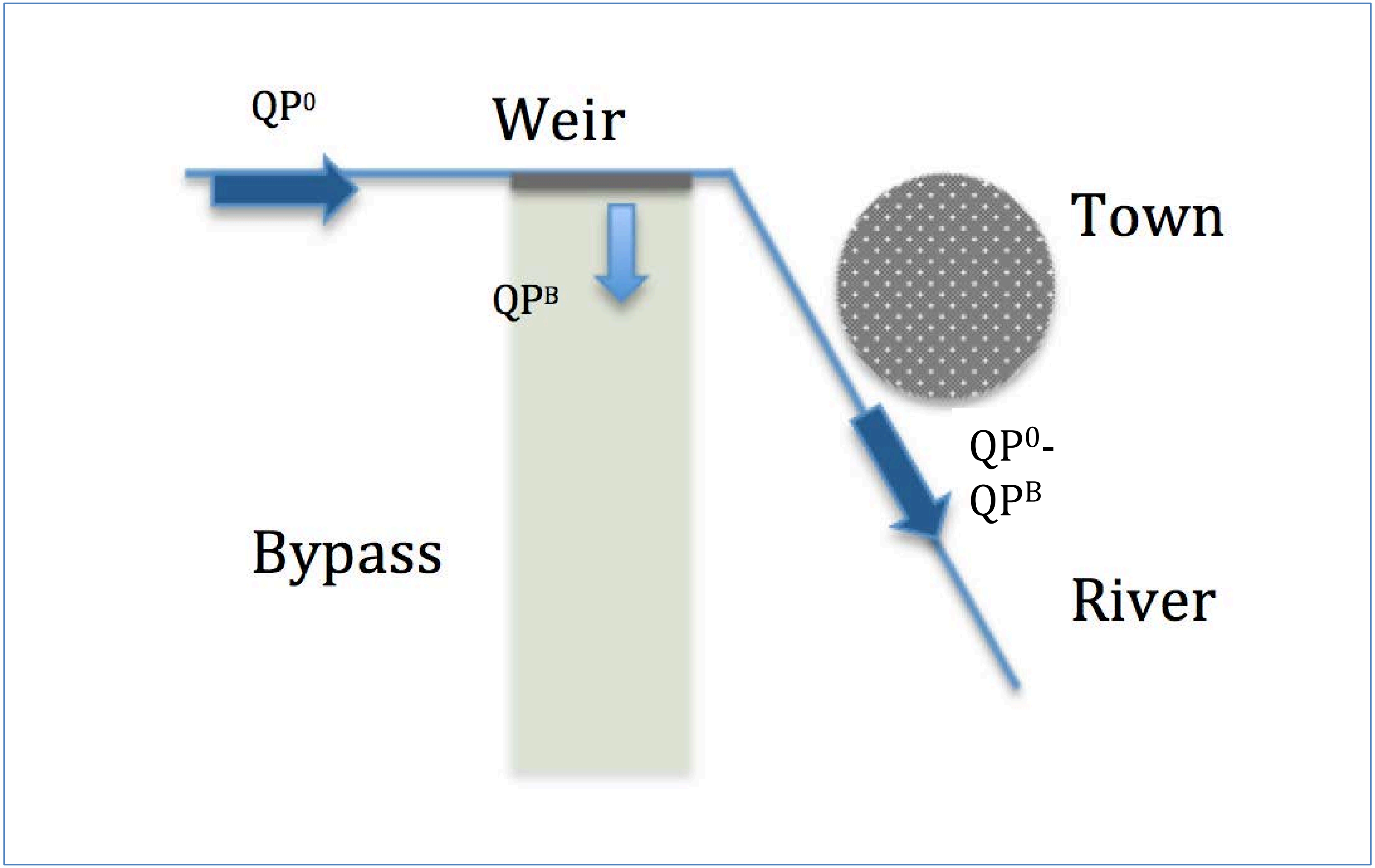
Habitat Loss

- 95% of floodplains lost
- Converted to agriculture and urban development.



