Instream Flow Enhancement and Groundwater Recharge Planning

A Workshop at the 34th Annual Salmonid Restoration Conference held in Fortuna, CA from April 6-9, 2016.

Workshop Overview

- Workshop Coordinators:
  - Lisa Hulette, The Nature Conservancy
  - Tasha McKee, Sanctuary Forest

Coho salmon in California are on the brink of extinction, and if current trends continue, Chinook salmon and steelhead trout are close behind. Dependent largely on the small forested tributaries of the Coast Ranges for spawning and the first year of their lives, salmon populations have been significantly reduced by the devastating effects of logging, agriculture, and urbanization. Populations of coho salmon in the state have fallen from more than 500,000 fish to fewer than 5,000 in less than a century.

Water scarcity issues now pose the single biggest threat to salmonid recovery. Drought, land use impacts and human water use are all contributing factors. With climate change and prediction of future droughts we are urgently called upon to restore ground and surface water hydrology and develop conservation programs to reduce human use impacts.

This workshop will address streamflow and groundwater recharge science, including project implementation, resource management challenges and new policy directions designed to provide salmon and steelhead the best chance for survival across their freshwater life-cycle. Presenters will discuss strategies for increasing instream flow from state wide action plans to water conservation and transaction programs to restoration of ground and surface water hydrology. Several different approaches to groundwater recharge will be presented in different settings such that participants will walk away with a broad understanding of techniques and their application. An interactive groundwater planning exercise will take participants through the steps of preliminary assessment and planning of groundwater recharge projects. Two contrasting project types will be used for the exercise and participant teams will be assisted in the preparation and sharing of a groundwater recharge project. Permitting for groundwater recharge projects will also be addressed including the new Water Quality Certification for Small Habitat Restoration Projects.

Presentations

Instream Flow Enhancement and Groundwater Recharge Planning: Part 1

(Slide 5) California Water Action Plan; Enhance Water Flows in Stream Systems Statewide
Daniel Worth, State Water Resources Control Board

(Slide 36) Providing Flows for Salmonids in Drought Years and Beyond
Daniel Schultz, State Water Resources Control Board, Division of Water Rights, Public Trust Unit

(Slide 87) South Fork Eel River Water Conservation Program —A Variable Diversion Rate Strategy for Coastal Watershed Management
Dr. William Trush, Humboldt State University River Institute

(Slide 123) Effect of Water Transactions on Water Quality and Adult Fall-Run Chinook Salmon in the Shasta River
Ann Willis, University of California Davis Center for Watershed Sciences

Presentations

Instream Flow Enhancement and Groundwater Recharge Planning: Part 2

(Slide 153) Aquatic Habitat Is More than Skin Deep - Linkages Between Human Activities, Reduced Groundwater Abundance, and Aquatic Ecosystem Health
Brad Job, Civil Engineer, Pacific Watershed Associates

(Slide 195) Reconnecting Hillslope Hydrology- Road Run-Off and Infiltration
Joel Monschke, Civil Engineer and Geomorphologist, Stillwater Sciences

Meadow and Floodplain Restoration and Active and Passive Groundwater Recharge
Eric M. Ginney, Environmental Science Associates (ESA)
*presentation not included

(Slide 210) Quantifying Groundwater Recharge and Storage Increases from Meadow Restoration in the Sierra Nevada
David Shaw, P.G., Balance Hydrologics, Inc.

(Slide 254) Restoring an Incised Coastal Stream- Groundwater Recharge Outcomes
Tasha McKee, Sanctuary Forest, and Brad Job, Pacific Watershed Associates

34th Annual Salmonid Restoration Conference

California Water Action Plan: Enhance Water Flows in Stream Systems Statewide

Daniel Worth

April 7, 2016

Fortuna, CA

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Parts of Presentation

1. Provide a short summary of what the Water Boards do
2. Discuss efforts to enhance stream flows statewide
3. Provide an example of flow related issues and the benefits of improving flow conditions

State Water Resources Control Board
and
Regional Water Quality Control Boards

- State Water Board
  - Water allocation and water quality authority
  - Develops State-wide water policy
  - Issues permits for cross regional projects
- Regional Water Boards
  - Develops basin plans to protect water quality
  - Issues permits for regional projects
  - 9 Regional Boards
    - North Coast Regional Water Quality Control Board

California Water Action Plan

California natural resources Agency

cdfa
California Department of Food & Agriculture

California Environmental Protection Agency (Cal/EPA)

California Water Action Plan (WAP)

January 22, 2014

- Developed at direction of Governor Brown by:
  - California Department of Food and Agriculture
  - California Environmental Protection Agency
  - California Natural Resources Agency
- Plan will guide state efforts to:
  - Enhance water supply reliability
  - Restore damaged and destroyed ecosystems
  - Improve resilience of California's infrastructure
- Outlines California's near- and long-term water priorities, including drought

- Action 4 – Protect and Restore Important Ecosystems
  - Sub-action: **<u>Enhance Water Flows in Stream Systems Statewide (Page 12 of WAP)</u>**

"The State Water Resources Control Board and the Department of Fish and Wildlife will implement a suite of individual and coordinated administrative efforts to enhance flows statewide in at least five stream systems that support critical habitat for anadromous fish. These actions include developing defensible, cost-effective, and time-sensitive approaches to establish instream flows using sound science and a transparent public process. When developing and implementing this action, the State Water Resources Control Board and the Department of Fish and Wildlife will consider their public trust responsibility and existing statutory authorities such as maintaining fish in good condition."

Priority Streams
California Water Action Plan
PRIORITY STREAMS
PRIORITY WATERSHEDS
Mainstem Rivers
1:3,500,000
Instream Flow Unit
Division of Water Rights
California Water Boards
0 20 40 80 120 160
Miles
N
S
E
W
SHASTA RIVER
MILL CREEK
SOUTH FORK EEL RIVER
MARK WEST CREEK
VENTURA RIVER
Klamath River
Eel River
Sacramento River
Russian River
Eureka
Redding
Chico
Reno
Carson City
Santa Rosa
Vacaville
Sacramento
Napa
Fairfield
Stockton
Antioch
San Francisco
Livermore
Modesto
Fremont
San Jose
Fresno
Salinas
Visalia
CALIFORNIA
NEVADA
Bakersfield
Santa Maria
Lompoc
Lancaster
Palmdale
Victorville
Santa Clarita
Oxnard
Riverside
101
80
50
395
505
5
280
210
95

Potential
State Water Board Work

- The enhancement and establishment of instream flows could include:
  - Science
  - Enforcement
  - Water rights actions
  - Policy development
  - Cooperative agreements
  - CEQA
  - Grant funding
  - Outreach

Where are we in the flow enhancement process?

- Held meetings with regional and headquarters staff in all five of the priority watersheds
- Developing contracts for:
  - Hydrology and groundwater modeling
  - Water rights evaluation tools
- Identifying gauging needs
- Compiling and evaluating existing information

Why Does California Need Instream Flow Requirements?

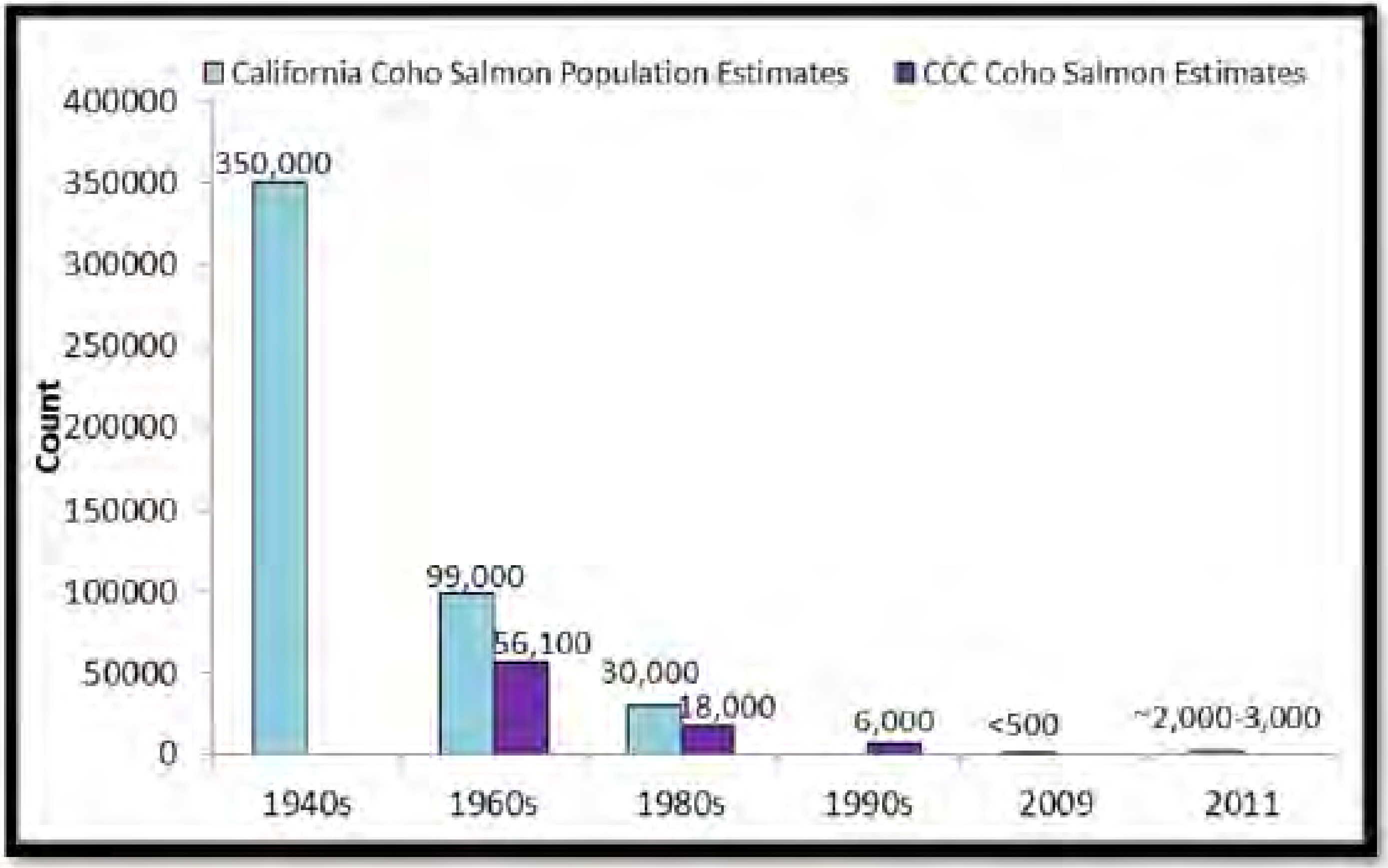


Figure 3: Historical estimates of coho salmon spawners across ESU

What does instream flow have to do with fish?

- Instream flows affect nearly all of the other habitat attributes that fish experience, including:
  - Depth
  - Velocity
  - Temperature
  - Water Quality
  - Sediment
  - Habitat Structure and Complexity
  - Food Availability

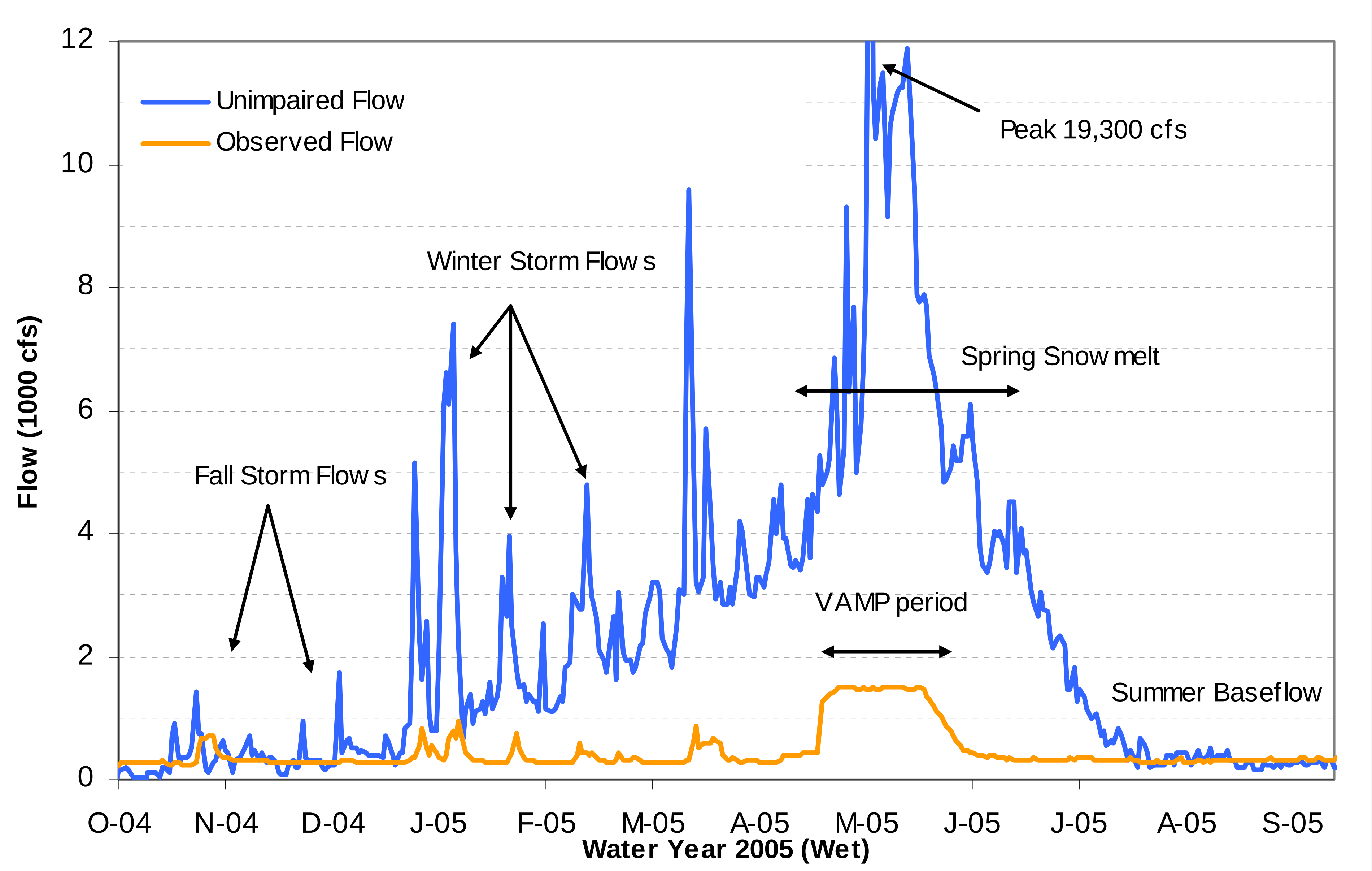
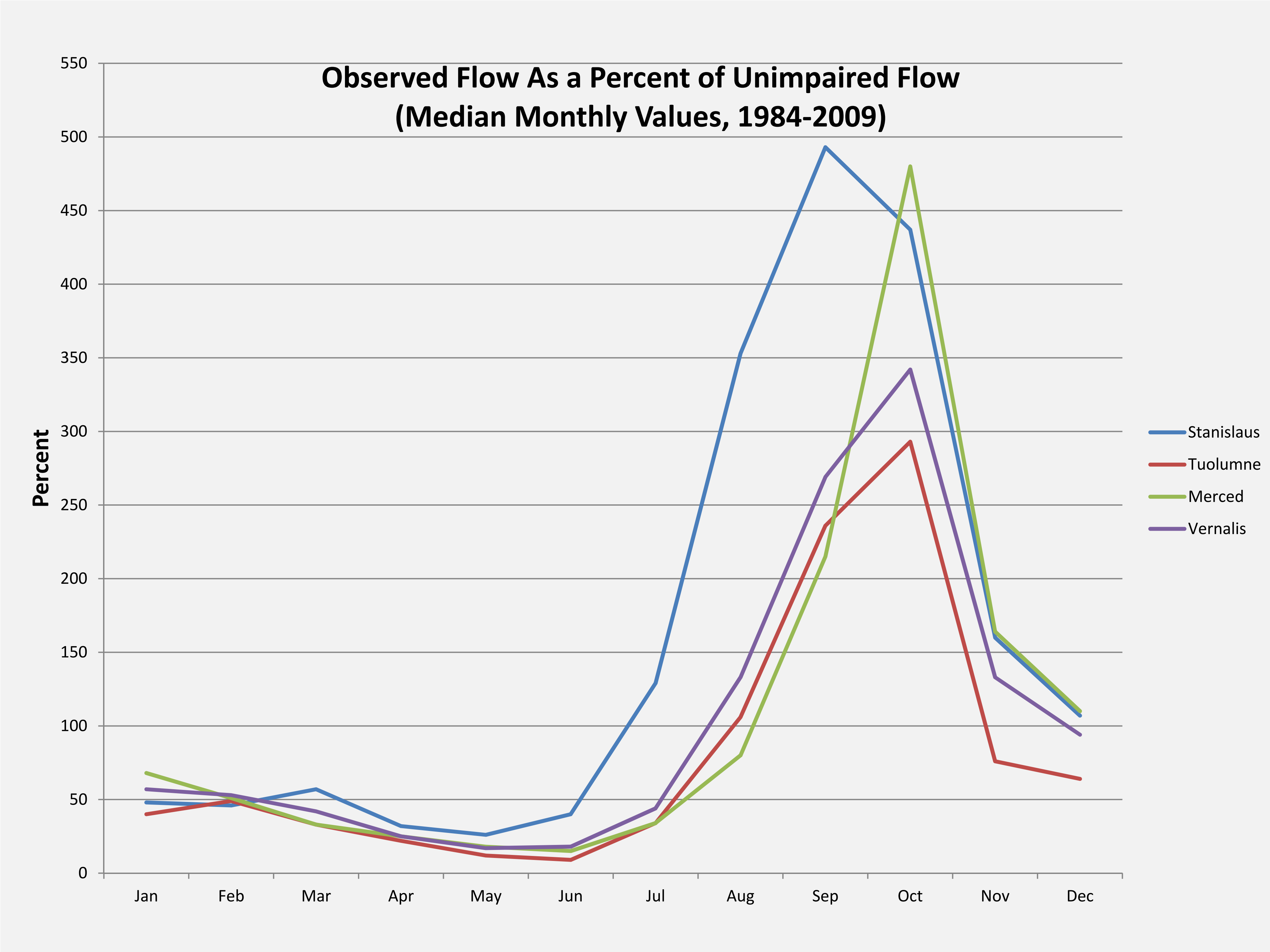
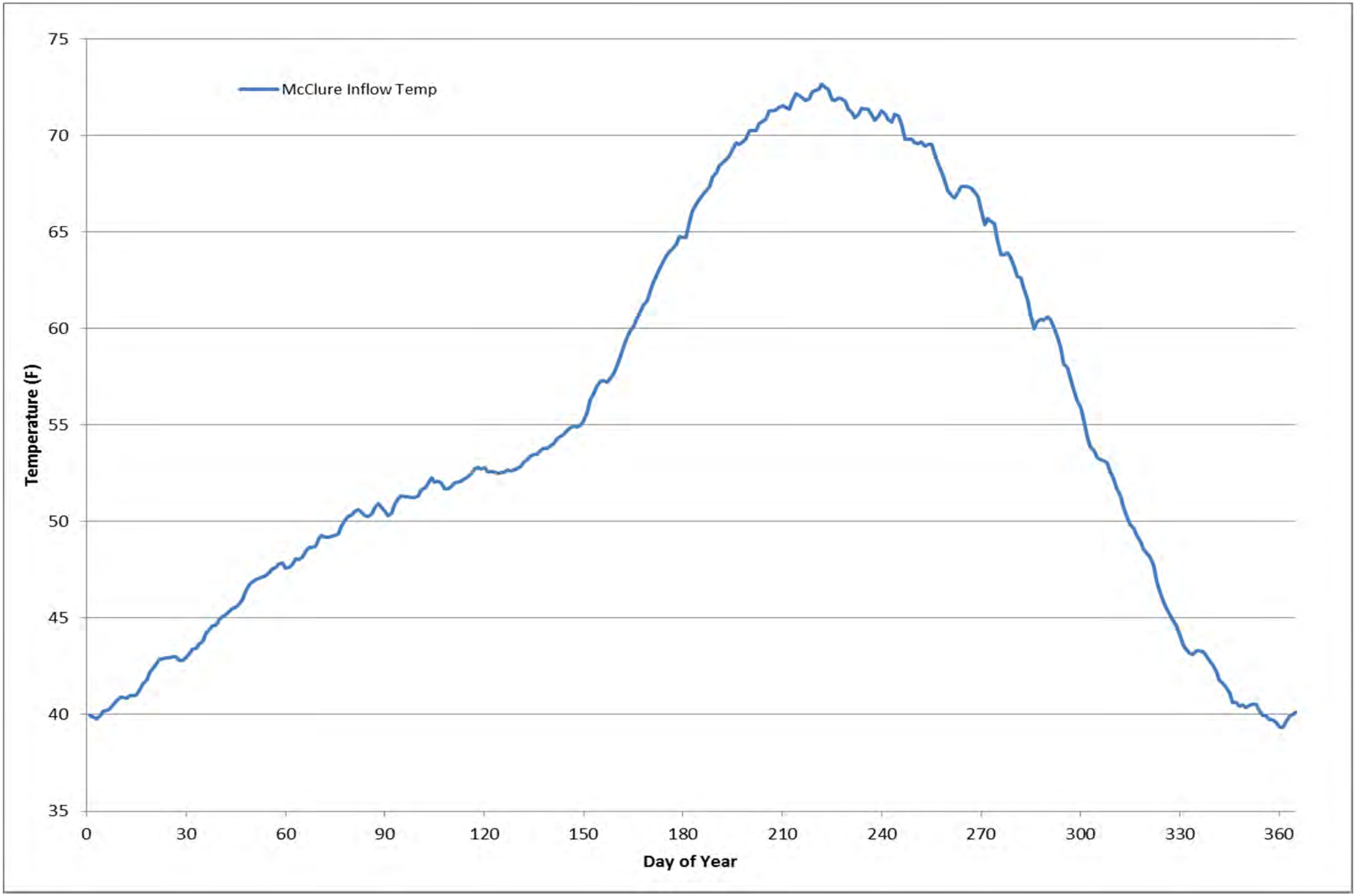
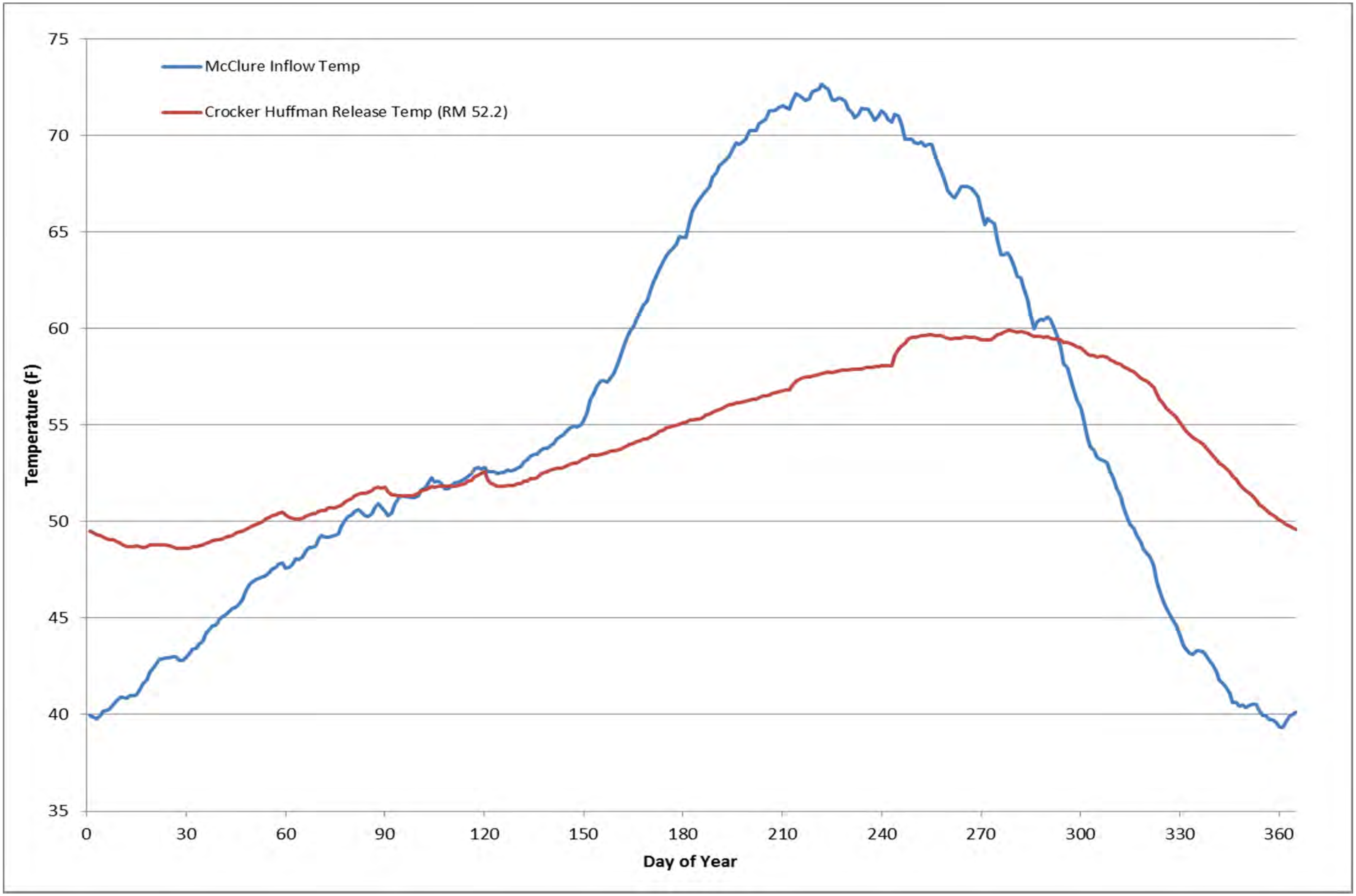


Figure 1: Typical Stanislaus River Annual Hydrograph of Daily Average Unimpaired and Observed Flows during a Wet Water Year (2005) Illustrating Important Hydrograph Components

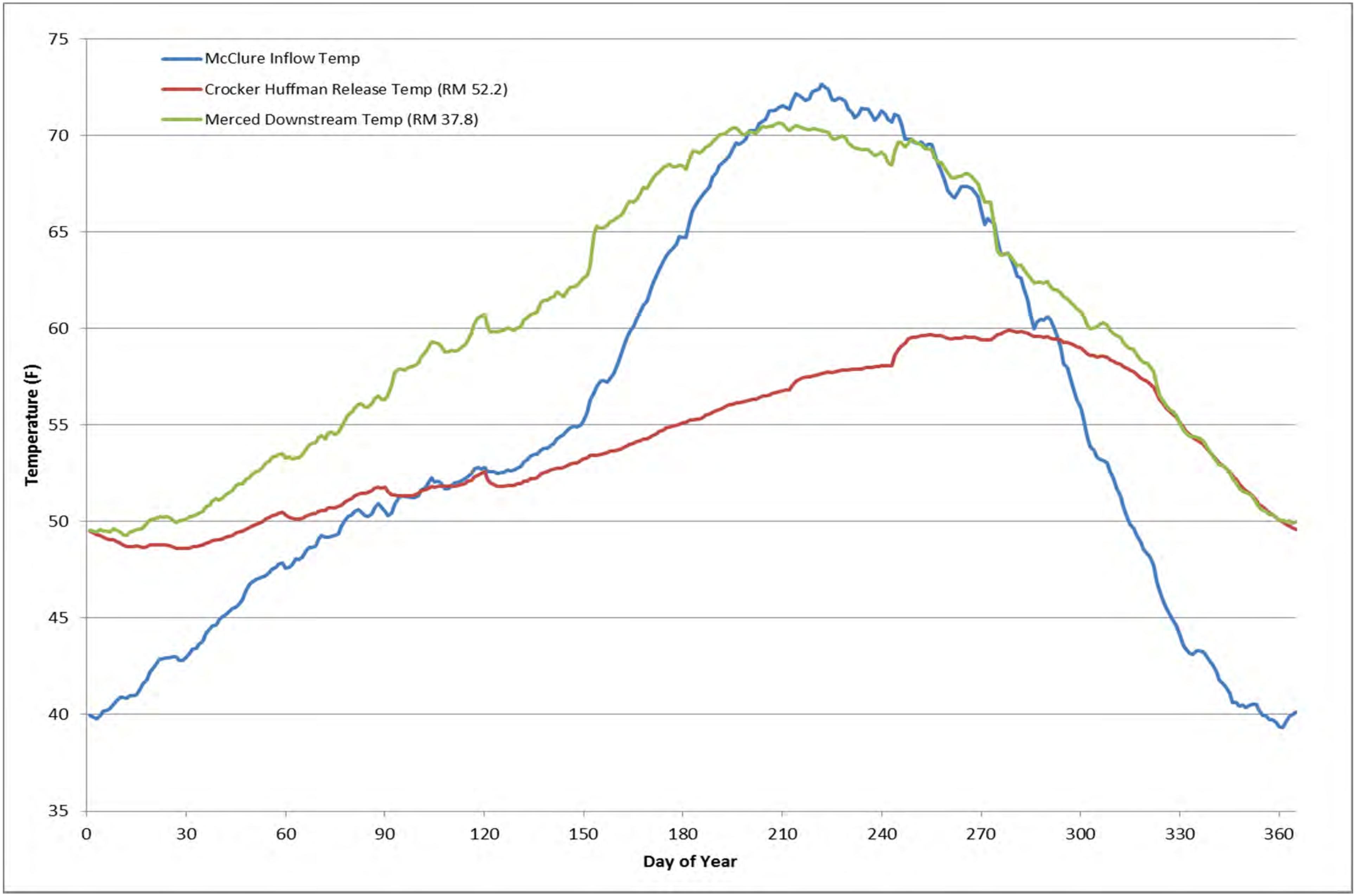

Observed Flow As a Percent of Unimpaired Flow
(Median Monthly Values, 1984-2009)
Percent
550
500
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Stanislaus
Tuolumne
Merced
Vernalis



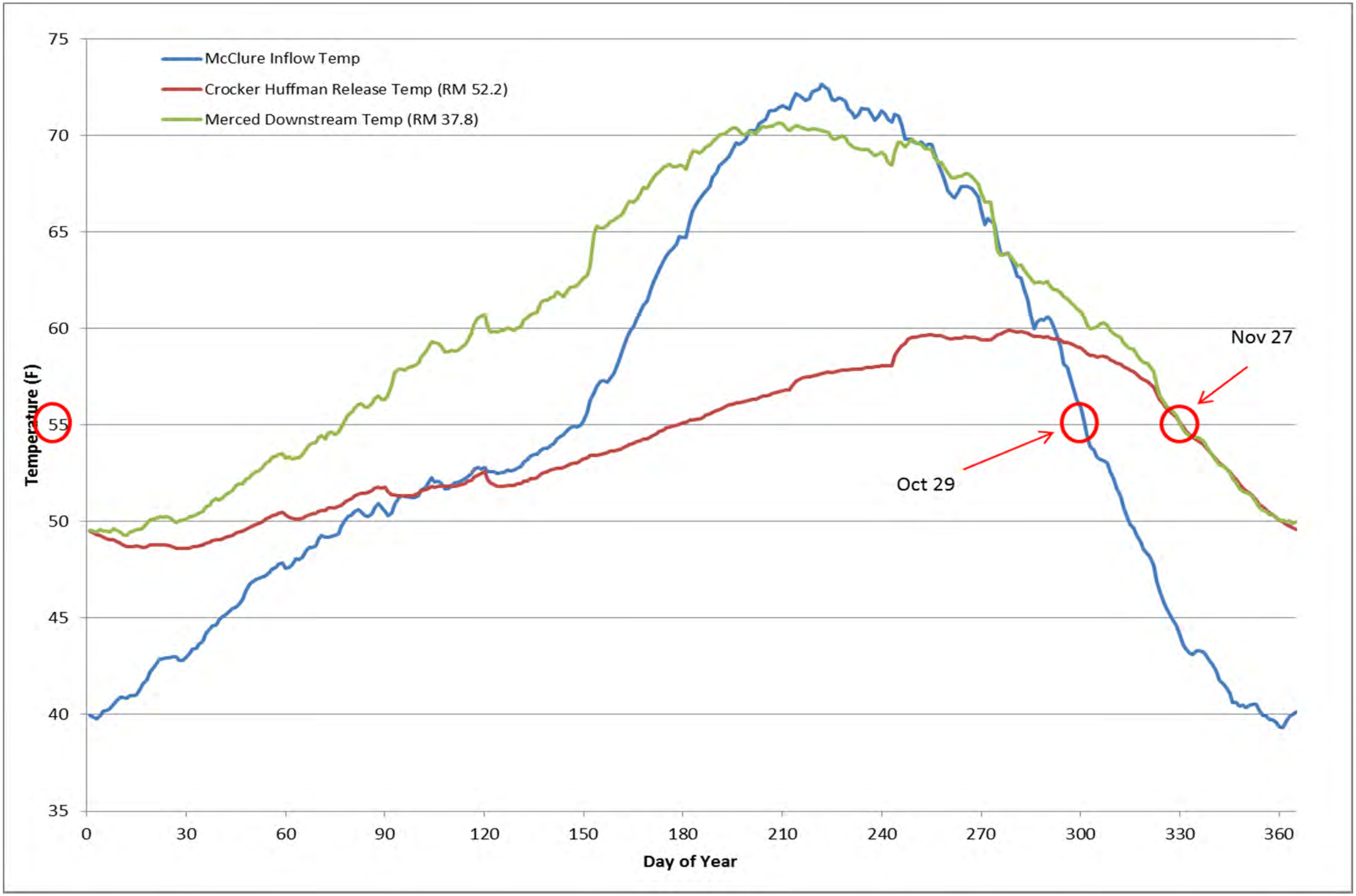
Merced River average daily temperature under Baseline conditions from 1960 to 2010.



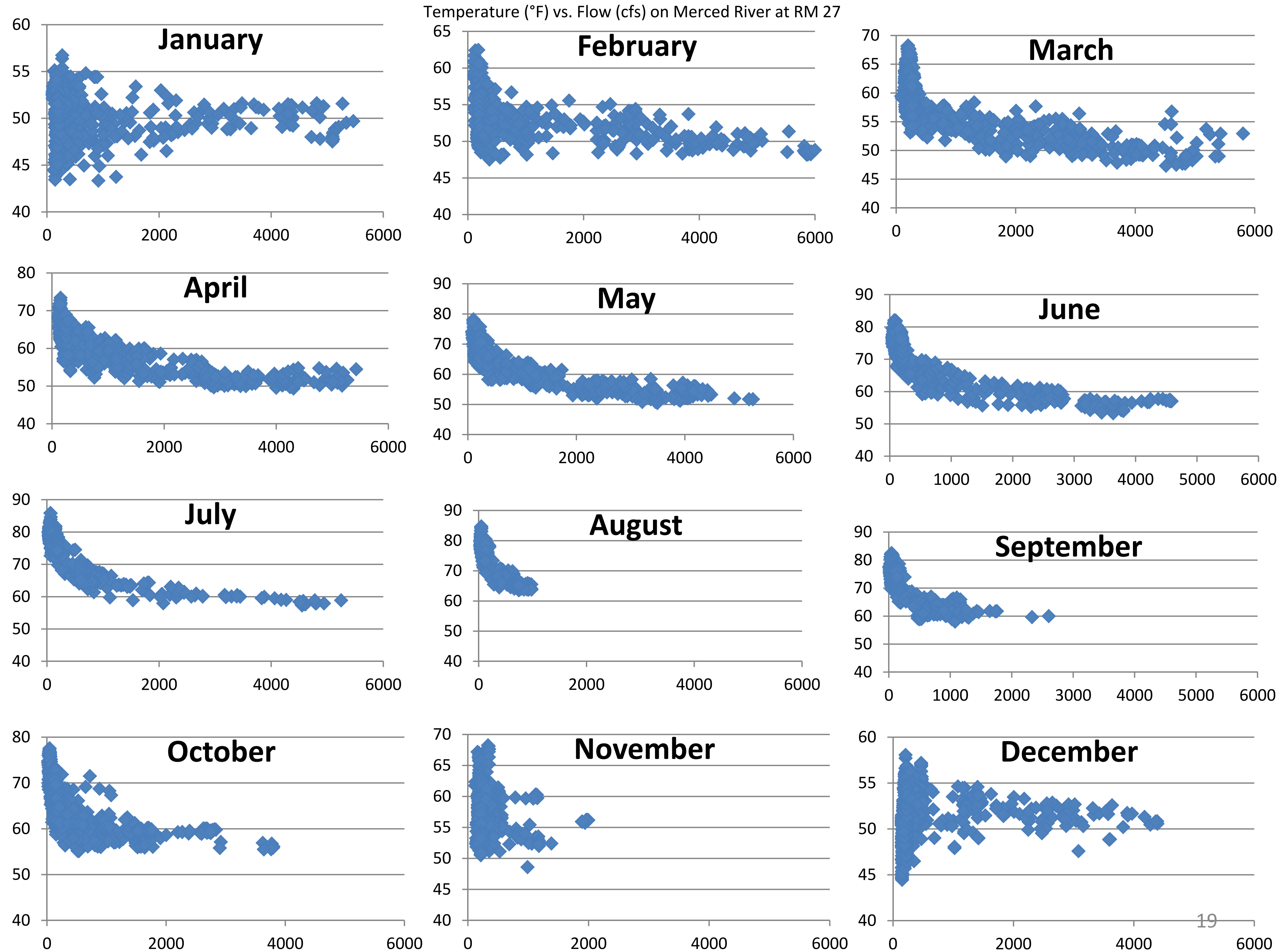
Merced River average daily temperature under Baseline conditions from 1960 to 2010 at two different locations.



Merced River average daily temperature under Baseline conditions from 1960 to 2010 at three different locations.



Merced River average daily temperature under Baseline conditions from 1960 to 2010 at three different locations, which illustrates that both fall and spring temperature windows have been altered compared to natural conditions. There is an approximately one month delay from when fall-run Chinook salmon should be able to access optimal spawning temperatures (less than 55.4 °F) to when they can under current conditions.


Temperature (°F) vs. Flow (cfs) on Merced River at RM 27
January
February
March
April
May
June
July
August
September
October
November
December

Merced River		Confluence (RM0)						1/4 River (RM13)						1/2 River (RM27)						3/4 River (RM37.8)					
Life Stage	Month / USEPA Criteria (°F)	Base	Percent Unimpaired Flow					Base	Percent Unimpaired Flow					Base	Percent Unimpaired Flow					Base	Percent Unimpaired Flow				
			20%	30%	40%	50%	60%		20%	30%	40%	50%	60%		20%	30%	40%	50%	60%		20%	30%	40%	50%	60%
R	Feb (55.4)	**74%**	-2%	-1%	1%	2%	3%	**73%**	-2%	-1%	1%	2%	4%	**81%**	-3%	-2%	-1%	2%	2%	**74%**	-2%	-2%	0%	3%	5%
R	Mar (55.4)	**24%**	-1%	-1%	-1%	2%	6%	**25%**	-1%	0%	0%	3%	7%	**29%**	-1%	0%	3%	7%	13%	**28%**	-1%	0%	4%	7%	14%
CR	Mar (60.8)	**70%**	0%	2%	5%	11%	16%	**72%**	0%	1%	6%	12%	17%	**85%**	0%	3%	7%	10%	11%	**87%**	-1%	1%	6%	8%	9%
CR	Apr (60.8)	**22%**	-1%	5%	10%	25%	34%	**25%**	-1%	7%	17%	32%	43%	**39%**	-2%	17%	26%	38%	45%	**43%**	3%	21%	32%	40%	45%
CR	May (60.8)	**8%**	0%	6%	8%	15%	24%	**12%**	2%	10%	17%	30%	37%	**18%**	6%	21%	26%	37%	43%	**24%**	12%	25%	32%	40%	45%
S	Apr (57.2)	**7%**	-1%	0%	1%	5%	10%	**9%**	-1%	2%	2%	9%	14%	**12%**	0%	5%	6%	14%	19%	**16%**	0%	6%	8%	17%	22%
S	May (57.2)	**2%**	0%	0%	0%	0%	1%	**5%**	0%	0%	0%	3%	8%	**7%**	0%	1%	1%	9%	15%	**10%**	0%	6%	9%	16%	24%
S	Jun (57.2)	**0%**	0%	0%	0%	0%	0%	**2%**	0%	0%	0%	-1%	-1%	**8%**	-2%	-2%	-2%	-3%	-3%	**11%**	0%	-2%	-1%	-3%	-2%
SR	Jun (64.4)	**16%**	2%	0%	1%	7%	13%	**21%**	3%	3%	5%	11%	15%	**26%**	3%	8%	10%	16%	21%	**28%**	6%	13%	18%	26%	31%

Life Stage	Month	USEPA Criteria	Merced River			
			Avg. # of Miles in Compliance per Day		Change	
		(°F)	(mile/days)			%
			Baseline	50 % unimpaired flow		
R	Feb	55.4	38.3	39.2	0.9	2%
R	Mar	55.4	16.1	19.0	2.9	18%
CR	Mar	60.8	41.0	45.3	4.4	11%
CR	Apr	60.8	20.3	36.1	15.7	77%
CR	May	60.8	12.3	28.6	16.4	134%
S	Apr	57.2	9.3	16.8	7.5	81%
S	May	57.2	6.1	12.4	6.3	102%
S	Jun	57.2	5.3	5.5	0.2	3%
SR	Jun	64.4	13.7	23.6	9.9	72%

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Water Temperature

Myrick and Cech (2001 p. iii) suggest that "water temperature is perhaps the physical factor with the greatest influence on Central Valley salmonids, short of a complete absence of water"

I add that restoring habitat will be useless to native fish if water temperatures are not adequate

Average monthly flow from 1922 to 2003

Tuolumne River		April					
Flow (cfs)	Floodplain Acreage	**Base**	20%	30%	40%	50%	60%
75	0	**100%**	0%	0%	0%	0%	0%
150	0	**100%**	0%	0%	0%	0%	0%
300	0	**94%**	2%	5%	6%	6%	6%
500	0	**70%**	12%	22%	28%	30%	30%
1000	0	**52%**	0%	13%	27%	40%	45%
1100	Initiates	**44%**	-2%	15%	33%	44%	54%
1250	56	**41%**	-1%	11%	29%	39%	50%
1500	152	**37%**	-1%	4%	20%	38%	45%
2000	305	**33%**	-1%	-1%	2%	18%	37%
3000	520	**21%**	0%	0%	-2%	-4%	5%
4000	673	**11%**	0%	-1%	0%	-1%	-2%
5000	791	**5%**	0%	0%	-1%	-1%	-1%

Floodplain

Jeffres et al. 2008

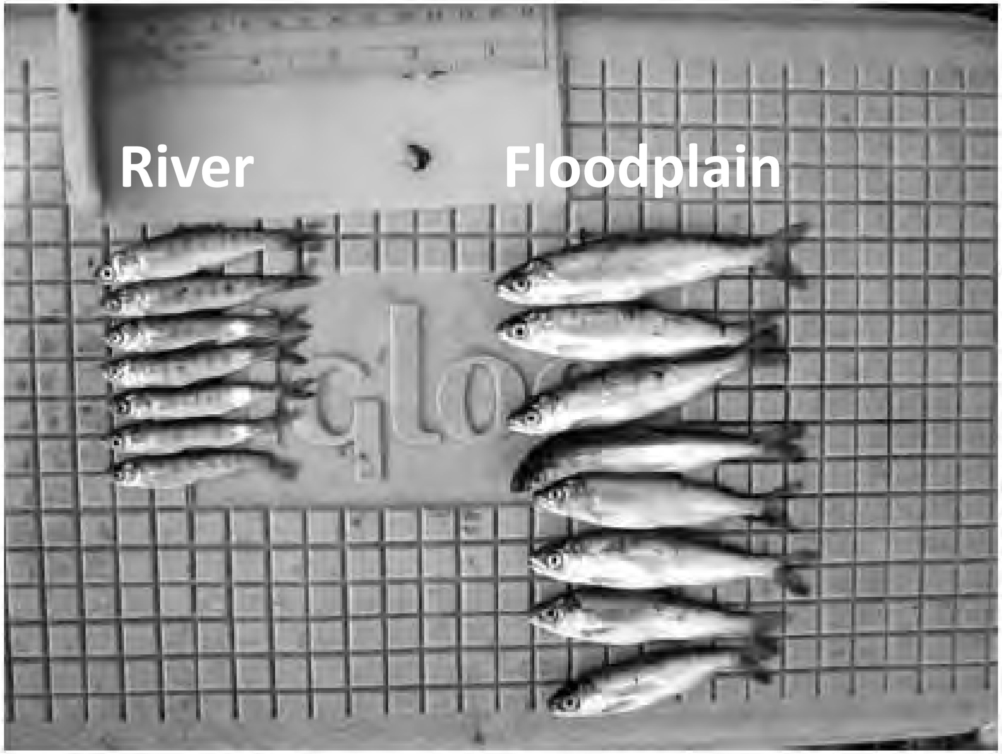


Fig. 7 Comparison of a single enclosure of fish reared in intertidal river habitat below floodplain (*left*) and a single enclosure of fish reared in the floodplain vegetation (*right*) after 54 days in respective habitats at the end of the second year of the study

*Tolerate higher temperatures with full food rations

There are many benefits to a more natural flow regime

- Quantifying benefits from flow enhancement can be challenging
  - We can’t ask for flow just to have more flow

- Breaking things down into time and space is something that people can understand

Summary

- State Water Board and CDFW are just beginning an effort to enhance stream flows statewide
- Why are we trying to improve flow conditions?
  - Habitat attributes that are extremely important to native fish can be improved by providing a more natural flow regime
- Communicating the problems and also the solutions is extremely important
  - Communicate the benefits of your projects
    - What is it your trying to accomplish?
    - How does your project fit into the big picture?

For More Information

- **California Water Action Plan – Enhance Water Flows in Stream Systems Statewide**
  - http://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/#heading
- **Email Subscription List**
  - http://www.waterboards.ca.gov/resources/email_subscriptions/swrcb_subscribe.shtml
- daniel.worth@waterboards.ca.gov

CA State Water Board Emergency Actions to Protect Fish in Key Tributaries to the Sacramento and Russian Rivers Under Extreme Drought

Photo: Derek Acomb, CDFW

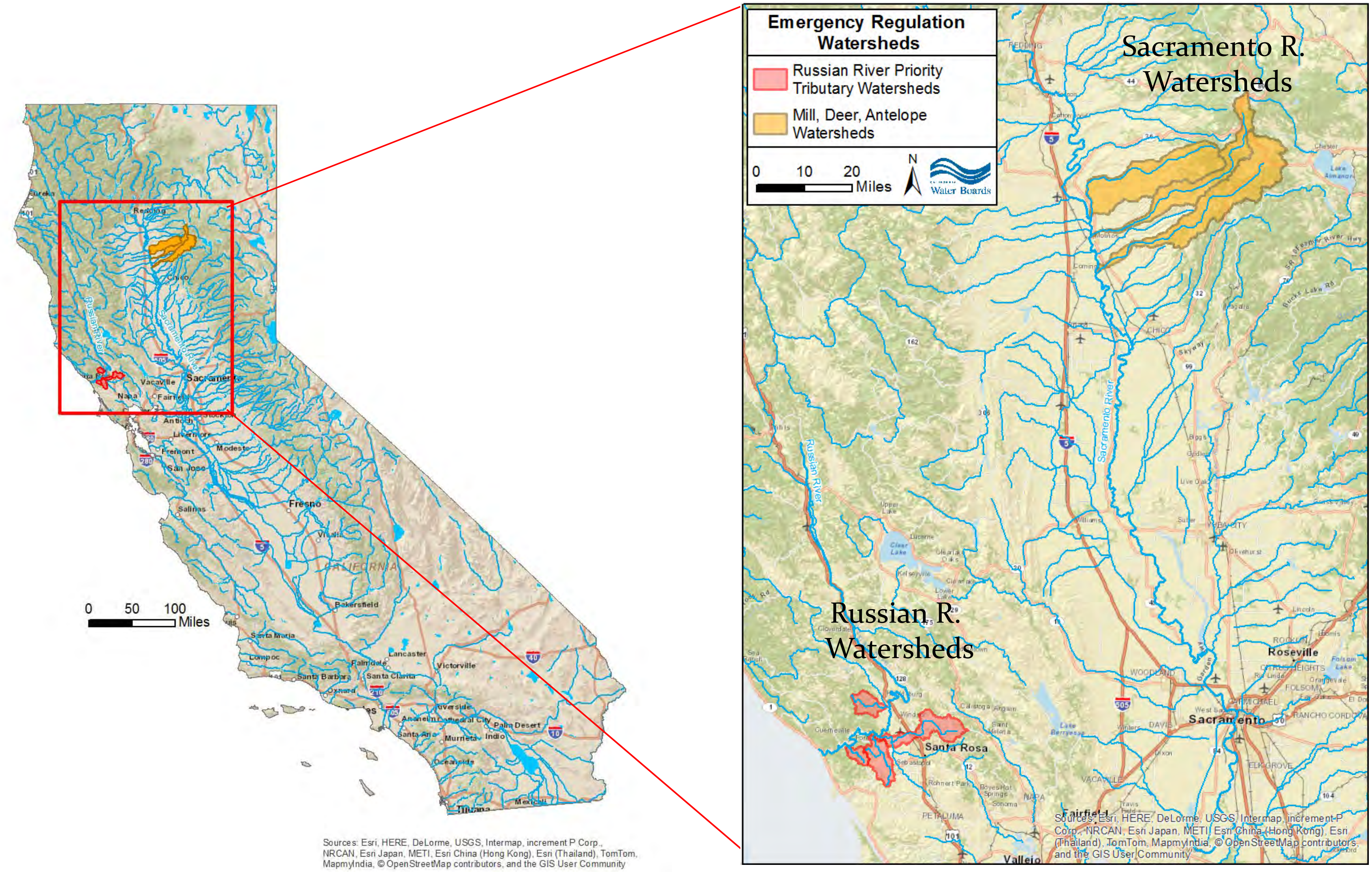
CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Daniel Schultz
Public Trust Unit Chief
Division of Water Rights
April, 2016

Presentation Outline

- **Russian River Tributaries (Dutch Bill, Green Valley, Mark West, and Mill Creeks)**
  - Problem
  - Actions taken
  - Results
  - Future actions
- **Sacramento River Tributaries (Mill, Deer, and Antelope Creeks)**
  - Problem
  - Actions taken
  - Results
  - Future actions

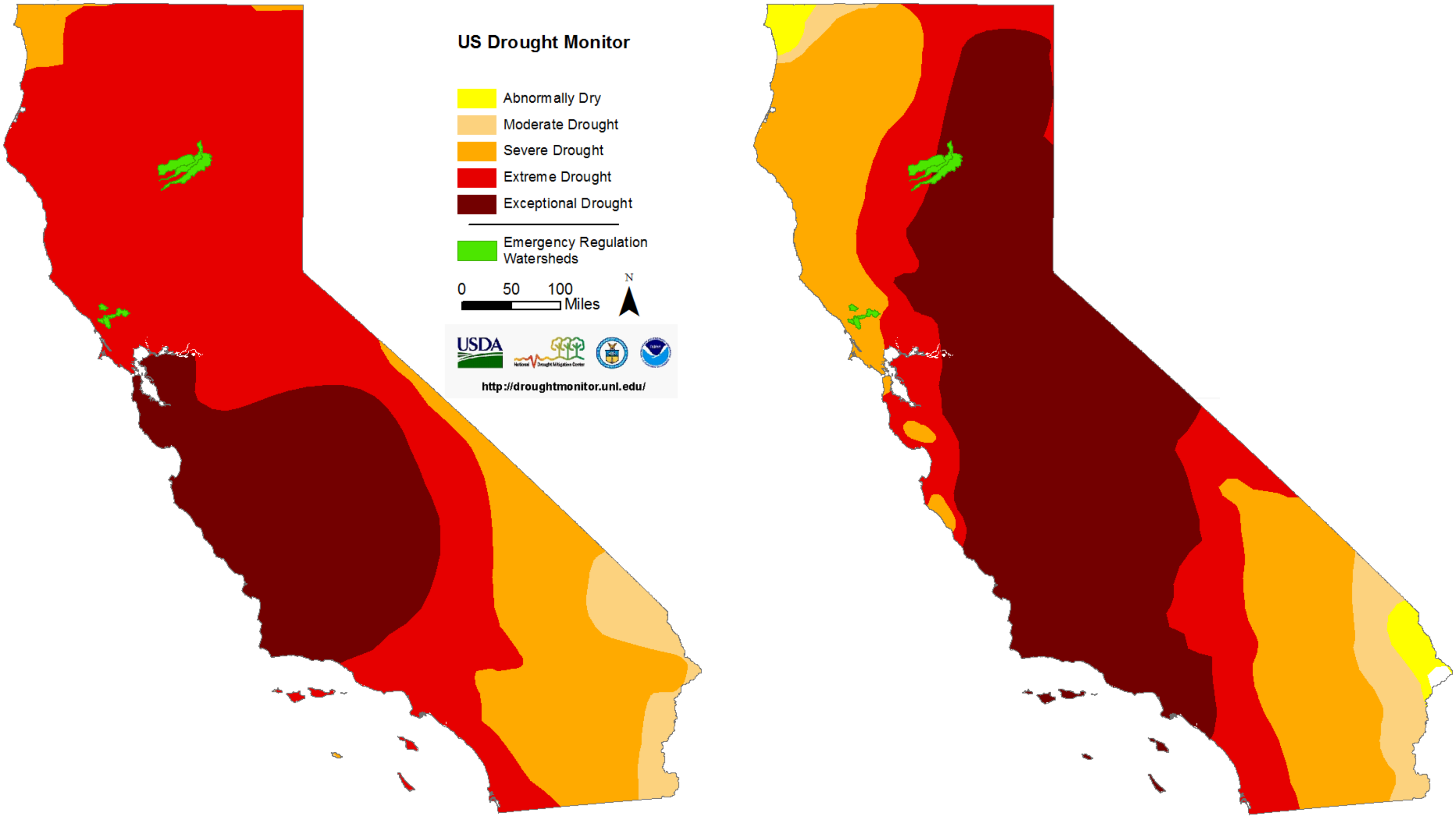
Emergency Regulation Watersheds



Context: Drought

April 22, 2014

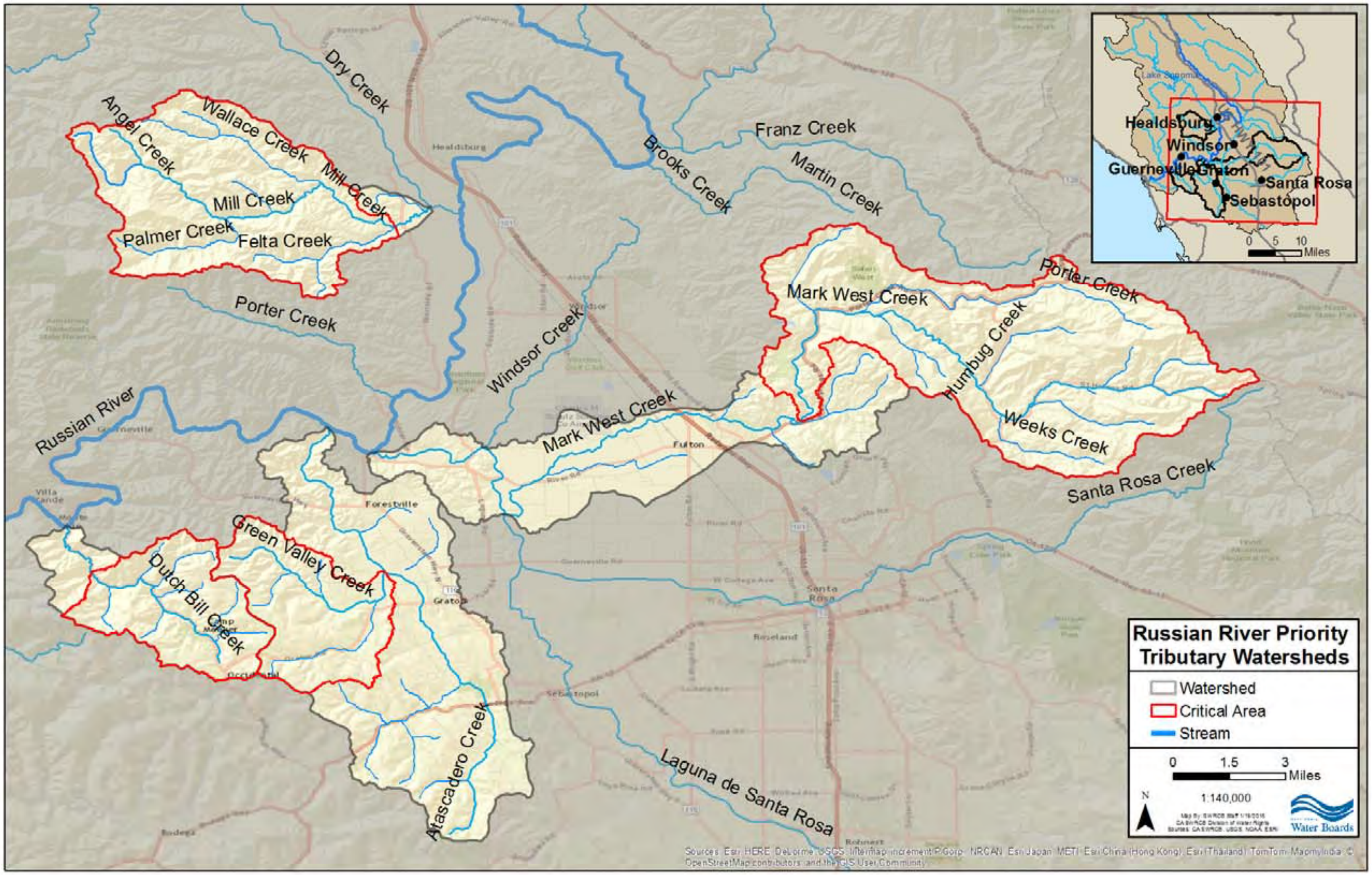
April 21, 2015



Context: Drought

Imagery from NASA Earth Observatory

Russian River Priority Watersheds

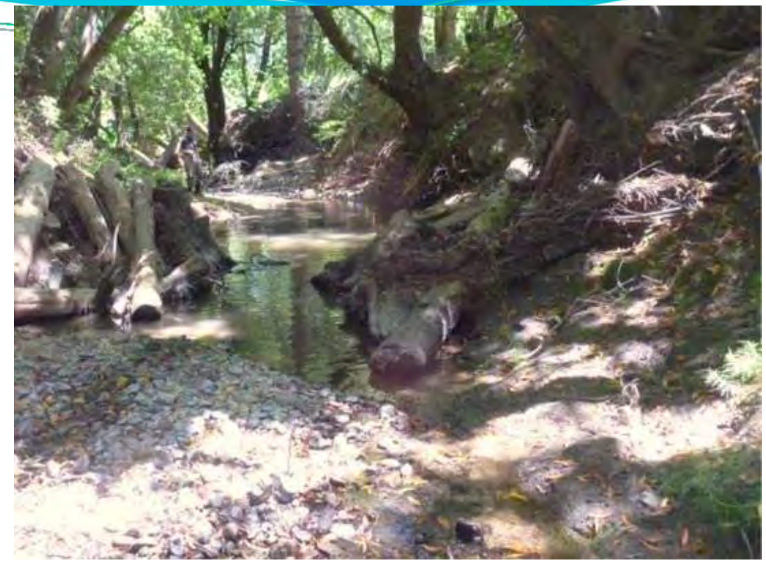


Problem

- Pressures on surface water
  - Surface and hydrologically connected groundwater diversions
  - Unconsolidated rural domestic water use
  - Agricultural (vineyard) use
- Problem
  - Drought and high water demand cause significant stretches of tributaries to become **ponded or dry during summer rearing period for juvenile salmonids**

