Outline

Background

Methods (Drive-by)

Findings (recent applications)

Where to From Here?

Discussion!
Why TNC developed EFT

1. Evaluate ecological trade-offs of alternative water projects and water project operations.
2. Develop a broader set of functional ecological flow guidelines.
Link hydrogeomorphic models to representative suite of functional ecosystem indicators in one decision analysis tool for evaluating multiple trade-offs
Application of the Ecological Flows Tool to Complement Water Planning Efforts in the Delta & Sacramento River

Multi-Species Effects Analysis & Ecological Flow Criteria

Ecosystem Restoration Program Agreement E0720044

Final Report
April 30, 2014
Sufficient detail …

Model Complexity

- ability to understand model behaviour
- ease of application (data, cost)
- ease of interdisciplinary linkage
- community of users (shrinks)

Things that increase w complexity
- spatial / temporal resolution
- acceptability to disciplinary specialist
- perceived “realism” of process representation
- cost
- tuning & equifinality

Things that decrease w complexity
- high
- low
- simple
- intermediate
- very complex

EFT
Ecological Flows Tool
“...The panel believes it is essential that a ... dedicated project to build a simplified ecosystem model ... [including] existing modeling capabilities ... will require a full-time multidisciplinary team devoted for at least several years...”

~ CALFED Science Advisory Panel, June 24, 2008

“... A variety of modeling approaches needed ... including those ... model the behavior of a complex system by simplifying it... Developing a decision analysis tool for the Delta, similar to SacEFT, should be considered.”

1 decision support platform

13 species

Invasive sp. deterrence
Steelhead trout
Spring, Fall, L Fall, Winter-run Chinook salmon
Green sturgeon
Western pond turtle
Fremont Cottonwood
Bank swallow
Splittail
Longfin smelt
Delta smelt
Tidal wetlands

DelteEFT
Delta Ecological Flows Tool

SacEFT
Sacramento River Ecological Flows Tool
25 performance indicators

- Invasive sp. deterrence
- Steelhead trout
- Tidal wetlands
- Delta smelt
- Spiltnail
- Bank swallow
- Fremont Cottonwood
- Green sturgeon
- Spring, Fall, L Fall, Winter-run Chinook salmon
- Western pond turtle
- Trout
- Freshwater wetland area - TW7
- Spawning success (index) - DS1
- Habitat suitability (index) - DS2
- Entrainment risk (index) - DS4
- Abundance (index) - LS1
- Potential spawning habitat - SSI
- Suitable habitat potential - BSV1
- Suitable habitat potential at spawning site - BSV2
- Preliminary sedimentation during nesting - BSV3
- Preliminary sedimentation during nesting at spawning site - BSV4
- Reintroduction during nesting - BSV5
- Reintroduction during nesting at spawning site - BSV6
- Juvenile mortality risk (passage time) - CS9
- Juvenile temperature stress - CS10
- Juvenile stranding index - CS1
- Juvenile development in Yolo Bypass - CS7
- Egg-to-larvae survival - CS11
- Adult survival - CS12
Over 70 scientists

<table>
<thead>
<tr>
<th>Core Team</th>
<th>SacEFT Workshop Participants</th>
<th>Delta EFT Workshop Participants &amp; DeltaEFT Design contributors</th>
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<tr>
<td>Ryan Luster, TNC</td>
<td>Tricia Brachter, DFG</td>
<td>Peter Kimley, UC</td>
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<td>Mike Roberts, (formerly TNC)</td>
<td>Ron Schlaff, DFG</td>
<td>Eric Larsen, UC Davis</td>
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<td>Greg Golet, TNC</td>
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<td>Campbell Ingram, Delta Conservancy</td>
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<td>Anthony Sarcinio, (formerly TNC)</td>
<td>Stacy Cepello, DWR</td>
<td>Buford Holt, USBR</td>
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<td>Marc Neitz, Essa</td>
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<td>David Marmorek, Essa</td>
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<td>Dave Vogel</td>
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<td>Ted Sommer, DWR</td>
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</table>
Outline

Background

Methods (Drive-by)

Findings (recent applications)

Where to From Here?