Sacramento Valley Current River Floodplain Ecosystem

Flood Bypass Basic Scheme



Optimal Capacity: Flood Risk Reduction Only

The Objective is to maximize the Net Benefits:

$$\text{Max } Z = B(\Delta QC^{B}) - C(\Delta QC^{B})$$

$$B(\Delta QC^{B}) = B_{F}(\Delta QC^{B}) = \int p_{i} \times [D_{i}(QP_{i}^{0}) - D_{i}(QP_{i}^{R})]$$

$$C(\Delta QC^{B}) = C_{L}(\Delta QC^{B}) + C_{C}(\Delta QC^{B}) + C_{W}(\Delta QC^{B}) = c_{L} * \Delta QC^{B} + c_{C} * \Delta QC^{B} + c_{W} * \Delta QC^{B}$$

Constraints:

$QP_{i}^{B} \leq QC^{B} + \Delta QC^{B}$	Floodwater conveyed into the bypass ≤ expanded capacity
$QC^{B} + \Delta QC^{B} \leq QC^{W}$	Expanded capacity ≤ weir capacity
$QP_{i}^{R} = QP_{i}^{0} - QP_{i}^{B}, i = 1{:}N$	Operated peak flow = unregulated peak flow – floodwater conveyed
$\Delta QC^{B} \leq \Delta QC_{max}^{B}$	Bypass expansion ≤ maximum expansion (land availability)
$\Delta QC^{B} \geq 0$	Expansion non negative

Optimal Capacity: Multiple Benefits

$$\text{Max } Z = B(\Delta QC^B) - C(\Delta QC^B)$$

$$B(\Delta QC^B) = B_F(\Delta QC^B) \boxed{+ B_A(\Delta QC^B) + B_R(\Delta QC^B) + B_G(\Delta QC^B)}$$

$$= \int p_i \times [D_i(QP_i^0) - D_i(QP_i^R)] \boxed{+ b_A * \Delta QC^B + b_R * \Delta QC^B + b_G * \Delta QC^B}$$

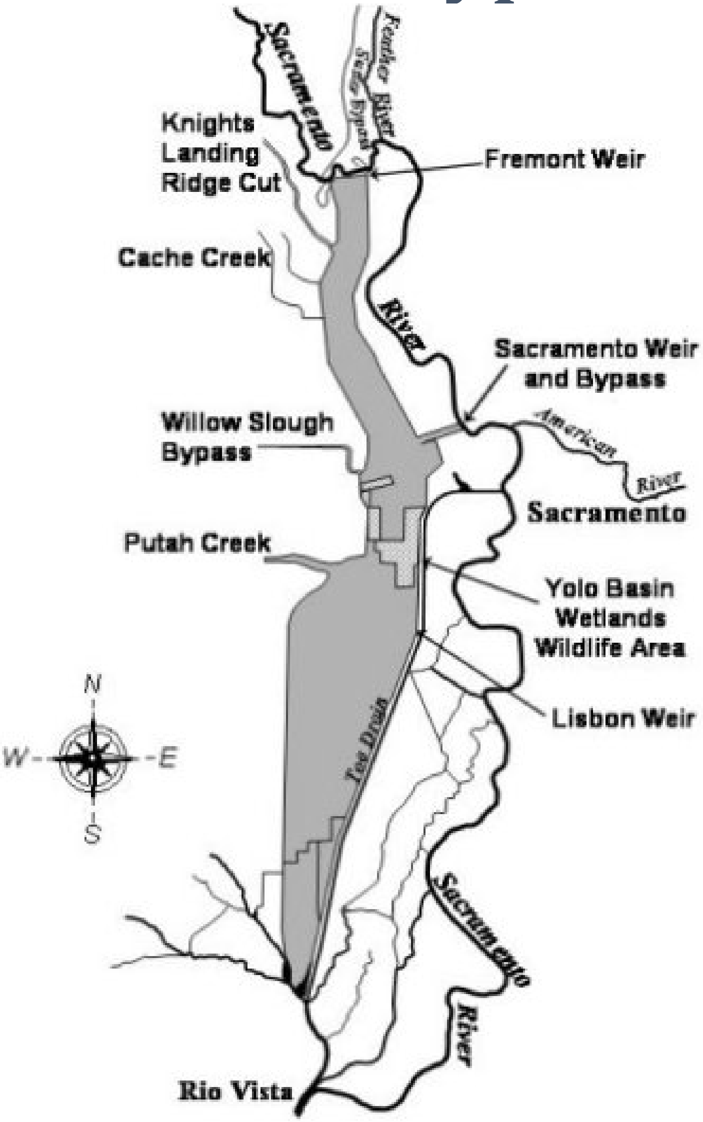
$$C(\Delta QC^B) = C_L(\Delta QC^B) + C_C(\Delta QC^B) + C_W(\Delta QC^B)$$

