Flexibility in Flood Management Systems
with application to California’s Central Valley, USA

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“An increase in... the flexibility and adaptive capacity of water management regimes should be a primary management goal.”

(Pahl-Wostl et al 2007)
“Towards a definition of flexibility: in search of the Holy Grail” (Golden and Powell, 2000)

Flexibility is:

the inherent ability of a system... to cope with or adapt to uncertain and changing conditions, ...in a timely and cost-effective manner.

(DiFrancesco and Tullos, in review)
Characteristics of Flexible Water Management Systems

Characteristics

Flood system components (S: Structural, NS: Non-structural)

Slack - degree of excess capacity; underutilization (Turner and Lankford, 2005)
- Storage capacity of reservoirs/bypasses/easements (S)
- Stream conveyance capacity, reservoir release capacity, bypass inflow/outflow (S)
- Available flood management funds (NS)

Intensity - degree of repetitiveness; diversity of options (Turner and Lankford, 2005)
- Number of on-stream or off-stream reservoirs, bypasses, or easements (S)
- Number of agencies capable of assisting in flood management (NS)

Connectivity - ability to exchange matter, energy, and/or organisms (Duncan, 1995; Byrd and Turner, 2000)
- Magnitude/duration/frequency of river-floodplain connection (S)
- Use of surface-ground water conjunctive use operations (S)
- Longitudinal flux of water and materials (S)

Adjustability - ability to add, modify, and remove any component of the system (Duncan, 1995)
- Time and/or cost required to adjust the physical system or operations (S & NS)

Compatibility/Coordination - ability to utilize and share available information (Duncan, 1995; Byrd and Turner, 2000)
- Amount of data and information available for decision making (NS)
- Tools available to enhance use of data and information (NS)
**Hypothesized relationship between flexibility and adaptive capacity**

**Flexibility characteristics**
- Slack
- Intensity
- Connectivity
- Adjustability
- Compatibility/Coordination

**Increased ability to cope or adapt**
- Robustness
- Adaptability

**Quickly and cost-effectively**
- Responsiveness
- Efficiency
Application of Flexibility Framework
Comparison of management approaches in the 2012 Central Valley Flood Protection Plan (CVFPP)
Sacramento & San Joaquin River Basins
California’s Central Valley, USA

• Area
  ○ Sacramento Basin ≈ 70,500 km²
  ○ San Joaquin Basin ≈ 39,000 km²

• Climate
  ○ Mediterranean – wet winter, dry summer
  ○ Sierra snow melt
“Battling the Inland Sea”
(Robert Kelley, 1989)

State Plan for Flood Control (SPFC)

- 4 dams; 10 major multi-purpose
- \( \approx 2,600 \text{ km of levees, } \frac{1}{2} \text{ “high concern” } \)
- 7 relief bypasses

Some of the highest flood risk in the U.S.
(USACE 2002)

Photo credits, top left, down then across: Center for Sacramento History, Dottie Smith, Anthony Dunn, Dave Feliz, Adrian Mendoza, CA-DWR
Central Valley Flood Protection Plan (CVFPP, 2012)

- Primary Goal – Improve Flood Risk Management
- Secondary - O& M, Ecosystems, Institutional Support, Multiple-Benefits

CVFPP Management Approaches

- **Design Capacity**
  (State Plan for Flood Control – SPFC)
  - Levees in all areas

- **Lower Risk**
  (Protect High Risk Communities - PHRC)
  - Levees in high risk population centers

- **Enhance System**
  (Enhance Flood System Capacity - EFSC)
  - Levees in all areas, and multi-benefit projects

Systemwide Investment
(State Systemwide Investment Approach (SSIA))
Comparison of Approaches - diversity of projects

(2012 Central Valley Flood Protection Plan)
Comparison of Approaches - diversity of projects

- Land Use and Floodplain Management Integration
- Purchasing and Relocating Homes in Floodplains
- Raising and Waterproofing Structures and Building Berms
- Sacramento Channel and Levee Management and Bank Protection
- Develop and Implement Enhanced O&M Programs and Regional Organizations
- Identification and Repair of After Event Erosions
- Additional Forecasting and Notification
- Local Flood Emergency Response Planning
- All Weather Roads on Levee Crowns
- Additional Flood Information Collection and Sharing
- Known and Identified Erosion Repairs
- Site-Specific Rural Agricultural Improvement
- Rural Setback Leves
- Non-Urban - Design Capacity Improvements
- Small Community Levee Improvement 100-Year Protection
- Non-SPFC Urban Levee Improvements
- Urban improvement
- System Erosion and Bypass Sediment Removal Project
- Easements
- New Reservoir Storage
- Forecast-Coordinated/Forecast-Based Operations
- Flood System and Fish Passage Structures
- Improve Existing Levees
- New Levee Construction
- Ecosystem Restoration and Enhancement
- Agricultural Conservation Easement
- Land Acquisition

(2012 Central Valley Flood Protection Plan)
Comparison of Approaches - flexibility characteristics enhanced (expenditure $)

Design Capacity

Lower Risk

Enhance System

Systemwide Investment

- Slack
- Intensity
- Connectivity
- Adjustability
- Compatibility/ Coordination

Introduced inflexibilities???
(ex. more/ stronger levees decrease connectivity)
Hypothesized relationship between flexibility and adaptive capacity

Flexibility characteristics:
- Slack
- Intensity
- Connectivity
- Adjustability
- Compatibility/Coordination

Increased ability to cope or adapt:
- Robustness
- Adaptability

Quickly and cost-effectively:
- Responsiveness
- Efficiency
## Approach Comparison - Costs and benefits

<table>
<thead>
<tr>
<th>Approach</th>
<th>Cost range ($ Billion)</th>
<th>Implementation time (yrs)</th>
<th>Expected Annual Damages ($ Million)</th>
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</thead>
<tbody>
<tr>
<td>No project</td>
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<td>329</td>
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<tr>
<td>State Plan Flood Capacity (SPFC)</td>
<td>18 to 23</td>
<td>30 to 35</td>
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<td>Protect High Risk Communities (PHRC)</td>
<td>8 to 10</td>
<td>15 to 20</td>
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<tr>
<td>Enhance Flood System Capacity (EFSC)</td>
<td>32 to 41</td>
<td>35 to 40</td>
<td>64</td>
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<tr>
<td>State Systemwide Investment (SSIA)</td>
<td>14 to 17</td>
<td>20 to 25</td>
<td>111</td>
</tr>
</tbody>
</table>

(2012 Central Valley Flood Protection Plan)
Responsiveness and efficiency – current conditions

Cost effectiveness

Time effectiveness
Conclusions and Future Work

- **So far...**
  - Framework for operationalizing “flexibility” in water resources
  - Application to 2012 Central Valley Flood Protection Plan Approaches
    - Primary expenditures → Slack
    - Enhance System (EFSC) & Systemwide Investment (SSIA) Approaches → More diverse enhancement of flexibility characteristics
    - Lower Risk Approach (PHRC) → most cost- and time- effective, followed by Systemwide Investment (SSIA)

- **Ongoing work...**
  - More detailed case study and inter-basin comparisons
  - Robustness and adaptability (climate change projections)
    - Relationship between flexibility, robustness and adaptability
  - Peak flexibility?
  - Apply definition to other water resources objectives
• Thank you!
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  o Cristina Mateus, Matt Cox, Cara Walter (Rivers Lab Group)
• Questions???
• Follow-up
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