Reconciling Fish, Farms and Fowl on an Engineered Floodplain in California: the Yolo Bypass

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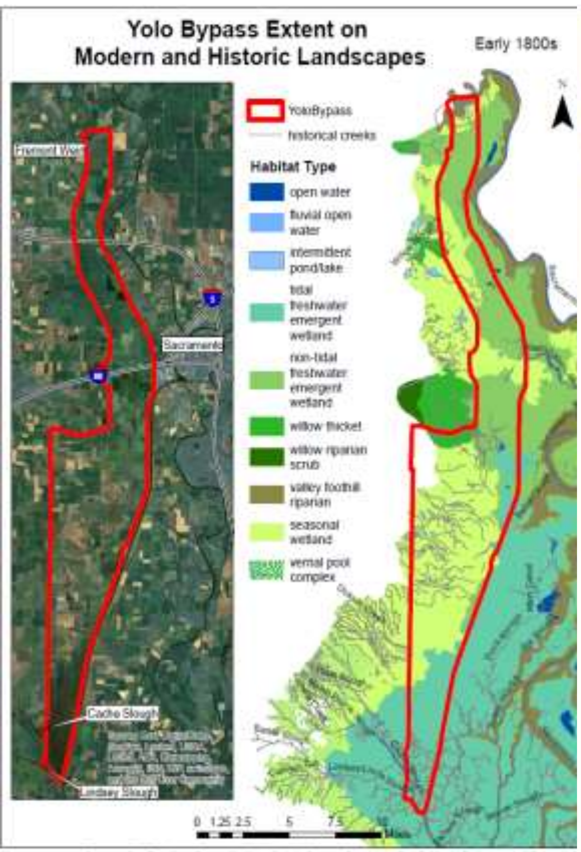
What's So Special About the Yolo Bypass Today?

Location

Many uses

BDCP

But More Importantly…

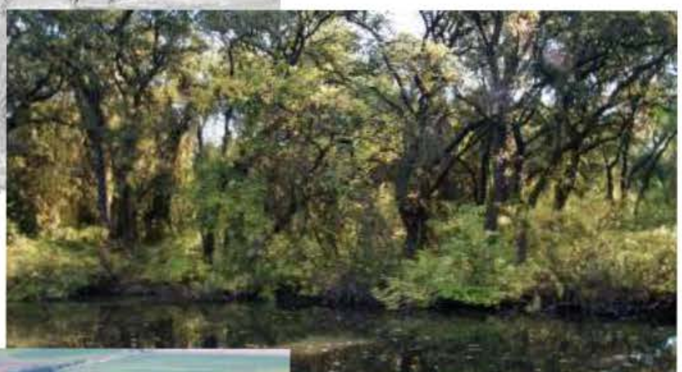


Test Case for Floodplain Reconciliation:

Can an ecologically functioning floodplain exist in a highly engineered system?

What is Reconciliation(as opposed to Restoration)?

And why are we talking about it on the Yolo Bypass?

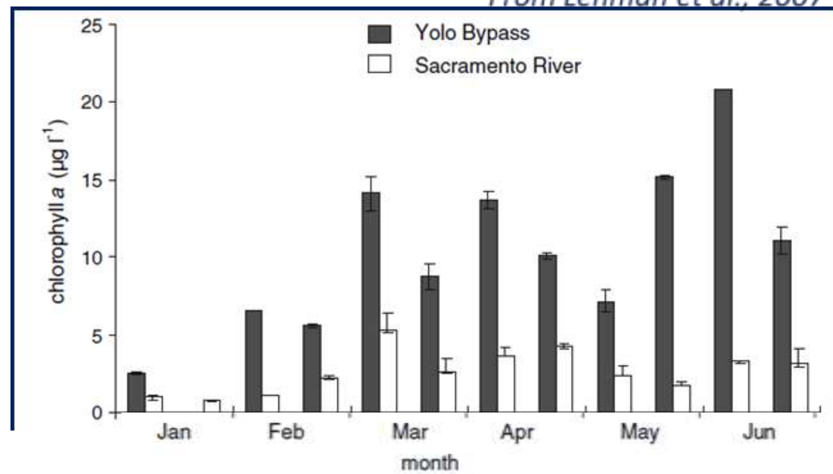


In Many Ways, the Bypass is already a reconciled system…

Table 1. Counts of several major bird groups from 12 monthly surveys at Yolo Basin Wildlife Area during 1998 and 1999. The total number of individuals is shown for each year with the total number of species (in parentheses). Note that the observations represent the results of one survey day each month and therefore do not represent annual population estimates. Source: Dave Feliz, California Department of Fish and Game, unpublished data.

Bird Group	1998 Total	1999 Total	Dominant Species (top three)
Diving ducks	4,631 (7)	6,281 (7)	Ruddy, canvasback, scaup
Puddle ducks	44,493 (7)	173,323 (7)	Wigeon, mallard, shoveler
Geese and swans	136 (5)	192 (4)	Canada goose, white-front goose, snow goose
Raptors	224 (11)	269 (13)	Northern harrier, red-tailed hawk, Swainson's hawk
Shorebirds	3,485 (14)	18,530 (11)	Western sandpiper, dowitcher spp., dunlin
Wading birds	452 (2)	1,222 (2)	Black-necked stilt, American avocet