$$= c_L * \Delta QC^B + c_C * \Delta QC^B + c_W * \Delta QC^B$$

Constraints:

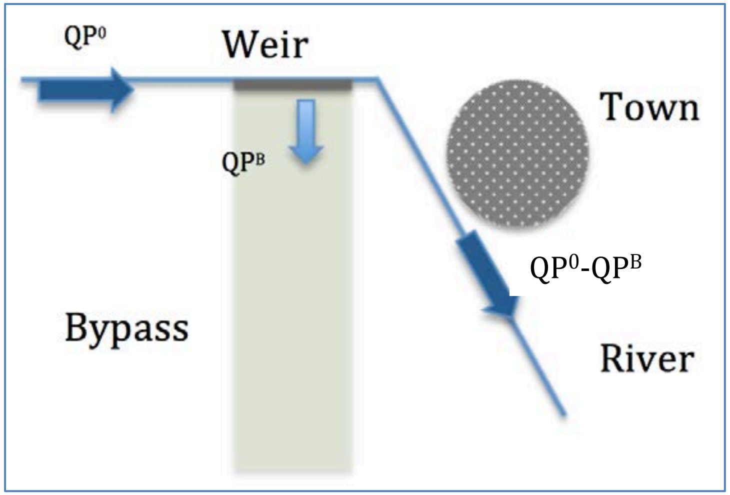
$QP_i^B \leq QC^B + \Delta QC^B$	Floodwater conveyed into the bypass ≤ expanded capacity
$QC^B + \Delta QC^B \leq QC^W$	Expanded capacity ≤ weir capacity
$QP_i^R = QP_i^0 - QP_i^B, i = 1{:}N$	Operated peak flow = unregulated peak flow – floodwater conveyed
$\Delta QC^B \leq \Delta QC^B_{max}$	Bypass expansion ≤ maximum expansion (land availability)
$\Delta QC^B \geq 0$	Expansion non negative

LP Model Application: the Yolo Bypass



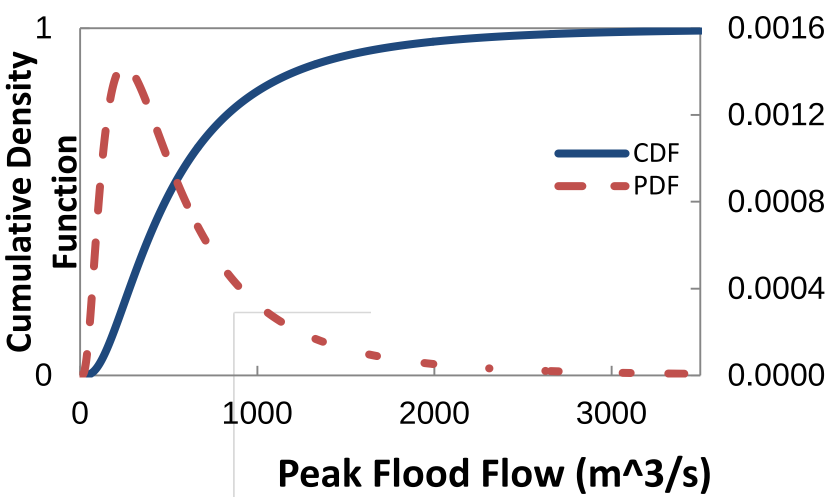
Yolo Bypass system in Sacramento Valley in California (CA Department of Water Resources http://www.water.ca.gov/aes/yolo/)

