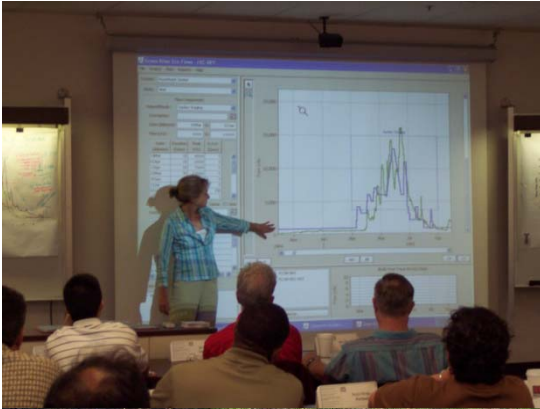


HEC-EFM and GeoEFM Tools for restoration planning

John Hickey, HEC



Outline

Concepts: Let's think about...

- Ecosystems associated with rivers and wetlands
- Human influences
- Hydrographs

Intro for Ecosystem Functions Model

- How does EFM allow users to investigate hydrographs?

Outline

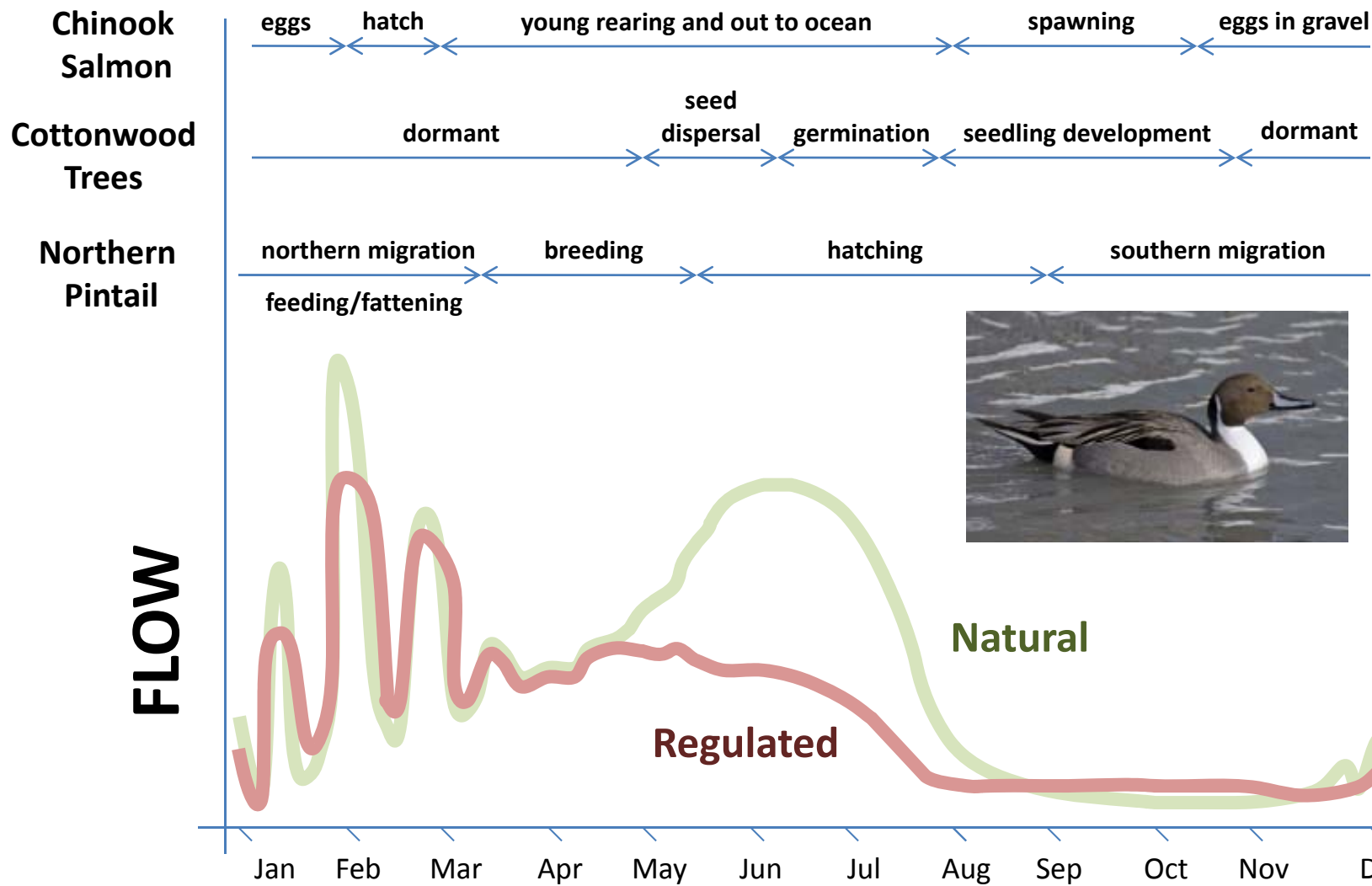
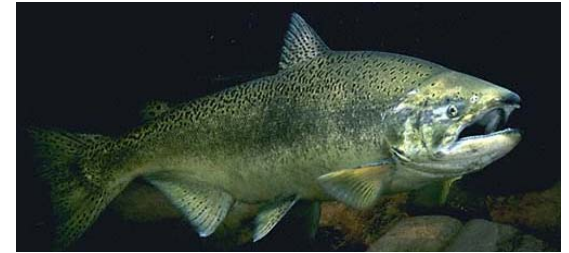
Concepts: Let's think about...

- Ecosystems associated with rivers and wetlands
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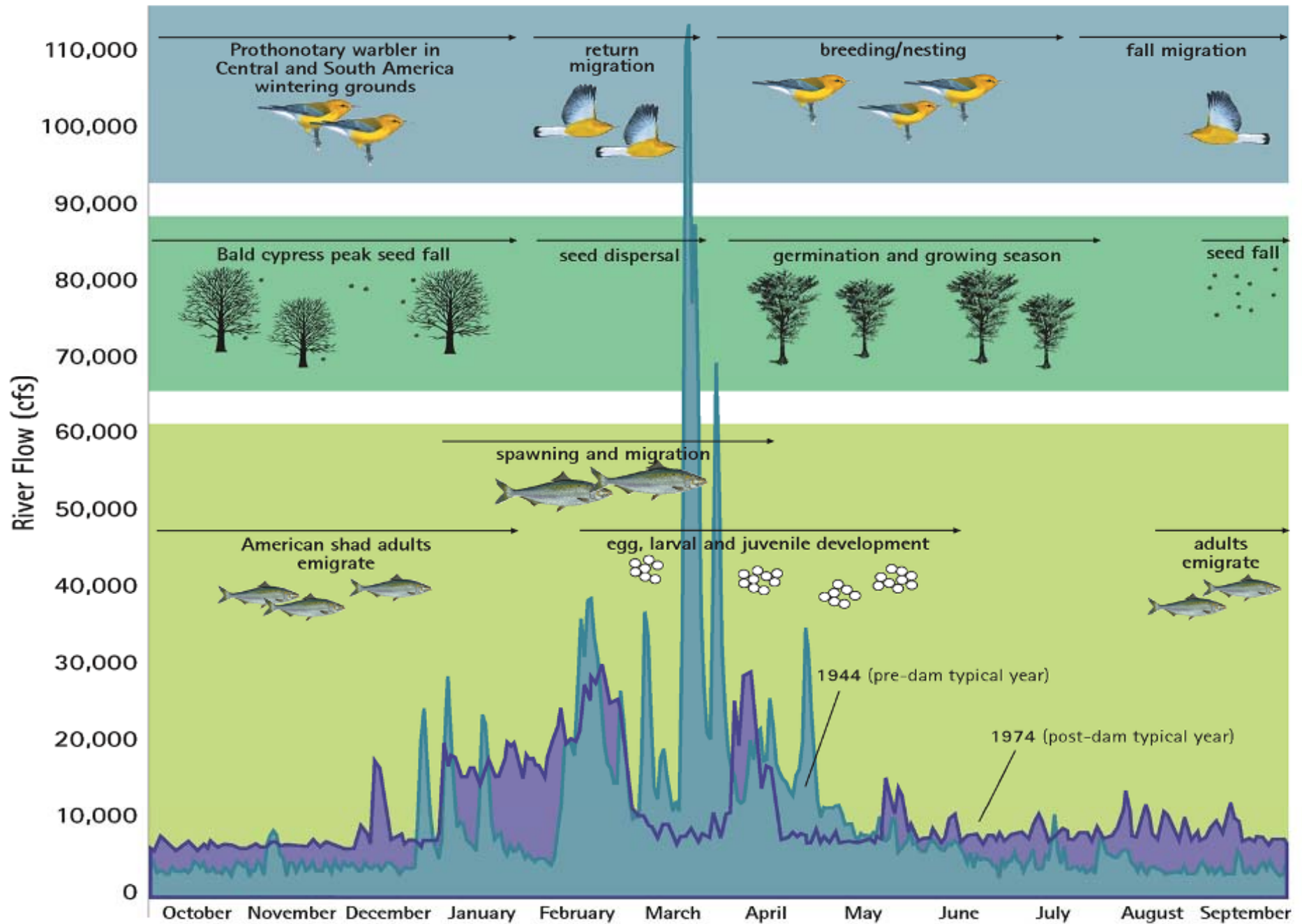
Intro for Ecosystem Functions Model

- How does EFM allow users to investigate hydrographs?

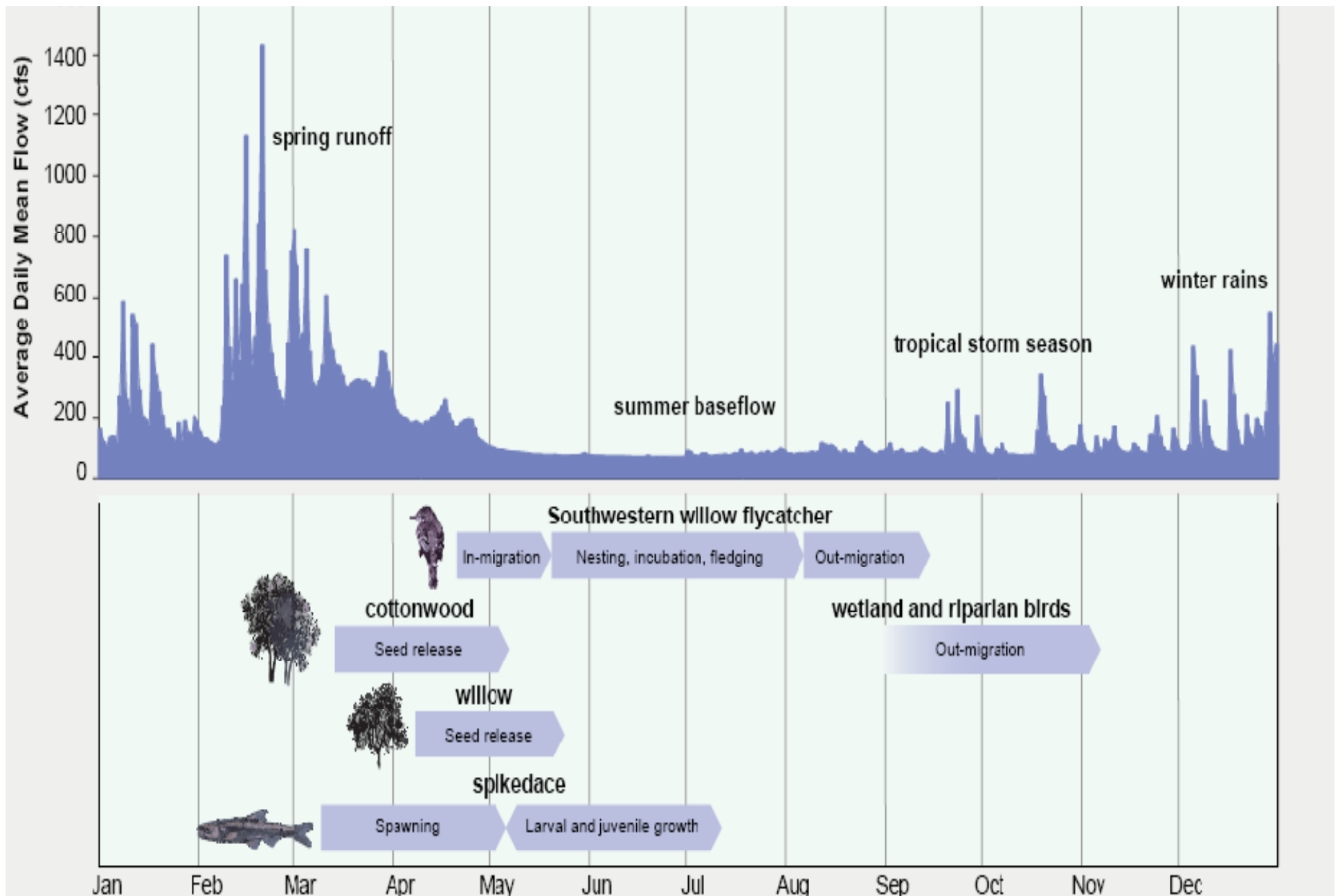
Hydrology and Ecology



Ecological Model of the Savannah River



Model for a Southwestern River Ecosystem



Outline

Concepts: Let's think about...

- Ecosystems associated with rivers and wetlands
- Human influences
- Hydrographs

Intro for Ecosystem Functions Model

- How does EFM allow users to investigate hydrographs?



Water Quality



117,808
Peak since
estimates
began

Winter-run salmon coming back

"Is this a success story? I suppose so. ... (But) there's still a lot more to be done, and it took a long time to get here."

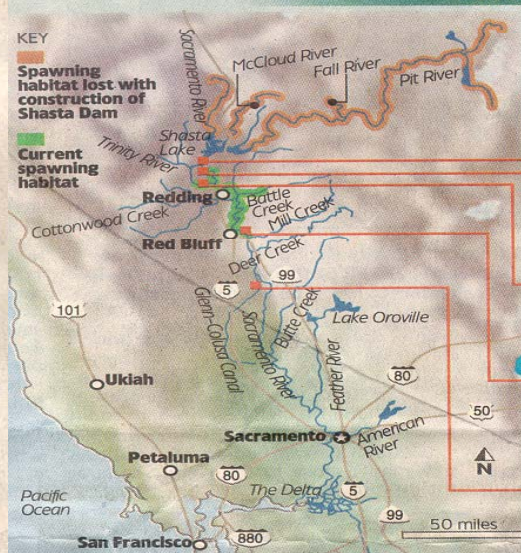
Dan Frost

Redding attorney who advocates for salmon and other fish in the Sacramento River



Source: California Department of Fish and Game

MAJOR PROJECTS



Winter-run salmon almost went extinct in the early 1990s. Since then, federal and state agencies have spent more than \$200 million to help revive this species, as well as other fish that spawn in the upper Sacramento River.

Shasta Dam: \$80 million

Using underwater robots, engineers added a temperature control device that allows cold water to be released from varying depths of Lake Shasta. The device helps ensure that salmon downstream have the ideal water temperatures to spawn – lower than 57 degrees.

Livingston Stone National Fish Hatchery: \$900,000

To jump-start the numbers of winter-run salmon, the federal government built an emergency hatchery at the base of Shasta Dam in 1997. Each year, the hatchery raises and releases more than 100,000 winter-run fingerlings, some of which are now returning to the upper Sacramento after three years at sea.

Iron Mountain Mine: \$30 million

Some of the world's most acidic water washes from this ripped-apart mountain during heavy rains. To prevent this waste from flushing into the river and killing fish, private contractors, under direction from the U.S. Environmental Protection Agency, built a new treatment plant in 1994. It now neutralizes 90 percent of the mine's caustic runoff.

Red Bluff Diversion Dam: \$20 million

Since 1966, this 752-foot-wide dam has spanned the Sacramento River, shunting water into the Tehama-Colusa irrigation canal and blocking 40 miles of habitat for migrating fish. The U.S. Bureau of Reclamation now keeps the dam's 11 gates open from September through May, and is considering building a pumping plant for the canal, so the gates can stay up year-round. It has also improved fish screens at the dam.

Glenn-Colusa fish screens: \$75 million

Starting in the 1930s, pumps that diverted water from the river to Glenn-Colusa Irrigation District killed millions of young salmon. Four years ago, the district obtained federal and state money to help it install improved fish screens on the pumps.

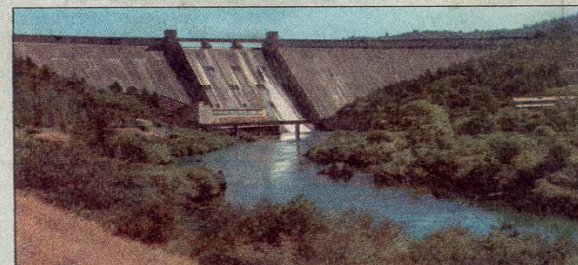
Winter-run salmon

Winter-run chinook salmon are unique to the Sacramento River, and differ from other salmon in several ways.



