STILLAGUAMISH SUMMER FLOW RESPONSE TO CLIMATE VARIABILITY & IMPLICATIONS FOR HABITAT RESTORATION AND SALMON POPULATIONS

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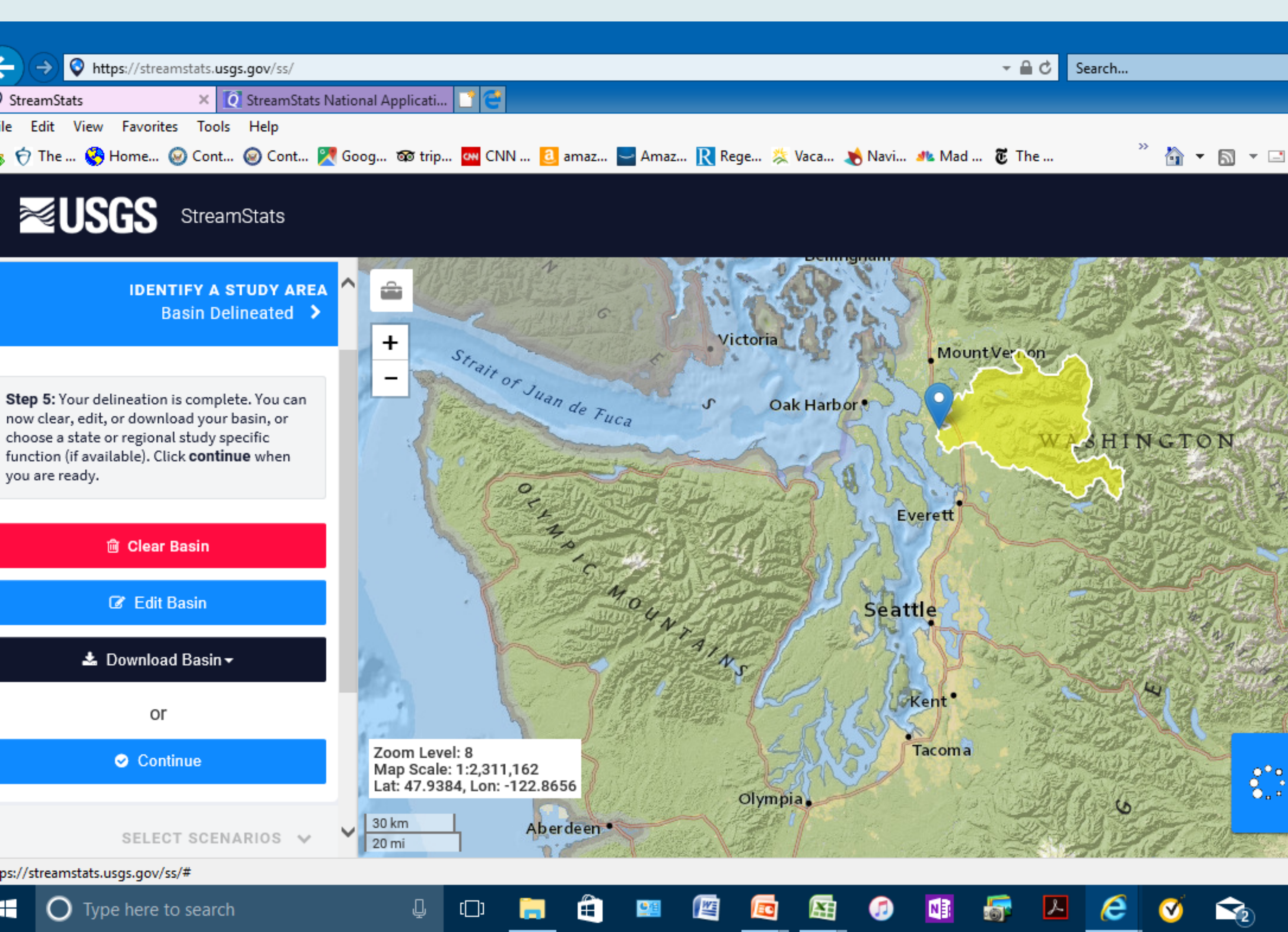
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IDENTIFY A STUDY AREA
Basin Delineated
Step 5: Your delineation is complete. You can now clear, edit, or download your basin, or choose a state or regional study specific function (if available). Click continue when you are ready.
Clear Basin
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Victoria
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Oak Harbor
Mount Vernon
WASHINGTON
Everett
OLYMPIC MOUNTAINS
Seattle
Kent
Tacoma
Olympia
Aberdeen
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30 km
20 mi
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WITH CLIMATE CHANGE IN WESTERN WA……
….. WE EXPECT THE FOLLOWING

- Warmer air temperatures, esp. in summer
- Precipitation – less in summer, more in winter
- Less snowpack/ Receding glaciers
- More flow in winter/ Less in summer
- Earlier spring runoff

- Higher stream temperatures (STILLY TEMP TMDL)
  - NorWeST Temp Modeling (Isaak et al.)

WHAT WILL MAKE FISH HABITATS MORE TEMPERATURE RESILIENT TO CLIMATE CHANGE

- More summer flow
- More groundwater input (recharge)
- More shade
- More channel structure
- More floodplain complexity

PROTECT/RESTORE – BEECHIE ET AL. 2013

STILLAGUAMISH – WHAT, WHERE AND HOW?

2010-2015 Centennial Clean Water (319) Grant

1.) Baseflow Analysis – Low flow gauging history

2.) Watershed Characterization – WDOE methods (Stanley et al.)

3.) Temperature Assessment

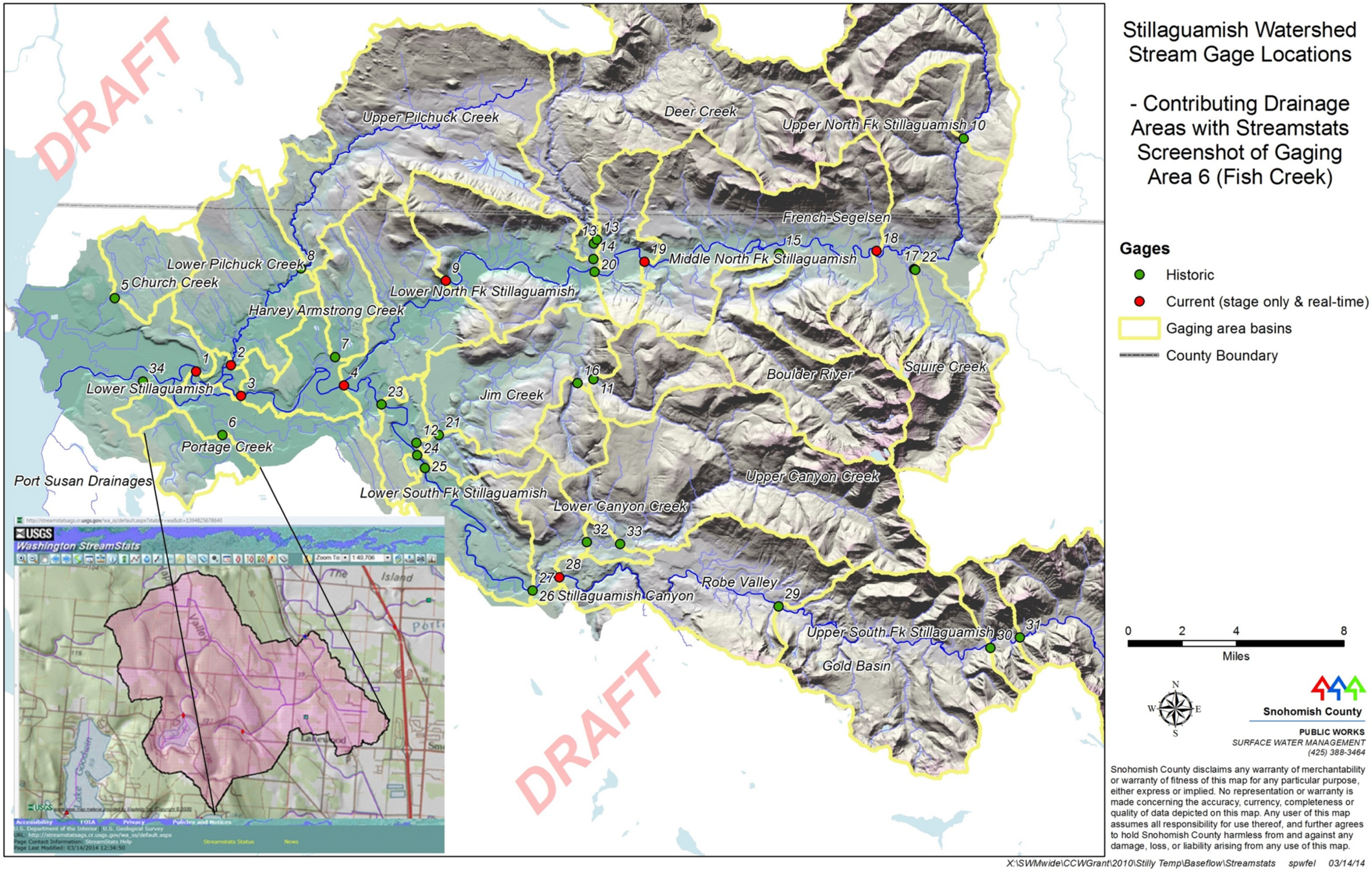
Thermal infrared (FLIR) mapping;

Thermal profiling (2011) w/ USGS

2008-2012 Summer Temperature (242 site-year combos)

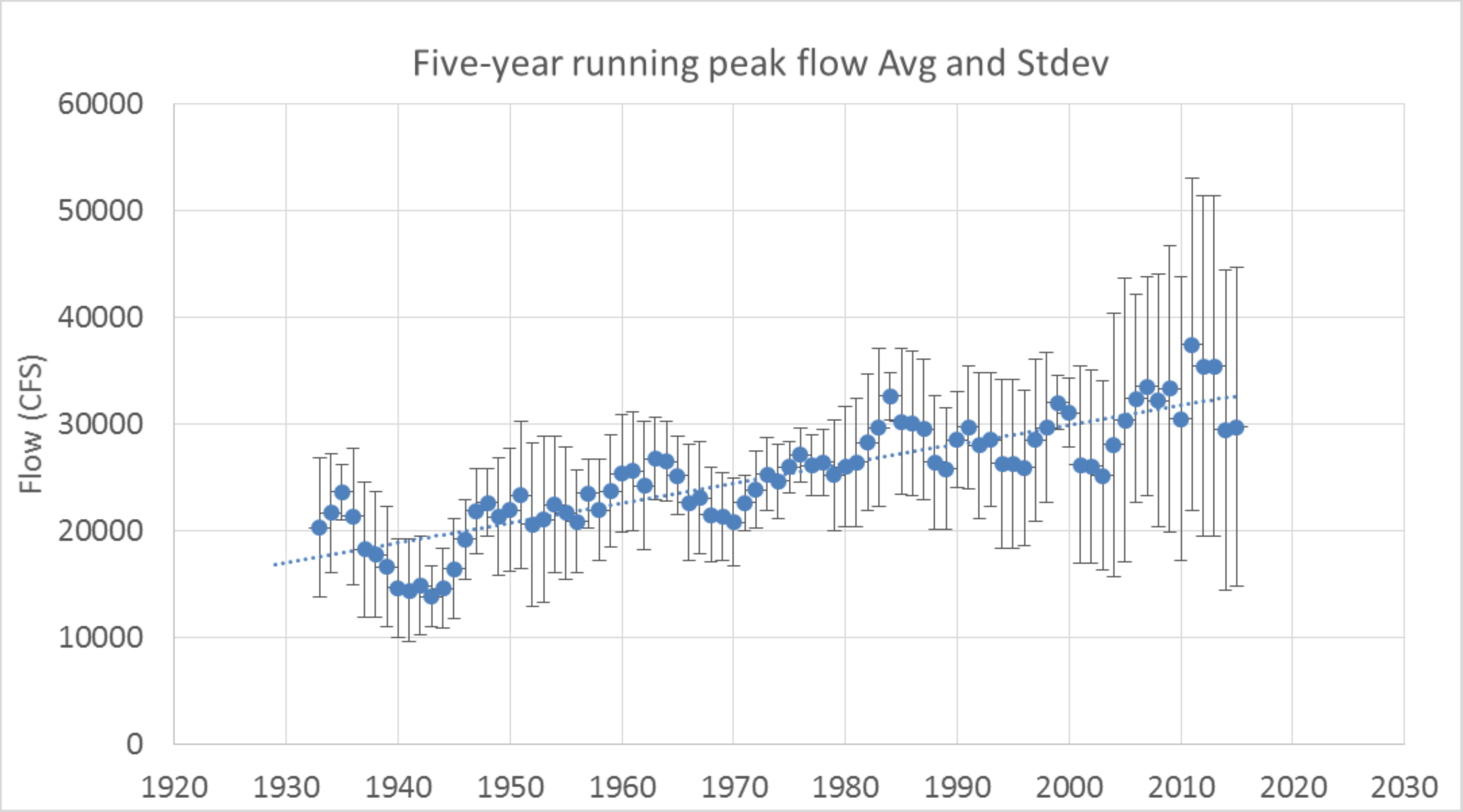
4.) Seepage Flows – Pilchuck Creek 2011; Jim Creek 2012