Flowing Water

=

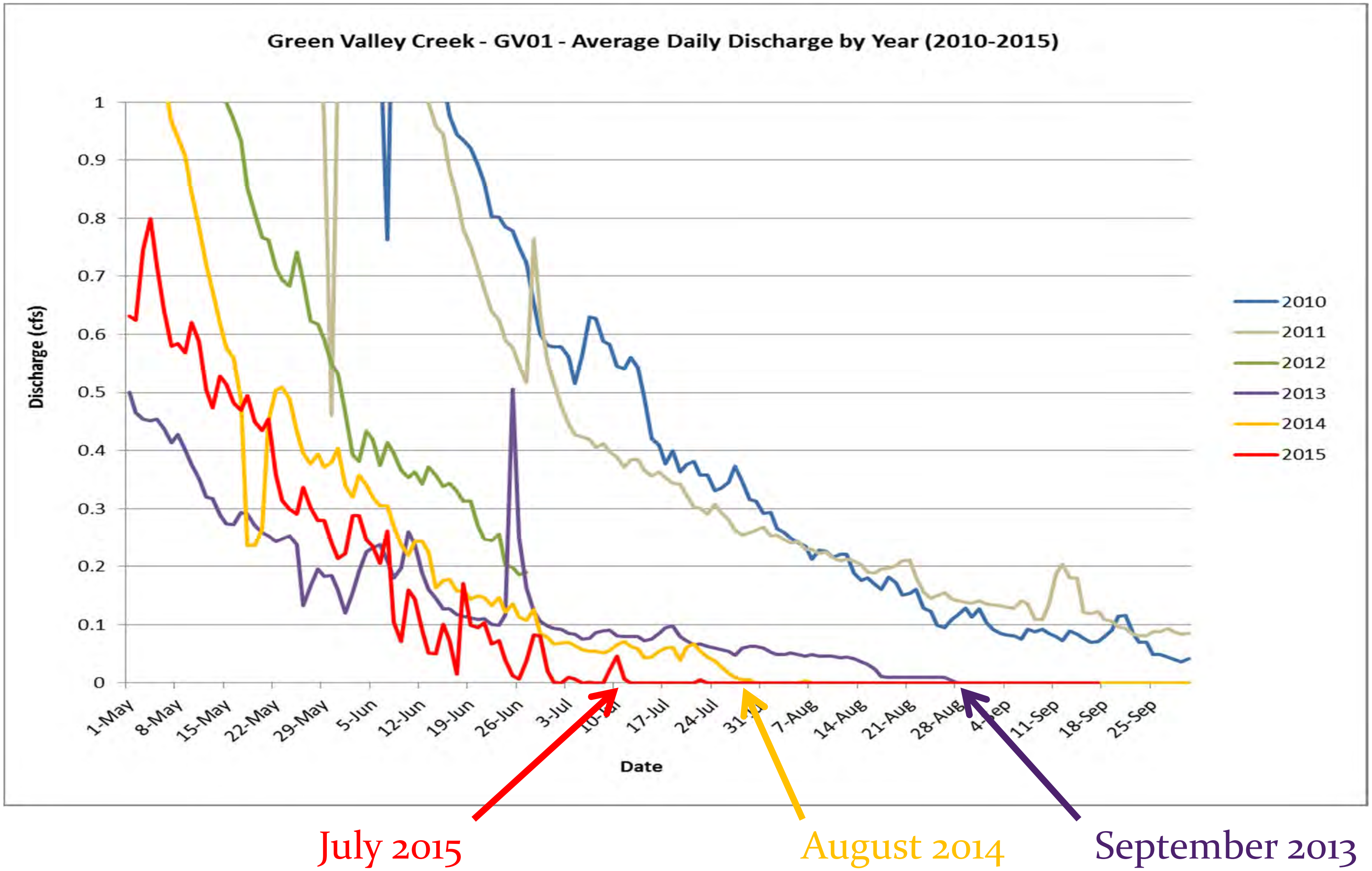


No Flowing Water

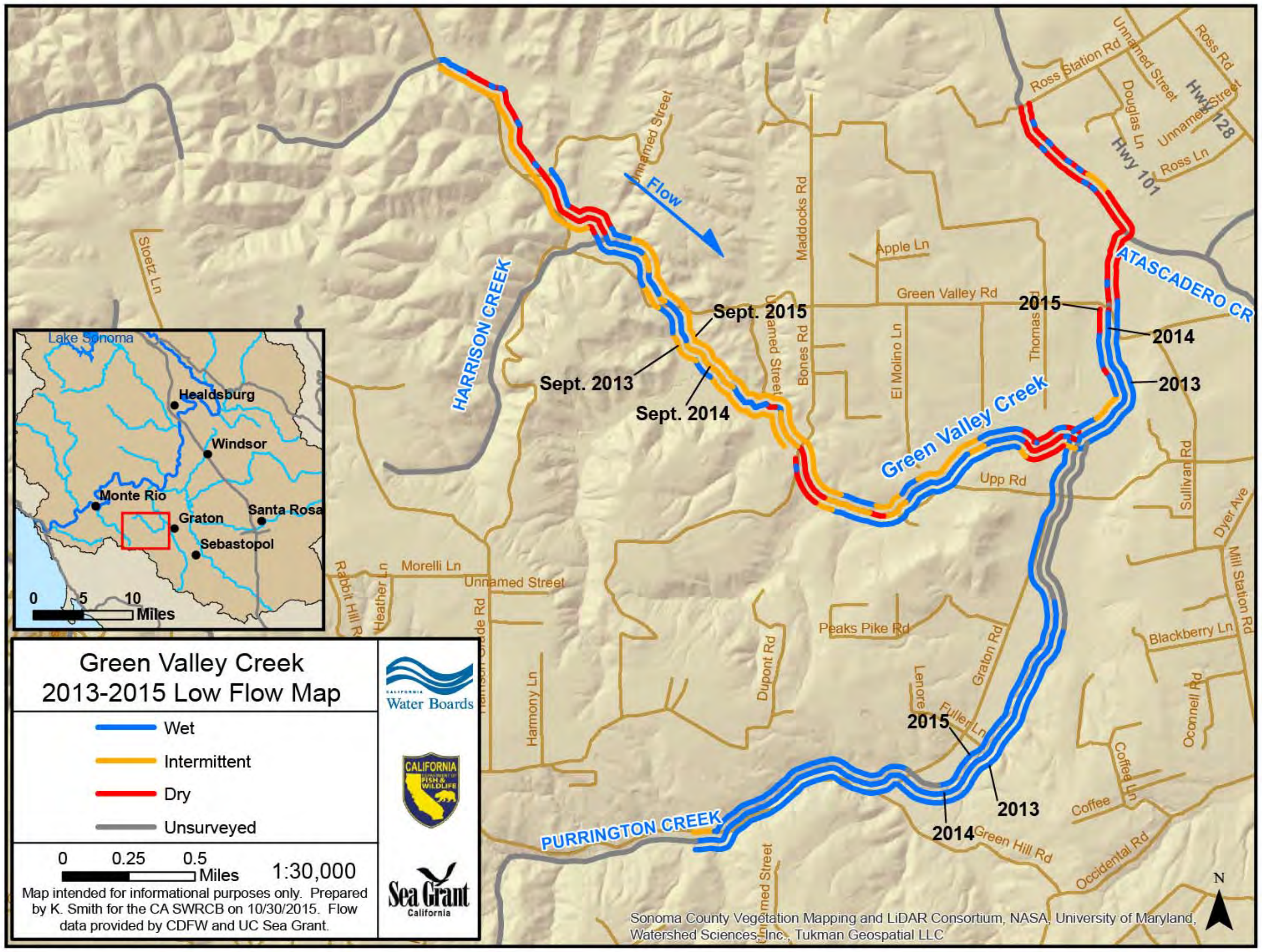
=

8

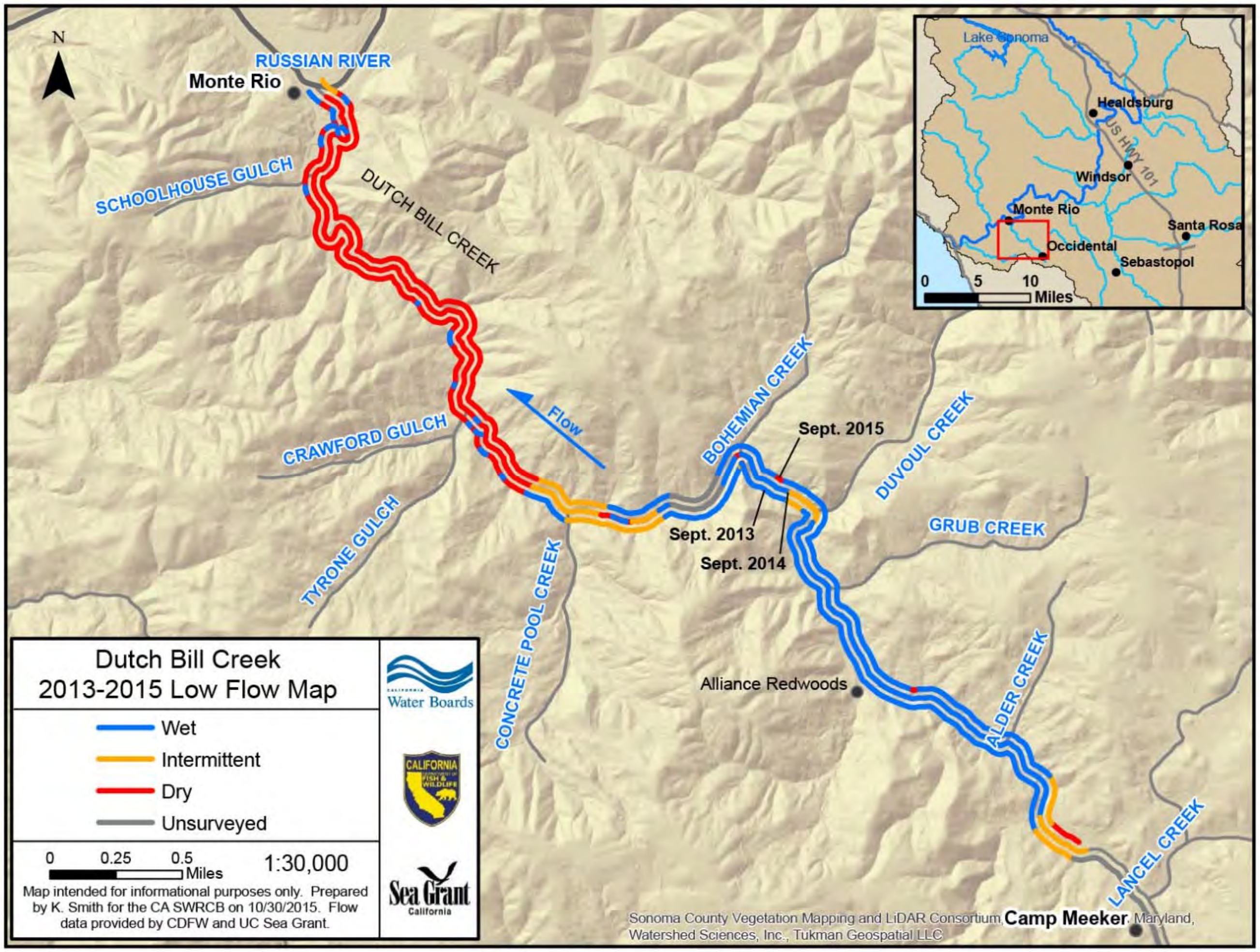
Green Valley Creek Flow (2010-2015)



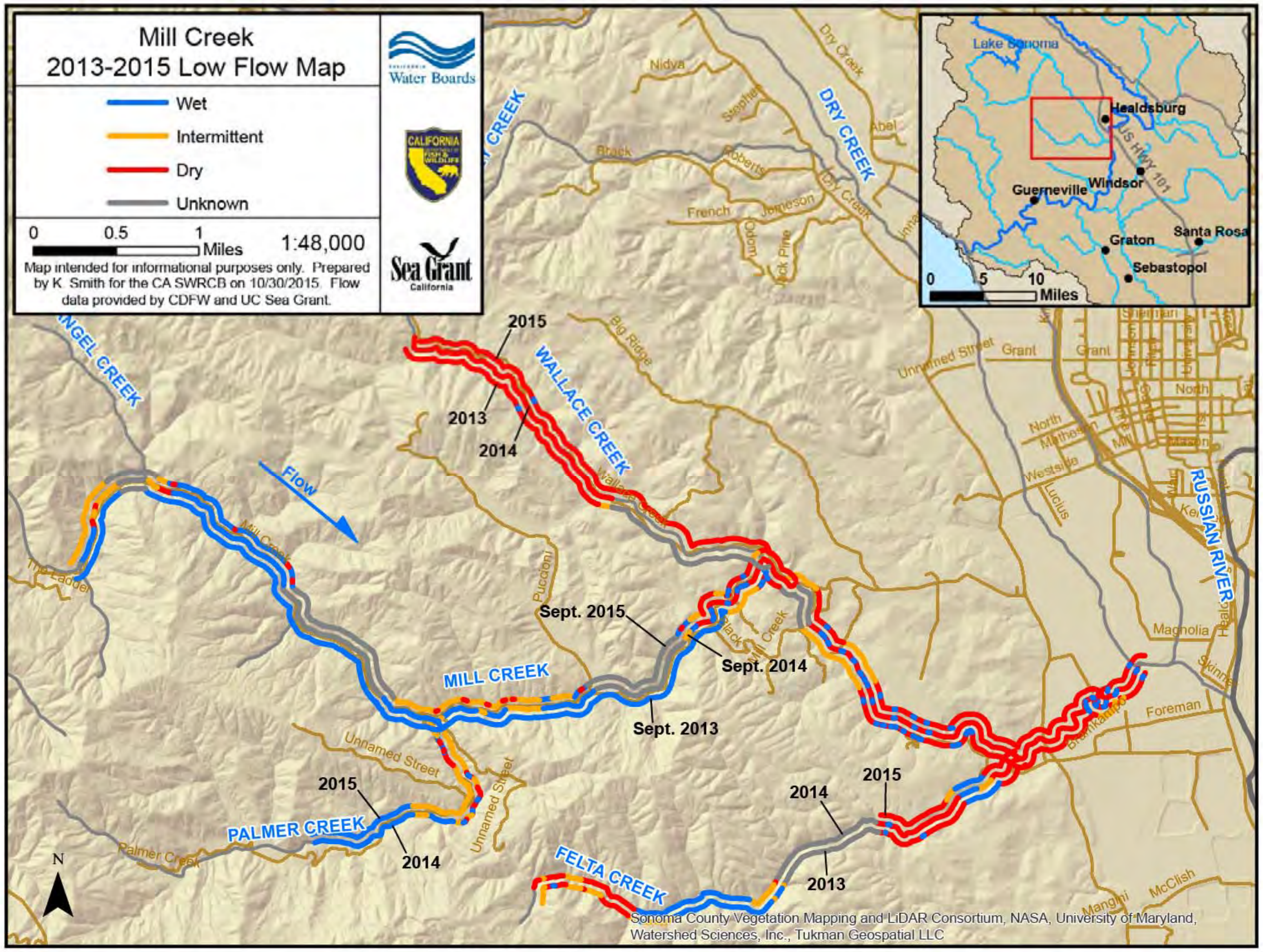
Green Valley Creek Wet/Dry Map 2013-2015



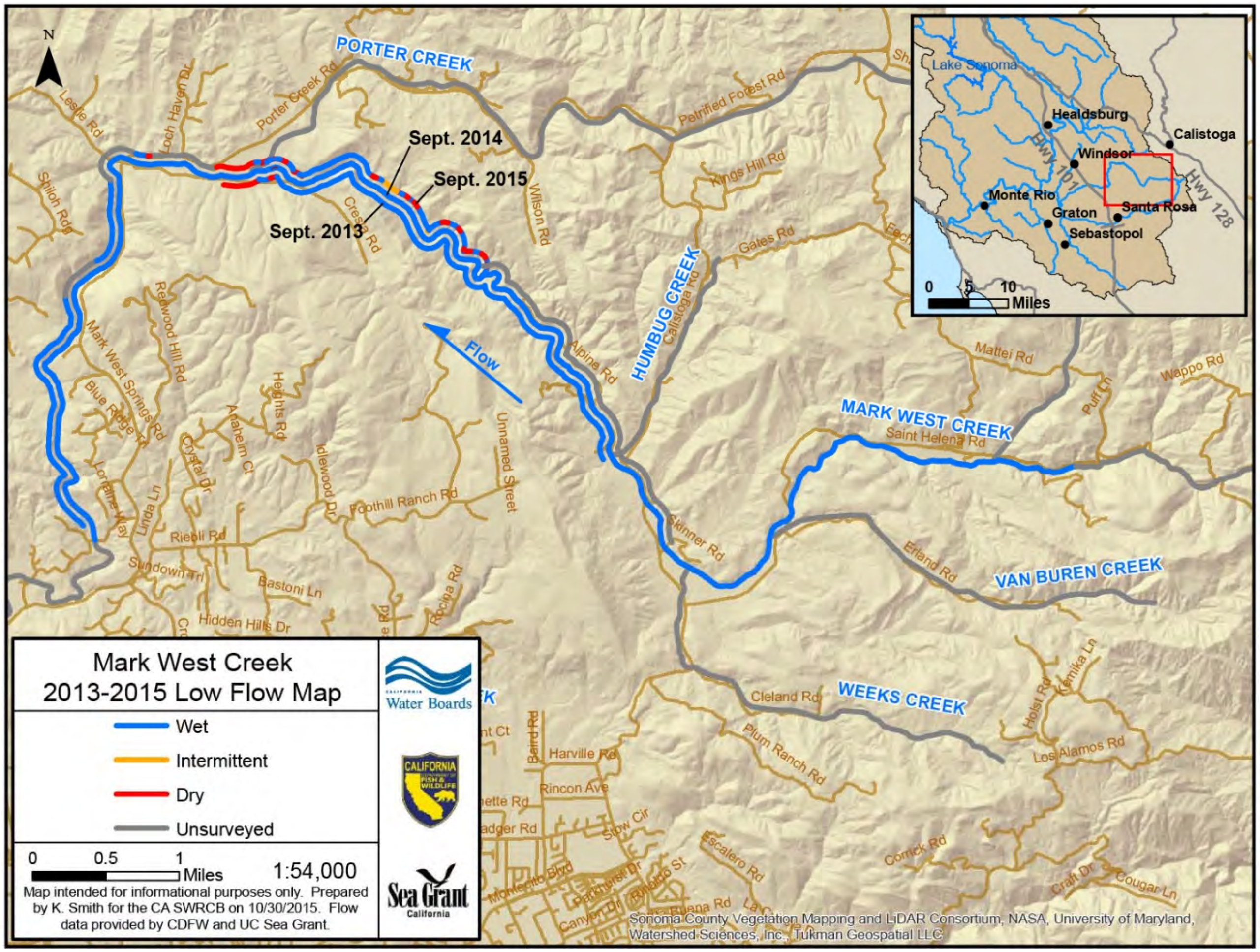
Dutch Bill Creek Wet/Dry Map 2013-2015



Mill Creek Wet/Dry Map 2013-2015



Mark West Creek Wet/Dry Map 2013-2015



Actions to Address Problem

- June 17, 2015 – The Water Board adopted an emergency regulation (went into effect July 6, 2015 following Office of Administrative Law approval):
  1. **Reduce Rate of stream flow recession**
     - Enhanced water conservation measures (on top of state-wide regulations) in critical areas of watersheds
       - Limitations on non-agricultural outdoor water use
       - Expired on March 30, 2016
  2. **Collect information** for ongoing drought conditions and potential future actions
     - Information Order (re-adopted and went in effect March 31, 2016)
       - Water source and use information
  3. **Non-Regulatory CDFW Voluntary Drought Initiative (VDI) Agreements**
       - Conservation VDIs
       - Flow enhancement VDIs

Enhanced Water Conservation

Emergency Conservation Measures

Russian River Tributaries Conservation Measures (CCR §876)

http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/water_action_russianriver.shtml

Prohibited for Everyone

- Irrigation of all ornamental turf*
- Runoff of water when irrigating
- Outdoor irrigation of landscapes from 8am-8pm*
- Outdoor irrigation during & 48 hours following measureable precipitcation*
- Outdoor irrigation of landscapes more than two days per week*
- Using water to wash sidewalks & driveways
- Washing of motor vehicles except at car wash facilities with a recirculating system*
- Using water in a fountain or other decorative water feature without a recirculating system*
- Using water to fill or refill decorative ponds, fountains or other decorative water features*

*Use of gray water or untreated rainwater is allowed.

Note: The Russian River Tributaries water conservation measures apply to all potable and non-potable water from areas within the four tributary watersheds of Dutch Bill Creek, Green Valley Creek, Mark West Creek and Mill Creek. Water may be used to address immediate health and safety needs and where used exclusively for irrigation of commerical agriculture.

State-Wide Conservation Measures (CCR §863-866)

http://www.waterboards.ca.gov/water_issues/programs/conservation_portal/emergency_regulation.shtml

Prohibited for Everyone

- Using of potable water to wash sidewalks & driveways
- Runoff when irrigating with potable water
- Using hoses with no shutoff nozzles to water cars
- Using of outdoor irrigation during & 48 hours following measurable precipitation
- Using potable water to irrigate ornamental turf on public street medians
- Using potable water to irrigate landscapes of new homes & buildings inconsistant with CBSC & DHCD requirements

Required for Water Suppliers

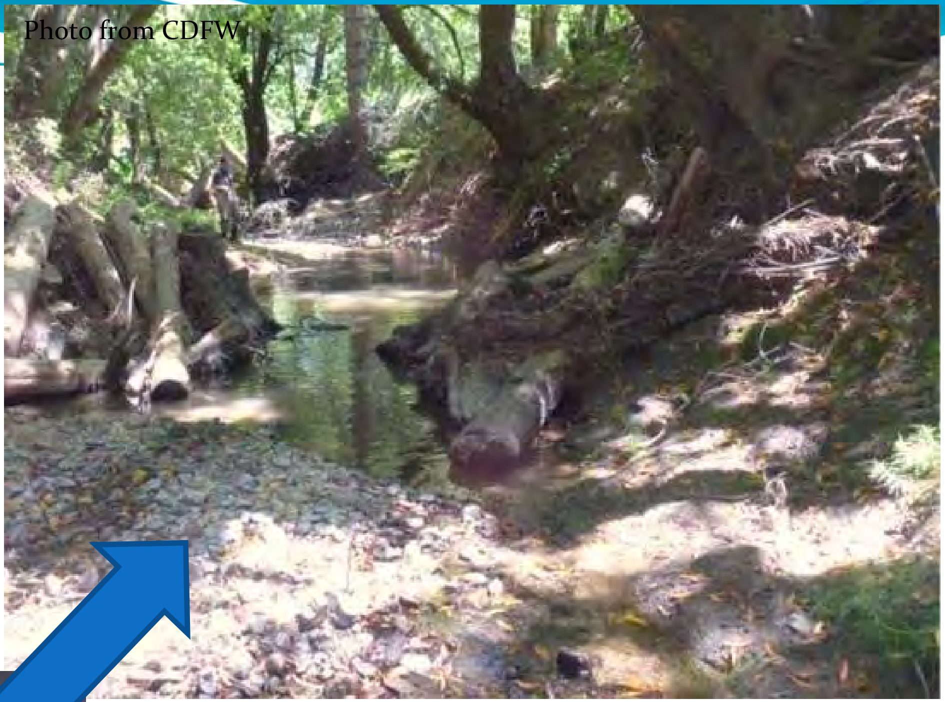
- Achieve designated conservation standard (4%-36%)
- Notify customers about leaks that are within the customer's control
- Report on water use, compliance & enforcement

Required for Business

- Restaurants & other food service establishments can only serve water to customers on request
- Hotels & motels must provide guests with the options of not having towels & linens laundered daily

Last Updated 07/02/2015

Just a trickle…



(Green Valley Creek)

Results

Photographer Unknown; Found on NOAA Fisheries Image Gallery on 3/21/16

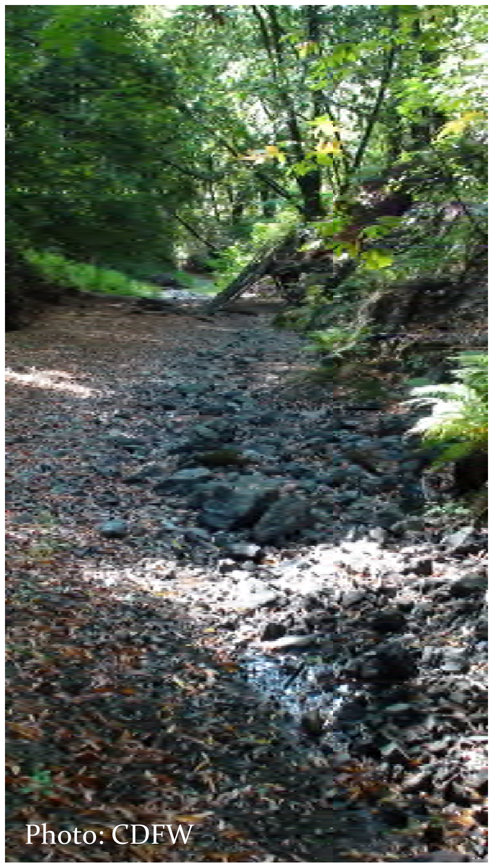
Voluntary Drought Initiative (VDI) Agreements

2015 CDFW VDIs:

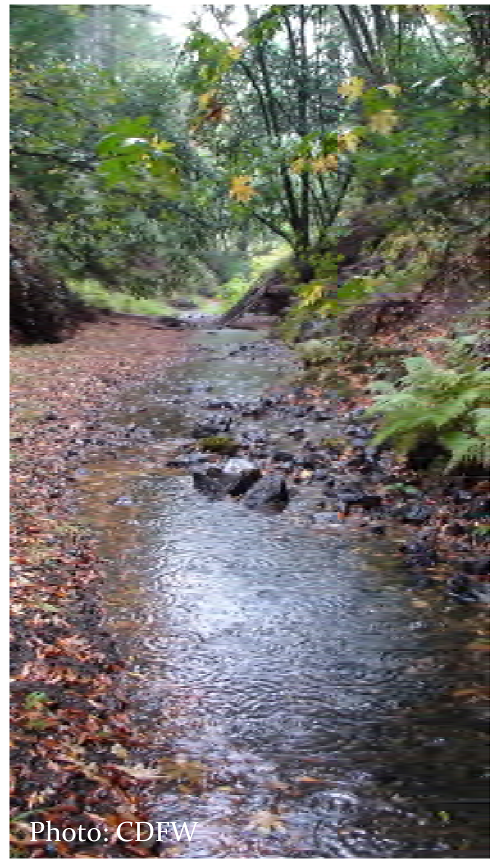
- 35 Residential Conservation VDIs
- 7 Winery/ Vineyard Conservation VDIs
- 3 Flow Enhancement VDIs for Green Valley Creek
- 2 Flow Enhancement VDIs for Dutch Bill

Flow Enhancement: Green Valley Creek at Bones Road

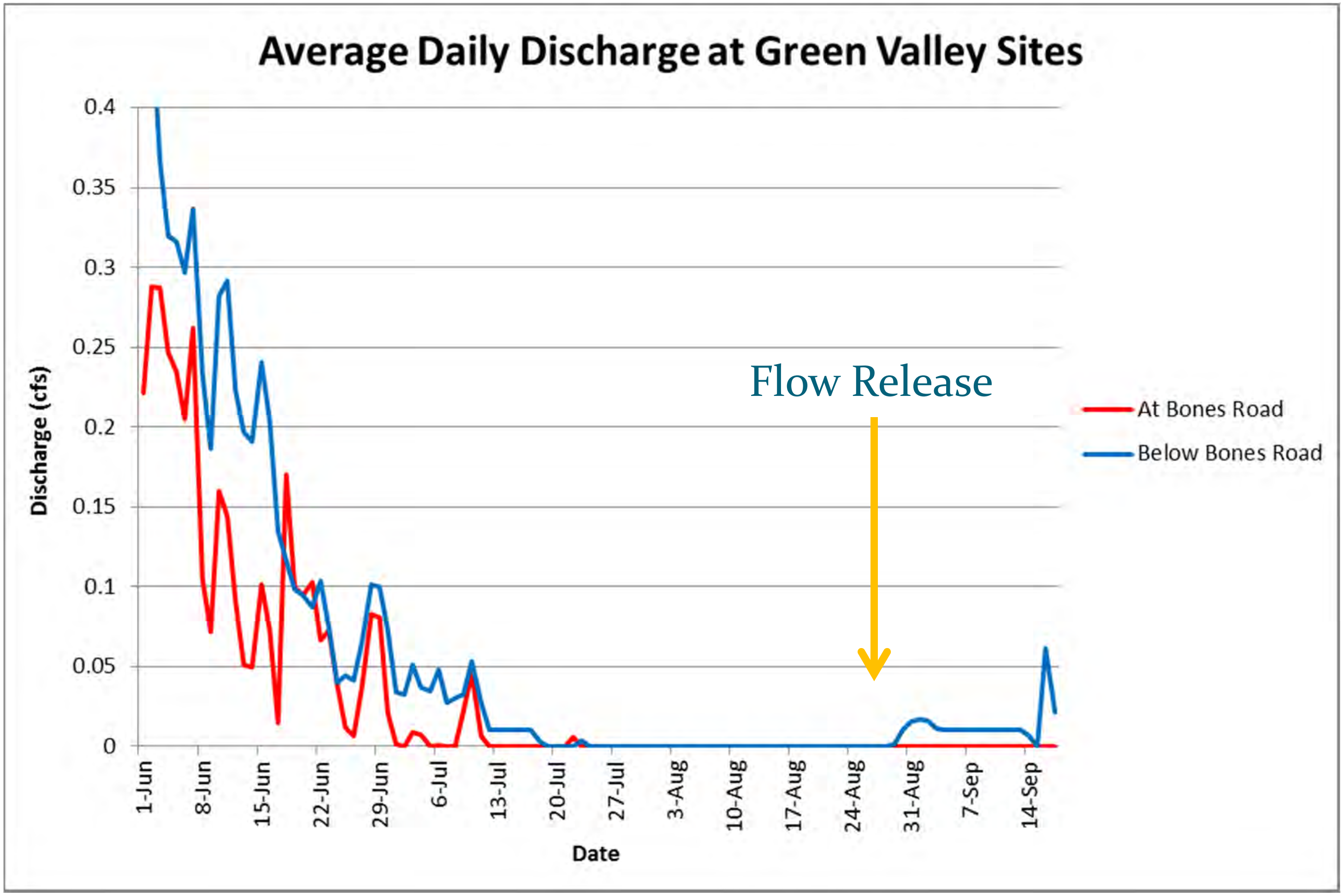
Before



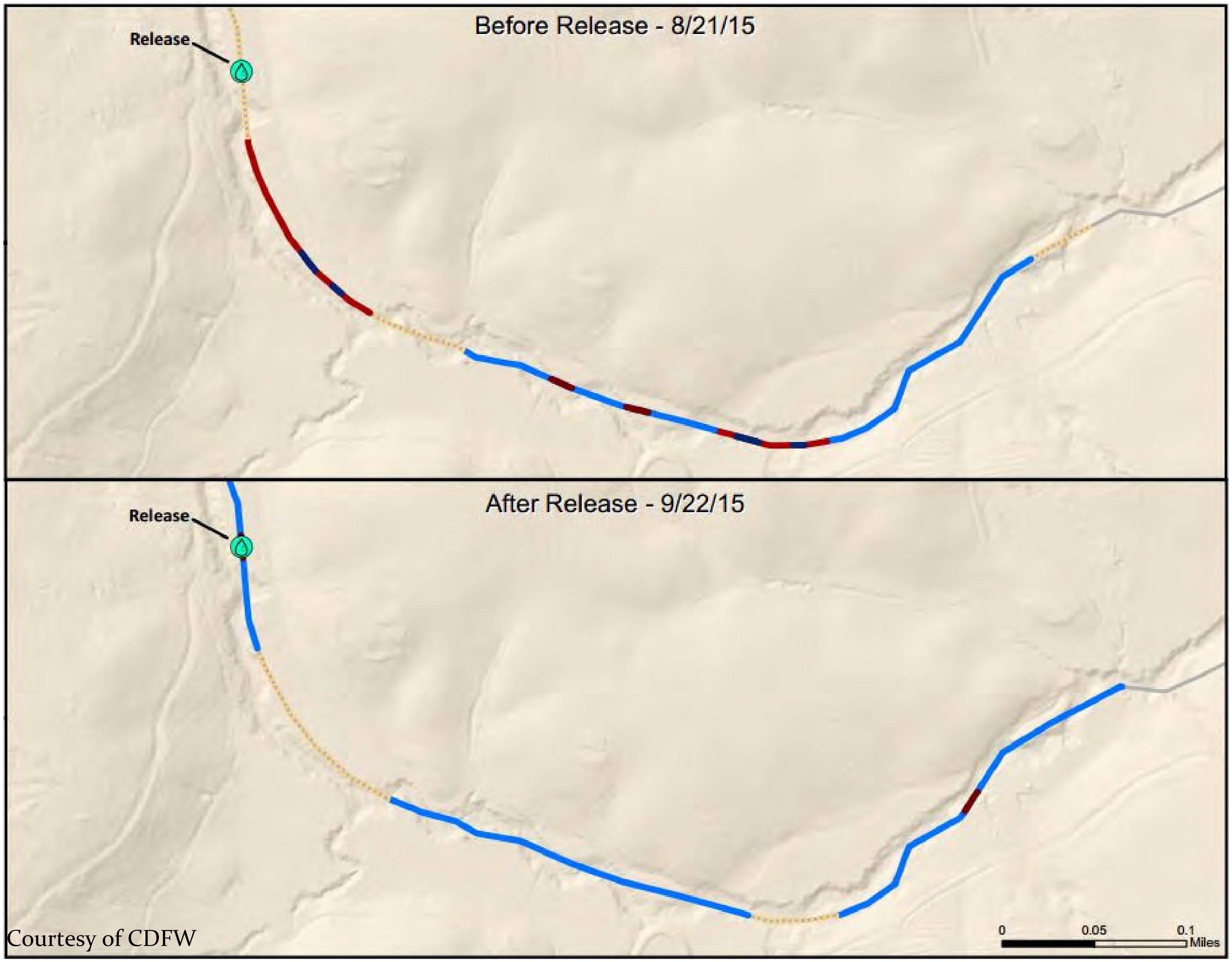
After



Flow Above and Below Bones Road Water Release Point



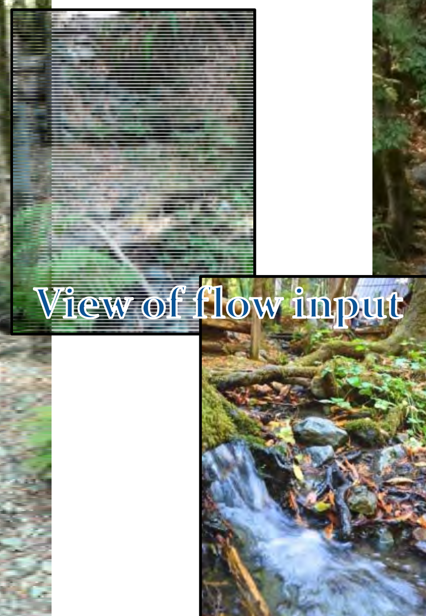
Bones Road Release Before and After



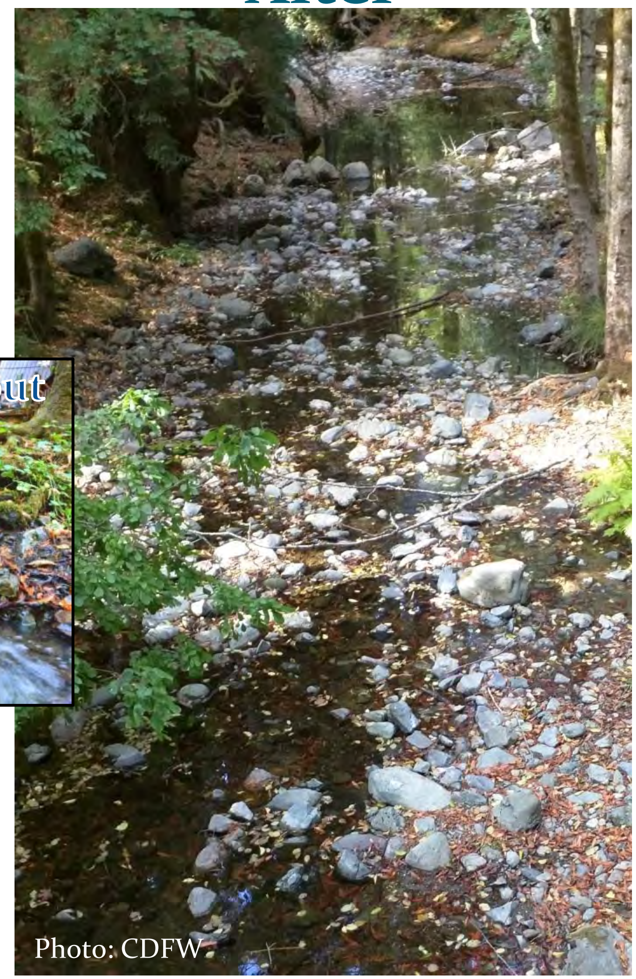
Flow Enhancement:

Dutch Bill Creek at Camp Meeker

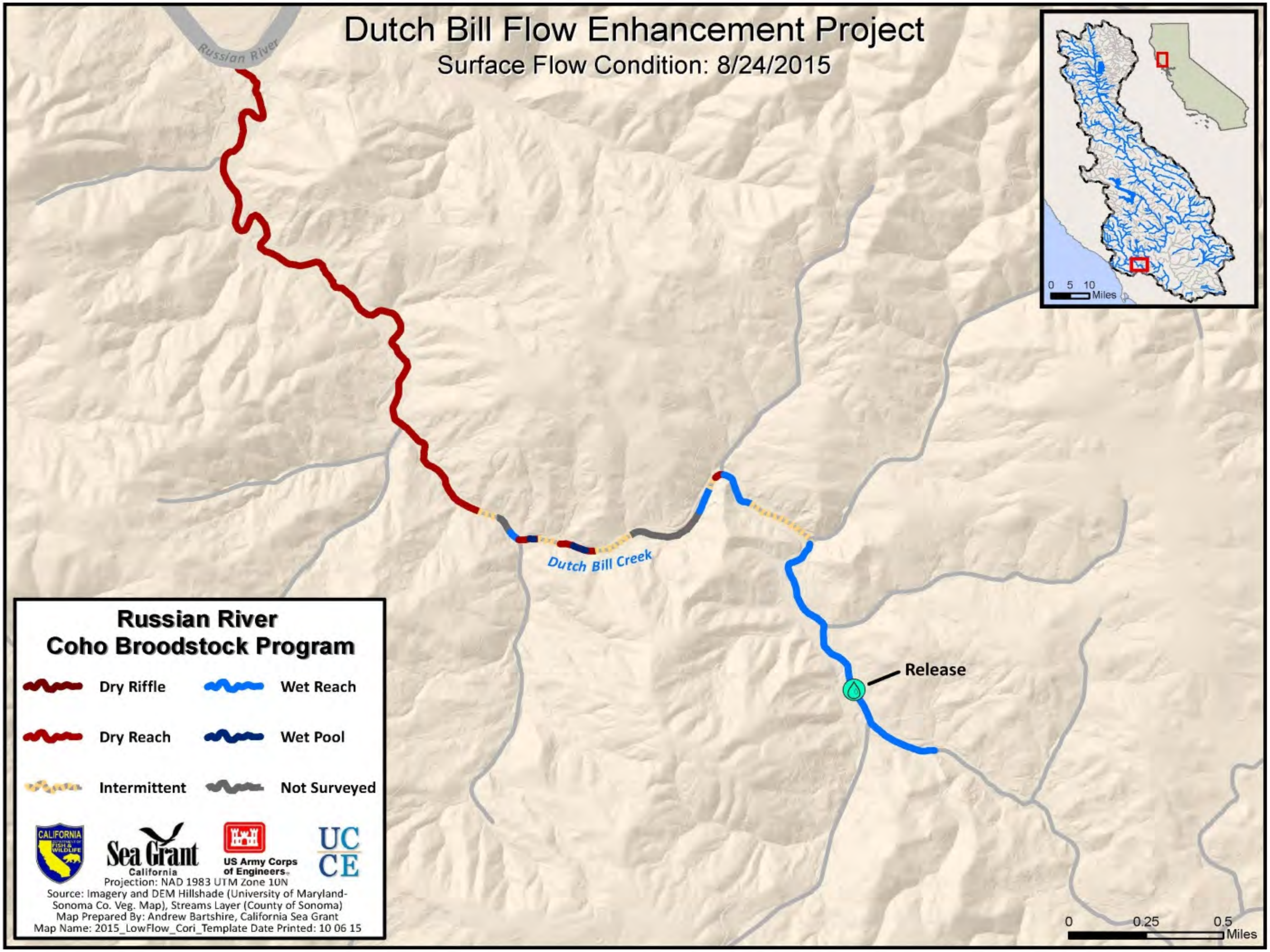
Before

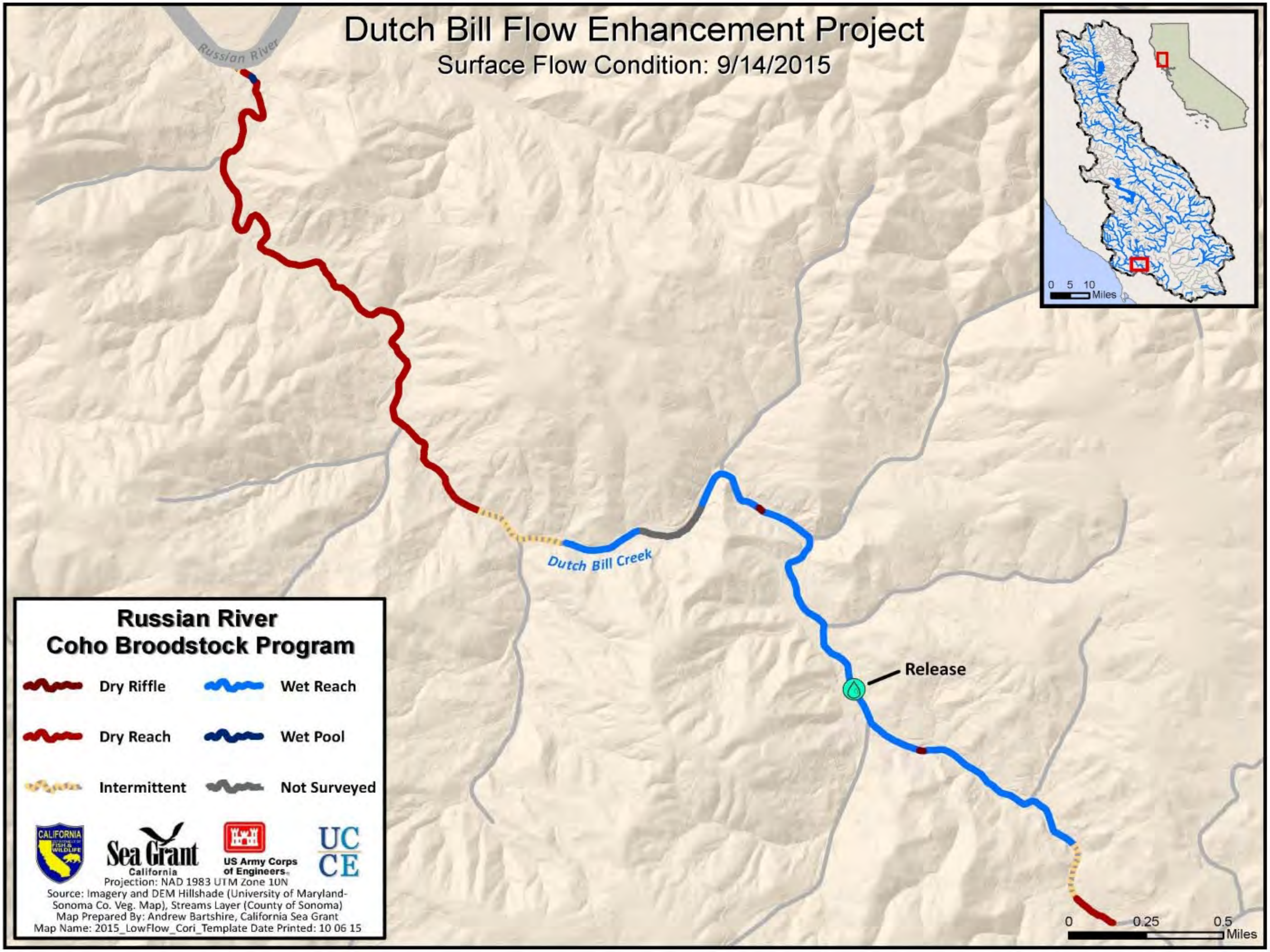


After



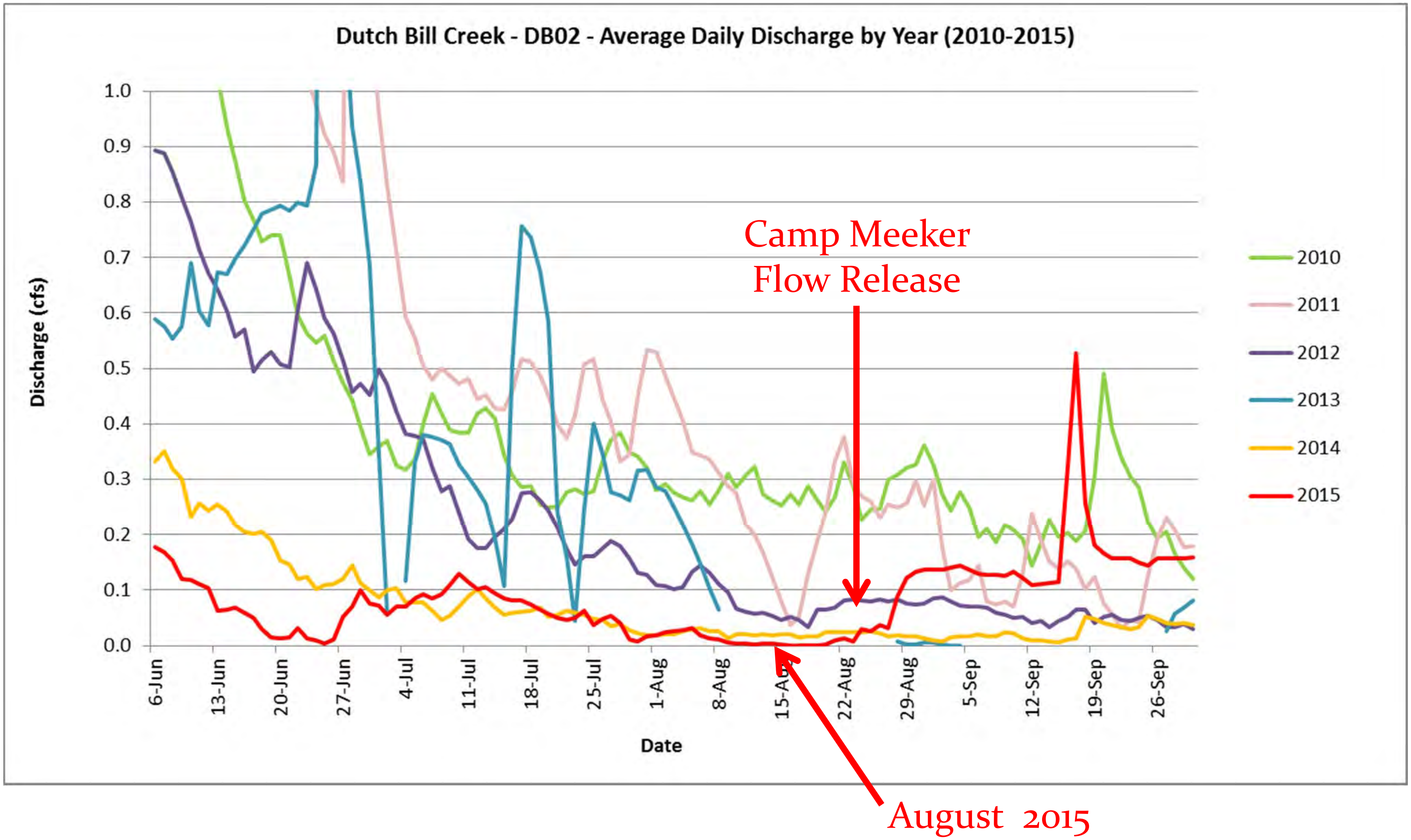
Point of Flow Input


Dutch Bill Flow Enhancement Project
Surface Flow Condition: 8/24/2015
Russian River
Dutch Bill Creek
Release
Russian River
Coho Broodstock Program
Dry Riffle
Wet Reach
Dry Reach
Wet Pool
Intermittent
Not Surveyed
Sea Grant
California
US Army Corps
of Engineers
UC
CE
Projection: NAD 1983 UTM Zone 10N
Source: Imagery and DEM Hillshade (University of Maryland-
Sonoma Co. Veg. Map), Streams Layer (County of Sonoma)
Map Prepared By: Andrew Bartshire, California Sea Grant
Map Name: 2015_LowFlow_Cori_Template Date Printed: 10 06 15
0
0.25
0.5
Miles
0 5 10
Miles



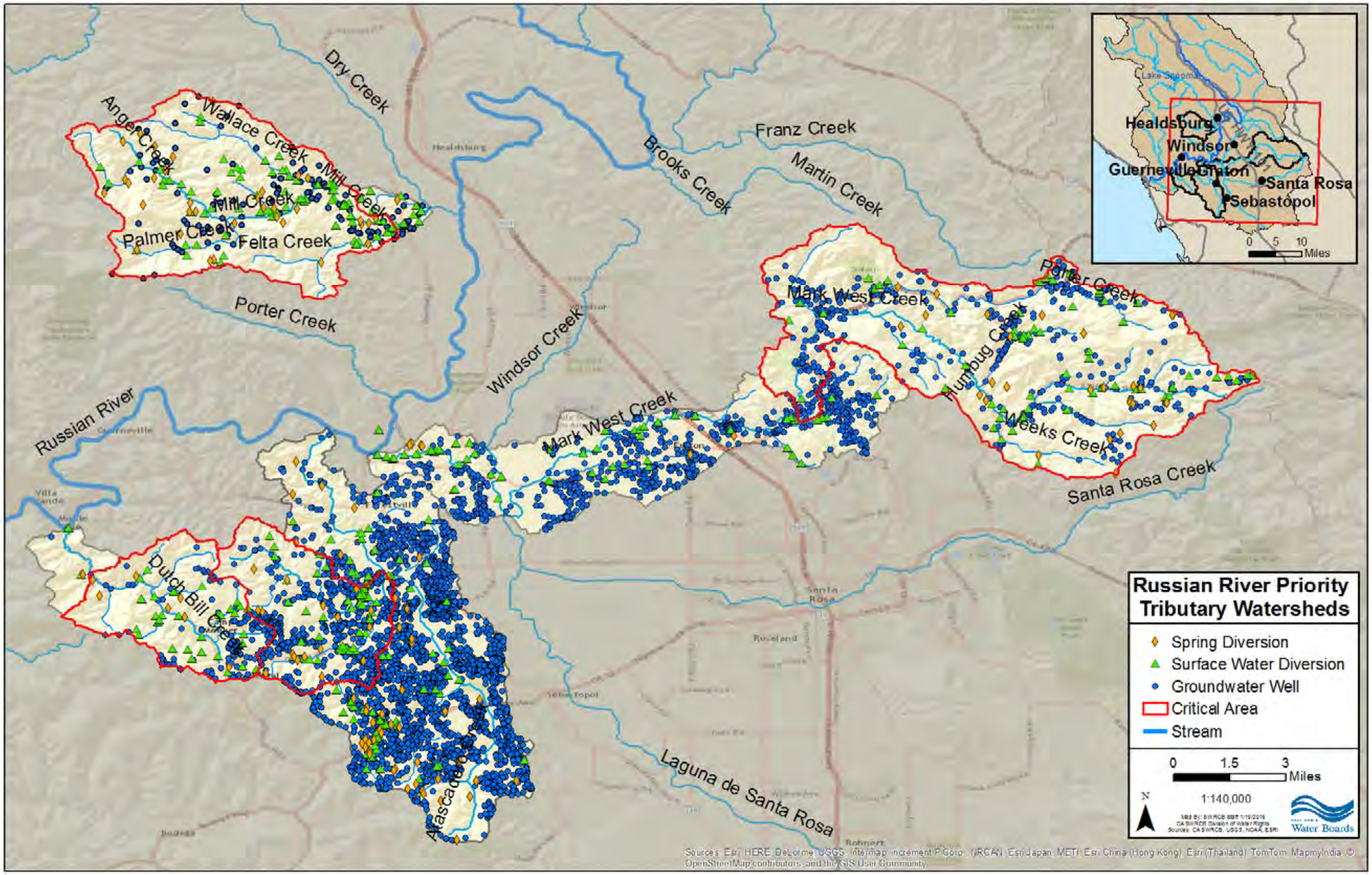
Dutch Bill Flow Enhancement Project
Surface Flow Condition: 9/14/2015
Russian River
Dutch Bill Creek
Release
Russian River
Coho Broodstock Program
Dry Riffle
Wet Reach
Dry Reach
Wet Pool
Intermittent
Not Surveyed
Sea Grant California
US Army Corps of Engineers
UC CE
Projection: NAD 1983 UTM Zone 10N
Source: Imagery and DEM Hillshade (University of Maryland-Sonoma Co. Veg. Map), Streams Layer (County of Sonoma)
Map Prepared By: Andrew Bartshire, California Sea Grant
Map Name: 2015_LowFlow_Cori_Template Date Printed: 10 06 15
0 0.25 0.5 Miles
0 5 10 Miles

Dutch Bill Creek Flow (2010-2015)



Information Order Preliminary Results: Water Diversions

Based on response data as of 1/11/2016.

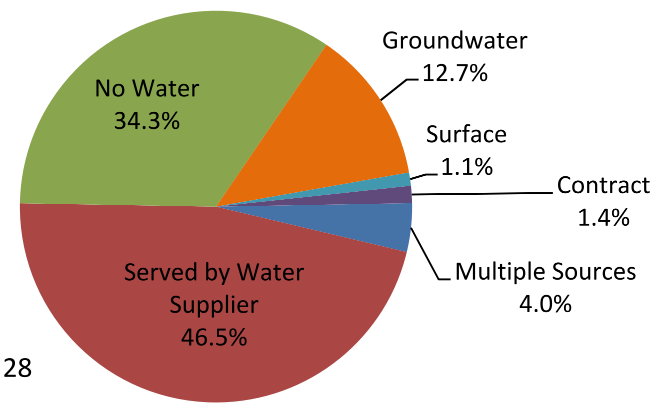


Preliminary Results: Water Sources by Parcel

Based on response data as of 1/11/2016.

Dutch Bill Creek Watershed

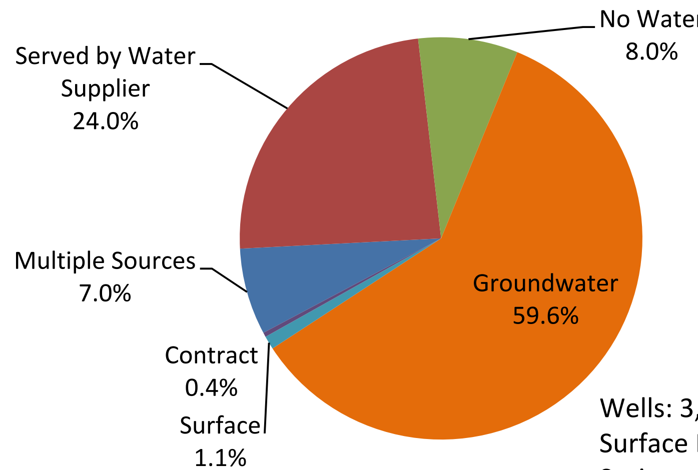
Total Reporting Parcels = 1,197 (of 1,395)



Wells: 154
Surface Diversions: 28
Springs: 9

Green Valley Creek Watershed

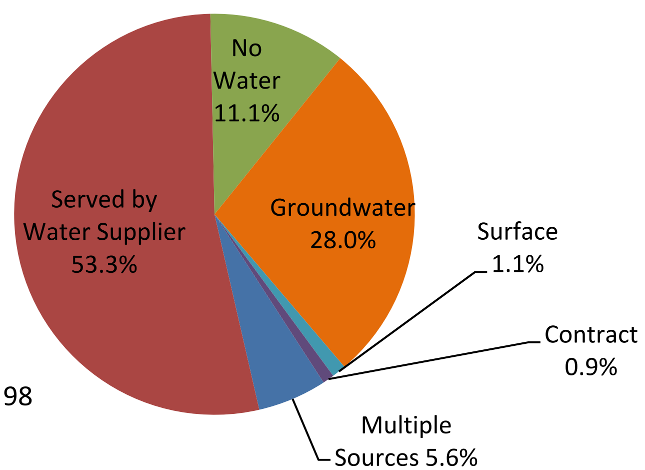
Total Reporting Parcels= 5,134 (of 5,676)



Wells: 3,174
Surface Diversions: 169
Springs: 69

Mark West Creek Watershed

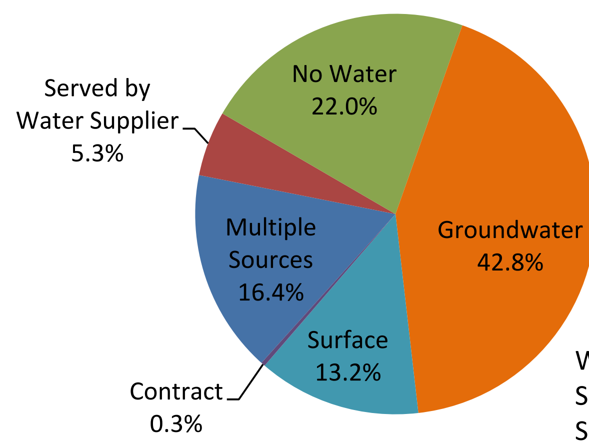
Total Reporting Parcels = 4,303 (of 4,909)



Wells: 1,283
Surface Diversions: 98
Springs: 34

Mill Creek Watershed

Total Reporting Parcels = 304 (of 345)



Wells: 139
Surface Diversions: 82
Springs: 36

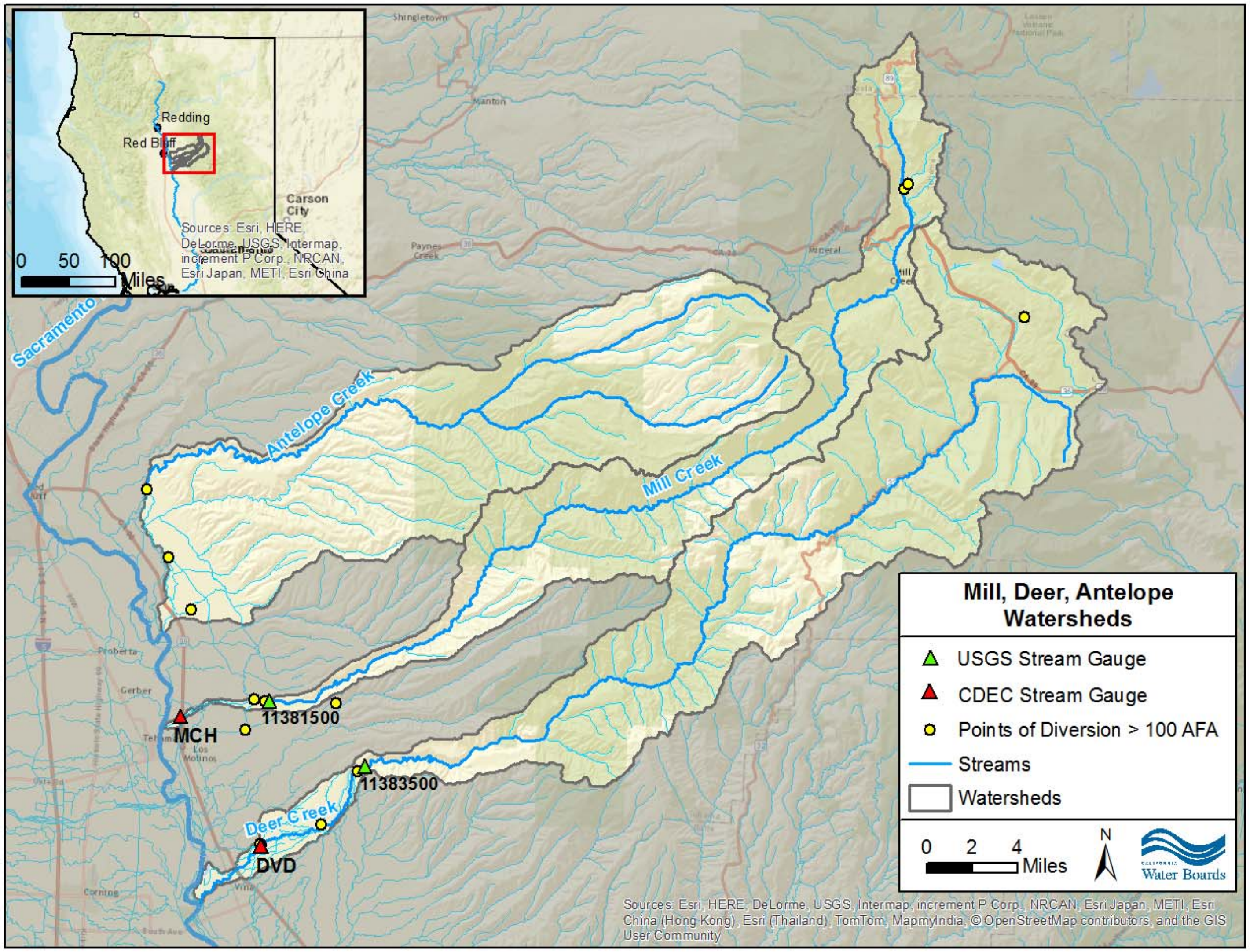
How Could Actions Be More Effective In the Future?