Discussion !
Management actions evaluated

Reservoir Operations & Conveyance
- Sacramento River dam / diversion operations
- Delta conveyance & pumping operations
- Coordinated operational criteria (e.g., biological opinions, D-1641 variations)
- External climate forcing
- Alternative human population demands

Bank protection & gravel augmentation
- River meander, soil erosion
- Effects on bank swallow habitat suitability, large woody debris recruitment, flows
- TUGS model, effects on salmon spawning habitat suitability
<table>
<thead>
<tr>
<th>Focal Species &amp; Habitats</th>
<th>Ecological Objectives</th>
<th>Performance Indicators</th>
<th>Foundation Research</th>
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</thead>
</table>
| Fremont cottonwood       | Maximize areas available for riparian initiation, and rates of initiation success at individual index sites. | FC1 Cottonwood seedling initiation index  
FC2 Risk of scour after successful initiation | Mahoney and Rood 1998; Roberts et al. 2002; Roberts 2003; HEC-RAS supplemented stage-discharge relations; Alexander 2004 |
| Bank swallow             | Maximize availability of suitable nesting habitat  
BASW1 Suitable habitat potential (bank length, m)  
BASW2 Risk of inundation and bank sloughing during nesting | | Garrison (1998, 1999); Moffatt et al. (2005); Stillwater Sciences (2007); Heneberg (2009); Natural Resources Conservation Service (2011) |
| Western pond turtle habitat, mainstem Sacramento River | Maximize availability of habitat for foraging, basking, and predator avoidance | LWD1 Index of old vegetation recruited to Sacramento River (ha) | Larsen (1995); Larsen and Greco (2002); Larsen et al. (2006)  
2007 GIS layer Sacramento River GIS portal representing mature vegetation |
| Green sturgeon           | Maximize quality of habitat for egg incubation | GS1 Egg to larvae survival (proportion) | Cech et al. (2000); ESSA Technologies Ltd. (2005) |
| Chinook salmon Steelhead trout | Maximize quality of habitat for adult spawning  
Maximize quality of habitat for egg incubation  
Maximize availability and quality of habitat for juvenile rearing | CS1 Area suitable spawning habitat (000s ft²)  
CS3 Thermal egg-to-fry survival (proportion)  
CS5 Redd scour (scour days)  
CS6 Redd dewatering (proportion)  
CS2 Area suitable rearing habitat (000s ft²)  
CS4 Juvenile standing index | Vogel and Marine (1991); USFWS / Mark Gard (2003, 2005a); USFWS (2005b); USFWS (2006) |
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<td>Egg-to-larvae survival (proportion)</td>
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<td>CS4</td>
<td>Juvenile stranding (index)</td>
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Mahoney and Rood 1998; Roberts et al. 2002; Roberts 2003; HEC-RAS supplemented stage-discharge relations; Alexander 2004

Recommendations from Riparian ecologists at the SacEFT v.1 peer review and refinements workshop (see SacEFT Design Document Section 4.3.4, pp. 96-102).

Garrison (1998, 1999); Moffatt et al. (2005); Stillwater Sciences (2007); Heneberg (2009); Natural Resources Conservation Service (2011)

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Vogel and Marine (1991); USFWS / Mark Gard (2003, 2005a); USFWS (2005b); USFWS (2006)
# Ecologically important life history timing

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<td>Spring smolt migration (CS 7,9,10)</td>
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Coupled modeling

**CALSIM-II**
- Monthly flows

**USRDOM**
- Daily flow disaggregation
- Northern boundary = Keswick
- Southern boundary = Knights Landing

**SRWQM**
- Daily flow disaggregation
- Daily water temperatures
- Same boundaries as USRDOM

**Sacramento River**
- The Unified Gravel-Sand (TUGS) sediment transport model
- Meander Migration (MM) model

**Delta**
- DSM2 (HYDRO-QUAL-PTM)
  - Flow, stage, salinity, water temperature, particle fate, turbidity (if avail.)
  - Tides, hydrodynamics
  - Boundary conditions = stage at Martinez, monthly water diversions into Delta
  - Own node-link representation

**EFT Database**
- Hydro-ecological response algorithms
Ecologically important index locations

| EFT Short Name | Gauge or Common Name Location | River Code | RM | RKI | D9M2 Name | CDEC Name | Gauge Owner | Native Code | CS | CSS | D51 | D52 | D54 | D56 | S11 | S14 | T16 | T20 | I1 | I1D1 | I1D2 | I1D3 |
|----------------|------------------------------|------------|----|-----|-----------|-----------|-------------|-------------|----|-----|-----|-----|-----|-----|-----|-----|-----|----|-----|-----|-----|
|                |                              |            |    |     | 5G         | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | F   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 1G         | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 7G         | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 12G        | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 14G        | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 19G        | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 22G        | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 24G        | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
|                |                              |            |    |     | 28G        | EFL        | USGS        |             | F  | F   | F   | T   | F   | T   | F   | T   | F   | F   | F   | T   | F   | I   | I   |
Outline

- Background
- Methods
- Types of output
- Findings (recent applications)
- Where to From Here?
- Discussion!
Relative suitability rating

Habitat centered performance measure

Driving variable(s) (flow, water temp, channel migration rate, etc.)