	Winter-run salmon	Fall-run salmon
Peak migration upriver	March	September
Peak spawning period	May – June	October–November
Typical spawning age	3 years	4 years
Peak migration of young salmon to sea	September	January–March
Status	Endangered	Not listed

Sources: U.S. Bureau of Reclamation; U.S. Environmental Protection Agency; California Department of Fish and Game; National Marine Fisheries Service; U.S. Fish and Wildlife Service



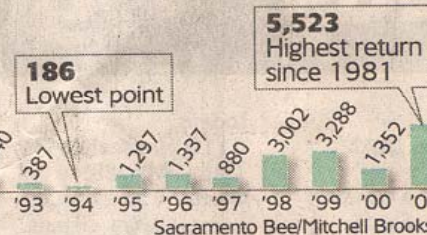
Shasta Dam at Shasta Lake

Sacramento Bee/Chris Crewell

Sacramento Bee/Mitchell Brooks

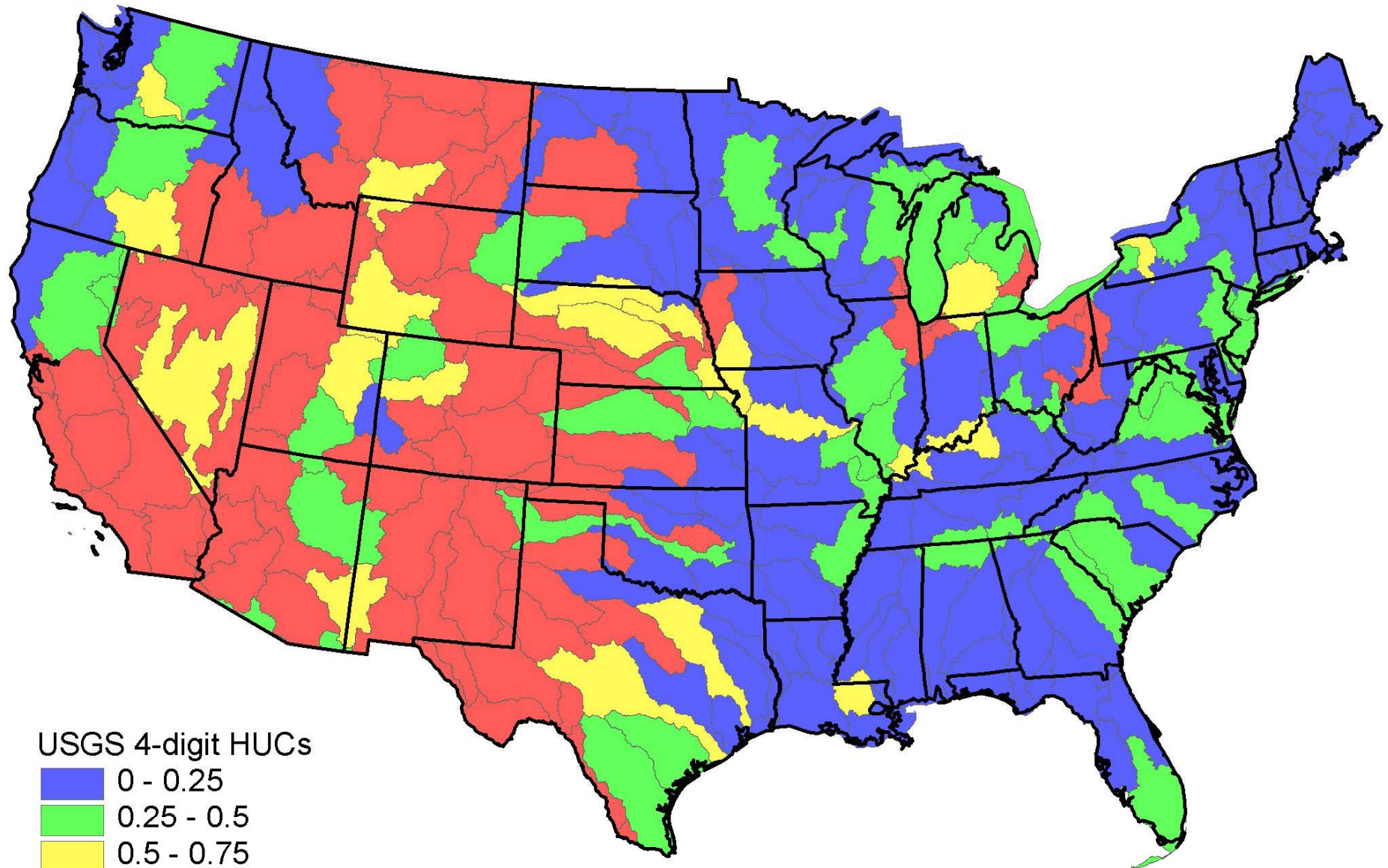
Decline of the winter run

Annual estimated winter-run chinook salmon. Run size at Red Bluff Diversion Dam, 1967 through 2001.

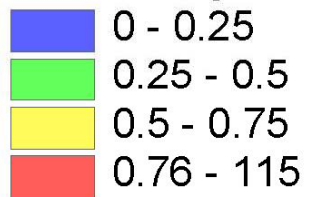


Sacramento Bee/Mitchell Brooks

Water Development in United States



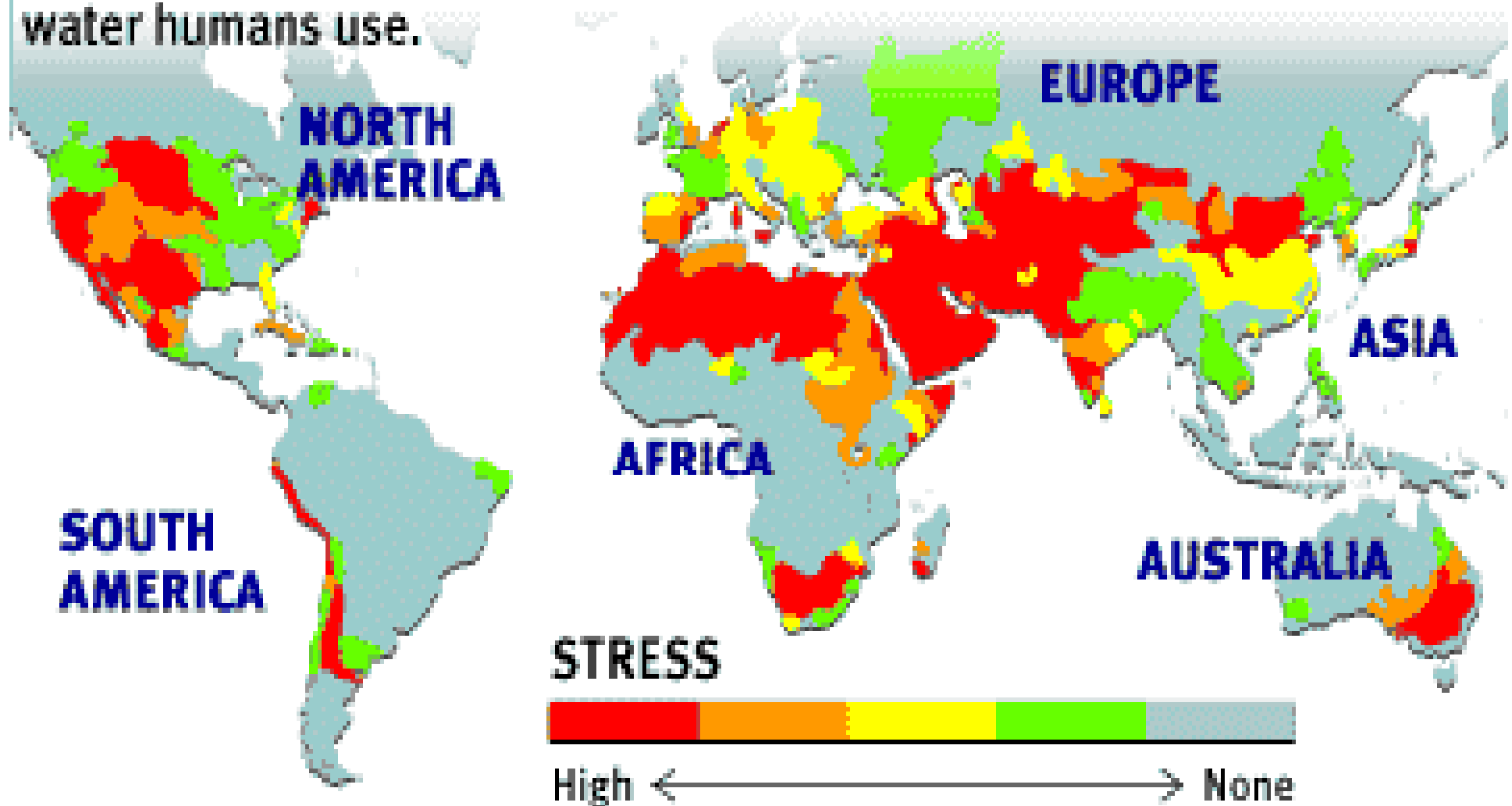
USGS 4-digit HUCs



Ratio of water consumed relative to annual average surface flow

Stressed out

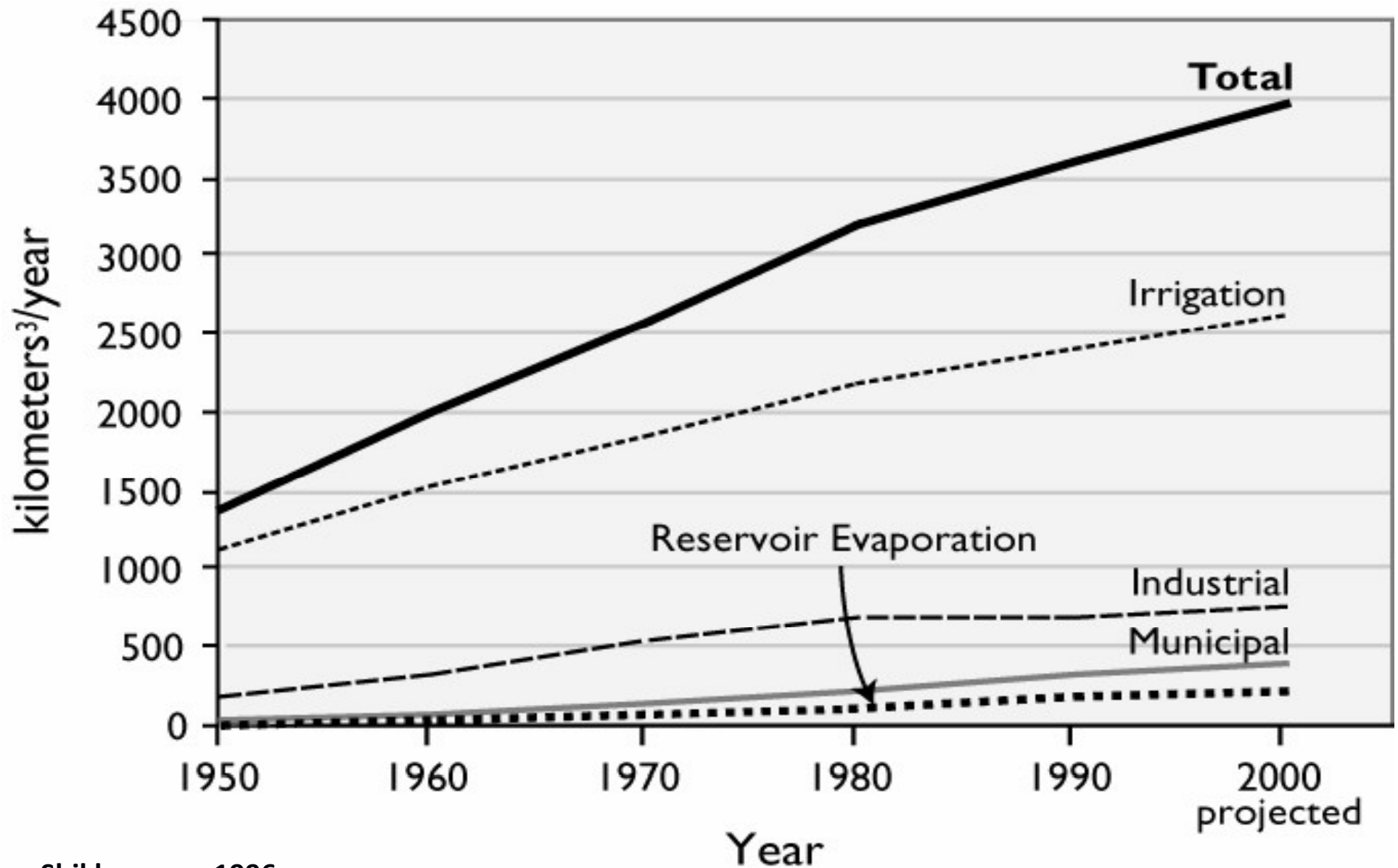
This map shows stress on the world's major river basins, comparing the amount of water available to the amount of water humans use.



SOURCE: World Commission on Water in the 21st Century

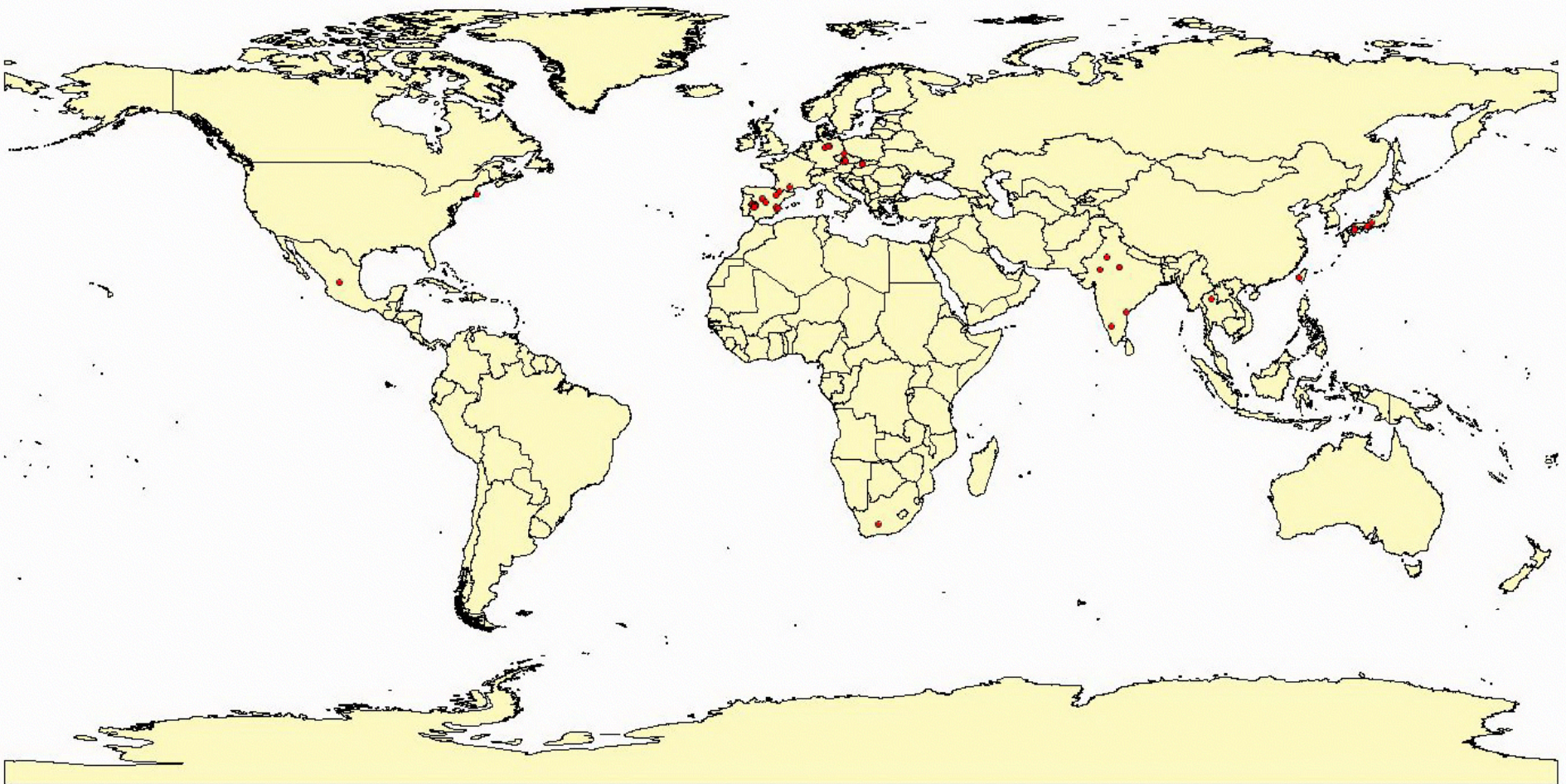
MSNBC

Global Water Consumption



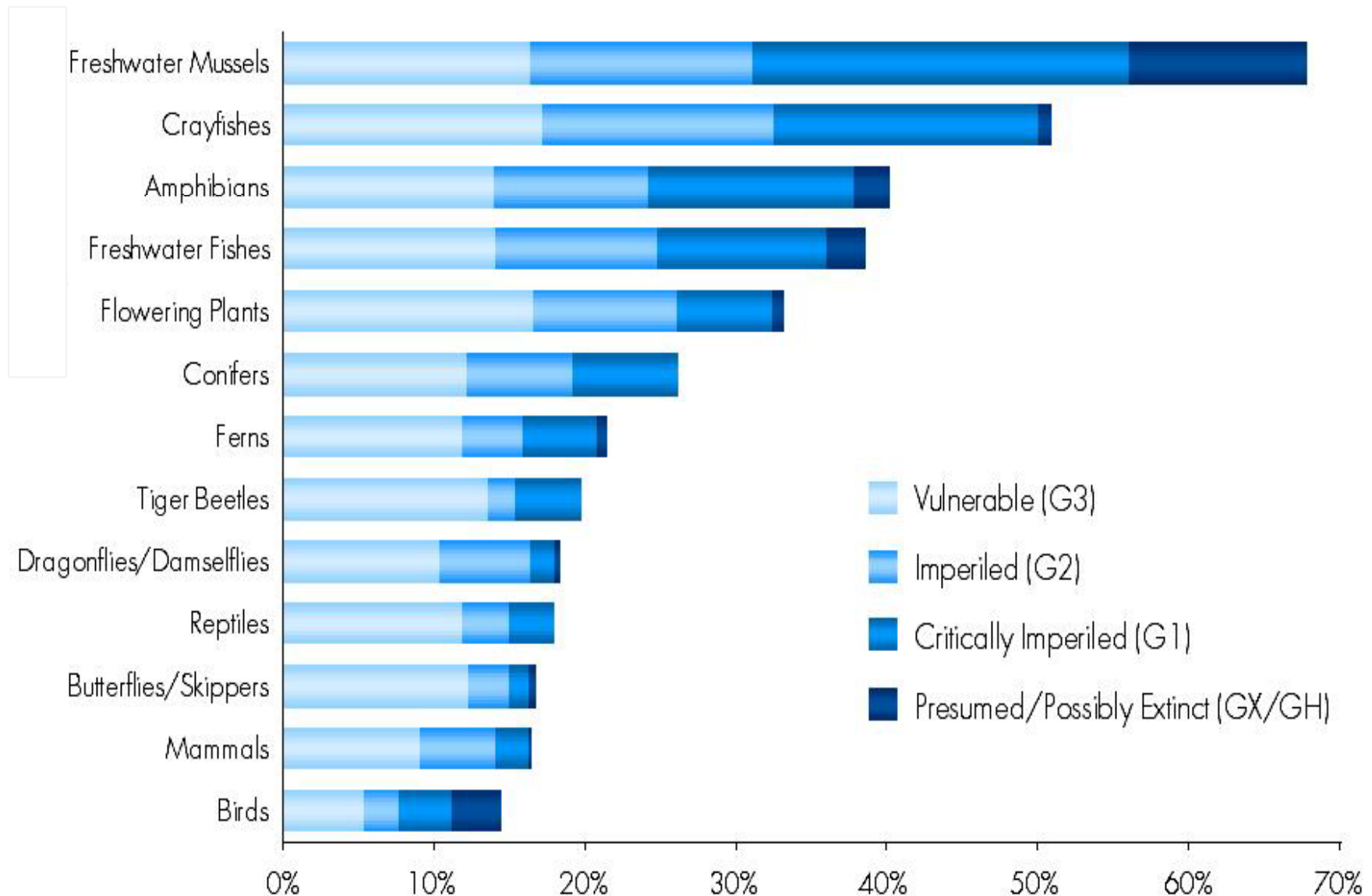
The History of Global Dam Development

before 1750



Map shows 23,427 large dams worldwide. Dam data are from Greifswald University, the ICOLD World Register of Dams, the FAO African Dams Database, the U.S. National Inventory of Dams, and The Nature Conservancy.