Simplifications

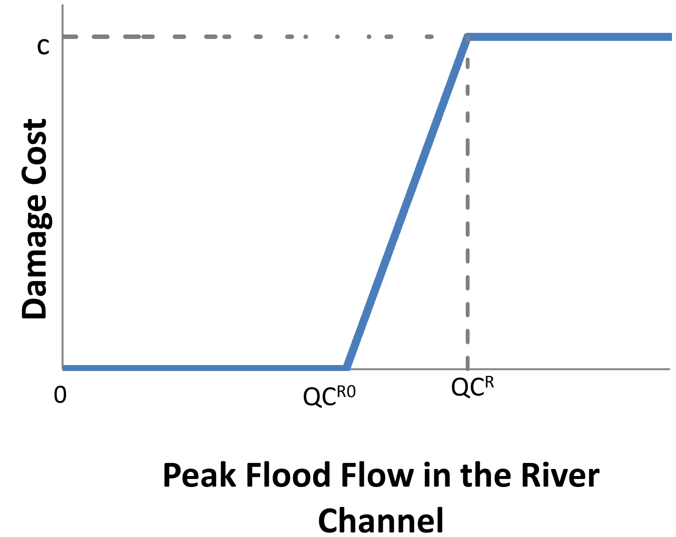


- Bypass shape rectangular
- One only inflow into the bypass
- Bypass capacity equal to weir capacity
- Constant velocity of water in the bypass
- Log-normal distribution of the annual peak flow
- Linear flood damage, dependent on the stage flow level respect to the channel geometry
- 100 years project life