GOOD

FAIR

POOR
Output: Annual “roll-up”
Output: Multi-year “roll-up”
Table 2.11: EFT effects analysis – high-level roll-up using the relative suitability (RS) method. The method reports the percentage change in the years with good/favorable conditions compared to a reference case. This standardizes the comparison units in terms of a relative suitability rating and is internally consistent and able to accurately identify alternatives that are better or worse. The RS method does not provide an assessment of *absolute* suitability.

<table>
<thead>
<tr>
<th>Focal species</th>
<th>Performance indicator (incomplete listing)</th>
<th>Effect Alternative vs. Reference case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alt. 1</td>
</tr>
<tr>
<td><strong>Upper and Middle Sacramento River Indicators</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall Chinook</td>
<td>Suitable spawning habitat (CS1)</td>
<td>15</td>
</tr>
<tr>
<td>Late Fall Chinook</td>
<td>Suitable spawning habitat (CS1)</td>
<td>-3</td>
</tr>
<tr>
<td>Winter Chinook</td>
<td>Juvenile stranding (CS4)</td>
<td>-14</td>
</tr>
<tr>
<td></td>
<td>Suitable rearing habitat (CS2)</td>
<td>10</td>
</tr>
</tbody>
</table>
### Output: effect size (ES)

<table>
<thead>
<tr>
<th>Focal species</th>
<th>Performance indicator (incomplete listing)</th>
<th>Reference case</th>
<th>Alt. 1</th>
<th>Alt. 2</th>
<th>Alt. n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Upper and Middle Sacramento River Indicators</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall Chinook</td>
<td>Suitable spawning habitat (CS1; 000s ft²)</td>
<td>3,738</td>
<td>4,081 (9.2%)</td>
<td>4,069 (8.9%)</td>
<td>3,998 (6.9%)</td>
</tr>
<tr>
<td>Late Fall Chinook</td>
<td>Suitable spawning habitat (CS1; 000s ft²)</td>
<td>1,272</td>
<td>1,195 (-6.0%)</td>
<td>1,187 (-6.7%)</td>
<td>1,232 (-3.1%)</td>
</tr>
<tr>
<td>Winter Chinook</td>
<td>Juvenile stranding index (CS4)</td>
<td>0.085</td>
<td>0.106 (-2.1%)</td>
<td>0.094 (-0.9%)</td>
<td>0.101 (-1.6%)</td>
</tr>
<tr>
<td></td>
<td>Suitable rearing habitat (CS2; 000s ft²)</td>
<td>37,153</td>
<td>37,602 (1.2%)</td>
<td>37,804 (1.8%)</td>
<td>37,101 (-0.1%)</td>
</tr>
</tbody>
</table>
Output: effect size (ES) box plots

Delta Smelt - Larval & juvenile entrainment

Steelhead - Smolt temperature stress

Scenario
- Historical
- NAA-Current
- NAA-ELT
- NAA-LLT

Temperature stress (degree days)
Output: within year daily results @ specific locations
Output: Spatial visualizations / animations

http://youtu.be/WcwRdM3f6Ao
<table>
<thead>
<tr>
<th>Focal species</th>
<th>All Alternatives</th>
<th>ESO-ELT (237)</th>
<th>LOS-ELT (238)</th>
<th>HOS-ELT (242)</th>
<th>Primary benefit / [Challenge]</th>
<th>Caveats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Chinook</td>
<td>↑</td>
<td></td>
<td></td>
<td></td>
<td>CS1</td>
<td></td>
</tr>
<tr>
<td>Late Fall Chinook</td>
<td>↑</td>
<td>&lt;benefit from ELT baseline conditions, not the alternatives&gt;</td>
<td></td>
<td></td>
<td>CS2, CS7 [CS10]</td>
<td>Delta thermal stress (CS10)</td>
</tr>
<tr>
<td>Spring Chinook</td>
<td>¬</td>
<td>↑</td>
<td>↑</td>
<td>¬</td>
<td>CS1, CS6, CS2</td>
<td></td>
</tr>
<tr>
<td>Winter Chinook</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td></td>
<td>Delta thermal stress (CS10)</td>
</tr>
<tr>
<td>Steelhead</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td></td>
<td>Delta thermal stress (CS10)</td>
</tr>
<tr>
<td>Bank Swallows</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green sturgeon</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td>[GS1]</td>
<td></td>
</tr>
<tr>
<td>Fremont cottonwood</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large woody debris</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Splittail</td>
<td>↑</td>
<td></td>
<td>¬</td>
<td></td>
<td></td>
<td>Fremont weir notch included in all project alternatives</td>
</tr>
<tr>
<td>Delta Smelt</td>
<td>¬</td>
<td></td>
<td>¬</td>
<td></td>
<td>[DS2]</td>
<td></td>
</tr>
<tr>
<td>Longfin Smelt</td>
<td>¬</td>
<td></td>
<td></td>
<td>↑</td>
<td>LS1</td>
<td></td>
</tr>
<tr>
<td>Invasive Deterrence</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td>[ID2]</td>
<td></td>
</tr>
<tr>
<td>Tidal Wetlands</td>
<td>¬</td>
<td></td>
<td></td>
<td>¬</td>
<td></td>
<td>We do not consider physical habitat restoration effects in this EFT analysis (did not have post restoration DEM)</td>
</tr>
</tbody>
</table>
Recent EFT applications