LOW FLOW GAUGING HISTORY – FROM 1913



PEAK FLOW AND INCREASING INTERANNUAL VARIABILITY

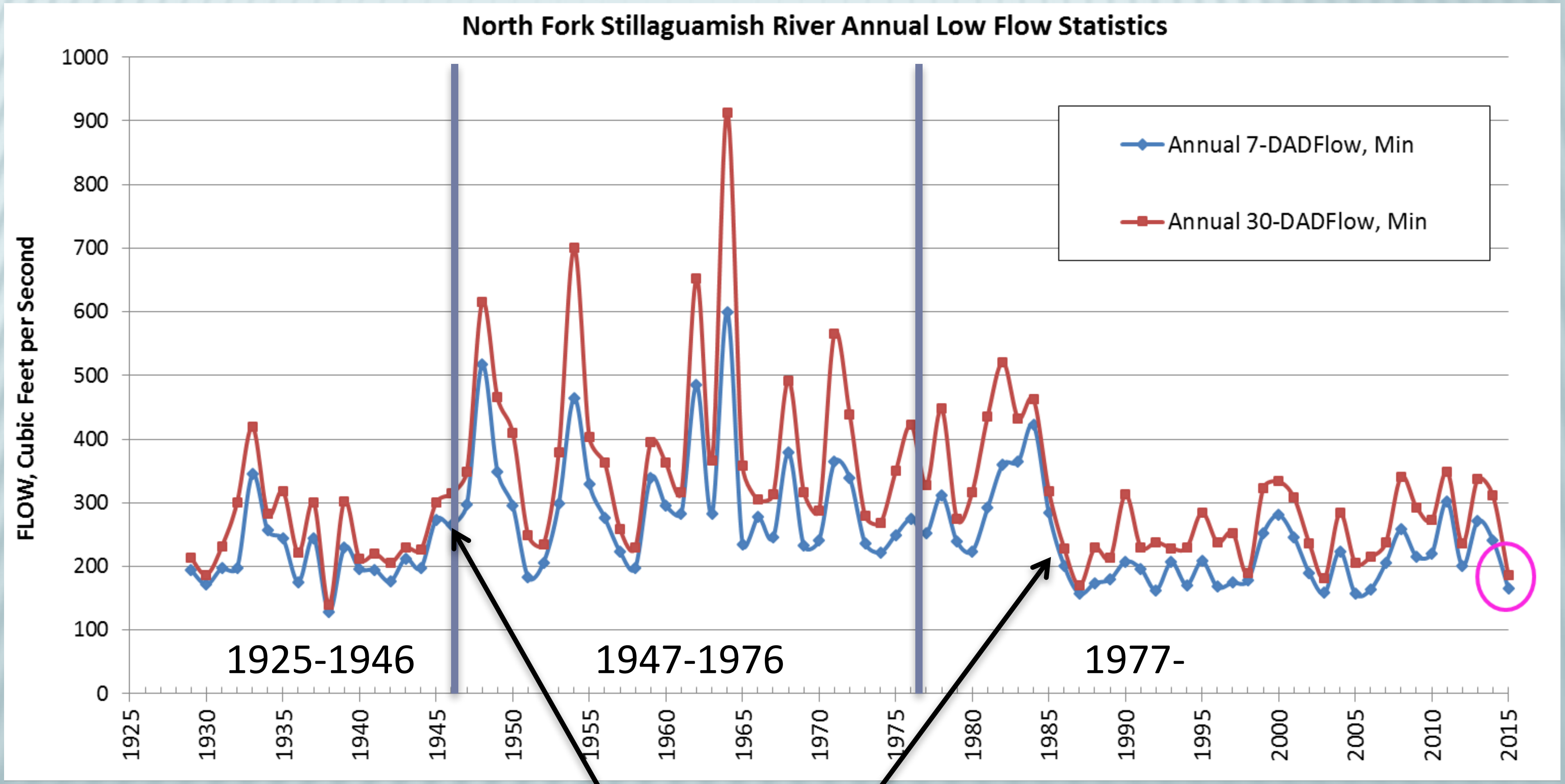
NF STILLAGUAMISH RIVER (USGS GAGE 12167000)



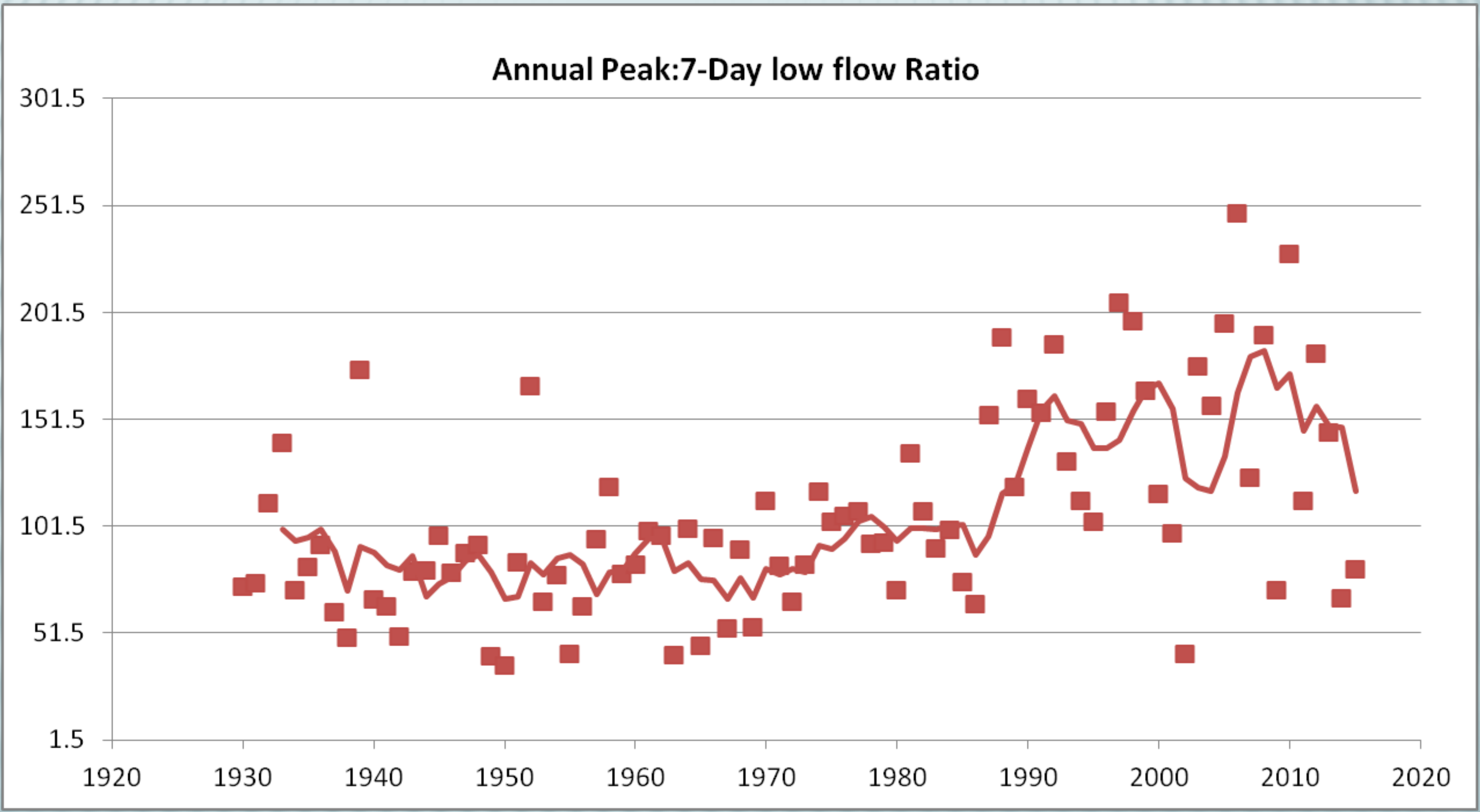
- https://nwis.waterdata.usgs.gov/nwisweb/data/img/USGS.12167000.19281009.20141126..0.peak.pres.gif

SUMMER LOW FLOW

NF STILLAGUAMISH RIVER (USGS GAGE 12167000)

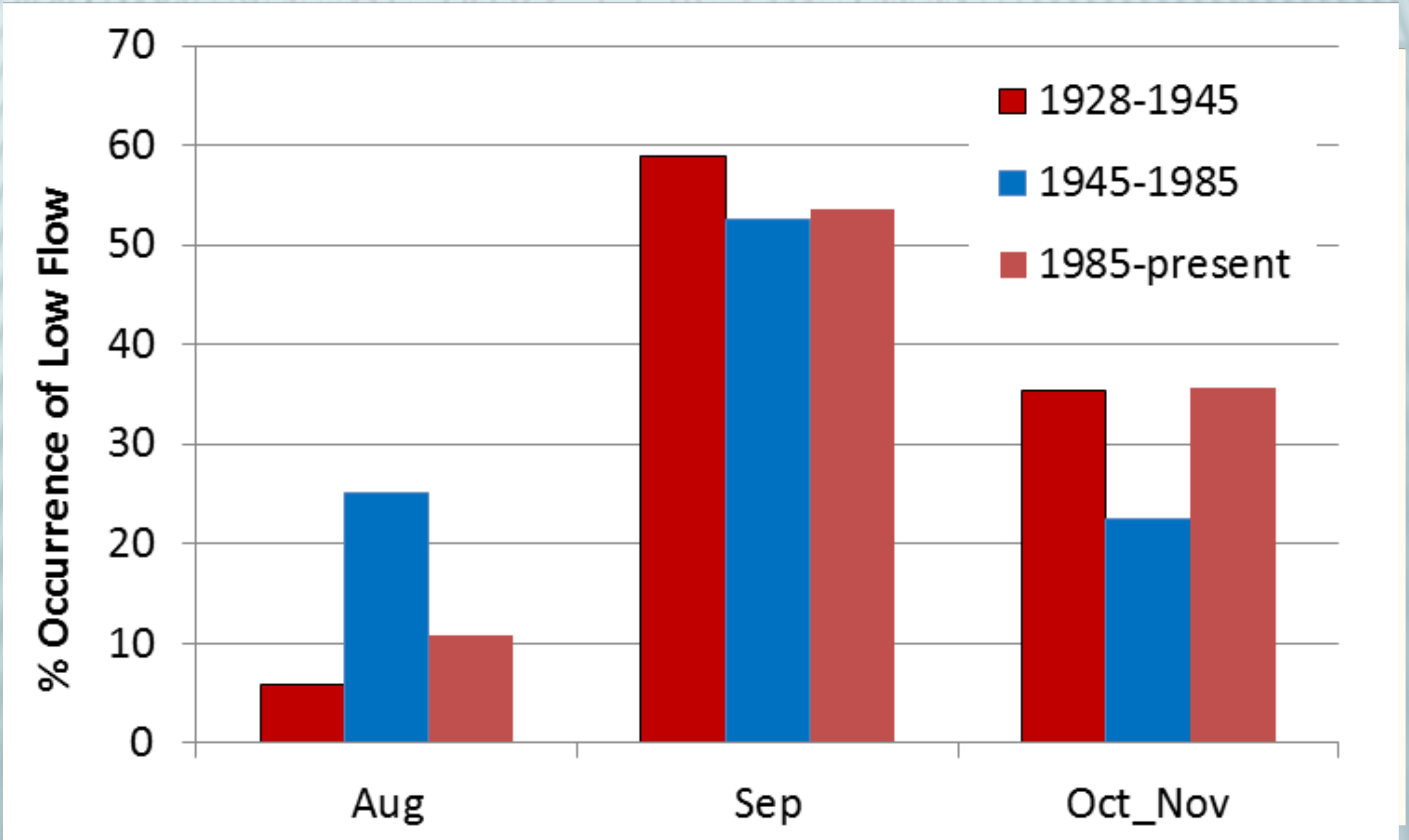


Distinct changes in pattern of low flow magnitude/variability

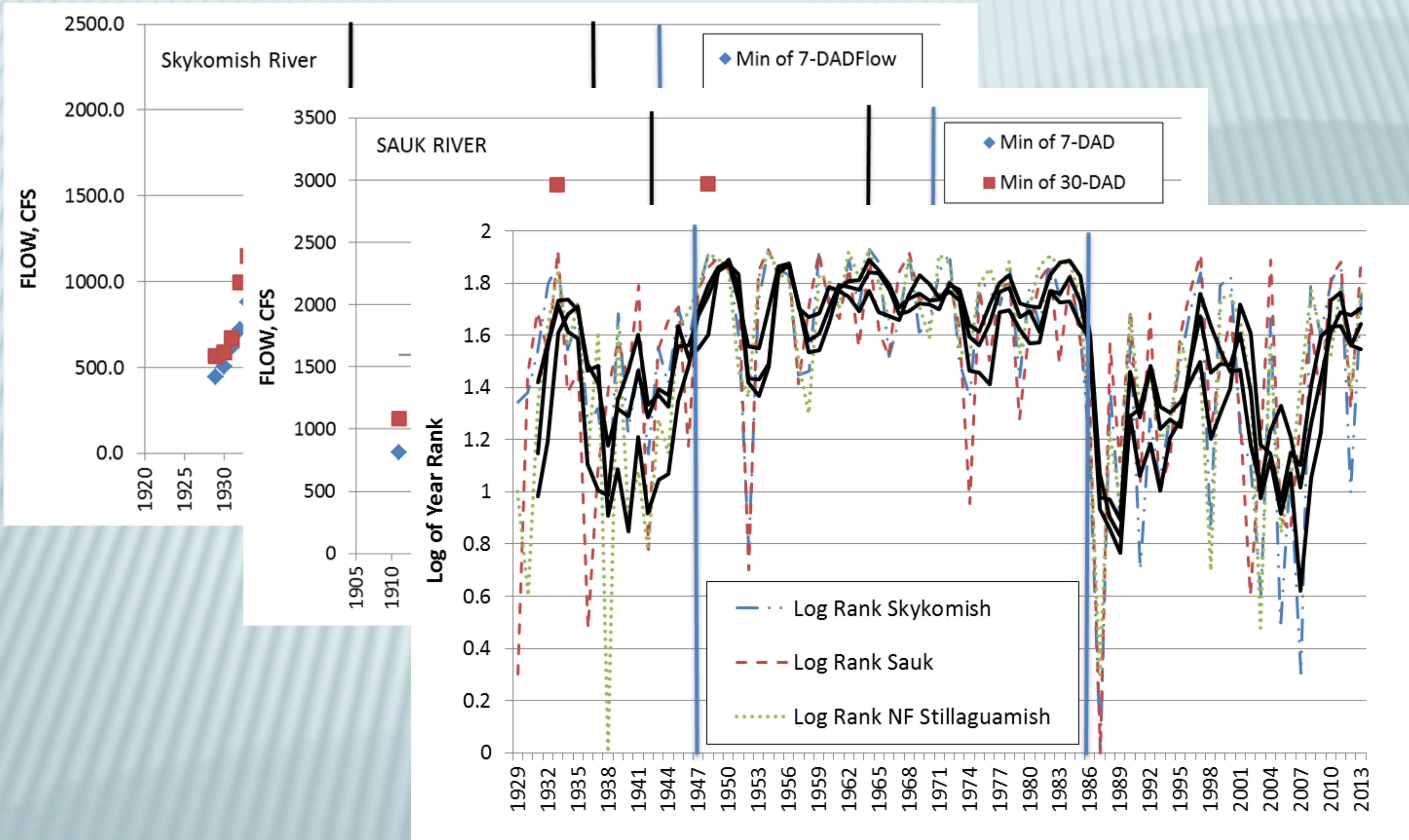


Annual Peak:7-Day low flow Ratio
301.5
251.5
201.5
151.5
101.5
51.5
1.5
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