Flood Damage Evaluation

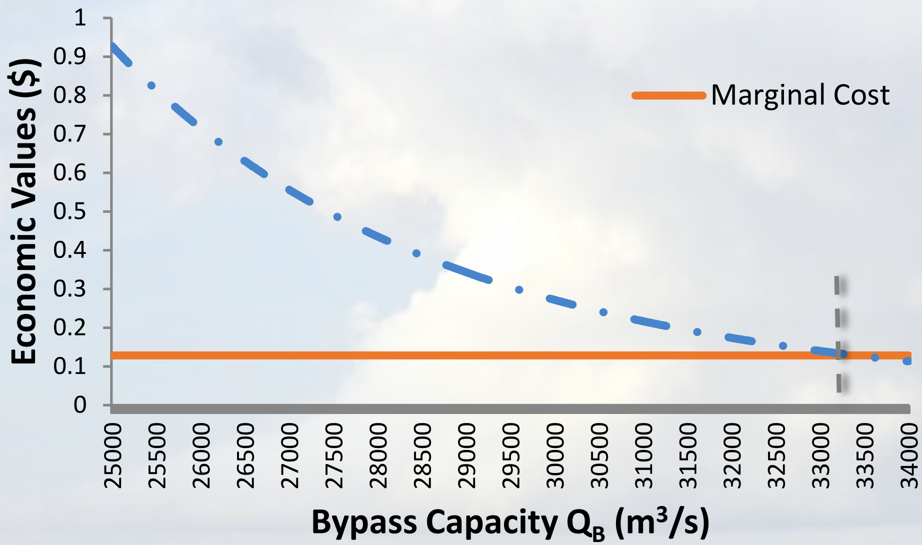


Annual Flood Flow Frequency Distribution, assuming a log-normal distribution

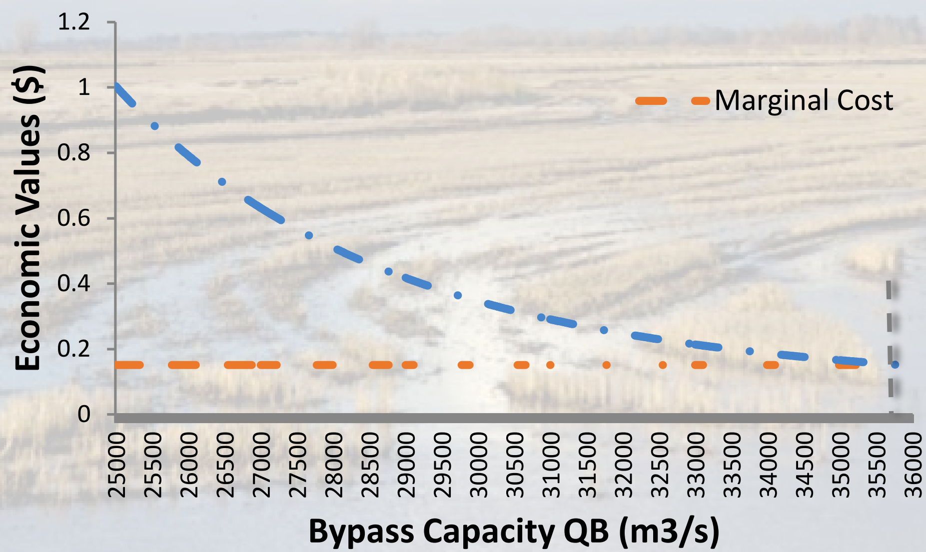


Flood Damage Function assumed to be linear. c catastrophic damage

Results



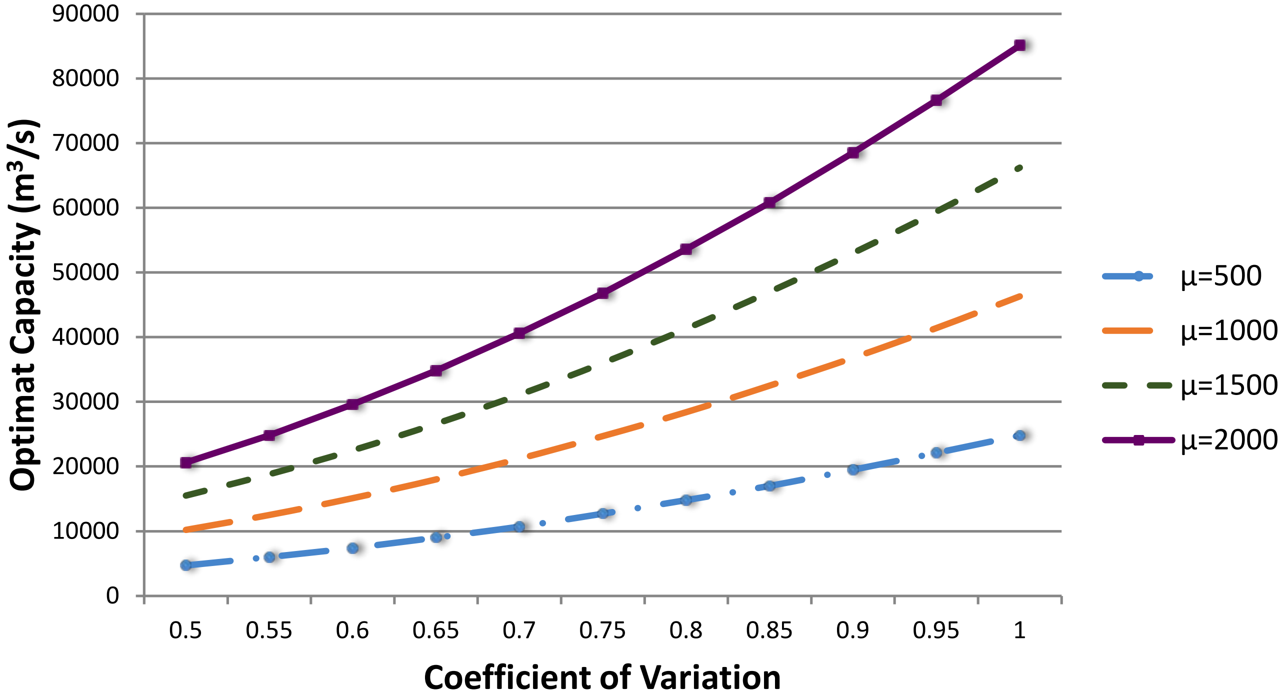