Proportion of U.S. Species at Risk



Source: *Precious Heritage* (TNC 2000)

Outline

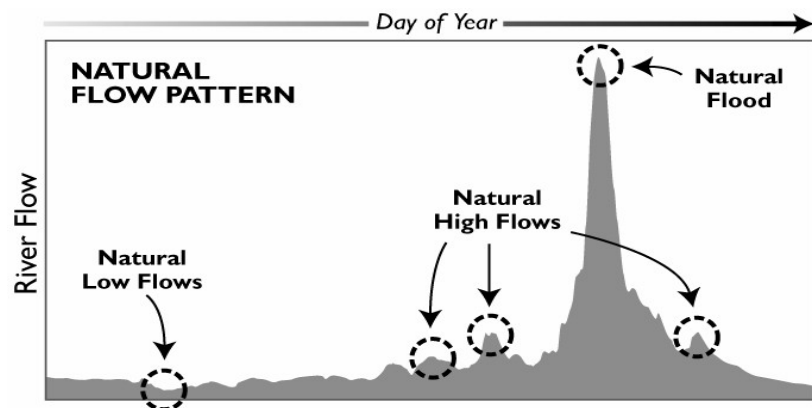
Concepts: Let's think about...

- Ecosystems associated with rivers and wetlands
- Human influences
- Hydrographs

Intro for Ecosystem Functions Model

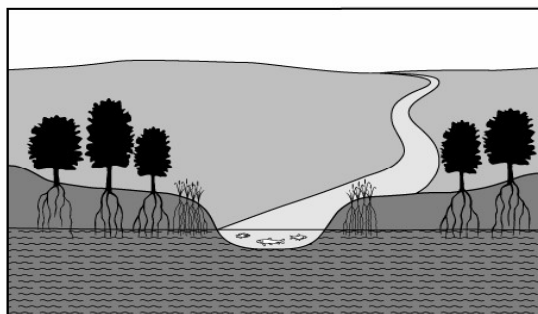
- How does EFM allow users to investigate hydrographs?

Connections between Flow and Ecology



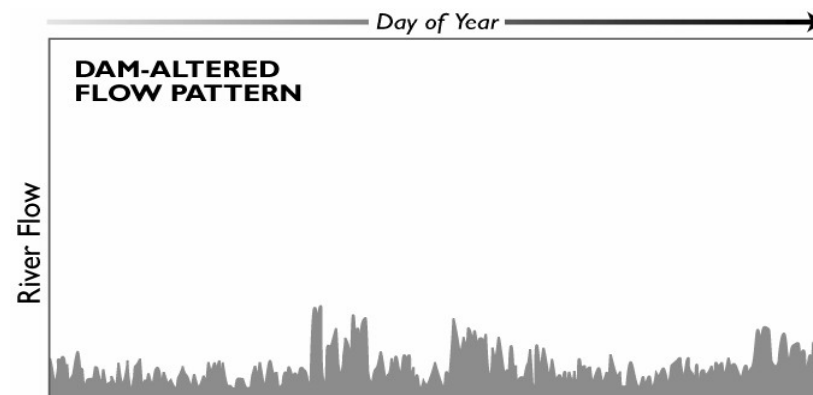
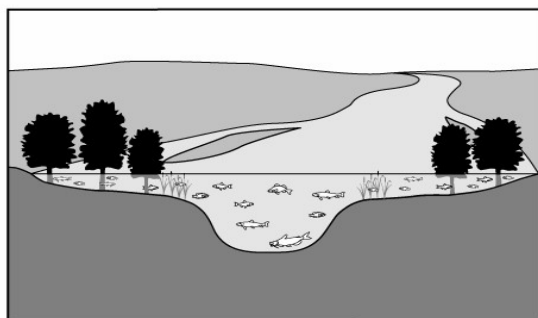
Natural Low Flow

- Fish have adequate oxygen and can move up- or downstream to feed
- Riparian vegetation sustained by shallow ground water table
- Insects feed on organic material carried downstream
- Birds supported by healthy riparian vegetation and aquatic prey



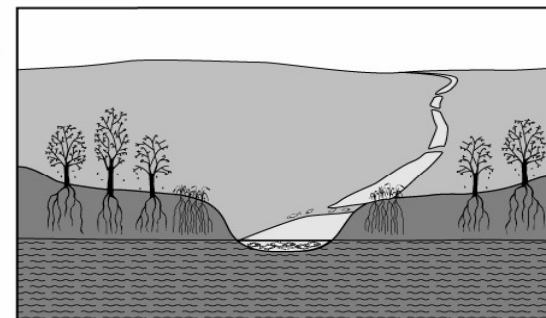
Natural Flood

- Fish are able to feed and spawn in floodplain areas
- Riparian plant seeds germinate on flood-deposited sediments
- Insects emerge from water to complete their lifecycle
- Wading birds and waterfowl feed on fish and plants in shallow flooded areas



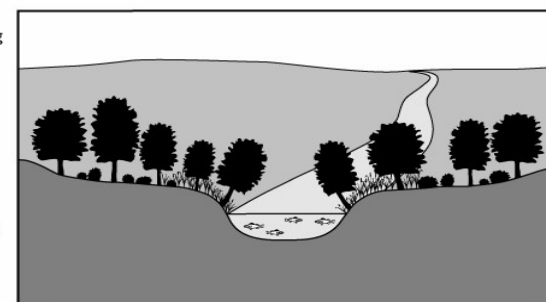
Inadequate Low Flow

- Fish are overcrowded in poor-quality water, cannot move to other feeding areas
- Riparian plants wilt when ground water table drops too low
- Insects suffer when water levels rise and fall erratically
- Birds unable to feed, rest, or breed in tree canopy



Absence of Flood

- Fish unable to access floodplain for spawning and feeding
- Riparian vegetation encroaches into river channel
- Insect habitats smothered by silt and sand
- Many birds cannot use riparian areas when plant species change



Getting into EFM...

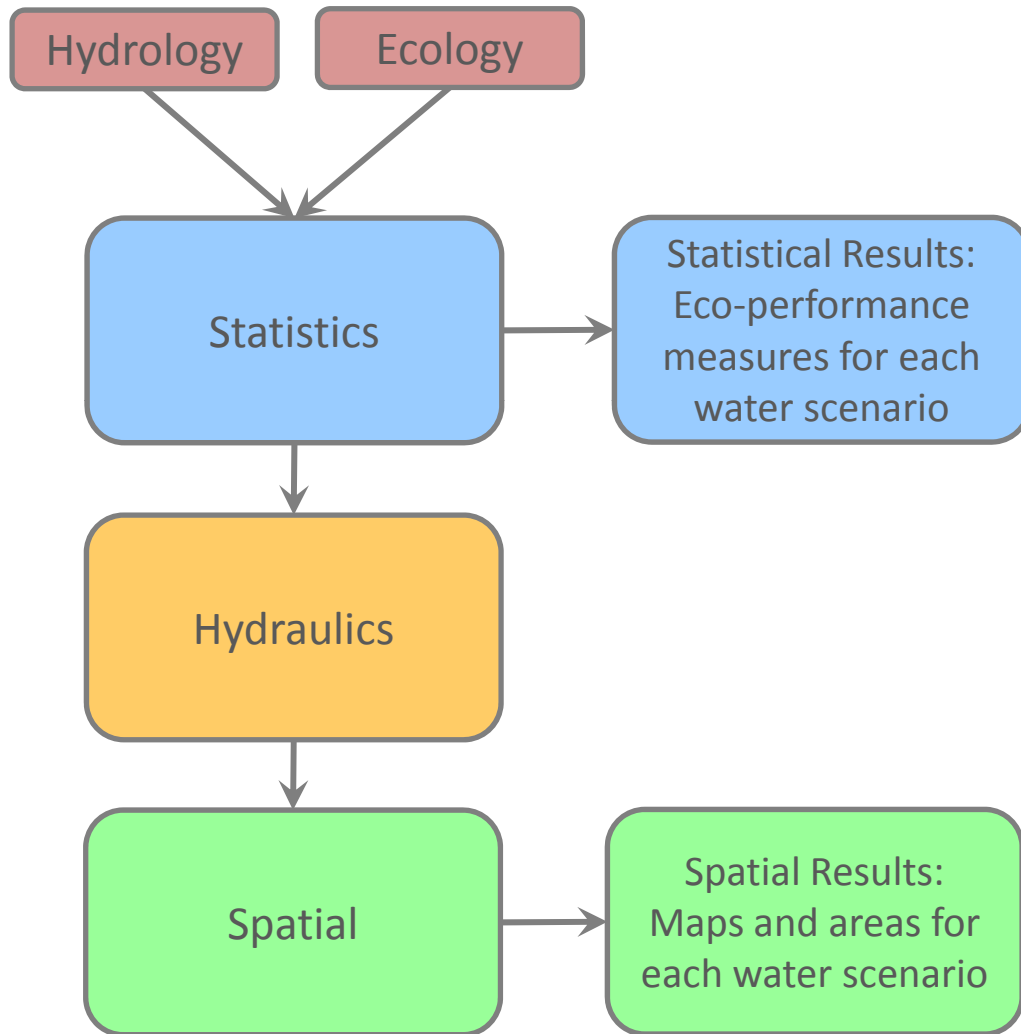
Key points so far

- Ecosystems evolve in concert with hydrologic patterns
- Humans alter natural hydrologic patterns
- If understood, connections between ecology and hydrology can be used to help guide water and ecosystem management

Intro for Ecosystem Functions Model

- How does EFM allow users to look at hydrographs?

Ecosystem Functions Model (EFM) Process



HEC-EFM

San Joaquin Demo.efm - HEC-EFM

File Edit Plot Help

Model information

Title: San Joaquin River near Vernalis, CA

Author: COE-DWR

Location:

Description: EFM

EFM model pathname: C:\TE

Flow regimes (paired time series)

Ref	Active	Identifier
☒	☒	SJQ Gaged
☐	☒	SJQ Natural

Relationship name: Splittail Spawning

Description: Splittail spawn in shallow vegetated floodplain areas between February and May. Eggs require sustained high flows for approximately 21- to 28-days before hatching. Good spawning conditions need to occur, on average, at least once every four years.

Options

☒ Write computation arrays

☒ Hypothesis tracking - increased flow will

☐ + ☐ - ☐ Curve eco-health

☒ Confidence tracking: ★★★★★

Index ☒ A ☒ B ☐ C ☐ D ☐ E

Statistical queries

☒ Season

From: 02/01 (m/d)

To: 05/31 (m/d)

☒ Duration of 24 days

For each duration, compute:

Minimums

From computed values, select the:

Maximum

☐ Rate of change: ☐ Stage ☐ Flow

feet per days

☐ Rising ☒ Falling ☐ Absolute

Time series specifications

☐ 25 % exceedance (4.00-yr)

☒ Flow frequency ☐ Flow duration

to Water year range

☒ 1997 Individual water year

☐ Relationship-defined water year

Geographical queries

Depth Shallow habitat 0- to 3-ft

Vegetation Requires presence

Other queries (nonstandard)

☐ Reverse lookup for cfs

☐ Count number of peaks between and cfs

Manage Tags for Geographical Queries

Project tags

Tags are simple names that identify sets of spatial data layers important to an EFM project. Project tags are available for use in each relationship. The following tags have been created for this project:

Depth, Vegetation, Land Use, Velocity, Soils

Activate tags for each relationship

Relationship	Selected Tags
Splittail Spawning	Depth, Vegetation
Striped bass winter habitat	
Benthic macroinvertebrate biodiversity	
Wetland health	Velocity, Land Use
Riparian tree recruitment	Soils, Vegetation
Riparian tree inundation	Depth
Wetland health reverse lookup	

OK Apply Cancel

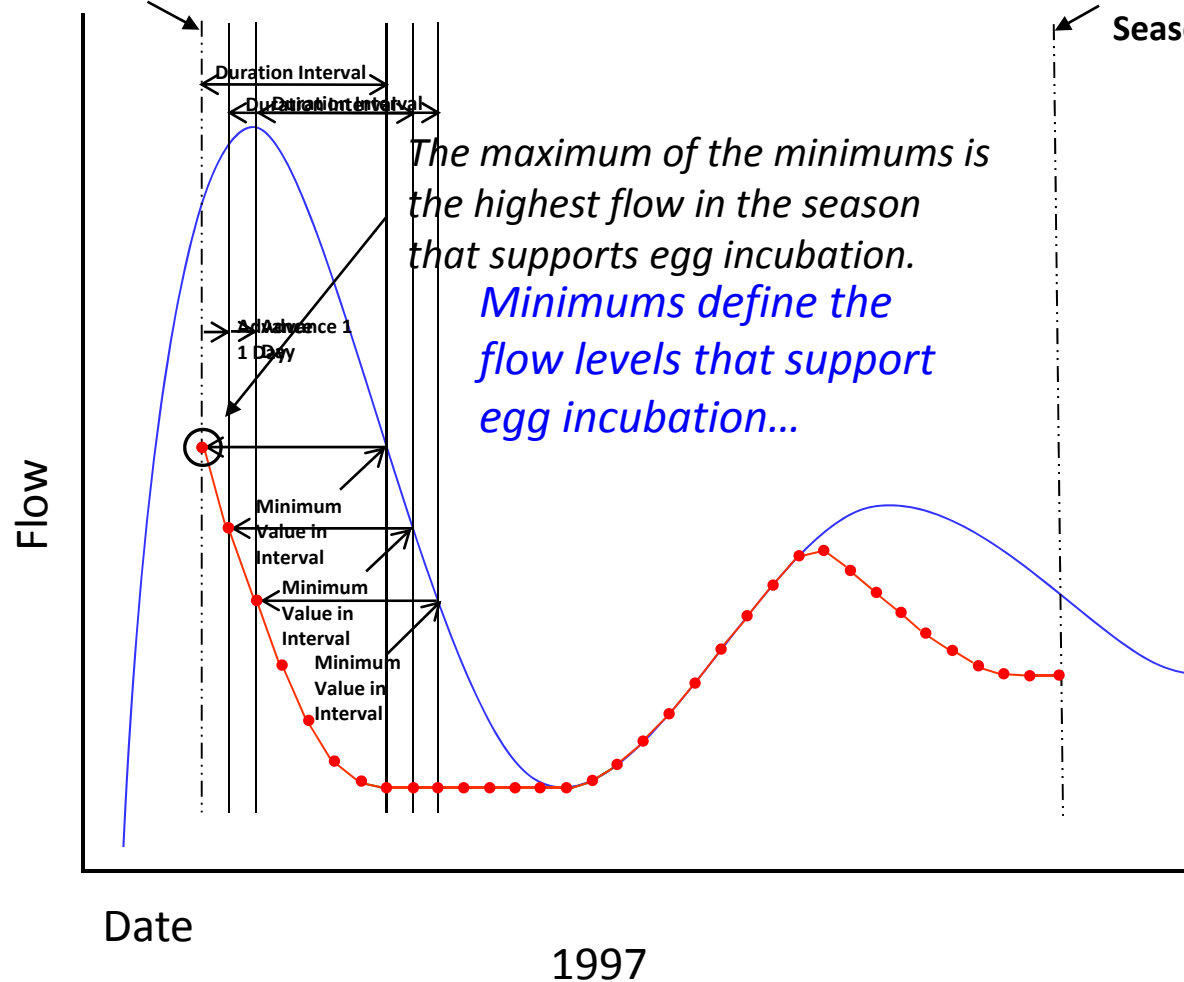
- Analyze up to ~37,000 flow regimes at once
- User-defined stats link hydro and ecology
- Geo queries add spatial aspects to relationships

Helps determine eco-responses to changes in river and wetland flow regimes...