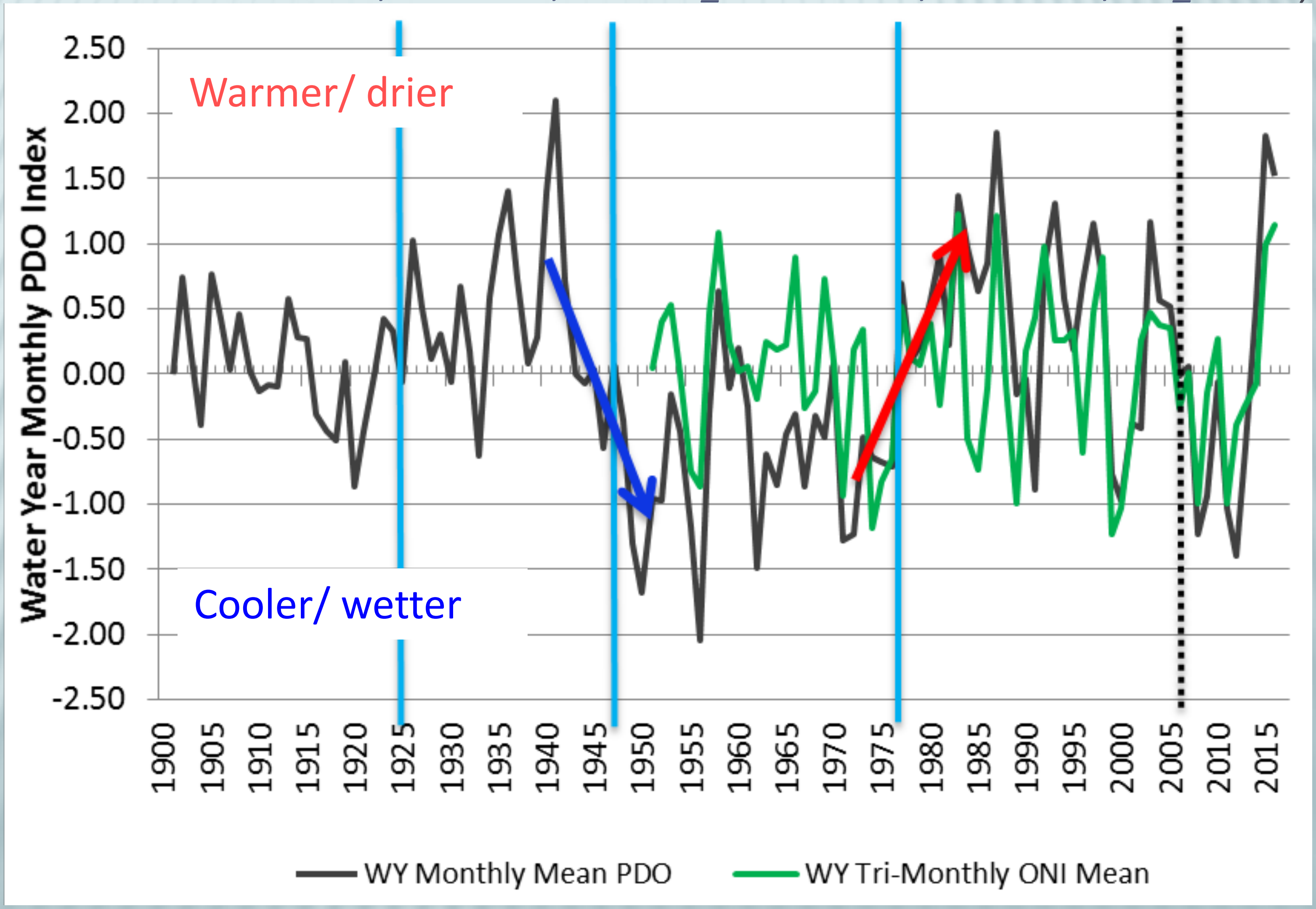
NF STILLAGUAMISH RIVER 30-DAY MINIMUM FLOW '47-'85 WAS 55% HIGHER



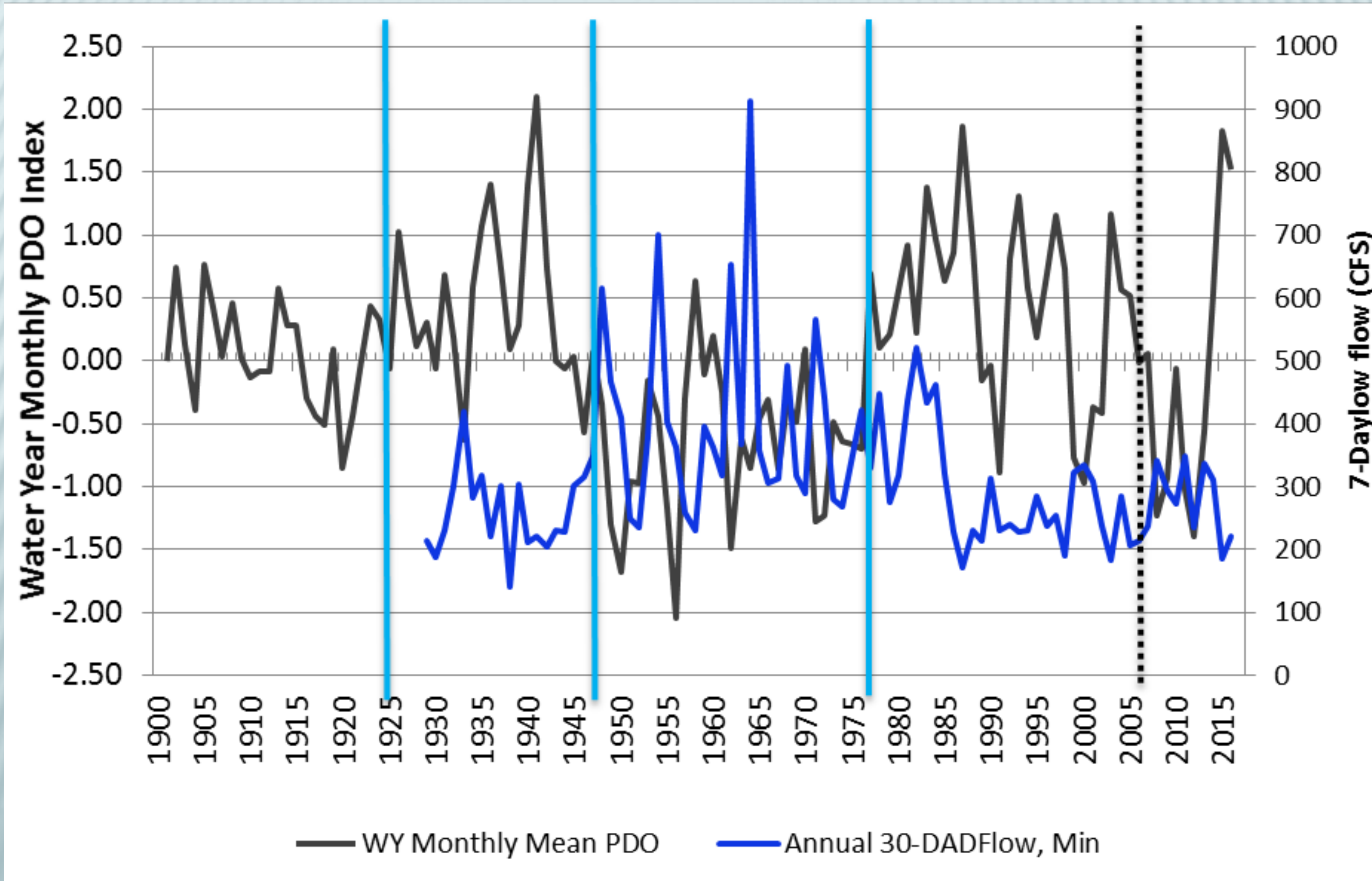
REGIONAL COHERENCE



PACIFIC DECADAL OSCILLATION *(MANTUA - HTTP://RESEARCH.JISAO.WASHINGTON.EDU/PDO/PDO.LATEST.TXT)* – EL NINO SOUTHERN OSCILLATION *(OCEANIC NIÑO INDEX - HTTP://ORIGIN.CPC.NCEP.NOAA.GOV/PRODUCTS/ANALYSIS_MONITORING/ENSOSTUFF/ONI_V5.PHP)*

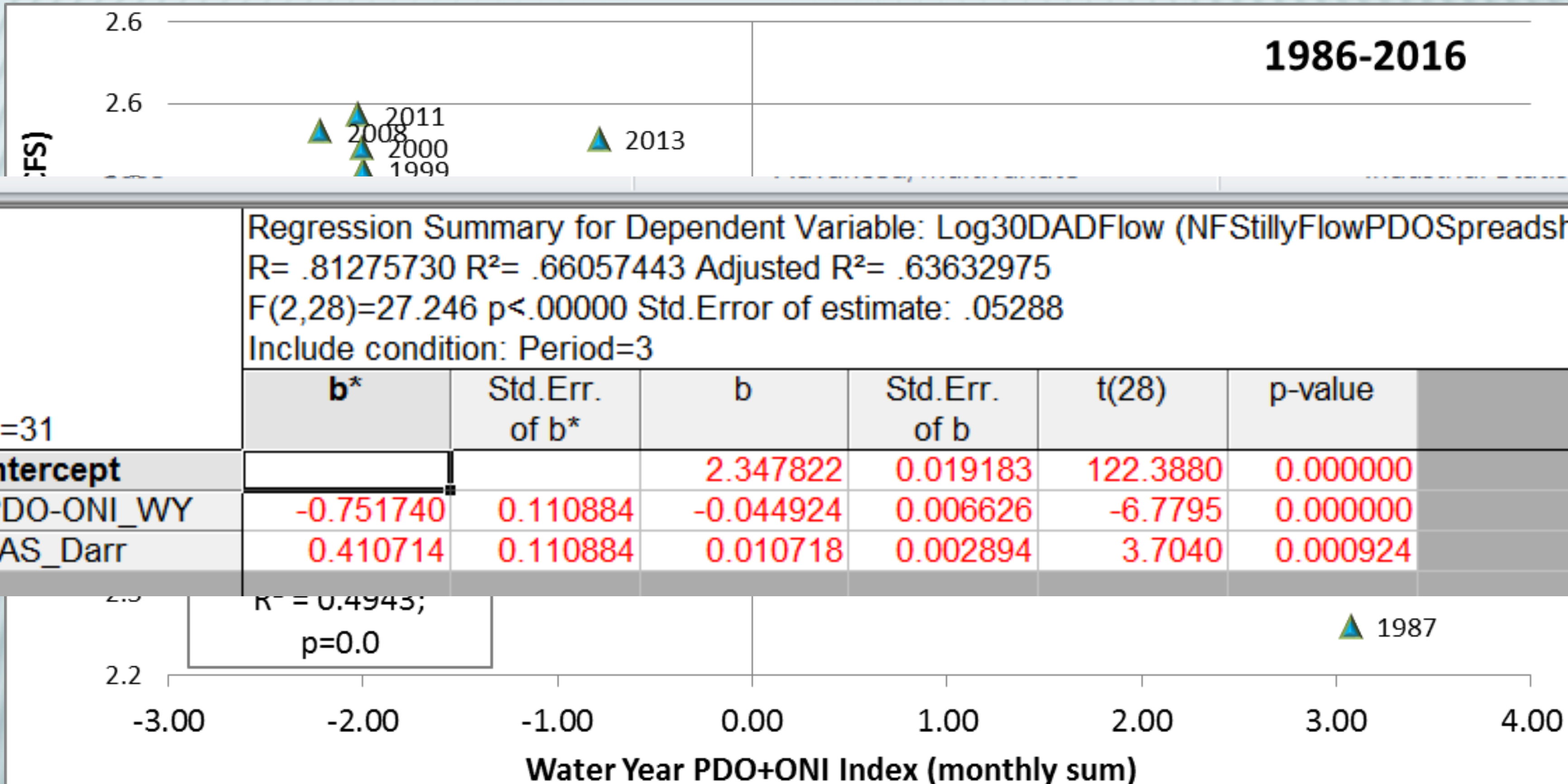


PDO AND NF STILLY FLOW – INVERSE PATTERN?