From Lehman et al., 2007



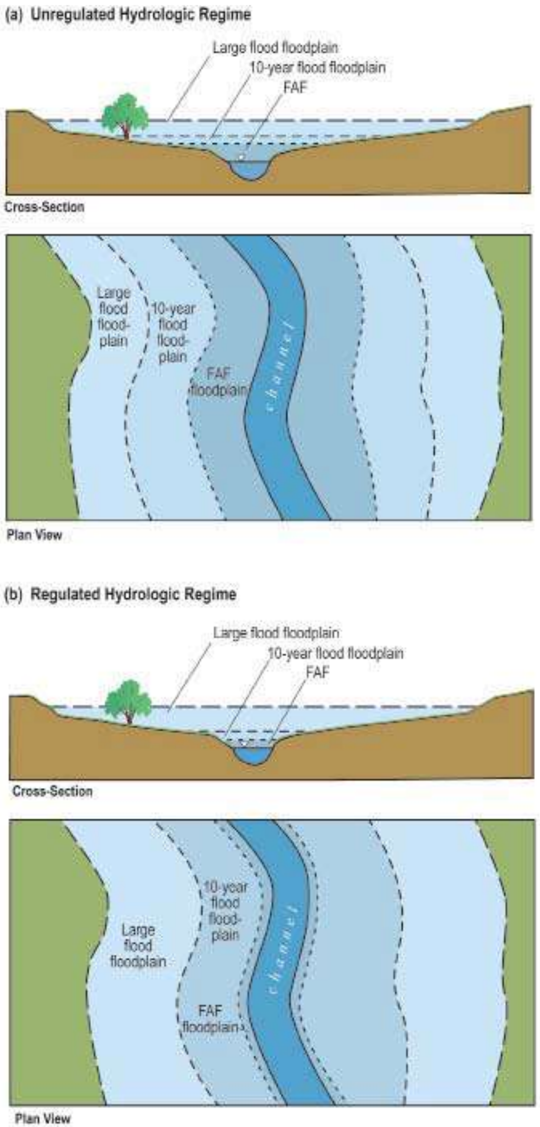
- **Sommer et al. (2001) and Knaggs Ranch Experiments**

Chinook salmon that rear in Yolo Bypass grow faster than those remaining in the Sacramento River

- **Feyrer et al., 2006**

Splittail reproduction is correlated to Yolo Bypass flooding

But there is room for improvement



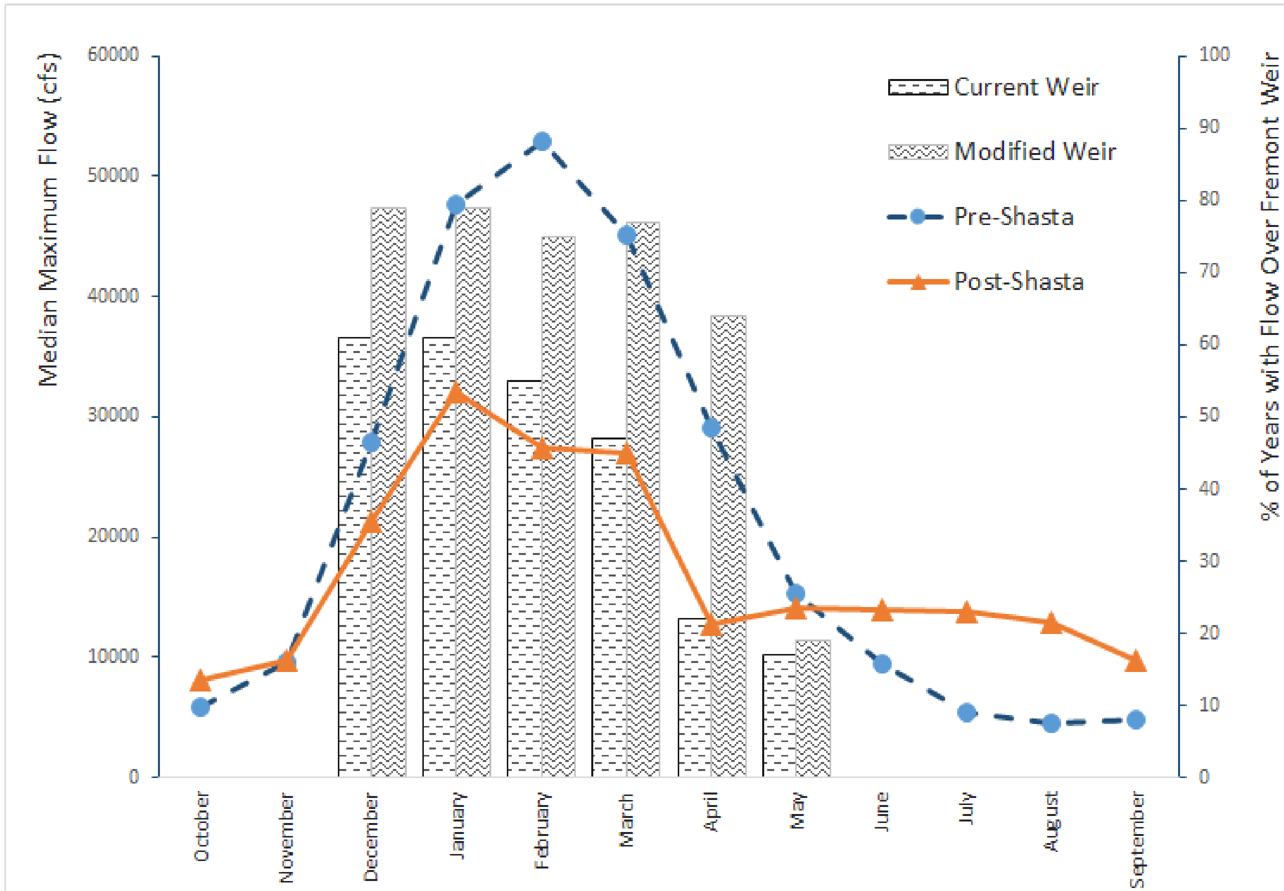
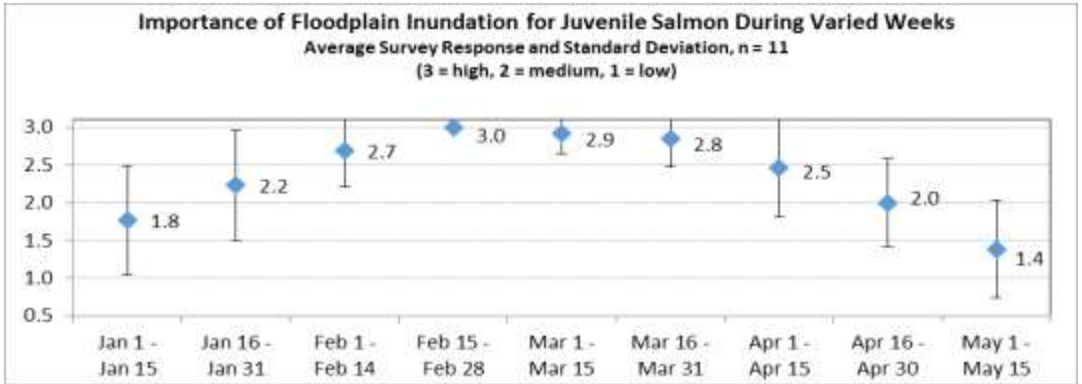