EFM Math: Splittail Spawning

Beginning of Season

End of Season



Statistical queries

☒ Season

From: 02/01 (m/d)

To: 05/31 (m/d)

☒ Duration of 8 days

For each duration, compute:

Minimums

From computed values, select the:

Maximum

☐ Rate of change: ☒ Stage ☐ Flow

feet per days

☐ Rising ☒ Falling ☐ Absolute

Time series specifications

☐ 25 % exceedance (4.00-yr)

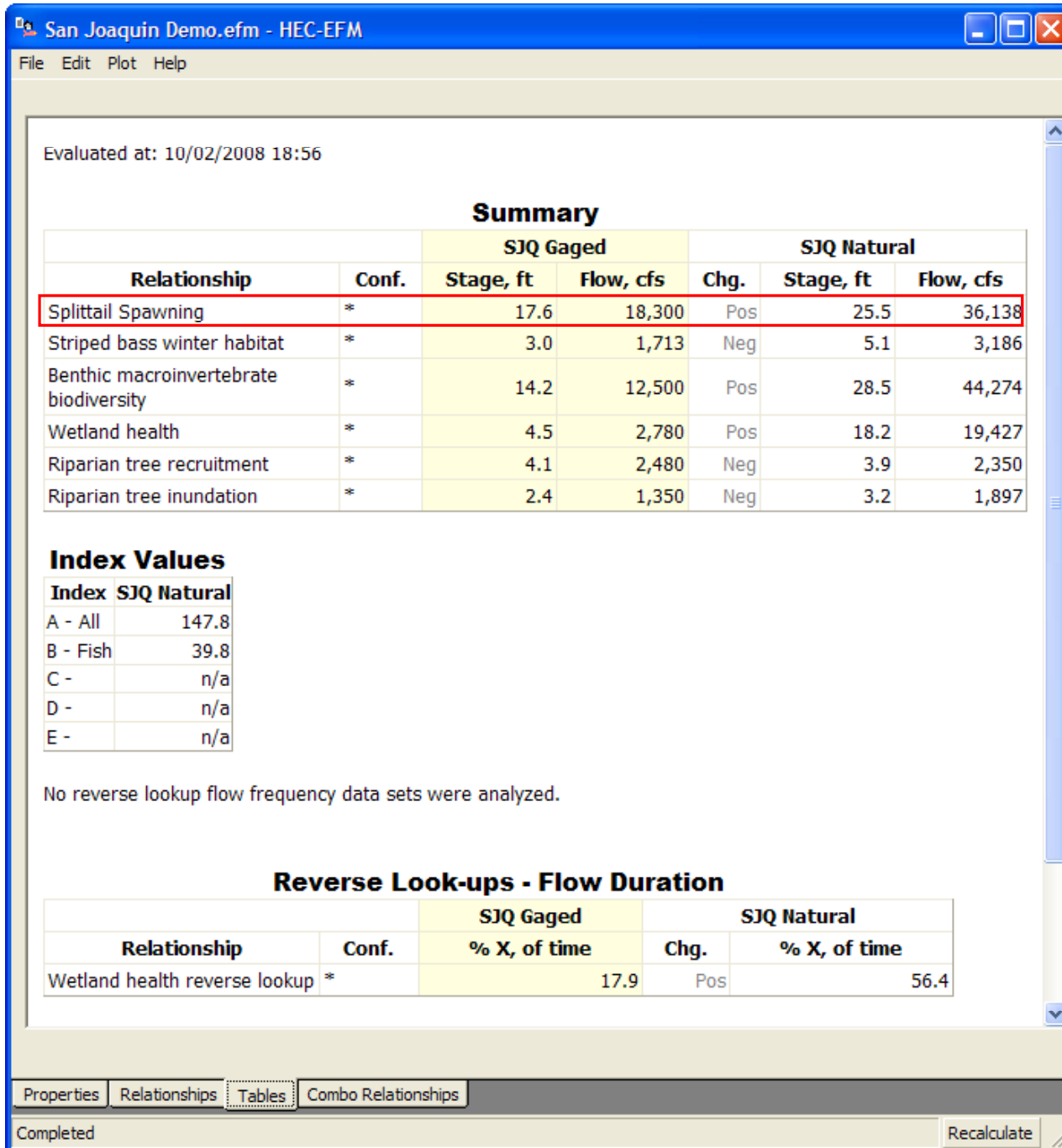
☒ Flow frequency ☐ Flow duration

☐ to Water year range

☒ 1997 Individual water year

☐ Relationship-defined water year

Feature has been used for fish spawning and vegetation drowning...



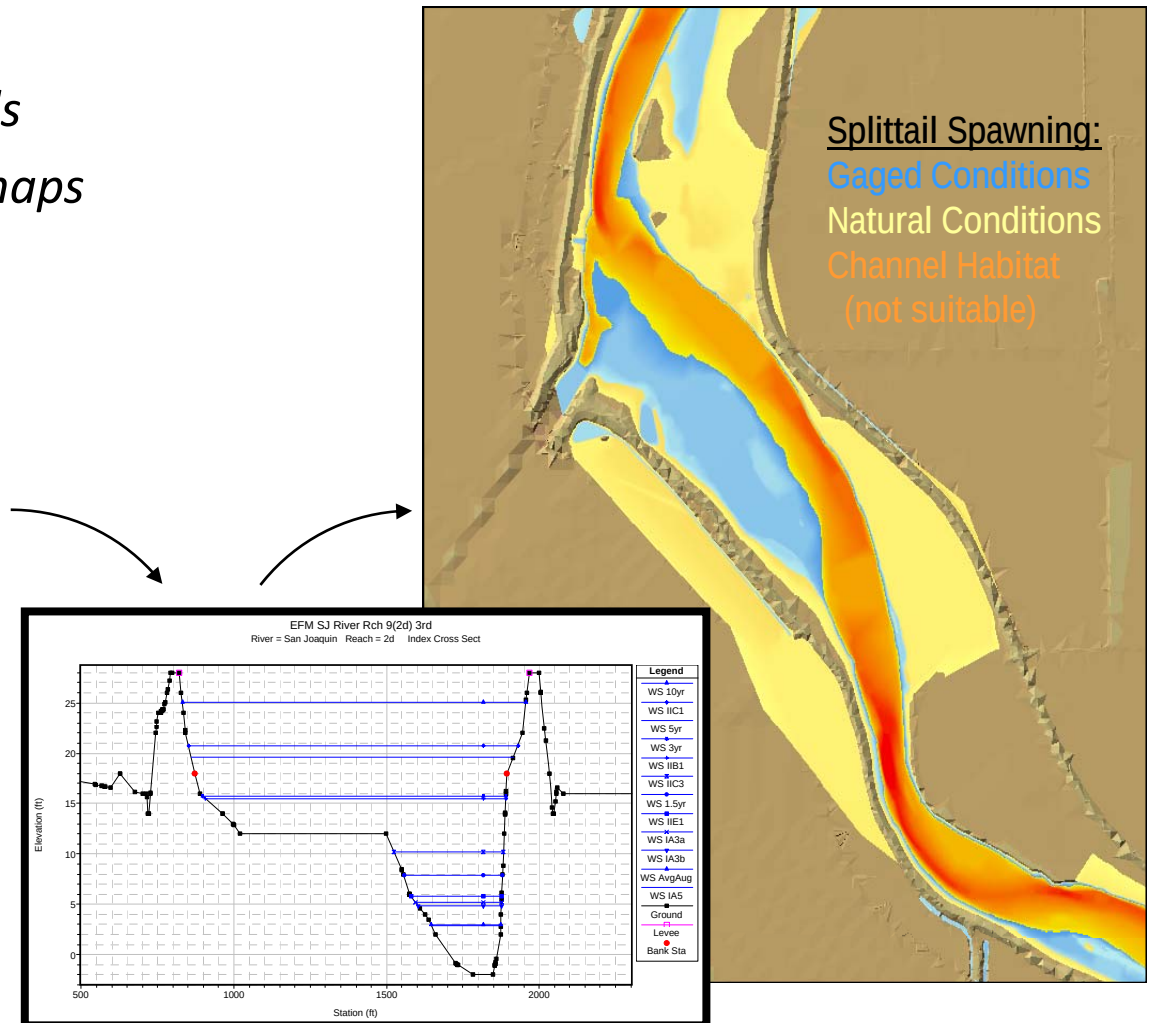
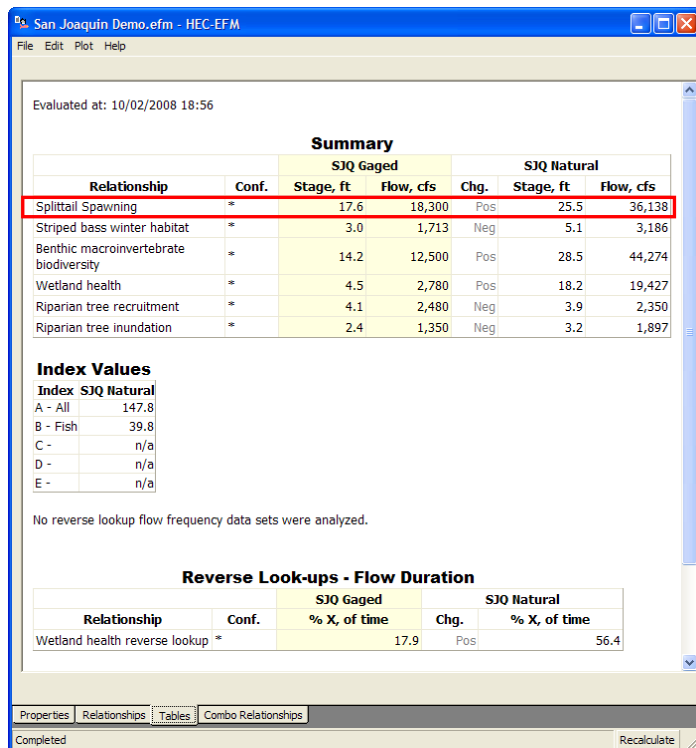
HEC-EFM

- Uses daily time series of flow and stage
- Computes statistics that are eco-relevant (as defined by users)
- Compare management scenarios for multiple eco-relationships

Statistical results investigated spatially with hydraulic models and GIS...

HEC-EFM - from Statistical to Spatial...

- Statistical results are input to hydraulic models to develop:
 - *Water surface profiles*
 - *Depth and velocity grids*
 - *Inundation boundary maps*
 - *Shear stress...*



EFM Applications and Relationships...



• Farmington River, CT.....*Floodplain forest, shrubs, buttonbush*

• Sandy River Delta, OR.....*Chinook salmon*

• Bill Williams River, AZ.....*Cottonwood, willow, saltcedar*

• Mississippi River, MO.....*Waterfowl, bluegill, plants*

• Truckee River, NV.....*Mayflies and cottonwood*

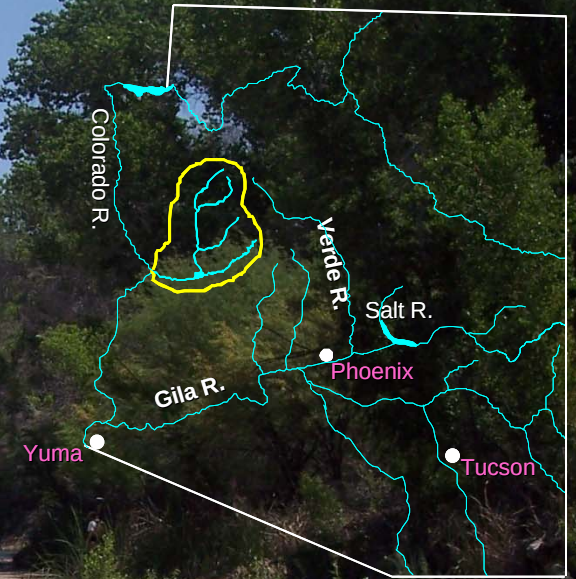
• Ashuelot Rivers, NH.....*Mussels, host fish*

• Savannah River, GA/SC.....*Shad, bass, shoals lily*

• Sacramento/San Joaquin, CA...*Splittail, geomorph, LWD*

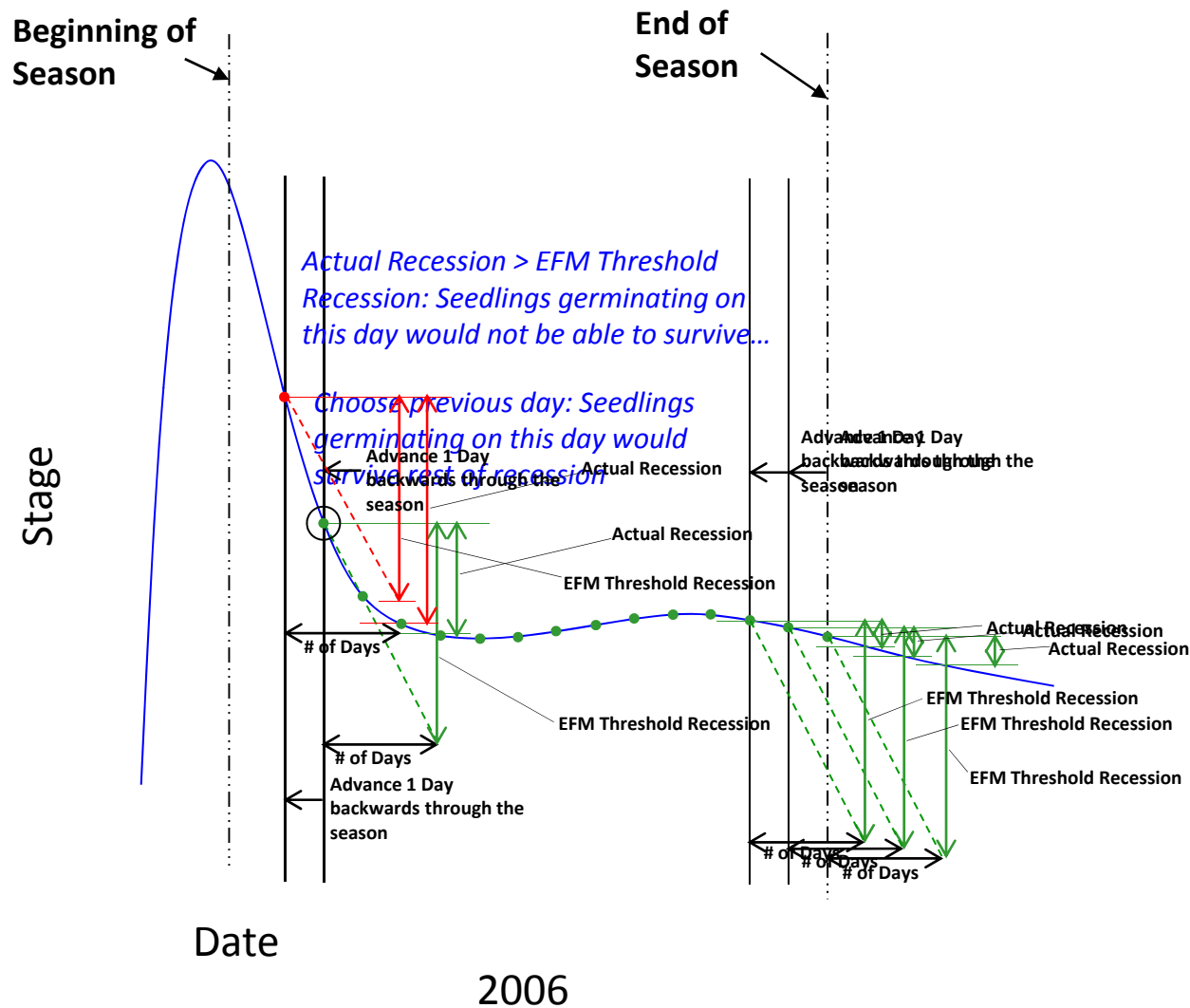


EFM Application – Cottonwood Bill Williams River, AZ



DA = 5200 sq. mi.