RELATIONSHIP BETWEEN PDO AND FLOW

- 20% of annual variability in 30-day low flow explained by PDO



Regression Summary for Dependent Variable: Log30DADFlow (NFStillyFlowPDOSpreadsheet2)
R= .81275730 R²= .66057443 Adjusted R²= .63632975
F(2,28)=27.246 p<.00000 Std.Error of estimate: .05288
Include condition: Period=3

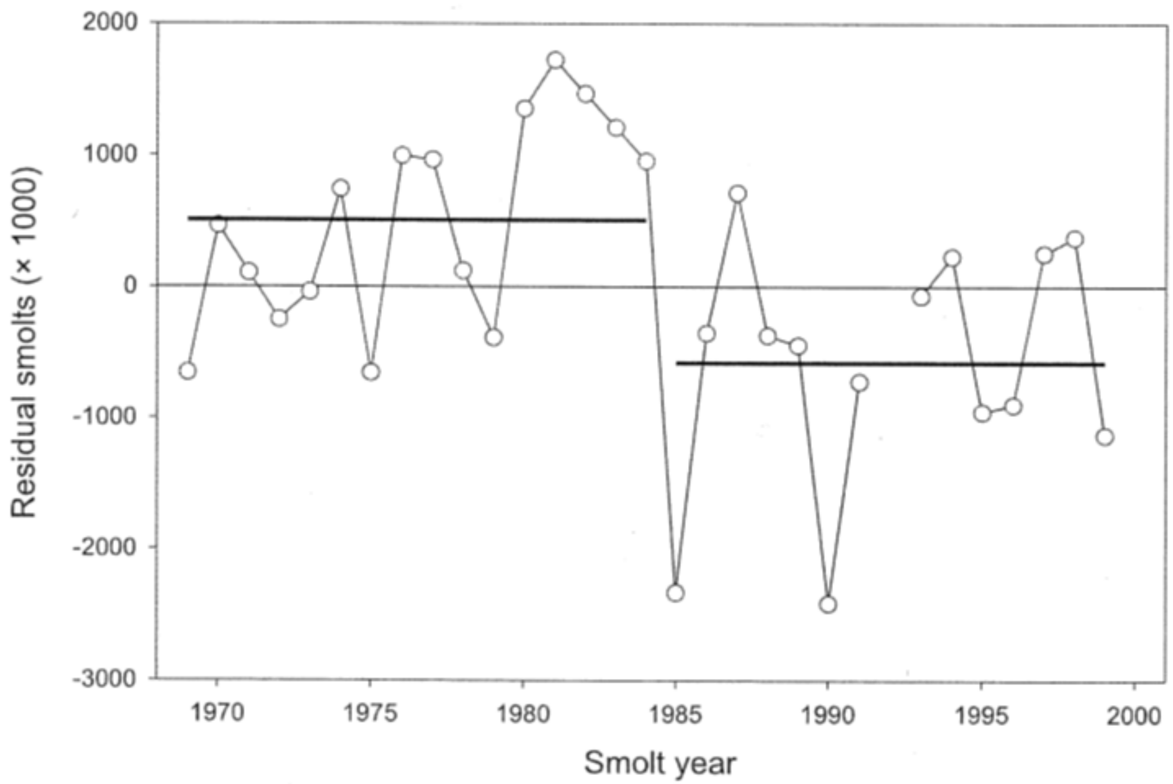
N=31	b*	Std.Err. of b*	b	Std.Err. of b	t(28)	p-value
Intercept			2.347822	0.019183	122.3880	0.000000
PDO-ONI_WY	-0.751740	0.110884	-0.044924	0.006626	-6.7795	0.000000
JAS_Darr	0.410714	0.110884	0.010718	0.002894	3.7040	0.000924

- 50% of within-phase annual variability 30-day low flow explained by PDO+ONI

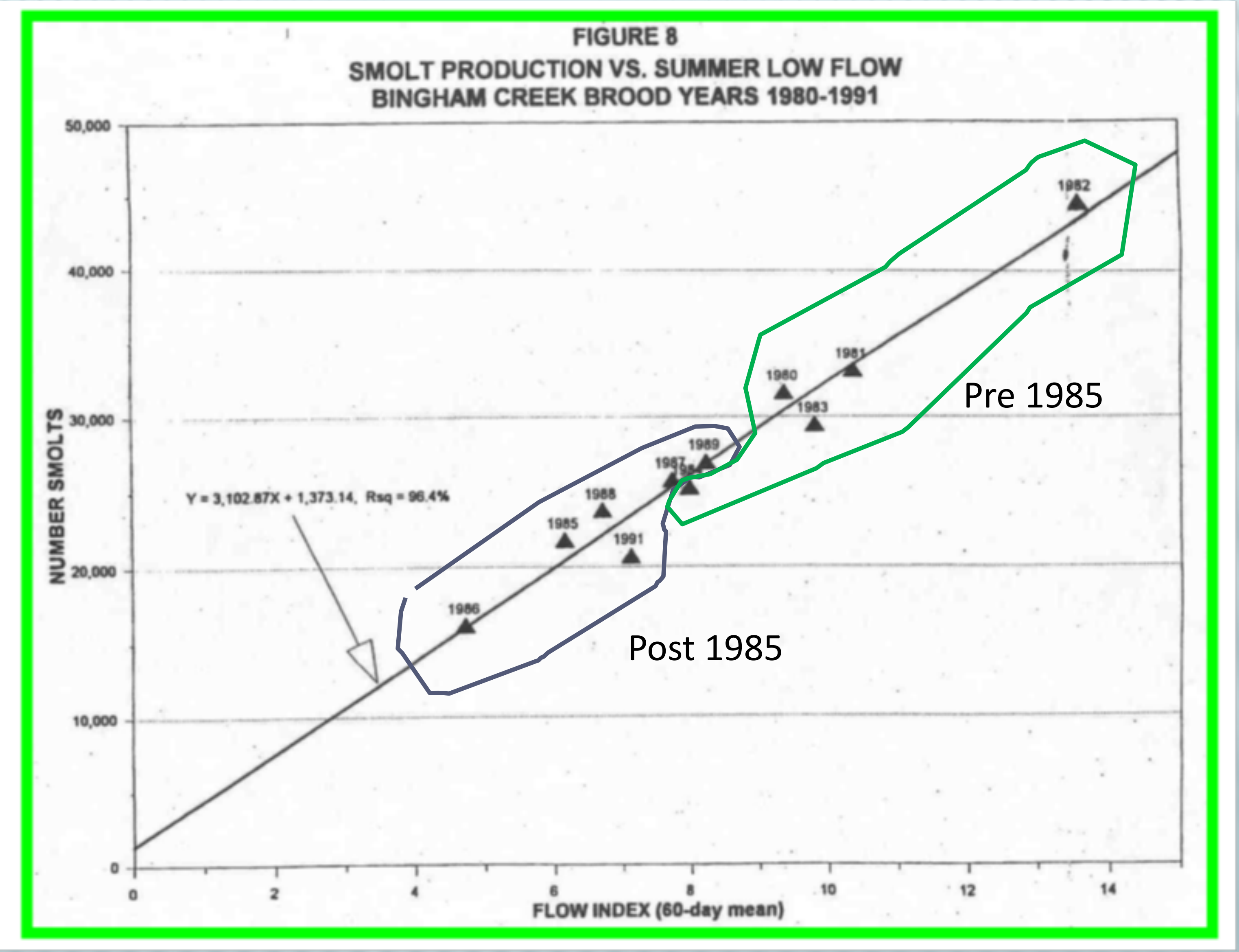
WHAT HAPPENED IN 1985?

- Lawson et al. 2004 - "either a discontinuity in the data set or an unidentified event occurred in 1985 and has persisted to the present, generally reducing smolt production."

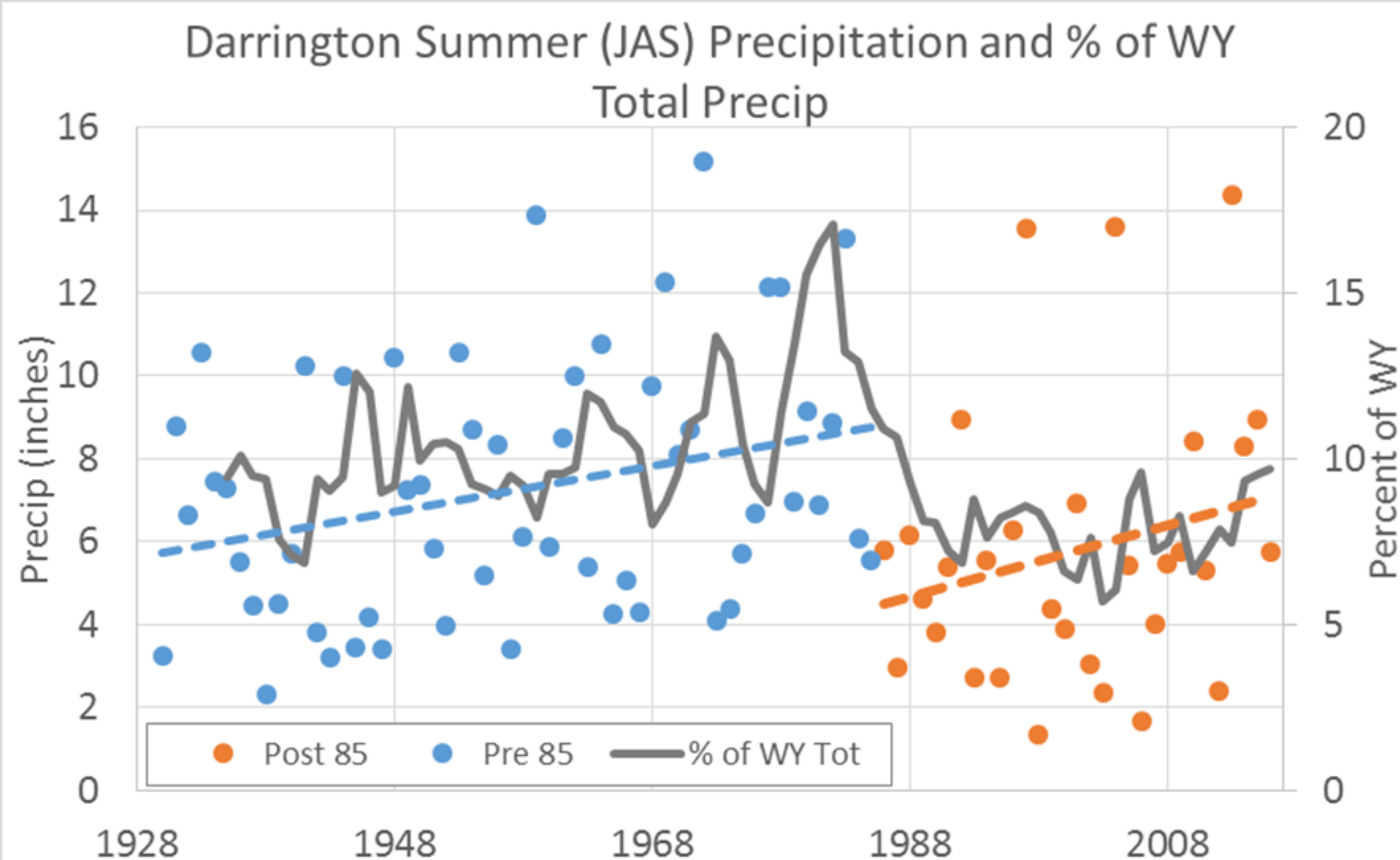
Fig. 5. Intervention analysis of residuals from the generalized additive model for Oregon coastal natural coho salmon (*Oncorhynchus kisutch*) smolts. Thick horizontal lines represent mean residuals for the time periods 1970–1984 and 1985–1999.



FROM WDFW – COHO SMOLT PRODUCTION 1980-1991 (REFERENCED BY BRAD CALDWELL, WDOE)



SUMMER PRECIPITATION CRATERED



FROM PUGET SOUND PARTNERSHIP

Stream flow trends at 29 locations in select Puget Sound rivers

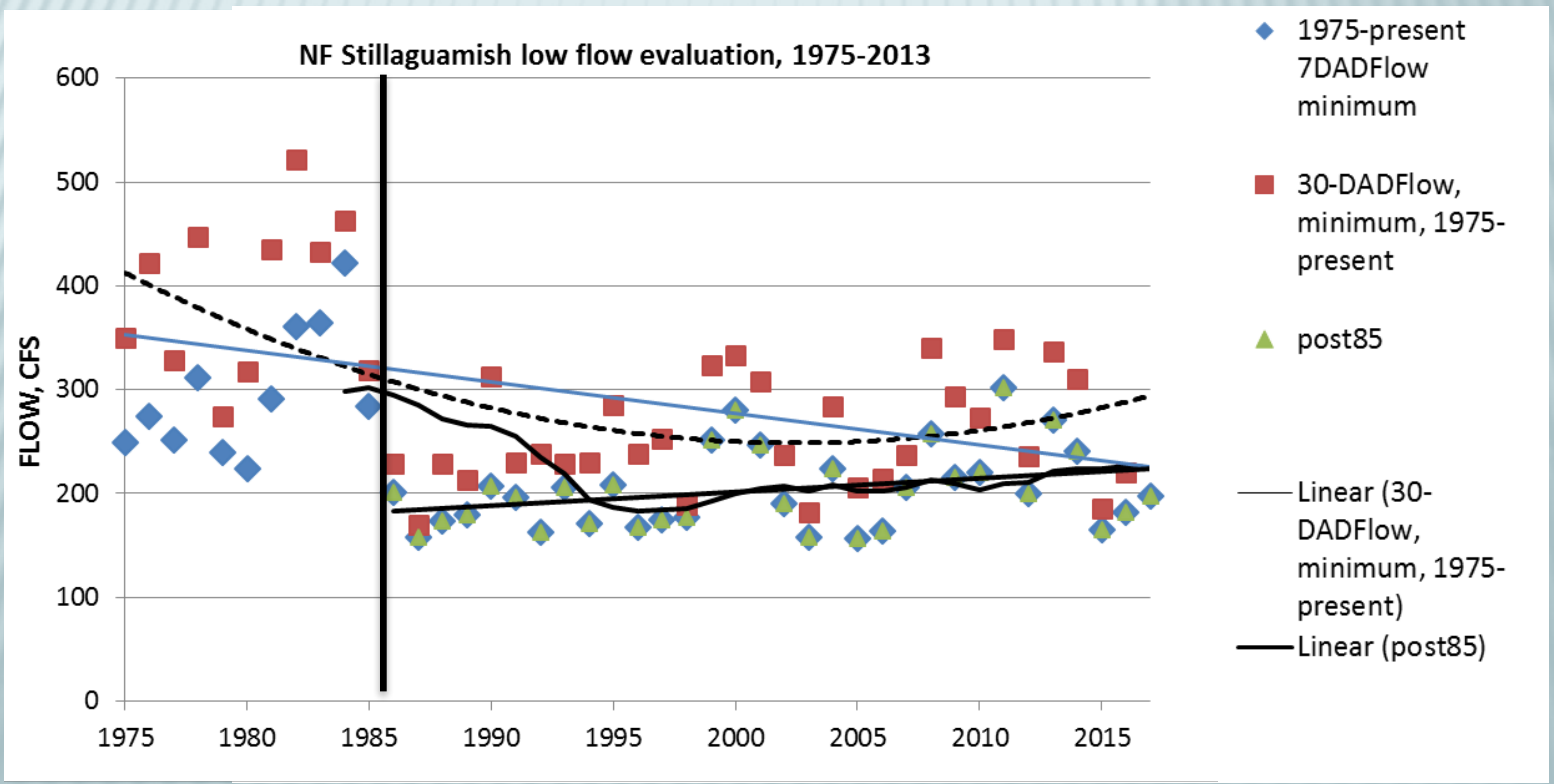
30-day average summer low flow, 1975-2012

Figure 1. Summer low flow trends by category.