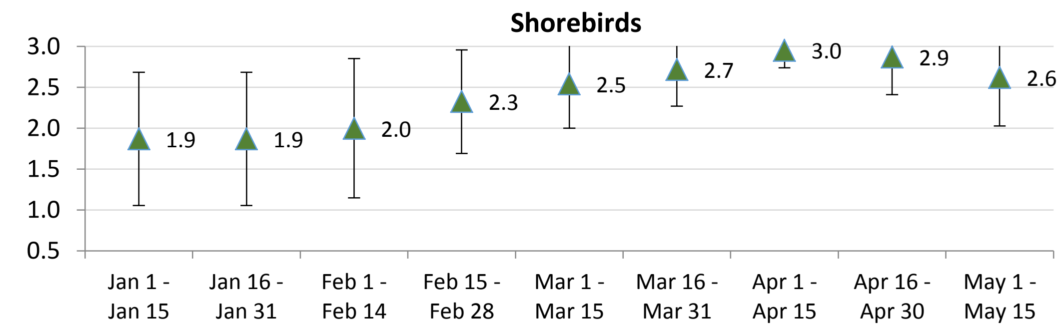
Figure 3. Median monthly high flows in the Sacramento River at Red Bluff, before and after the construction of Shasta Dam (Source: waterdata.usgs.gov), and proposed monthly increases in flood frequency on the Yolo Bypass (U.S. Department of the Interior et al. 2013). Reservoir operations flatten out the flow distribution through time, decreasing the liklihood of flooding in the winter and especially in the spring. Proposed modifications to the Fremont Weir seek to increase availability of flows during these months to more closely resemble historical flooding.

Source: Williams et al. 2009

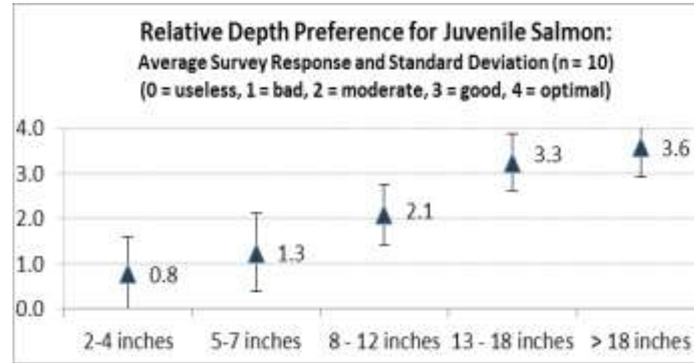
Plans to notch the Fremont Weir are not without some Perceived Conflicts…

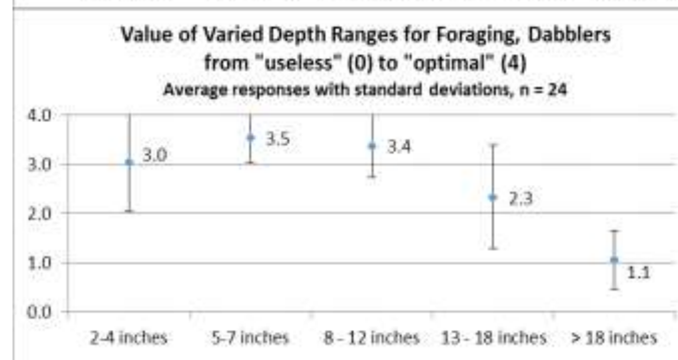
Timing:

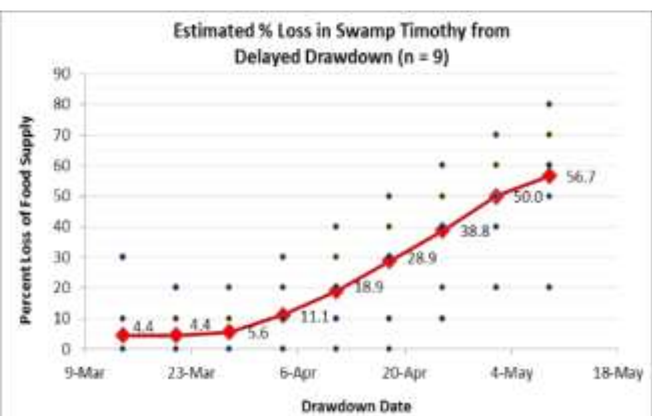


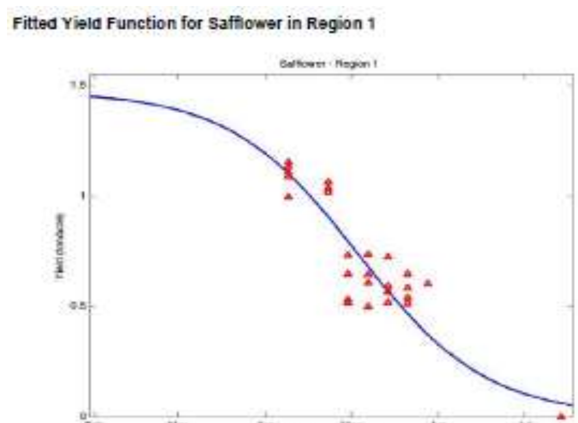


Depth









Remaining Questions for the Yolo Bypass….

1. What do the tradeoffs between economics and fish and bird habitat on the bypass actually look like?

2. Can additional flows be applied to this landscape in a way that improves fish habitat while still supporting water birds, recreation, and farming? (And if so, how?)

3. What are the land use and policy implications? How much and what kinds of mitigation are necessary to get to a more reconciled system? How much engineering is necessary?