EFM Math - Cottonwoods



Statistical queries

☒ Season

From: 03/01 (m/d)

To: 04/13 (m/d)

☒ Duration of 1 days

For each duration, compute:

From computed values, select the:

☒ Rate of change: ☒ Stage ☐ Flow

0.12 feet per 3 days

☐ Rising ☒ Falling ☐ Absolute

Time series specifications

☐ 10 % exceedance (10.00-yr)

☒ Flow frequency ☐ Flow duration

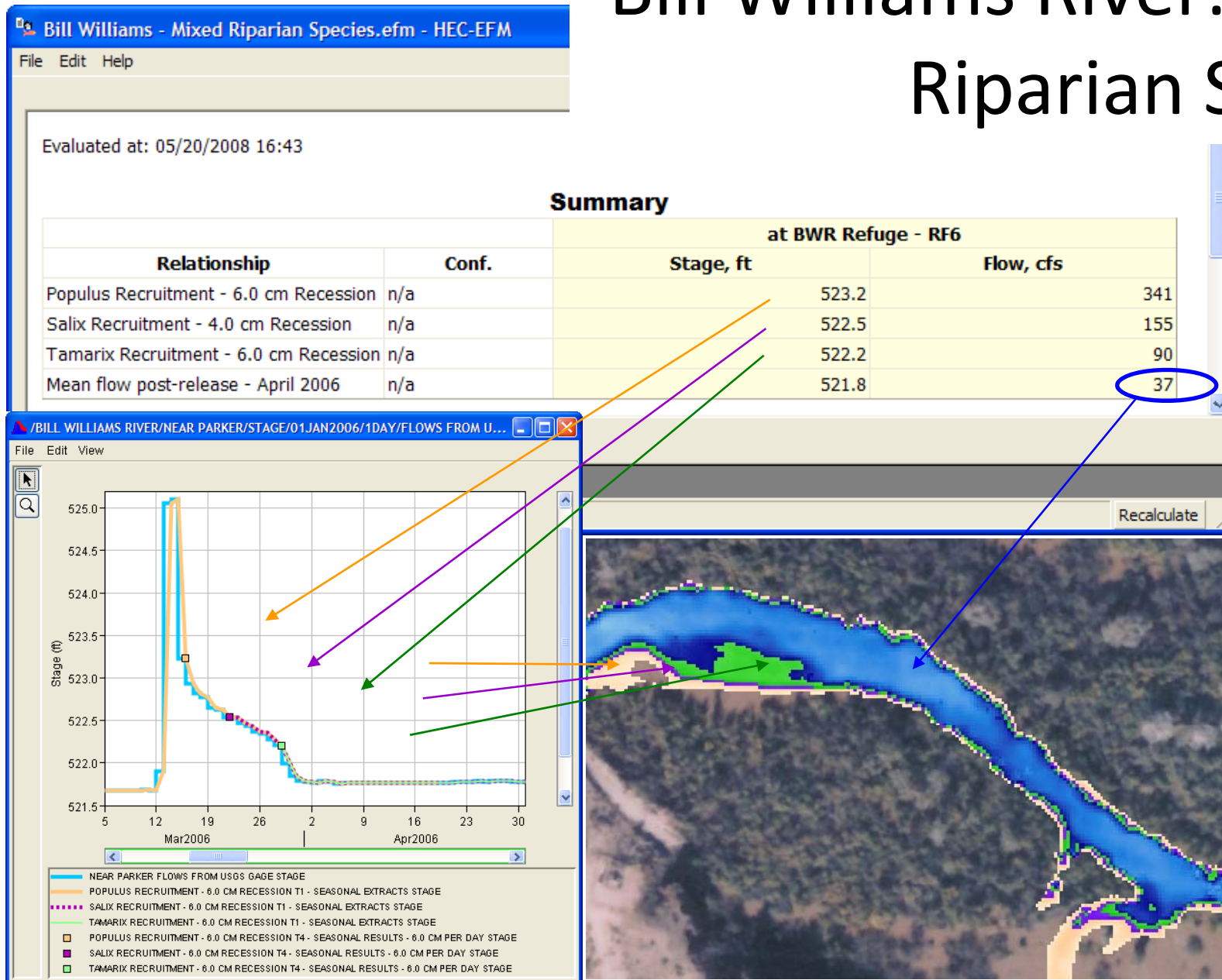
☐ to Water year range

☒ 2006 Individual water year

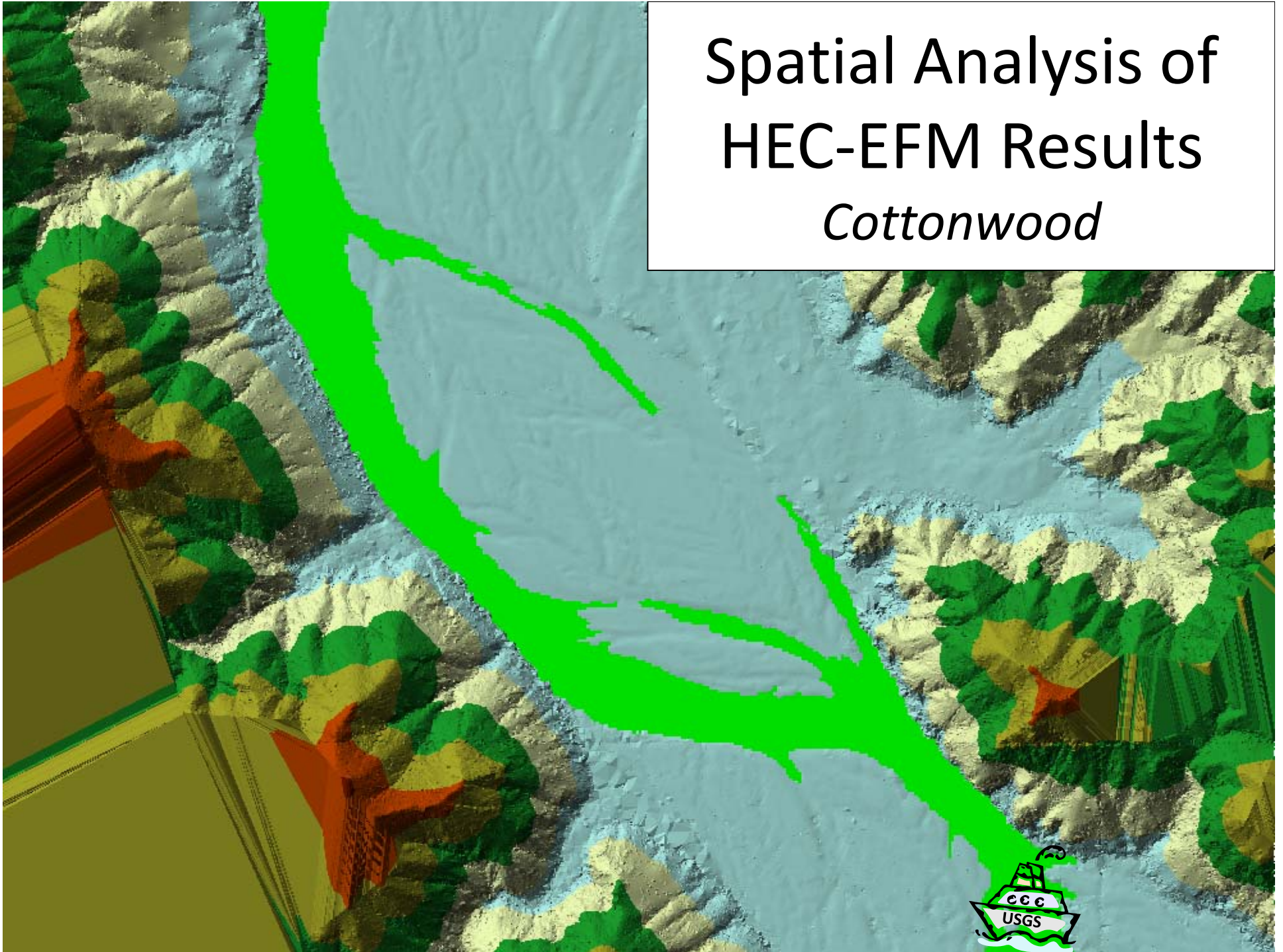
☐ Relationship-defined water year

*Feature has been used for
cottonwood, willow, and
saltcedar seedling
recruitment...*

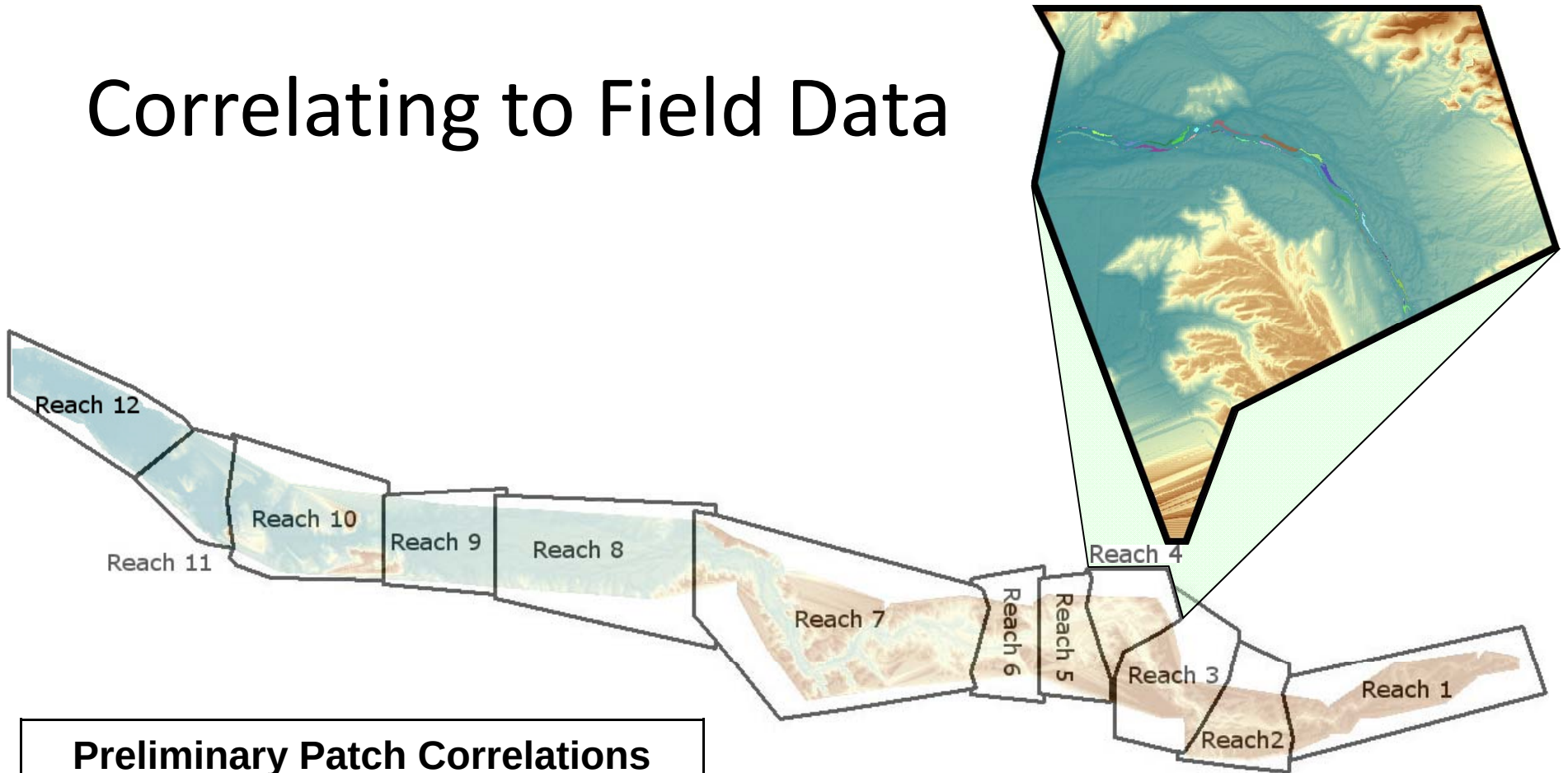
Bill Williams River: Mixed Riparian Species



Spatial Analysis of HEC-EFM Results *Cottonwood*



Correlating to Field Data



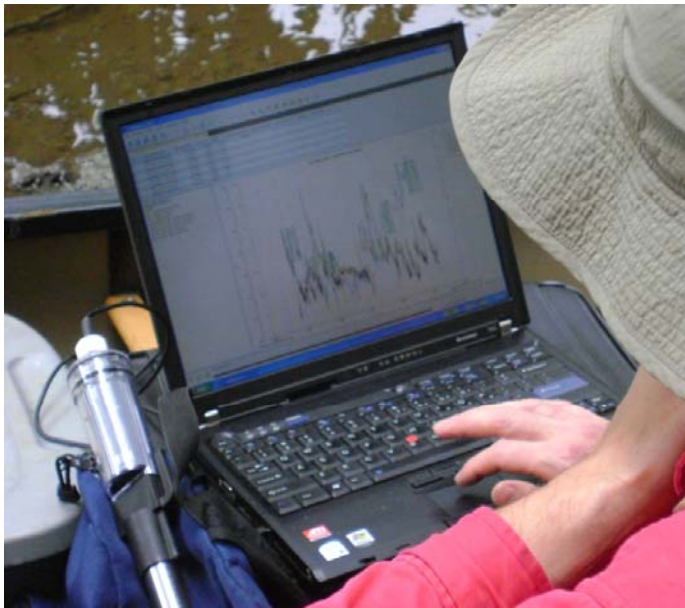
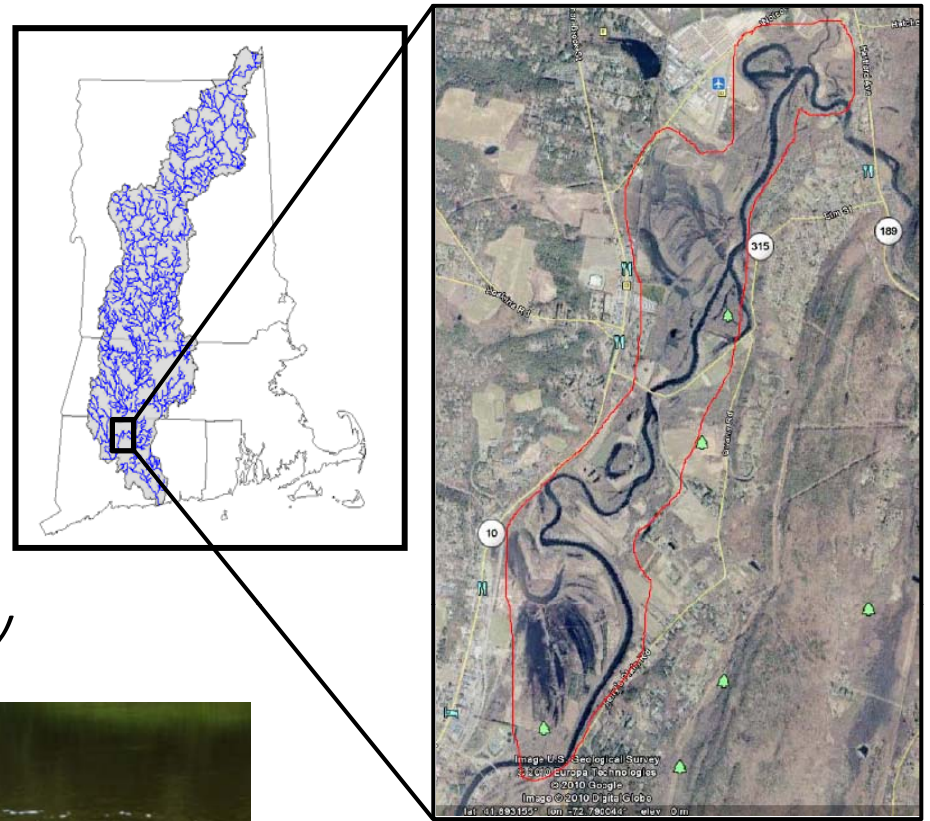
Preliminary Patch Correlations		
Simulated v. Observed Patches	Species	Correlation
	Cottonwood	0.77
	Willow	0.81
	Tamarisk	0.82