Source: USGS Flow Gaging Network

FLOWS AND "MANAGEMENT"

- 1975 start point ignores variability and flow response since 1985
- For 31 years , increasing base flow; p=0.071
- If "Changing trajectory" is goal, must use moving avg/ polynomial



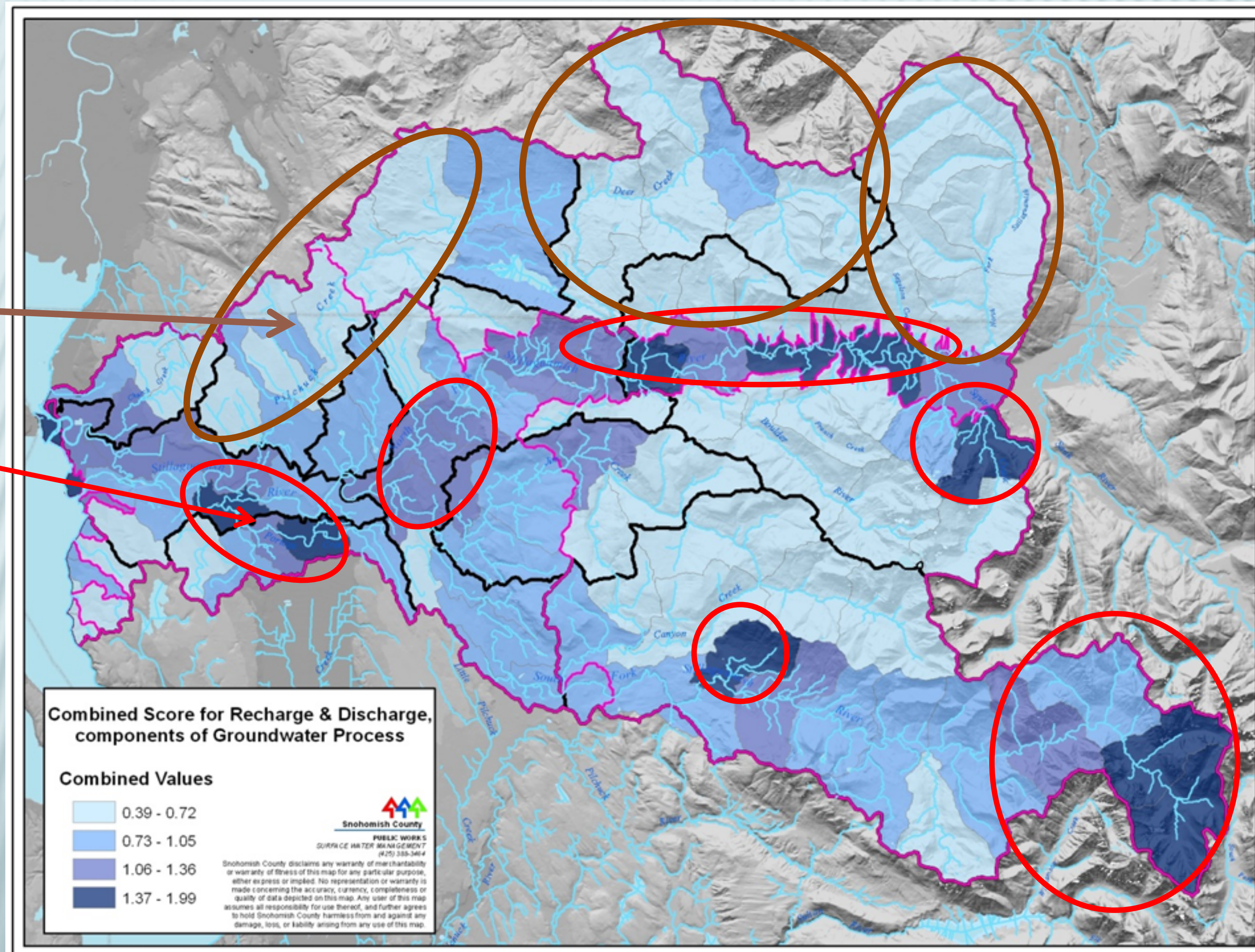
GROUND WATER PROCESS - COMBINED RECHARGE/ DISCHARGE

Weak

vs

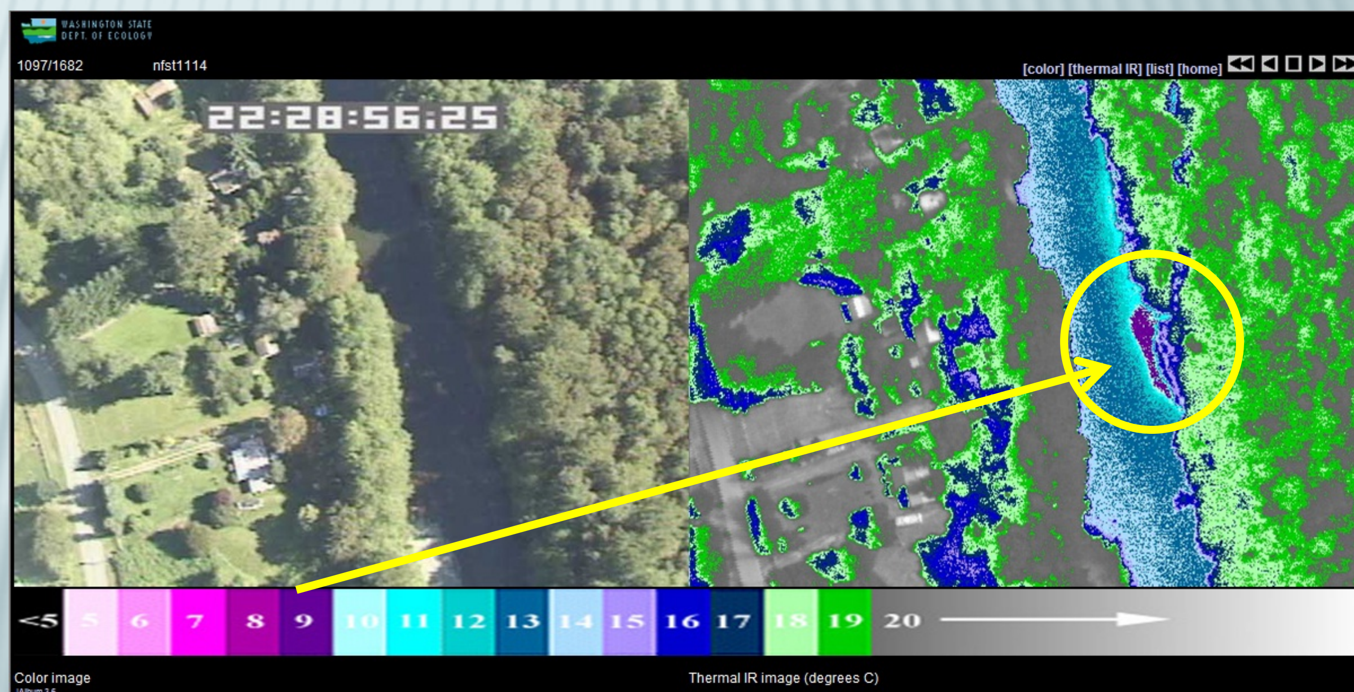
Strong

GW flow process



THERMAL INFRARED MAPPING (2001)

- Identifies colder, discrete flow input to mainstem rivers
- Point locations at Habitat Unit scale (10-100m) – 2 dimensions
- Source type – Hydrography/ LiDAR/ past channel migration
- Relative size
- Relative temp
- Rank



TEMP/FLOW SOURCE

- Classification of source type is relevant to evaluating potential effect from location, temperature differences, and size of temperature anomalies

Source Type	Floodplain	Hyporheic	Side Channel	Seep/ Spring	Surface Water	Tributary

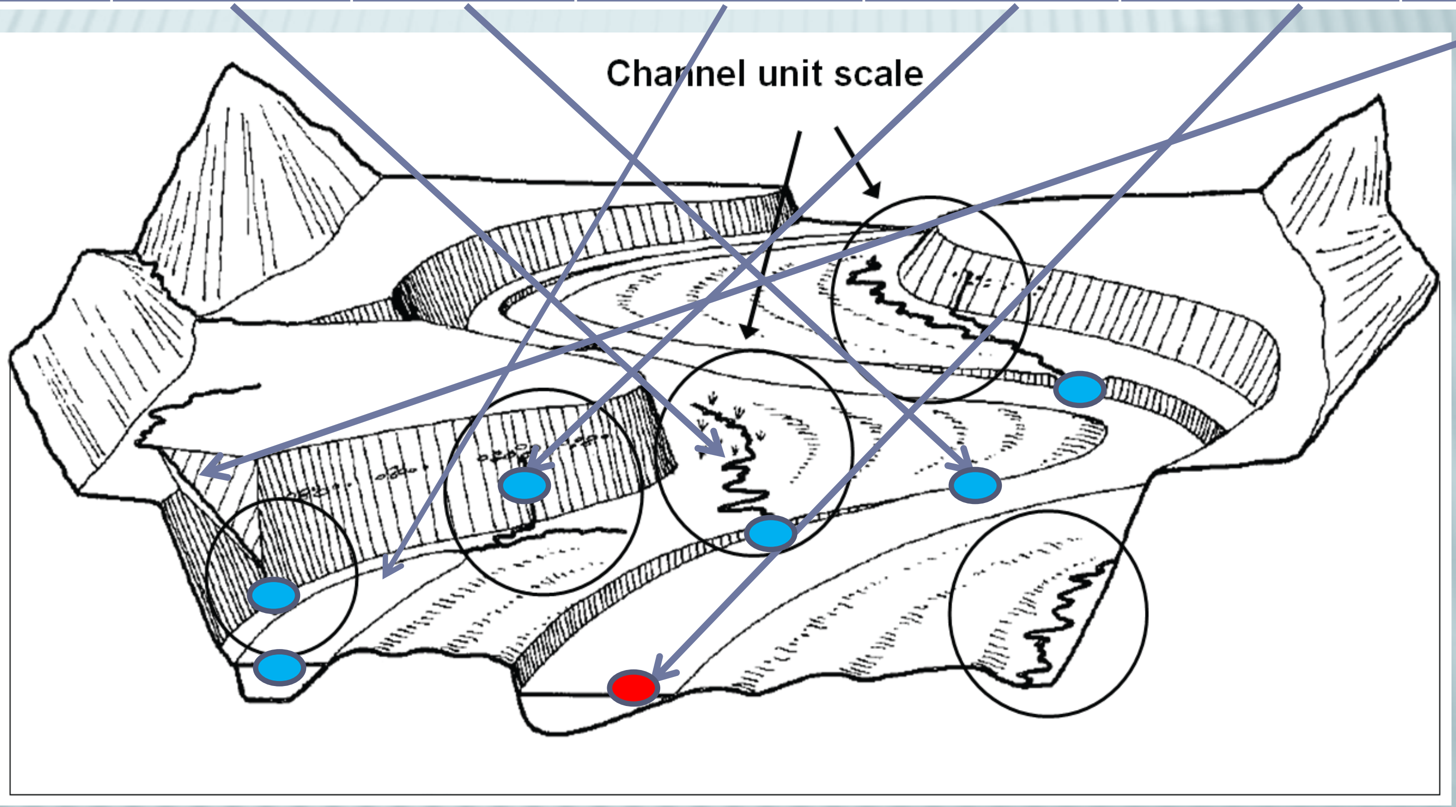
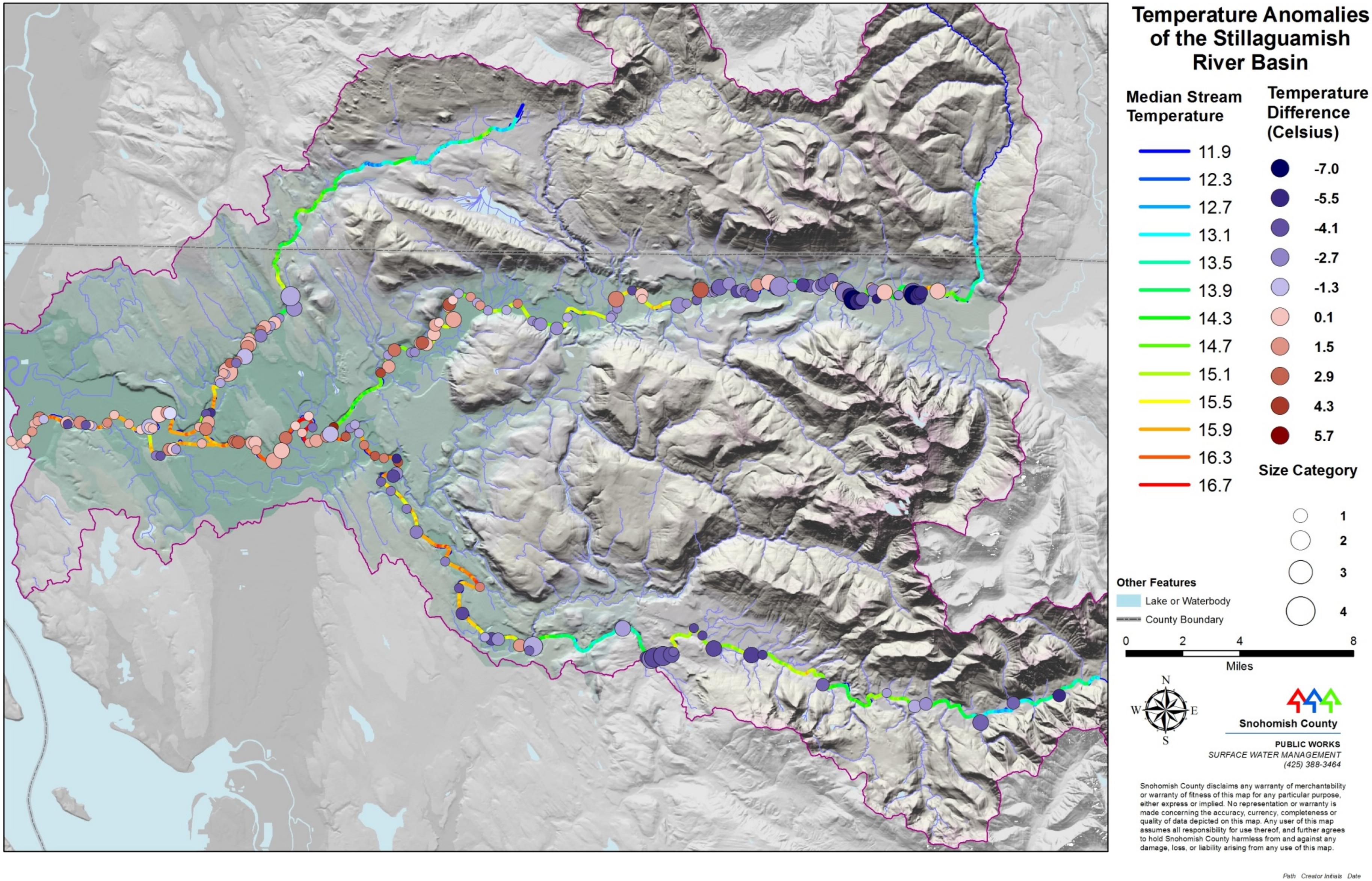