- Initiate actions earlier (May instead of July)
- Seek out additional voluntary agreements for flow enhancement
- Increase the number of flow gauges to improve real-time monitoring and assess effectiveness of actions
- Continued landowner education and outreach

Future Actions to Address Instream Flow Issues: Russian River Tributaries

- California Water Action Plan (Mark West Creek is 1 of 5 priority streams for flow enhancement)
  - Enhance water supply reliability
  - Restore damaged and destroyed ecosystems
  - Improve the resilience of California's infrastructure –
- Sustainable Groundwater Management Act (SGMA)
  - Formation of groundwater sustainability agencies
  - Development of groundwater sustainability plans for 127 high and medium priority groundwater basins – Aquifer under Mark West Creek watershed included
- Outreach/Education
- Improve water application efficiencies

Mill, Deer, and Antelope Watersheds



Site Introduction: Mill, Deer, and Antelope Creeks

- Protected fish:
  - Central Valley spring-run Chinook salmon (State and Federal - Threatened)
  - Central Valley steelhead (Federal - Threatened)
- Relatively unaltered watersheds
  - No major impoundments
  - Cool, perennial headwaters accessible to anadromous salmonids

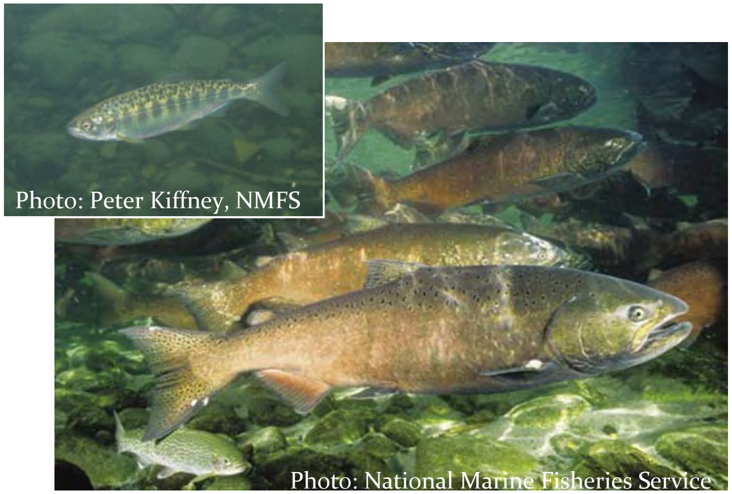


Photo: Peter Kiffney, NMFS
Photo: National Marine Fisheries Service


Photo: US National Park Service
Photo: Morgan Bond

Photo: Mill Creek Conservancy
From http://www.millcreekconservancy.com/photo-gallery.html

Problem

- Pressures on surface water
  - Large water diversions reduce flows in the lower watersheds
- Problem
  - Due to drought and water withdrawals, there is **insufficient flow and cool temperatures for adult and juvenile migrations through the lower reaches**

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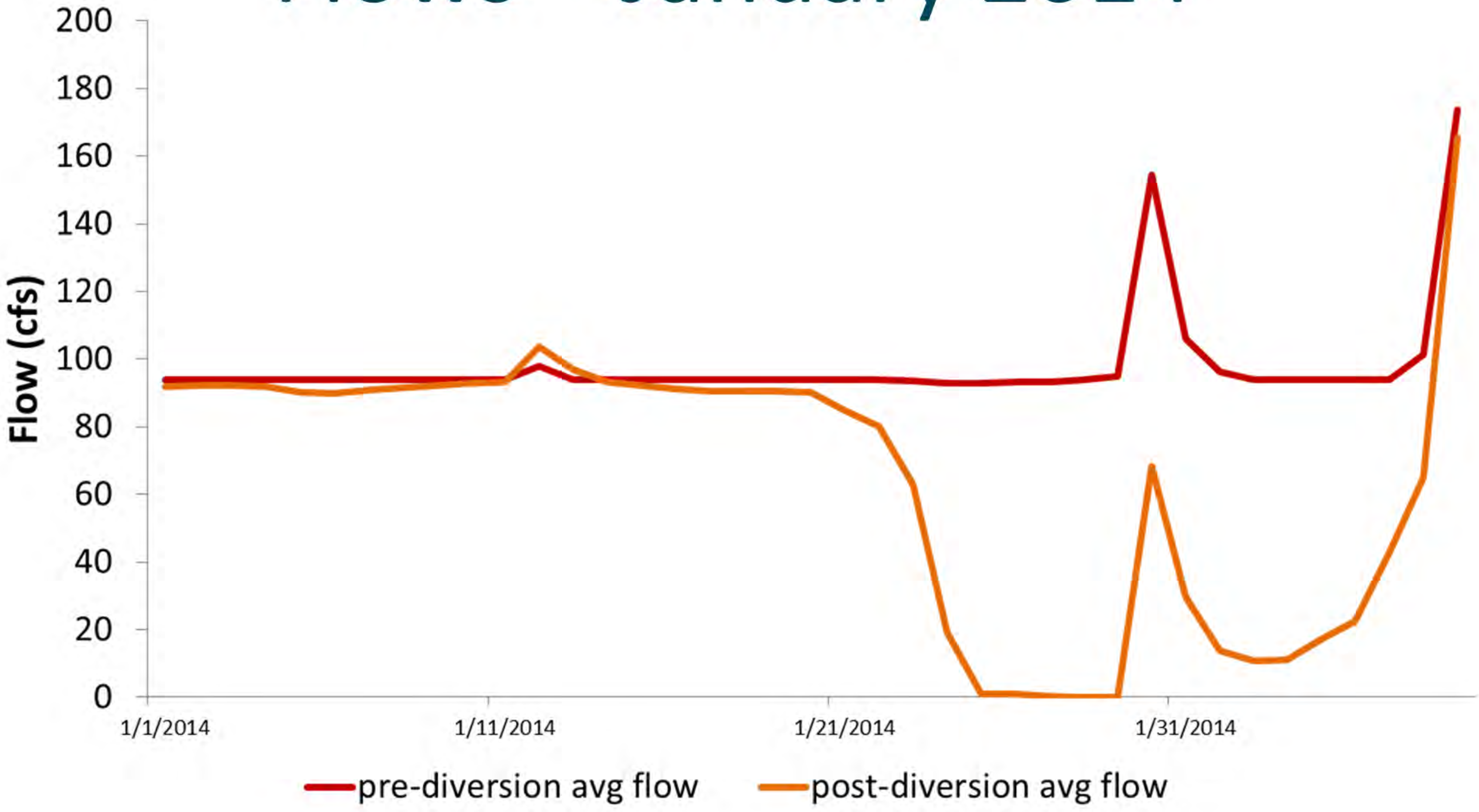
Exceptional Diversion Example
Mill Creek – January 27, 2014

Slide Provided Courtesy of CDFW

Post vs Pre Diversion Mill Creek Flows – January 2014



Slide Provided Courtesy of Dept. of Fish and Wildlife

Actions Taken

- Required flow regime
  - Base and pulse flows schedule
    - Targeted adult and juvenile migrations
  - Achieved through combination of emergency regulations and voluntary agreements
    - Water Board adopted Emergency Regulation curtailing diversions (was in effect June 2, 2014-Feb. 28, 2015)
    - Water Board updated and re-adopted Emergency Regulation (was in effect March 30, 2015-Dec. 29, 2015)
    - CDFW and NMFS voluntary agreements with water diverters
      - Mill and Antelope Creeks in 2014
      - Mill Creek in 2015

2014/15 Flow Requirement Timing

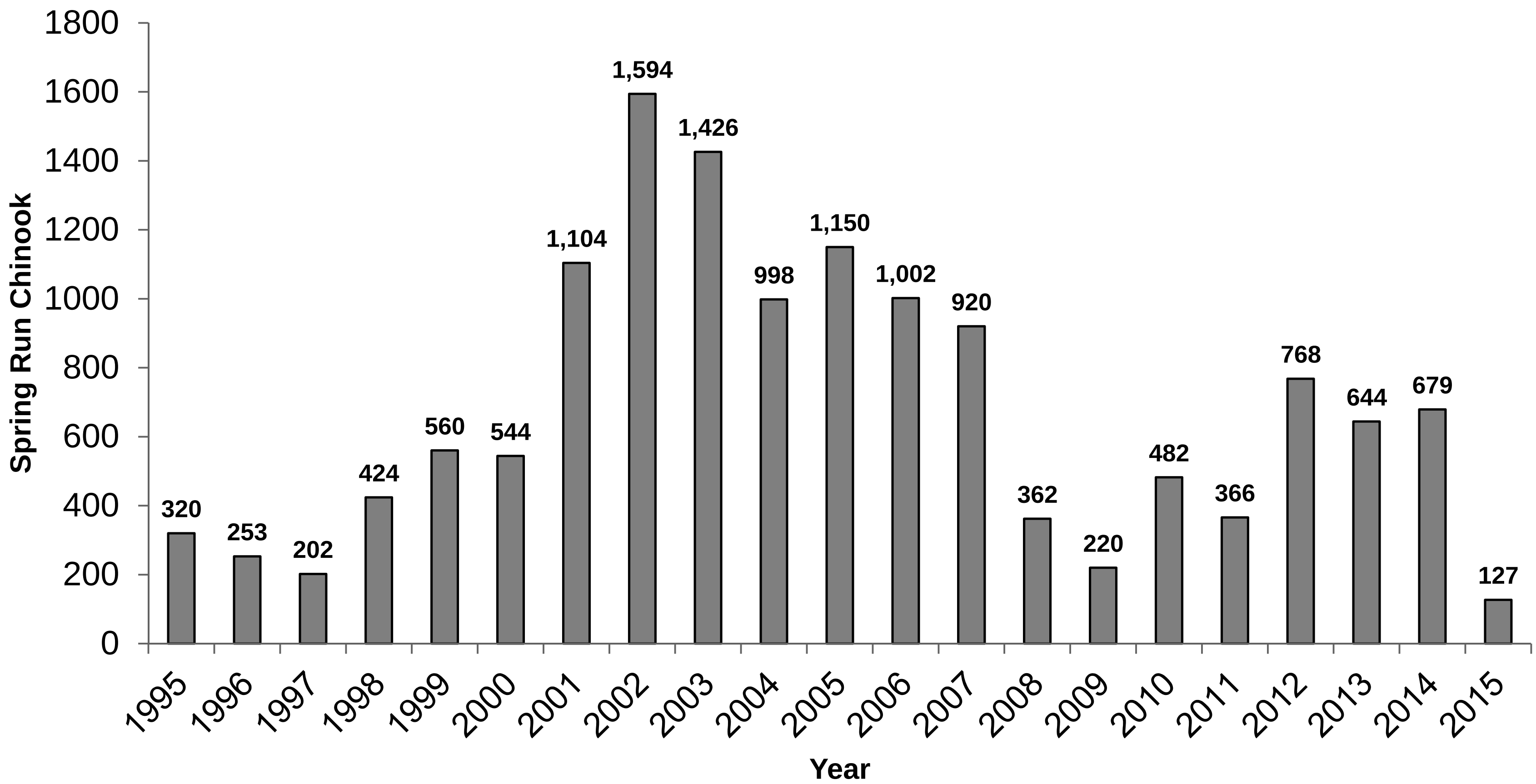
	2014			2015						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July
Mill Creek and Deer Creek										
Adult Base Flow 50cfs										
Juvenile Base Flow 20cfs										
Adult Pulse Flow 100cfs										
Juvenile Pulse Flow 100cfs										
Antelope Creek										
Adult Base Flow 35cfs										
Juvenile Base Flow 20cfs										
Adult Pulse Flow 70cfs										
Juvenile Pulse Flow 70cfs										

2015/16 Flow Requirement Timing

	2015			2016						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July
Mill Creek and Deer Creek										
Adult Base Flow 50cfs										
Juvenile Base Flow 20cfs										
Adult Pulse Flow 100cfs										
Juvenile Pulse Flow 100cfs										
Antelope Creek										
Adult Base Flow 35cfs										
Juvenile Base Flow 15cfs										
Adult Pulse Flow 70cfs										
Juvenile Pulse Flow 70cfs										

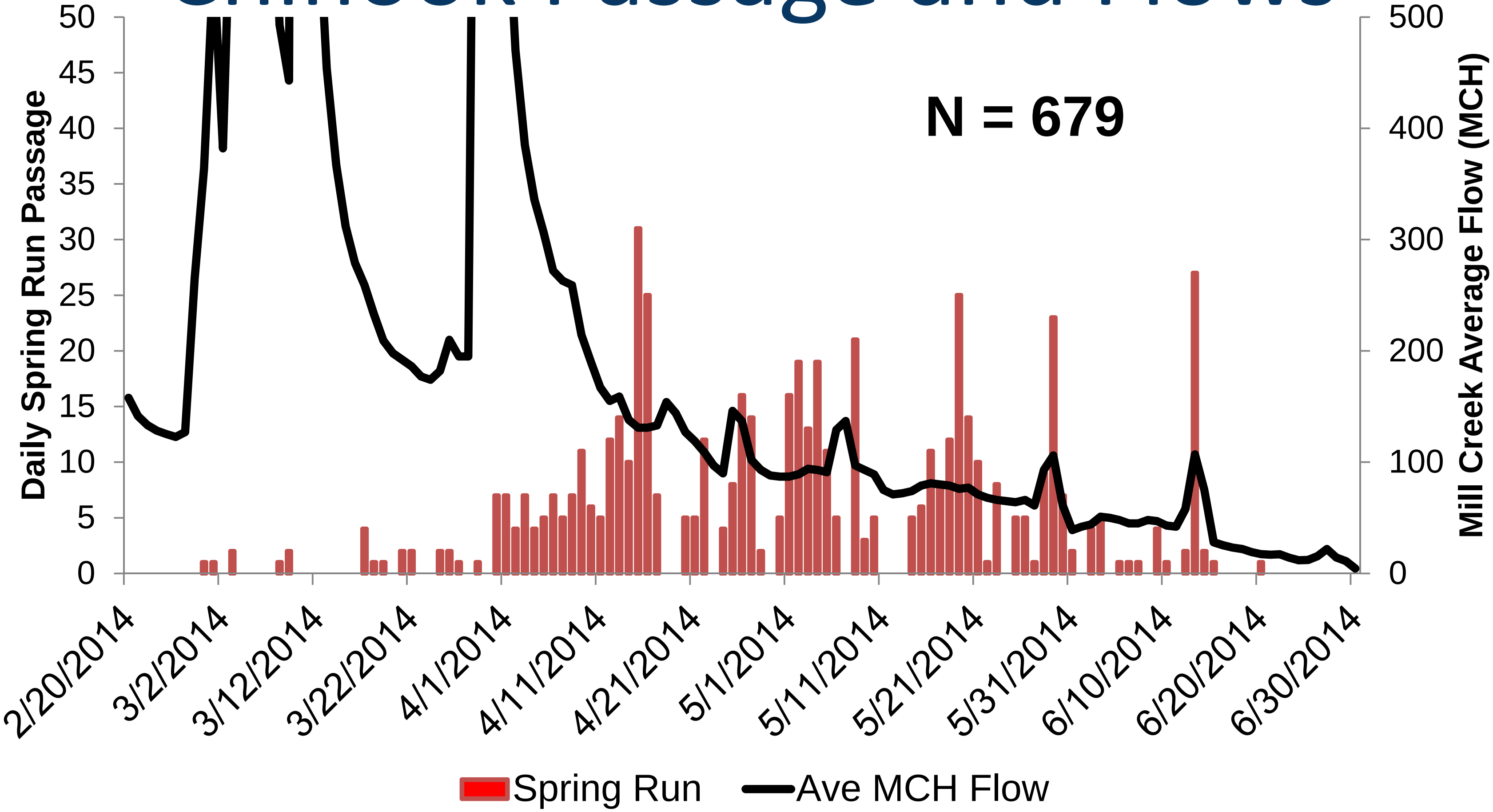

Results
38
Photo: Michael Humling, US Fish & Wildlife Service

Mill Creek Spring-Run Chinook Population Estimates



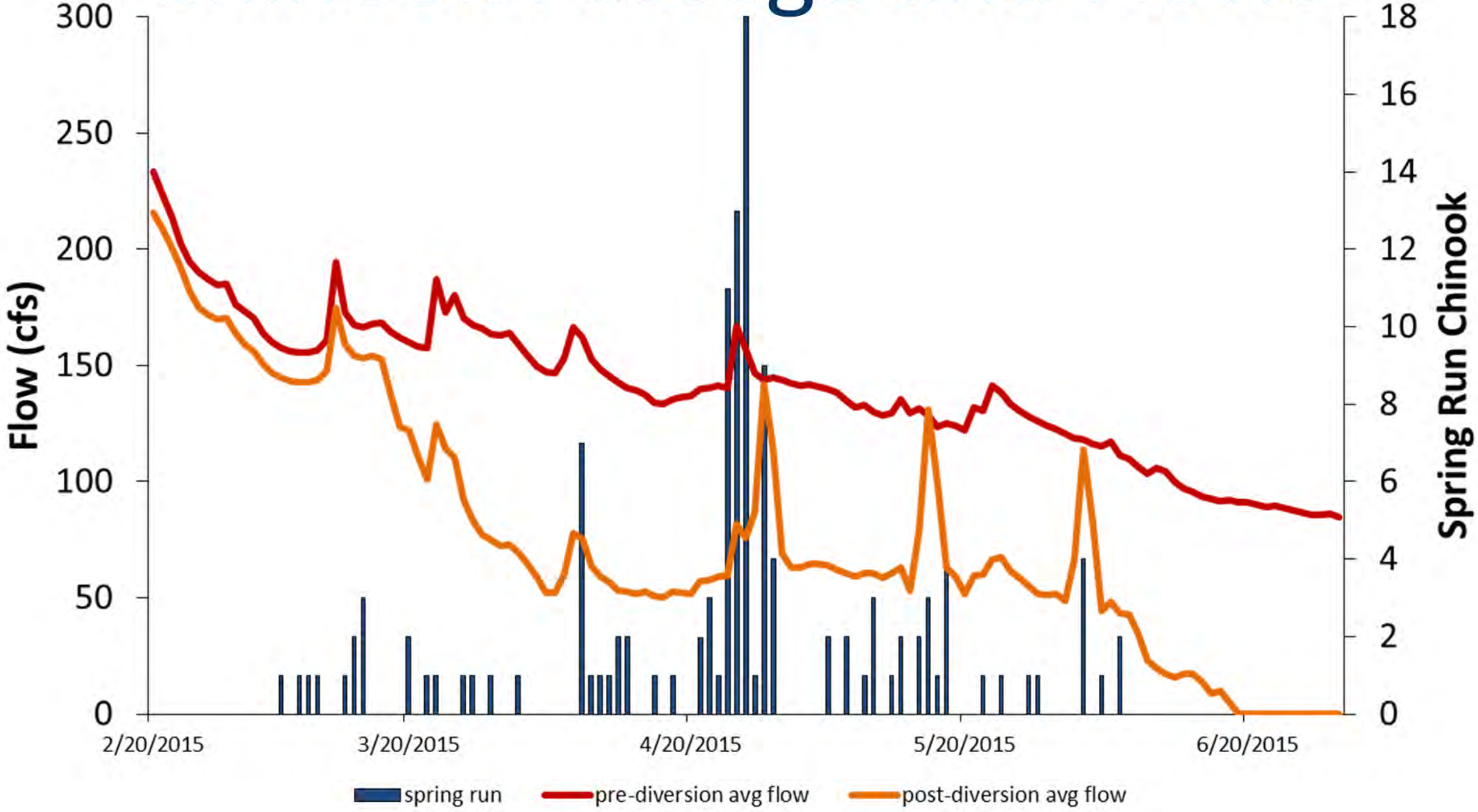
Graph courtesy of CDFW

Mill Creek 2014 Spring-Run Chinook Passage and Flows



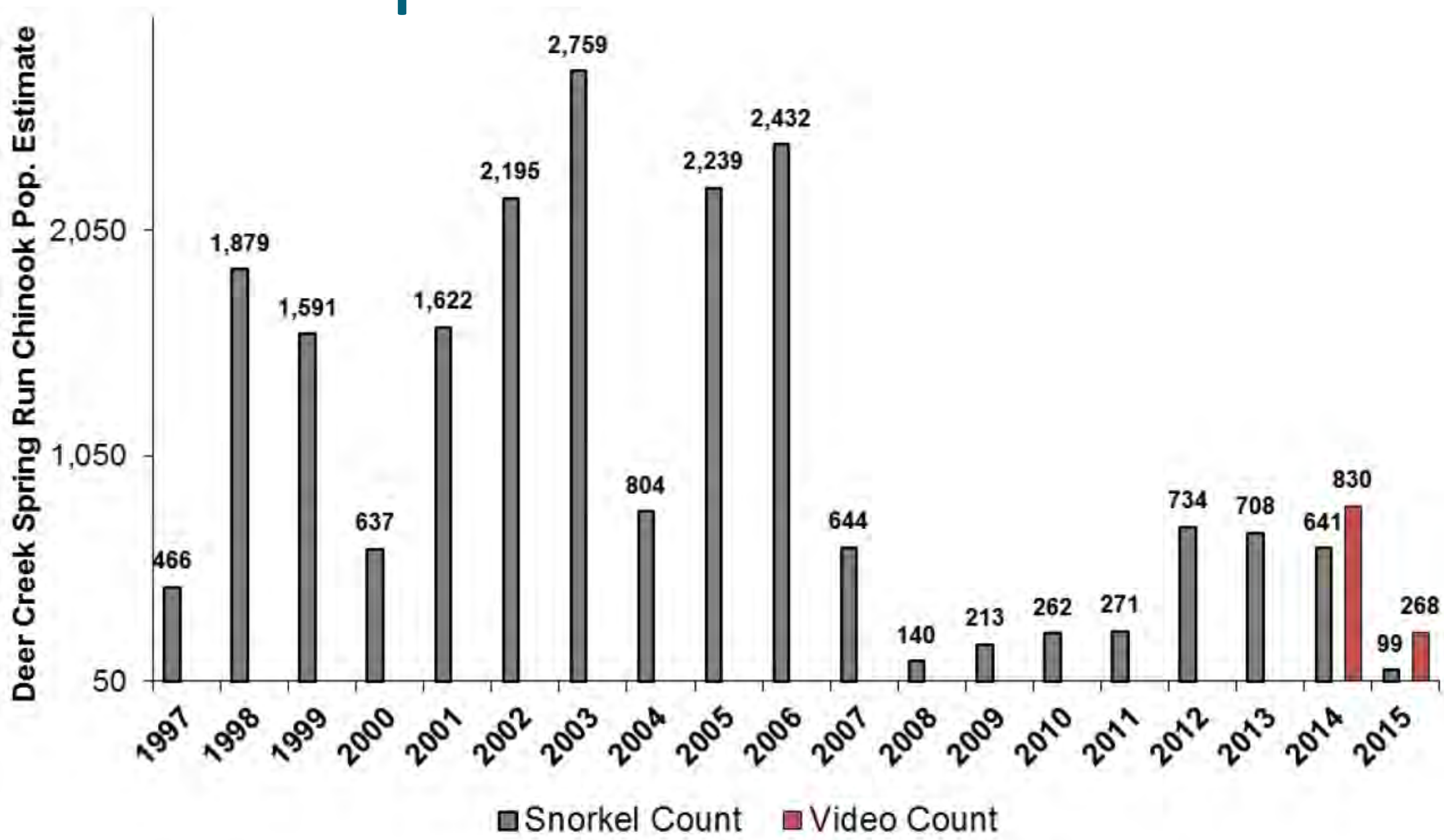
Slide Provided Courtesy of Dept. of Fish and Wildlife

Mill Creek 2015 Spring-Run Chinook Passage and Flows



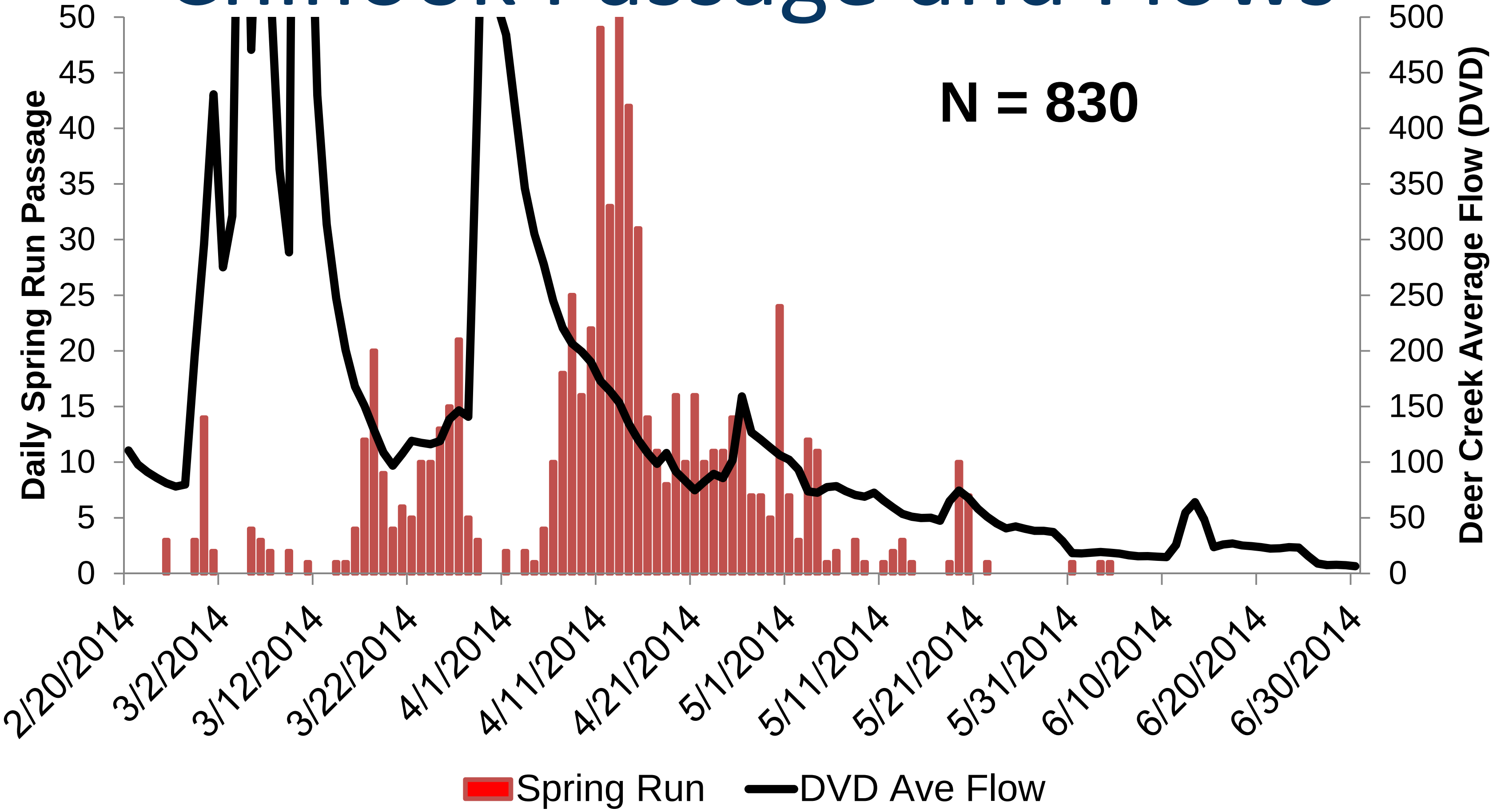
Slide Provided Courtesy of Dept. of Fish and Wildlife

Deer Creek Spring-Run Chinook Population Estimates



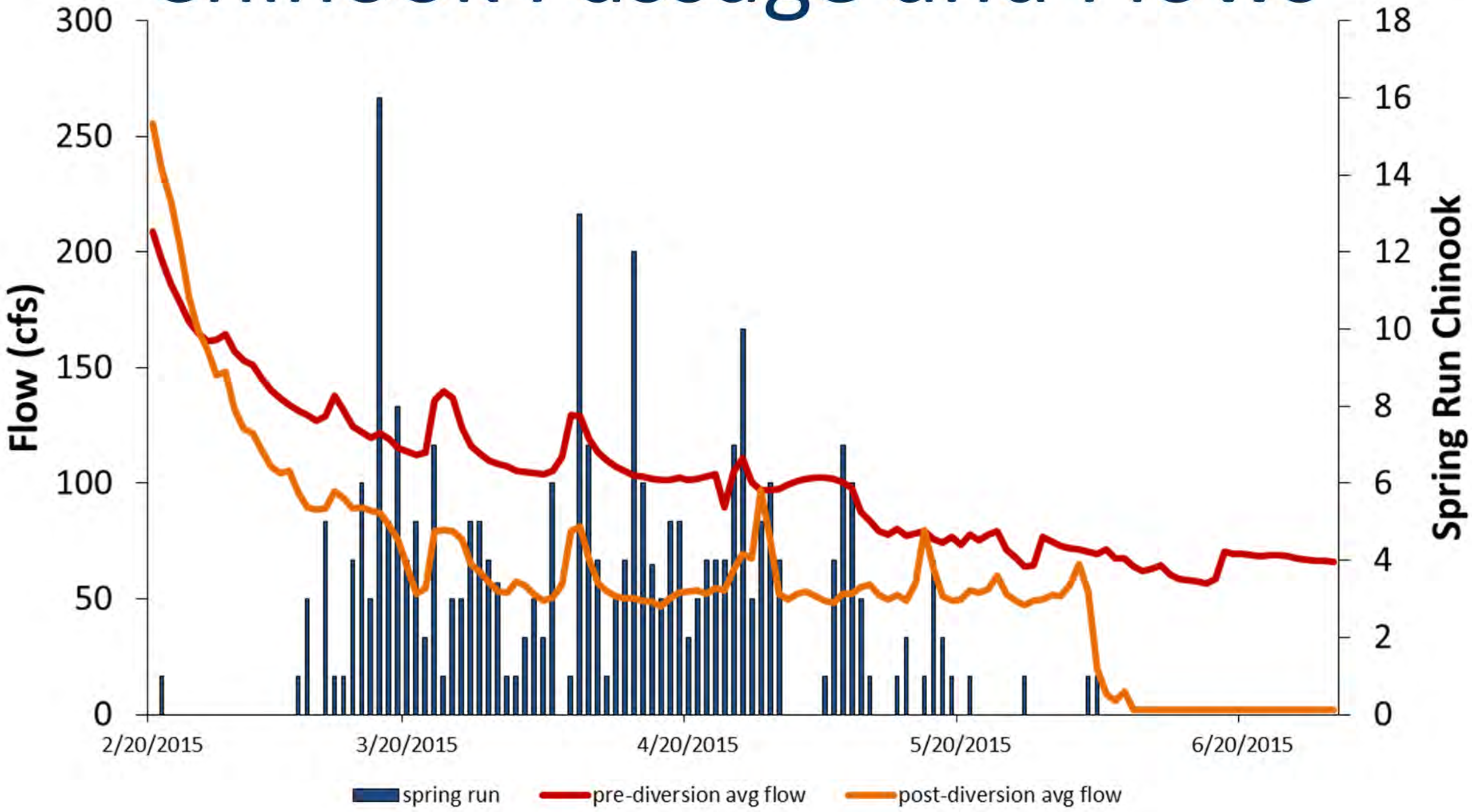
Graph courtesy of CDFW

Deer Creek 2014 Spring-Run Chinook Passage and Flows



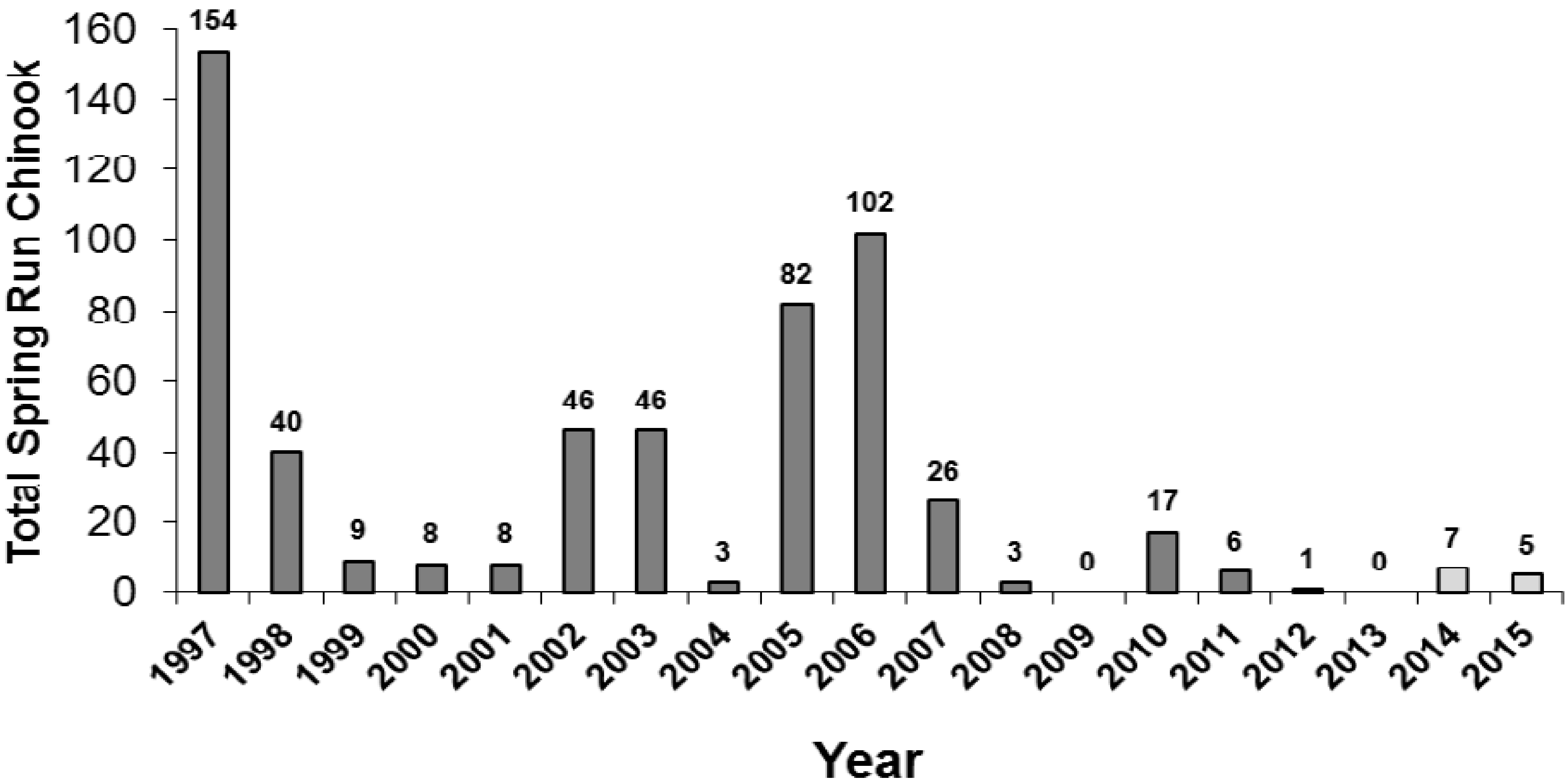
Slide Provided Courtesy of Dept. of Fish and Wildlife

Deer Creek 2015 Spring-Run Chinook Passage and Flows



Slide Provided Courtesy of Dept. of Fish and Wildlife

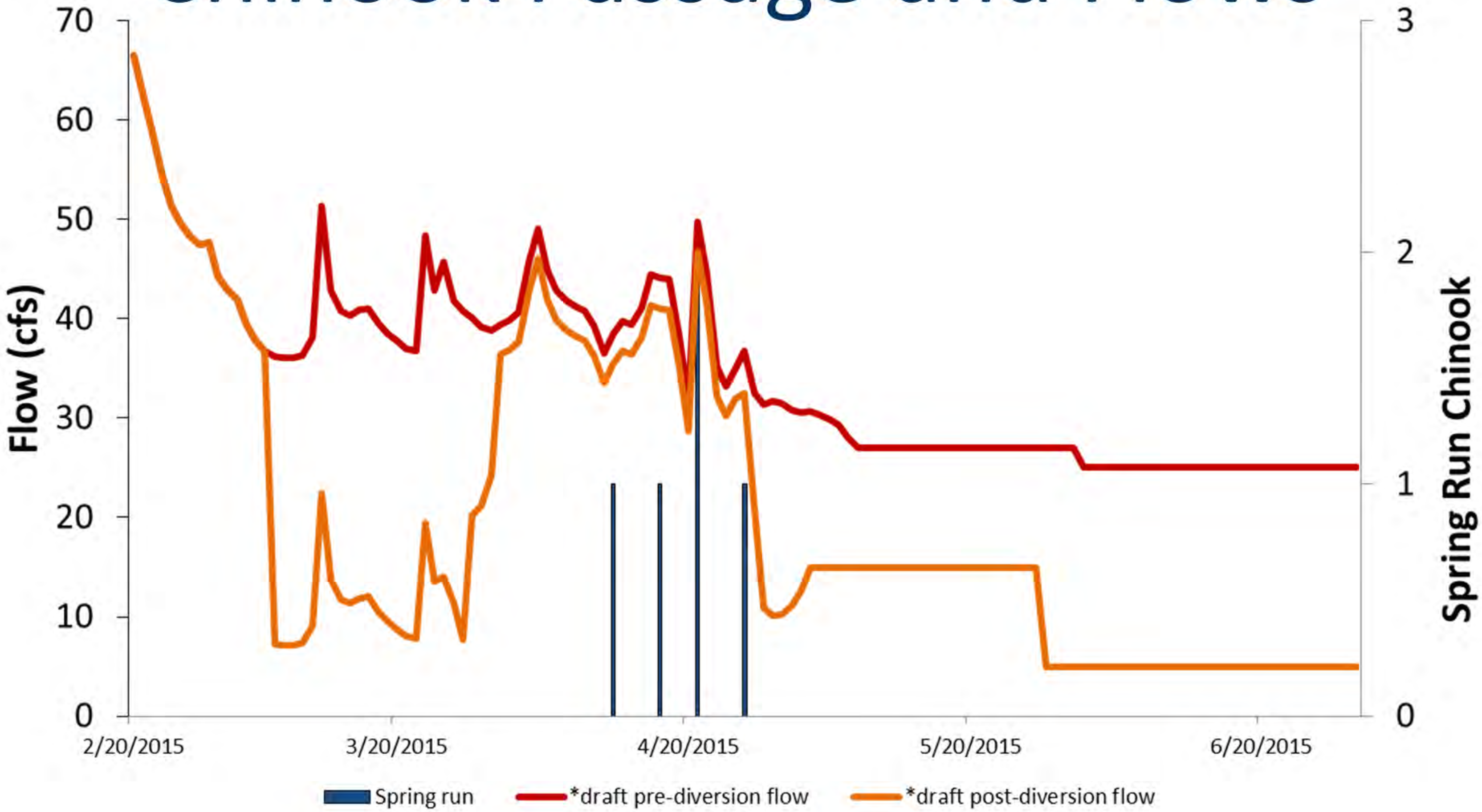
Antelope Creek Spring-Run Chinook Population Estimates



Graph courtesy of CDFW

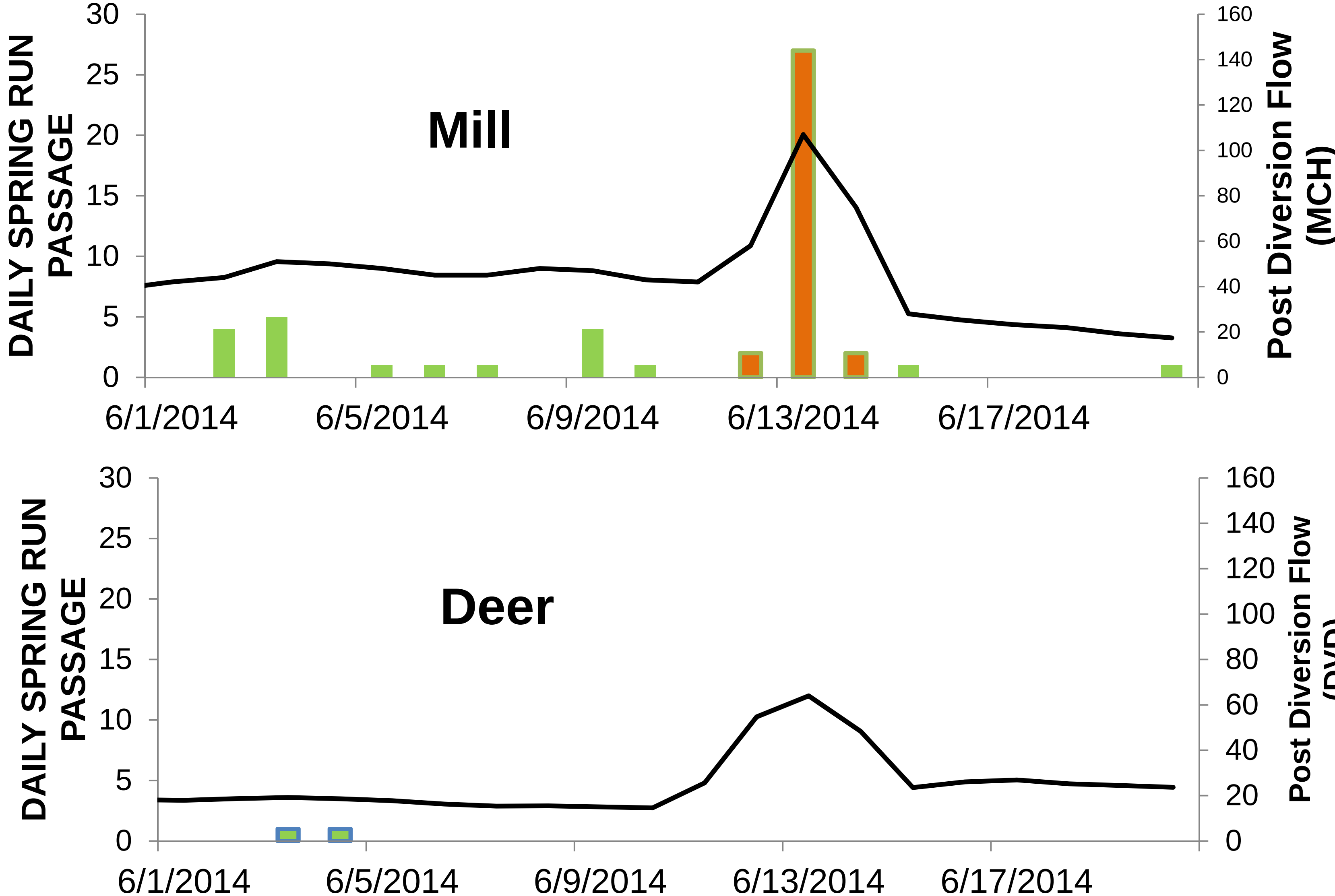
45

Antelope Creek 2015 Spring-Run Chinook Passage and Flows



Slide Provided Courtesy of Dept. of Fish and Wildlife

June Pulse Flow Response: Mill vs Deer



Slide Provided Courtesy of Dept. of Fish and Wildlife

2014-2015 Adult Fall-Entry Steelhead Population Estimates

Year	Deer	Mill	Antelope
2014	77	202	17
2015	3	54	3

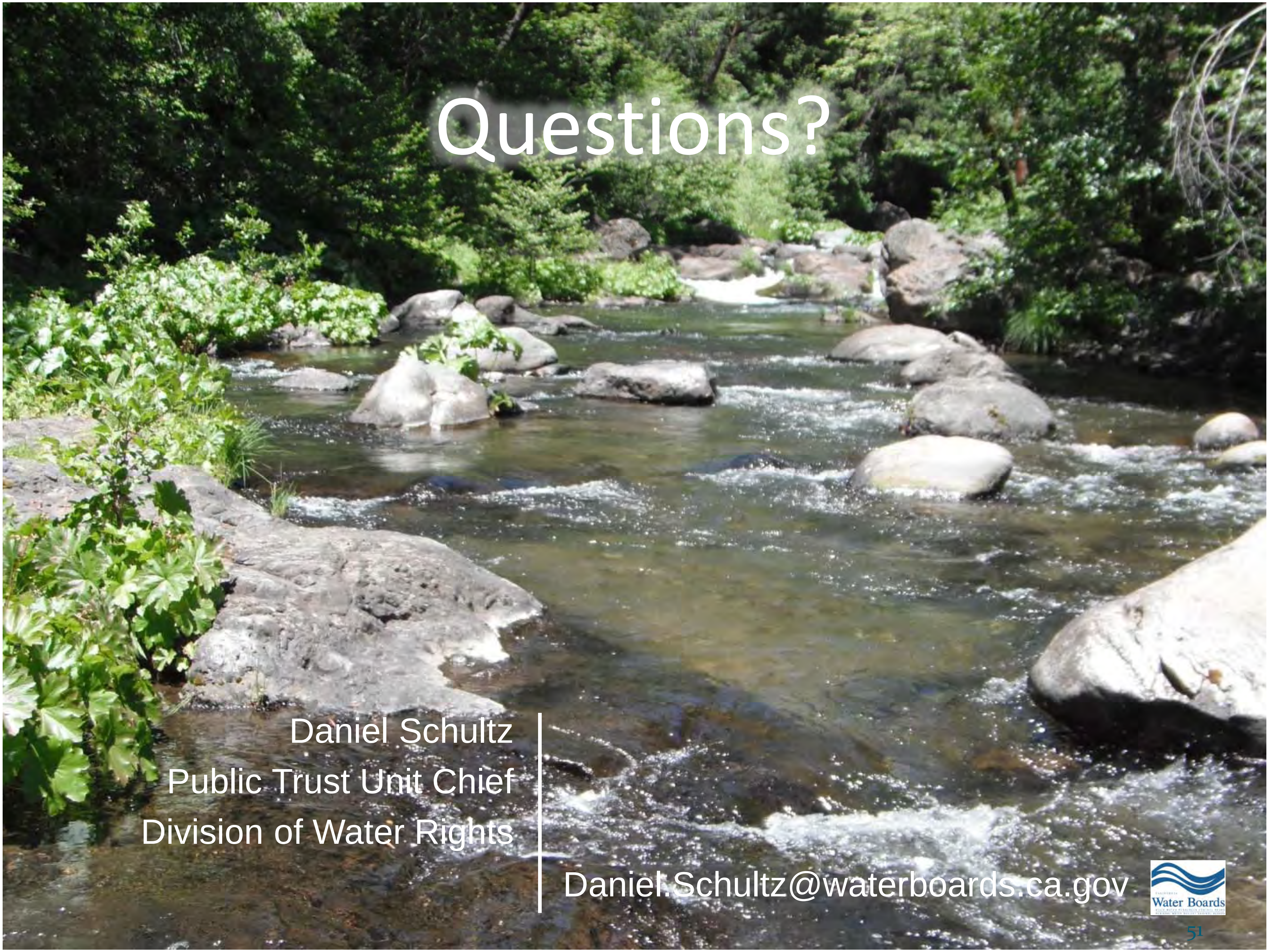
Slide Provided Courtesy of Dept. of Fish and Wildlife

Future Actions to Address Instream Flow Issues: Mill, Deer, and Antelope

- Phase 4 of Bay-Delta Effort
  - Develop Flow Objectives for tributaries to the Sacramento and San Joaquin Rivers
- California Water Action Plan
  - Mill Creek is 1 of 5 priority streams for flow enhancement

Webpages

- **Russian River Tributaries Emergency Regulation:** http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/water_action_russianriver.shtml
- **Mill, Deer, Antelope Emergency Regulation:** http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/mill_deer_antelope_creeks.shtml
- **California Water Action Plan:** http://resources.ca.gov/california_water_action_plan/
- **Sustainable Groundwater Management Act:** http://groundwater.ca.gov/


Questions?
Daniel Schultz
Public Trust Unit Chief
Division of Water Rights
Daniel.Schultz@waterboards.ca.gov
Water Boards
51

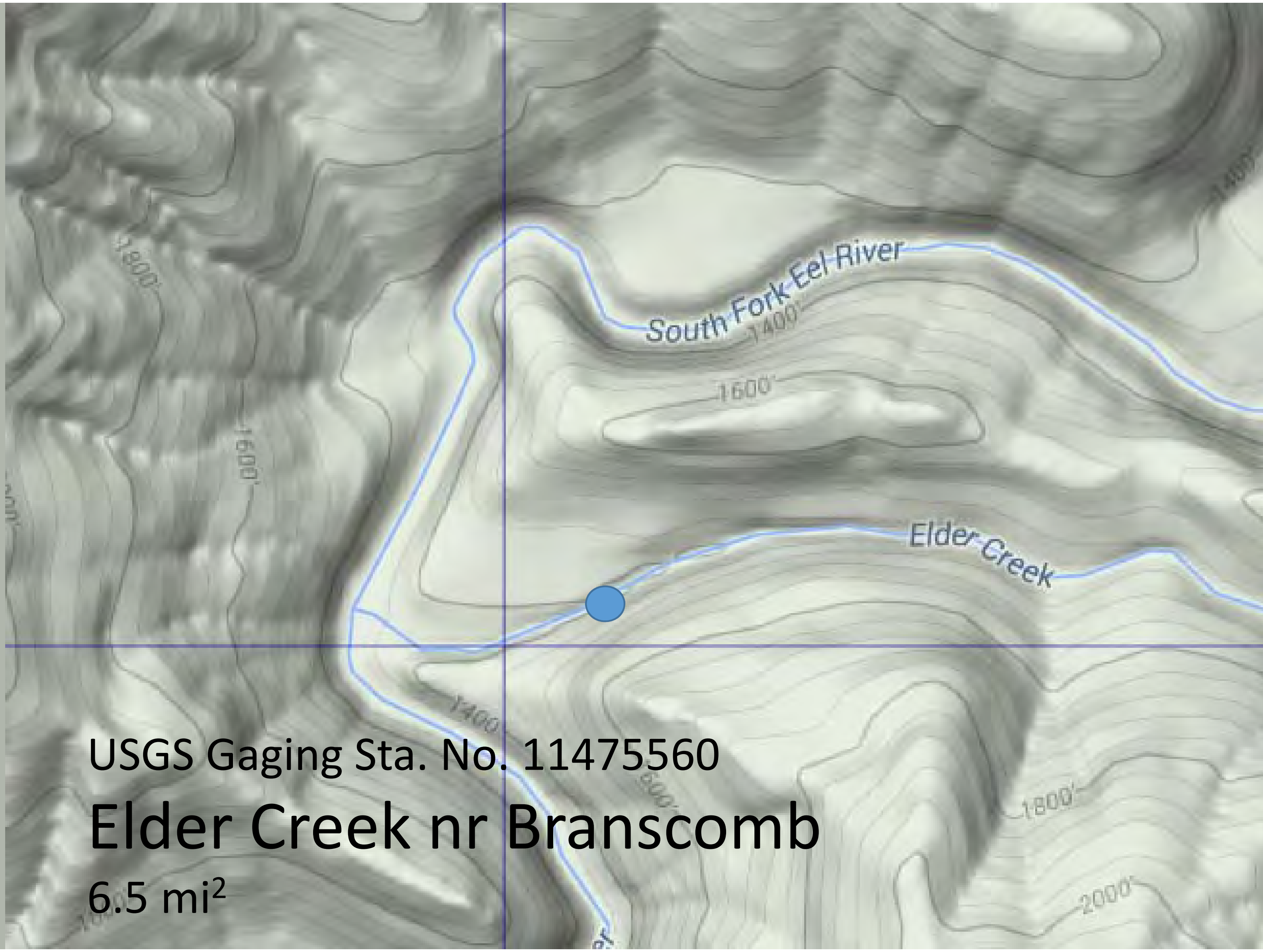
A Variable Diversion Rate Strategy for Northern California Coastal Streams




POLICY FOR MAINTAINING INSTREAM FLOWS IN NORTHERN CALIFORNIA COASTAL STREAMS

EFFECTIVE FEBRUARY 4, 2014

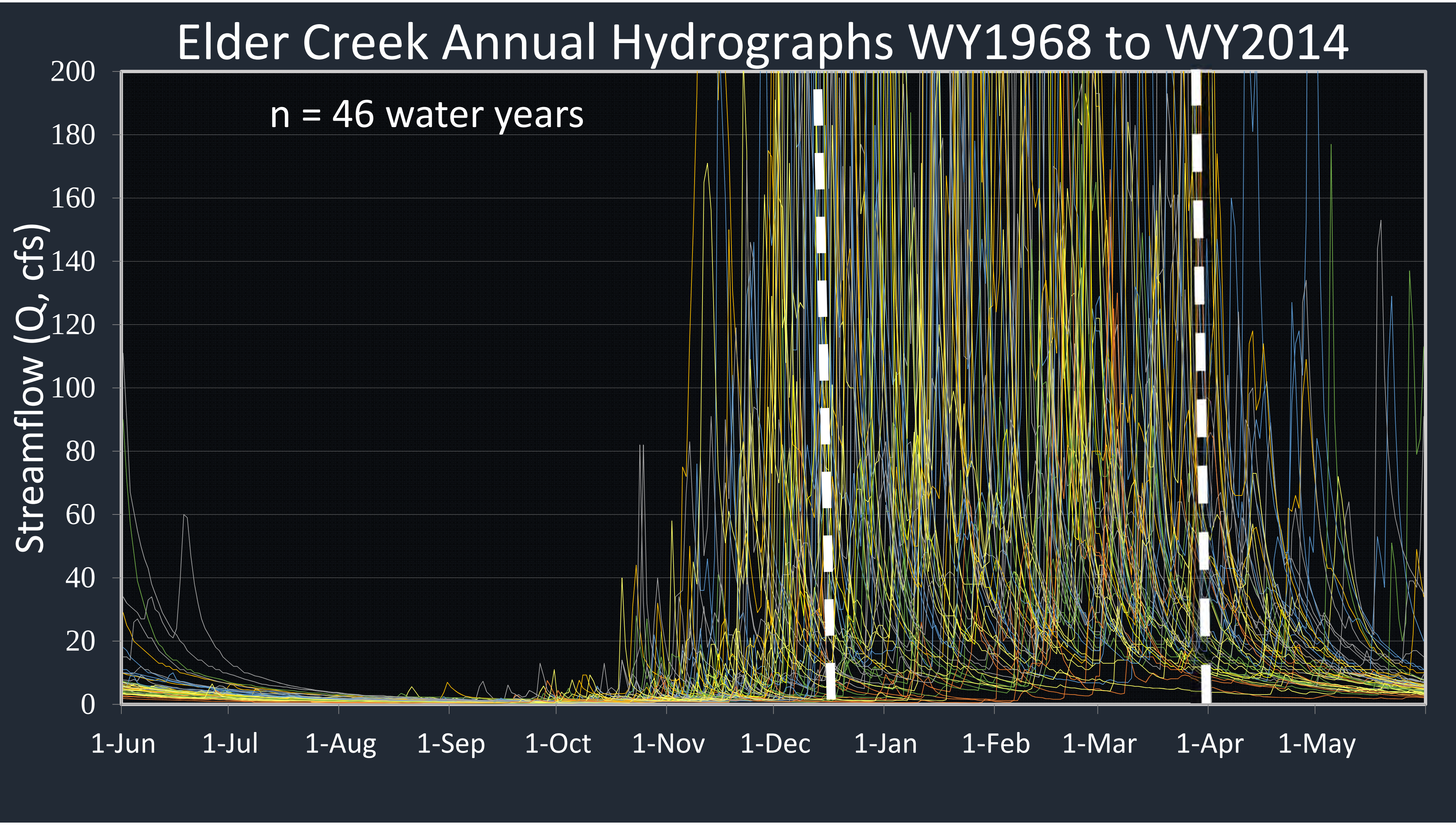
DIVISION OF WATER RIGHTS
STATE WATER RESOURCES CONTROL BOARD
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY



USGS Gaging Sta. No. 11475560

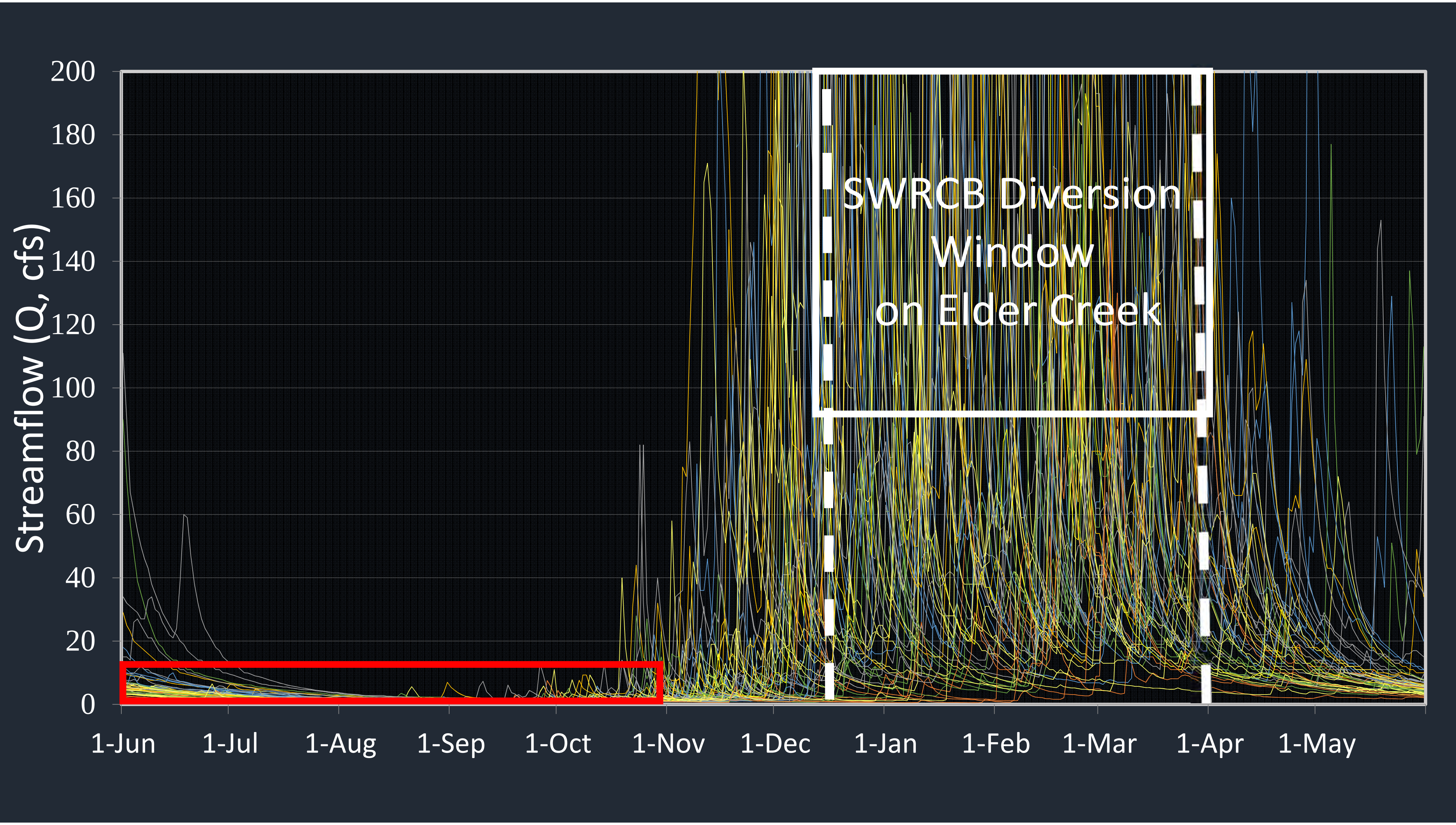
Elder Creek nr Branscomb

6.5 mi^2

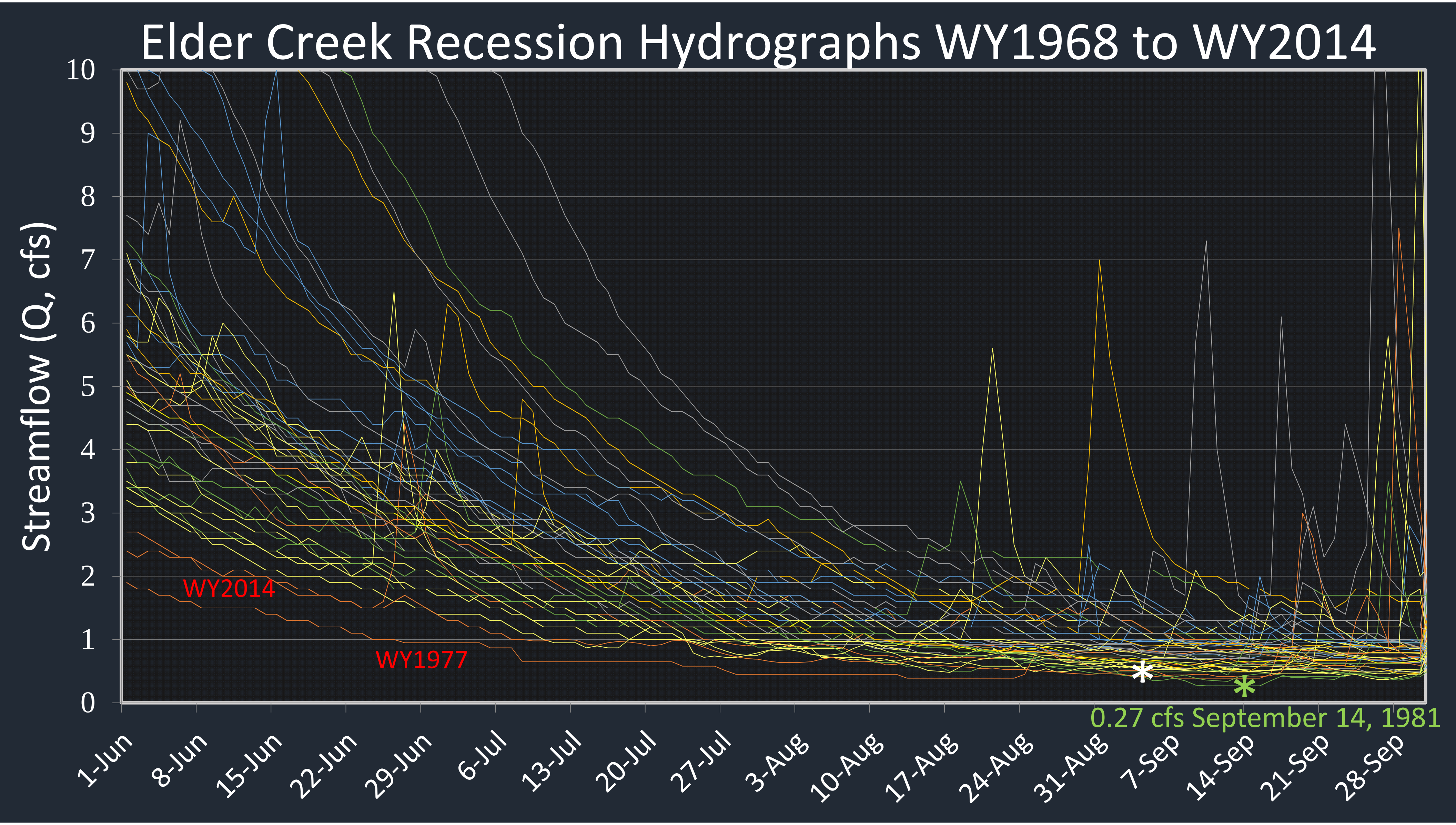

Elder Creek Annual Hydrographs WY1968 to WY2014
n = 46 water years
Streamflow (Q, cfs)
200
180
160
140
120
100
80
60
40
20
0
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May

$$Q_{MBF3} = 8.7 * Q_{AVE} * (DA)^{-0.47}$$

$$Q_{MBF3} = 90.6 \text{ cfs}$$



Streamflow (Q, cfs)
200
180
160
140
120
100
80
60
40
20
0
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
SWRCB Diversion Window on Elder Creek


Elder Creek Recession Hydrographs WY1968 to WY2014
Streamflow (Q, cfs)
10
9
8
7
6
5
4
3
2
1
0
WY2014
WY1977
*
*
0.27 cfs September 14, 1981
1-Jun
8-Jun
15-Jun
22-Jun
29-Jun
6-Jul
13-Jul
20-Jul
27-Jul
3-Aug
10-Aug
17-Aug
24-Aug
31-Aug
7-Sep
14-Sep
21-Sep
28-Sep

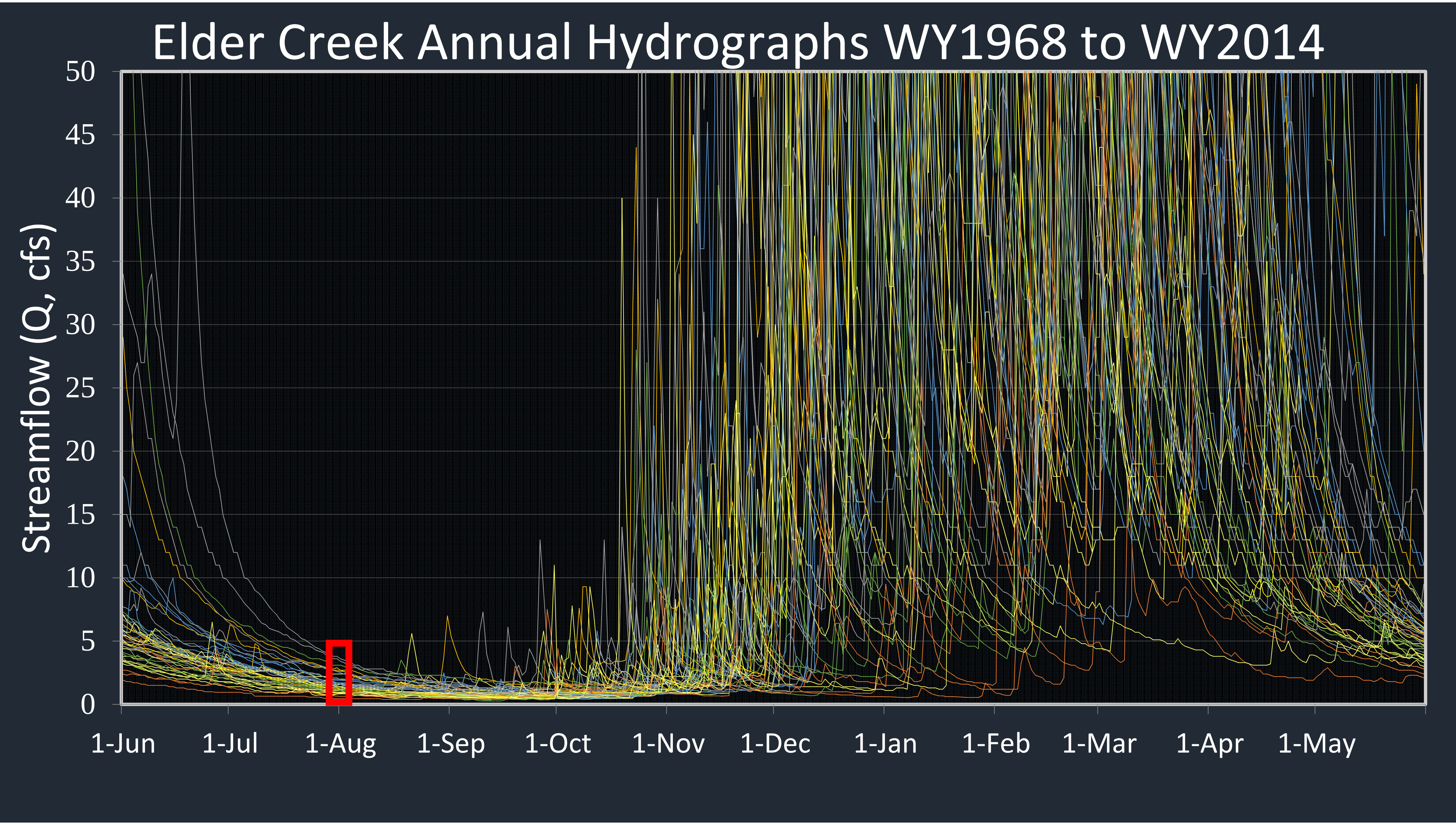

September 4, 2007
Q* = 0.43 cfs
jscheingross -at- caltech.edu

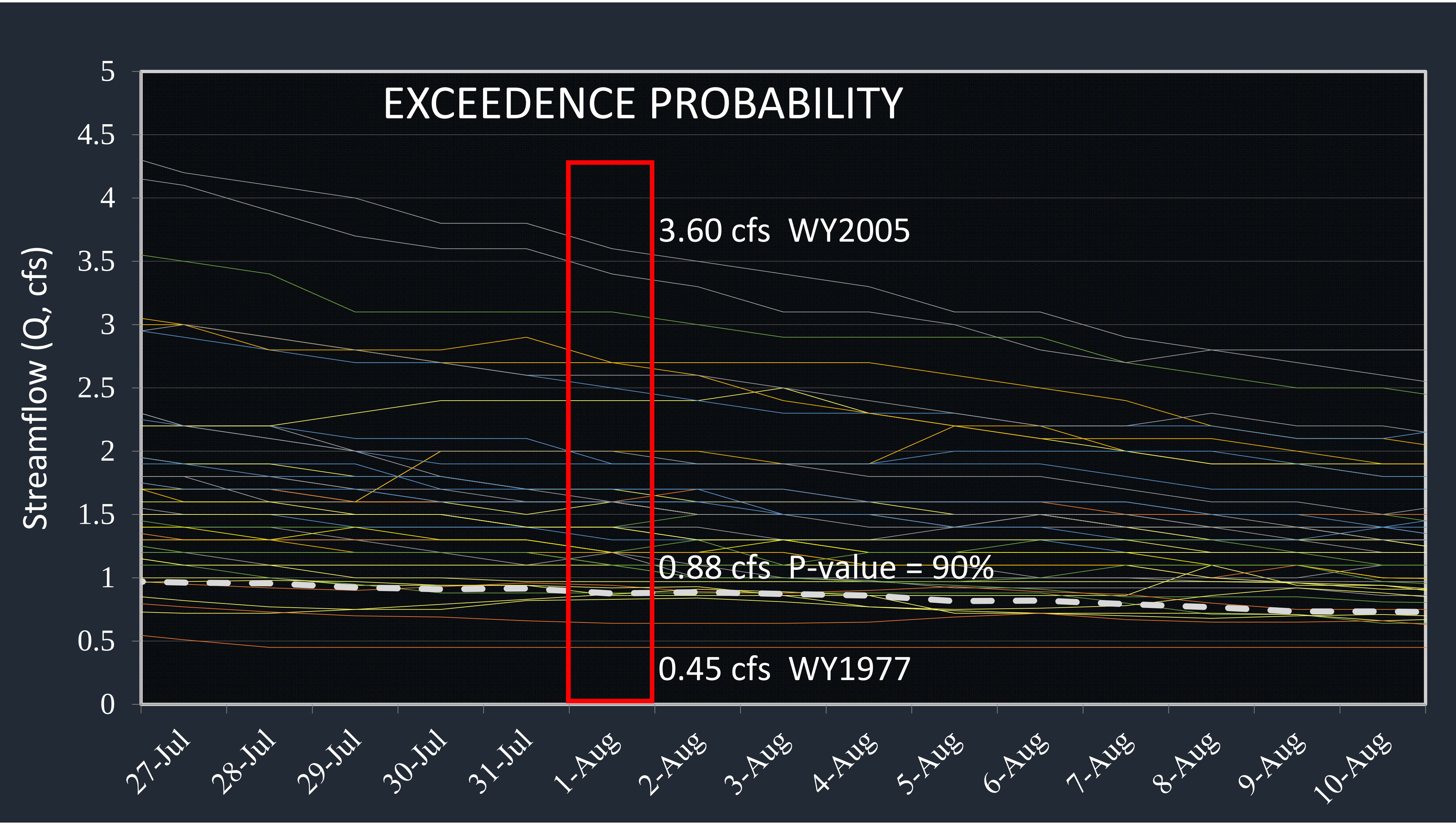
Remember in discovering on the flow of water to adduce first experience and then reason.