Floodplain Vegetation

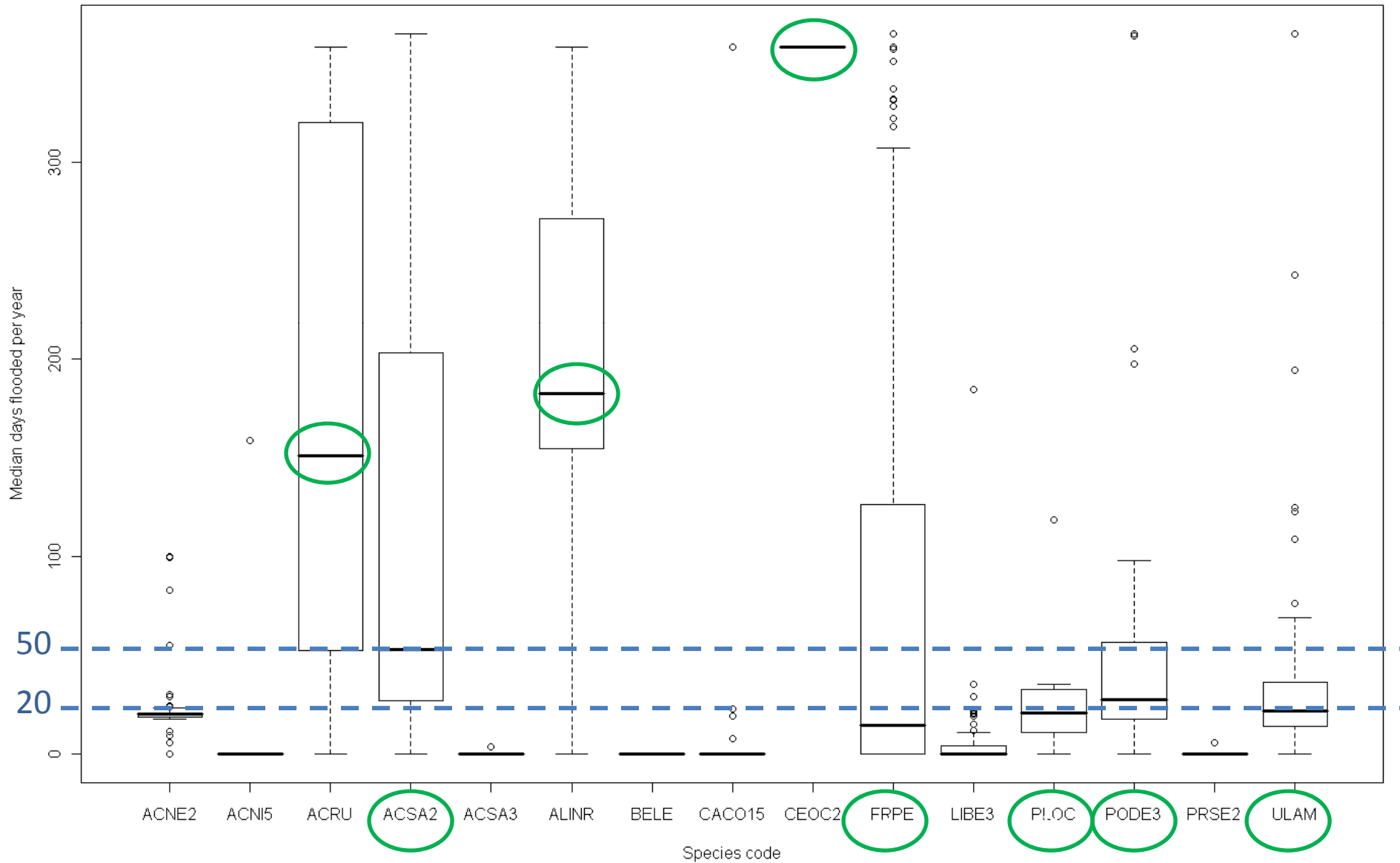
Farmington River, CT

Field Work: Vegetation Survey

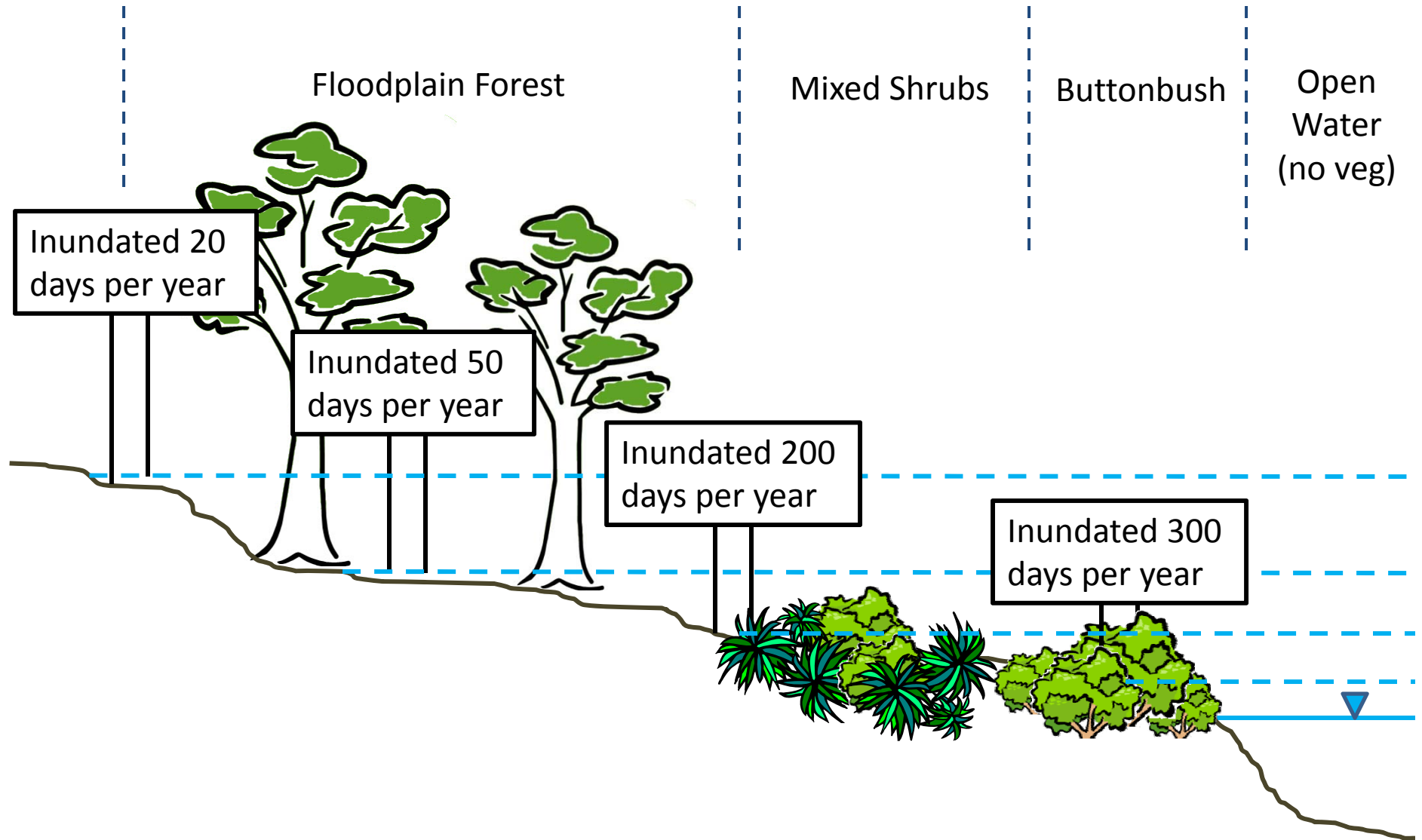
- Survey vegetation and elevation data along floodplain transects
- Monitor channel water levels with pressure transducer
- *How much flooding is needed for healthy floodplain ecosystem?*



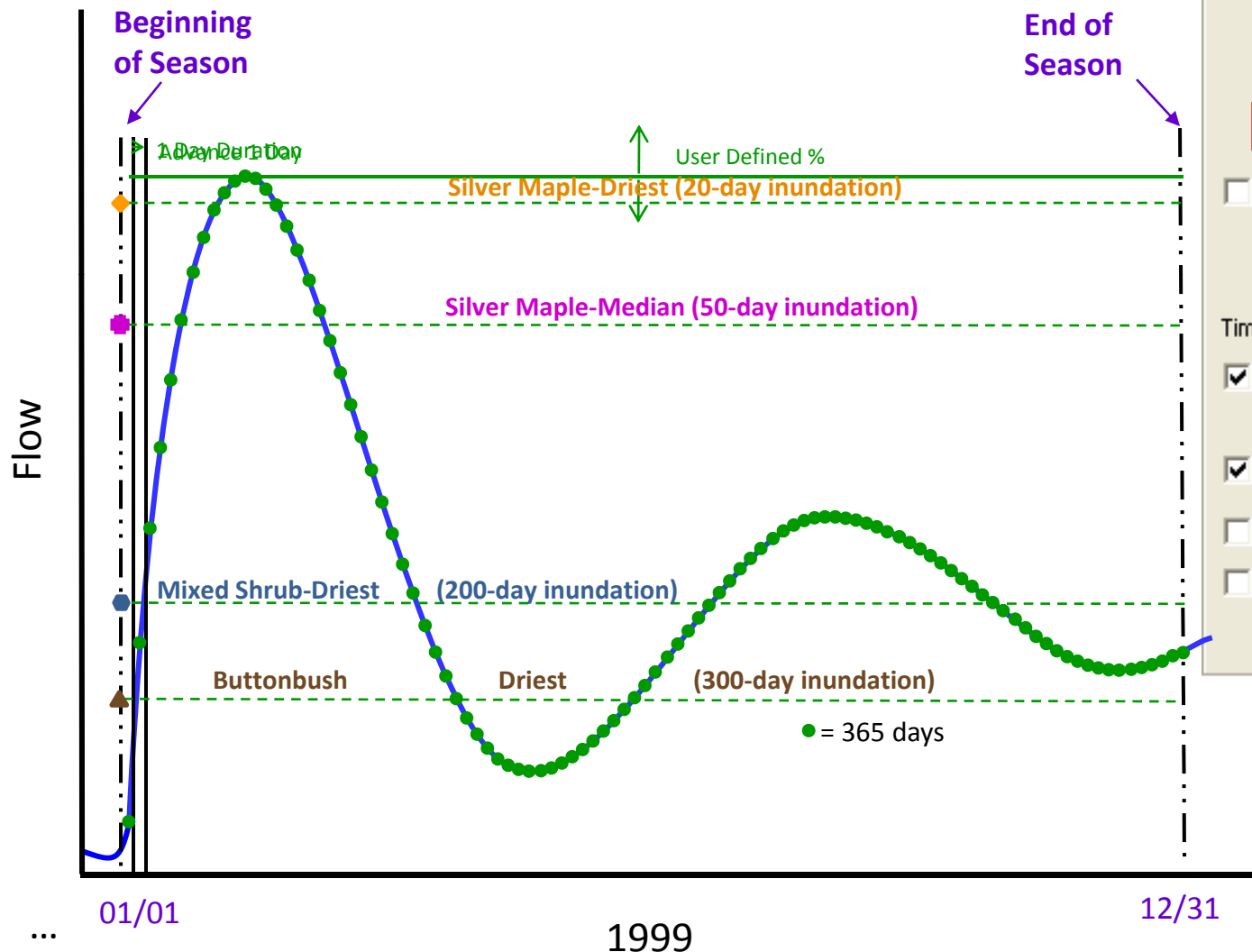
Tree results: Duration of flooding



Floodplain Vegetation



EFM Math: Floodplain Vegetation



Statistical queries

☒ Season

From: 01/01 (m/d)

To: 12/31 (m/d)

☒ Duration of 1 days

For each duration, compute:

Means

From computed values, select the:

User Defined % 94.5

☐ Rate of change: ☒ Stage ☐ Flow

feet per days

☐ Rising ☒ Falling ☐ Absolute

Time series specifications

☒ 50 % exceedance (2.00-yr)

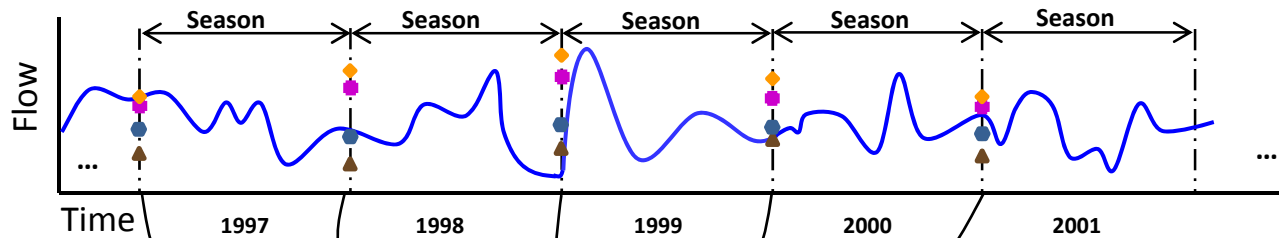
☒ Flow frequency ☐ Flow duration

☒ 1972 to 2008 Water year range

☐ Individual water year

☐ Relationship-defined water year

Each year is considered and then ranked...

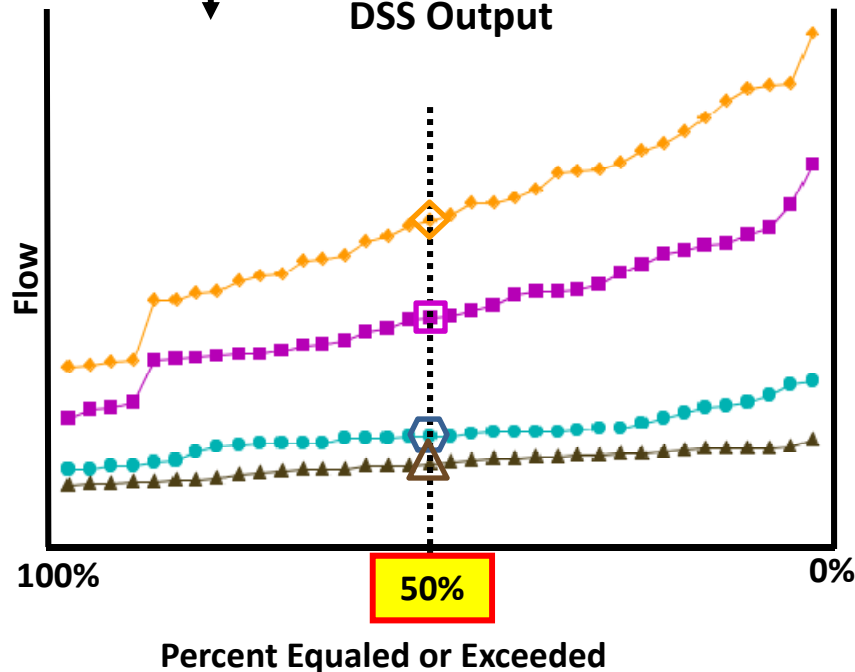


Buttonbush XML Output

Rank	Frequency	WY	Flow	Stage
1	.0270	1972	726.0	726.000
2	.0541	1979	659.9	659.880
3	.0811	1973	641.9	641.940
4	.1081	2006	640.0	640.000
5	.1351	1975	639.0	639.000
6	.1622	2003	636.8	636.790
7	.1892	1992	620.6	620.592
8	.2162	1996	594.1	594.148
9	.2432	2004	501.0	501.000
10	.2703	2000	580.0	580.000
11	.2973	1990	575.8	575.820
12	.3243	1989	572.9	572.910
13	.3514	1994	555.0	554.970
14	.3784	1976	553.0	553.000
15	.4054	1987	529.9	529.910
16	.4324	1906	525.0	525.040
17	.4595	1974	524.0	524.000
18	.4865	1991	494.9	494.940
19	.5135	1983	486.0	486.000
20	.5405	1993	461.9	461.940
21	.5676	1984	460.0	460.000
22	.5946	1982	459.7	459.730
23	.6216	1998	430.9	430.910
24	.6487	2005	430.0	430.000
25	.6757	1988	424.0	424.000
26	.7027	1978	409.0	409.000
27	.7297	1999	390.0	389.970
28	.7568	1997	389.0	388.970
29	.7838	2007	343.0	343.000
30	.8108	1995	326.8	326.820
31	.8378	1977	322.9	322.940
32	.8649	1985	313.0	313.000
33	.8919	1981	309.9	309.940
34	.9189	2001	305.0	304.970
35	.9460	1980	290.6	290.592
36	.9730	2002	274.0	274.000

Seasonal
Results

DSS Output



Statistical queries

☒ Season
 From: 01/01 (m/d)
 To: 12/31 (m/d)

☒ Duration of 1 days
 For each duration, compute:
 Means
 From computed values, select the:
 User Defined %

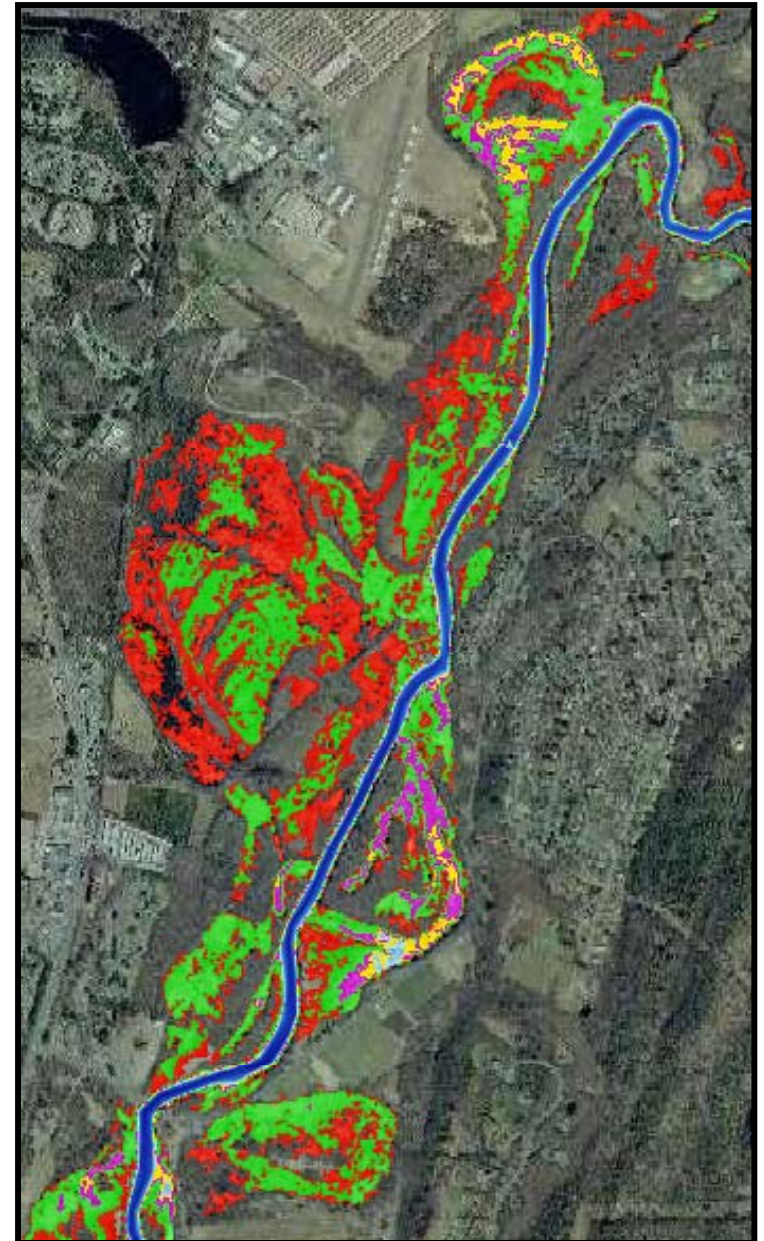
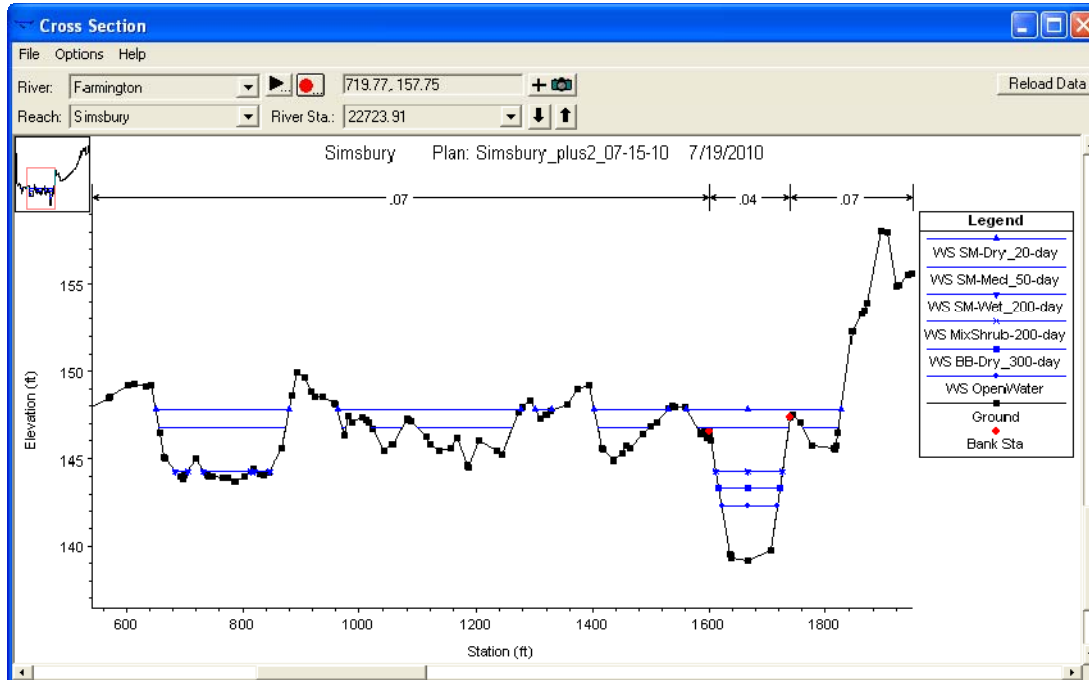
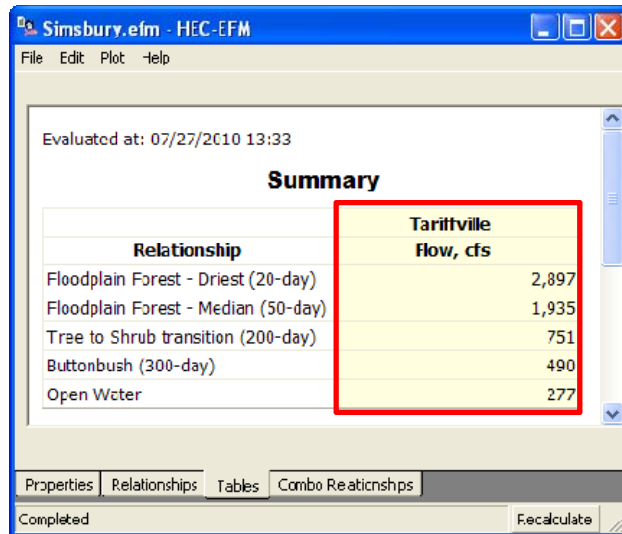
☐ Rate of change: ☒ Stage ☐ Flow
 feet per days
☐ Rising ☒ Falling ☐ Absolute