Pulling It All Together…

Using a Spreadsheet Multi-Objective Model to Analyze Tradeoffs and Suggest Promising Management Alternatives

Decision Variables

Direct:

- **Total Acres of Each Land Use Type** in 6 Agricultural Zones
- **Acres Flooded** (by land use type and zone), further separated by:
  - **Depth** (2 – 4 in., 5 – 7 in., 8 – 12 in., 13 – 18 in., or > 18 in.)
  - **Timing** (weekly time steps)

Implied:

- **Duration**

3 Primary Objectives

Economics:

- **Agriculture**
- **Hunting & Recreation**
- **Maintenance**

Bird Habitat Quality:

- **Current Year Foraging for dabbling ducks and shorebirds**
- **Following Year's Food Supply**
- **Complexity**

Fish Habitat Quality:

- **Rearing habitat for juvenile Chinook salmon and splittail, and spawning habitat for adult splittail**
- **Complexity**

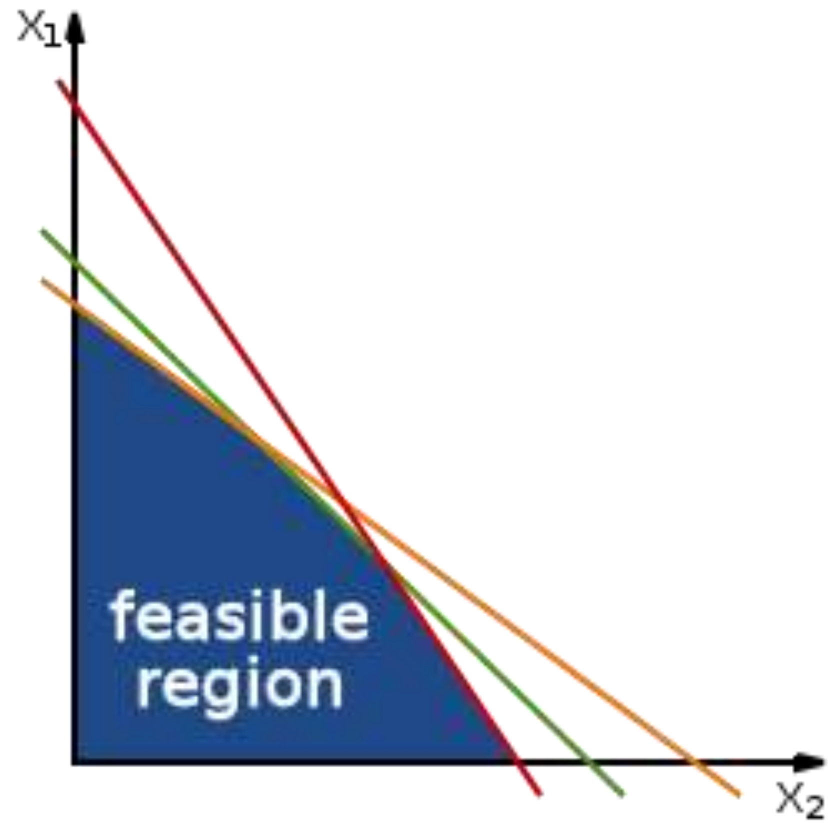
Constraints

Physical Realities:

- **Maximum Total Area**
- **Min and Max Land Use Areas**
- **Continuity of Land Use**
- **Continuity of Flooding**

- **Maximum Duration**

- **Non-negativity…**



And Two of the Objectives:

- **Minimum Habitat Quality for Fish**
- **Minimum Habitat Quality for Birds**

Spreadsheet Optimization Model

Start Date of Flooding

February 12th

YOLO BYPASS TOTAL PROFIT: $ 8,693,022

ZONE 1 TOTAL PROFIT: $ 994,863.48

ZONE 1 decision variable - ACREAGES

Week 1

Depth Zone	Rice (R)	Wild Rice (WR)	Corn (C)	Tomato (T)	Pasture (P)	Safflower (S)	Fallow (F)	Seasonal Wetland (SW)	Permanent Wetland (PW)	Hunted (private) Wetlands (HW)	Riparian (RP)
0	341.2	0.0	58.3	303.3	812.9	201.2	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	265.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flooded:	0	0	0	0	265.049	0	0	0	0	0	0

Total Revenue Wk 1: $ 1,263,476

Quantitative multi-objective models can integrate vast amounts of data and describe complex relationships b/w decisions and system objectives.

- Over 3000 decision variables
- Each decision effects the economic and habitat performance functions in unique ways

Salmon Benefit Function - WEIGHTS

Value of Inundation in Weeks 1 through 8

2/12 - 2/18	2/19 - 2/25	2/26 - 3/4	3/5 - 3/11	3/12 - 3/18	3/19 - 3/25	3/26 - 4/1	4/2 - 4/8	SUM	MAX
100	100	97	97	97	95	95	82	763	764
0.05	0.1	0.2	0.25	0.15	0.1	0.1	0.05	1	

Relative Value of Depth Zones 1 - 5

2 - 4 in	5 - 7 in	8 - 12 i	13 - 18	>18 in	SUM
22	35	58	91	100	306

Maximum Flooded Acreage: 20000

Total Acres & Land Use	Com-plexity
0.7	0.3

SUM LAND USE 829

Land Use Type	R	WR	C	T	P	S	F	SW	PW	HW	RP
Relative Benefit	76	76	46	46	78	53	79	100	78	100	97