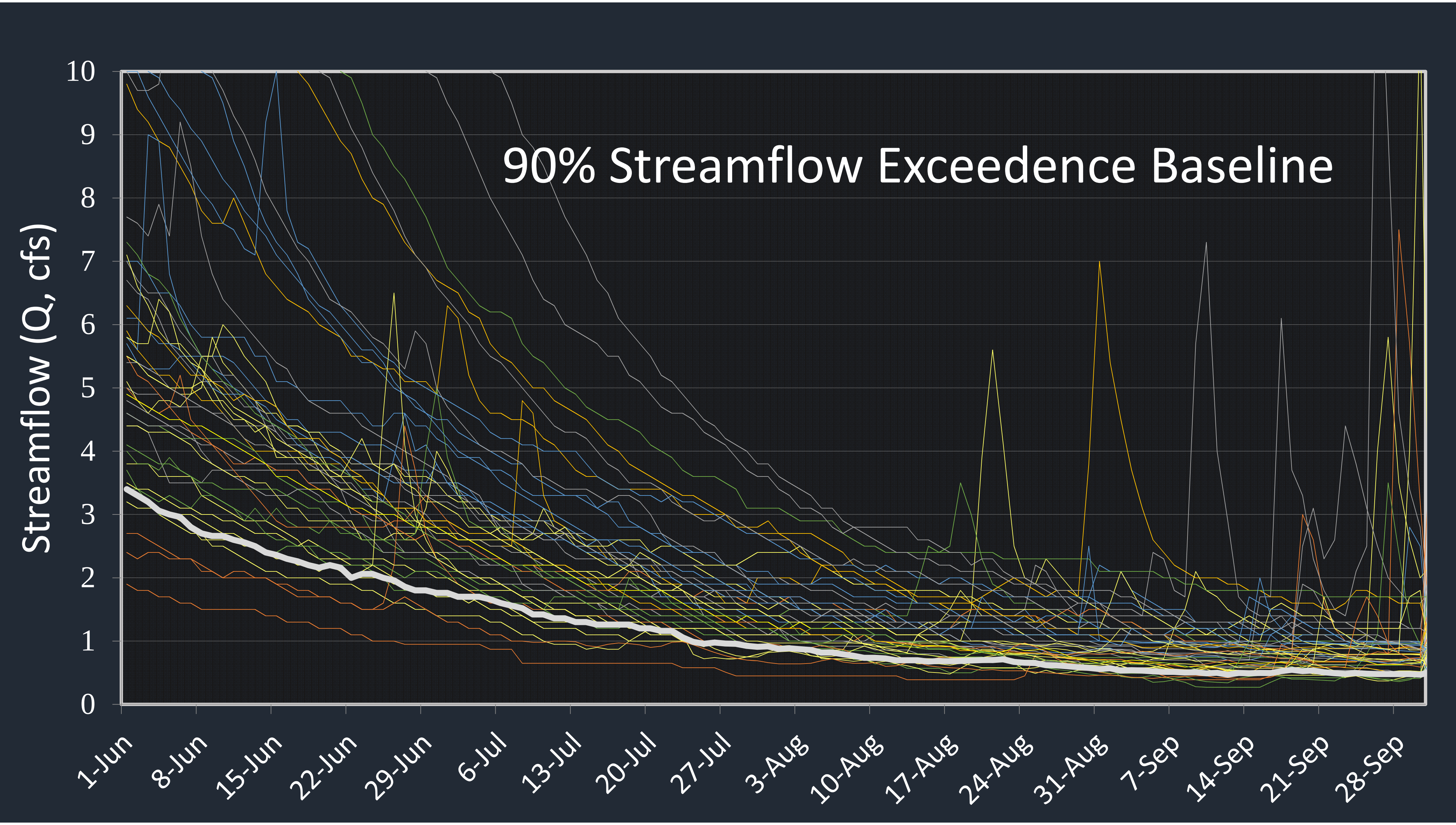
Leonardo da Vinci

Adduce … to bring forward in argument


September 4, 2007
Q* = 0.43 cfs
193 gallons/minute
448.8 gallons per minute (gpm) @ 1 cfs
How Many Gallons Per Minute?
jscheingross -at- caltech.edu


Elder Creek Annual Hydrographs WY1968 to WY2014
Streamflow (Q, cfs)
50
45
40
35
30
25
20
15
10
5
0
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May

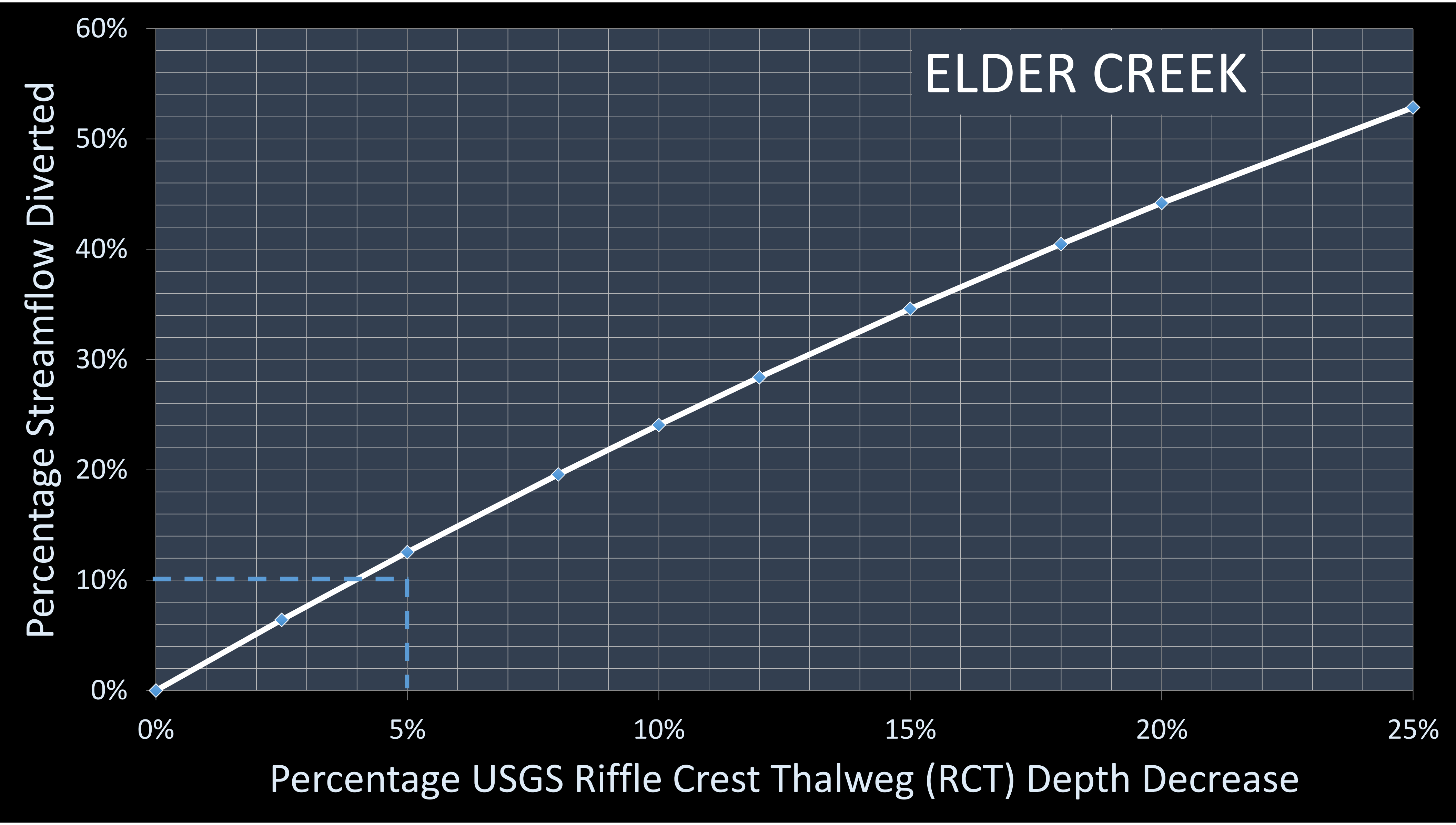

EXCEEDENCE PROBABILITY
3.60 cfs WY2005
0.88 cfs P-value = 90%
0.45 cfs WY1977
Streamflow (Q, cfs)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
27-Jul
28-Jul
29-Jul
30-Jul
31-Jul
1-Aug
2-Aug
3-Aug
4-Aug
5-Aug
6-Aug
7-Aug
8-Aug
9-Aug
10-Aug

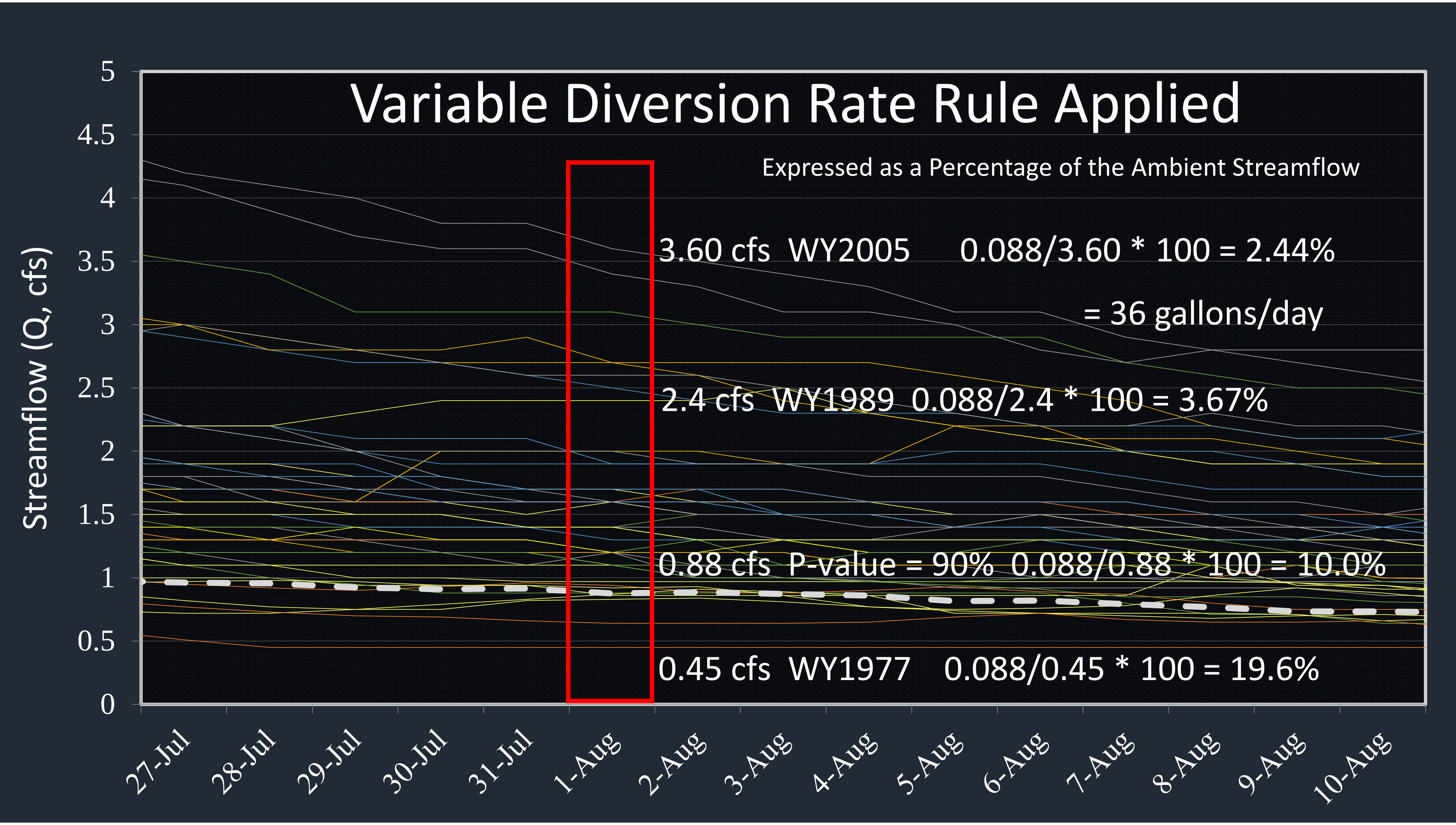

90% Streamflow Exceedence Baseline
Streamflow (Q, cfs)
0
1
2
3
4
5
6
7
8
9
10
1-Jun
8-Jun
15-Jun
22-Jun
29-Jun
6-Jul
13-Jul
20-Jul
27-Jul
3-Aug
10-Aug
17-Aug
24-Aug
31-Aug
7-Sep
14-Sep
21-Sep
28-Sep

A variable diversion rate strategy from spring through early-autumn can maintain a stream ecosystem's capacity for self-renewal, or health. Under a variable diversion rate strategy, if properly executed, juvenile salmonids will be stressed … but to no measurable extent greater than they would experiencing the unimpaired recession hydrograph May through October.

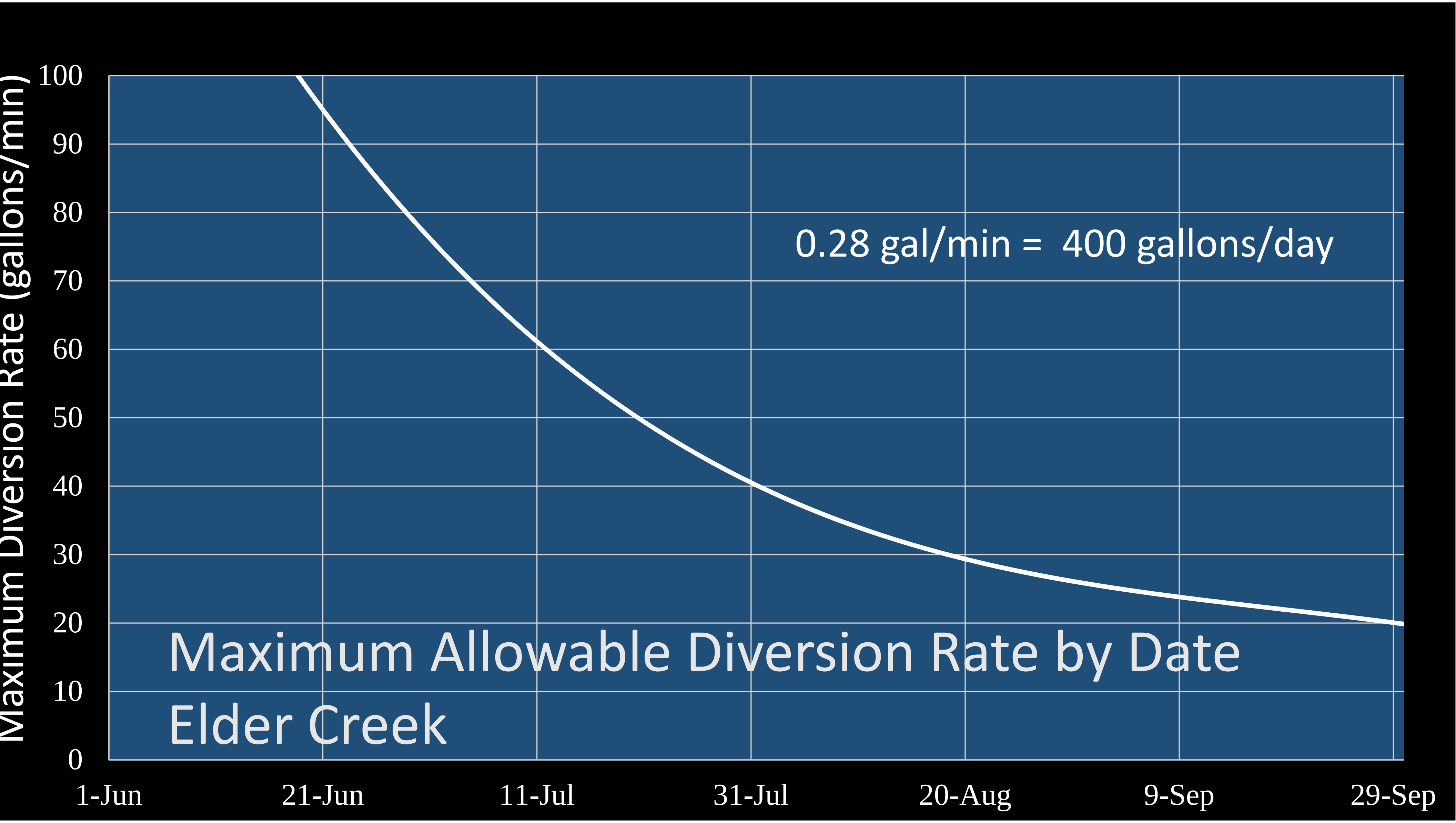
Variable Diversion Rate Rule

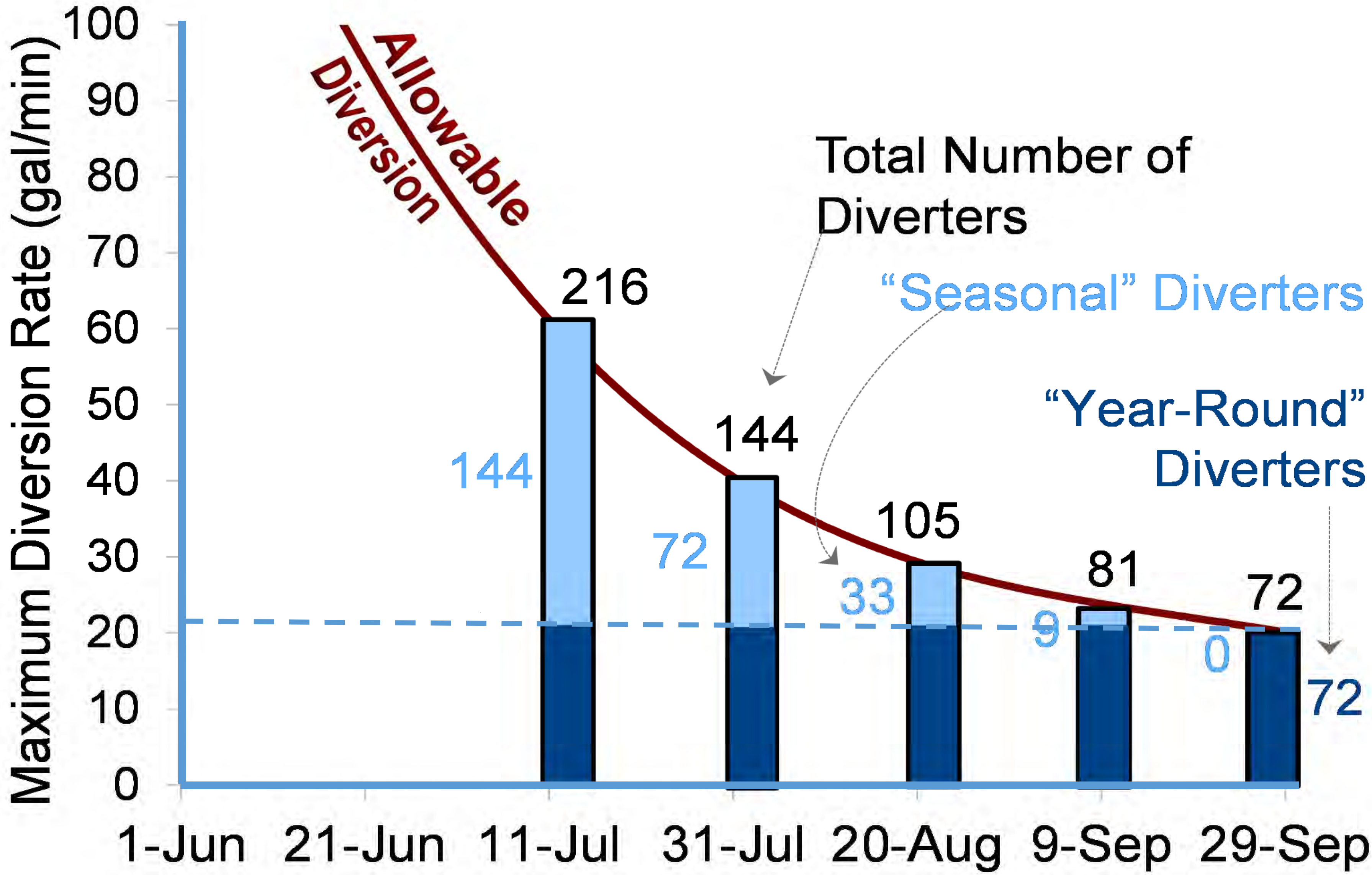
The VDR Rule requires the maximum allowable diversion rate applied on each date of a Point-of-Diversion's Streamflow Exceedence Baseline decrease stream stage by no greater than 5%. Therefore, the VDR protocol defines a maximum allowable diversion rate for each date of the Recession hydrograph. These maximum allowable diversion rates varied from 8% to 12% of the unimpaired streamflow based on the tributaries investigated.

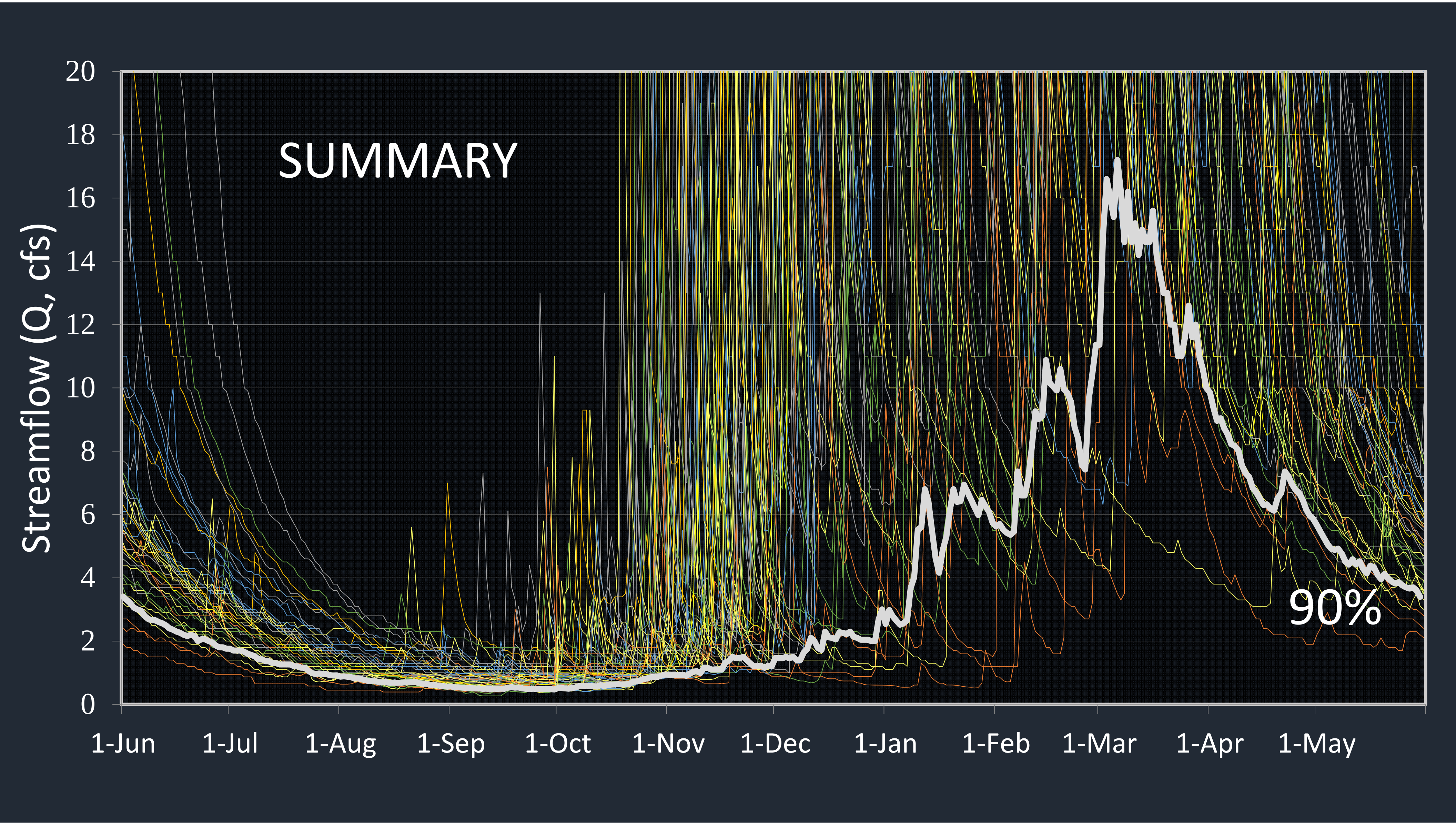

ELDER CREEK
Percentage Streamflow Diverted
60%
50%
40%
30%
20%
10%
0%
0%
5%
10%
15%
20%
25%
Percentage USGS Riffle Crest Thalweg (RCT) Depth Decrease

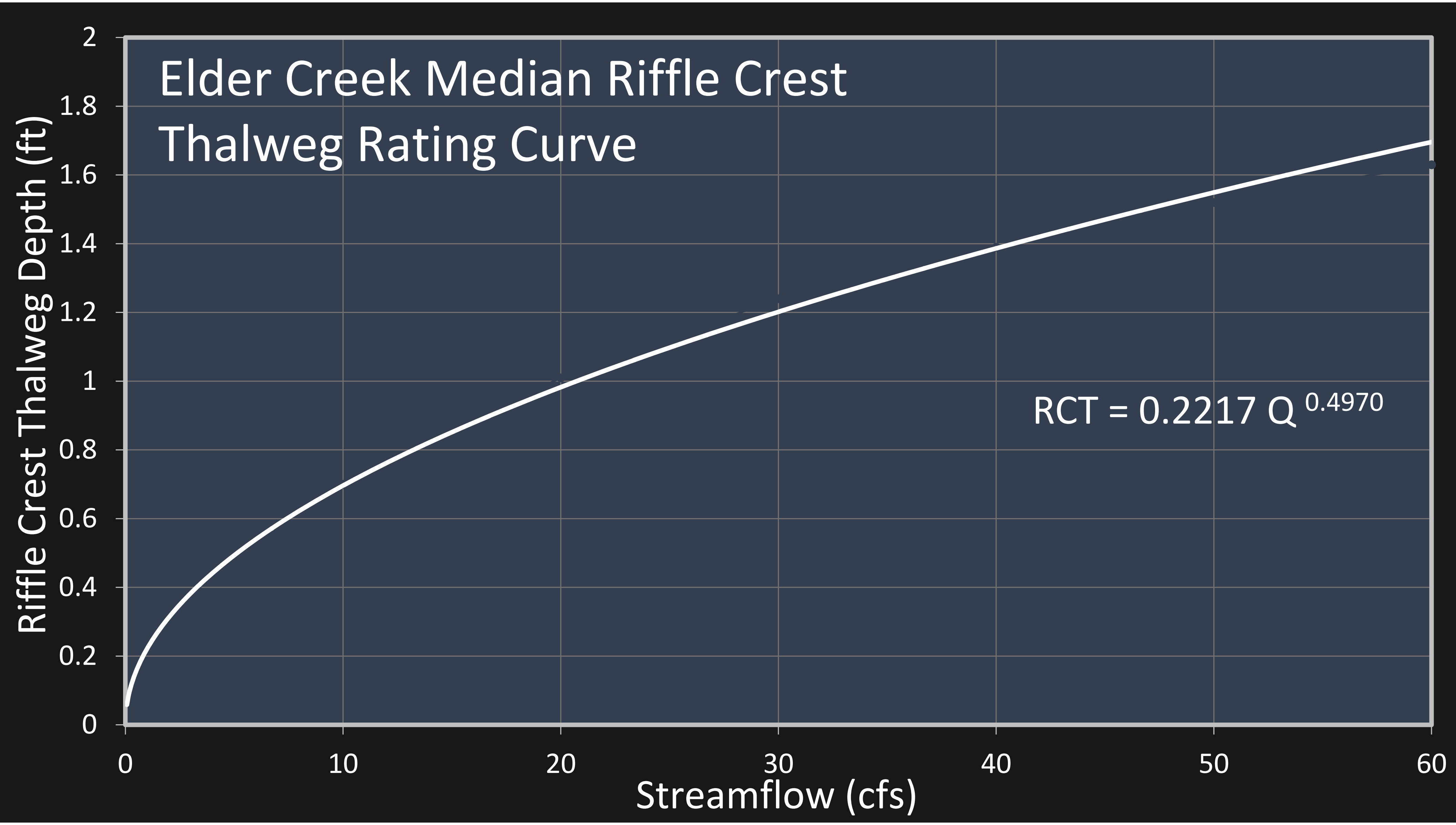


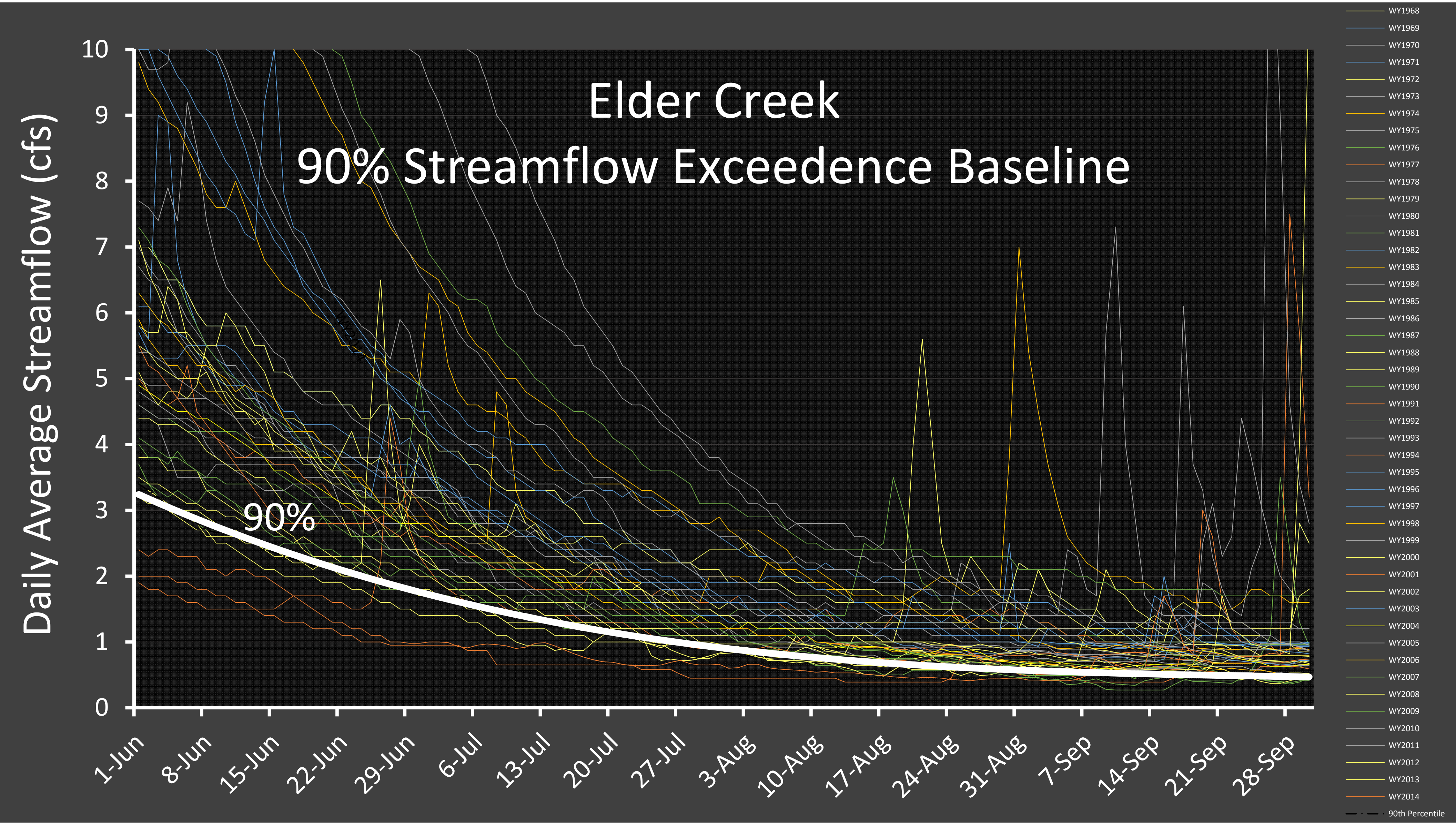
Variable Diversion Rate Rule Applied
Expressed as a Percentage of the Ambient Streamflow
3.60 cfs WY2005 0.088/3.60 * 100 = 2.44%
= 36 gallons/day
2.4 cfs WY1989 0.088/2.4 * 100 = 3.67%
0.88 cfs P-value = 90% 0.088/0.88 * 100 = 10.0%
0.45 cfs WY1977 0.088/0.45 * 100 = 19.6%
Streamflow (Q, cfs)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
27-Jul
28-Jul
29-Jul
30-Jul
31-Jul
1-Aug
2-Aug
3-Aug
4-Aug
5-Aug
6-Aug
7-Aug
8-Aug
9-Aug
10-Aug


Maximum Diversion Rate (gallons/min)
100
90
80
70
60
50
40
30
20
10
0
1-Jun
21-Jun
11-Jul
31-Jul
20-Aug
9-Sep
29-Sep
0.28 gal/min = 400 gallons/day
Maximum Allowable Diversion Rate by Date
Elder Creek


Maximum Diversion Rate (gal/min)
100
90
80
70
60
50
40
30
20
10
0
Allowable Diversion
Total Number of Diverters
"Seasonal" Diverters
"Year-Round" Diverters
216
144
144
72
105
33
81
9
72
0
72
1-Jun
21-Jun
11-Jul
31-Jul
20-Aug
9-Sep
29-Sep


SUMMARY
Streamflow (Q, cfs)
20
18
16
14
12
10
8
6
4
2
0
90%
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May


Elder Creek Median Riffle Crest
Thalweg Rating Curve
RCT = 0.2217 Q 0.4970
Riffle Crest Thalweg Depth (ft)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
Streamflow (cfs)


Elder Creek
90% Streamflow Exceedence Baseline
Daily Average Streamflow (cfs)
90%
0
1
2
3
4
5
6
7
8
9
10
1-Jun
8-Jun
15-Jun
22-Jun
29-Jun
6-Jul
13-Jul
20-Jul
27-Jul
3-Aug
10-Aug
17-Aug
24-Aug
31-Aug
7-Sep
14-Sep
21-Sep
28-Sep
WY1968
WY1969
WY1970
WY1971
WY1972
WY1973
WY1974
WY1975
WY1976
WY1977
WY1978
WY1979
WY1980
WY1981
WY1982
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WY1994
WY1995
WY1996
WY1997
WY1998
WY1999
WY2000
WY2001
WY2002
WY2003
WY2004
WY2005
WY2006
WY2007
WY2008
WY2009
WY2010
WY2011
WY2012
WY2013
WY2014
90th Percentile

USING OLD IDEAS IN NEW WAYS

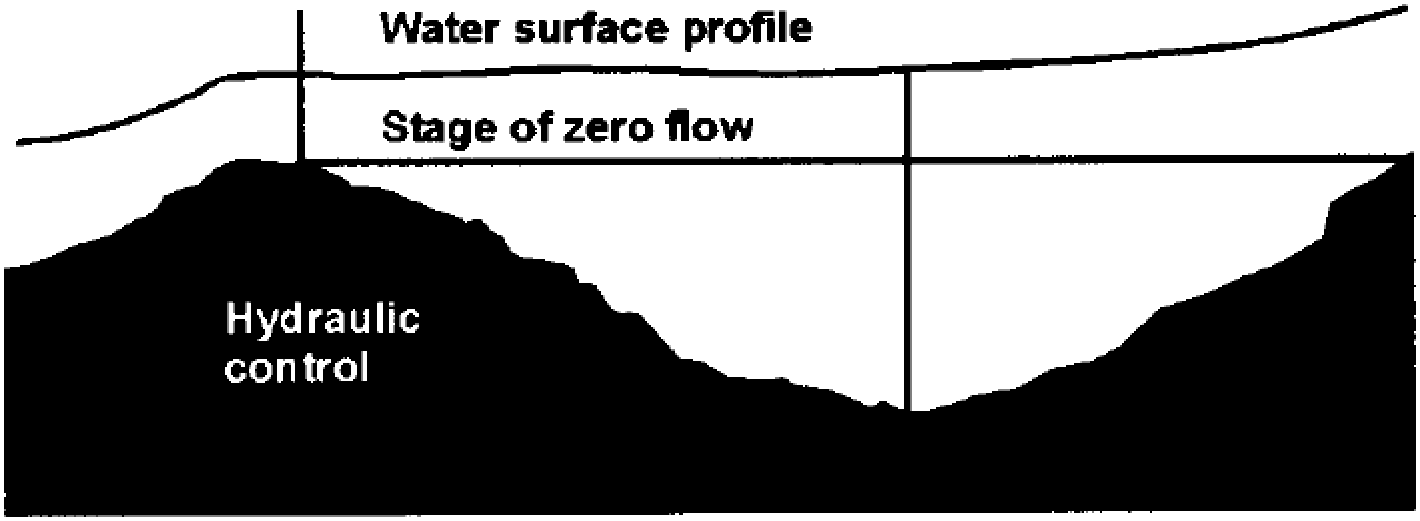
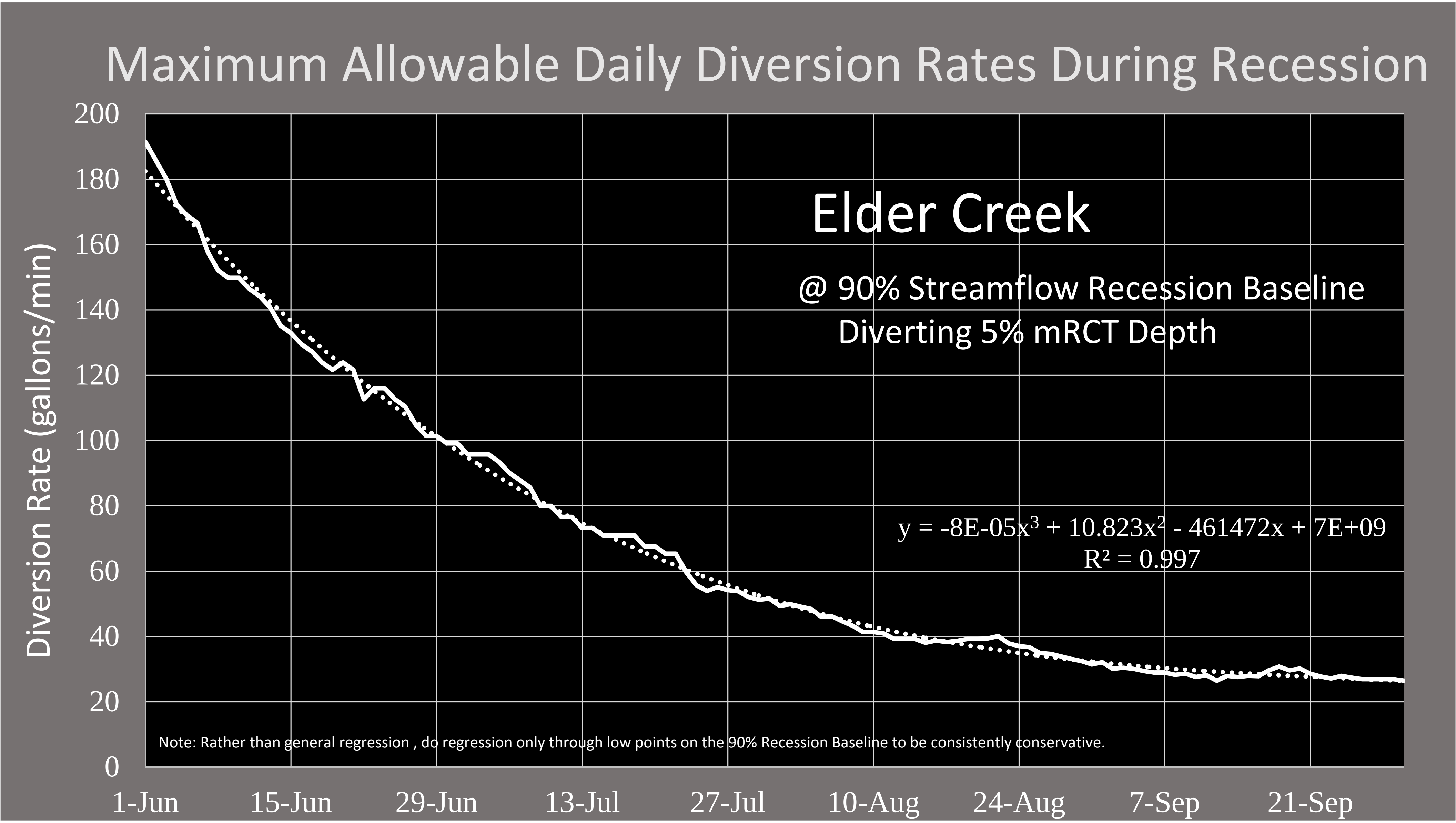


Fig. 4-27. Longitudinal profiles of stream thalweg and water surface, illustrating how a vertical constriction (riffle) behaves as a hydraulic control. The lowest elevation across the riffle (i.e., the thalweg evaluation) is the stage of zero flow.

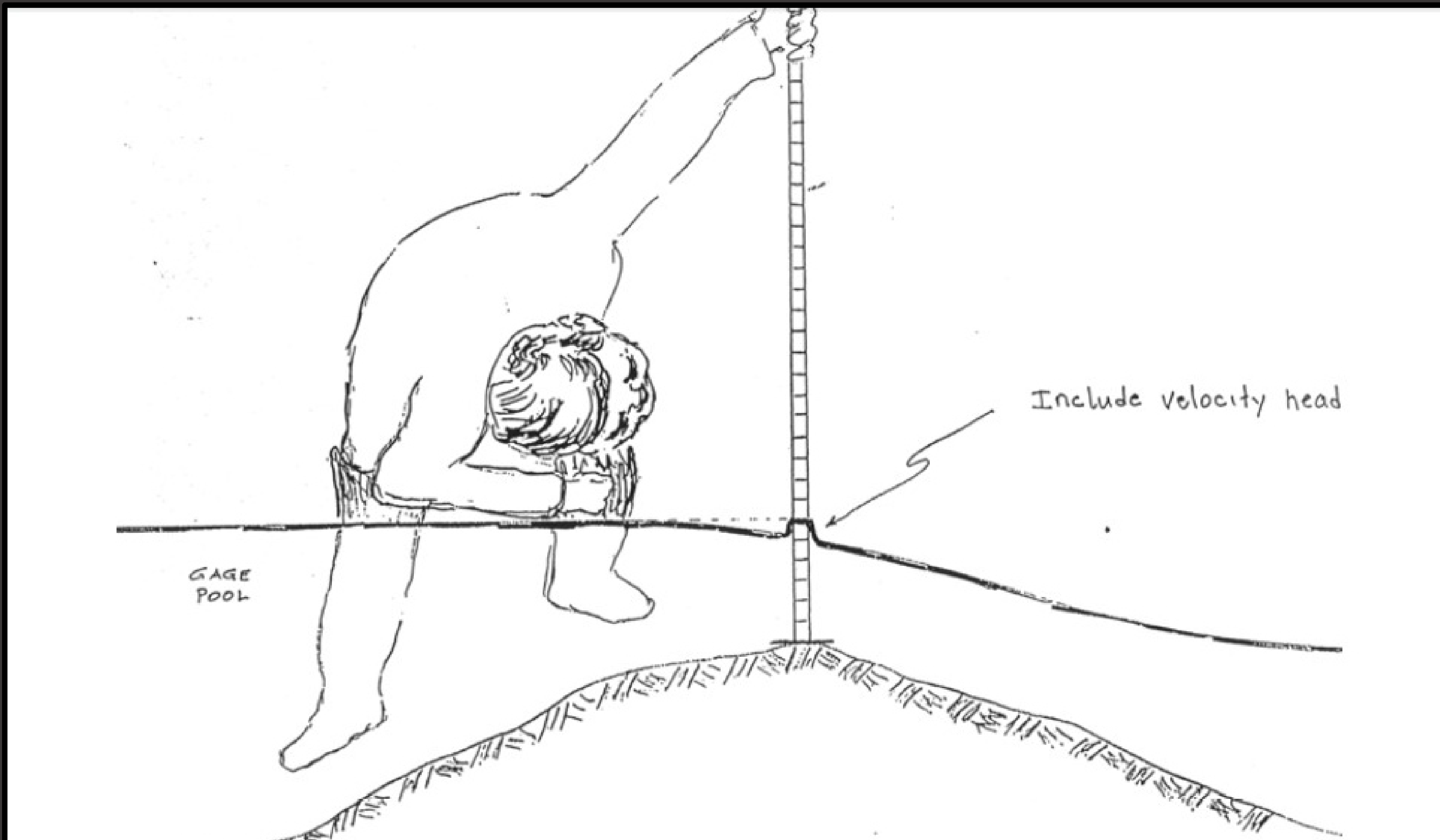
"Be aware that you are not limited to the "default" variables. With a little imagination PHABSIM can usually be tweaked to include microhabitat attributes known to be important to the target species."

"Fixity of purpose requires flexibility of method." H.G. Wolff



Maximum Allowable Daily Diversion Rates During Recession
Elder Creek
@ 90% Streamflow Recession Baseline
Diverting 5% mRCT Depth
y = -8E-05x3 + 10.823x2 - 461472x + 7E+09
R² = 0.997
Note: Rather than general regression , do regression only through low points on the 90% Recession Baseline to be consistently conservative.
Diversion Rate (gallons/min)
200
180
160
140
120
100
80
60
40
20
0
1-Jun
15-Jun
29-Jun
13-Jul
27-Jul
10-Aug
24-Aug
7-Sep
21-Sep

A cumulative variable diversion rate strategy from spring through early-autumn can maintain a stream ecosystem's capacity for self-renewal, or health. Under a variable diversion rate strategy, if properly executed, juvenile salmonids will be stressed … but to no significantly greater extent than they would experiencing the unimpaired recession hydrograph May through October.


Include velocity head
GAGE
POOL

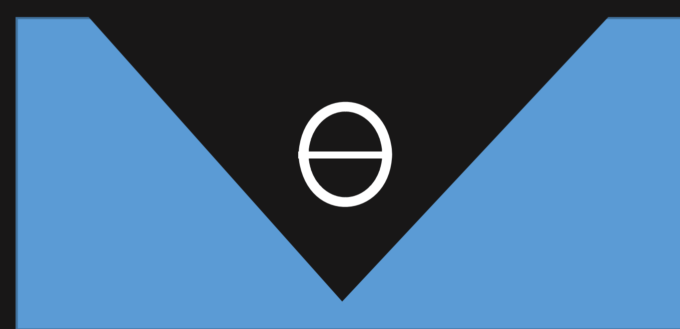
RCT Depth (ft)
1.6
1.2
0.8
0.4
0
0
5
10
15
20
25
30
35
40
45
50
Streamflow (Q, cfs)
USGS Gaging Sta. No. 11475560 Elder Creek nr Branscomb

Rectangular Weir

$Q = c_d \, L \, h^{3/2}$

Triangular Weir

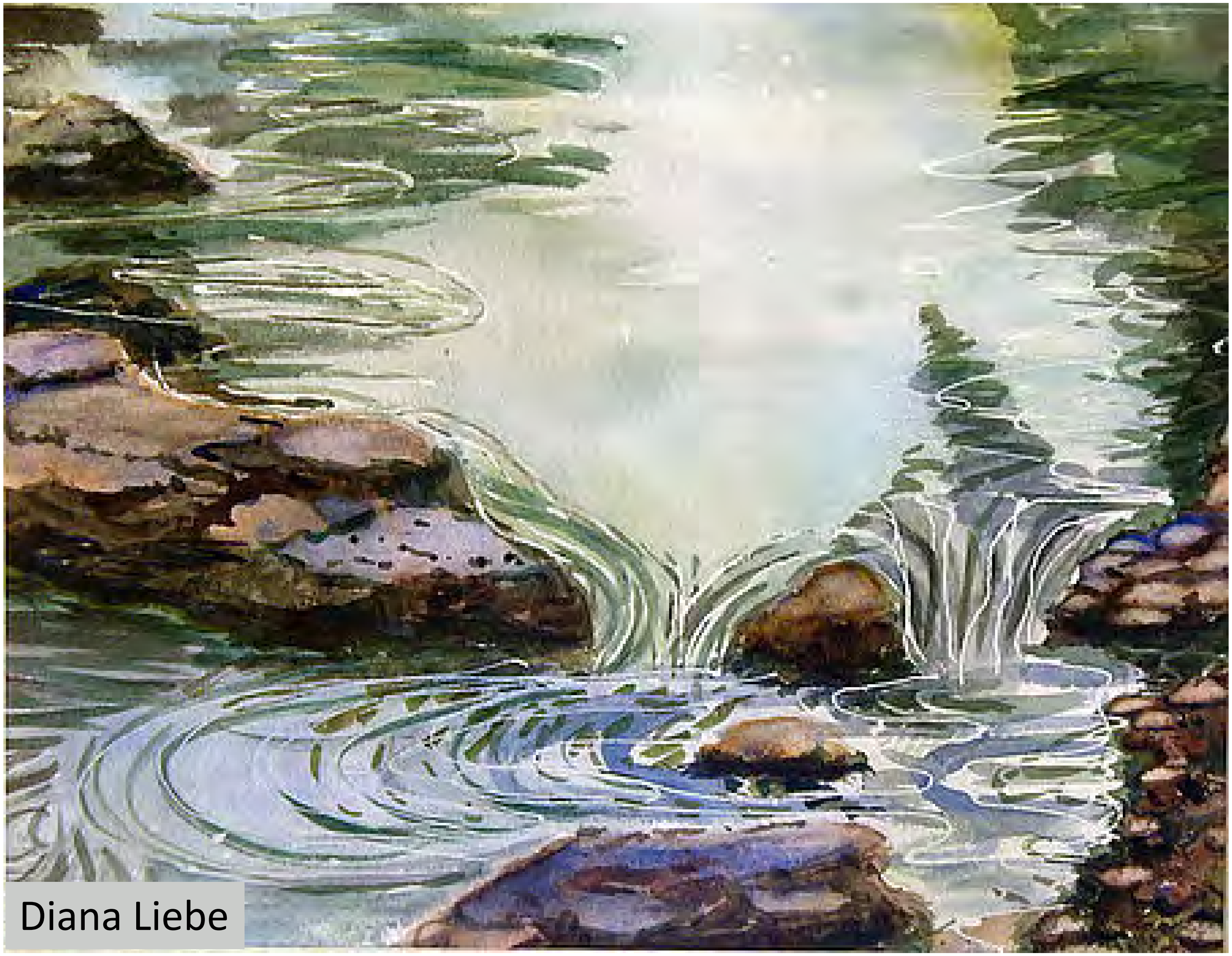
$Q = c_d \tan(\Theta/2) \, h^{5/2}$

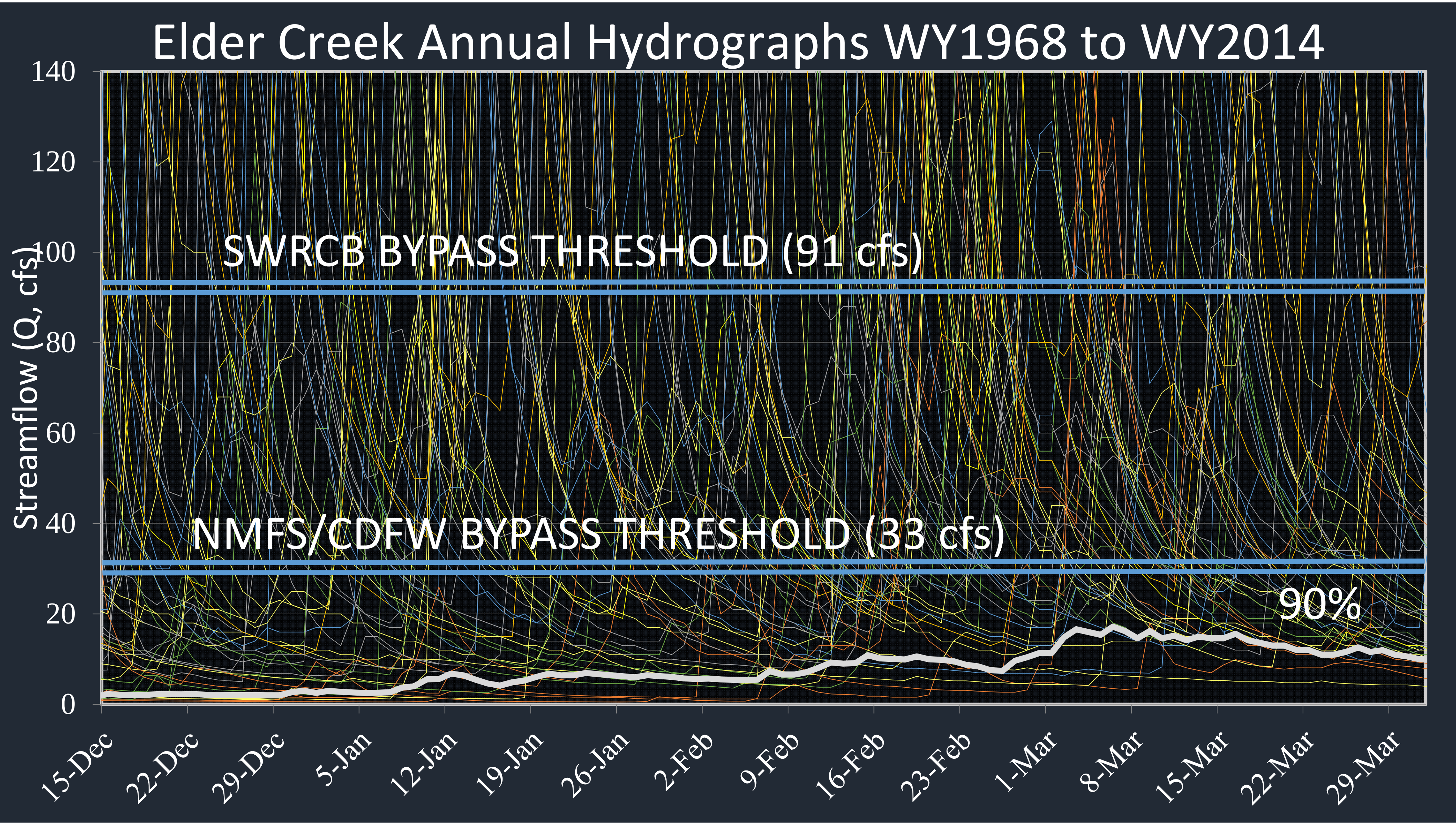


THIS IS NOT A PERCENTAGE OF FLOW DIVERSION STRATEGY

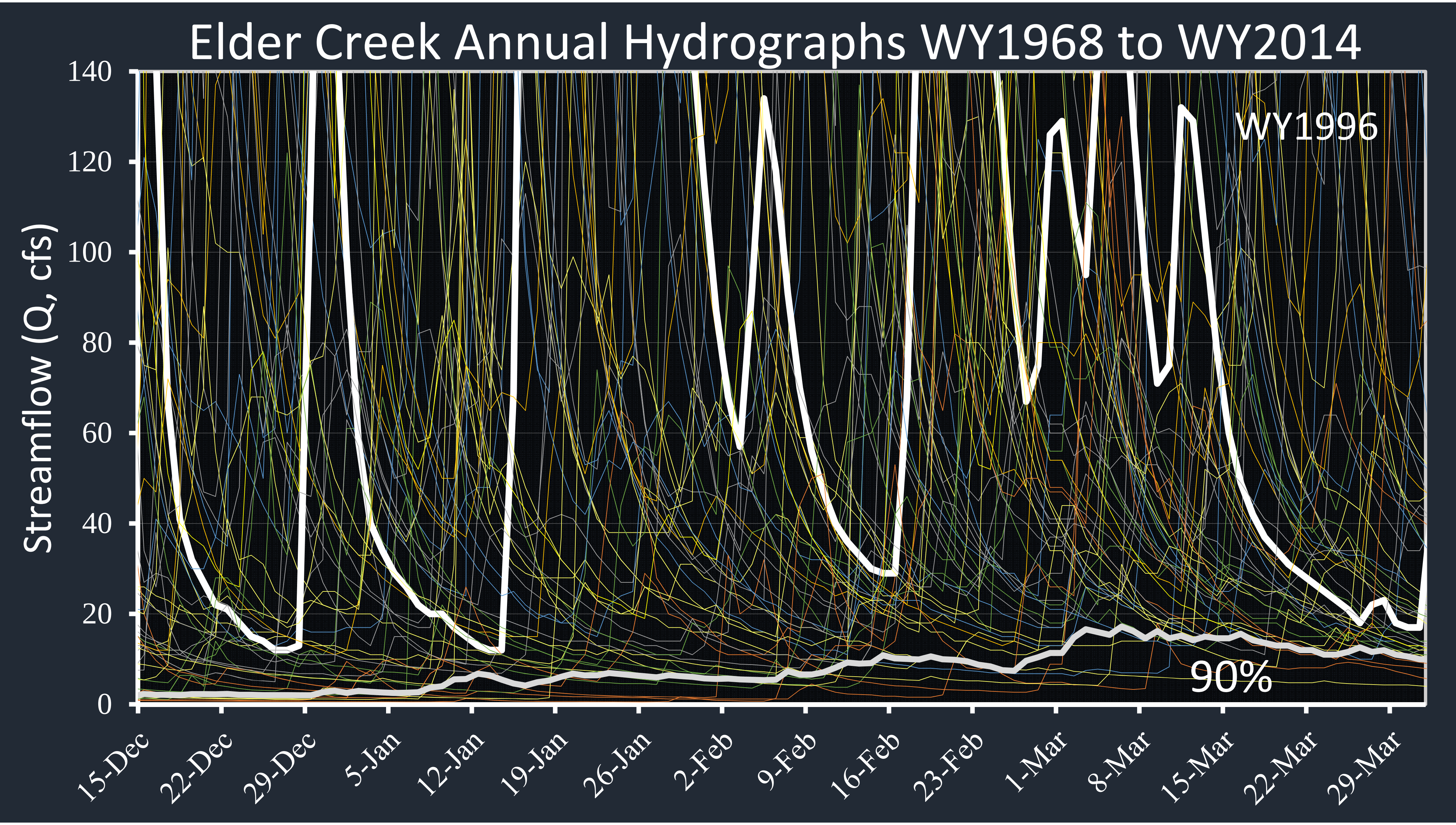
Because: (1)