Time series specifications
☒ 50 % exceedance (2.00-yr)
☒ Flow frequency ☐ Flow duration
☒ 1972 to 2008 Water year range
☐ Individual water year
☐ Relationship-defined water year

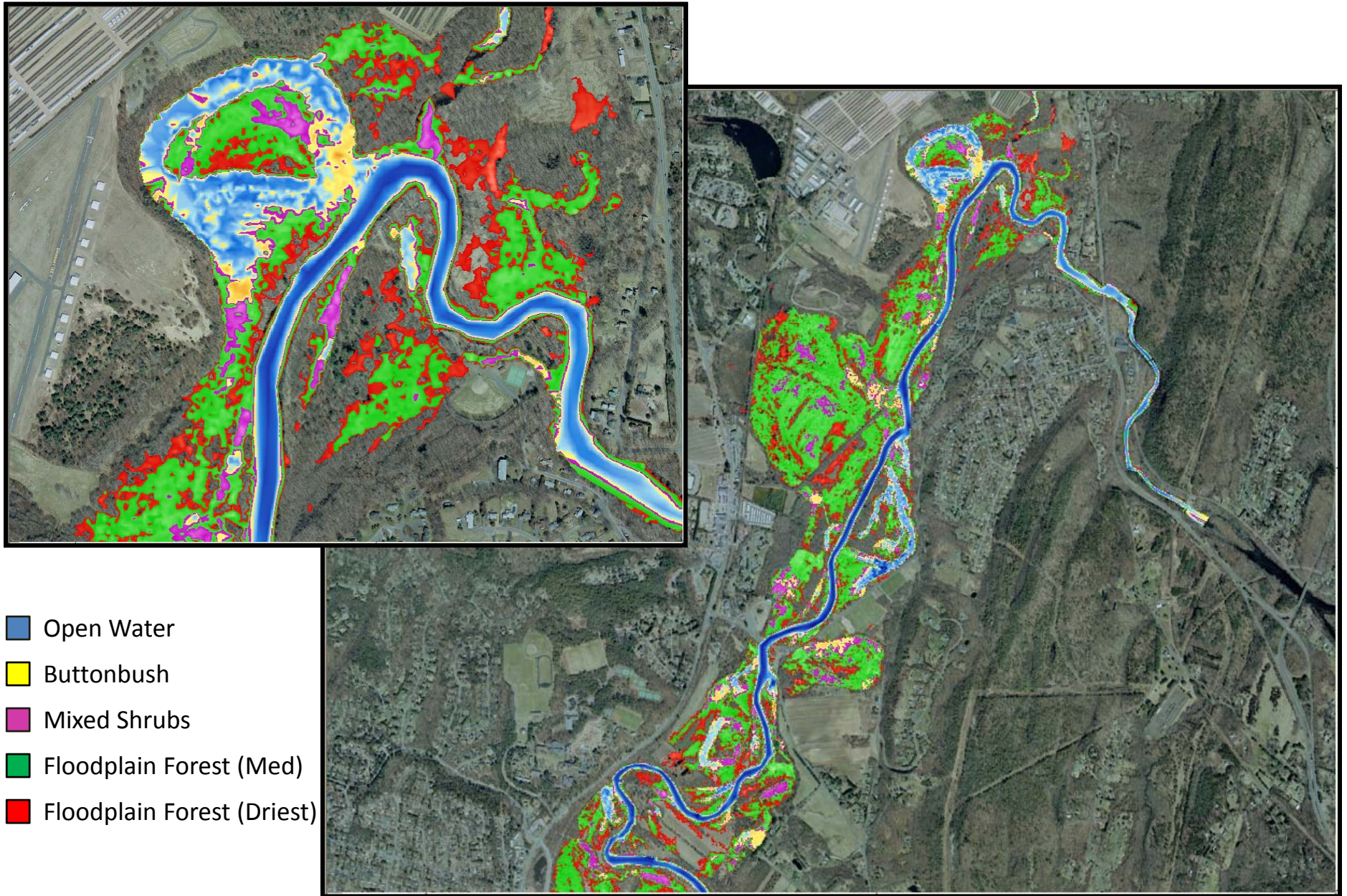
- ◆ Silver Maple-driest (20-d inundation)
- ◆ Silver Maple-median (50-d inundation)
- Mixed Shrub-driest (200-d inundation)
- ▲ Buttonbush-driest (300- inundation)

Statistical results reported in EFM interface and used in river hydraulic models for mapping...

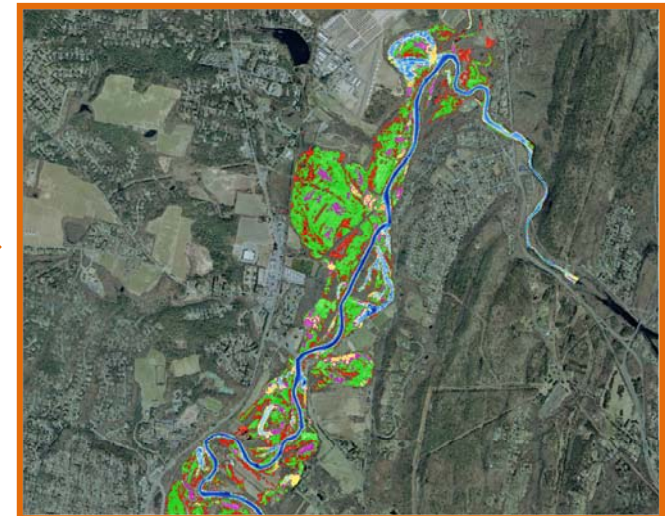
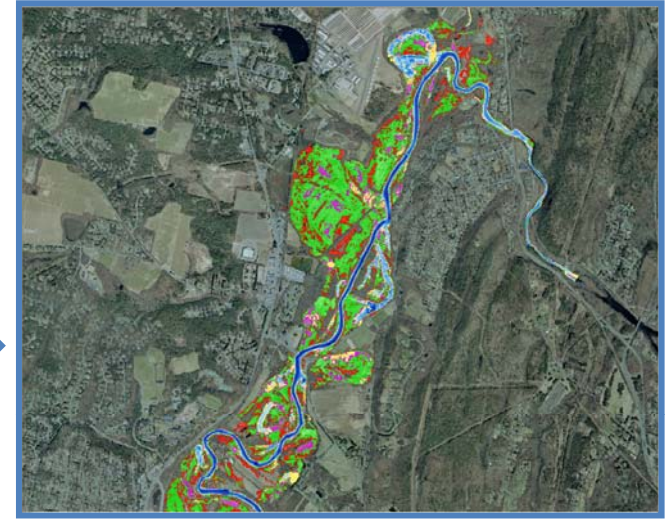
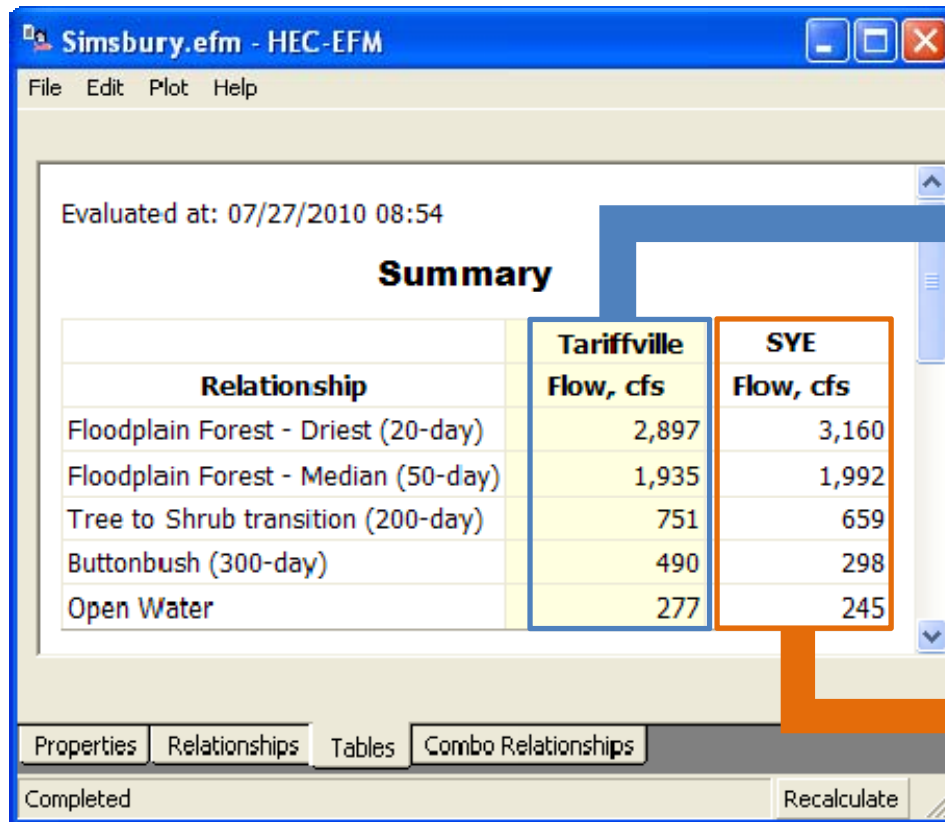
HEC-EFM – From Statistical to Spatial...