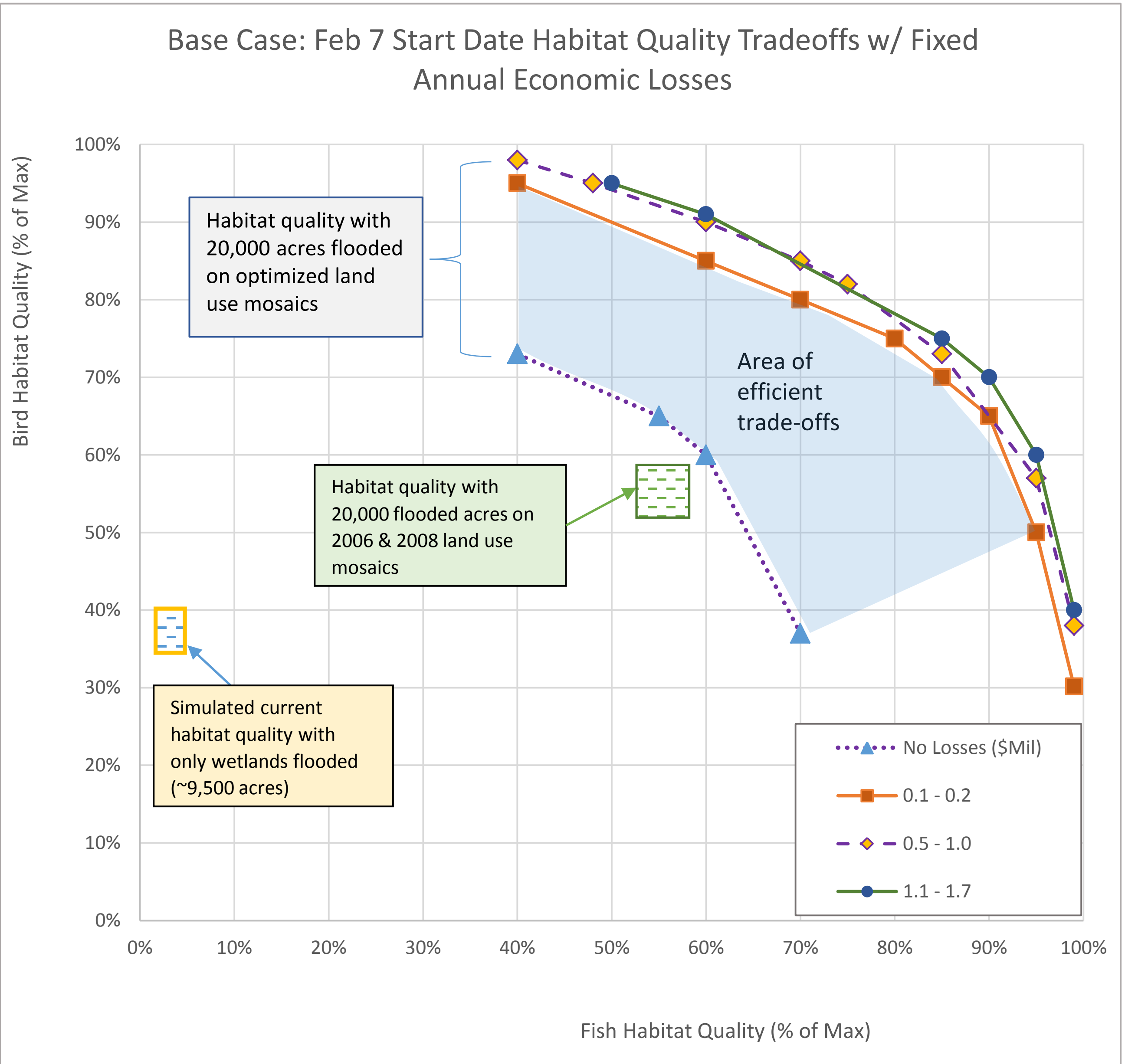
Models can also incorporate new knowledge or test varied assumptions.

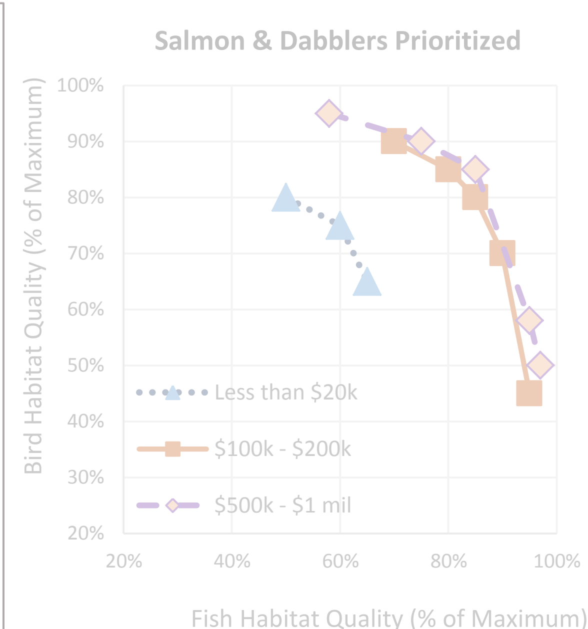
- All habitat function weights are adjustable
- So are agricultural parameters, and land and water management constraints

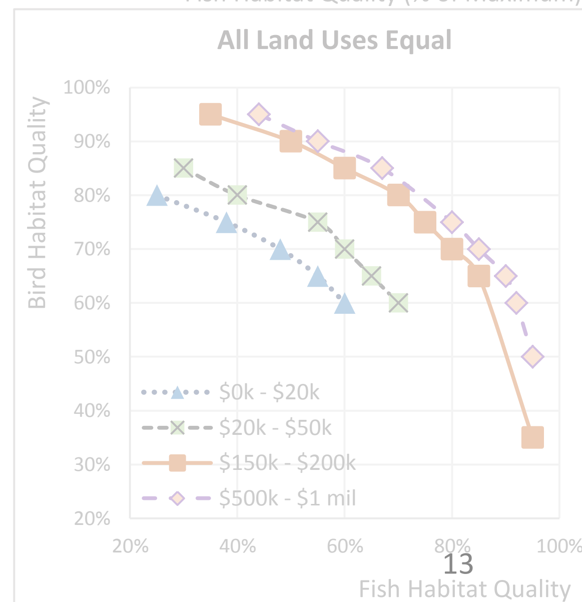
Running the model under a range of habitat assumptions

- All land uses equal for fish
- Complexity weight reduced (all species)
- Salmon and dabblers prioritized over splittail and shorebirds
- More linear timing and duration preferences