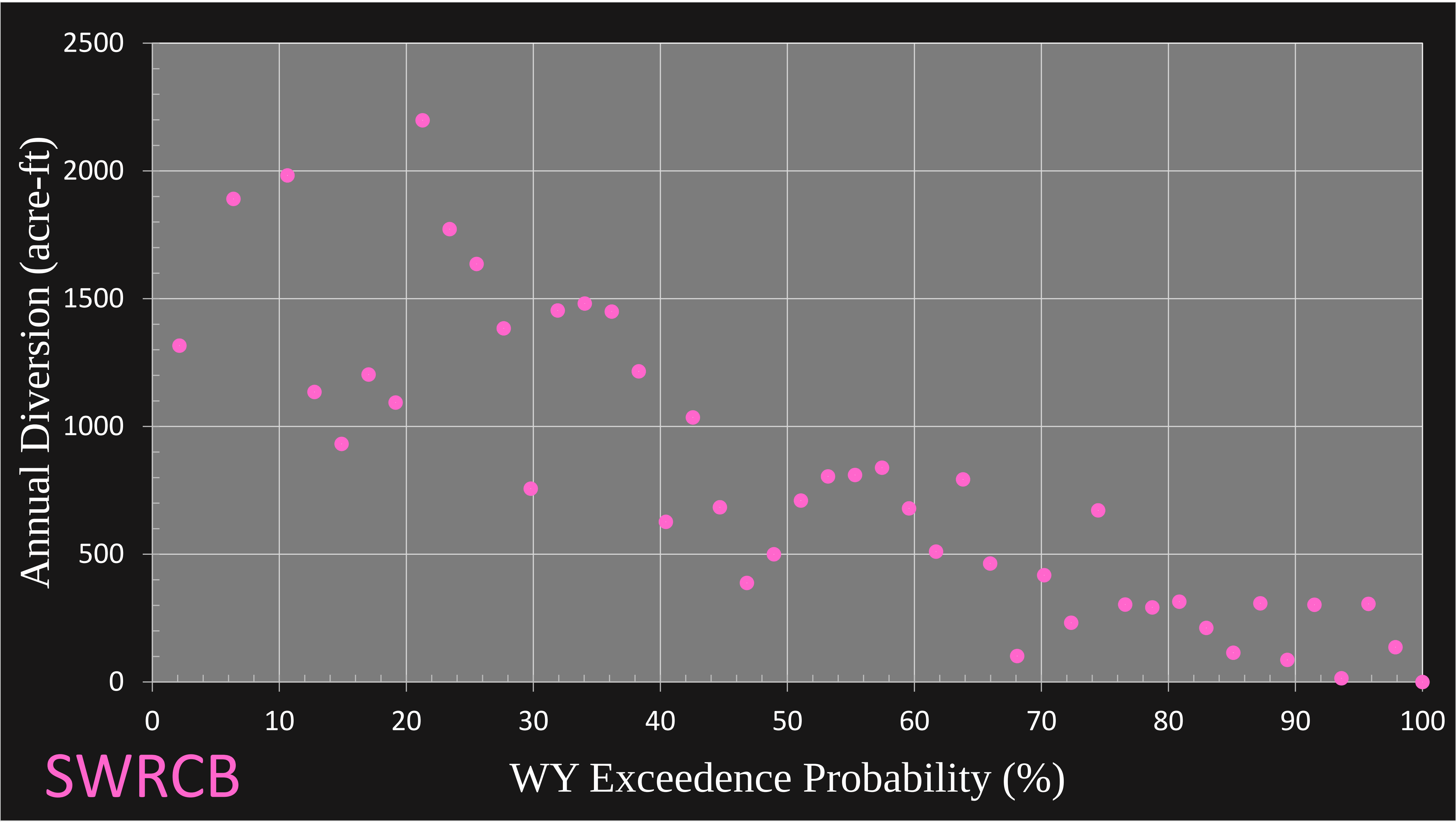
08Feb Time Offset =

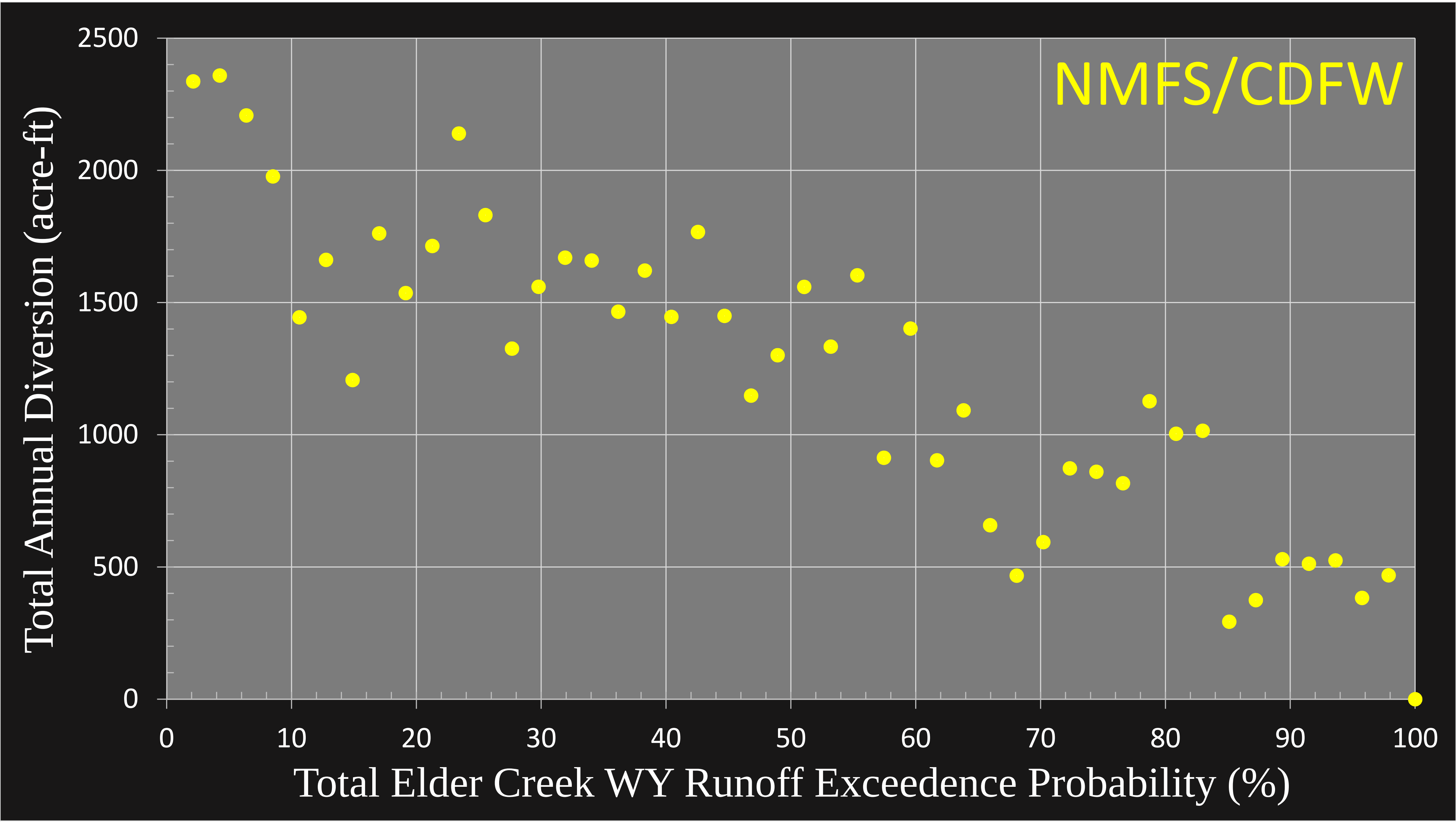

Diana Liebe



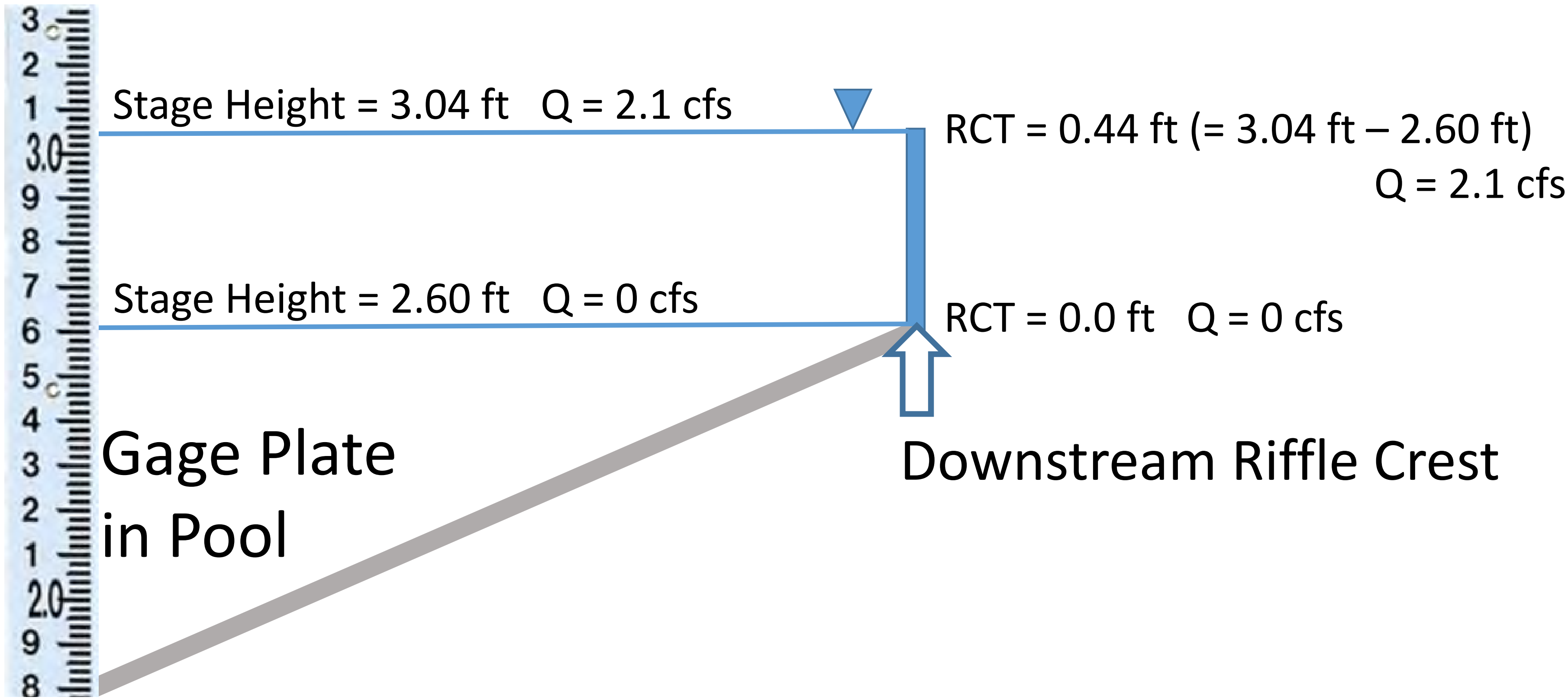
Elder Creek Annual Hydrographs WY1968 to WY2014
SWRCB BYPASS THRESHOLD (91 cfs)
NMFS/CDFW BYPASS THRESHOLD (33 cfs)
90%
Streamflow (Q, cfs)
0
20
40
60
80
100
120
140
15-Dec
22-Dec
29-Dec
5-Jan
12-Jan
19-Jan
26-Jan
2-Feb
9-Feb
16-Feb
23-Feb
1-Mar
8-Mar
15-Mar
22-Mar
29-Mar


Elder Creek Annual Hydrographs WY1968 to WY2014
Streamflow (Q, cfs)
140
120
100
80
60
40
20
0
15-Dec
22-Dec
29-Dec
5-Jan
12-Jan
19-Jan
26-Jan
2-Feb
9-Feb
16-Feb
23-Feb
1-Mar
8-Mar
15-Mar
22-Mar
29-Mar
WY1996
90%


2500
2000
1500
1000
500
0
Annual Diversion (acre-ft)
0
10
20
30
40
50
60
70
80
90
100
WY Exceedence Probability (%)
SWRCB


NMFS/CDFW
Total Annual Diversion (acre-ft)
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90
100
Total Elder Creek WY Runoff Exceedence Probability (%)

By knowing stage height at Q = 0 cfs (zero streamflow), a USGS Stage-Q Rating Curve can be calibrated as a RCT-Q Rating Curve



Instream flows: new tools to quantify water quality conditions for returning adult Chinook salmon

Amy Campbell, The Nature Conservancy
Ann Willis, UC Davis Center for Watershed Sciences

April 7, 2016
Salmonid Restoration Federation Conference
Fortuna, CA

Presentation Outline

- Brief background and history of the Shasta River Fall Flow Program
- Monitoring Program Overview

Deadly fish disease found in lower Klamath River

By The Times-Standard

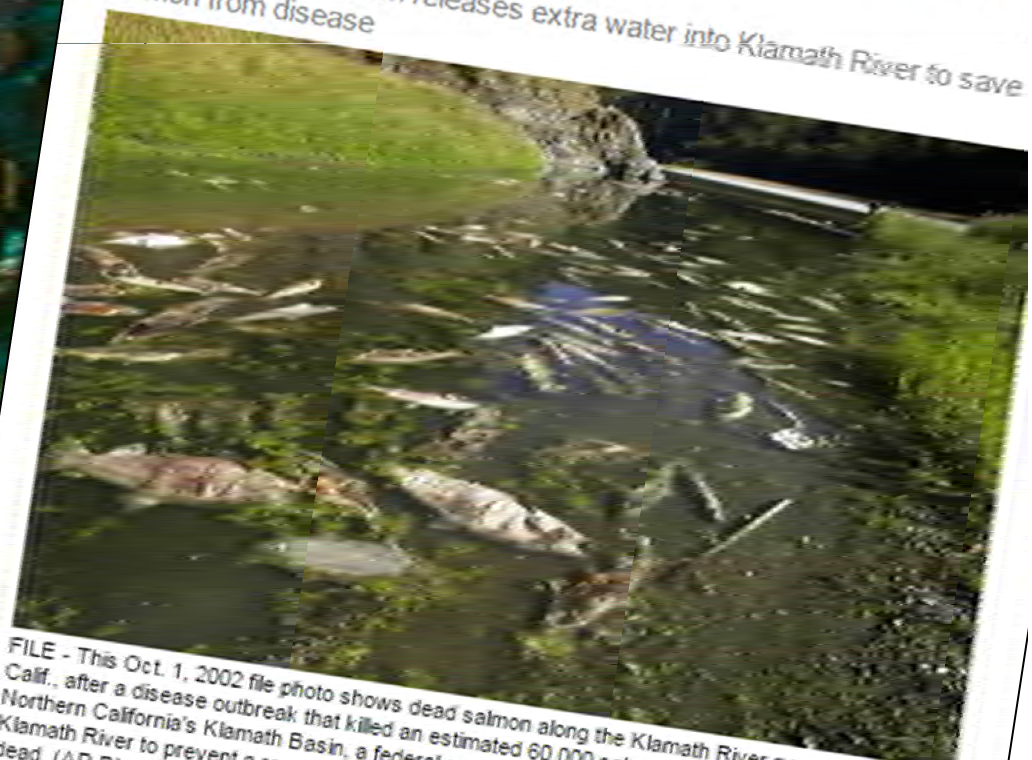
POSTED: 07/23/15, 10:15 AM PDT | UPDATED: ON 07/23/2015

0 COMMENTS

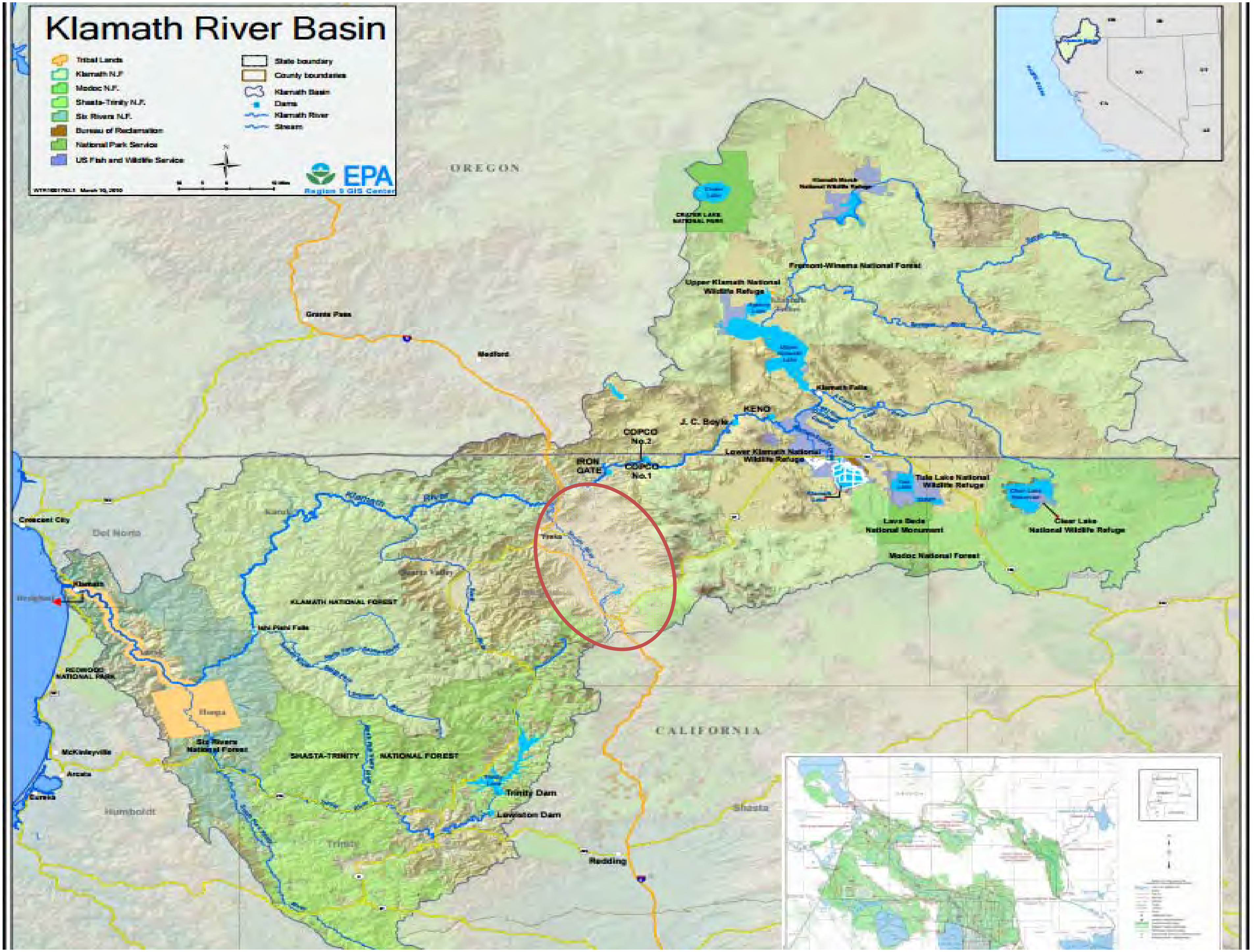
National

Feds release extra water to save Klamath salmon from disease

Bureau of Reclamation releases extra water into Klamath River to save salmon from disease



FILE - This Oct. 1, 2002 file photo shows dead salmon along the Klamath River near Klamath, Calif., after a disease outbreak that killed an estimated 60,000 salmon. With water scarce in Northern California's Klamath Basin, a federal agency is again releasing cool, clean Klamath River to prevent a repeat of the 2002 fish kill that left tens dead. (AP Photo/Joe Cavaretta, File) (Joe Cav


Klamath River Basin
Tribal Lands
Klamath N.F
Modoc N.F.
Shasta-Trinity N.F.
Six Rivers N.F.
Bureau of Reclamation
National Park Service
US Fish and Wildlife Service
State boundary
County boundaries
Klamath Basin
Dams
Klamath River
Stream
EPA
Region 9 GIS Center
OREGON
CALIFORNIA
Grants Pass
Medford
Crescent City
Del Norte
Klamath
REDWOOD NATIONAL PARK
Hoopa
Six Rivers National Forest
McKinleyville
Arcata
Eureka
Humboldt
Trinity
KLAMATH NATIONAL FOREST
SHASTA-TRINITY NATIONAL FOREST
Trinity Dam
Lewiston Dam
Redding
Shasta
Yreka
IRON GATE
COPCO No.2
COPCO No.1
J. C. Boyle
KENO
Klamath Falls
Upper Klamath National Wildlife Refuge
Upper Klamath Lake
Klamath Marsh National Wildlife Refuge
CRATER LAKE NATIONAL PARK
Fremont-Winema National Forest
Lower Klamath National Wildlife Refuge
Tule Lake National Wildlife Refuge
Lava Beds National Monument
Clear Lake National Wildlife Refuge
Modoc National Forest

Shasta River Water Transaction Program-
Community wide Fall Flow Program

- When?: ~last two weeks of September
- Where?: lower 7 miles of the Shasta River
- How much?: >70 cfs but as much as we can get.
- Quality?: All water is created equal
- Who?: Entire Shasta Valley ag community.

Shasta Valley Community-wide Fall Flow Program – Critical Thresholds

Health: documented 50 dead fish over a 3 day period

Temperature and Dissolved Oxygen:

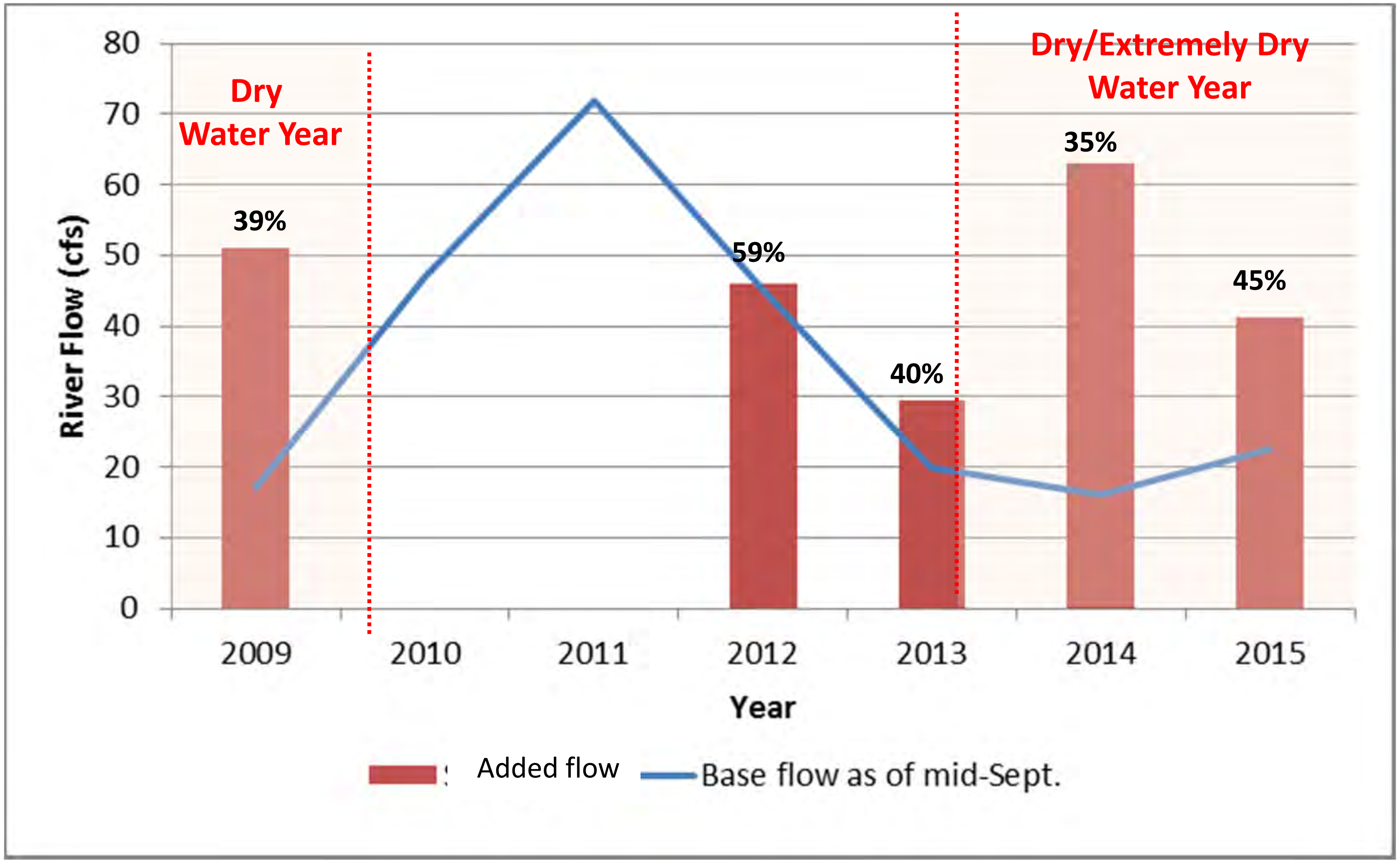
- max temp. 20 degrees C.
- DO levels < than 8 ppm.

Abundance: > 2000 adults in the system prior to the end of the irrigation season (October 1st).

Volume: Ideally flows by Sept. 15th be > 70 cfs.

Air temperature: close monitoring of long-range forecast

Results of Fall Flow Program 2009-2015



Journal of Water Resources, Planning and Management

Instream Flows: New Tools to Quantify Water Quality Conditions for Returning Adult Chinook Salmon

Ann D. Willis[1]; Amy M. Campbell[2]; Ada C. Fowler[3]; Christopher A. Babcock[4]; Jeanette K. Howard[5]; Michael L. Deas, P.E., M.ASCE[6]; and Andrew L. Nichols[7]

Abstract: This paper examines the effect of implementing a water transaction program to address potential water quality limitations for returning adult fall-run Chinook salmon in a stream system where the agriculture is the dominant land and water use. Water transactions are becoming an increasingly used approach to provide instream flows during periods when there are competing water uses. Water transactions are often used to achieve ecological objectives, but their water quality or biological effects are rarely quantified. The effects of a water transaction implemented in the Shasta River were evaluated by using a spreadsheet model to quantify changes in dissolved oxygen conditions as they relate to discharge, pool volumes, holding habitat capacity, and potential dissolved oxygen demand by holding fish. The results indicate that water transactions may mitigate potential water quality impairments by decreasing the residence time in holding habitat, and are particularly effective during periods when flows are low, holding habitats are near carrying capacity, and dissolved oxygen demand by fish is elevated. **DOI: 10.1061/(ASCE)WR.1943-5452.0000590.**

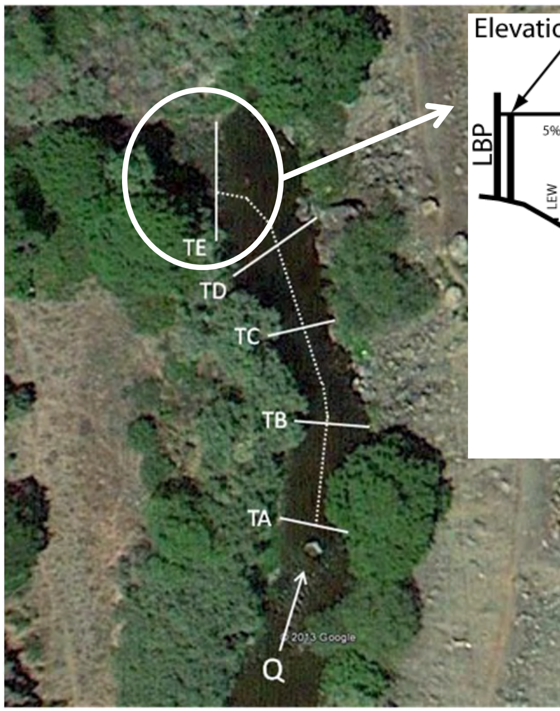
Monitoring program

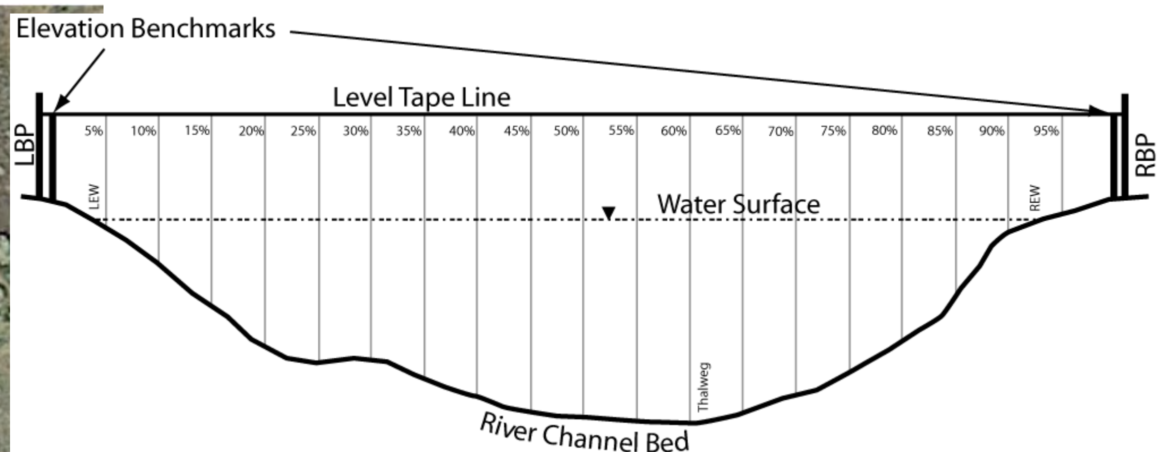
- Objectives
  - Quantify the effect of instream flow contributions for Fall Chinook, evaluate potential benefit
  - Inform future efforts and strategies
  - Relatively modest on-going monitoring resources
  - Ability to replicate approach in other areas
- Program elements
  - Discharge, physical geometry, water quality, and fish

Monitoring program

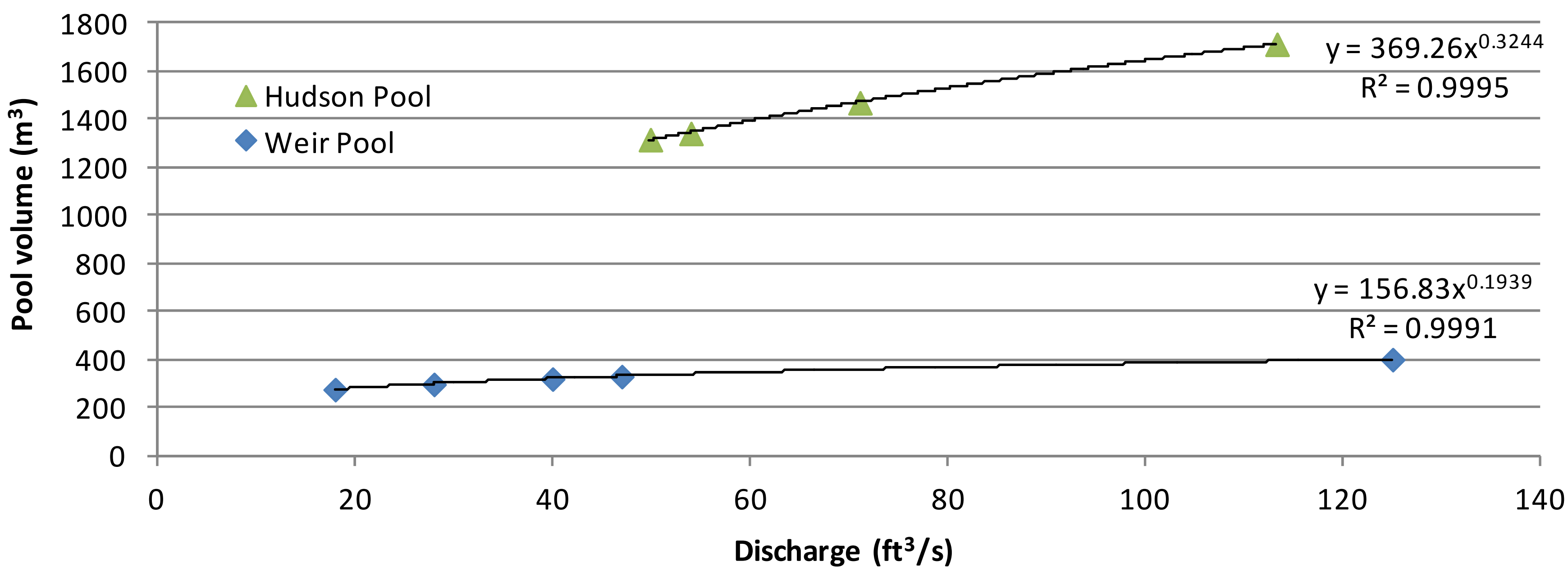
- Discharge
  - Automated gage at Shasta River near Yreka (SRY), available in real-time via CDEC
  - On-going
- Physical geometry
  - Pool volume surveys
  - Extensive monitoring during first year; after year 1, limited to no monitoring without channel-changing flows
- Water quality
  - Water temperature, dissolved oxygen data logger
  - Monitored during transaction period (typically late August through early October)
- Fish
  - Data provided by California Department of Fish and Wildlife

Aquatic habitat surveys





Aquatic habitat rating curves



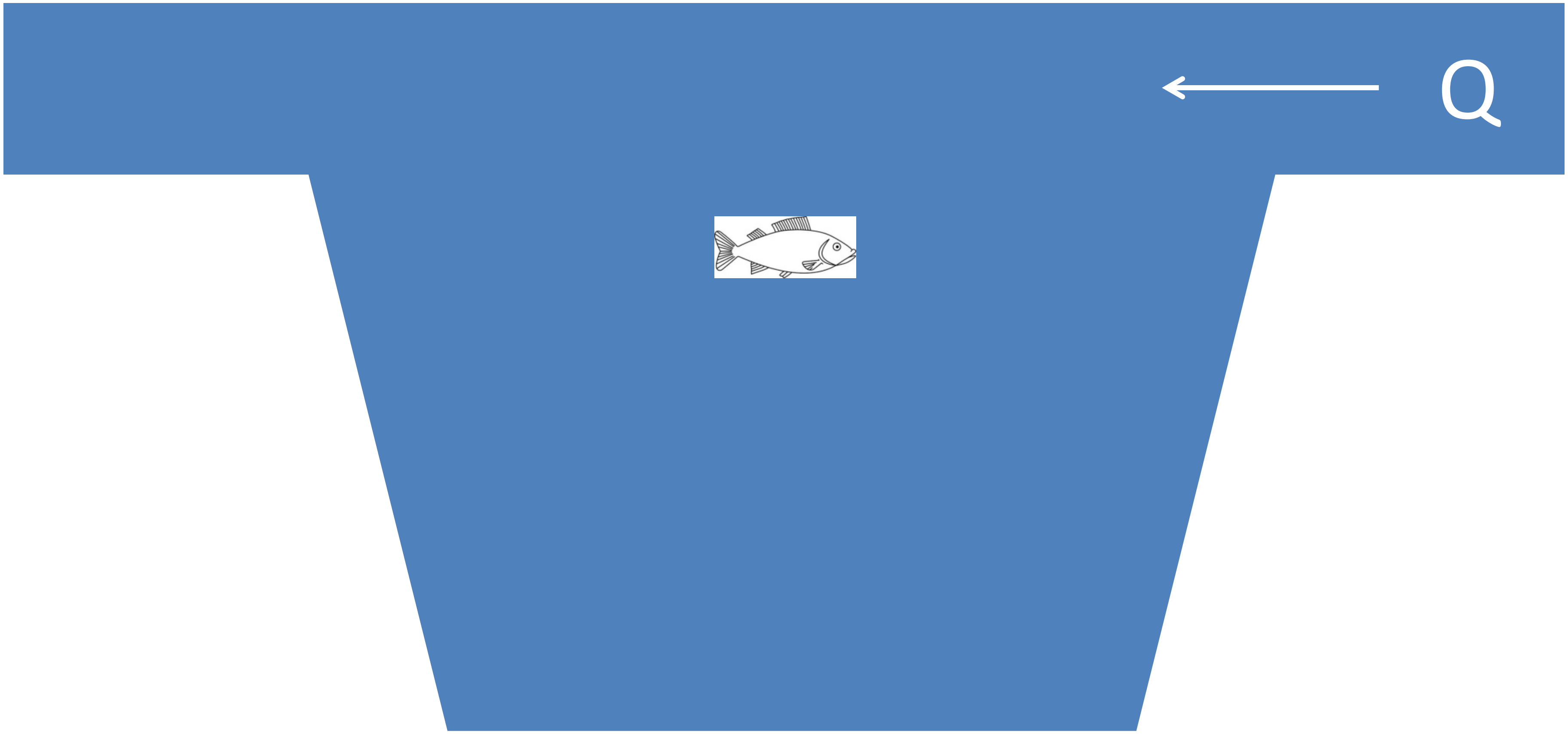
Water quality assessment tool

- Excel spreadsheet
- Relates
  - Stream flow
  - Pool volume
  - Water temperature
  - Dissolved oxygen
  - Oxygen demand by fish
- Quantifies effect of flow contribution to potential habitat capacity and water quality conditions

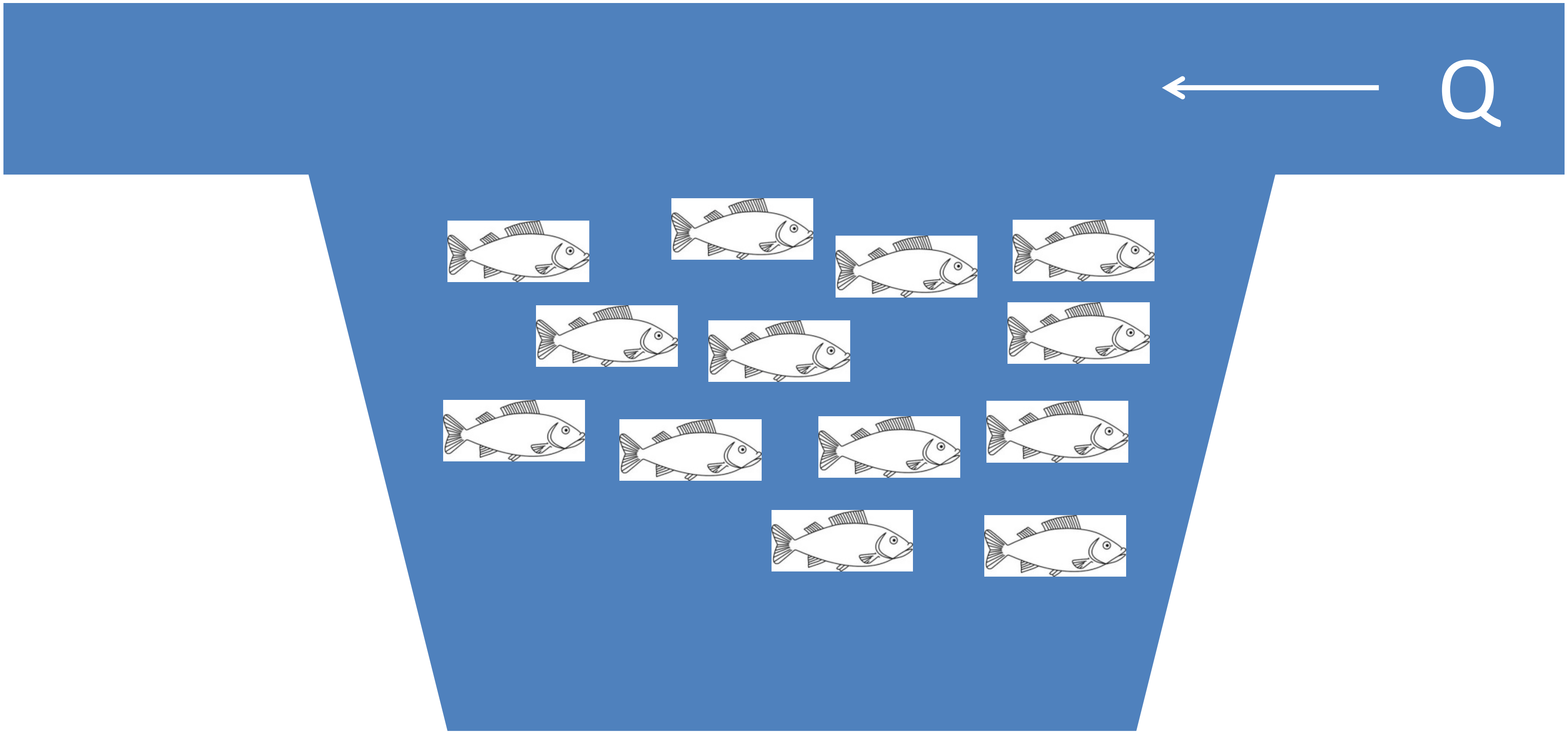
Concept

Concept

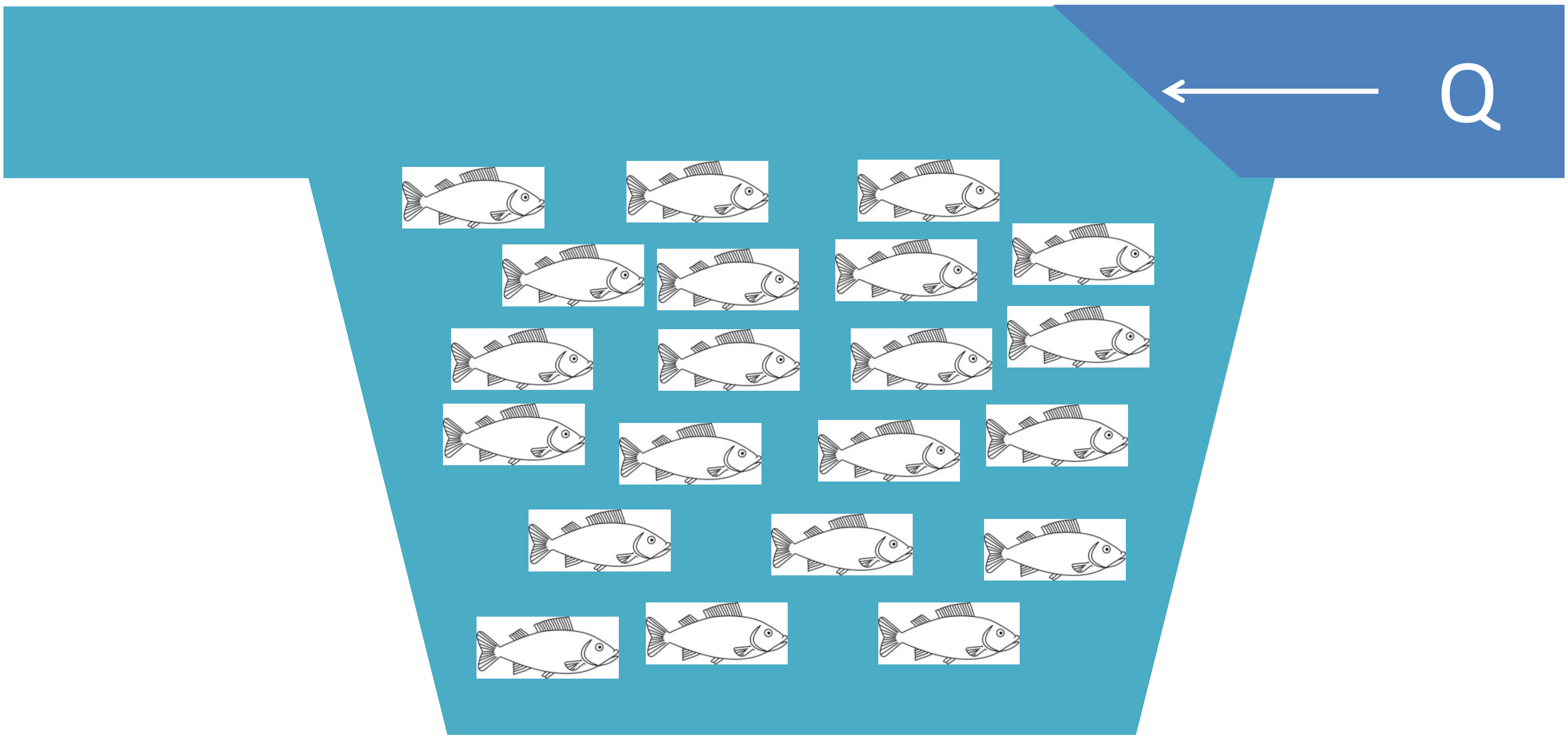
Concept



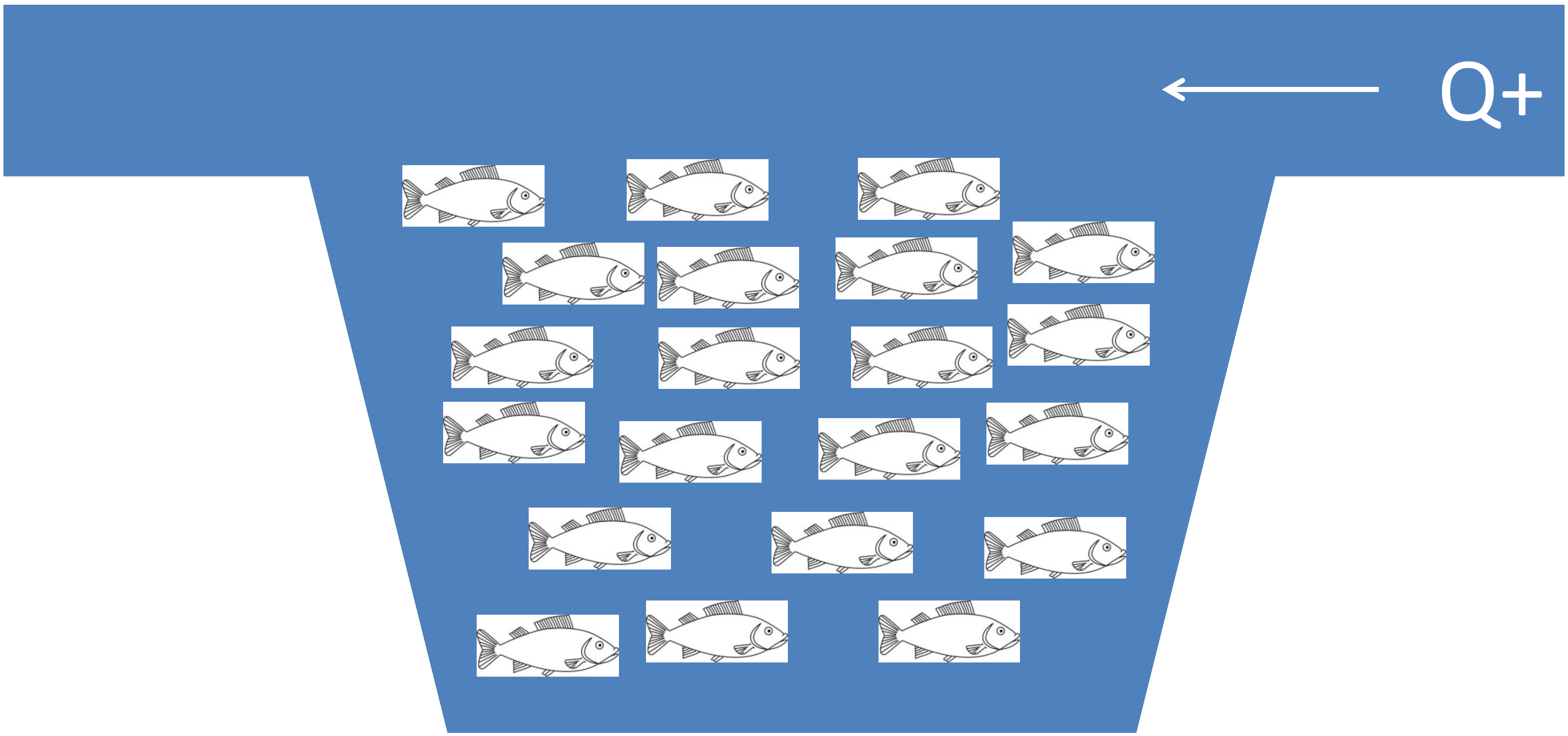
Concept



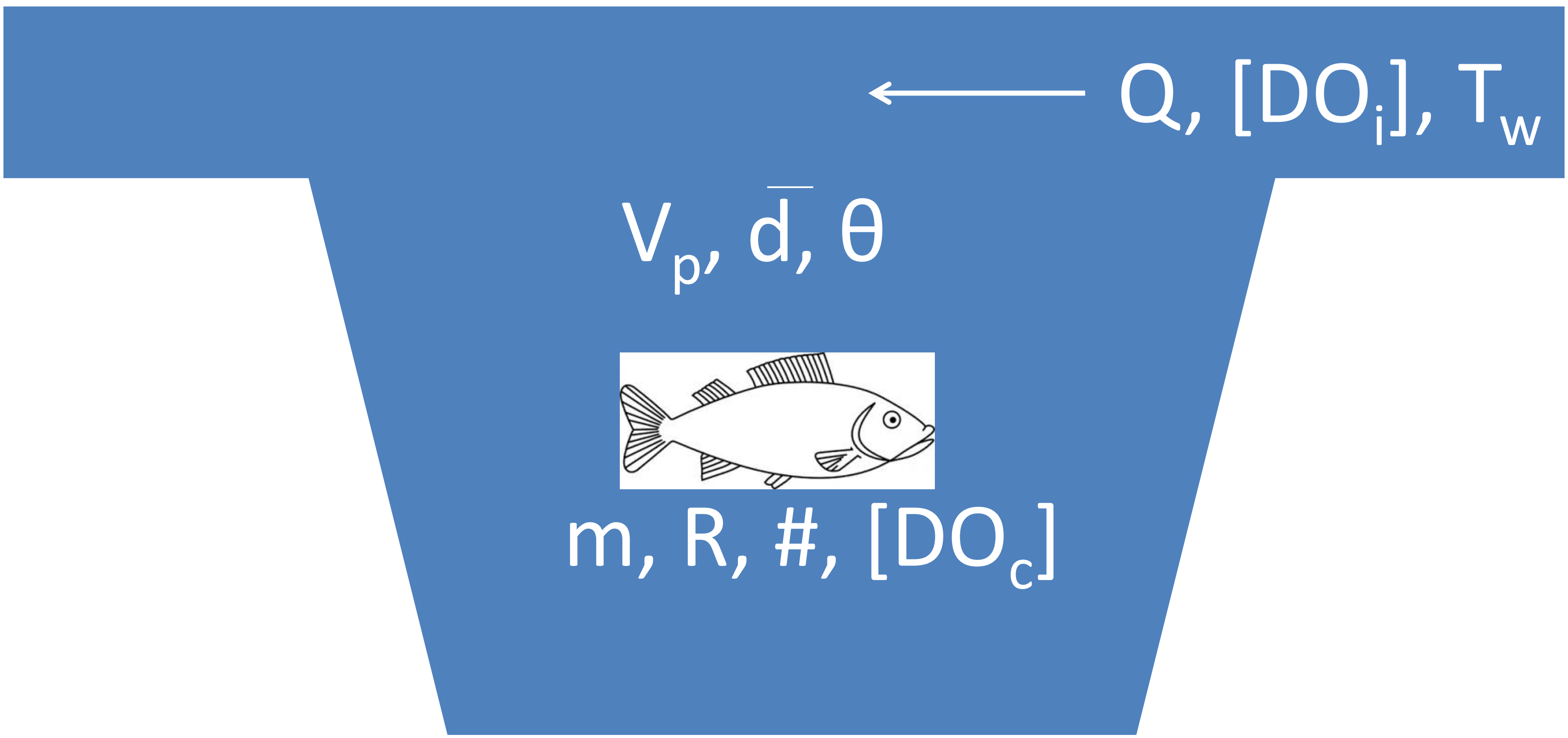
Concept



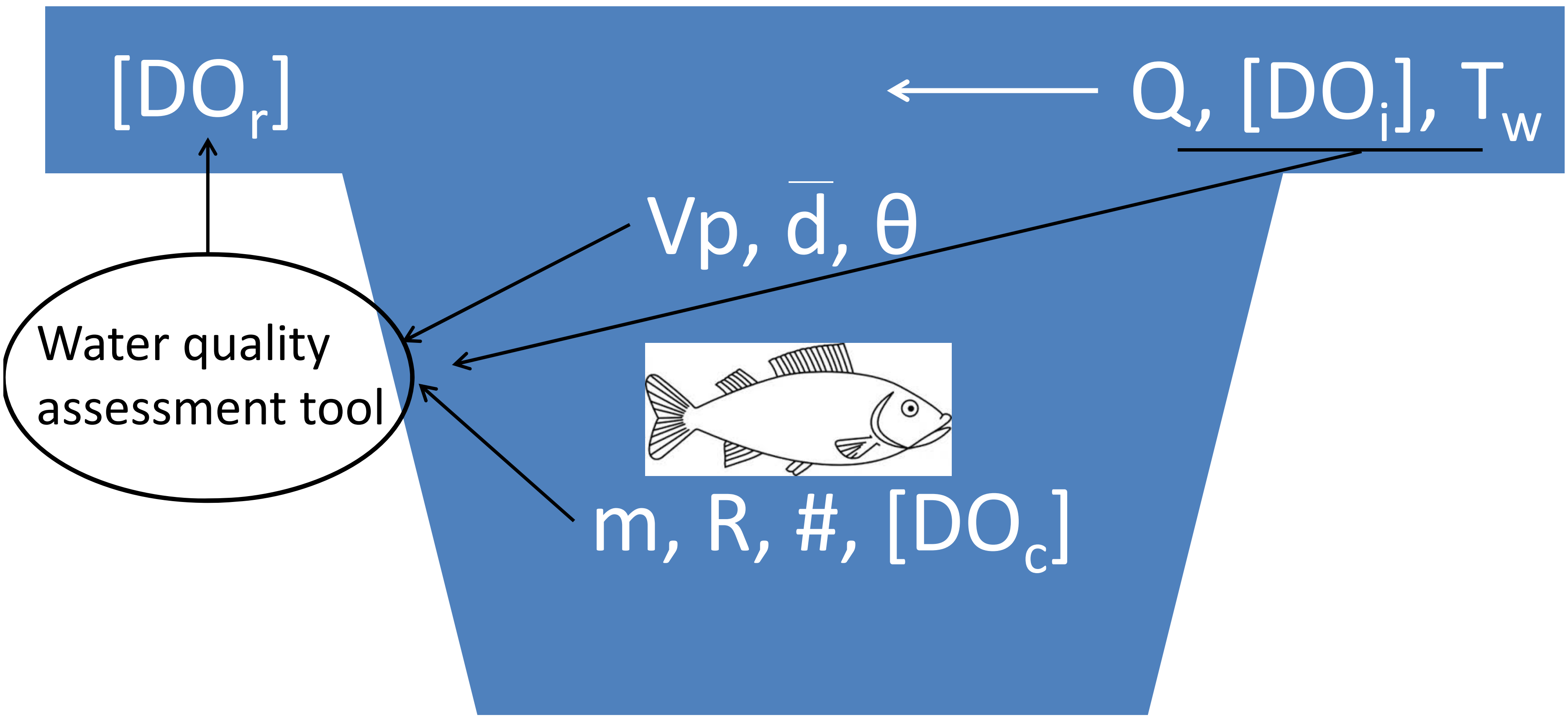
Concept



Concept



Concept



Equations

$$DO_r = \frac{(DO_i - DO_c)}{V_p}$$

Where DO_r = dissolved oxygen remaining (mg/L)
DO_i = dissolved oxygen initial supply (mg)
DO_c = dissolved oxygen consumed (mg)
V_p = pool volume (m^3)

$$DO_i = DO * Q * \theta$$

Where DO = measured DO in Weir Pool (mg/L)
Q = discharge m^3/s
θ = residence time (min)

$$DO_c = \dot{R} * m * \theta * F$$

Where $\dot{R}$ = the oxygen consumption rate by an adult Chinook salmon (mg/min/kg)
m = mass of an adult Chinook salmon (kg)
θ = duration of oxygen supply (equivalent to discharge residence time, min)
F = number of fish

$$\dot{R}_n = \dot{R}_i * Q_{10}^{(T_i - T_n)/10}$$

Where $\dot{R}_n$ = rate of oxygen consumption at water temperature n (mg/min/kg)
$\dot{R}_i$ = rate of oxygen consumption at temperature i (mg/min/kg)
Q_{10} = rate of change of oxygen consumption rate over a 10°C temperature interval, species-specific coefficient
T_i = water temperature at timestep i (°C)
T_n = water temperature at timestep n (°C)

$$F = A_s = V_p / \bar{d}$$

Where A_s = surface area of the pool (m^2)
d = average depth (m)

Equations

$$DO_r = \frac{(DO_i - DO_c)}{V_p}$$

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d = average depth (m)

Equations

$$DO_r = \frac{(DO_i - DO_c)}{V_p}$$

Where DO_r = dissolved oxygen remaining (mg/L)
DO_i = dissolved oxygen initial supply (mg)
DO_c = dissolved oxygen consumed (mg)
V_p = pool volume (m^3)

$$DO_i = DO * Q * \theta$$

Where DO = measured DO in Weir Pool (mg/L)
Q = discharge m^3/s
θ = residence time (min)

$$DO_c = \dot{R} * m * \theta * F$$

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m = mass of an adult Chinook salmon (kg)
θ = duration of oxygen supply (equivalent to discharge residence time, min)
F = number of fish

$$\dot{R}_n = \dot{R}_i * Q_{10}^{(T_i - T_n)/10}$$

Where $\dot{R}_n$ = rate of oxygen consumption at water temperature n (mg/min/kg)
$\dot{R}_i$ = rate of oxygen consumption at temperature i (mg/min/kg)
Q_{10} = rate of change of oxygen consumption rate over a 10°C temperature interval, species-specific coefficient
T_i = water temperature at timestep i (°C)
T_n = water temperature at timestep n (°C)

$$F = A_s = V_p / \bar{d}$$

Where A_s = surface area of the pool (m^2)
d = average depth (m)

Assumptions

- Dissolved oxygen evenly distributed through the pool at all times
- Other oxygen supplies (e.g., reaeration) and demands (e.g., decay) are negligible
- Fish always at maximum pool capacity
- No crowding, no disease
- All fish have same respiratory demand
- Single layer of fish

Transaction assessment*

Feature	Without transaction	With transaction (+10 cfs)
Discharge (average)	13.2 ft^3/s	23.2 ft^3/s
Residence time (average)	12 minutes	7 minutes
Fish capacity (average)	408 fish	457 fish
Dissolved oxygen (average /min)	7.3 mg/L (5.6 mg/L) 86% (69%)	7.7 mg/L (6.5 mg/L) 92% (80%)
Water temperature (average/max)	20.6 °C (23.5 °C)	20.6 °C (23.5 °C)

*Results presented for Sept 10 – Sept 16, 2013

Conclusions: Monitoring program

- Key components include
  - discharge
  - physical geometry surveys
  - water quality conditions, and
  - number of fish present in the system
- Monitoring resources are modest assuming no channel changing flows
- Location selection is important

Acknowledgments/Partners

American Rivers
Aquaterra
Bureau of Reclamation
California DFW
California Trout
NOAA Restoration Center
NFWF
SWRCB
Scott River Water Trust
Shasta and Scott River Watermaster District
Shasta Valley Ag Community
Shasta Valley RCD
Siskiyou County
UCD Center for Watershed Sciences
Watercourse Engineering, Inc.


Ann Willis
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Amy Campbell
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Journal of Water Resources, Planning and Management

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Groundwater and its Impacts on Streamflow, Slope Stability, and Water Quality

Brad Job, P.E.

Sr. Civil Engineer

Pacific Watershed Associates, Inc.

Overview

- Groundwater and water scarcity in a changing climate
- The hydrologic cycle and water budgets
- Groundwater resources in the NW Calif.
- Watershed management imperatives
- Groundwater, slope stability, and sediment

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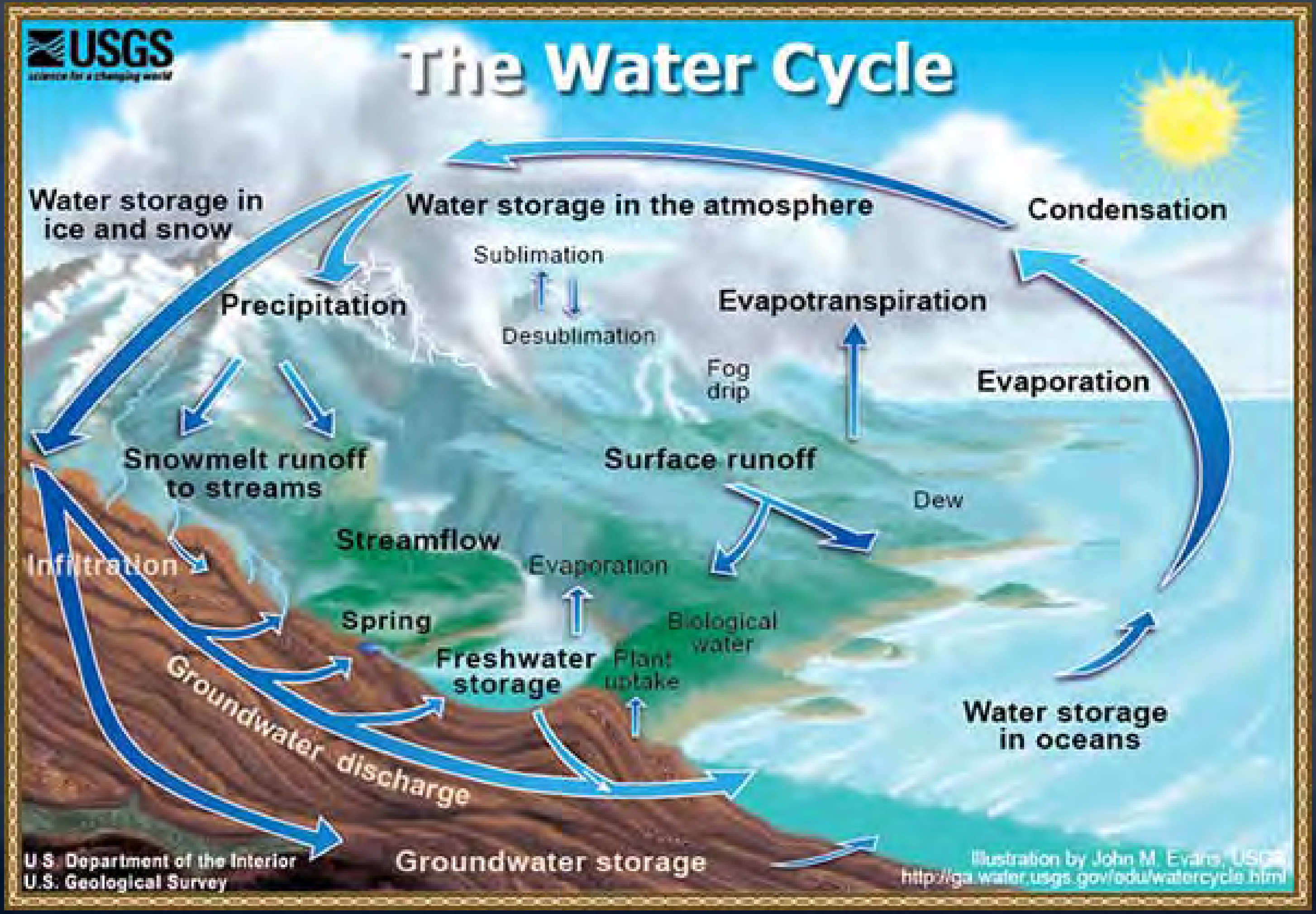
Hydrologic Cycle



Water balance $Q_{in} = Q_{out}$

Inputs

- Precipitation
- Fog drip
- Inter-basin transfers

Ouputs

- Ocean outflow
- Evapotranspiration
- Diversions*
- Evaporation
- Biological sequestration
- Inter-basin transfers

Two Types of Water Use

- Consumptive uses
  - Evapotranspiration
  - Irrigation
  - Evaporation
  - Biological sequestration
- Non-consumptive uses
  - Domestic water
  - Cooling water
  - Excess irrigation
  - Instream flow

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What is Groundwater?

- Groundwater accounts for ~20 % of the freshwater on Earth.
- Flow through porous media or in fractured rock.
- “Underground streams” are not common in most areas.
- Flow velocities can be from tens to billions of times slower than surface water.
- Interaction with surface hydrology.
  – Gaining and losing stream reaches.
  – Hyporheic flow in aggraded channels.