Flood damage reduction only



Multi-benefit

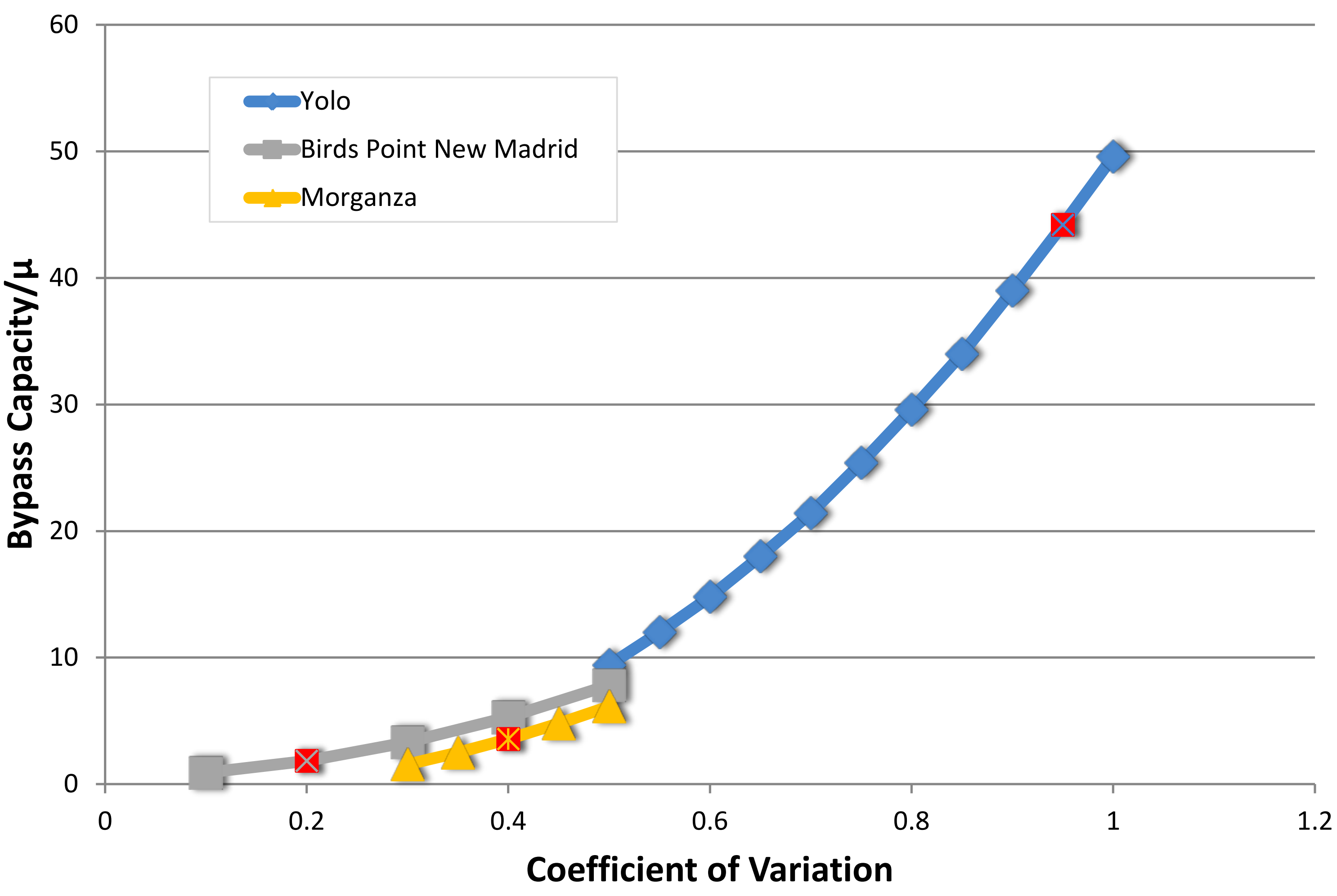
Photo Credit: Carson Jeffres

Sensitivity analysis : flood damage reduction only



Land use cost of purchase [$/acre]	Optimal bypass capacity [m^3/s]
1000	36600
2000	33390
3000	31560
4000	30310
5000	29360