Results: Tradeoffs

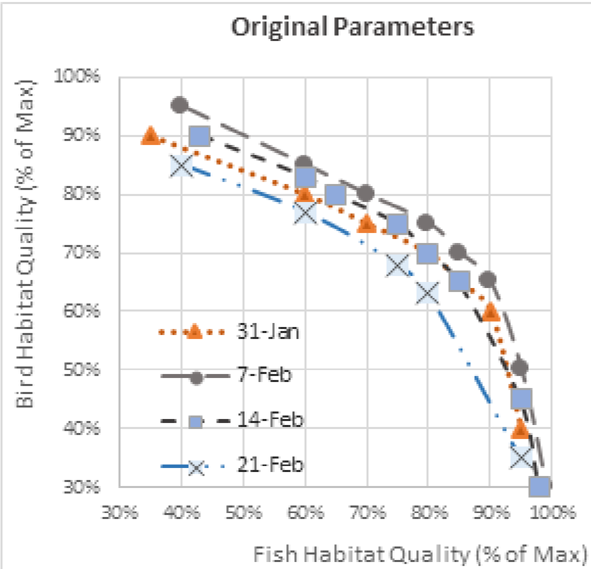


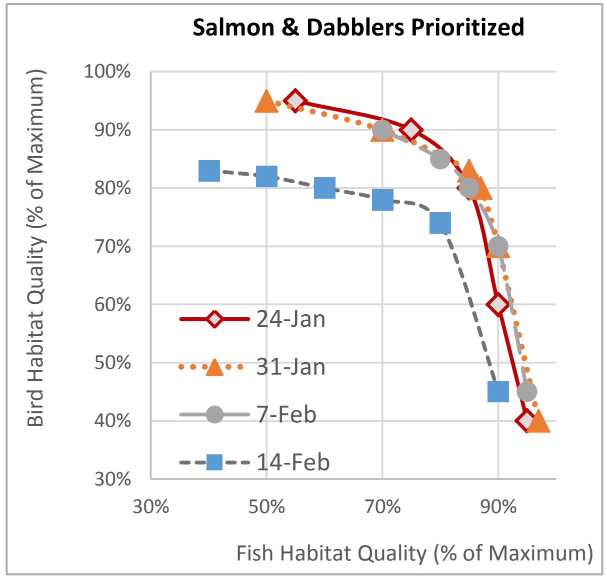


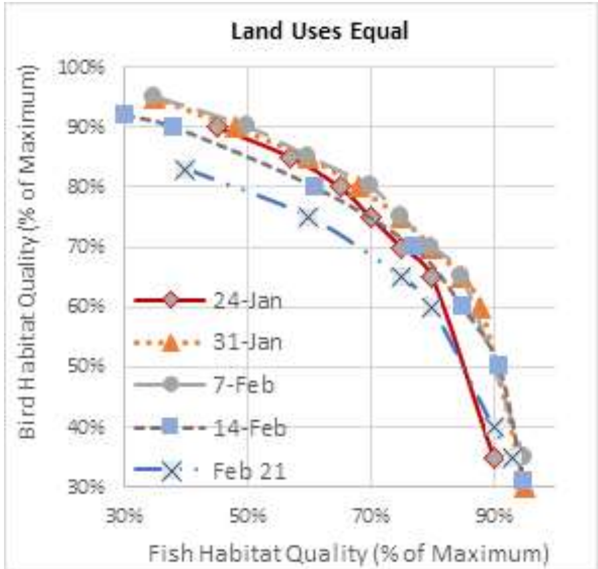


Results: Start Date

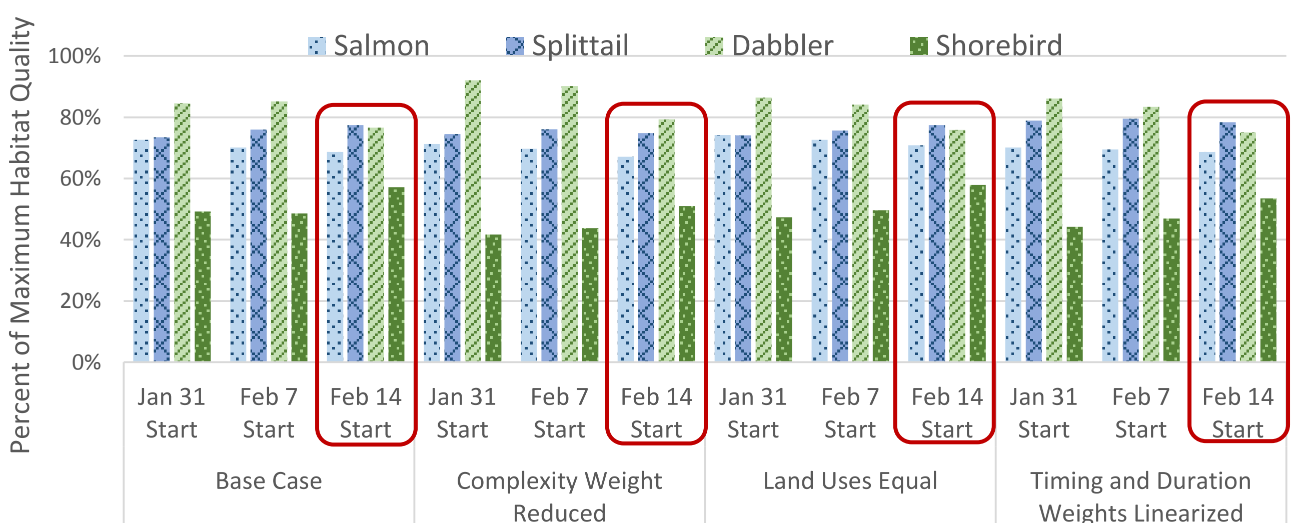
Habitat Tradeoffs with Varied Start Dates. Annual Losses Constant at $100k - $200k