Effects Analysis Application of SacEFT to North-of-the-Delta Offstream Storage Investigation
- SacEFT
- 5 alternatives including reference case
- Analysis based on RS method (only)

Effects Analysis Application to BDCP
- SacEFT & DeltaEFT
- 8 alternatives including reference case and future climate change variants
- Full analysis

Pilot investigation – Incorporating EFT Derived Ecological Flow Criteria to CALSIM
- Rule-sets converted to WRESL
- Winter-run chinook and Delta smelt

Recent EFT applications
## EFT effects analyses

### Step 1
- EFT baseline simulation *(relative suitability thresholds)*
- Study simulations:
  - Reference case
  - Alternatives
- Establish structure of comparisons

### Step 2
- Assess degree of change physical variables (flow, water temp, salinity, etc.)

### Step 3
- Examine changes in EFT perf. indicators using different methods (RS, ES, boxplots, etc.)
- Identify major trade-offs

### Step 4
- Perform weight of evidence net effect scoring (NES)
- Provide interpretative narrative
- Document caveats/limitations
BDCP effects analysis: Key Findings

1. LOS preferable for species in Sacramento River HOS preferable for Delta species.
   - LOS ecosystem benefits only slightly better for Sacramento River, results from HOS generally very similar.
   - Various trade-offs noted, HOS alternative is likely most preferable.
## BDCP effects analysis: Key Findings

<table>
<thead>
<tr>
<th>Winners</th>
<th>Losers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall-run Chinook,</td>
<td>❙ Green sturgeon,</td>
</tr>
<tr>
<td>❙ Late fall-run Chinook &amp;</td>
<td>❙ deterrence of invasives,</td>
</tr>
<tr>
<td>❙ Splittail</td>
<td>❙ brackish wetland habitats</td>
</tr>
</tbody>
</table>
2. Climate change dwarfed effects of operational alternatives,

- From ecosystem point of view, inadequate to compare future operations *relative to a progressively deteriorating baseline*. 
Deteriorating baseline comparisons mask “what matters” ecologically

**Ecological Flows Tool: Indicator $w$; % of simulation years with favorable conditions**

- Base Case 1 With operation alternative 1
- Base Case 2 With operation alternative 2
- Base Case 3 With operation alternative 3

**Climate and/or demand effect**

- Current ELT
- LLT
3. BDCP alternatives include some offsetting benefits.
   • e.g., Delta rearing conditions improved by notching Fremont Weir, higher X2 outflows, USFWS (2008), NMFS (2009) actions.
   • Relative benefit of flow mediated improvements will depend on detrimental effects of *warming water temperatures.*
4. Reservoir operational criteria cemented in BDCP effects modeling highly constrained, limiting ability of BDCP to fully explore and realize opportunities.
Caveats / Limitations

1. EFT focuses on flow operations & includes Yolo Bypass enhancement, does not evaluate all 22 conservation measures.

2. EFT addresses 13 species, not every species, nor food web interactions, nor attempt to model all behavioral movement & life-cycle survival progression
   • Framework ready for new species & performance indicators

3. EFT uses outputs from external hydrologic models (CALSIM, DSM2, etc.).
   • Easy to swap in results from any physical model in EFT
Pilot test: integrating EFT with systems operations models

Incorporating EFT derived ecological flow criteria to CALSIM
## Step 1: Define ecological flow criteria

### Bay Delta

#### Delta Smelt

<table>
<thead>
<tr>
<th>Indicator</th>
<th>DS4</th>
<th>Entrainment index</th>
</tr>
</thead>
</table>