Figure in Torgersen et al. 2012 (p. 42), adapted from Peterson and Reid, 1984

RESULTS – OVERALL MAP OF TEMPERATURE ANOMALIES

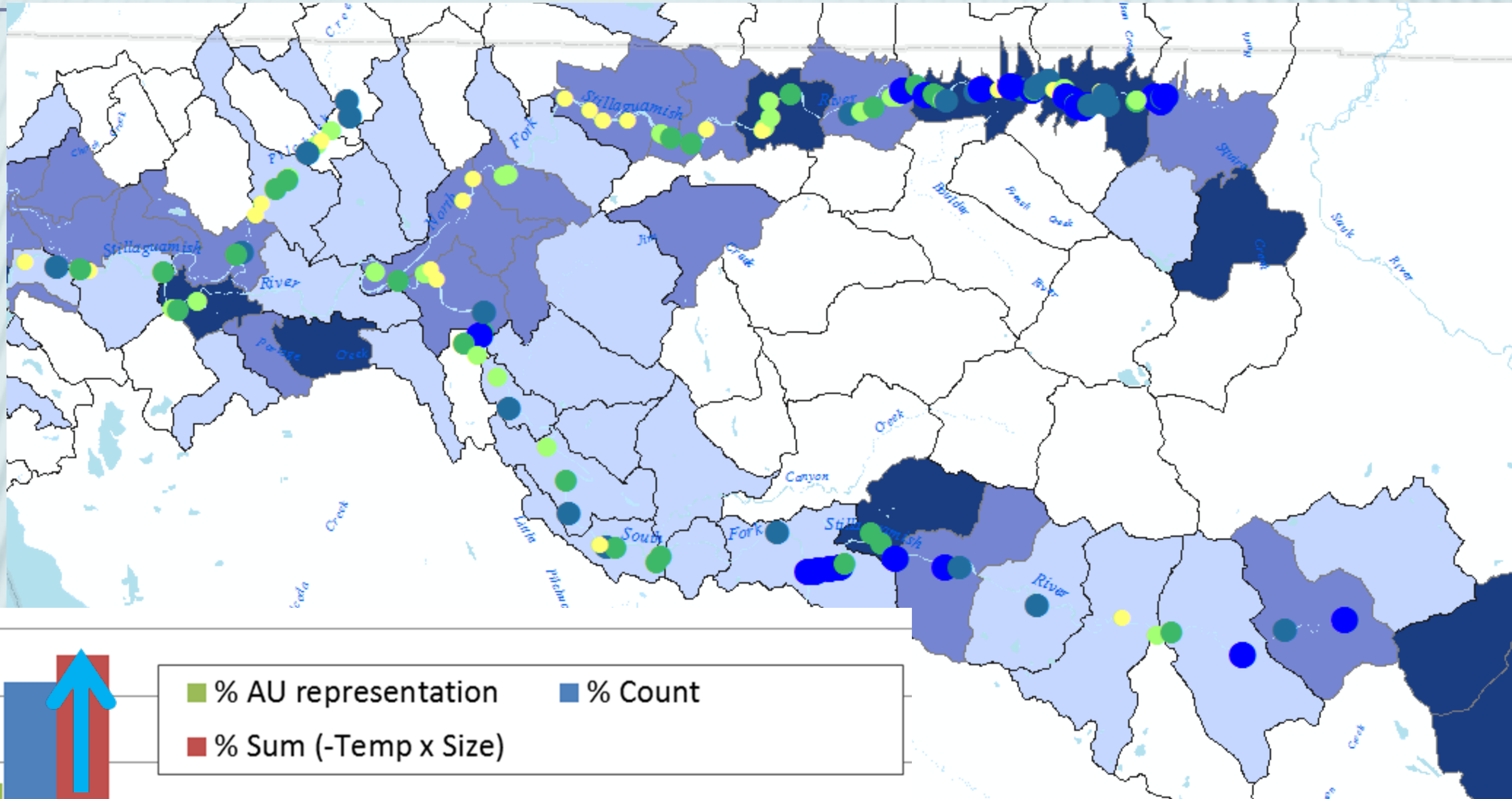


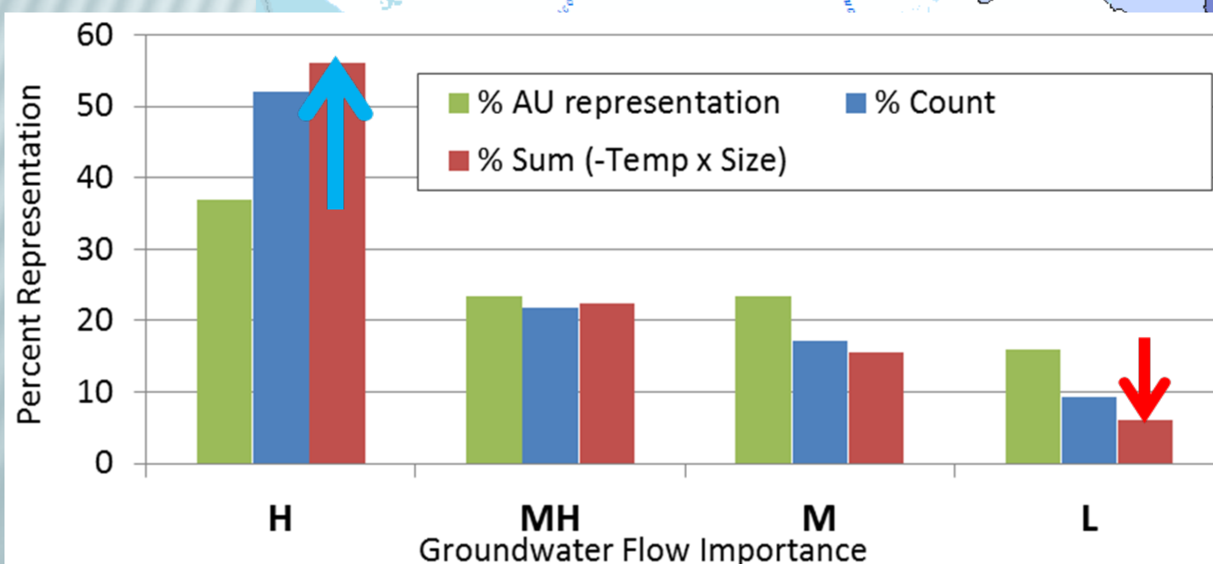
RESULTS – DISTRIBUTION BY SOURCE

Source Type	Stillaguamish Mainstem	North Fork	South Fork	Pilchuck Creek	Grand Total
Floodplain	4	18	7	4	32
Hyporheic		3		7	10
Side channel	1	18	4	1	24
Seep/ Spring	1	12	5	3	21
Surface water	44	24	6	11	85
Tributary	2	24	23	3	52
Confluence	2				2
Grand Total	54	99	44	29	226

- Stilly Mainstem – few coldwater inputs
- North Fork – almost ½ of all anomalies – distributed among sources
- South Fork – dominated by tributary junctions -
- Pilchuck – Higher hyporheic sources –
  - very low summer flow relative to channel area w/ exposed gravel bars

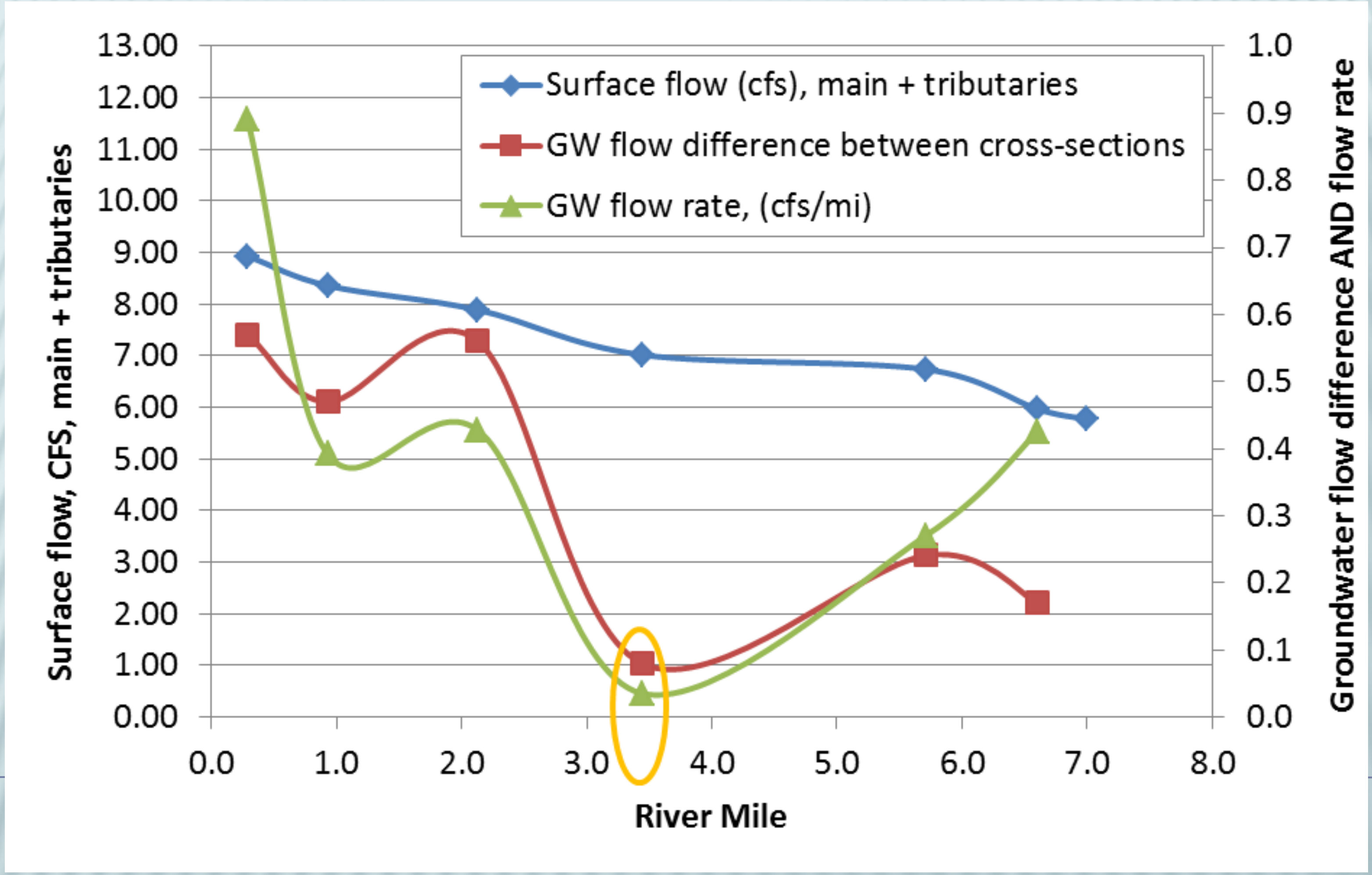
COLD-WATER REFUGE RANK BASED ON TEMPERATURE COMPARED TO GROUNDWATER IMPORTANCE





Statistically greater count and temperature effect (chi-square statistic, $p<0.001$) for locations with HIGH GW Importance (by area or count)