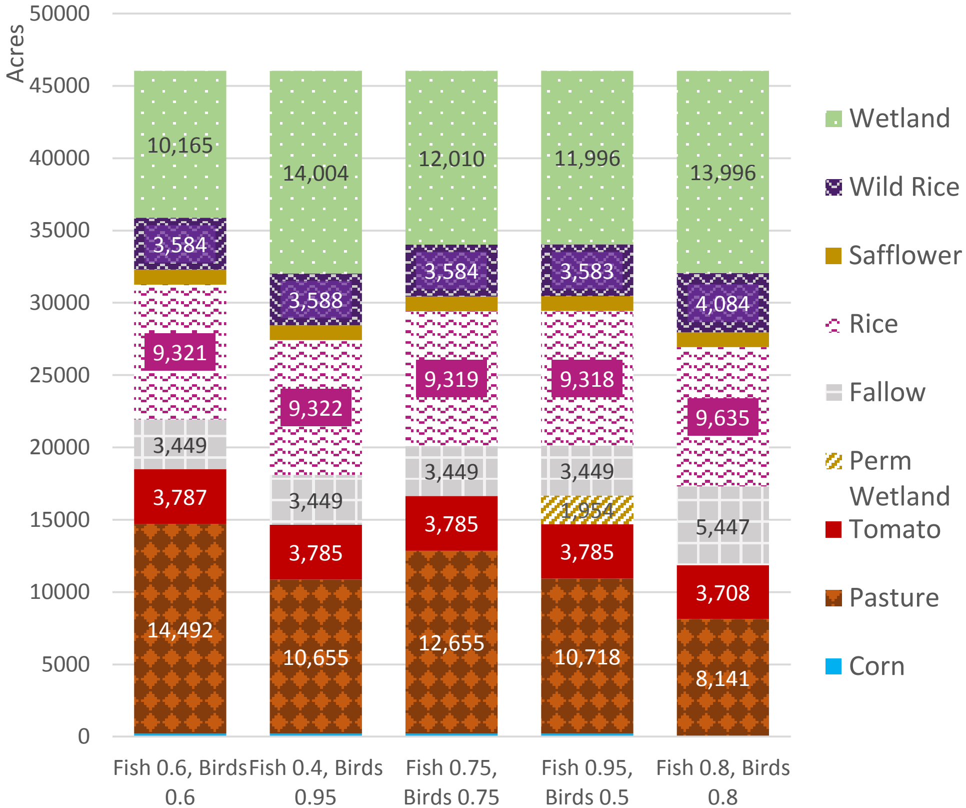
Achieving 75% Habitat Quality for Fish and Birds - Implications for Individual Species Given Varied Start Dates and Parameters



What Happens in the Area of Efficient Tradeoffs?

Permanent Land Use Change: Pasture converted to wetlands

(only Base Case shown)

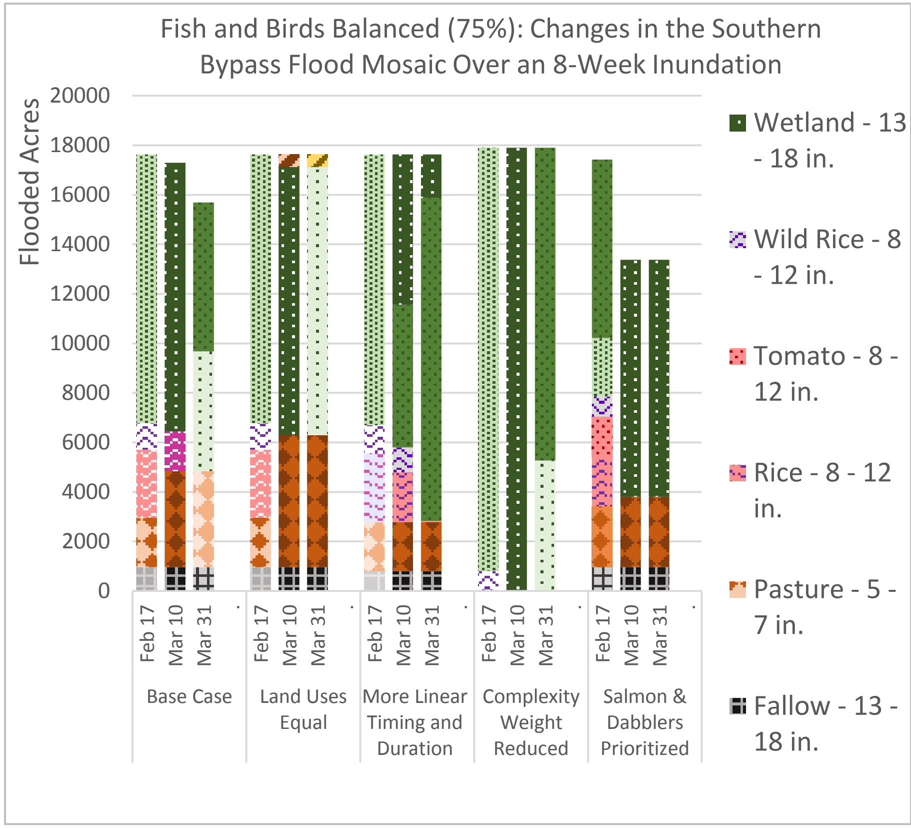


No Annual Losses

$100k - $200k Annual Losses

> $2 mil Annual Losses

Flood Management: Optimal placement (and **movement**) of water through time



More varied land uses in beginning, shifting to pasture and wetlands in later weeks. Depth varies with timing preferences for different bird and fish species.

Conclusions

Tradeoffs:

1. **We can do better for fish and birds on the bypass with little annual costs for farmers.**
2. **A compensation package of $100,000 - $500,000 per year to farmers or bypass landowners should be adequate for a reconciliation program**

Land Use

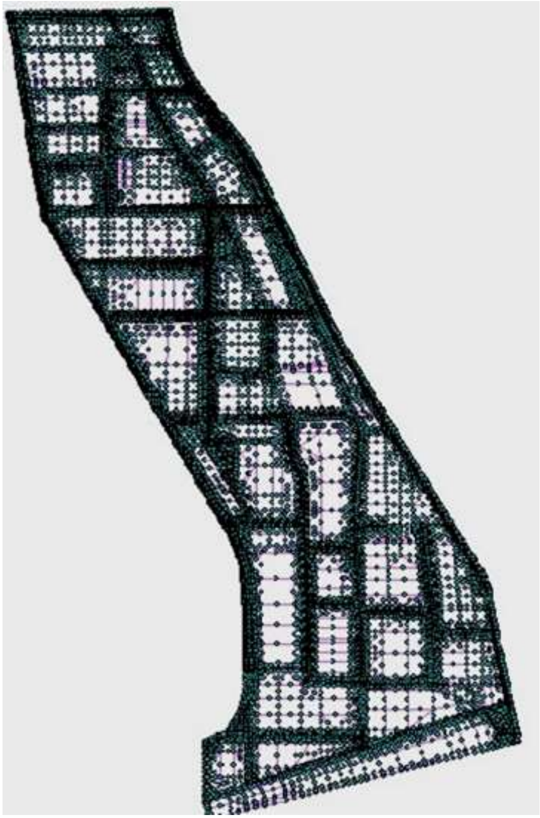
1. Cheapest way to improve habitat is to exchange some pasture in the southern bypass for wetlands.
2. Agricultural land uses can contribute to fish and bird habitat quality at very little cost, as long as flooding is optimized in space and time. (Rice and wild rice are a part of the flood mosaic in February, but are phased out in March.)
3. It might be worthwhile to grow additional acres of rice and wild rice as habitat.