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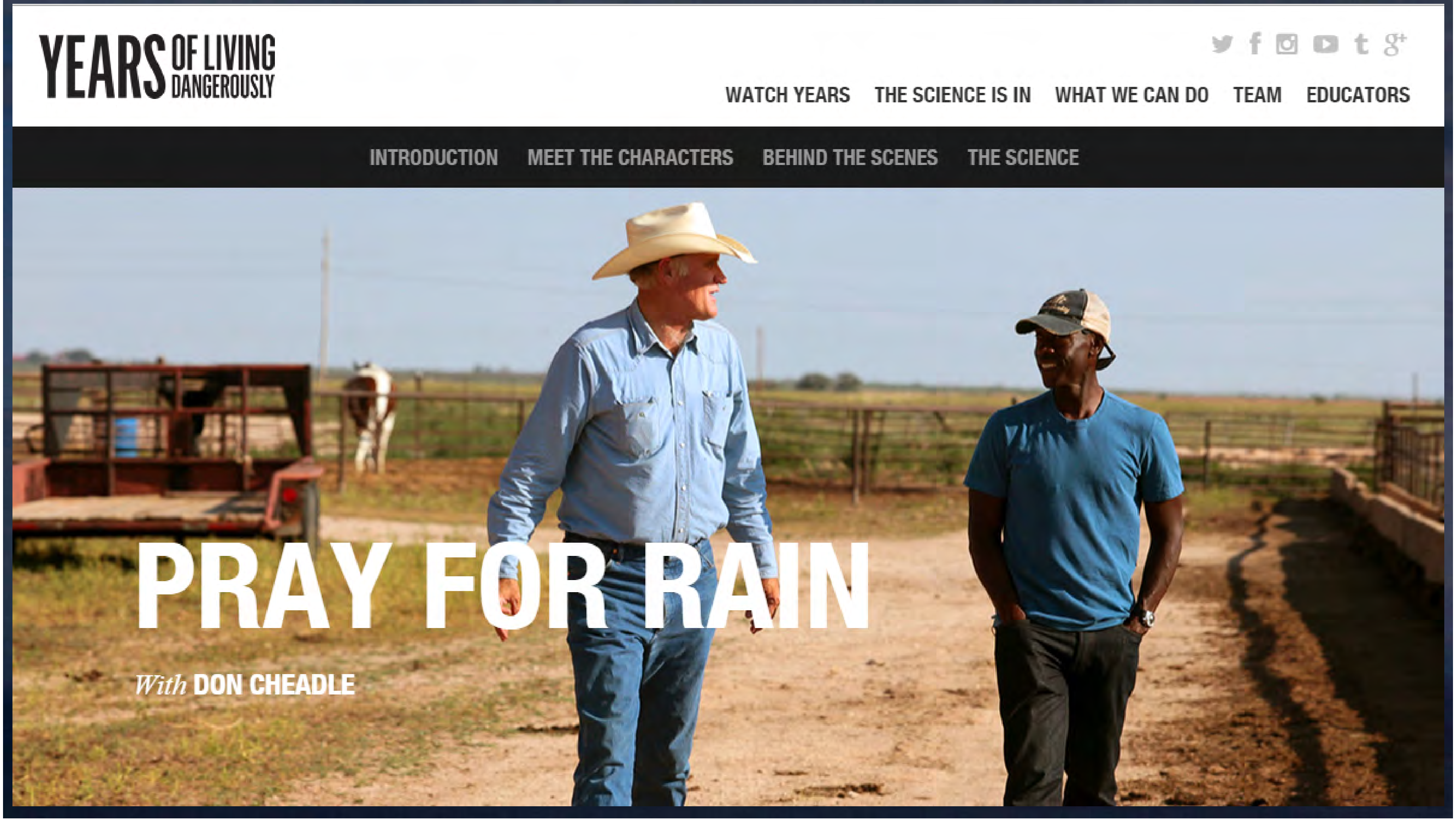
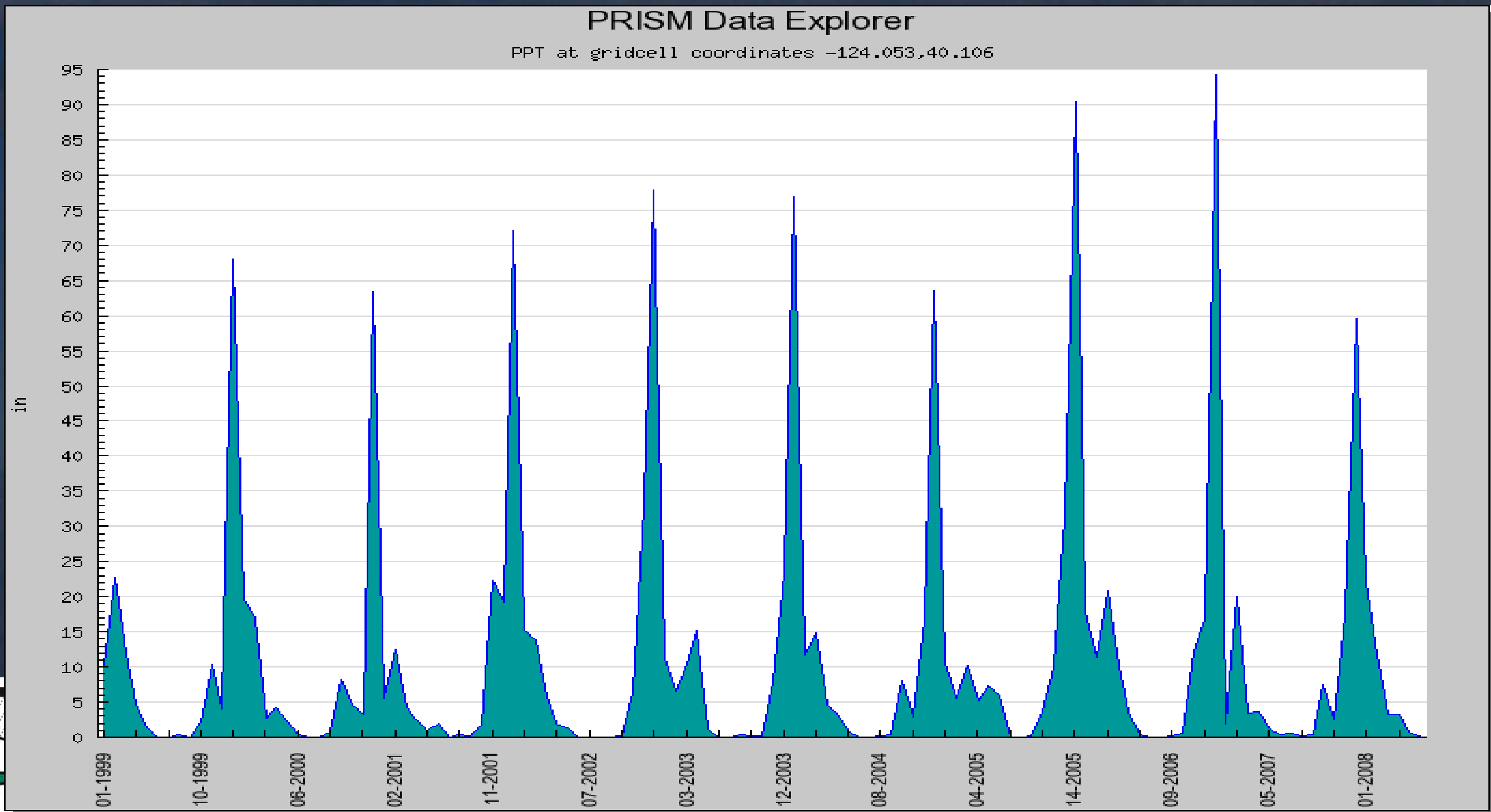
Darcy's Law $q = -K (\Delta h/\Delta L)$

Groundwater Depletion

It's Not Just Climate Change



Mediterranean Climate



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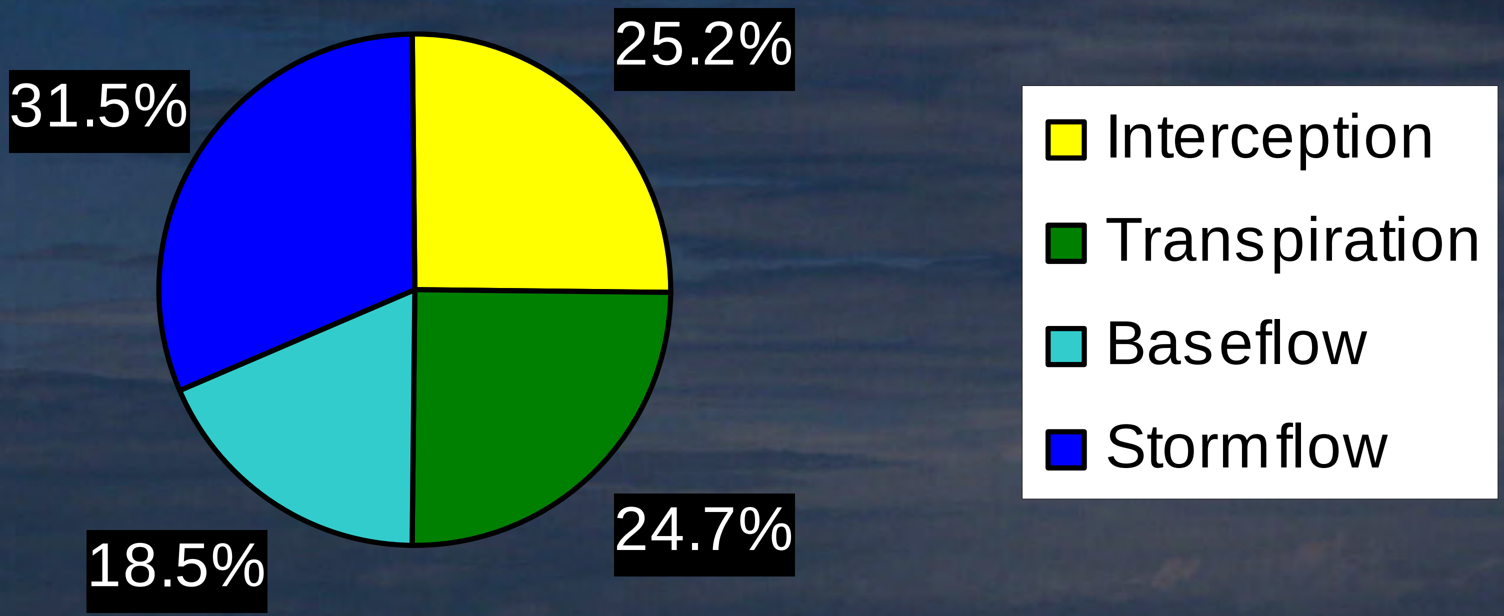
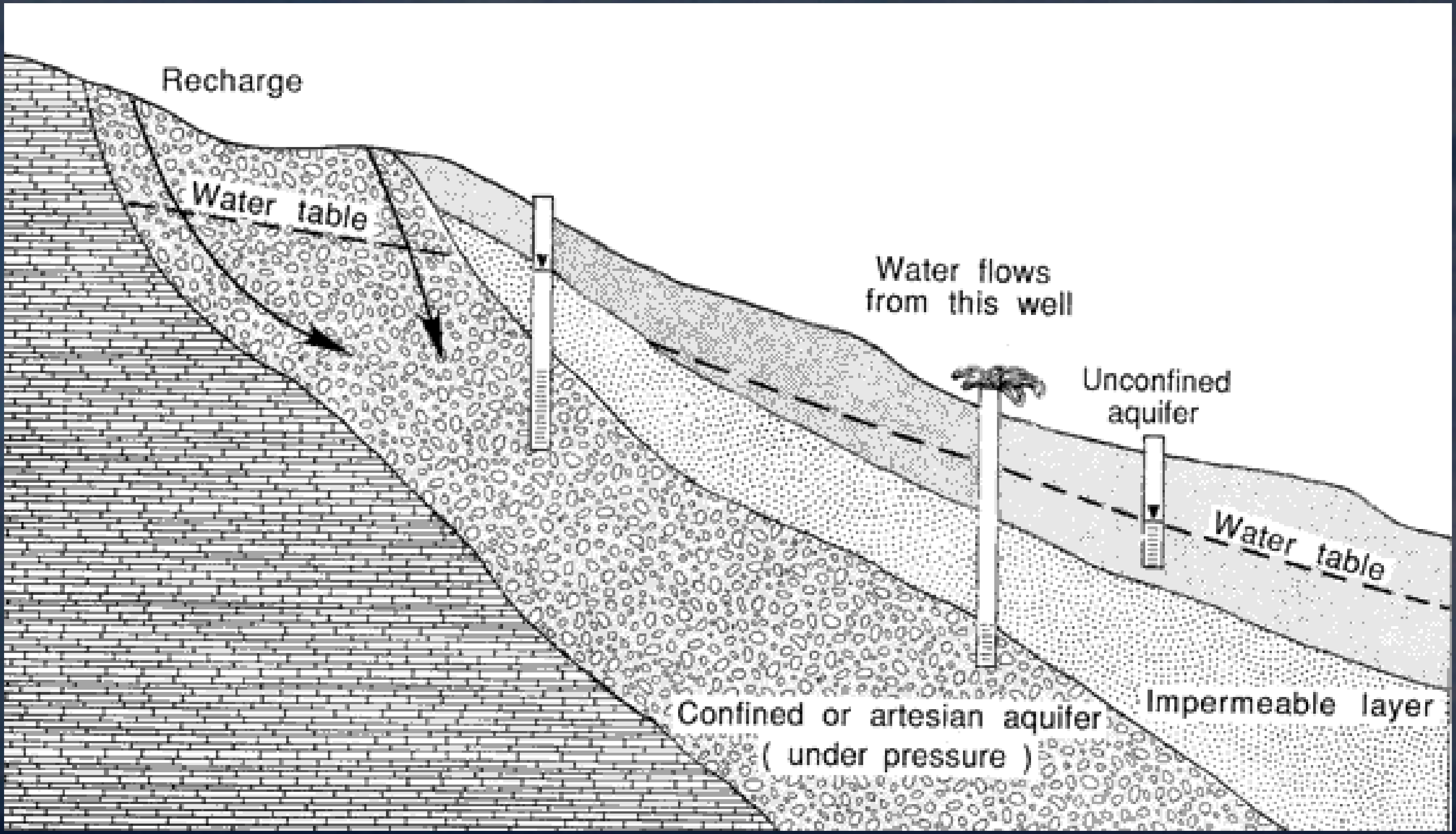
Caspar Creek Water Balance



The Classic Groundwater Paradigm



Kinds of Groundwater

- Shallow
  - Exists for parts of the year throughout watershed
  - In alluvial and colluvial deposits
  - Transient flow through soil pipes during and following storms
- Deep
  - Hard to find in the Coast Range of California
  - Rarely exploited
  - Fracture flow dominates
- Geologic
  - Not present

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Groundwater Resources in the Northwest California

- Limited resource
  - “Youthful” geology
  - Plastic bedrock
  - Shallow alluvial deposits
  - Fine-grained parent material
  - No “geologic” water
  - Steep gradients

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Anthropogenic Effects

- Almost every human activity has served to expedite the flow of water out of the watershed
  - Compaction
  - Impervious surfaces
  - Road cuts
  - Draining / channelization / entrenchment
  - Erosion
  - Overstocked forests

Draining / Channelization / Linearization / Entrenchment

- Ubiquitous where human development occurs
- Dikes and levees
- Reduces groundwater recharge associated with losing stream reaches
- Increases groundwater discharge into gaining stream reaches

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Gullying and Road Cuts

- Not unrelated
- Similar effects on shallow groundwater systems
- Typical mechanisms
  - Expose groundwater preferential flow paths
  - Dramatically decreases hydraulic residence time within the watershed
  - Dewaters down-slope

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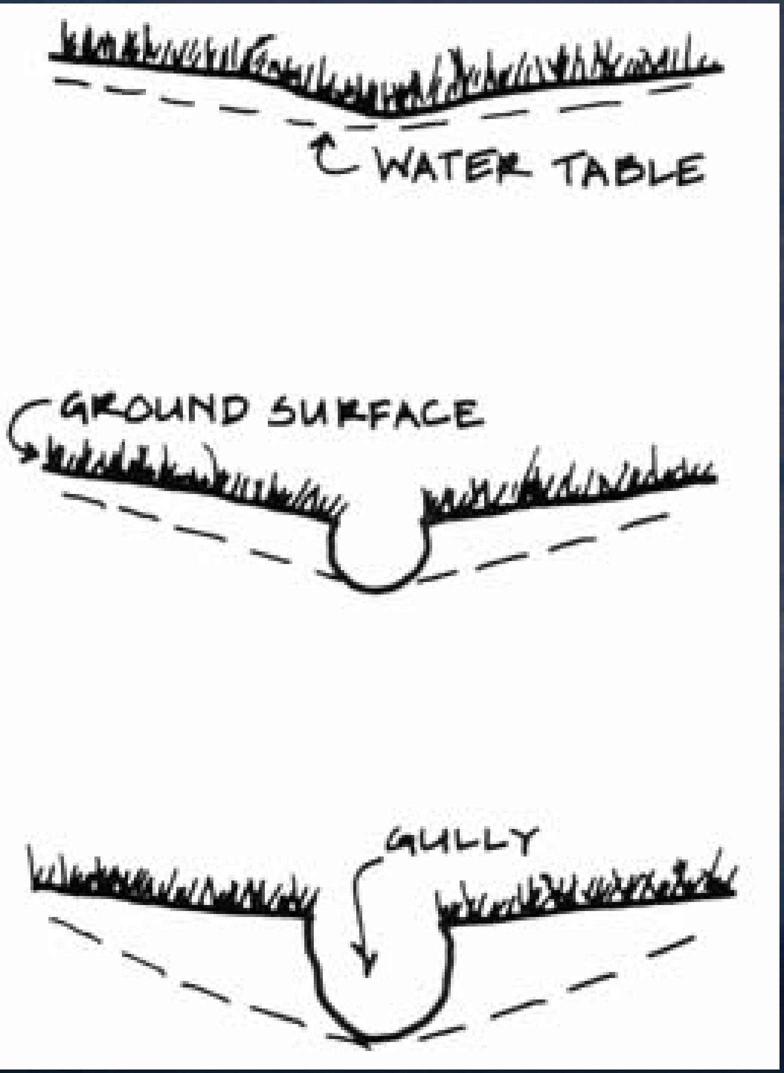
Gullies and Entrenched Stream




Baker Creek Groundwater
Recharge

Hydrology as a Transportation Problem

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Compaction & Impervious Surfaces

- Reduces infiltration rates and thereby increases runoff while reducing groundwater recharge
- Forest litter mediates infiltration and reduces soil moisture loss
- Also associated with:
  - loss of soil organic carbon
  - formation of rills and gullies due to increased overland flow velocities
  - changes in vegetation cover

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Wetland Restoration as a Cure

- Wetlands rely on groundwater
- Extend hydrograph later into the fall
- Dampen hydrologic peaks
- Mitigate effects of altered precipitation, humidity, and temperature regimes
- Offset anthropogenic changes
- Compliment aquatic and terrestrial habitat

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Ponds

- Ponds can be good for the entire watershed.
- Failure can be a giant liability.
- Engineering is required.
- Off-stream is simplest and best.
- Filling with rainwater is best.
- Potential for unintended water quality and ecological risks.
- Seepage > evaporation for groundwater benefits.

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Wetland and Pond Risk Factors

- Transient hydrologic conditions always adversely affect slope stability.
- Desiccation of expansive soils.
- Earthquake loading.
- Over-steepened landforms already exceeds stable angle of repose.

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Water Facts

- Almost all of California's rivers rely on groundwater for base flow during the dry season.
- 40%-60% of California's water supply is on groundwater.
- About 80%-85% over California's developed water resources go to agriculture.
- About 20% of California's water goes to grow alfalfa, which produces <0.1% of California's GDP.
- California uses more groundwater than any other state.
- Even with a wet winter, the lag time for infiltration means that groundwater supplies are still near all-time lows.

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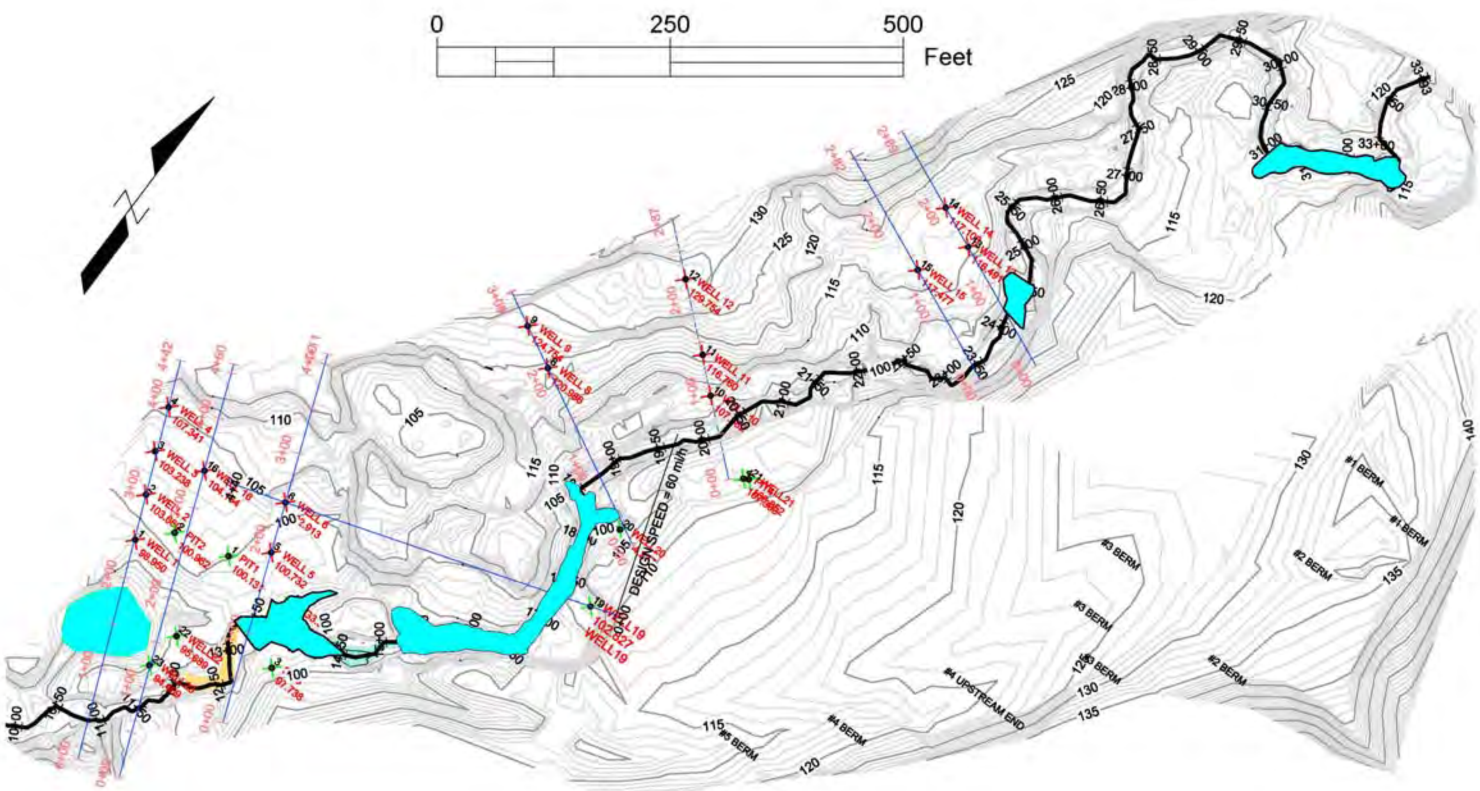
"Essentially, all models are wrong, but some are useful."

George E. P. Box

British mathematician and professor of statistics at the University of Wisconsin



Baker Creek
Extent of Inundation Associated with Structures

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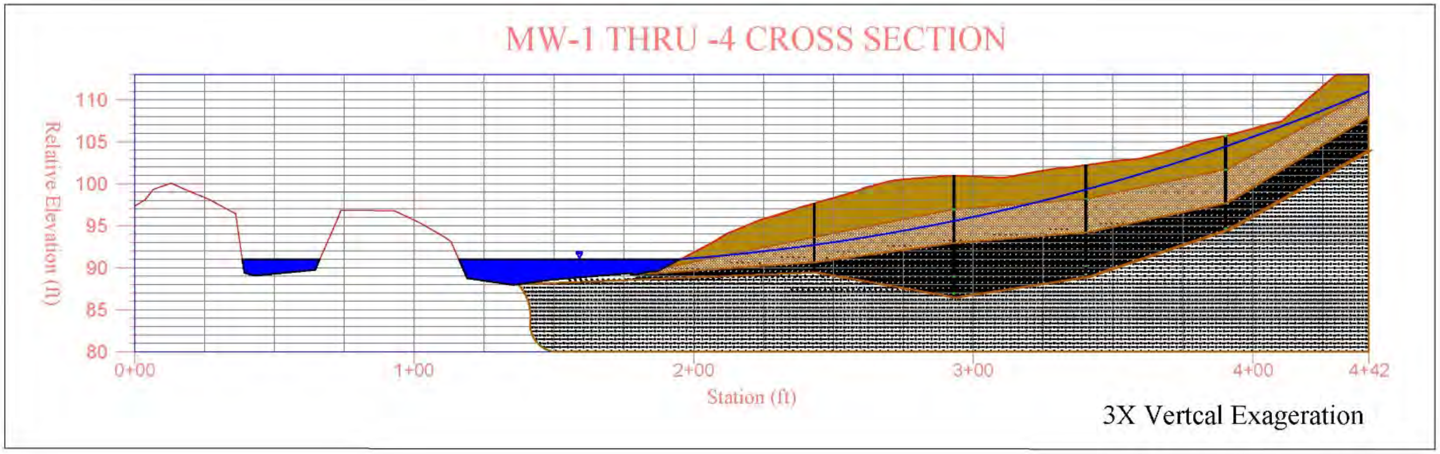

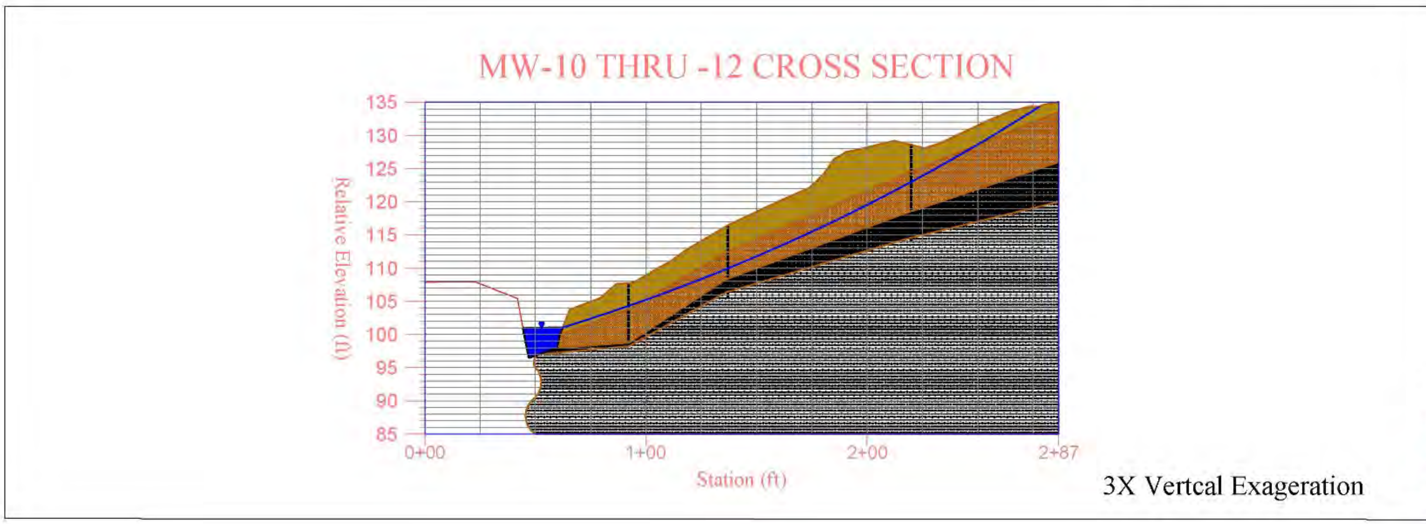

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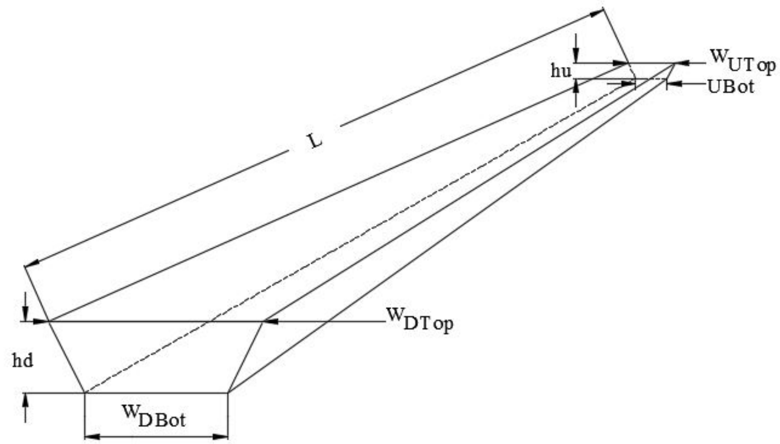
Estimate the Volume of a Prism



$$V = \left[\frac{\left(\frac{W_{DTop} + W_{DBot}}{2}\right) hd + \left(\frac{W_{UTop} + W_{UBot}}{2}\right) hu}{2} \right] * L$$

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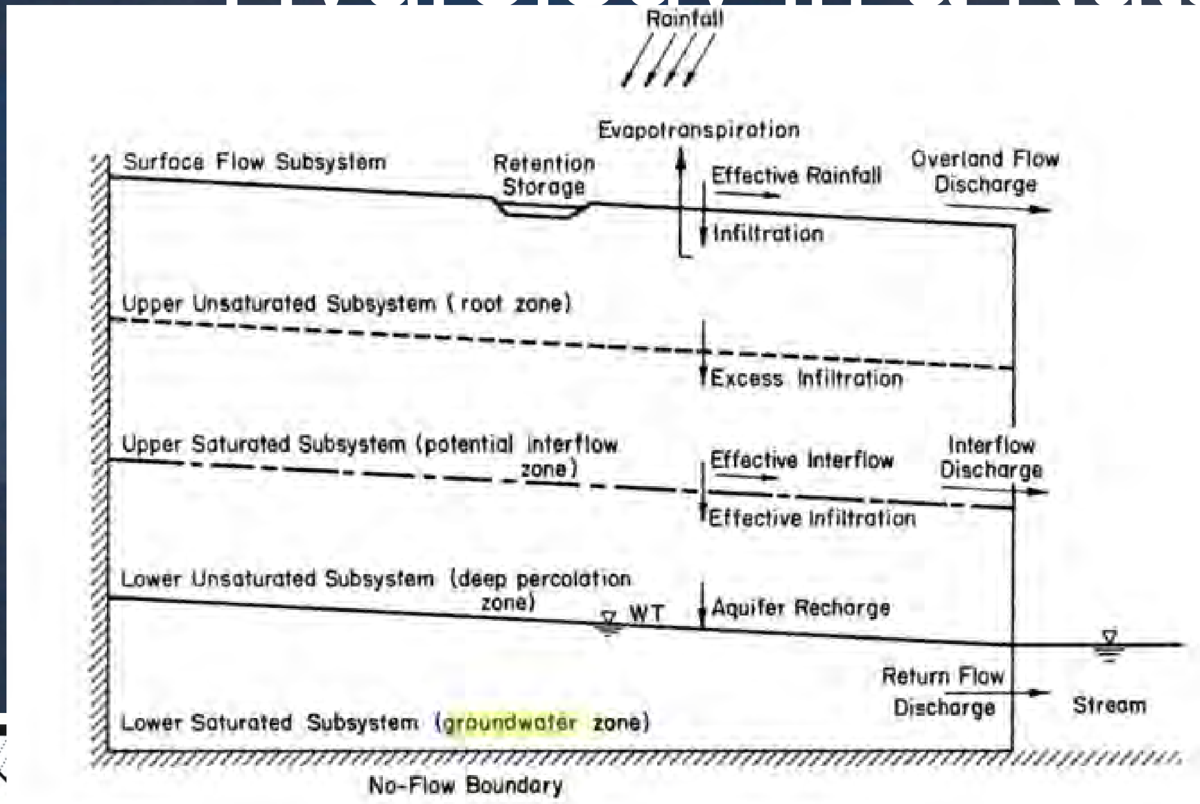
Surface and Subsurface Hydrology in a Nutshell



Unsaturated Flow in Hydrologic Modeling: Theory and Practice edited by H.J. Morel-Seytoux. 2012

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Mass Balance Equation

Input = Output + Storage

First Law of Thermodynamics - Conservation of Energy. One cannot create or destroy energy.

Porosity and It's Variants

$$\phi = \frac{V_V}{V_T}$$

where:

ϕ = porosity (unitless)

V_V = volume of void space that can be filled by a liquid (L^3)

V_V = volume of geologic medium (L^3)

Ideal Versus Real Porosity

A cubic packing of spheres has a porosity of 47.65%.

A rhombohedral packing of spheres has a porosity of 25.95 %.

Porosity of various granular media classifications:

- Well-sorted sand or gravel 25-50%
- Sand and gravel mixed 20-35%
- Glacial till 10-20%
- Silt 35-50%

Storativity – Porosity's Practical Cousin

$$S = \frac{dV_w}{dh}\frac{1}{A} = S_s b + S_y$$

Where:

- V_w = volume of water released from storage (L^3),
- h = hydraulic head (L),
- S_s = specific storage,
- S_y = specific yield,
- b = thickness of aquifer (L),
- A = area (L^2).

Can vary from 0 to ϕ

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Flow in Porous Media

Darcy's Law

$$q = -K\,(\Delta h/\Delta L)$$

Where:
q = discharge ($L^3\ t^{-1}$),
K = hydraulic conductivity ($L^3\ t^{-1}$),
Δh = change in head (L),
ΔL = change in horizontal distance (L).

Hydraulic Conductivities in Geologic Media

K (cm/s)	10^2	10	$10^0=1$	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Fat / Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoirs			Sandstones		Limestones		Granite	

It Gets Much Harder in 3 Dimensions Over Time

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

Where:

K_{xx}, K_{yy}, and K_{zz} = hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity ($L\ t^{-1}$),

h = potentiometric head (L),

W = volumetric flux per unit volume and represents sources and/or sinks of water (L^3t^{-1}),

S_s = specific storage (L^{-1}), and

t = time.

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MODFLOW

- Three-dimensional (3D) finite-difference groundwater model.
- First published in 1984 by USGS.
- Open domain software.
- Modelmuse (USGS) graphical user interface.
- Doesn’t analyze streamflow well.
- Other models, some proprietary, include FEFLOW, SVFlux, FEHM, HydroGeoSphere, MicroFEM, GMS, Visual MODFLOW, OpenGeoSys, HSPF, SWATCH

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Analog Approach

- Most big problems in life involve mass transport.
- Hydrologic cycle is simply mass transport via water's three phases.
- Our hydrologic problems are inversely analogous to traffic problems.
- Vast areas of seasonal wetlands have been destroyed by human land use practices.
- Not all locations are suitable/practicable for groundwater recharge due to:
  - Slope stability concerns,
  - Scale of hydraulic forces on structures,
  - Too far gone.

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Groundwater Pollution

- Fertilizers
  - N pollution causes methemoglobinemia in infants.
  - P pollution causes blue-green algae blooms.
- Other agricultural chemicals.
- Failed septic systems.
- Petroleum.
- Ridiculously expensive and time consuming to remediate

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Confounding Factors

1. Inadequate budget only allowed for mostly hand augered holes that probably did not penetrate alluvium/colluvium to the bedrock contact.
2. Epic droughts are a drag.
3. Inherent uncertainty associated with groundwater systems. Rocket science is much more straight forward and precise.
4. Seems plausible that increased habitat complexity and retention of moist fine-grain sediment deposits allowed larger reservoir of benthic invertebrates and larvae to survive the long dry seasons of 2012, 2013, and 2014.
5. When first envisioned, we anticipated 10 years to completion, with a new series of 6” jumps each year. But, low stormflow did not mobilize the bed in 2013 and 2014.

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Reconnecting Hillslope Hydrology through Management of Road Run-off

34th Annual Salmonid Restoration Conference
April 2016 – Fortuna, CA

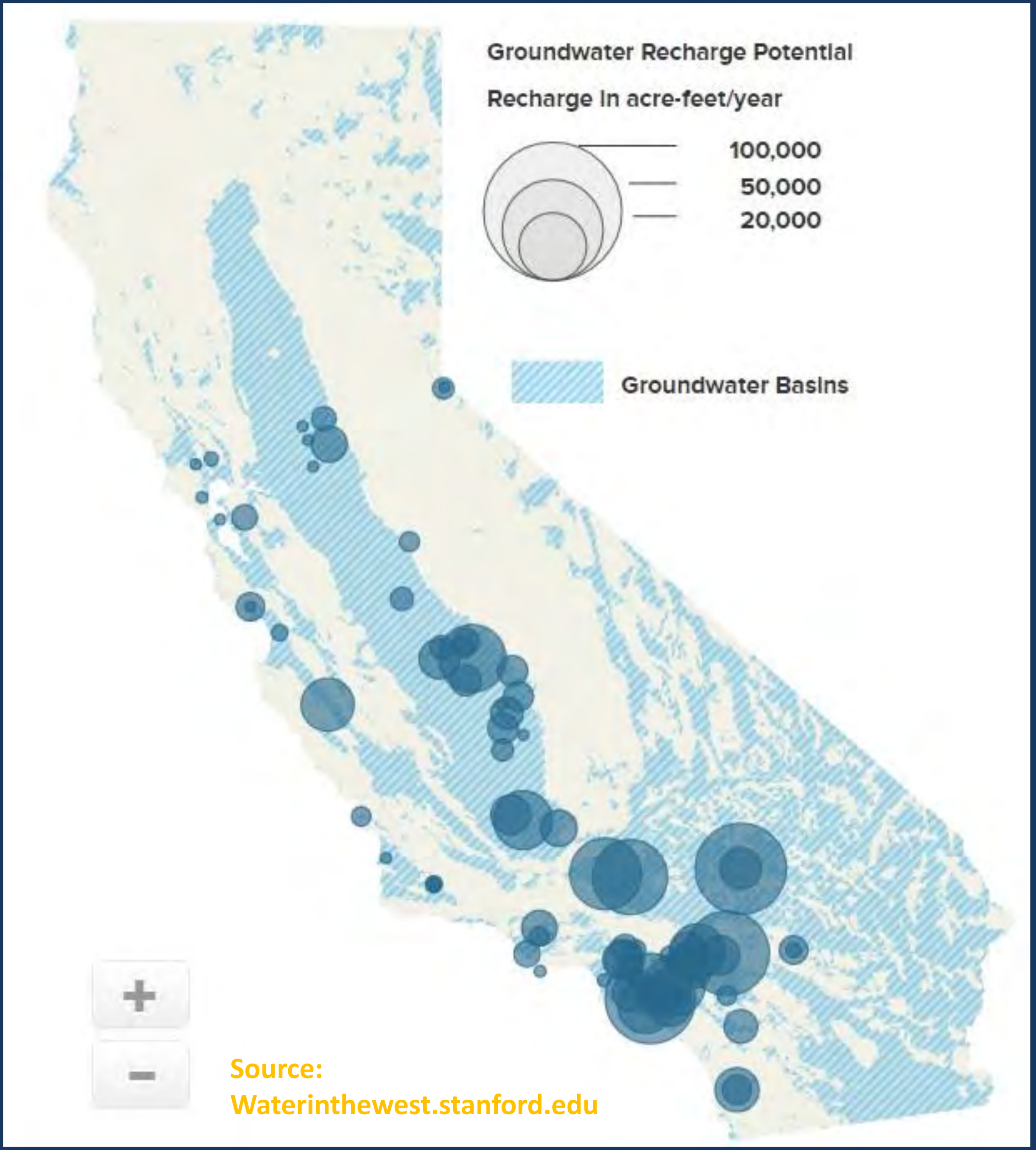
Joel Monschke PE
Stillwater Sciences
2855 Telegraph Ave., # 400
Berkeley, CA 94705

Presentation Overview

1. Groundwater recharge overview
2. Hillslope hydrologic processes
3. Current road/recharge projects
4. Specific road/recharge approaches
5. Cost/benefits/applicability of road/recharge approaches
6. Road/recharge conceptual design

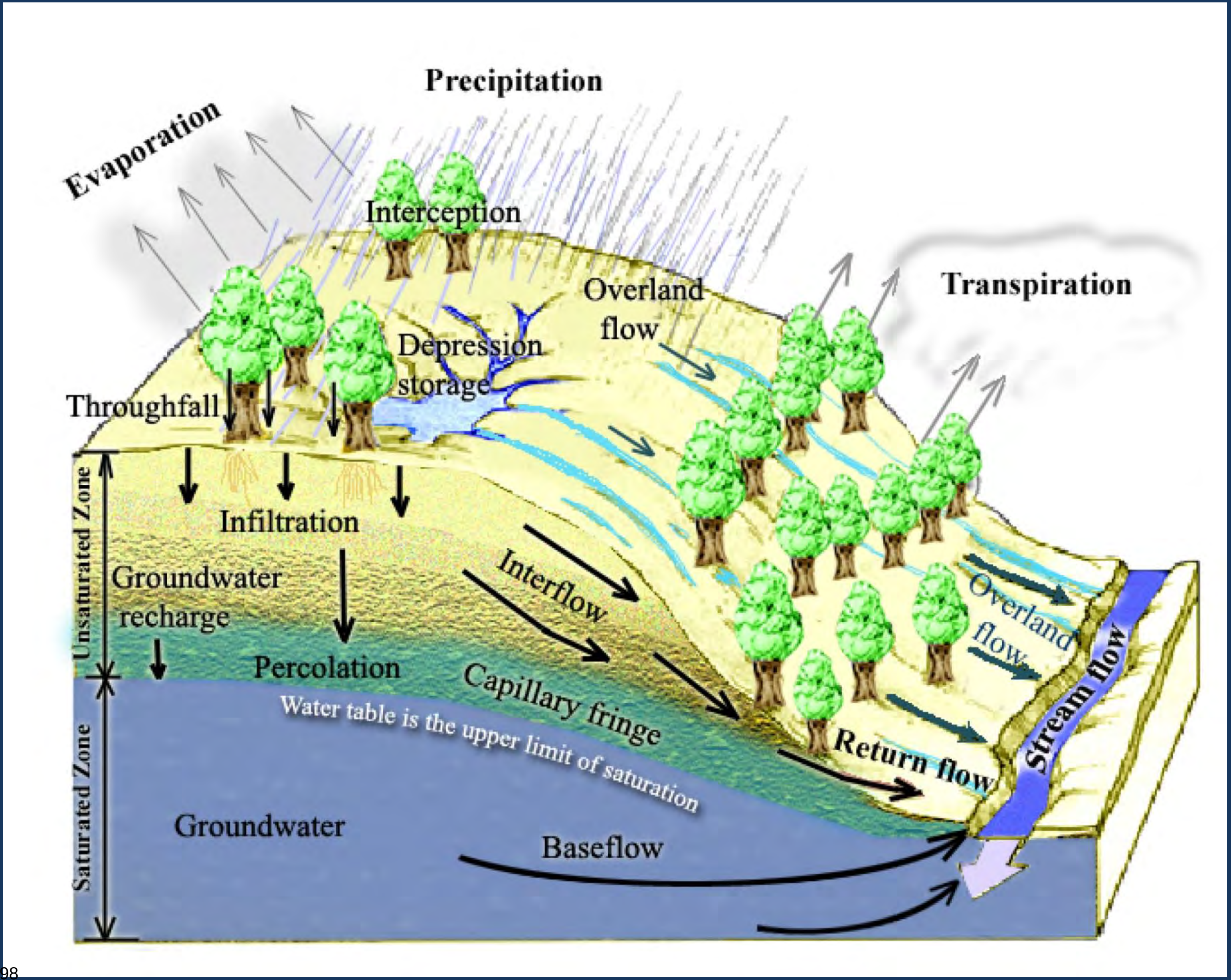
Groundwater Recharge Potential in California

- Much of California NOT underlain by “official” groundwater basin
- Highlights the need to better understand factors that drive hillslope hydrology at more localized “sub-watershed” scale



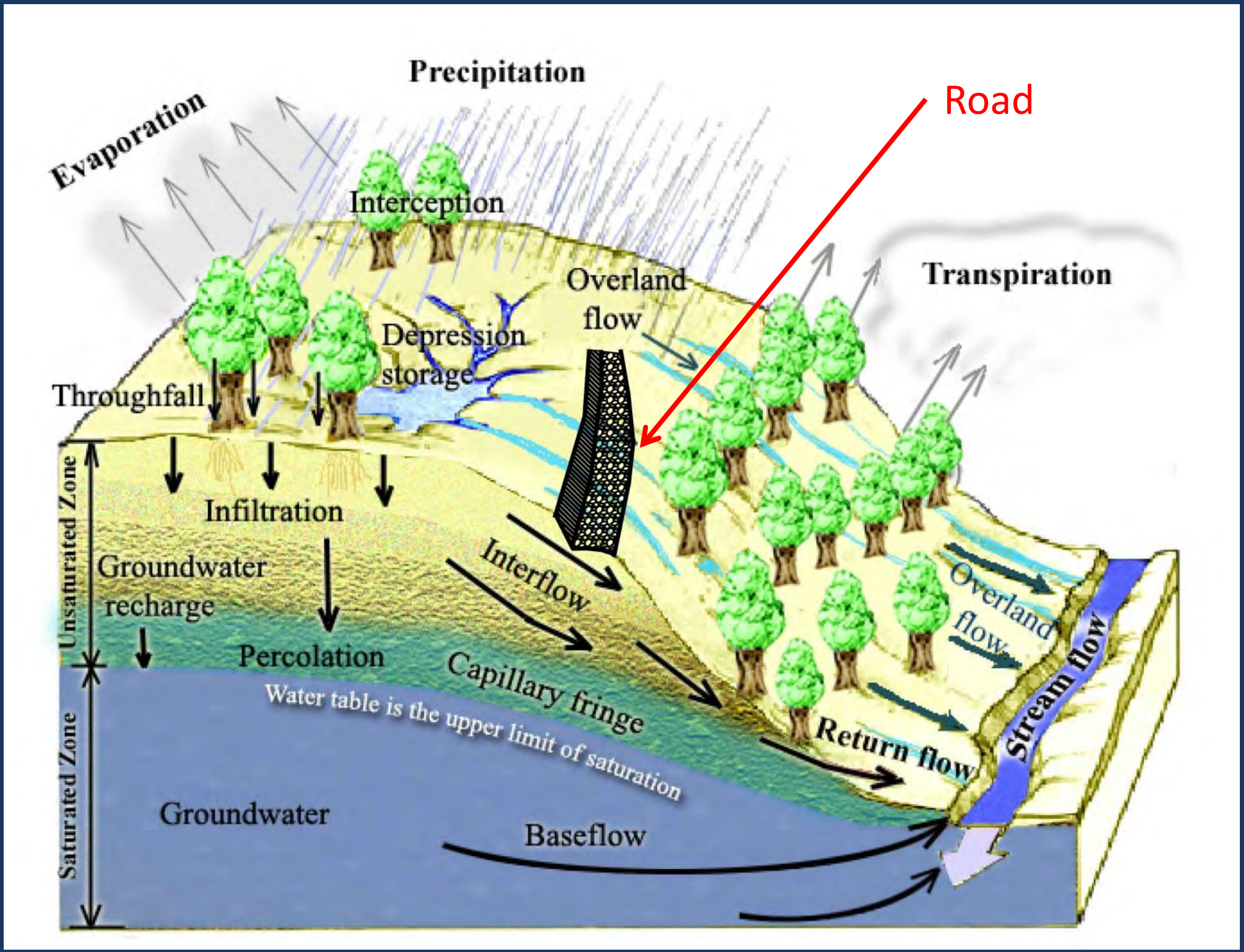
Source: Waterinthewest.stanford.edu

Hillslope Hydrologic Process Overview



Source: Tarboton 2003

Hillslope Hydrologic Process . . . . . with Roads



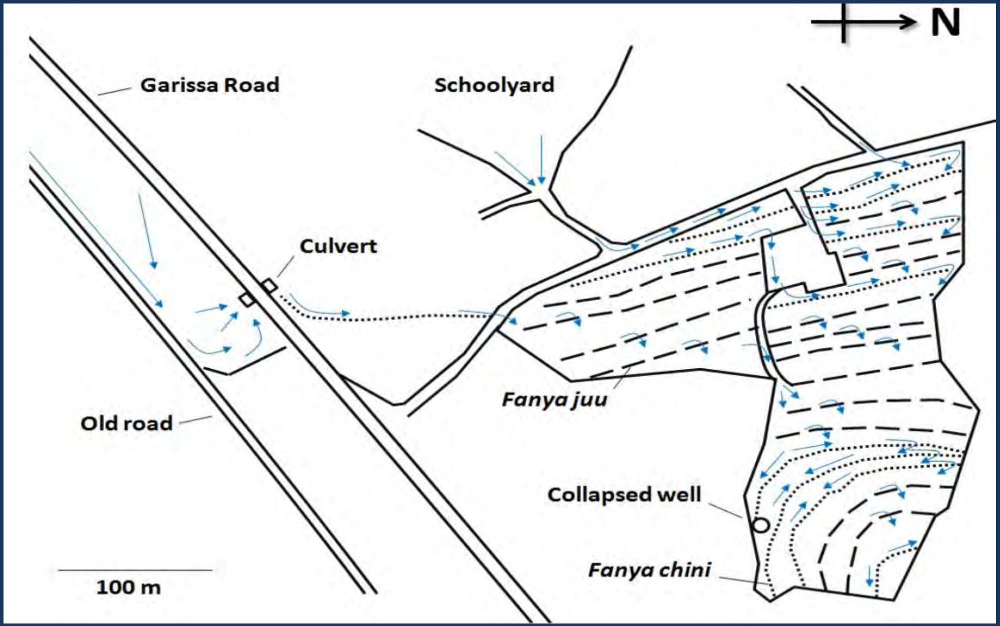
Source: Tarboton 2003

- **Infiltration** reduced due to replacement of topsoil/organic litter sponge with compacted road surface and cut/fill slopes
- **Overland Flow** paths are intercepted and concentrated in inboard ditch – generally routed directly to major tributaries
- **Interflow** is intercepted by road cutslope and converted into surface runoff

Current Innovative Road/Recharge Projects

Urban bio-swales with multi-benefit focus

Developing countries in arid regions (Africa, Middle East, India)



Source: Kubbinga 2012

General Management Actions that Improve Hillslope Hydrology

1. Reducing runoff concentration from active roads
   A. Ditch relief culverts
   B. Waterbars
   C. Rolling dips
   D. Outsloping

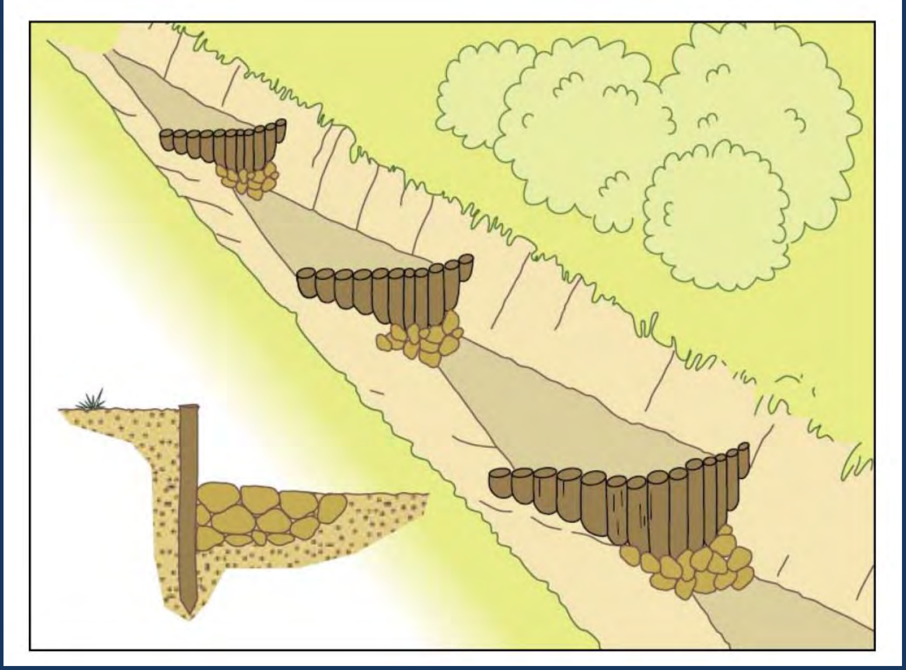
2. Decommission roads not in use
   A. Waterbars
   B. Partial recontour
   C. Full recontour

Specific Methods to Recharge Groundwater using Road Runoff

Off-channel Ponds

Source:
IFAD 2012

Check Dams



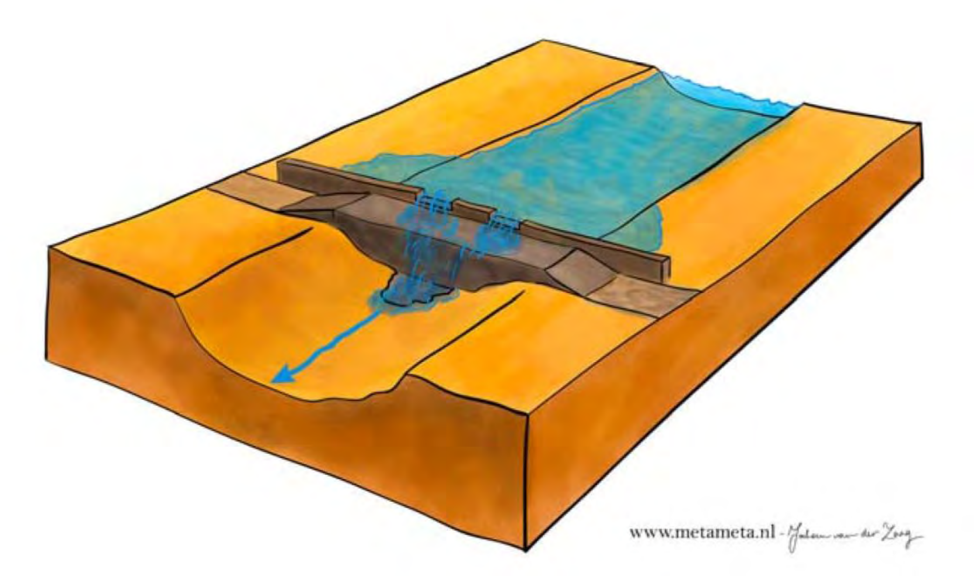
Important Note:
Applying these two methods in tandem (as appropriate) can be very beneficial

Specific Methods to Recharge Groundwater using Road Runoff

Seepage Cisterns

Source:
IFAD 2012

Dams in small tributaries (on-channel ponds)



Other:

- Gravel Infiltration Basins
- Bioswales
- Terraces

Cost, Benefits, Risks, and Applicability of Road-Recharge

	Off-channel Ponds	Check Dams	On-channel ponds	Seepage Cisterns	Terraces	Bio-Swales	Gravel Infiltration Basins
Cost per volume of water recharged	Moderate	High	Low	High	High	High	High
Applicability (feasibility and scale)	High	Moderate	Moderate	Low	Low	Low	Low
Increased erosion risk	Moderate	Low	High	Low	Moderate	Low	Low
Level of maintenance required	Moderate	Moderate	Moderate	Moderate	High	High	High
Hydrologic/ Geomorphic disruption	Moderate	Low	High	Low	Moderate	Low	Low
Water rights issues	Moderate	Low	High	Low	Low	Low	Low
Co-benefit: Sediment Capture	High	High	High	Moderate	High	High	Moderate
Co-benefit: water storage for human use	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Cost, Benefits, Risks, and Applicability of Road-Recharge

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Water rights issues	Moderate	Low	High	Low	Low	Low	Low
Co-benefit: Sediment Capture	High	High	High	Moderate	High	High	Moderate
Co-benefit: water storage for human use	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

General applicability in California

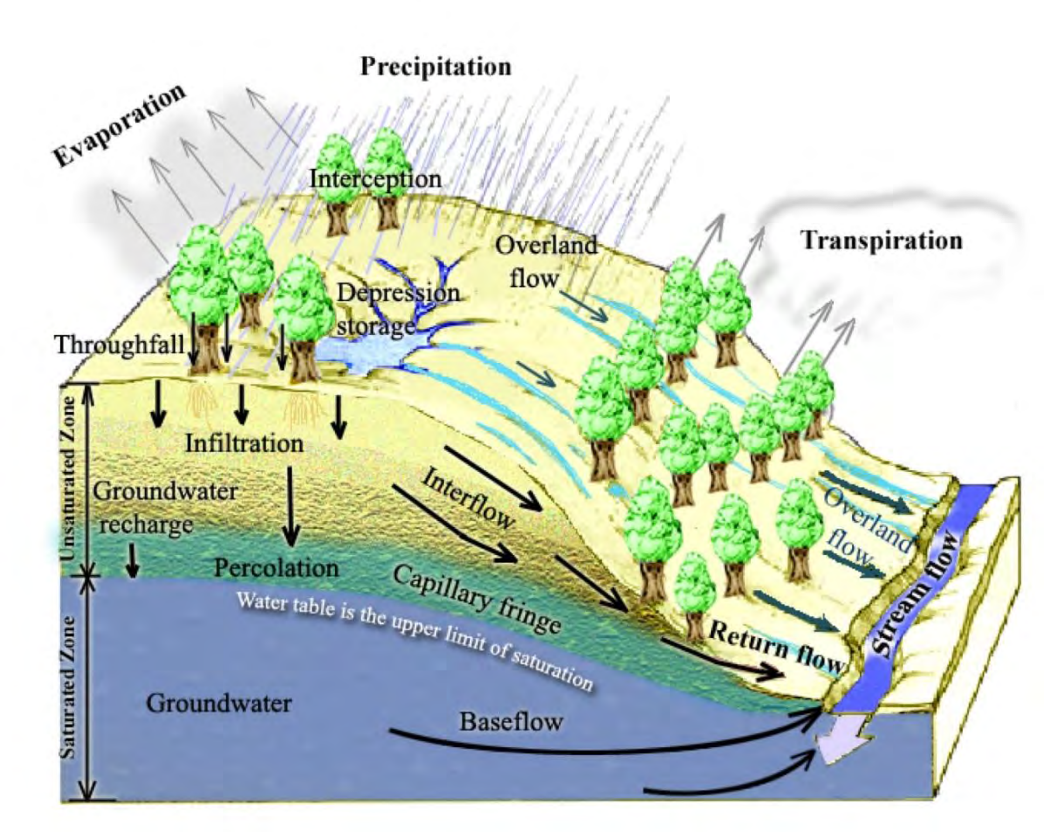
Research needed to understanding hydrologic cycle dynamics such as:

1. Existence of perched groundwater tables due to variations in soils/lithology

2. Better defined groundwater flow paths and velocities

3. Effects of vegetation on infiltration, groundwater, and streamflow

4. Effects of human use on infiltration, groundwater, and streamflow



Source: Tarboton 2003

Conceptual Design: Multi-Benefit Off-channel Ponds

Benefits:
- Groundwater recharge
- Sediment catchment from road network
- Water storage for irrigation

Requirements:
- Suitable soil
- Gentle/stable terrain
- $$$

Issues:
- Water rights: difficult to distinguish between "road runoff" and "Class III watercourses"
- How to measure recharge benefits
- Potential for reduced slope stability

Conclusions

- Strong potential for groundwater recharge projects that use road runoff
- Strategically placed ponds provide most potential benefit at lowest cost and risk
- Need to consider siting and scale: develop projects large enough to provide measureable benefit
- Need to design, implement, and monitor a few projects to demonstrate proof-of-concept
- The example project used for the following Interactive Exercise is exactly the type/scale of recharge project that could also be designed to capture road runoff

Thank You!

jmonschke@stillwatersci.com

Augmenting Groundwater Storage and Recharge through Montane Meadow Restoration

Salmonid Restoration Federation Conference

April 7, 2016

David Shaw, MLA, PG

Balance Hydrologics, Inc.
www.balancehydro.com

Overview

The Questions

The Approaches

Case Studies:

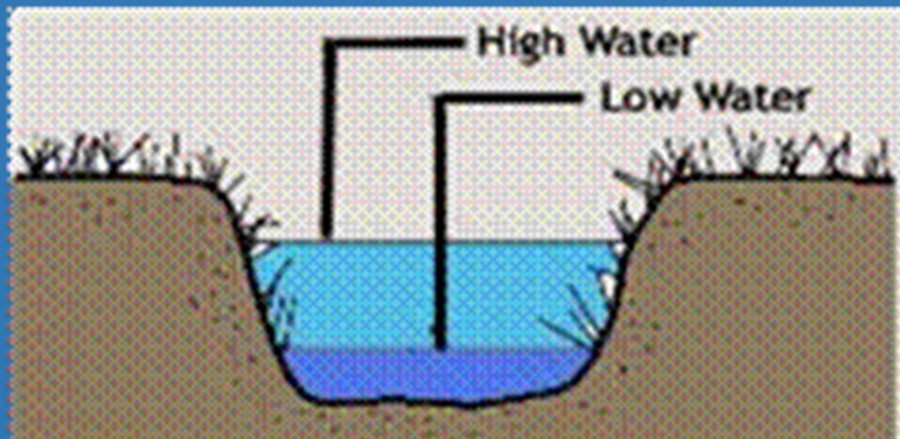
- Squaw Creek Inset Floodplain and Channel Widening
- Perazzo Meadows Plug and Pond

The Questions

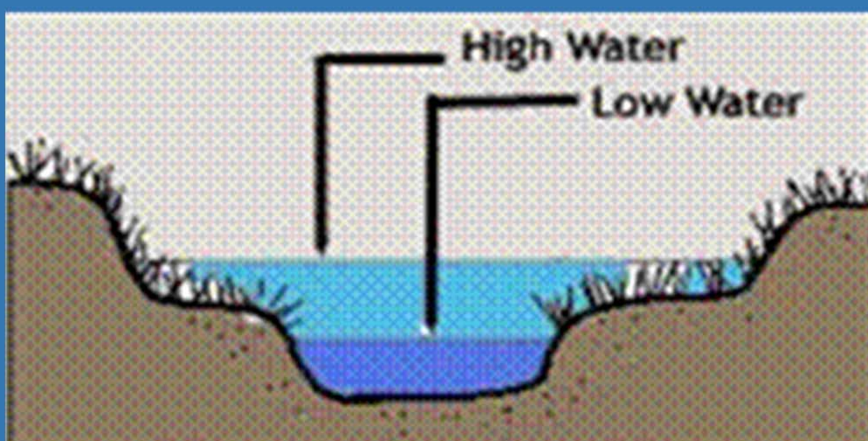
To what degree can inset floodplain and wetland creation increase groundwater recharge?

To what degree can meadow restoration increase groundwater storage?