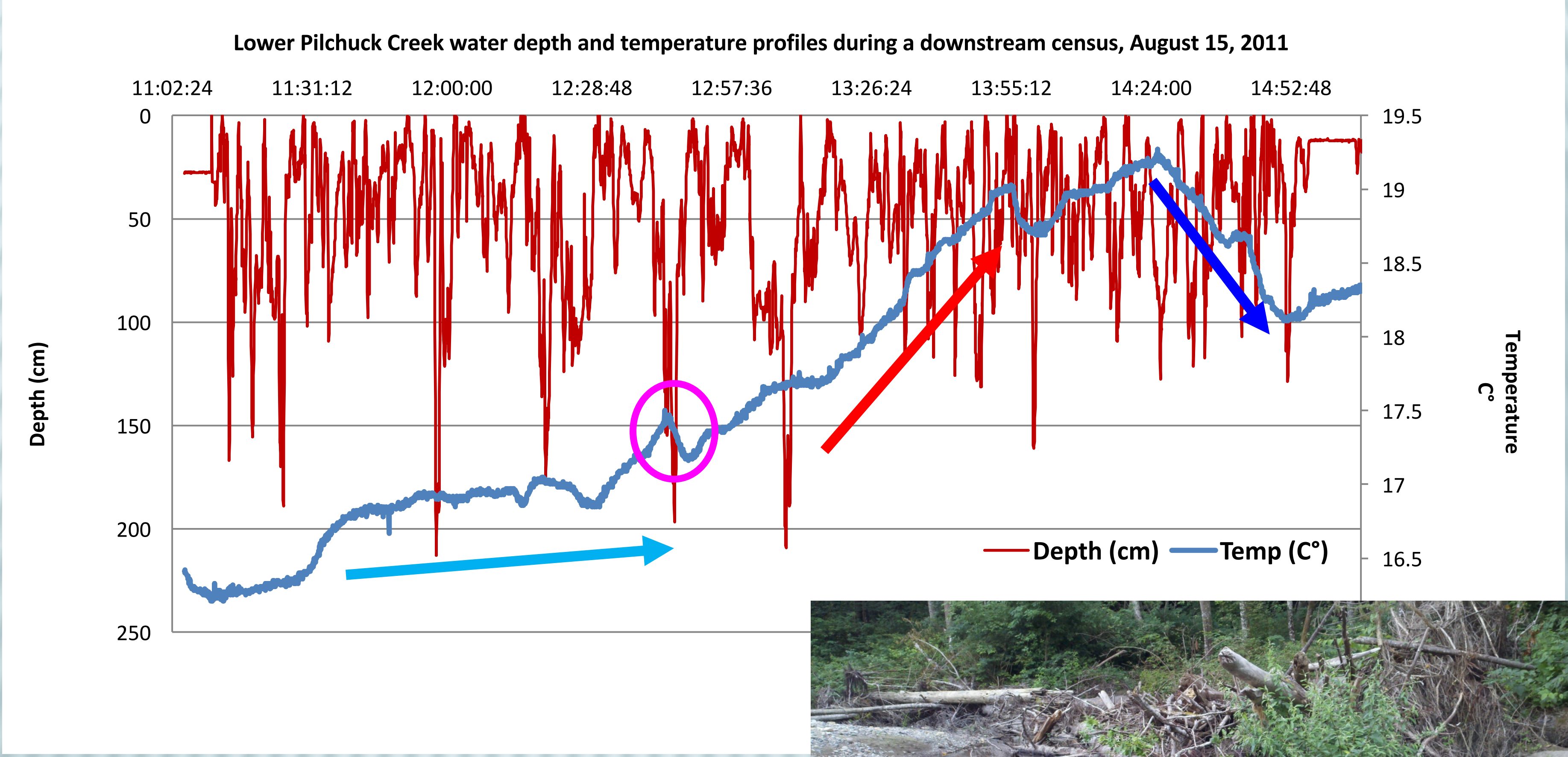
SEEPAGE RUN – CONFIRMS GW INFLOW



60% of total flow gain is groundwater derived – not from tributary inflow

76% of this GW inflow occurs downstream from Stanwood-Bryant Road

1-DIMENSION – GREAT IN STREAMS, CHEAP, FAST, CAN DISCRIMINATE TEMP IN HABITAT UNITS/REACH SCALE



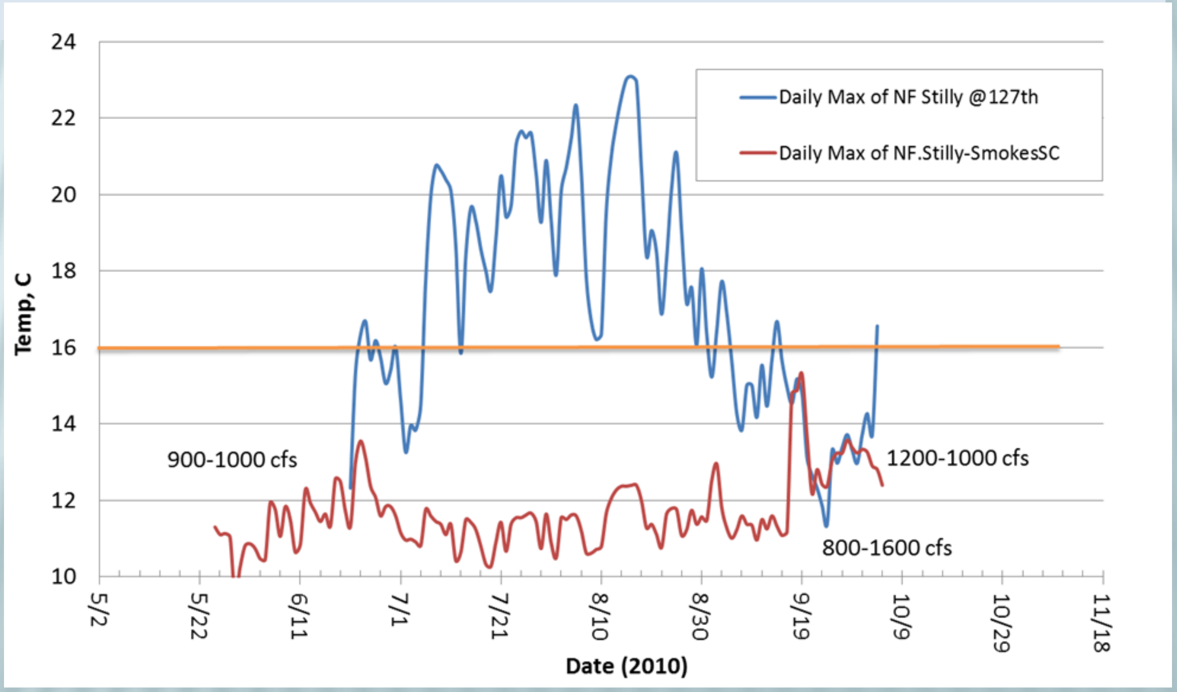
Limitation: Misses non-thalweg pools that have temp stratification

TRIBUTARIES, SIDE CHANNELS, MAINSTEMS

- Temp refuge may vary by area

Average of 7DADMax	MS	SC	TR
12.0 C Standard – Headwaters - > % Flow decline @ Squire	**17.1**	**13.7**	16.0
16.0 C Standard – Middle Reaches	**20.7**	**14.8**	16.6
17.5 C Standard – Puget Lowland	21.8	**22.9**	**16.3**
Grand Avg.	**20.5**	**17.2**	**16.4**

- NF Stilly side channel example

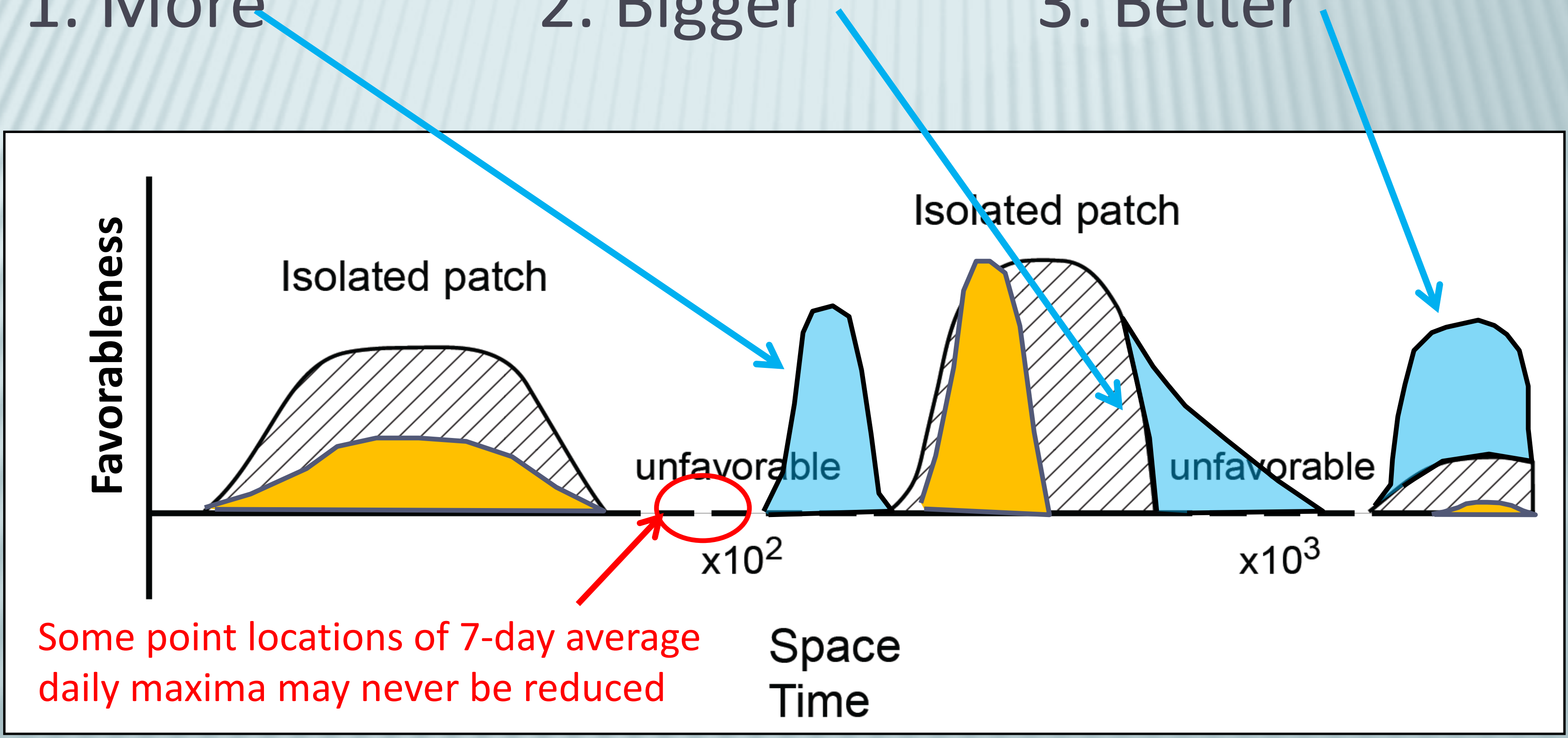


GENERAL CONCEPT FOR TEMPERATURE PROTECTION/IMPROVEMENT

For the moment, forget temp standards and criteria…..

Favorable Patchiness………..**Future**

1. More 2. Bigger 3. Better



Black and white in figure from Torgersen et al. 2012 (p. 29), adapted originally from Southwood, 1977

GENERAL STRATEGY FOR TEMPERATURE RESTORATION – *MORE, BIGGER, BETTER*

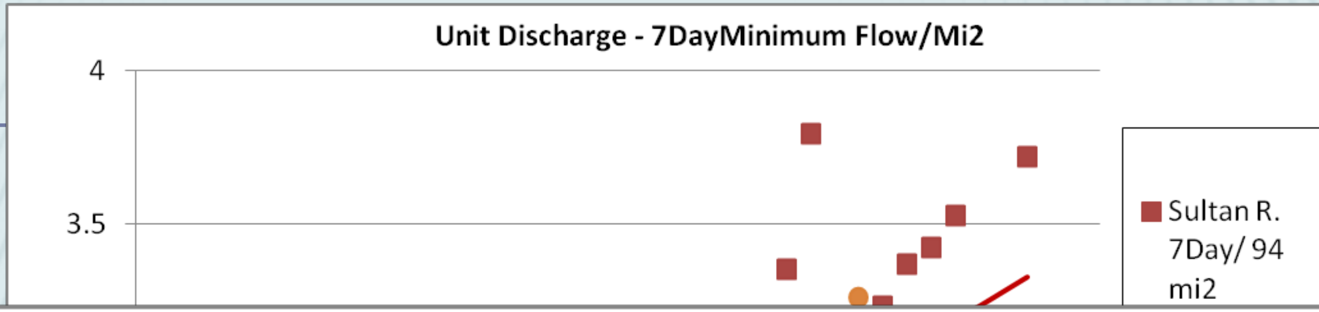
	More Refuges (#)	Bigger Effect (T)	Better Habitat (C, D, V)
Tributary	Yes, if can cool temp; Yes, if currently diverted	Flow and shading – subbasins	Instream and confluence restoration
Floodplain /Spring - brook	Yes; long-term, floodplain reconnection, channel migration, channel aggradation, recharge – short-term – connectivity to existing	Yes; long-term, same as left for increasing total size; short-term – shading and connectivity	Natural floodplain processes or enhancement of habitat quality – depends on impaired conditions, access and level of use
Side Channel	Yes; can be short-term and not process-based – reconnect isolated	Increase capacity of existing, shading,	Depends on impairment of existing – cover, LWD, edge quality
Spring	Only if currently diverted	Only if currently diverted or recharge-limited	Locations of spring discharge could be enhanced – LWD, cover, shading, edge
Hyporheic	Unknown, but may depend on aggradation and deeper scour in flow gaining reaches	Depends on more locations	Location specific based on mechanism of hyporheic enhancement such as log jam scour and stratification