Flooding Management

1. The best start date for an 8-week inundation is between late January and mid February. Later start dates in this range better balance benefits across individual fish and bird species. Earlier start dates favor salmon and dabblers.
2. Hydraulic management and movement of flows can significantly increase the cost-effectiveness of bypass inundation
3. Tools like this one can help guide this hydraulic management and integrate new knowledge into decision-making

Next Steps for this Model

- Iteration with a 2-D Hydrodynamic simulation model
  - Changing physical constraints in the multi-objective model to reflect realities of flow distribution across different zones
  - Modifying bypass infrastructure in the 2-D simulation model to replicate optimal solutions.



- Alter agricultural parameters to test sensitivity to changing economic trends, and look more closely at marginal costs for added rice

- Change habitat objectives as more knowledge becomes available.

Questions?

Sincere thanks to my advisors,

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And to all others whose input and expertise helped greatly with this work:

Peter Moyle, Richard Howitt, William Fleenor, Josue Medellin-Azuara, Cloe Garnache, Carson Jeffres, Jacob Katz, Catherine Lawrence, and many others

Extra Slides

Economic Objective

Revenues from farming A acres of land use *j* in zone *i*, starting in week *t*

Costs of farming A acres of land use *j* in zone *i*
(Developed in Howitt et al., 2013)

$$Max\ P = \sum_i \left[\left(\sum_j \sum_{\substack{t=start\\date}} \left(A_{jti,d=0} - A_{j(t-1)i,d=0} \right) * R_{jti} \right) - \sum_j \emptyset_{ij}\, e^{\gamma_{ij} * A_j} \right]$$

[Eqn 1]

Where

i = agricultural zone, as defined in Howitt et al. (2013)

j = land use type

d = depth

t = week

$A_{jti,\,d=0}$ = Acres of land use type j in zone i at time t that are no longer flooded.

R_{jti} = the annual revenues from land use j in zone i, available for use by time step t.

And $\emptyset_{ij}$ and γ_{ij} are cost parameters for farming A acres of land use j in zone i, taken from an agronomic model of the Yolo Bypass developed for a separate study (Howitt et al., 2013)

Habitat Quality Objectives

Land Use Type (j)	Weights (α_{sj})		Timing (t)	Weights (δ_{ts})	
	Splittail	Fall-Run Chinook Salmon		Splittail	Fall-Run Chinook Salmon
Rice	0.61	1.00*	Jan 1 - Jan 15	0.40	0.59
Wild Rice	0.63	1.00*	Jan 16 - Jan 31	0.47	0.74
Corn	0.31	0.46	Feb 1 - Feb 14	0.67	0.90
Tomato	0.31	0.46	Feb 15 - Feb 28	0.87	1.00
Pasture	0.73	0.78	Mar 1 - Mar 15	1.00	0.97
Fallow	0.71	0.79	Mar 16 - Mar 31	1.00	0.95
Riparian	0.92	0.97	Apr 1 - Apr 15	0.93	0.82
Seasonal Wetlands	1.00	1.00	Apr 16 - Apr 30	0.80	0.67
Permanent Wetlands	0.66	0.78	May 1 - May 15	0.47	0.46
Safflower	0.45	0.53			

Depth (d)	Splittail Weights ($\delta_{splittail, d}$)	Salmon Weights ($\delta_{salmon, d}$)	Dabbler Weights ($\delta_{dabbler,d}$)	Shorebird Weights ($\delta_{shorebird,d}$)
Zone 1: 2 – 4″	0.21	0.22	0.86	1.00
Zone 2: 5 – 7″	0.38	0.35	1.00	0.75
Zone 3: 8 – 12″	0.71	0.58	0.95	0.44
Zone 4: 13 – 18″	1.00	0.91	0.66	0.11
Zone 5: > 18″	1.00	1.00	0.30	0.04

	Weight ($\boldsymbol{\beta_{sA}}$ and $\boldsymbol{\beta_{sC}}$)	
Flood Characteristics	**Fish**	**Birds**
Total area, depth, and land use types flooded	0.7	0.68
Complexity (entropy) of flooded land uses	0.3	0.32

$$Max\ HQ_{fish\ or\ birds} = \sum_{s} P_s \sum_{\substack{t=start\\ date}} \omega_{ts}\, \delta_{ts} \sum_{d} \delta_{ds} \sum_{j} \beta_{sA} \left(\frac{A_{jtid} * \alpha_{sj}}{Max\left(A_{jtid} * \alpha_{sj}\right)} \right) + \beta_{sC} \left(\frac{Entropy\left(A_{jtid}\right)}{Max\ Entropy} \right)$$

[Eqn 2]

Where

P_s= the amount that habitat quality for species s contributes towards total fish or bird habitat quality (set at 0.5 initially so that salmon and splittail are equally prioritized for the total fish habitat quality score, and dabblers and shorebirds are equally prioritized for the total bird habitat quality score.)

ω_{ts} = marginal benefit of each additional week of flooding for species s

δ_{ts} = relative importance (weight) of flooding at time t for species s

δ_{d} = relative benefit (weight) of flooding in depth zone d for species s

α_{sj} = the relative benefit (weight) of land use j as habitat for species s

B_{sA} and β_{sC} = relative importance of total area and land use types flooded (A) versus complexity (C) for species s, where complexity is expressed with an entropy function.

A_{jtid} = the acreage of land use j in week t

Entropy is calculated as $E = \left(\frac{A_{jt,d>0}}{\sum A_j}\right) * -ln\left(\frac{A_{jt,d>0}}{\sum A_j}\right)$