Comparison of world's flood bypasses



Conclusions

- The model can be used by policy-makers as tool to address optimal use of bypass
- A Benefit-cost analysis can be applied to optimize the bypass expansion, as proved by the case studies
- Optimal results are affected mostly by mean peak annual flow magnitude and covariance

Limitations of the model and future developments

- Geometry of the bypass
- Land use analysis
- Damage does not depend only on stage level flow with respect to the channel geometry
- Effect of changes such as human activities in floodplain and climate change
- Policy guidelines about applicability of bypass
- Use of hydraulic modeling for a more accurate damage evaluation

Contact information

Alessia Siclari   asiclari@ucdavis.edu

Optimality Condition

$$\frac{\partial NetBenefit}{\partial \Delta QC^B} = \frac{\partial Z}{\partial \Delta QC^B} = 0$$

$$\frac{\partial B(\Delta QC^B)}{\partial \Delta QC^B} = \frac{\partial C(\Delta QC^B)}{\partial \Delta QC^B}$$

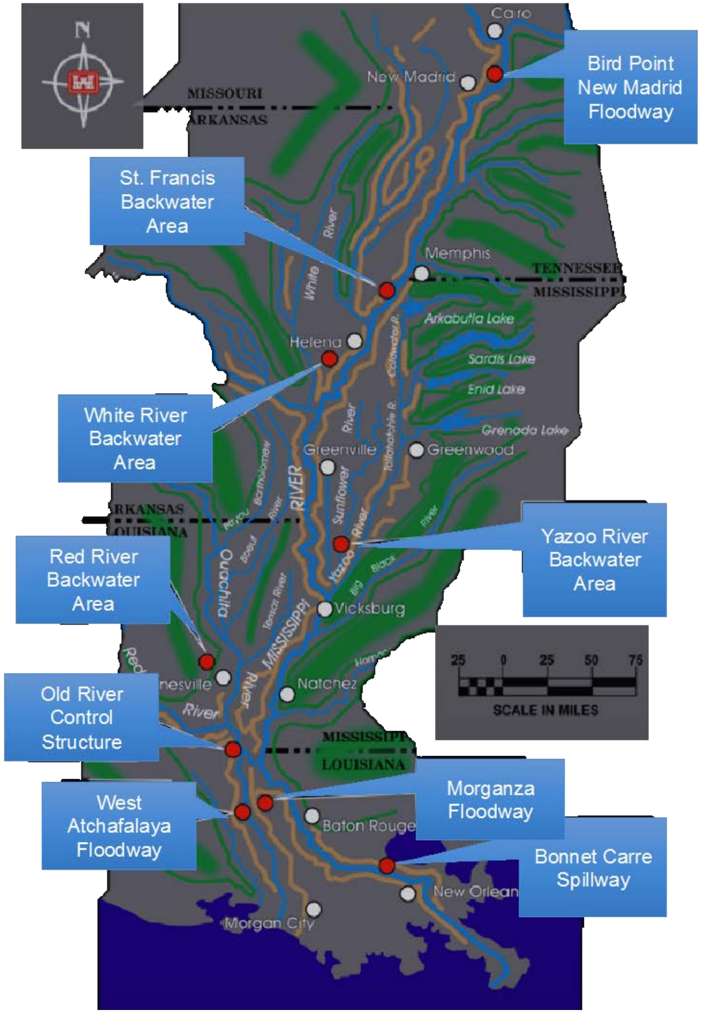
- An additional bypass capacity will bring more cost than benefit.