Gaged Simulated Vegetation Communities

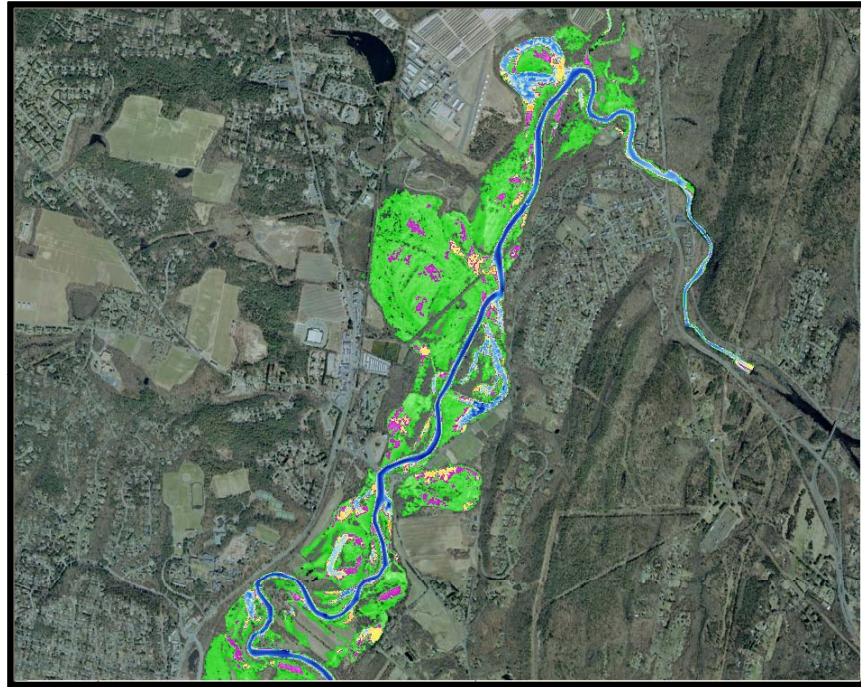


Comparing Flow Regimes: Gaged and Natural

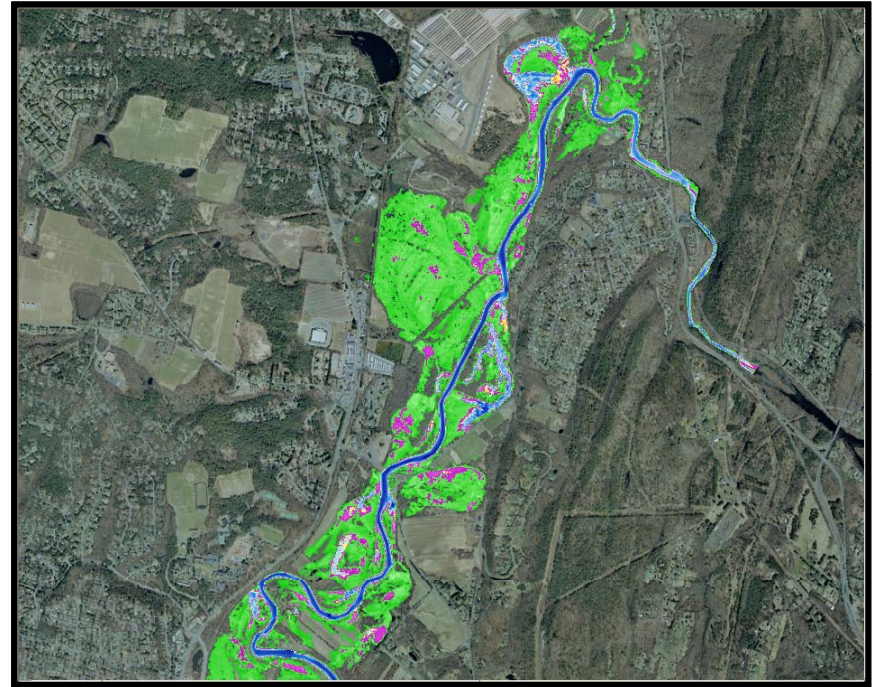


Comparing Flow Regimes: Gaged and Nat

Gaged

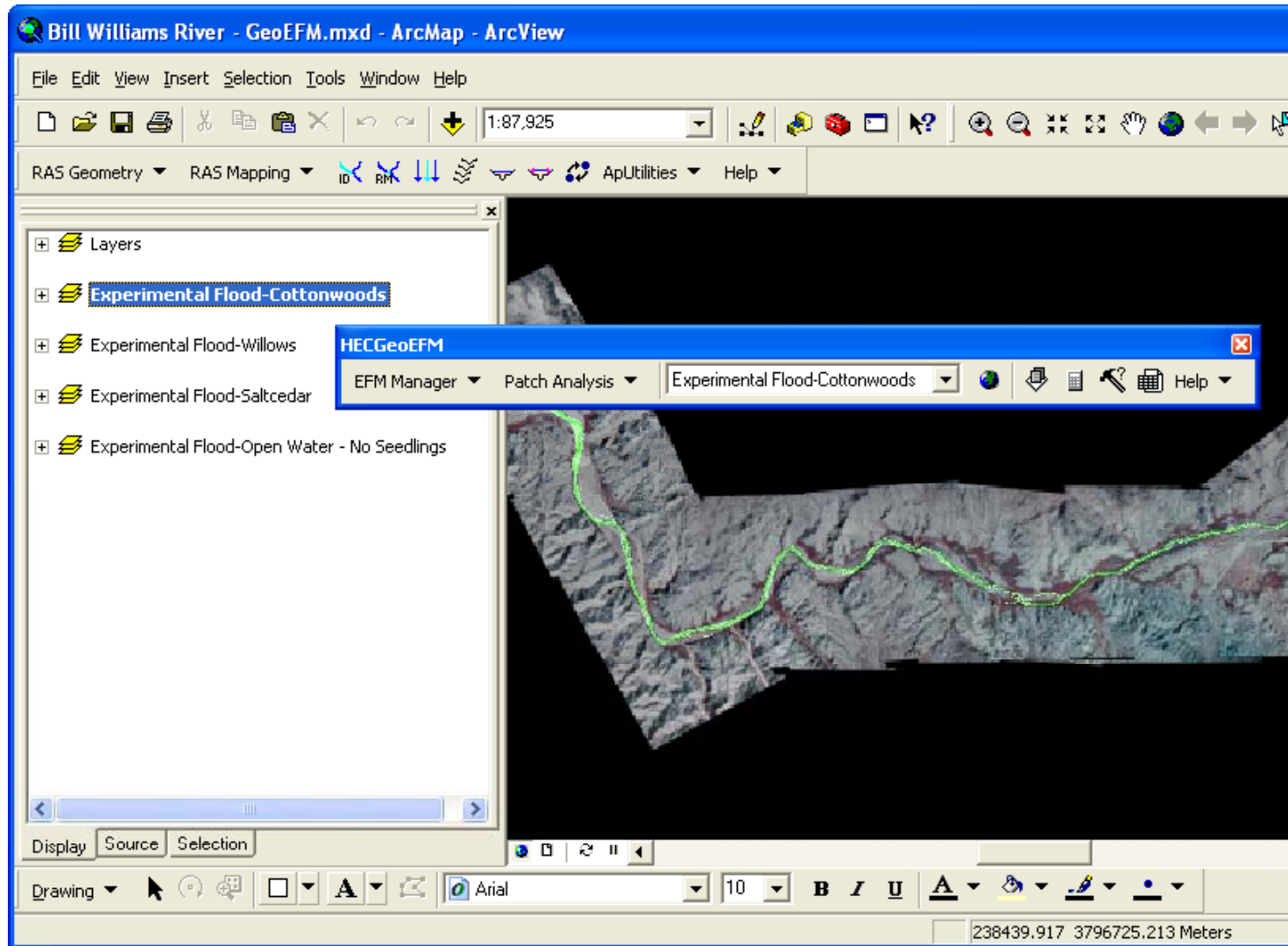


Natural



GeoEFM – Partnering HEC-ESRI

Toolbar for Arc 9.3



- ✓ Main Menu
- ✓ 3D Analyst
 - Advanced Editing
 - Animation
 - Annotation
 - ApUtilsNet9
 - Arc Hydro Tools 9
 - ArcPad
 - ArcScan
 - Batch Terrain Preprocessing 9
 - COGO
 - Cadastral Editor
 - Data Frame Tools
 - Dimensioning
 - Distributed Geodatabase
- ✓ Draw
 - EPA Aggregator
 - Editor
 - Effects
 - GPS
 - GeoDataset Exchange Tools 9
 - Geocoding
 - Geodatabase History
 - Geometric Network Editing
 - Georeferencing
 - Geostatistical Analyst
 - Graphics
- ✓ **HEC-GeoEFM**
 - HEC-GeoHMS Main View 9
 - HEC-GeoHMS Project View 9
- ✓ HEC-GeoRAS
 - Labeling

GeoEFM – Habitat Area

HEC-GeoEFM

EFM Manager ▾ Patch Analysis ▾ Experimental Flood-Cottonwoods ▾

Tabulate Spatial Results

Tabulating spatial results computes and displays areas for different combinations of flow regimes and relationships. Please select from the following options:

Report | Status

Report location: C:\Temp\Bill Williams River\EFM\Vegetation Analyses\

Report Name: Habitat Area

Select Option:

- ☐ Total Areas
- ☐ Change from Reference
- ☒ Both

Change from Reference:

- ☐ Percentage
- ☒ Difference in area

Select Units:

- ☐ Sq Feet
- ☒ Acres
- ☐ Sq Miles
- ☐ Sq Meters
- ☐ Hectares
- ☐ Sq Km

Select Flow Regime and Relationships

Reference Flow Regime	Tabulate Flow Regimes	Relationships
Experimental Flood	Experimental Flood	Cottonwoods
Full Record below Dam	Experimental Flood	Willows
Full Record at Science Site	Full Record at Science Site	Saltcedar
Experimental Flood		Open Water - No Seedlings
		Riparian Rework

OK Cancel

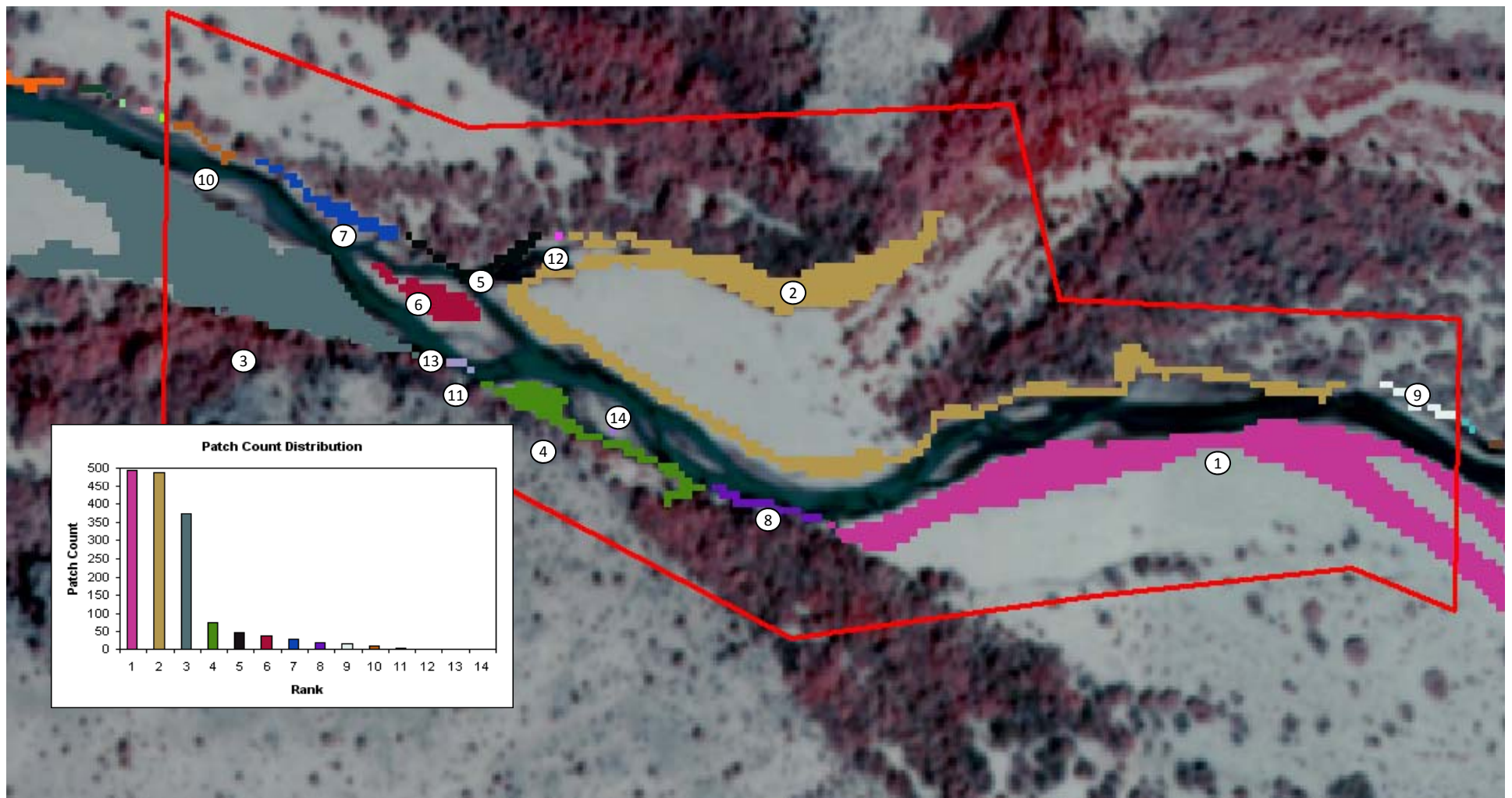
*...compute/tabulate habitat areas
for different management or
restoration scenarios*

Summary			
Relationship	Full Record below Dam	Experimental Flood	
	Area, acres	Area, acres	Change, acres
Open Water - No Seedlings	429	429	.0
Saltcedar	431	576	145.0
Willows	468	891	423.7
Cottonwoods	649	1,080	431.2

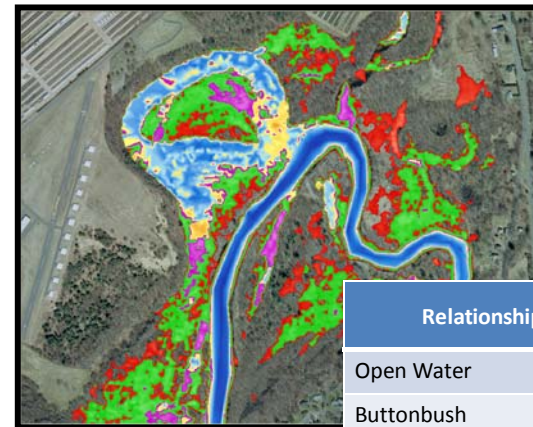
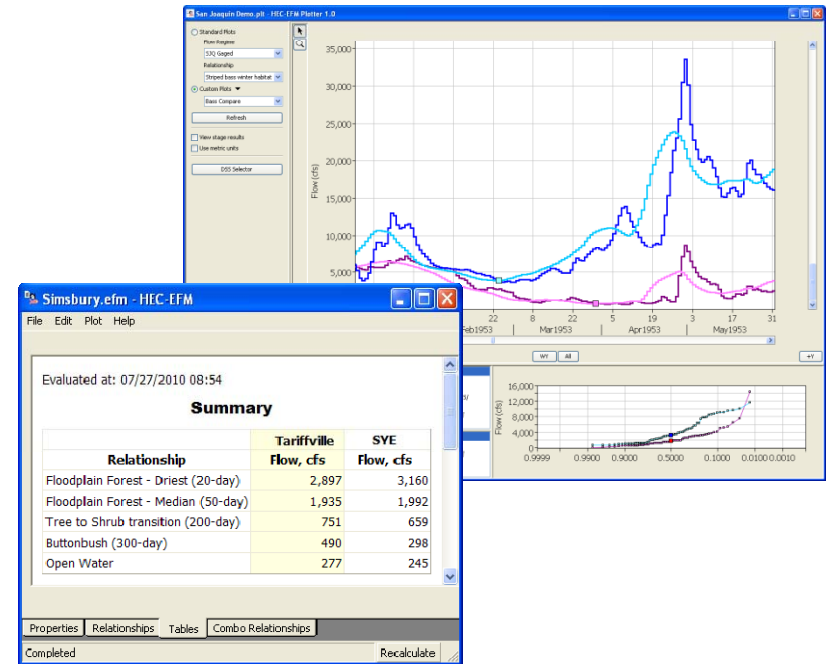
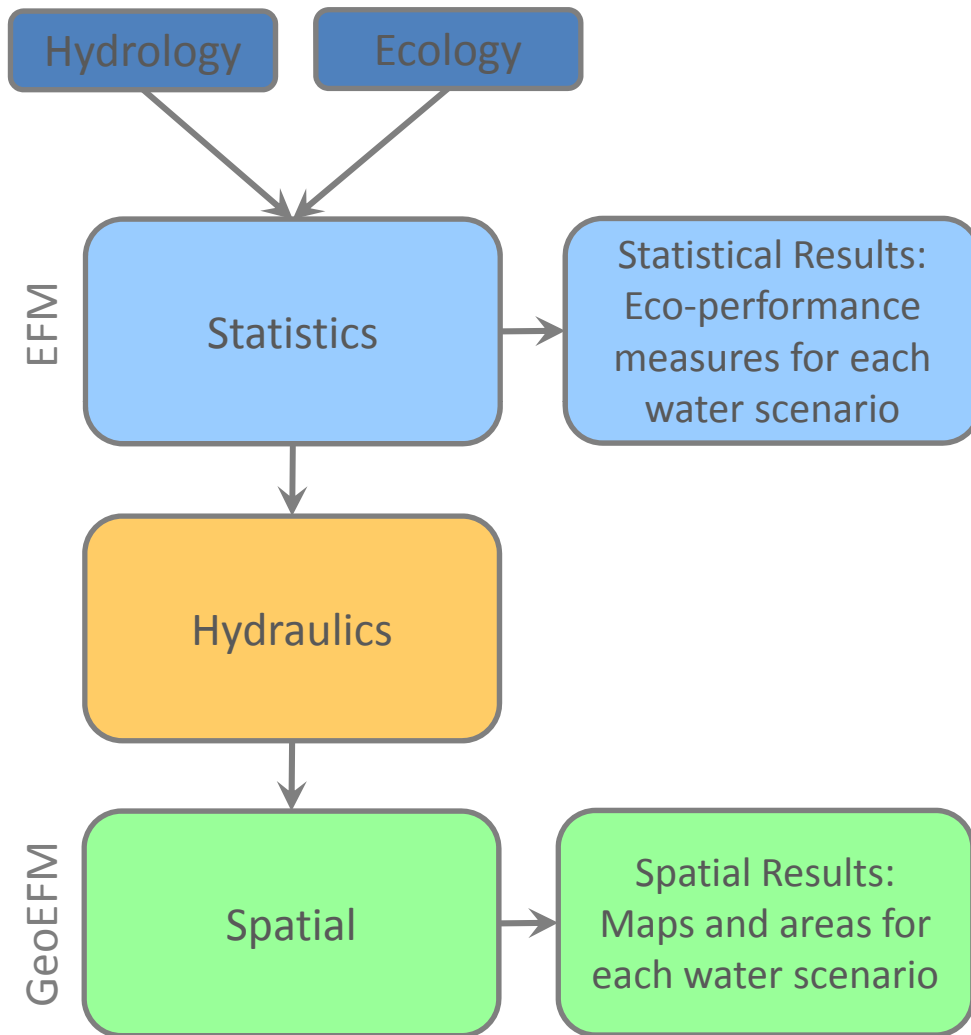


...corridors, distribution, interaction

GeoEFM – Habitat Connectivity

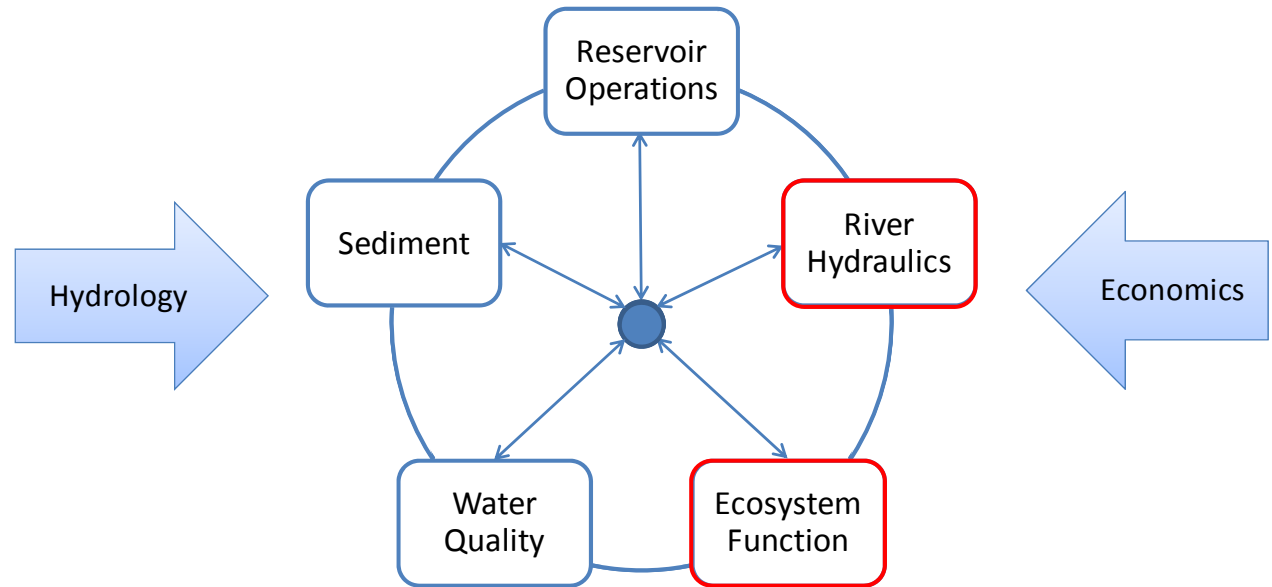


Ecosystem Functions Model (EFM) Process



Relationships	Gaged (acres)	SYE (acres)
Open Water	196	184
Buttonbush	79	20
Mixed Shrubs	113	147
Floodplain Forest	762	842

HEC-EFM Summary



- “Flow Regimes” = water management and/or ecosystem restoration scenarios
- “Relationships” = connections between hydrology and ecology
- EFM is generic...can be used to test many different types of Relationships
- EFM is powerful...can be used to test many different Flow Regimes
- Statistical output (direction of eco-change and magnitude of eco-change)
- Spatial output via hydraulic models (habitat areas and habitat connectivity)



For more information...

- www.hec.usace.army.mil/software/hec-efm/
- www.hec.usace.army.mil/software/hec-efm-plotter/
- www.hec.usace.army.mil/software/hec-geoefm/ (...coming soon)

EFM references

- Shafroth et al. 2010. Ecosystem effects of **environmental flows**: modelling and **experimental floods** in a dryland river. Freshwater Biology - January 2010.
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- USACE. 2006. Environmental Assessment update for the Savannah River **Drought Contingency Plan**. Savannah District.
- USACE. 2004. The Ecosystem Functions Model: A Tool for **Restoration Planning**. ERDC/TN SMART-04-4.
- USACE and Reclamation Board, State of California. 2002. **Ecosystem Functions** Model - Technical Studies Documentation, Appendix G. Sacramento and San Joaquin Rivers Basin Comprehensive Study, Sacramento, CA. <http://www.compstudy.net/reports.html>
- Jones and Stokes. 2000. Final functional relationships for the Ecosystem Functions Model, Sacramento and San Joaquin River Basins Comprehensive Study, Sacramento, CA.