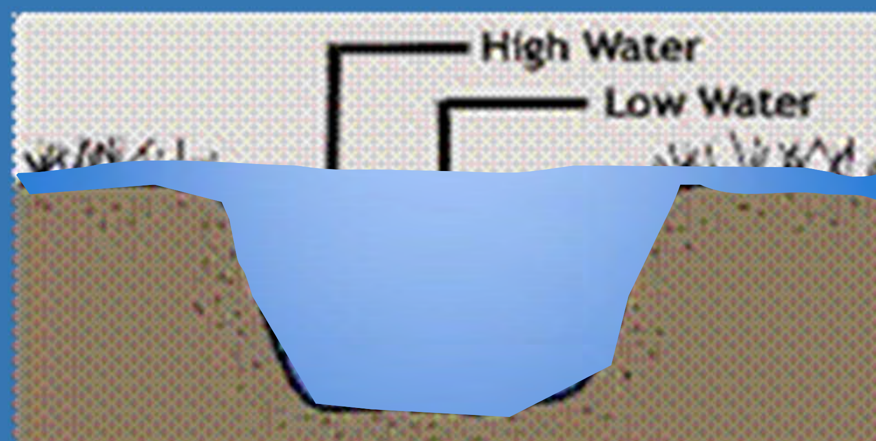
The Questions



Incised Channel

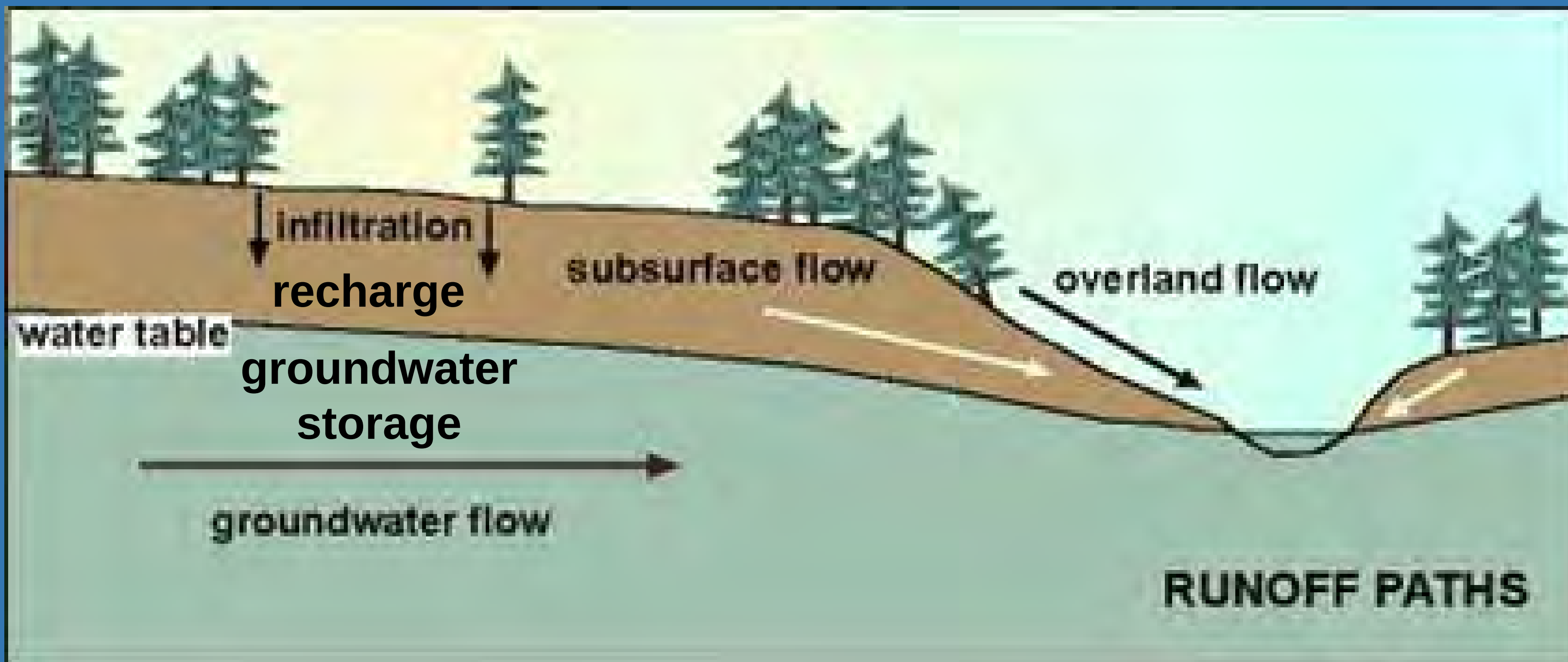


Inset Floodplain



Floodplain reconnection

Recharge and Storage



Approaches

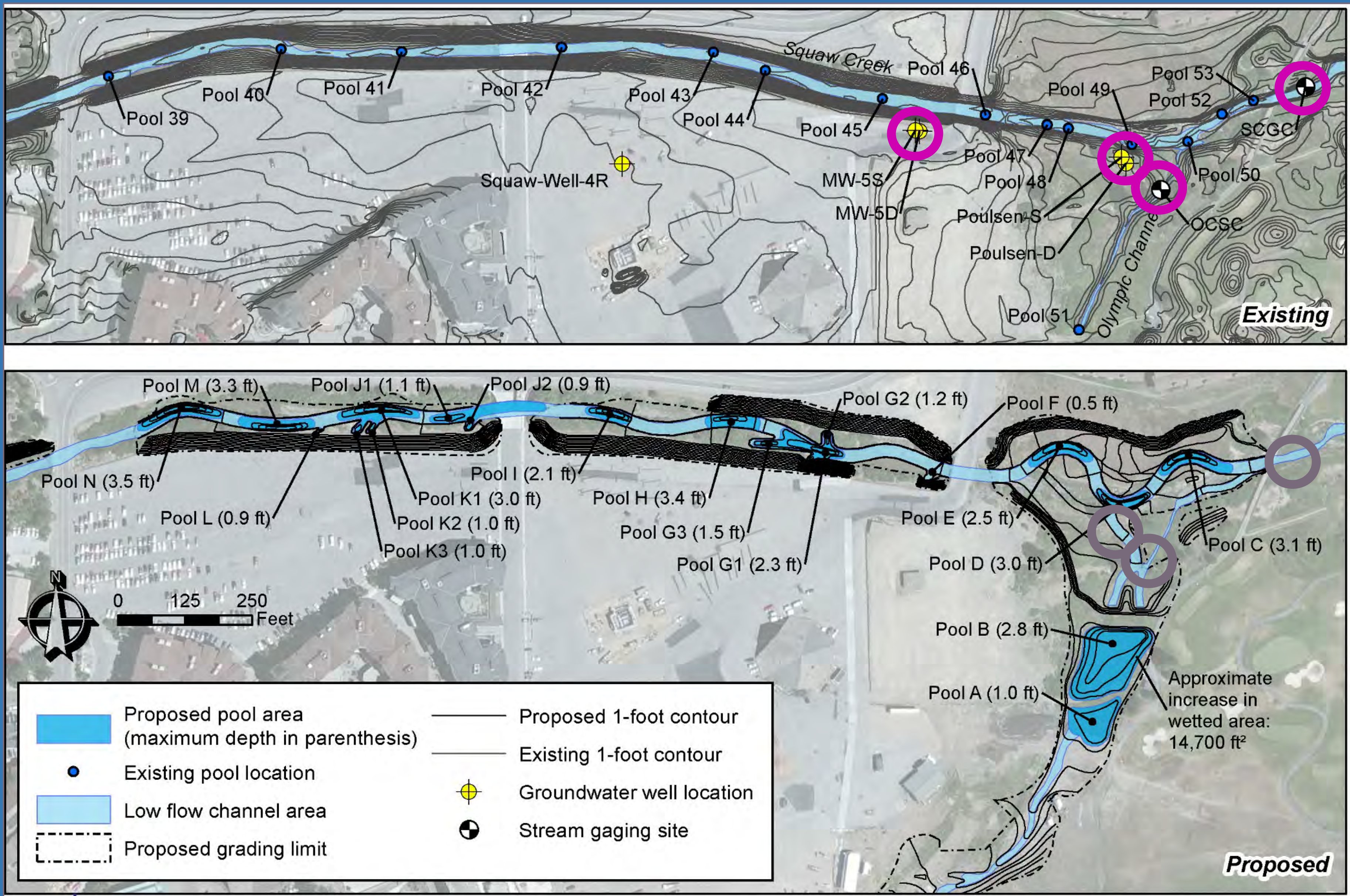
1. Pre-implementation: Estimate a potential change in recharge rates based on basic groundwater flow principles and local hydrologic data

2. Post-implementation: Estimate the change in groundwater storage based on shallow groundwater monitoring data for a completed project

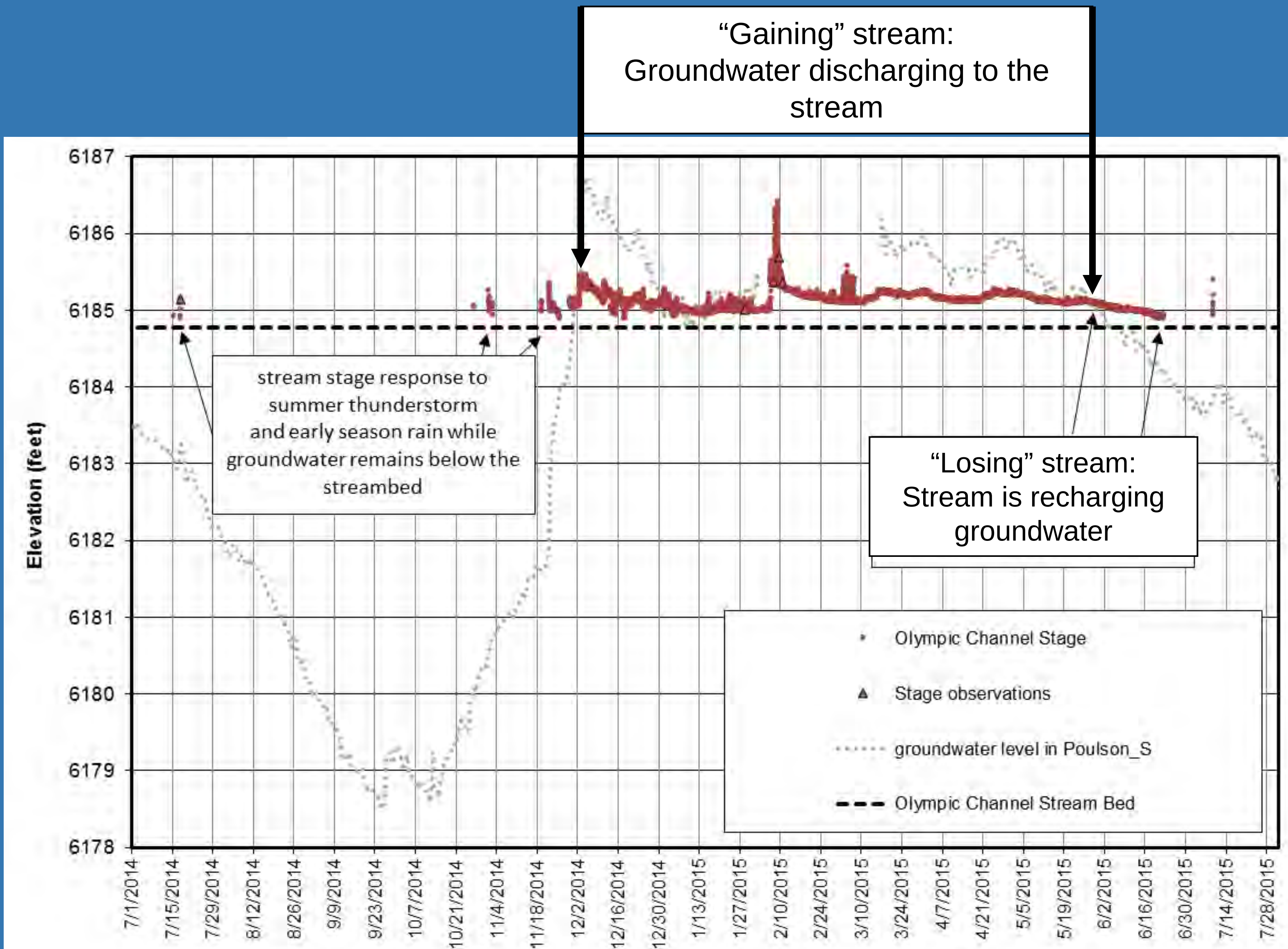
Change in Recharge Rates

Squaw Creek Restoration Project, Placer County, California

Squaw Creek Restoration Project, Placer County, California



Squaw Creek Restoration Project, Placer County, California



Darcy's Law

$$Q = K I A$$

Q = groundwater flow rate

K = hydraulic conductivity

I = hydraulic gradient

A = flow area

Darcy's Law

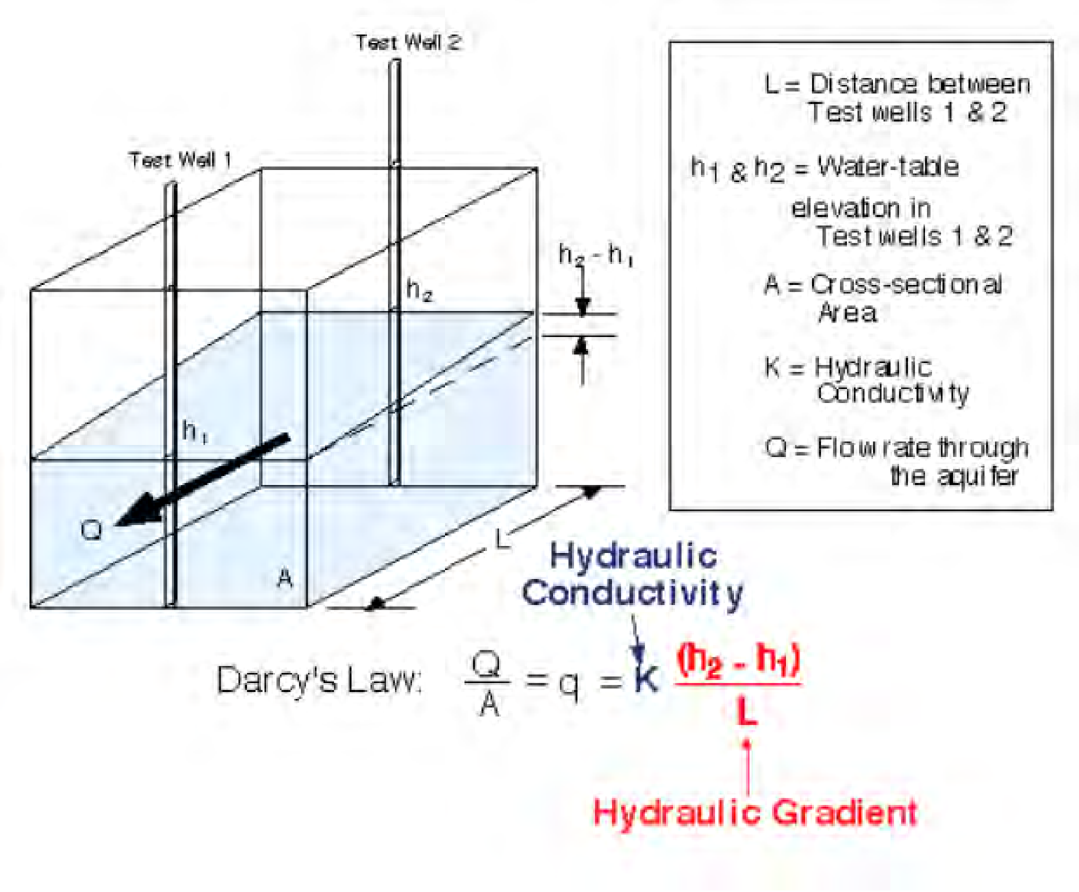
$$Q = K\,I\,A$$

$Q = ft^3 / s$ (cfs)

$K = ft / day$

$I = ft / ft$

$A = ft^2$



Hydraulic Conductivity

K = ft / day

Field Infiltration tests

Hydraulic Conductivity

K = ft / day

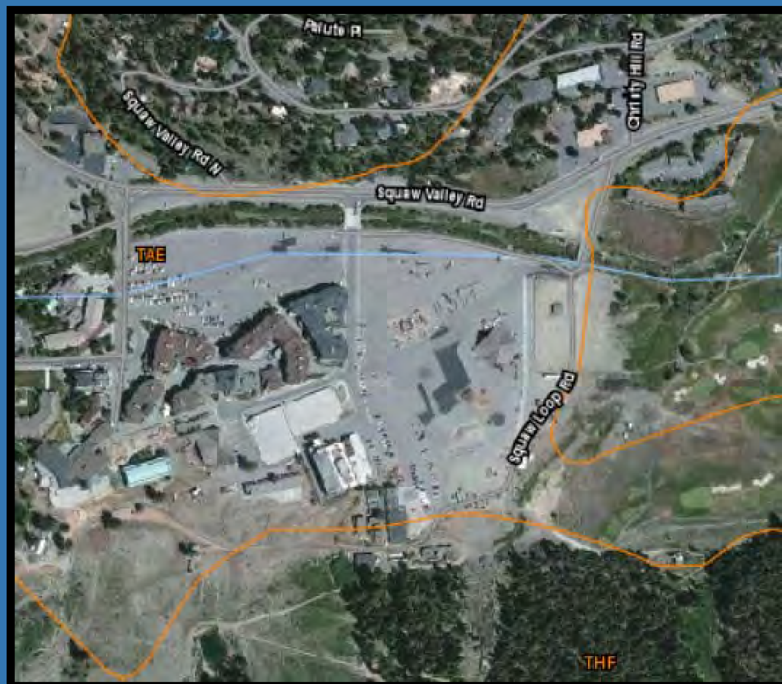
Published values:

NRCS Soil Survey
http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Saturated Hydraulic Conductivity (Ksat)

Saturated Hydraulic Conductivity (Ksat)— Summary by Map Unit — Tahoe National Forest Area, California (CA719)

Map unit symbol	Map unit name	Rating (micrometers per second)	Acres in AOI	Percent of AOI
AQB	Aquolls and Borolls, 0 to 5 percent slopes		42.9	10.8%
MKE	Meiss-Waca complex, 2 to 30 percent slopes	28.0000	1.8	0.4%
TAE	Tallac very gravelly sandy loam, 2 to 30 percent slopes	28.0000	157.5	39.6%
TAF	Tallac very gravelly sandy loam, 30 to 50 percent slopes	28.0000	20.4	5.1%
TBF	Tallac-Cryumbrepts, wet complex, 30 to 50 percent slopes	28.0000	16.8	4.2%
THF	Tallac-Gullied land-Cryumbrepts, wet complex, 30 to 60 percent s lopes	28.0000	71.0	17.8%
WAE	Waca-Windy complex, 2 to 30 percent slopes	28.0000	58.8	14.8%
WEE	Waca-Meiss-Cryumbrepts, wet complex, 2 to 30 percent slopes	28.0000	3.7	0.9%
WRG	Ledford variant-Rock outcrop complex, 30 to 75 percent slopes	28.0000	25.1	6.3%
Totals for Area of Interest			**398.0**	**100.0%**

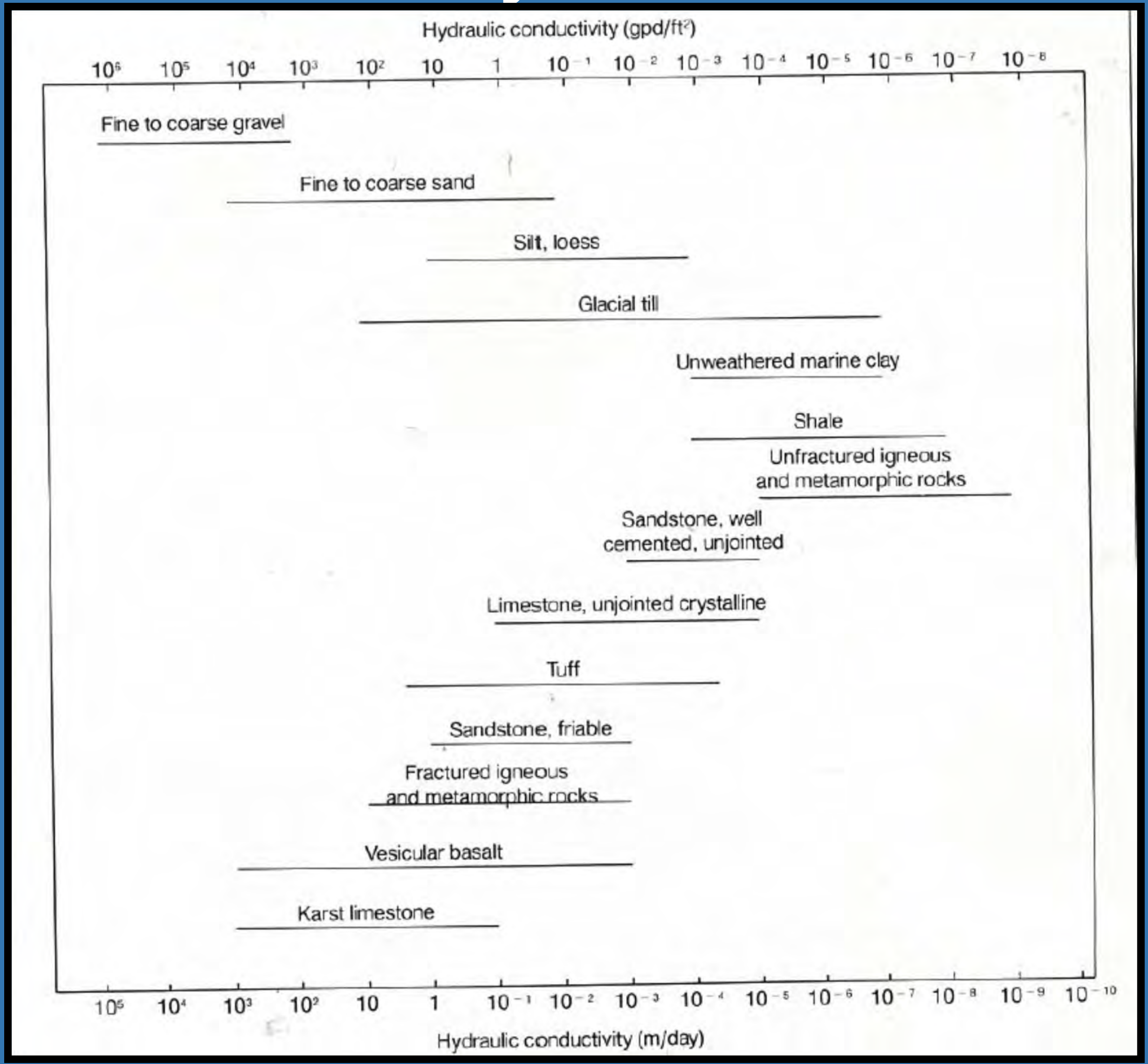


Hydraulic Conductivity

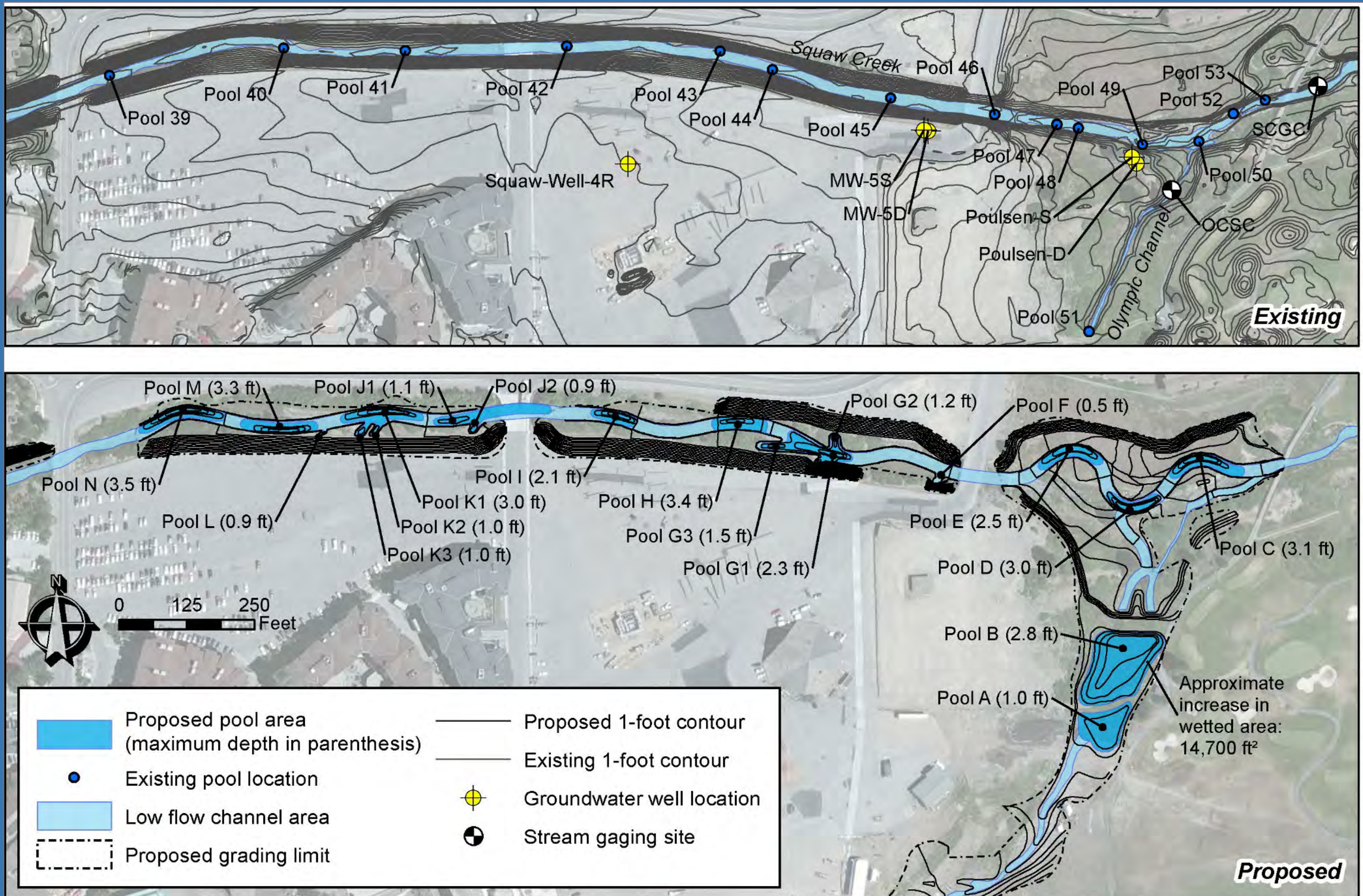
K = ft / day

Published values:

Driscoll, 1976, Groundwater and Wells, Johnson Filtration Systems



Squaw Creek Restoration Project, Placer County, California



Change in Recharge Rates

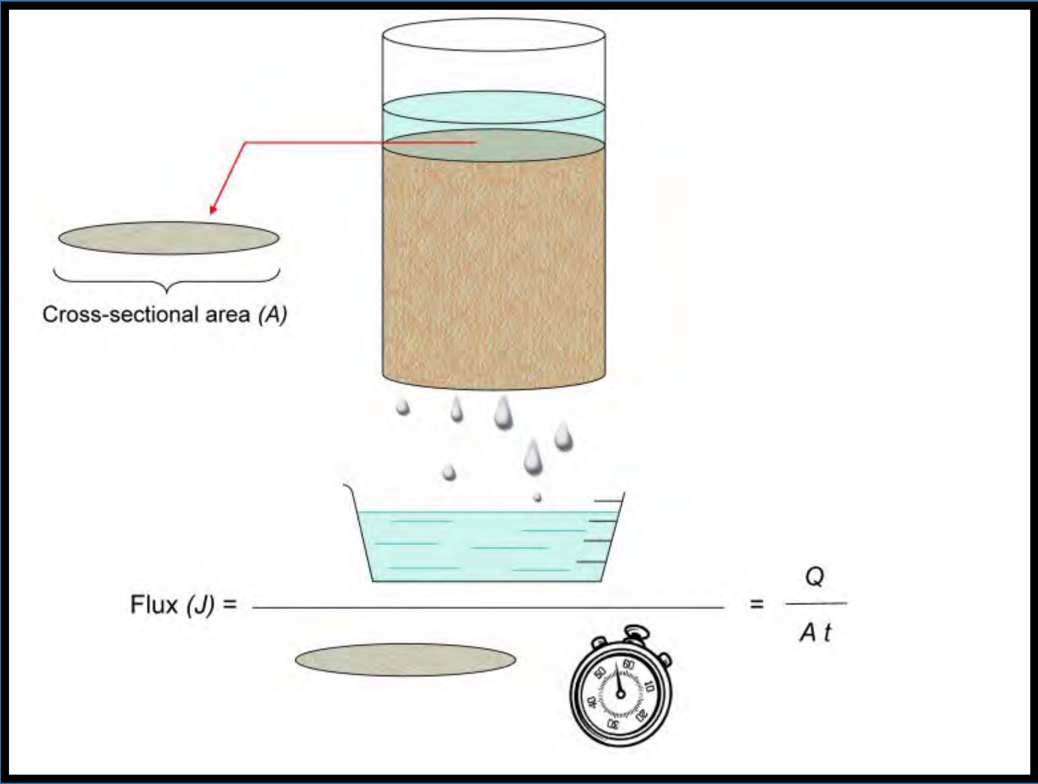
Squaw Creek Restoration Project, Placer County, California

	Existing Stream	Restored Stream	
Stream type	channel	Pool and swale	
Wetted area	1,670	20,716	(ft^2)
Hydraulic conductivity (K)	0.28	0.28	(ft/day)

Darcy's Law

$Q = K\ I\ A$

I = ft / ft = 1



Q = ft^3 / s (cfs)

K = ft / day

~~I = ft / ft~~

A = ft^2

Change in Recharge Rates

Squaw Creek Restoration Project, Placer County, California

	Existing Stream	Restored Stream	
Stream type	channel	Pool and swale	
Wetted area (A)	1,670	20,716	(ft^2)
Hydraulic conductivity (K)	0.28	0.28	(ft/day)
Hydraulic Gradient (I)	1	1	(ft/ft)

$$Q = K I A$$

Change in Recharge Rates

Squaw Creek Restoration Project, Placer County, California

	Existing Stream	Restored Stream	
Stream type	channel	Pool and swale	
Wetted area	1,670	20,716	(ft^2)
Hydraulic conductivity (K)	0.28	0.28	(ft/day)
Hydraulic Gradient	1	1	(ft/ft)
Calculated recharge rate under 2015 hydrologic conditions	**473**	**5,872**	**(ft^3/day)**

Change in Recharge Rates

Squaw Creek Restoration Project, Placer County, California

	Existing Stream	Restored Stream	
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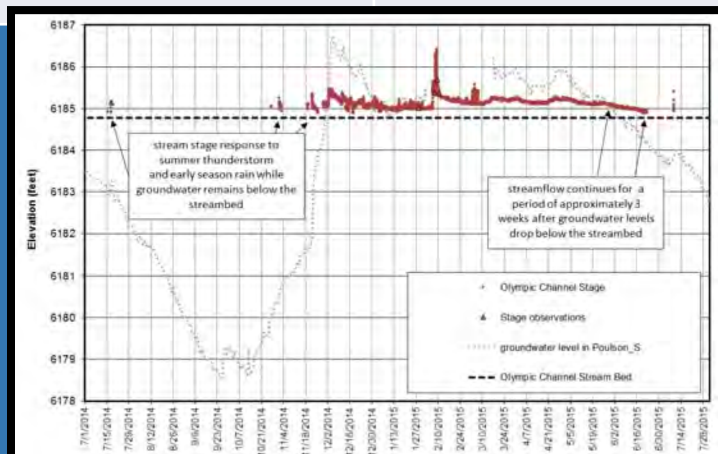
Calculated recharge rate under 2015 hydrologic conditions	473	5,872	(ft^3/day)
Duration of losing stream conditions	22	22	(days)



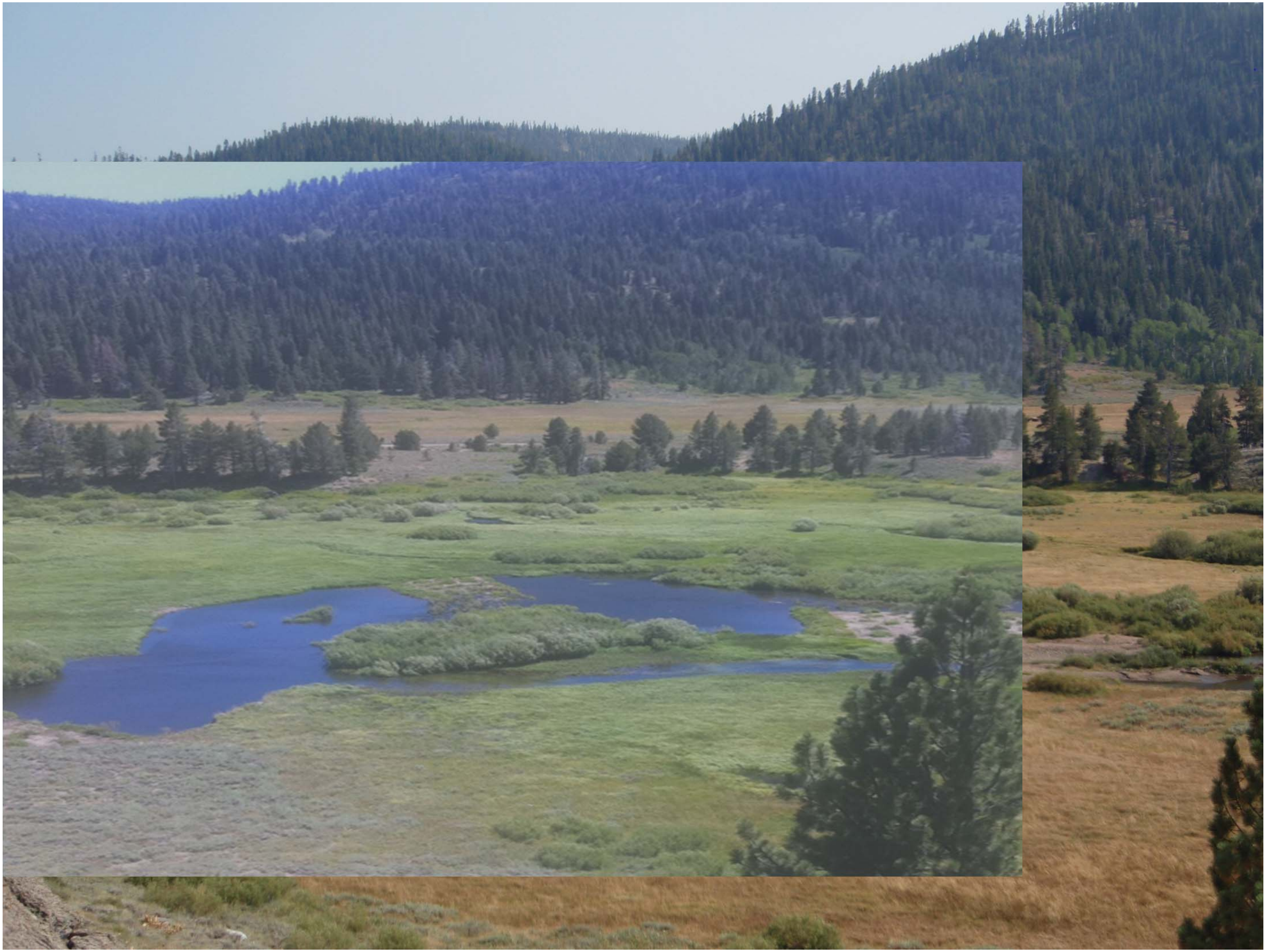
Change in Recharge Rates

Squaw Creek Restoration Project, Placer County, California

	Existing Stream	Restored Stream	
Stream type	channel	Pool and swale	
Wetted area	1,670	20,716	(ft^2)
Hydraulic conductivity (K)	0.28	0.28	(ft/day)
Hydraulic Gradient	1	1	(ft/ft)
Calculated recharge rate under 2015 hydrologic conditions	473	5,872	(ft^3/day)
Duration of losing stream conditions	22	22	(days)
Evaporation rate	23	283	(ft^3/day)
Evaporation rate	0.014	0.014	(ft/day)
Total recharge over the duration of losing stream conditions	**9,912**	**122,961**	**(ft^2)**
	0.23	**2.82**	**(acre-feet)**

Change in Storage

Perazzo Meadows Restoration Project, Sierra County, California



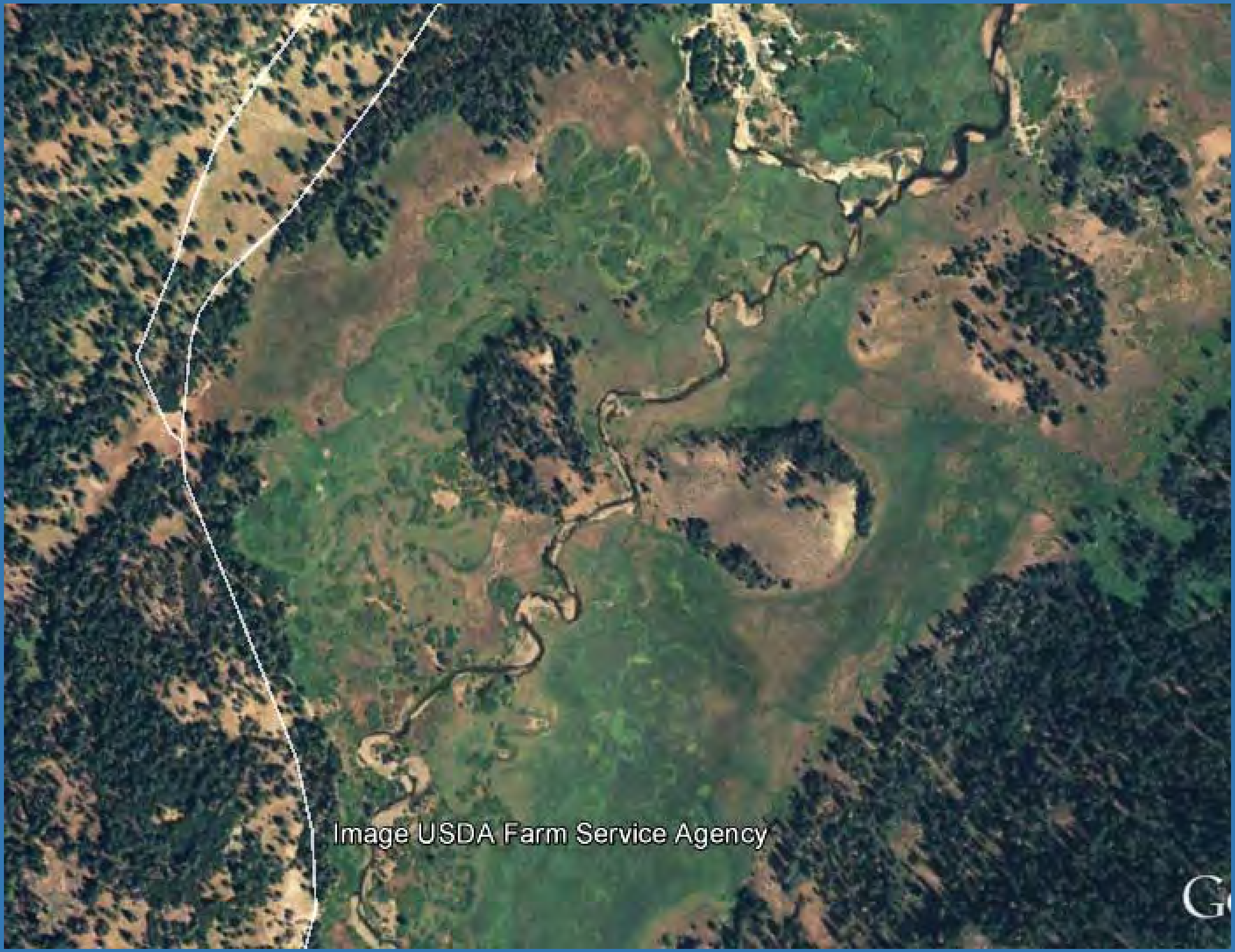
Perazzo Meadows Restoration Project, Sierra County, California

Perazzo Meadows Restoration Project, Sierra County, California

2007

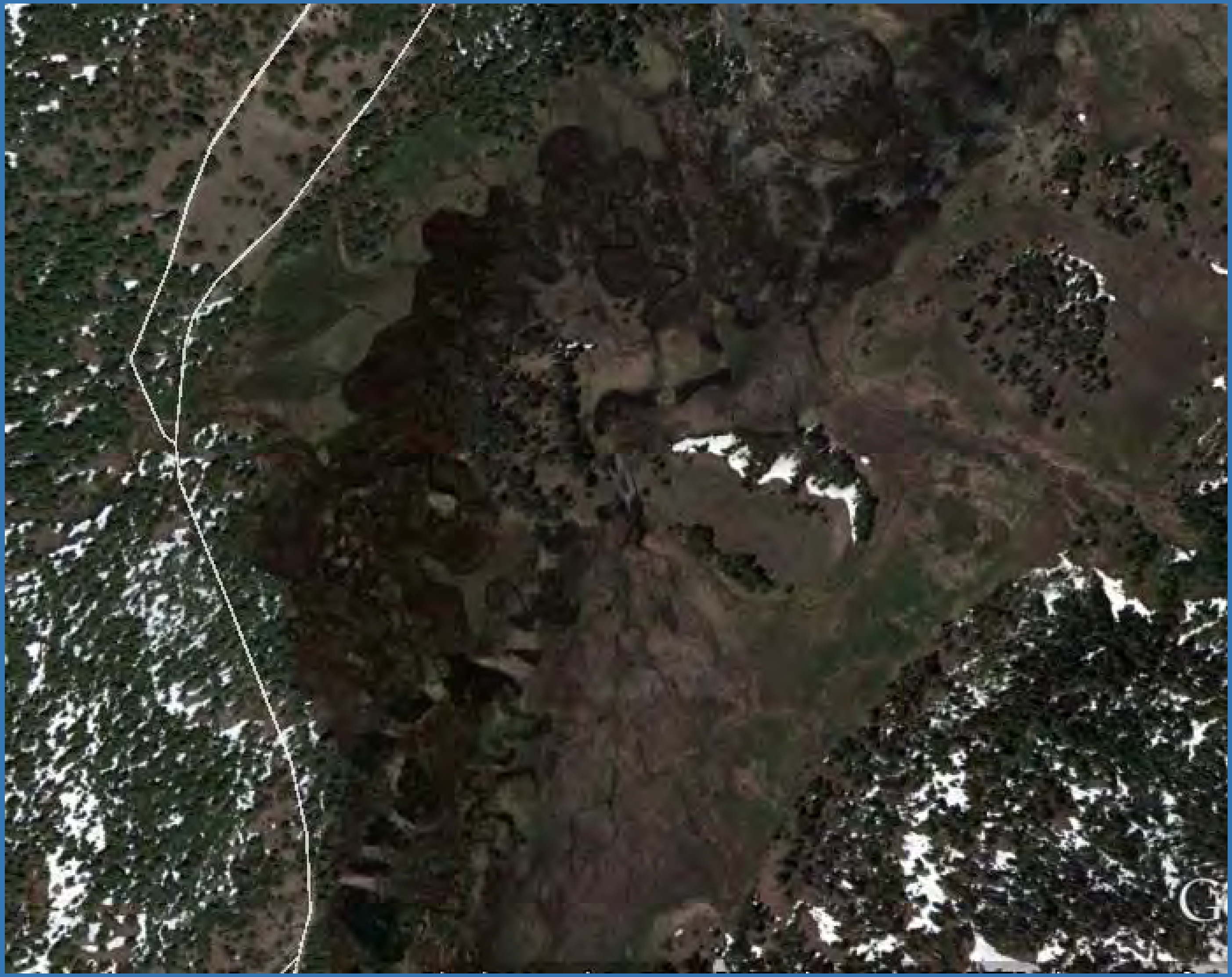
2012

Perazzo Meadows Restoration Project, Sierra County, California



June 2005

Perazzo Meadows Restoration Project, Sierra County, California

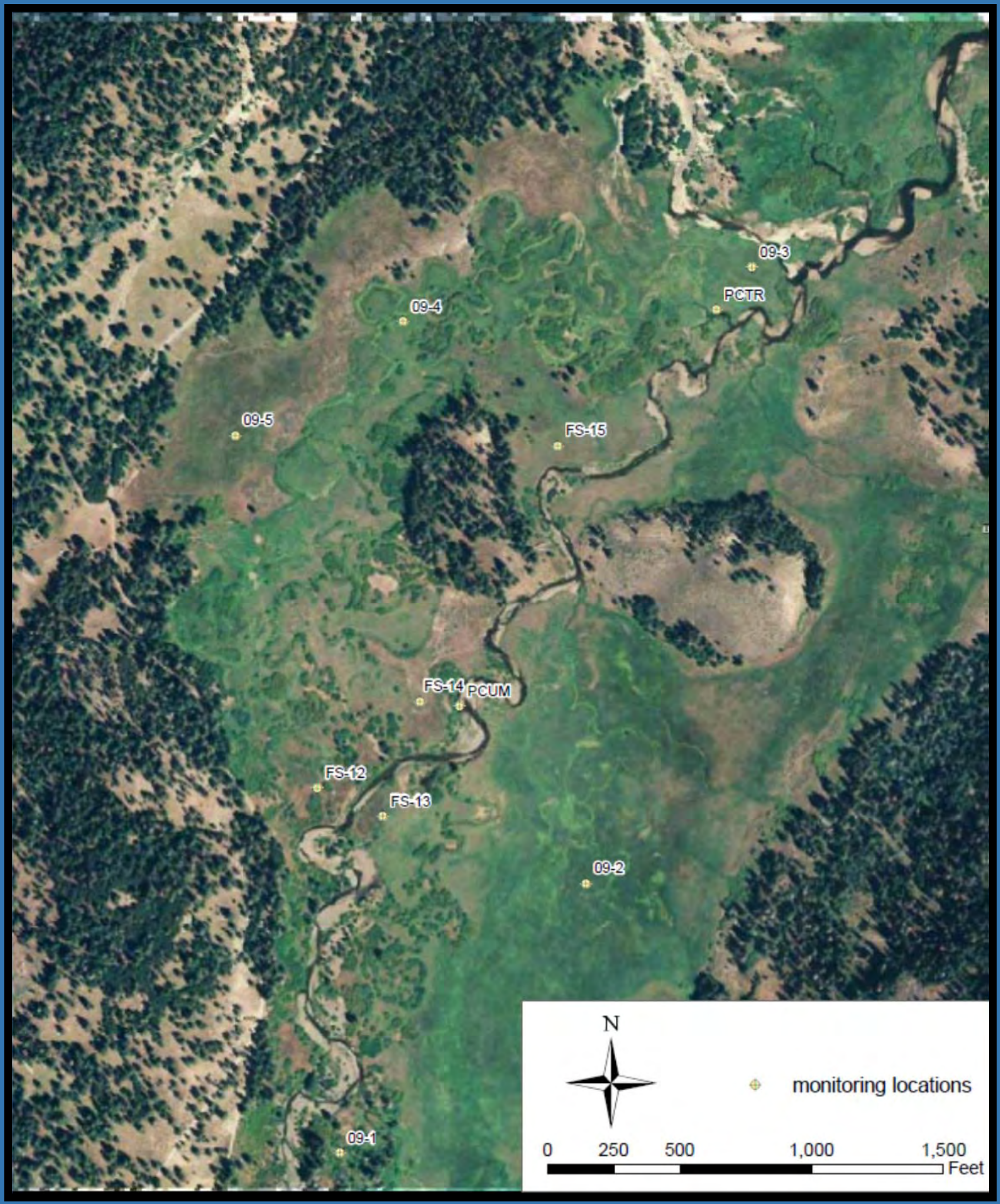


June 2011

Perazzo Meadows Restoration Project, Sierra County, California

August 2012

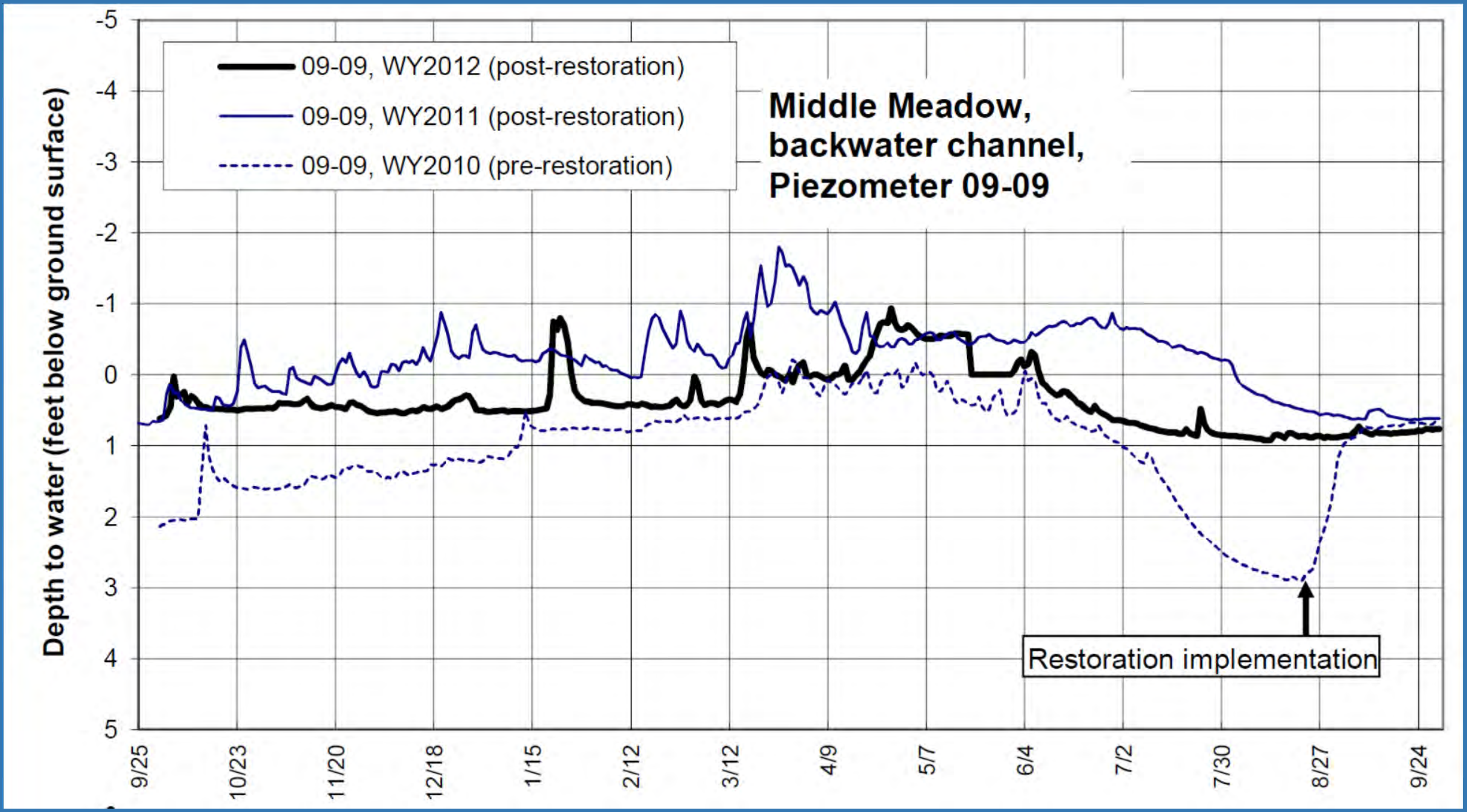
Groundwater Monitoring



Drive point piezometers

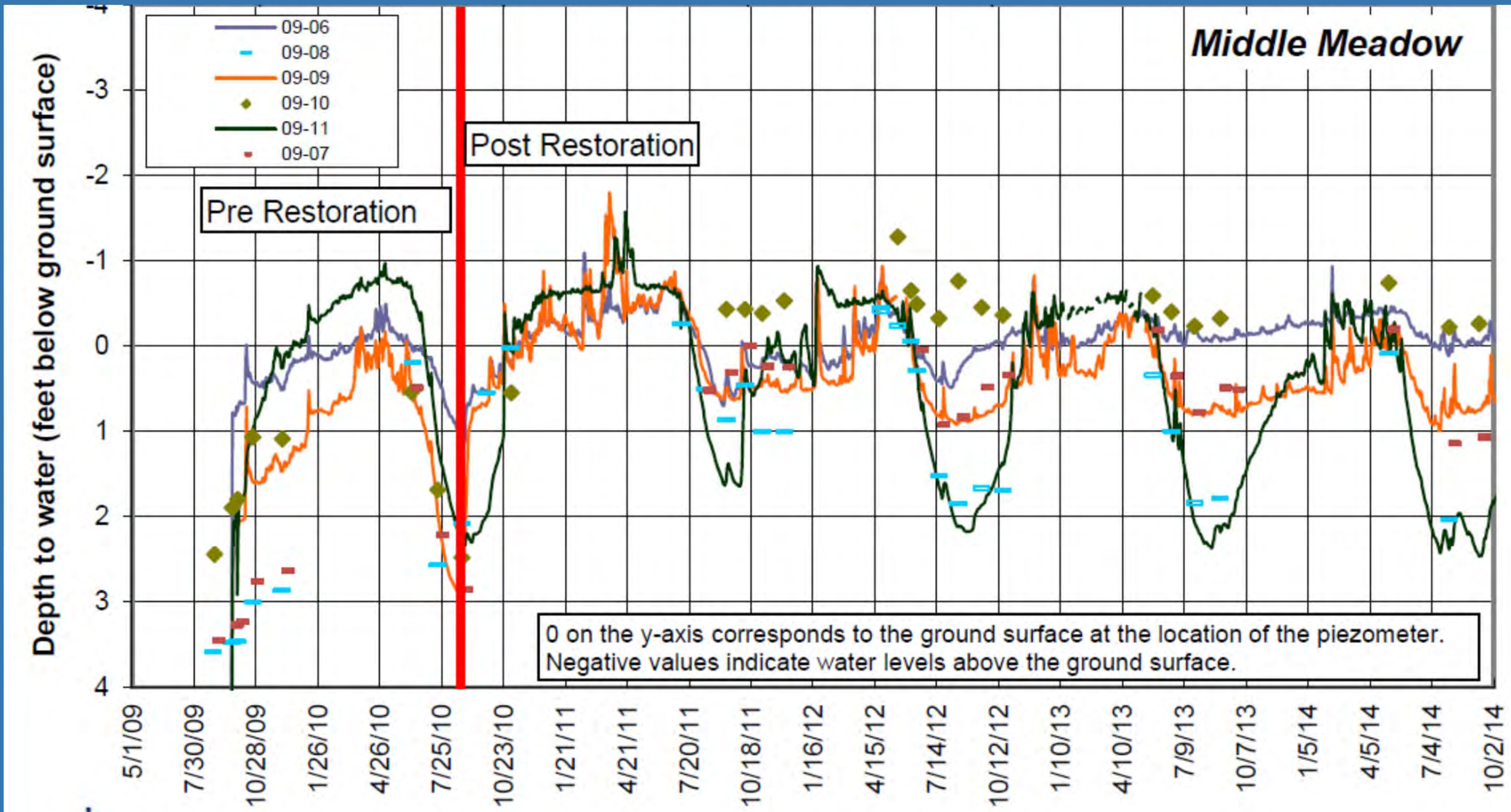
Perazzo Meadows Restoration Project, Sierra County, California

Plug and Pond restoration raises the water table, increases groundwater storage



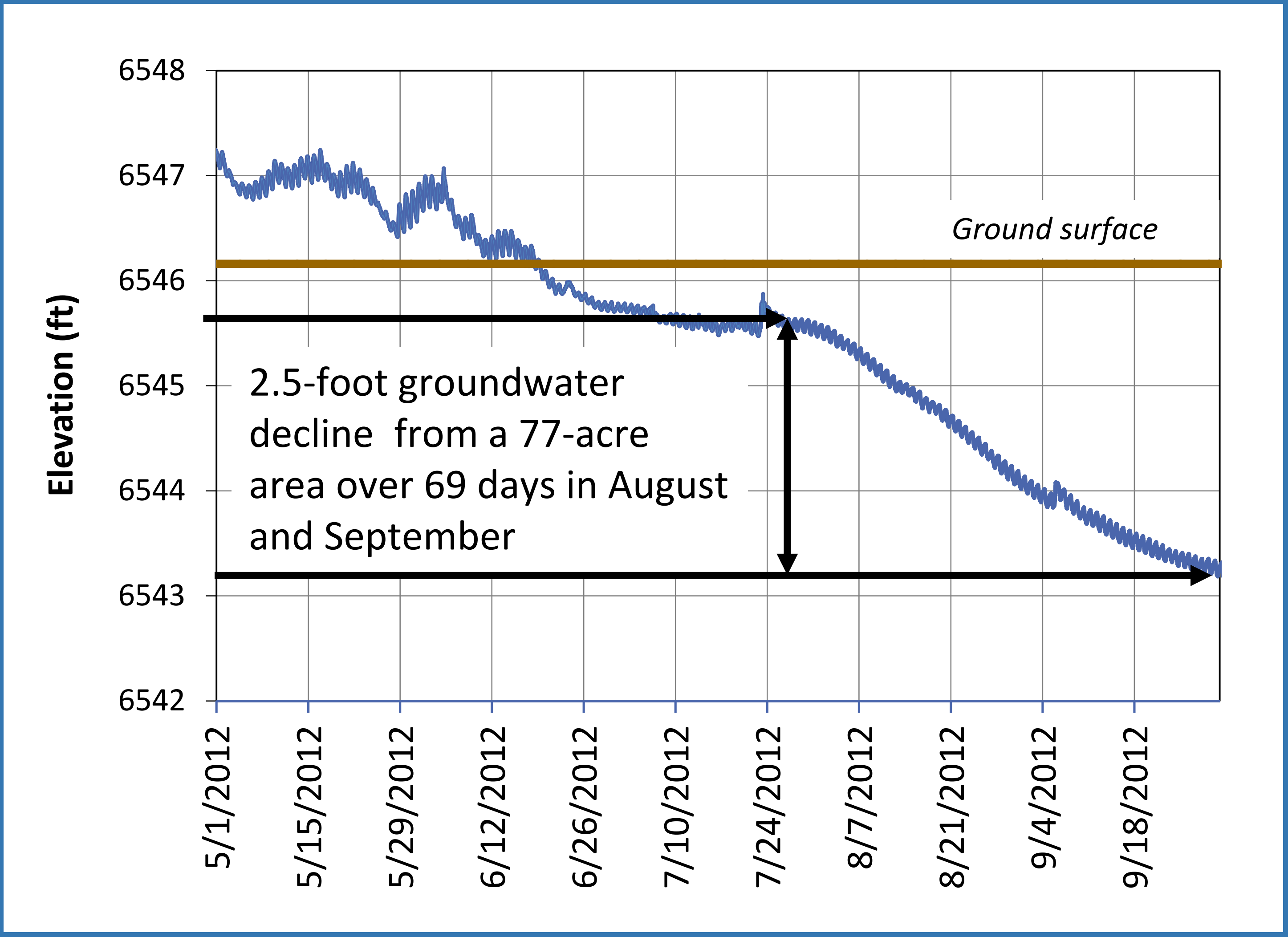
Perazzo Meadows Restoration Project, Sierra County, California

Variable groundwater response: 1 to 4-foot increase in summer groundwater conditions



Perazzo Meadows Restoration Project, Sierra County, California

Delayed release of groundwater from some areas

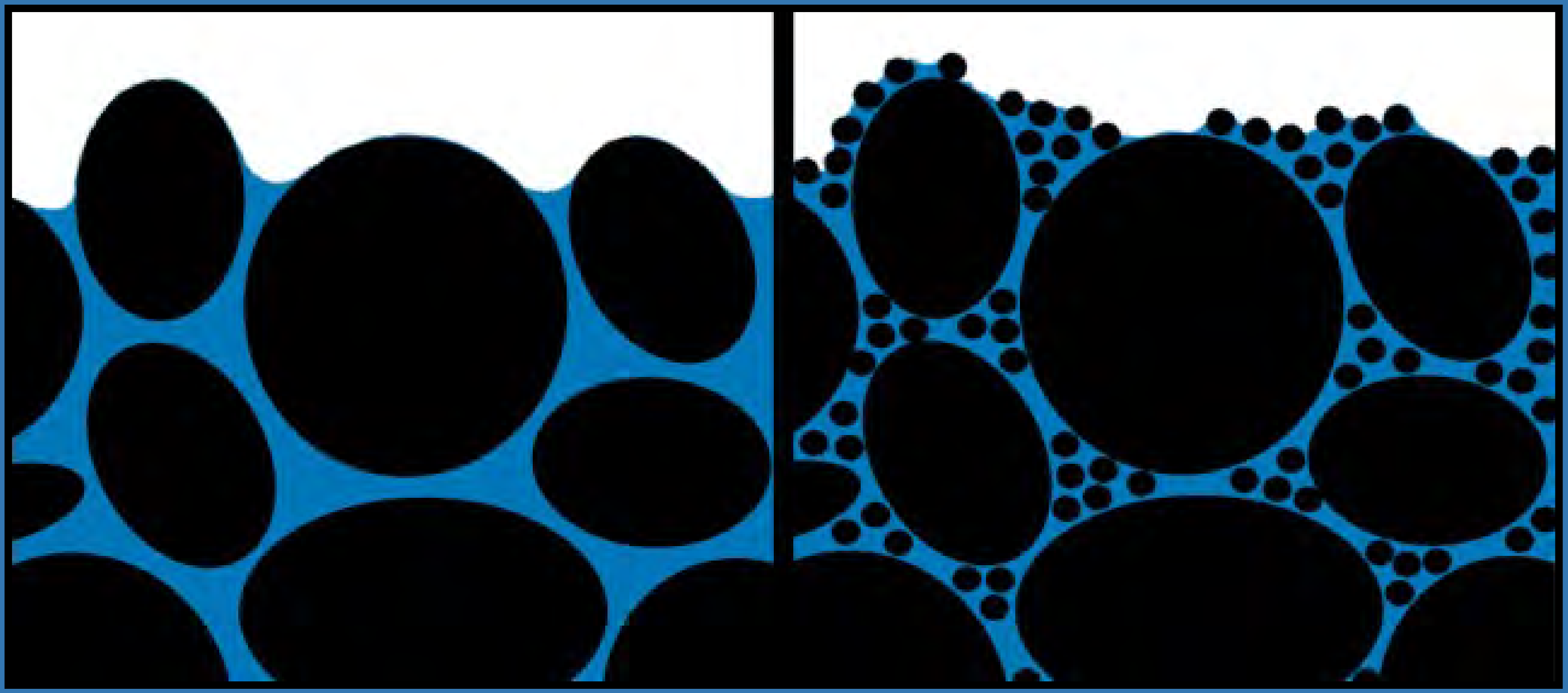


Perazzo Meadows Restoration Project, Sierra County, California

2.5-foot groundwater decline from a 77-acre area over 69 days

2.5 ft * 77 acres / 69 days = 2.8 ac-ft / day

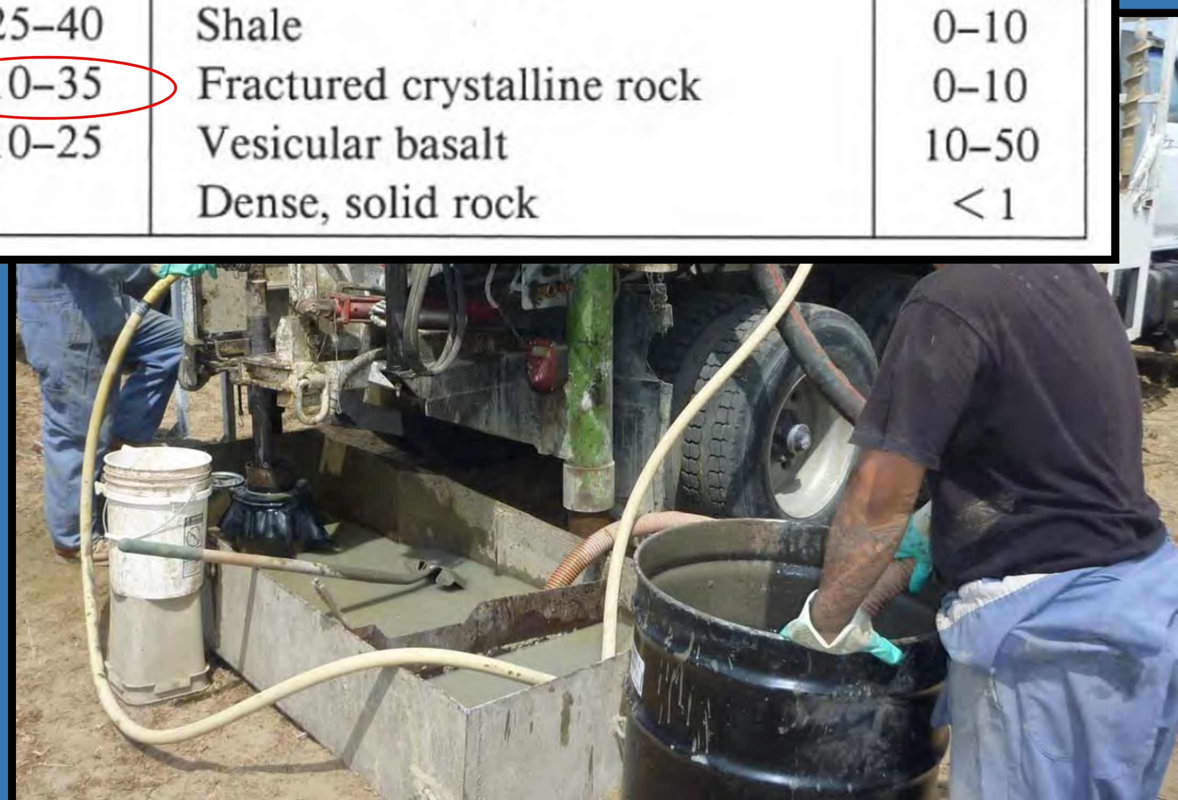
Porosity (Bulk Density)