Data

Bypass	bypass length [m]	10000
	velocity water in the bypass [m/s]	0.2
Weir	overtopping flow [m^3/s]	40
River	QCro Channel Base Flow [m^3/s]	200
	QCr Channel Capacity [m^3/s]	500
	cf Catastrophic damage [million $]	8200
	CV coefficient of variation	0.96
	μ mean [m^3/s]	748

Annual Unit Benefits of expanding the bypass	Ag Revenue Ba(ΔQCb) [$/acre]	550
	Restoration and Recreation Br(ΔQCb) [$/acre]	650
	Groundwater recharge Bg(ΔQCb) [$/acre]	50
(One time) Unit Costs of expanding the bypass	Land use cost of purchase Cl(ΔQCb) [$/acre]	2000
	Construction levee setbacks Cc(ΔQCb) [$/feet]	300
	Weir widening cost Cw(ΔQCb) [$/feet]	400

Mississippi River Basin



Value of floodplains

Floodplains are valuable in terms of Ecosystems, but how do we determine the economic value of a floodplain? The **Center for Resource Efficient Communities** (CREC) at UC Berkeley took into account:

- Flood risk reduction value (including flood stage reductions and avoided residual risk)
- Ecosystem service value (including habitat, food web support, carbon sequestration, water management and sediment services)
- Land use value (including agriculture, recreation and aesthetic values)
- System operations value (including integrated water management, option values, climate change accommodation, and maintenance and liability management)

APPROXIMATE MONETARY MAGNITUDES OF SERVICES OF CONNECTED CENTRAL VALLEY FLOODPLAINS

FLOOD PLAIN VALUE ACCOUNTS	CONCEPTUAL EXAMPLE	ANNUAL VALUE PER FLOODPLAIN ACRE	CONTEXT SENSITIVITY	NOTES
I. FLOOD RISK REDUCTION VALUE				
Reduced flood stage	Yolo Bypass widening	$100s - $1,000s	Depends on extent and intensity of development in affected areas	Assumes 100-year project lifetime and discount rate of 3%
Avoided residual risk	Various sites in Valley	$0 - $1,000s	Depends heavily on local topography	Assumes suburban development densities
II. ECOSYSTEM SERVICE VALUE				
Habitat (incl. food web support)	Central Valley salmon	$100s - $1,000s	Depends on commercial and recreational value of fishery	Same range as findings for habitat value of wetlands generally
Carbon sequestration	Delta	$10s - $100s	Depends on soil types and price of carbon	Delta has unusually good potential
Water quality maintenance	Valley-wide	<$0 - $100s	Depends upon intended uses of water	Effects can be negative as well as positive
Groundwater recharge	Gravelly Ford, Yolo Bypass	$0 - $100s	Requires suitable soils and aquifers	Value and recoverability of water varies by site
Sediment deposition	Cosumnes	$0 - $100s	Depends on channel morphology/hydrology	Avoided cost of channel dredging downstream
III. LAND USE VALUE				
Agriculture (net profits)	Yolo Bypass	$100s - $1,000s	Depends on crops and flow timing in the floodplains	Floodplain soils generally well suited to agriculture
Recreation	Delta	$100s	Depends on proximity to population centers	Care should be taken not to double-count habitat values
Visual and place values	Lower San Joaquin	$0 - $100s	Depends on visual accessibility of floodplain to homes	"Place-branding" value highly indeterminate
IV. SYSTEM OPERATIONS VALUE				
Integrated water management	Yolo Bypass	$100s	Depends on system architecture and reservoir operations	Calculating potential water supply gains is highly complex
Option value	Valley-wide	$0 - $10s (per $100m in future savings)	Depends on whether floodplain connection preserves lower-cost future management options	Assumes 50-year horizon at 7% discount rate; history of Yolo Bypass suggests that future management options could vary by >$800m.
Maintenance and liability	Valley-wide	Unknown	Depends on local soils, hydrology	Data insufficient to support generalizations