#### Objective & Rationale

The indicator simulates entrainment risk from the CVP and SWP export operations. Low flow years historically have higher incidences of entrainment than high flow years because fish are distributed closer to the points of diversion in low flow years, when a higher proportion of juveniles rear in the Delta (Moyle 1992; Sommer et al. 1997). The greatest entrainment risk from export operations is thought to occur during winter, but juveniles are also vulnerable; with peak of risk in May-June (Nobriga et al. 2001). The indicator is based on the results of a Particle Tracking Model (PTM) experiment (Kimmerer and Nobriga 2008), which simulates the fate of particles released in the Delta under a range of inflows and exports. In order to satisfy the PTM assumptions, the indicator applies only to the larval and juvenile life stages. (Design Document Section 2.2.2, pp. 89-100)

#### Timing

<table>
<thead>
<tr>
<th></th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

#### Locations

Combined Old + Middle River (OLD R A BACON ISLAND CA, ROLD024, 11313405) + (MIDDLE R AT MIDDLE RIVER CA, RMID015, 11312676)

#### Variable & Condition

- \( \leq \) Normal WYT: \( Q_{avg} > -2,000\text{cfs} \)
- \( > \) Normal WYT: \( Q_{avg} > 0\text{cfs} \)

<table>
<thead>
<tr>
<th></th>
<th>Recommended</th>
</tr>
</thead>
</table>

- \( \leq \) Normal WYT: \( Q_{avg} > 2,000\text{cfs} \)
- \( > \) Normal WYT: \( Q_{avg} > 0\text{cfs} \)

<table>
<thead>
<tr>
<th></th>
<th>Used in Pilot</th>
</tr>
</thead>
</table>

#### Other Triggers

Juvenile smelt detected through trawls

#### Recurrence

Annually

#### Potential conflicts & trade-offs

May conflict with export objectives

#### References

Kimmerer and Nobriga (2008)
Step 5: Results

Salmonid Winners

- CS1 Spawning WUA: Winter, +35% Good
- CS6 Redd Dewatering: Spring, +36%
- CS4 Juvenile Stranding: Winter, +34%

Salmonid Losers

- CS1 Spawning WUA: Spring, -15% Good
- CS1 Spawning WUA: Fall, -14%
- CS2 Rearing WUA: Steelhead, -13%

• Compare ecological change for Baseline and pilot Ecological Flows scenario
• Winter Chinook: notable improvement in CS1, CS6, CS4; decline in CS2
• Delta Smelt: moderate improvement (i.e., reduction) in entrainment

Jagger’s Law*: inverse correlations exist

* You can’t always get what you want
1. We successfully demonstrate EFT rule-sets can be “inserted” and generate beneficial effects in CALSIM ...without significantly impacting storage or exports

2. Irreconcilable, ceaseless trade-offs will always exist between species and ecoregions

- These trade-offs do not owe to failure to create clever enough models.

- A single, unchanging optimal solution does not exist.
A new paradigm: flexible ecosystem priorities
- Recognize multiple, equally acceptable solutions exist
- Smart, state-dependent priorities
- Build multi-objective, state-dependent optimization engine

Sustained refinement & application of EFT
- EFT one element of community modeling hub
- “Gathering place” for generally accepted functional relationships / algorithms
- Every CALSIM run should be coupled with an EFT run

Design adaptive management experiments, real-time decision support tools
- Disproportionate amount of effort devoted to water planning models in California

Where to from Here?
A New Paradigm: flexible ecosystem priorities

Existing

New Paradigm
Sustained Refinement & Application of EFT

- EFT one element of community modeling hub
- “Gathering place” for generally accepted functional relationships / algorithms
- Viewer distribution & training program

Where to from Here?

- EFT provides a very successful & rare example of synthesis & integration.
- Intuitive, durable user interfaces, data visualizations, data mining/exploration
- Leveraging investment more cost-effective than duplication / re-invention.
Where to from Here?

Design adaptive management experiments, real-time decision support tools
  • Disproportionate amount of effort devoted to water planning models in California

  • EFT can help winnow ecological flow mgmt alternatives & direct more efficient adaptive management experiments.
  • In-season modeling tools that build-in ecological guidelines needed that impact on-the-ground decisions.
EFT software:

esa.com/tools/ecological-flows-tool/
eft-userguide.essa.com/

Final Report:
Please contact Ryan Luster

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(250) 860-3824

Ryan Luster
rluster@tnc.org
(530) 897-6370, ext. 213