Porosity (Bulk Density)

Table 5.1 Porosities for Common Consolidated and Unconsolidated Materials

Unconsolidated Sediments	η (%)	Consolidated Rocks	η (%)
Clay	45–55	Sandstone	5–30
Silt	35–50	Limestone/dolomite (original & secondary porosity	1–20
Sand	25–40	Shale	0–10
Gravel	25–40	Fractured crystalline rock	0–10
Sand & gravel mixes	10–35	Vesicular basalt	10–50
Glacial till	10–25	Dense, solid rock	< 1

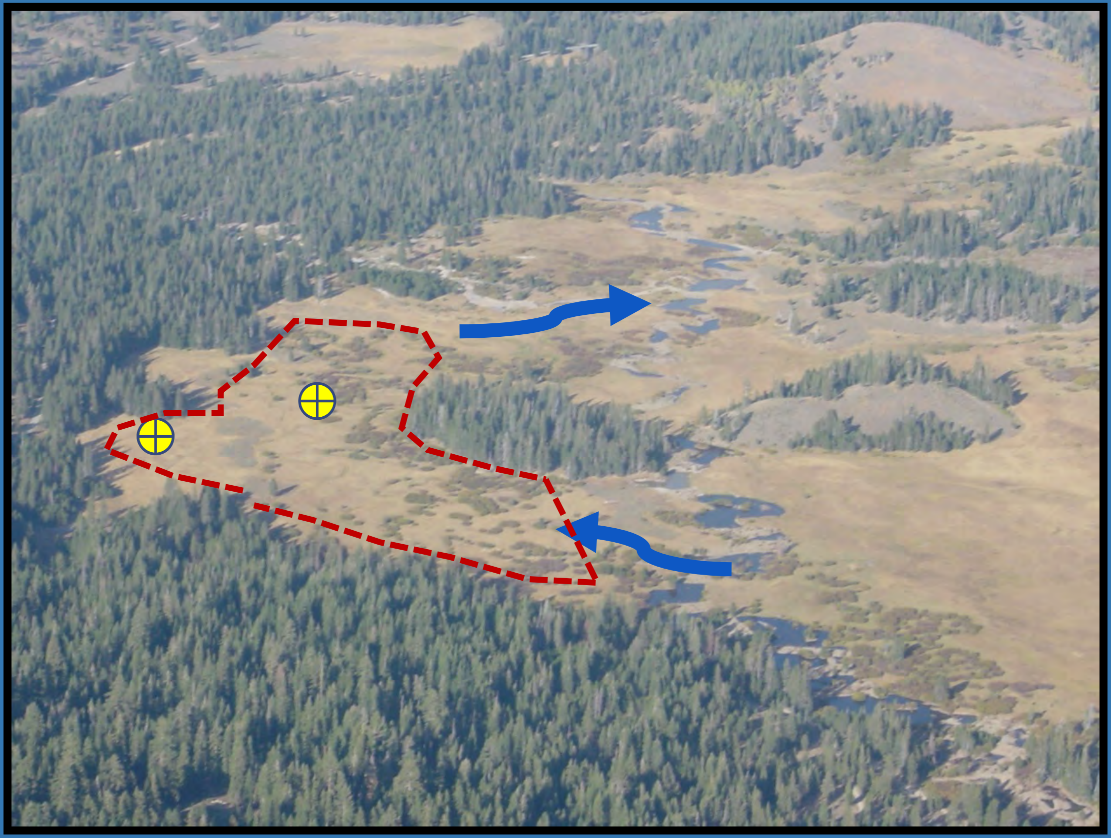


Perazzo Meadows Restoration Project, Sierra County, California

2.5-foot groundwater decline through the summer

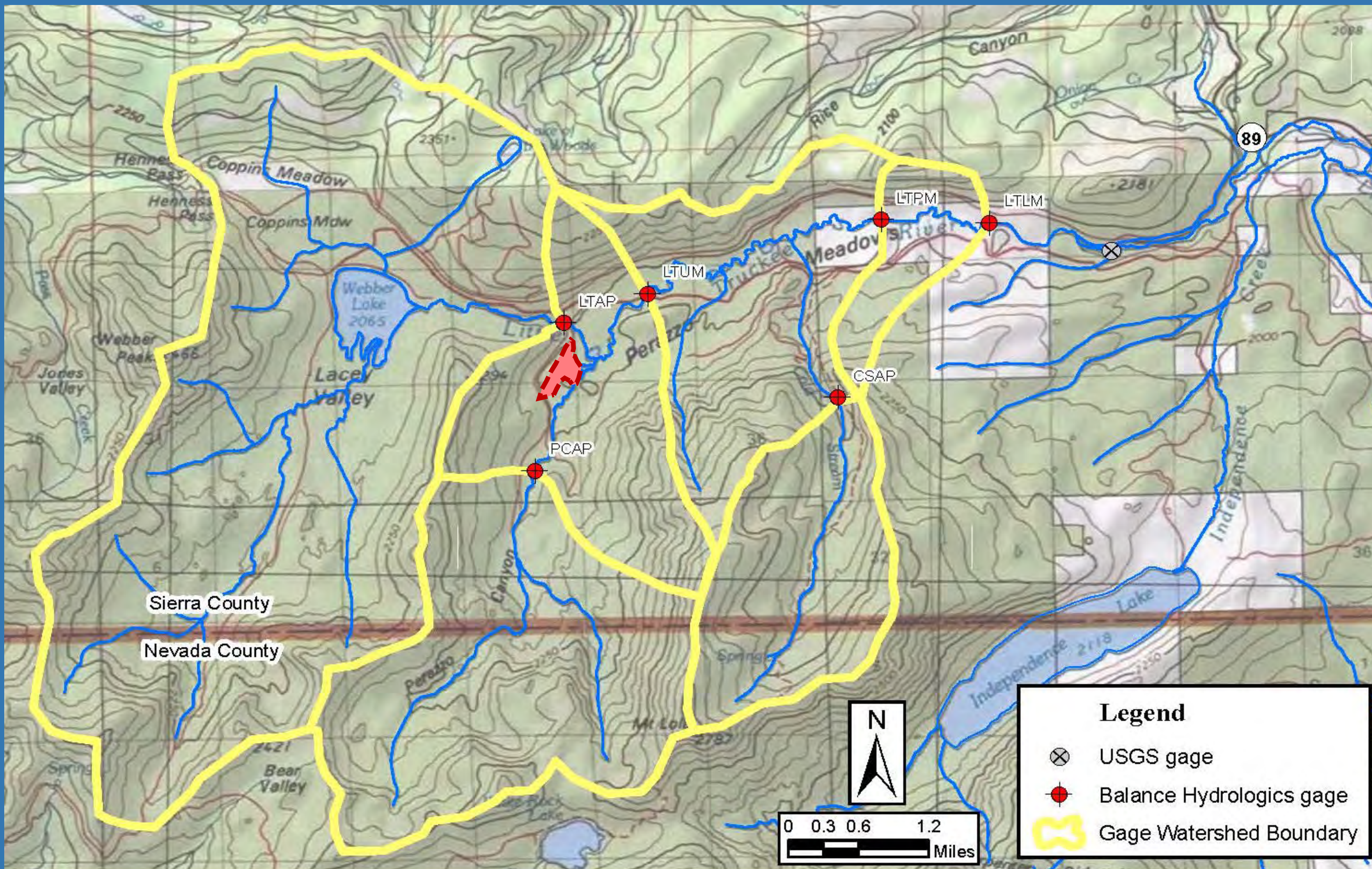
2.5 ft * 77 acres * **0.3** / 69 days = 0.84 ac-ft / day

0.84 ac-ft / day = 0.42 cfs



Perazzo Meadows Restoration Project, Sierra County, California

2.5-foot groundwater decline through the summer



Perazzo Meadows Restoration Project, Sierra County, California

2.5-foot groundwater decline through the summer

2.5 ft * 77 acres * **0.3** / 69 days = 0.84 ac-ft / day

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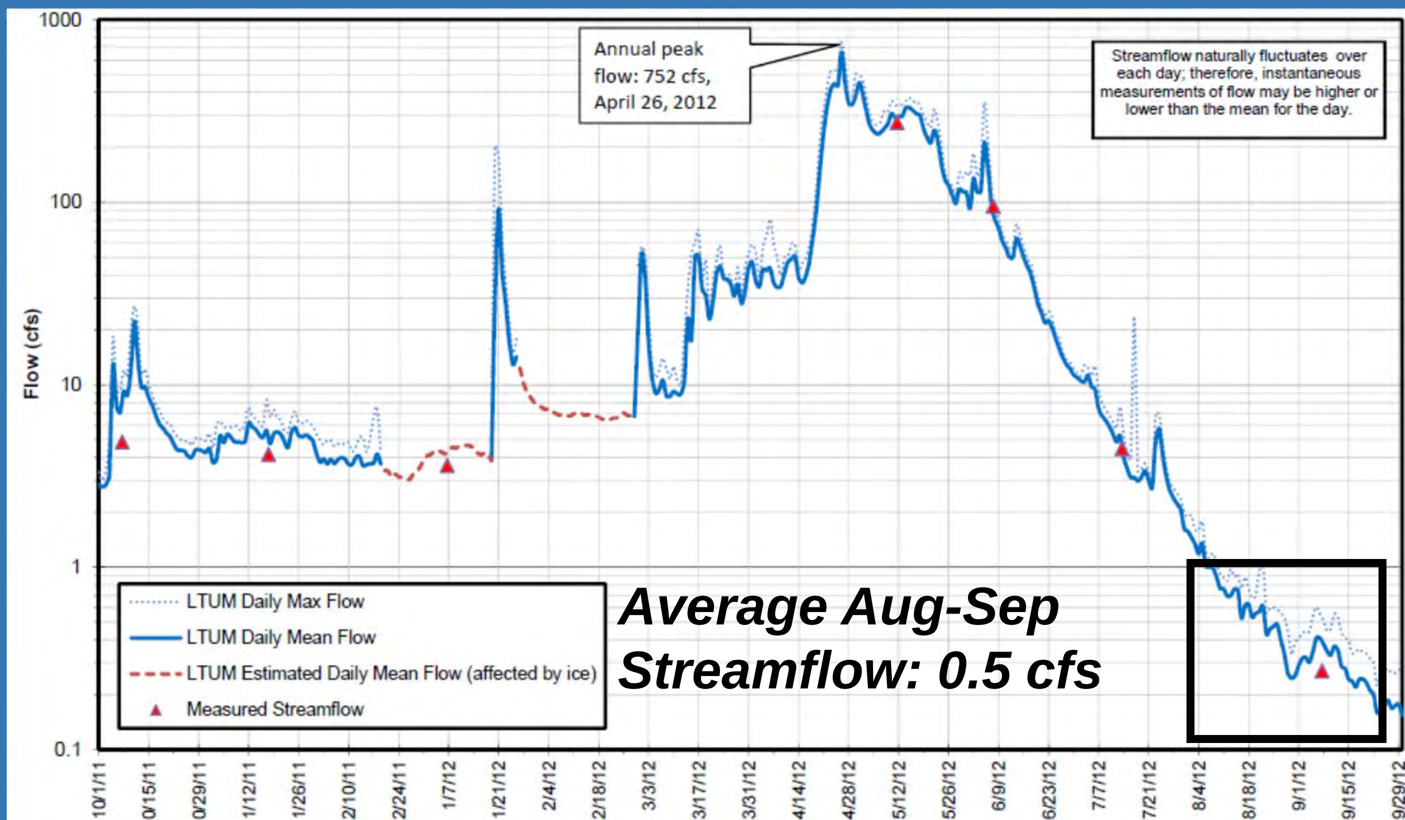


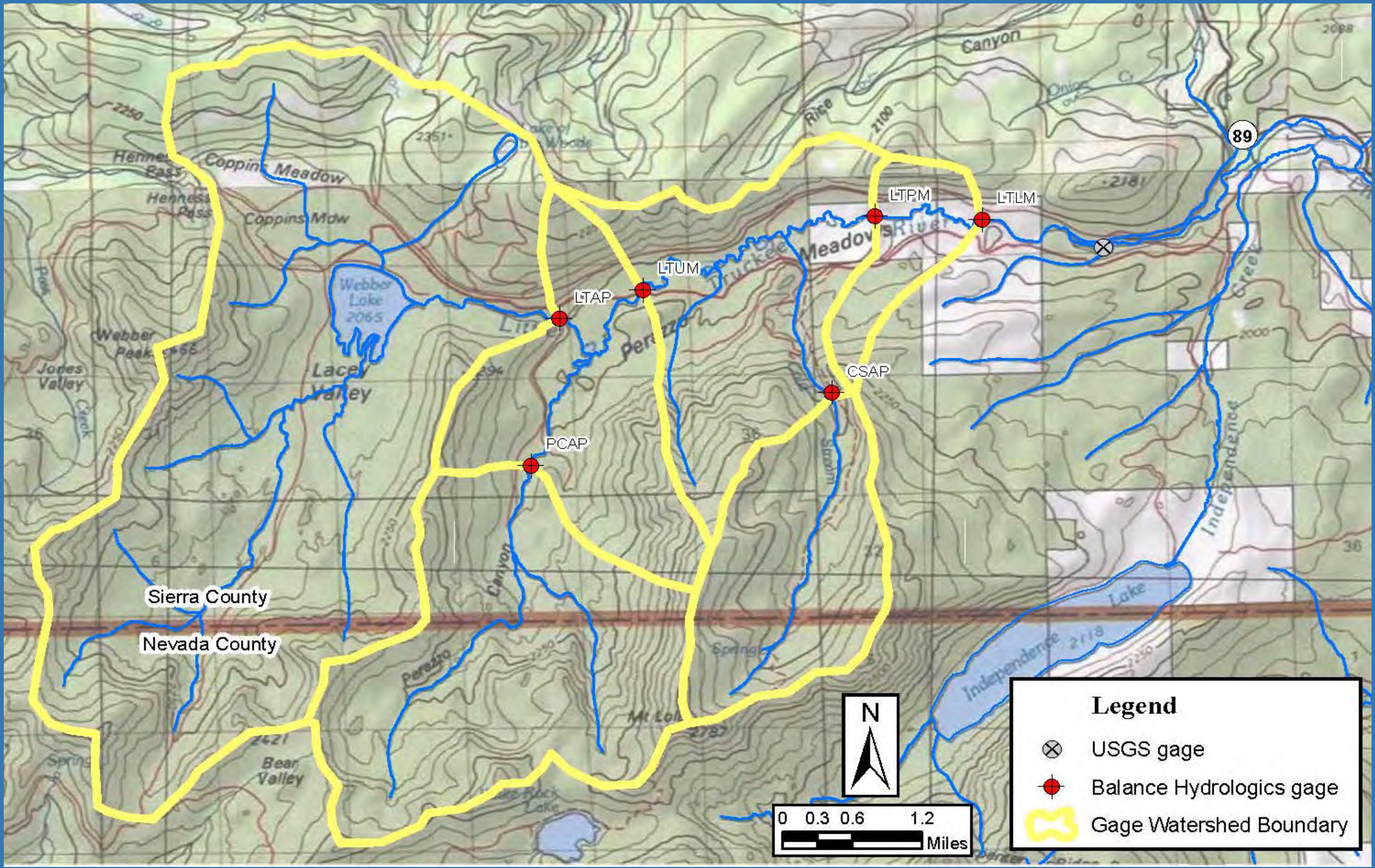
Summary

Standard principles of groundwater flow, in conjunction with accurate field data collection, can be used to project the effects of restoration on groundwater storage and recharge

Pre-project calculations can be used to inform design and evaluate feasibility

Restoration of Perazzo Meadows caused an increase in August and September 2012 streamflow of 0.4 cfs. This accounts for over 50% of the total flow at that location and 15% of the flow at


Thank you:
Truckee River Watershed Council
USFS Tahoe National Forest
Questions


LTPM
LTLM
LTUM
LTAP
CSAP
PCAP
Sierra County
Nevada County
Webber Lake
Meadows
Independence Lake
89
N
0 0.3 0.6 1.2
Miles
Legend
USGS gage
Balance Hydrologics gage
Gage Watershed Boundary

"Plug and Pond"

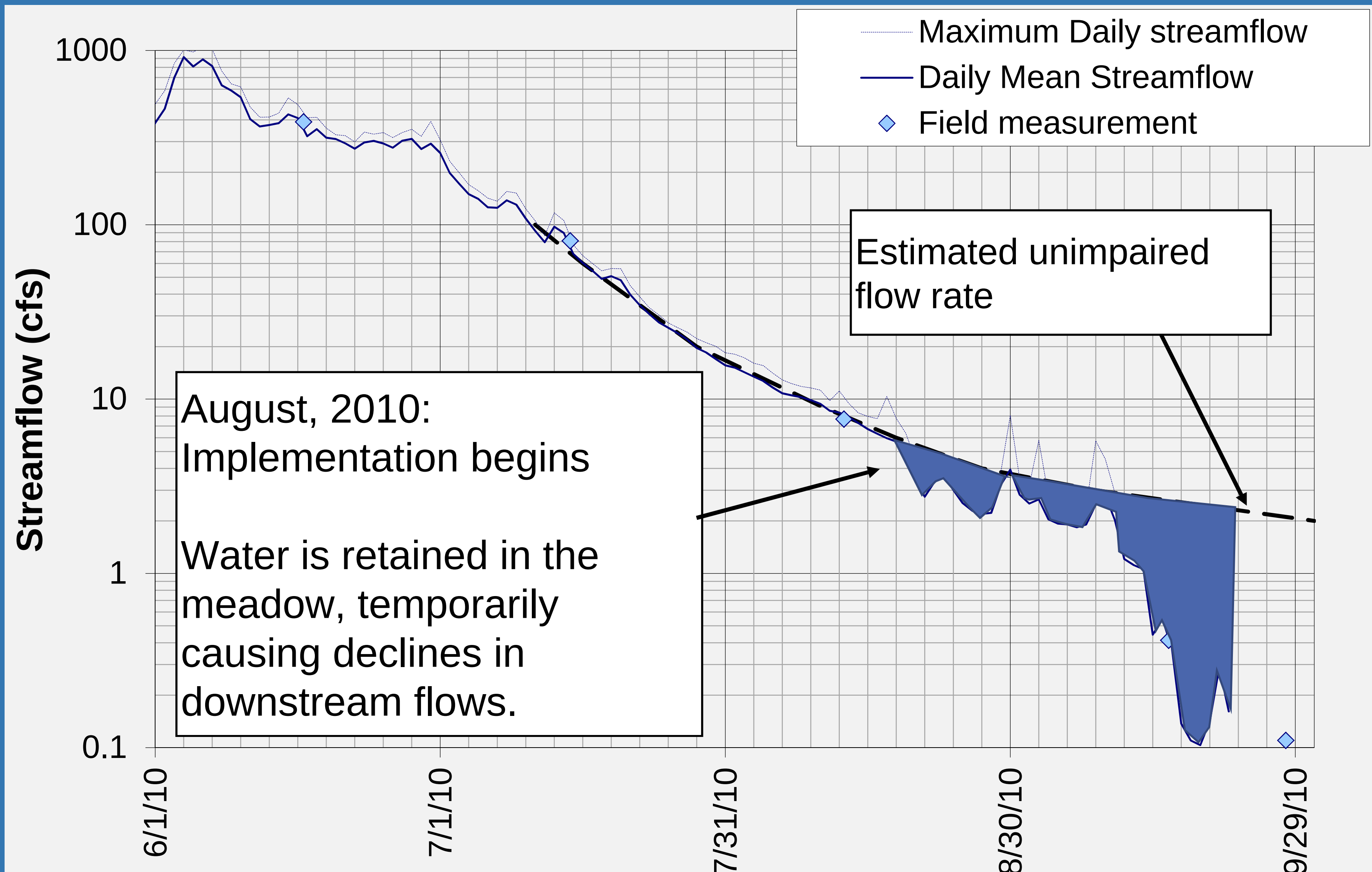
Before implementation:

August 2009

After implementation:

August 2012

Perazzo Meadows Restoration Project, Sierra County, California

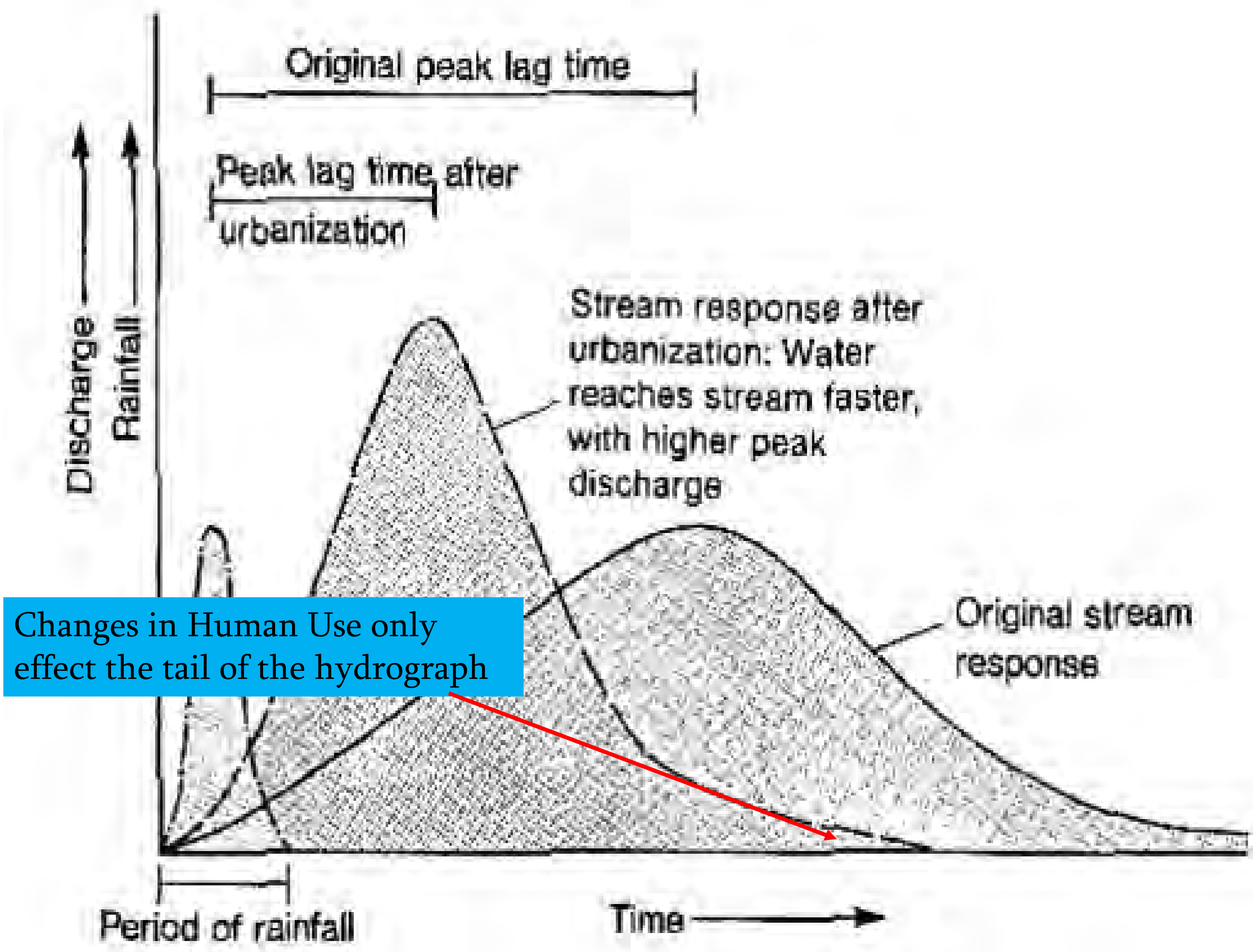

Maximum Daily streamflow
Daily Mean Streamflow
Field measurement
Estimated unimpaired flow rate
August, 2010: Implementation begins
Water is retained in the meadow, temporarily causing declines in downstream flows.
Streamflow (cfs)
1000
100
10
1
0.1
6/1/10
7/1/10
7/31/10
8/30/10
9/29/10

Sanctuary Forest

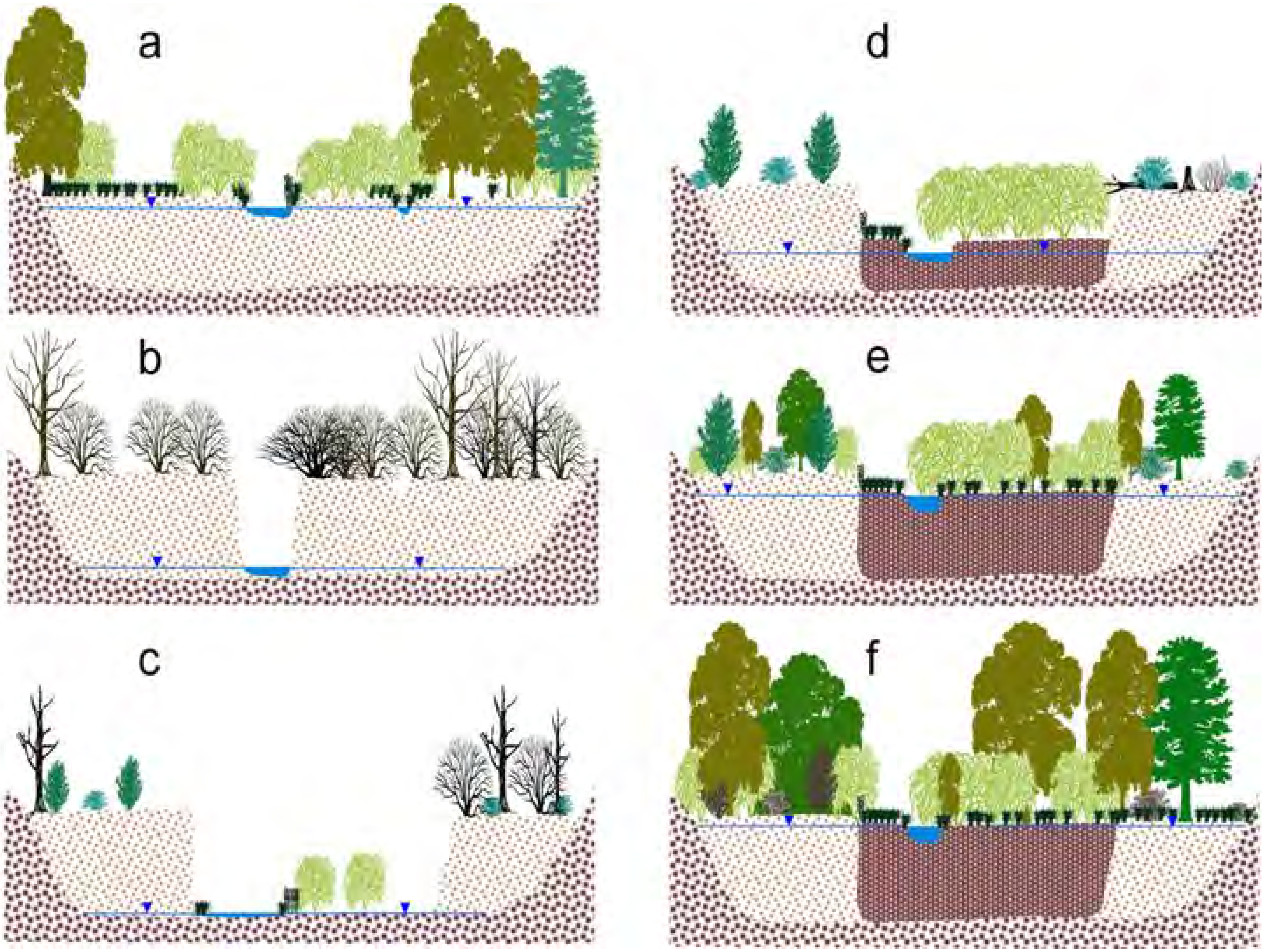
Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land."

—LUNA LEOPOLD

The Mattole Watershed
Rainbow Ridge
Lower North Fork Mattole
Taylor Peak
101
Petrolia
Mattole River
Prosper Ridge
Squaw Cr.
Mattole River
Upper North Fork Mattole
Honeydew
Gilham Butte
Wilder Ridge
Mattole Canyon Cr.
King Peak
Ettersburg
Telegraph Ridge
Bear Cr.
Garberville
Briceland
King Range National Conservation Area
Eubank Cr.
Thorn Junction
Shelter Cove
Whitethorn
Chemise Mountain
Humboldt Co.
Mendocino Co.
Elevation in feet
> 2500
1501 - 2500
1001 - 1500
501 - 1000
251 - 500
< 250
Peaks
Critical Coastal Areas
Mattole Watershed Boundary
Humboldt State Redwoods Park
King Range National Conservation Area
Punta Gorda Marine Potection Area
Area of Special Biological Significance
0 2.5 5 Miles


Original peak lag time
Peak lag time after urbanization
Discharge
Rainfall
Stream response after urbanization: Water reaches stream faster, with higher peak discharge
Original stream response
Changes in Human Use only effect the tail of the hydrograph
Period of rainfall
Time

Stream Incision and Loss of Groundwater



Entrenched streams

Restoring Streamflow for Fish, Wildlife and People

Learning From

Historic Mattole Instream Ponds

Beaver Ponds, Pacific Northwest

Historic Role of Large Wood

Dry Childhood Creek –Summer 1967

Instream Pond

Chris Maser 2005 - “this pond is similar to a beaver dam pond”

Beaver Dam Pond - Tributary to Alsea River

Pilot Research Project

Develop hypotheses, desired outcomes, and potential risks analyses

Perform site evaluation and pre- project monitoring

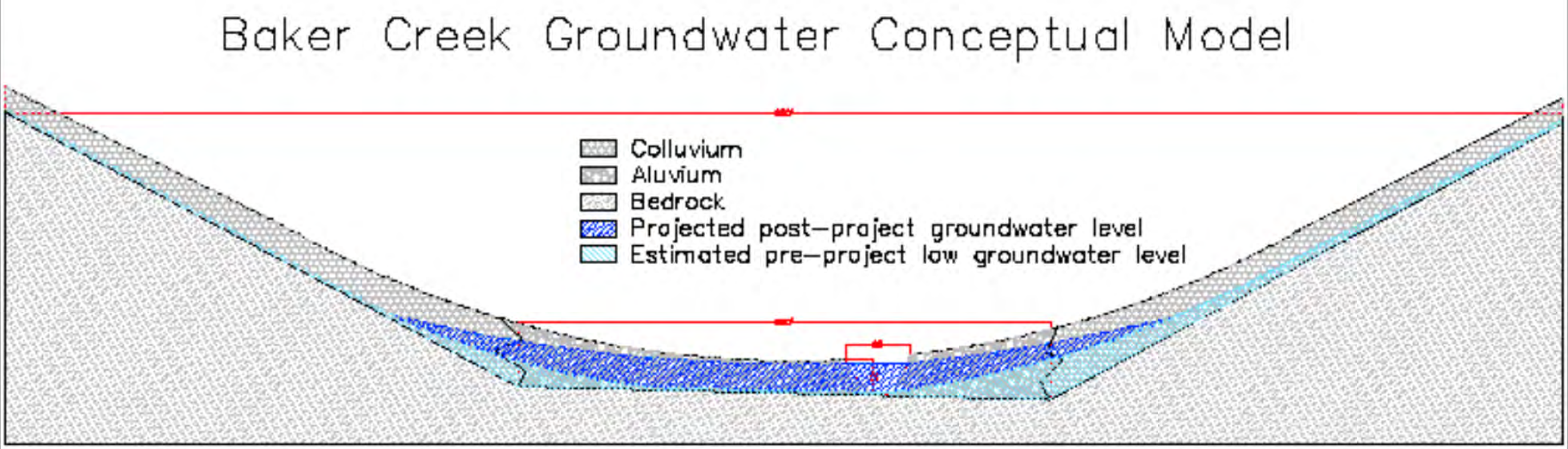
- longitudinal profiles, valley cross-sections and existing groundwater levels

Place instream logs to effect channel hydrologic and morphologic processes (place logs to reconnect offstream pond, swale, and floodplain)

Perform post project monitoring and evaluation

- Coho response, longitudinal profiles, groundwater levels, streamflow

Use project outcomes to further the science of habitat recovery for salmonids in the Mattole and beyond

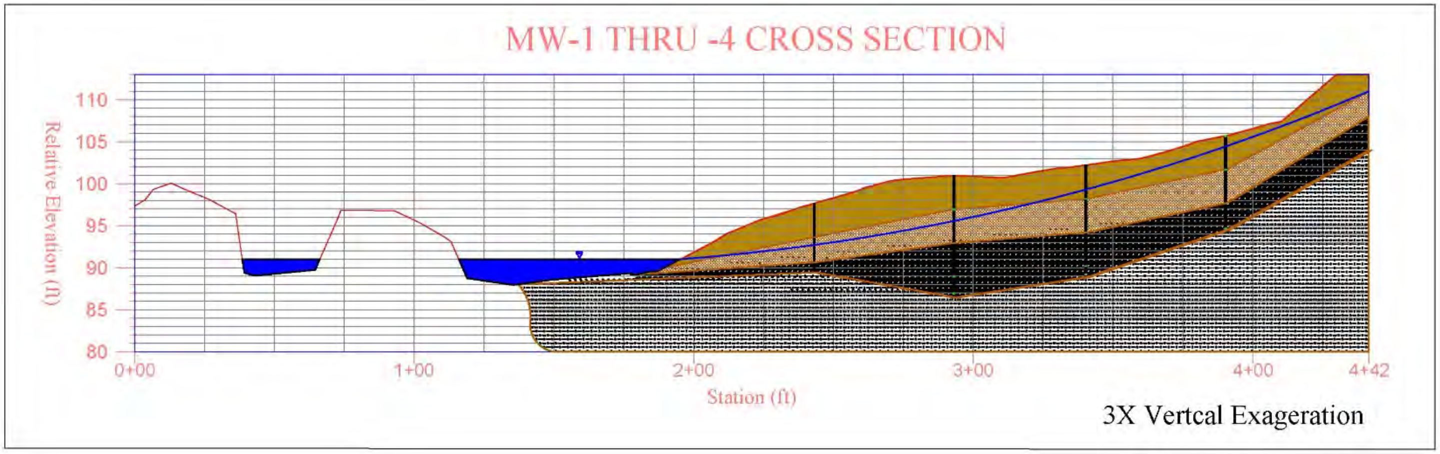


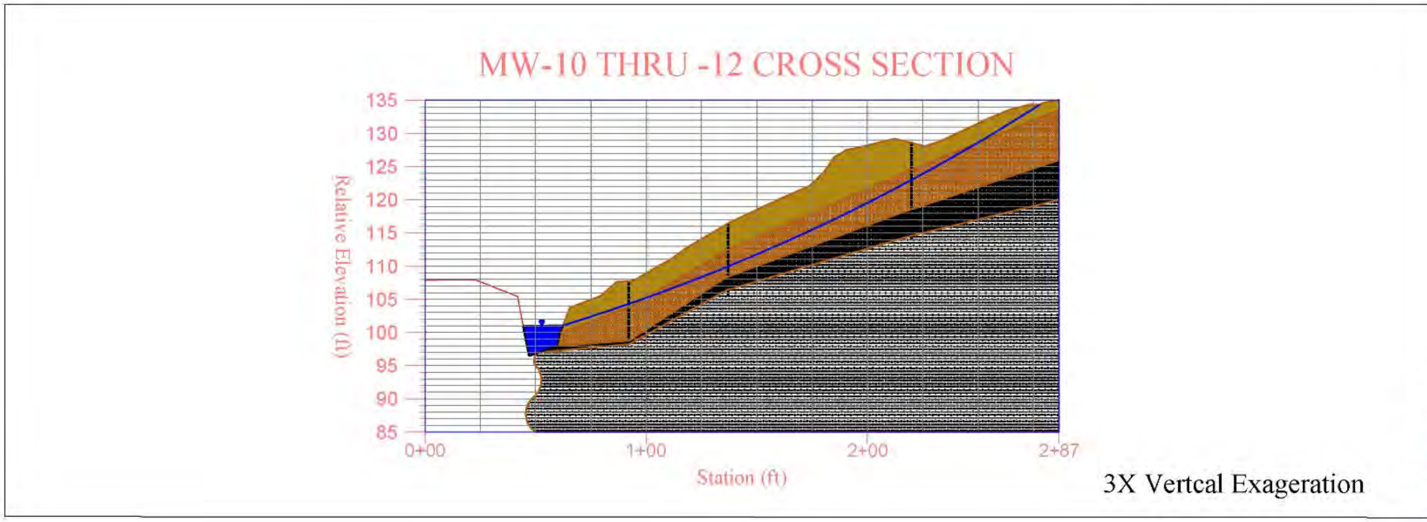
Estimated increase in groundwater storage and summer streamflow:

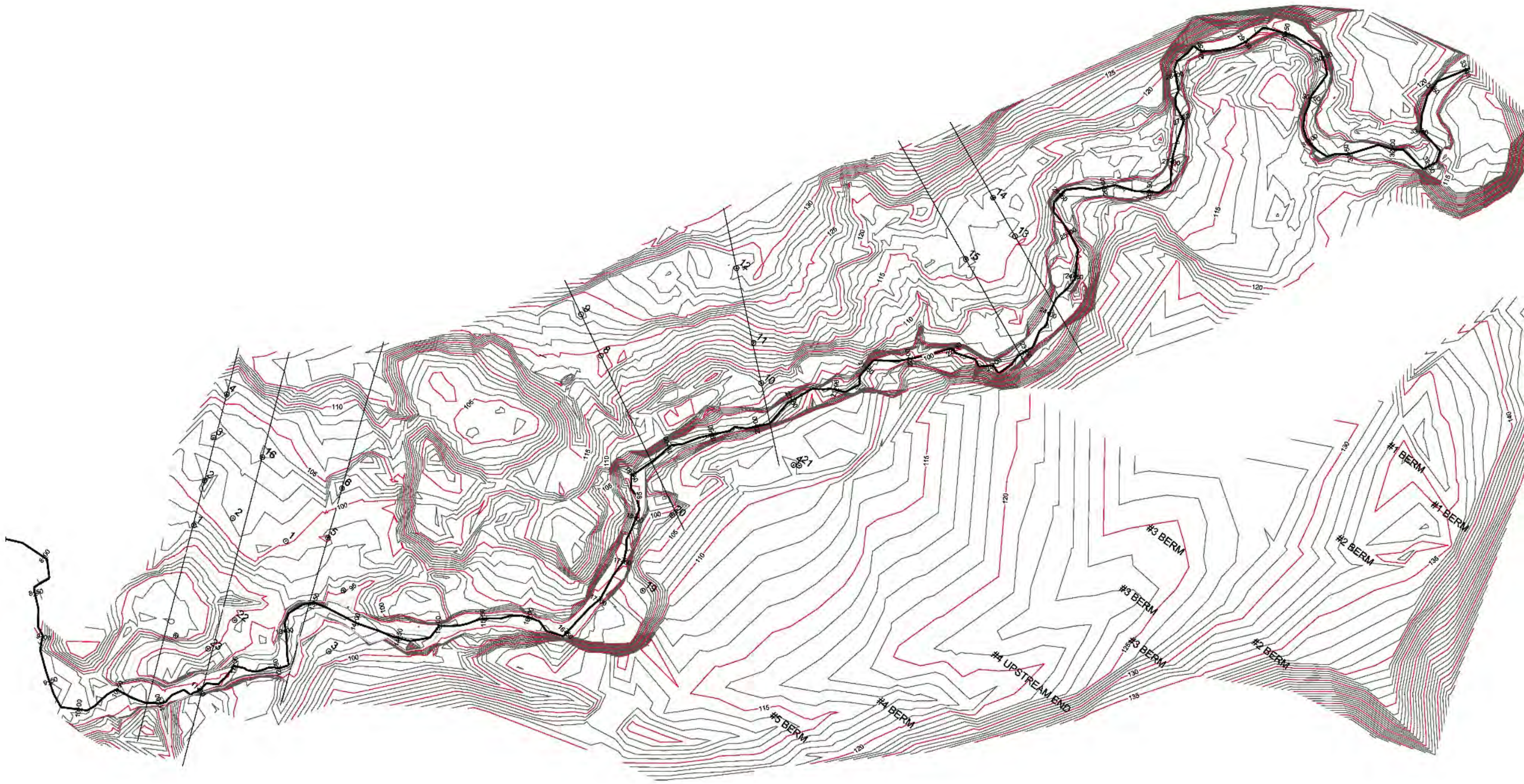
Maximum: 4 million gallons and 23 GPM average over 120 days

Minimum: 2 million gallons and 12 GPM average over 120 days

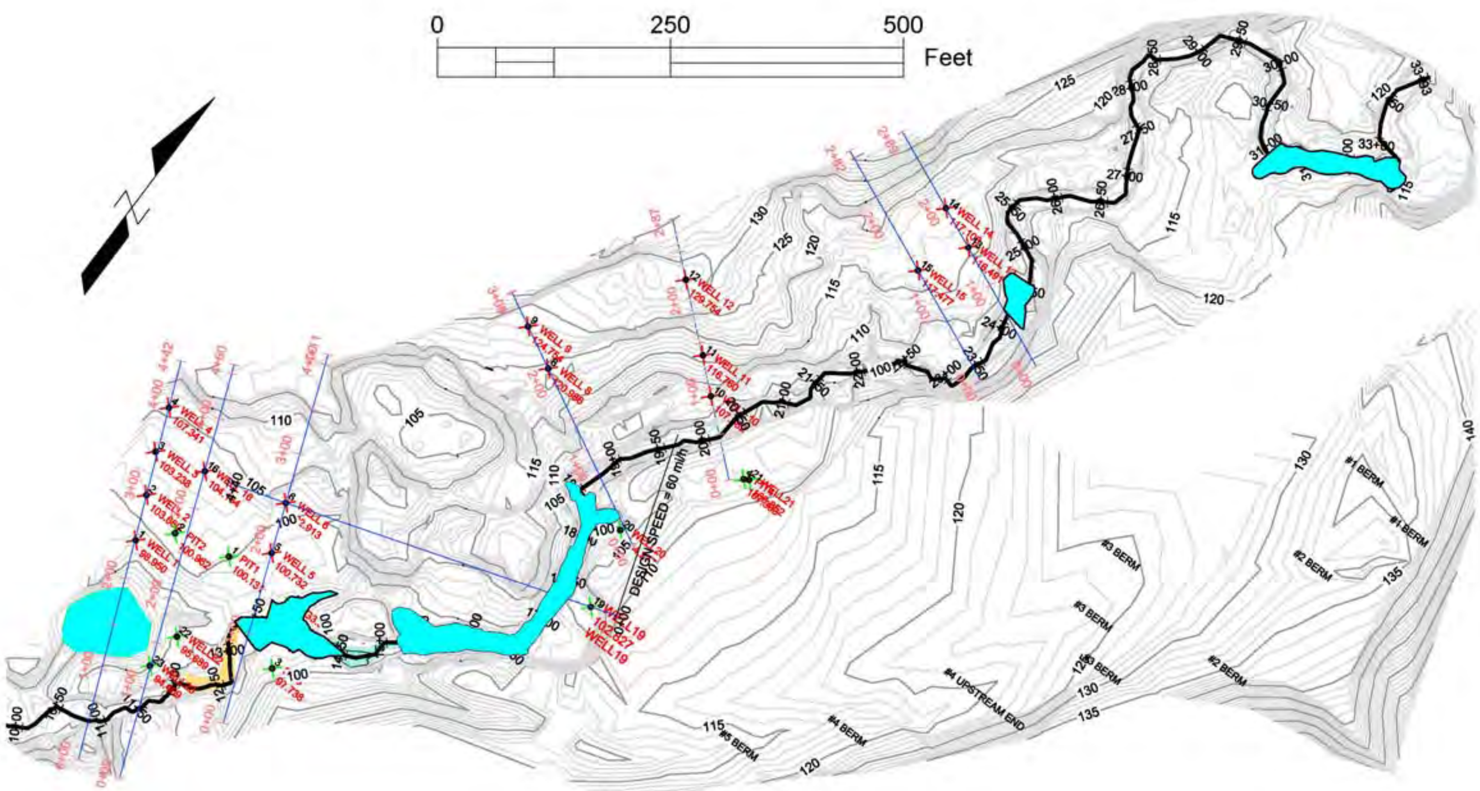
Assumptions: 6 ft rise in groundwater level over 1100 feet of valley length; maximum = valley width of 600 feet; minimum = valley width of 300 feet


MW-1 THRU -4 CROSS SECTION
Relative Elevation (ft)
110
105
100
95
90
85
80
0+00
1+00
2+00
3+00
4+00
4+42
Station (ft)
3X Vertcal Exageration


MW-10 THRU -12 CROSS SECTION
Relative Elevation (ft)
135
130
125
120
115
110
105
100
95
90
85
0+00
1+00
2+00
2+87
Station (ft)
3X Vertcal Exageration

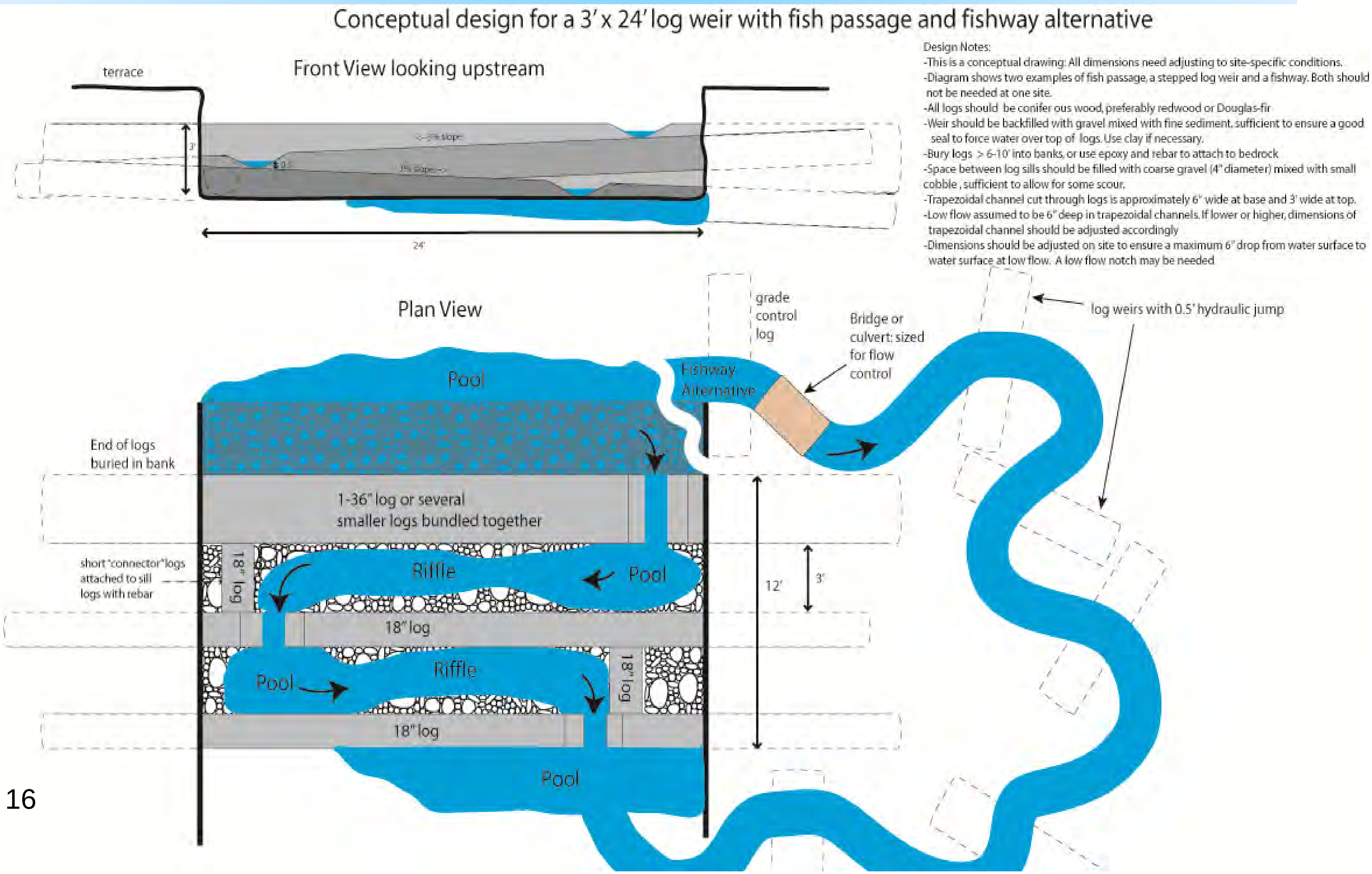


Baker Creek
Topography, Wells, Pits
Feb, 2015



Baker Creek
Extent of Inundation Associated with Structures

Log Step Pools/Check-Dams

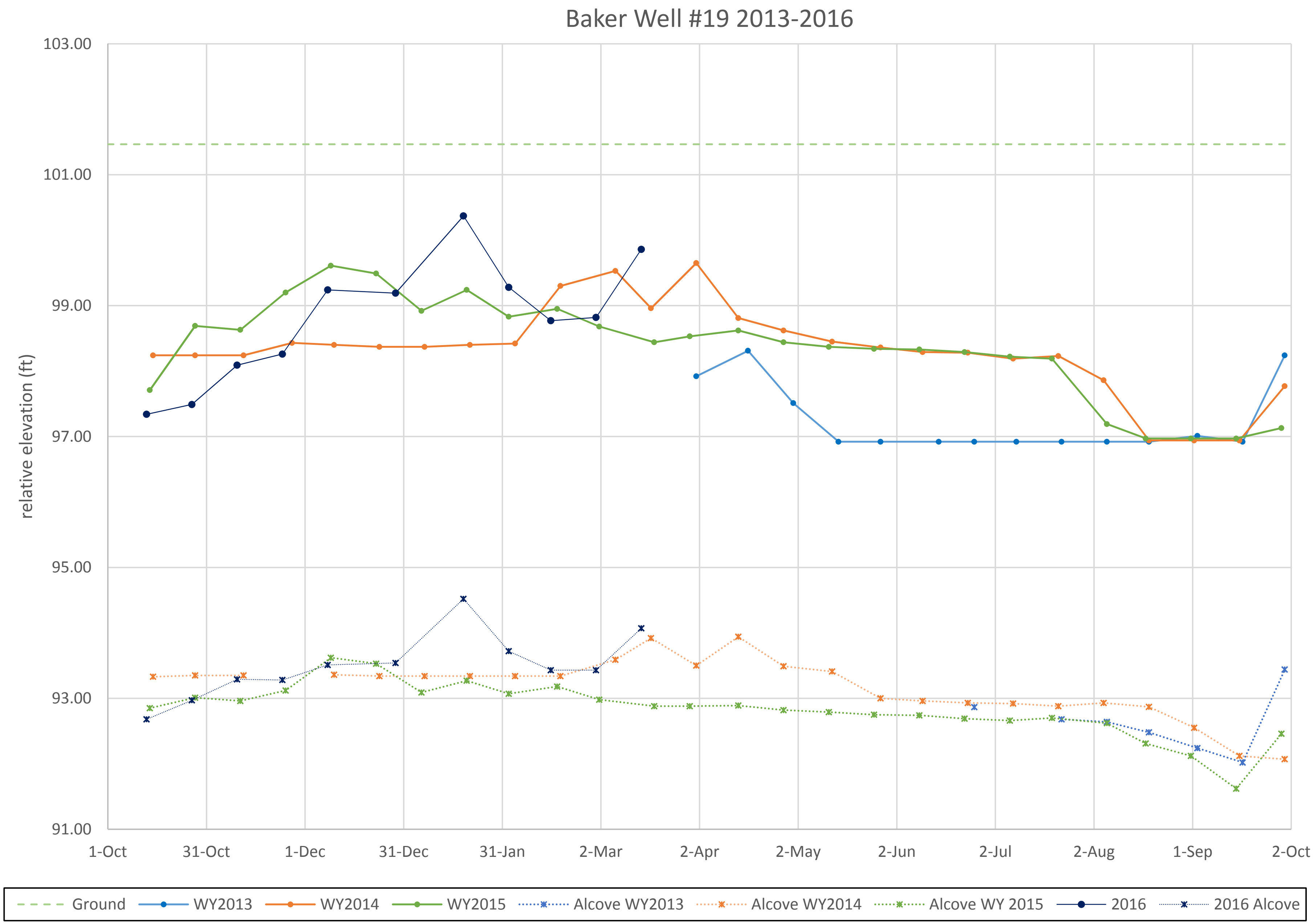


16

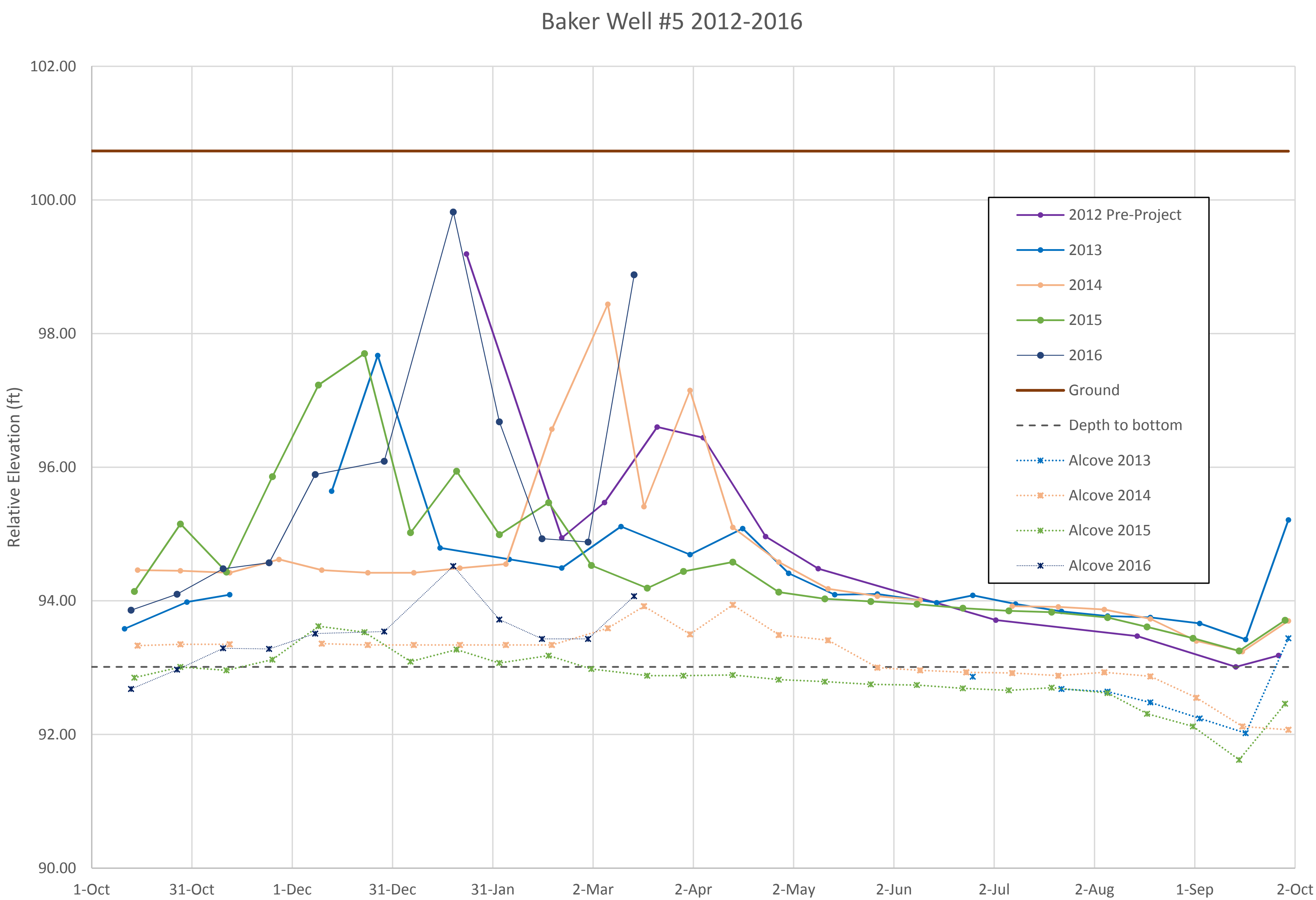

12.06.2015

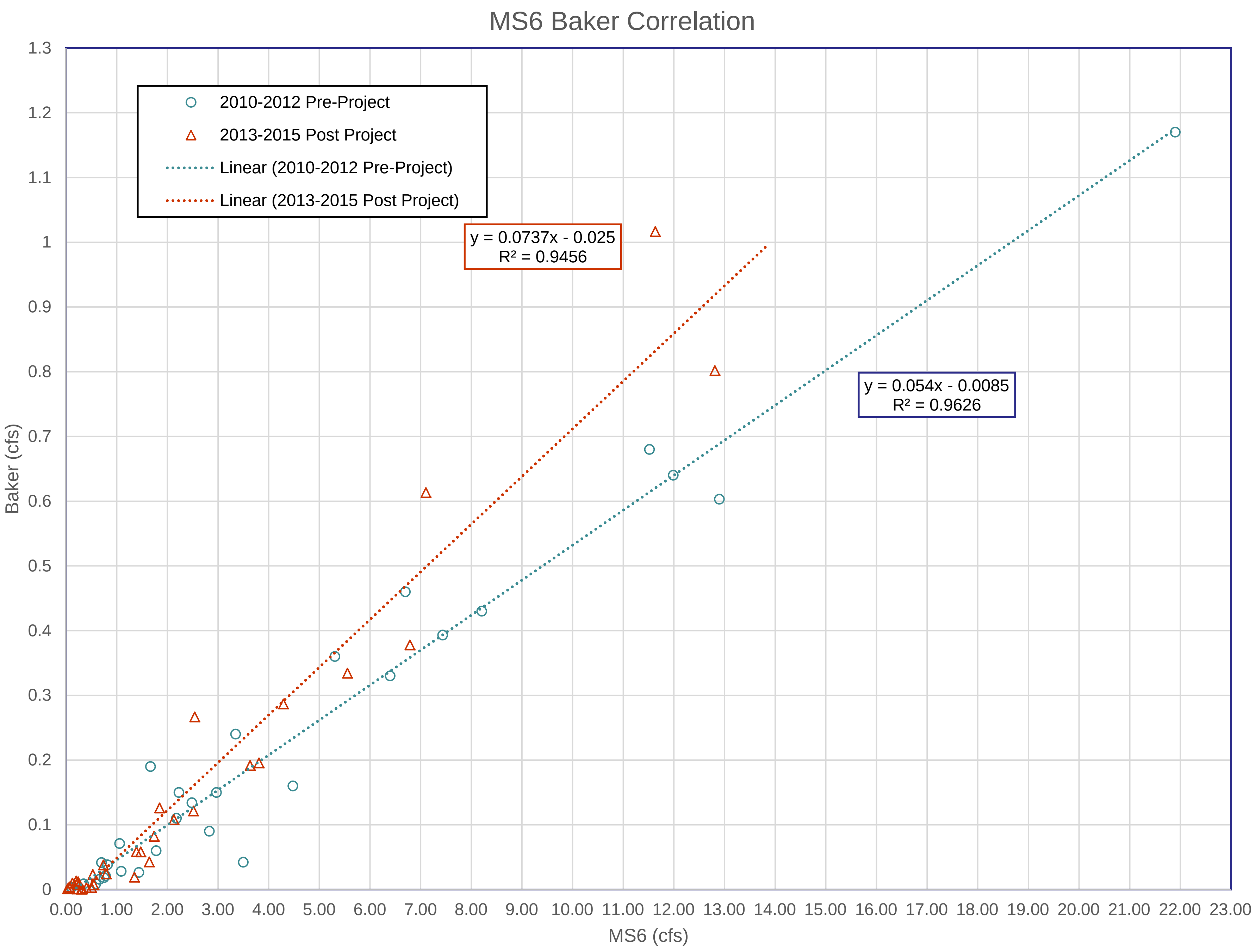
Baker Creek Groundwater Outcomes

- Increase in groundwater elevation within 50 ft of channel or adjacent to alcove/pond
- Groundwater elevation increase ~ equivalent to surface water increase
- Rate of groundwater declining limb less steep and lasted later in the season (even with drier year)
- Groundwater challenges-
  - Channel straightened
  - Channel deeply incised (4-8ft) and incised into bedrock
  - Fish passage constraints (difficult to raise surface water >3 ft)
  - Aggradation & full reconnection (10 + years)



Baker Well #19 2013-2016
103.00
101.00
99.00
97.00
95.00
93.00
91.00
relative elevation (ft)
1-Oct
31-Oct
1-Dec
31-Dec
31-Jan
2-Mar
2-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
Ground
WY2013
WY2014
WY2015
Alcove WY2013
Alcove WY2014
Alcove WY 2015
2016
2016 Alcove


Baker Well #5 2012-2016
Relative Elevation (ft)
102.00
100.00
98.00
96.00
94.00
92.00
90.00
1-Oct
31-Oct
1-Dec
31-Dec
31-Jan
2-Mar
2-Apr
2-May
2-Jun
2-Jul
2-Aug
1-Sep
2-Oct
2012 Pre-Project
2013
2014
2015
2016
Ground
Depth to bottom
Alcove 2013
Alcove 2014
Alcove 2015
Alcove 2016

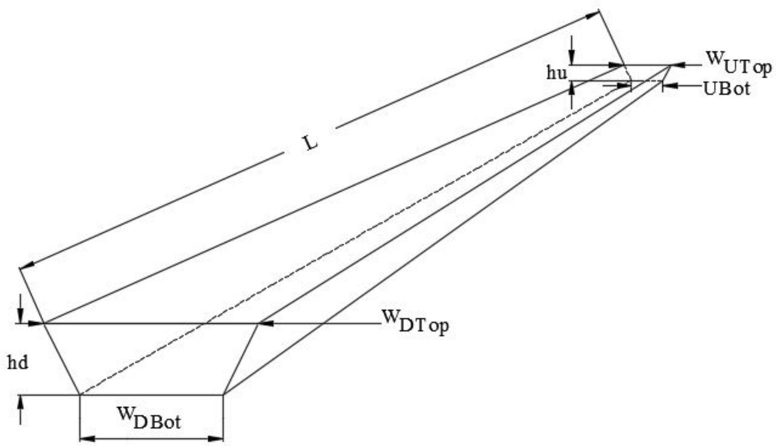


MS6 Baker Correlation
Baker (cfs)
MS6 (cfs)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.00 14.00 15.00 16.00 17.00 18.00 19.00 20.00 21.00 22.00 23.00
2010-2012 Pre-Project
2013-2015 Post Project
Linear (2010-2012 Pre-Project)
Linear (2013-2015 Post Project)
y = 0.0737x - 0.025
R² = 0.9456
y = 0.054x - 0.0085
R² = 0.9626

Baker Creek Streamflow Outcomes

- Streamflow increase as compared to control site (MS6) : measurable improvement in flow (greater than 10 gpm) until flow drops below 0.1 cfs (45 gpm).
- Avg flow improvement over 28 days (May 27- June 24, 2015) = 41 gpm & volume = 1.6 million gallons
- Flow improvement = instream surface water storage + groundwater
- Groundwater storage not sufficient to improve late summer flows in extreme drought year of 2015

Estimate the Volume of a Prism



$$V = \left[\frac{\left(\frac{W_{DTop} + W_{DBot}}{2}\right) hd + \left(\frac{W_{UTop} + W_{UBot}}{2}\right) hu}{2} \right] * L$$


Thank You
Artwork by Valery McKee