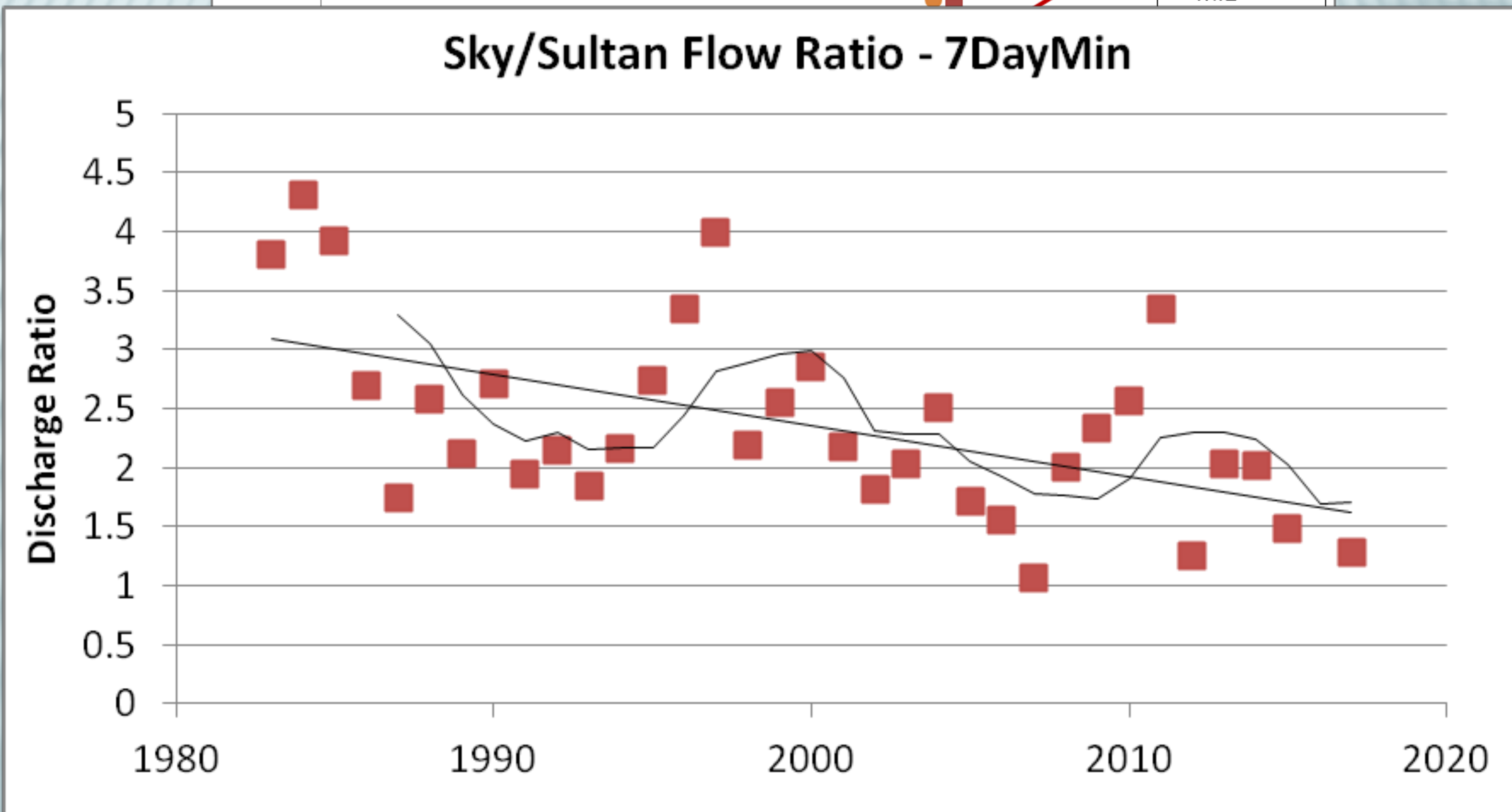
CONCEPTUAL FRAMEWORK FOR ACTIONS

Spatial Scale	Large- AUs (1-10km2)	Medium – River/ stream reach Scale (100-1000m)	Small- in channel Habitat Units (10-100m2)
Goals	Protecting & restoring water flow processes – Delivery/ Surface Storage/ Recharge/Discharge	Improving shading/ future LWD recruitment/ complex channel patterns and flow routing in floodplains for transient storage	Enhancing habitat & hydraulic complexity and connections for thermal refuge at point locations of cold discharge
Supporting Info./data	Watershed Characterization/ Hydrogeology/ Flow measurement (seepage runs and baseflow analysis)	Shade Deficits/ Bank armoring/ Channel morphology/ Floodplain connectivity/ Seepage runs/ FLIR imagery-mapping/ Longitudinal thermal profiling	Site-based summer temperature/ pool formation & stratification /side channel connectivity/ tributary junctions/ thermal profiling/ TIR imagery
Action/ Activity	Promote AU-scale solutions for targeted water flow process protection and restoration – focus on Recharge/Discharge	Riparian planting/ floodplain acquisition and restoration/ remove armoring to restore flow routing and channel forming processes	Construct Log jams/ connect side channels/ enhance tributary confluences
Response time	Long-term (>20 years)	Medium term (5-20 years)	Short-term (1-10 years)

STRATEGY THEMES FOR TEMP PROTECT/REST

1. Protect higher recharge/ discharge areas
    1. Evaluate supplemental GW pumping
2. Protect SW/GW flow to cold-water refuges
3. Restore cold-water confluences & downstream influenced area
    1. Excavate cold-water flow convergence
4. Restore/create side channel connectivity
5. Restore wood for scour and channel movement
6. Prioritize river meander process in flow-gaining reaches
7. Plant riparian buffers of floodplain tributaries
8. Increase transient floodplain storage for local recharge – beavers, roughness elements


Unit Discharge - 7DayMinimum Flow/Mi2
4
3.5
Sultan R. 7Day/ 94 mi2


Sky/Sultan Flow Ratio - 7DayMin
Discharge Ratio
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1980
1990
2000
2010
2020

ACKNOWLEDGEMENTS

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CONCLUSIONS

- Climate regime shifts have pronounced influence on summer low flow in Stillaguamish watershed between phases and significant interannual effect within phases
- “Strongly Declining” NF Stilly low flow cited by WDOE for PSP flow target not supported by this analysis with climate context
- *Degree of flow response varies by rivers/streams at the salmon population scale*
- *Decreased flow has documented and predictable effect on coho and steelhead*
- *Climate shift (cooler-wetter) is suggested from recent flow and PDO-ENSO. But may be “warmer-wetter”*
- **Higher elevation snow dominated (rain on snow) locations that are relatively intact and host relatively higher salmon abundance, such as Squire Creek, may be most affected**

PROJECT STRATEGIES AND RECOMMENDATIONS

1. Enhance stream confluence habitat at locations with cold-water refuges - (cover, depth, velocity).
   - **≈50 potential locations**
2. Connect/enhance floodplain habitats - side channels, alcoves, backwaters, with cold-water sources.
   - **16 potential locations – Lower SF Stilly Example**
3. Restore river meander processes to create multiple channel and habitat types across the floodplain, particularly in river reaches where flow gain occurs.
   - **Notable example is Lower North Fork Stillaguamish -**
4. Restore deep wood-formed pools to promote groundwater inflow.
   - **Examples are lower Jim Creek, Lower Pilchuck Creek, Lower NF**

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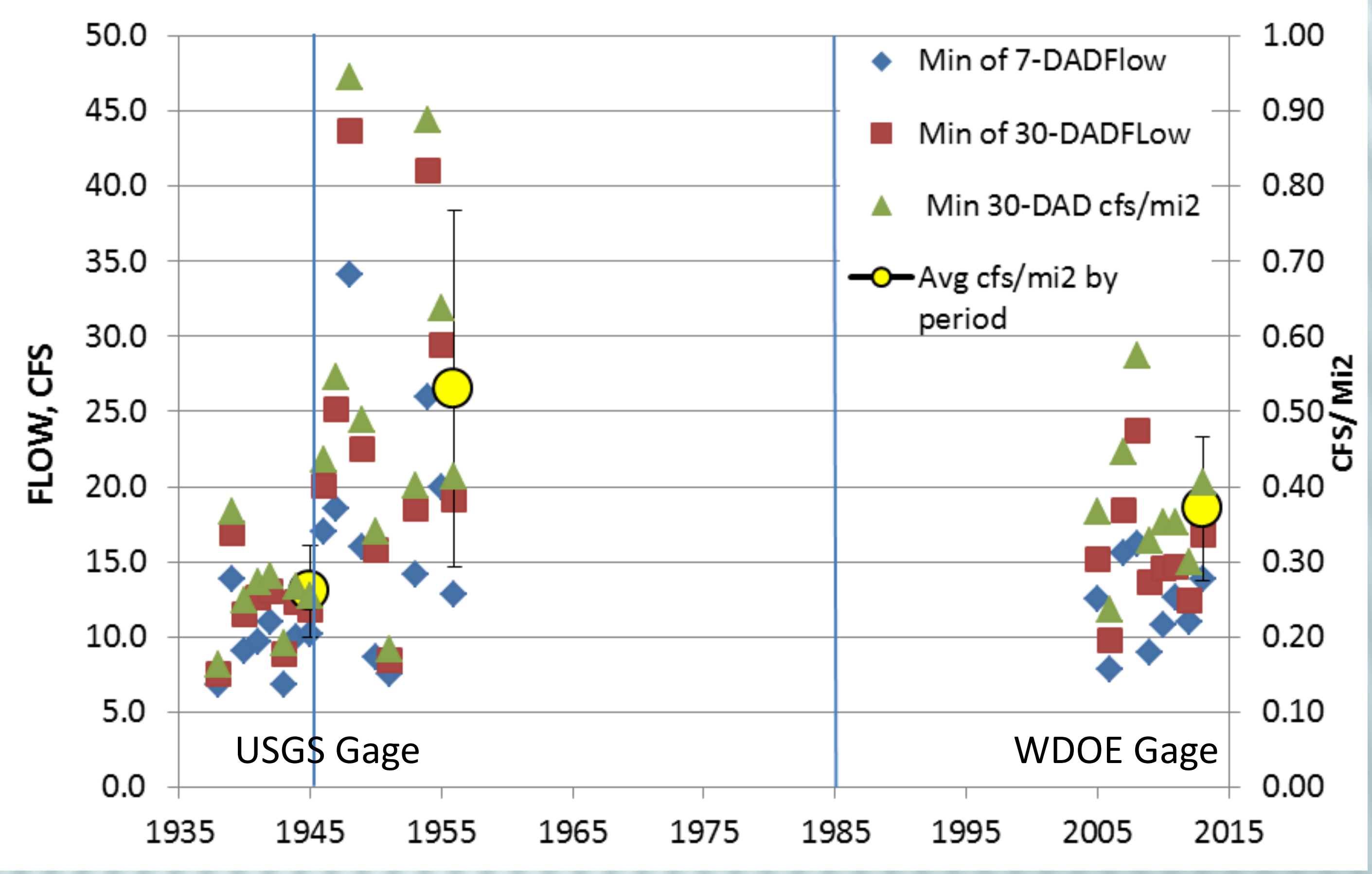
5. Plant riparian buffers to control stream temperature in floodplain tributaries, side channels, cold-water tributaries.

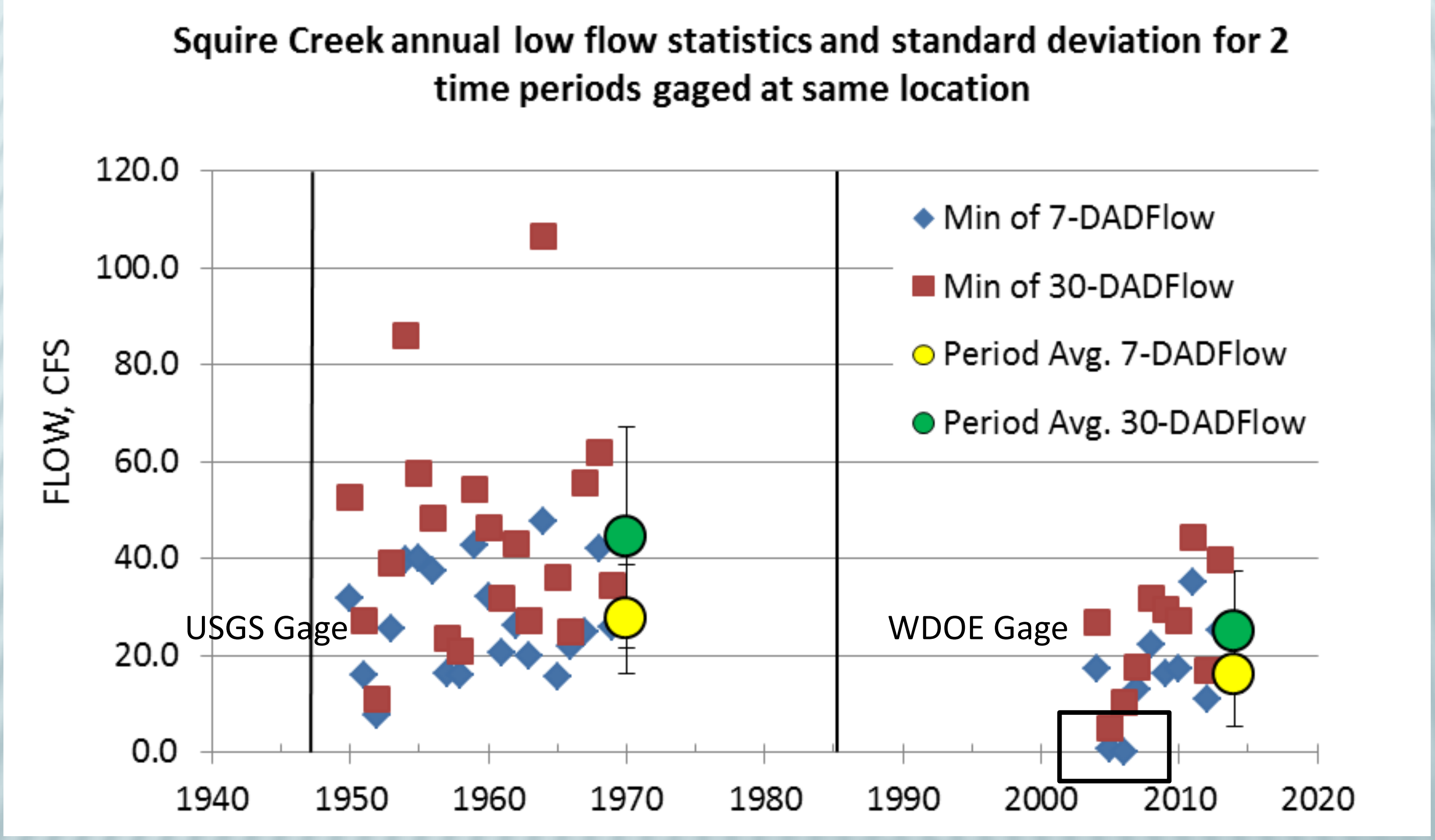
≈50 potential locations

Jim Creek – 2 gages, different locations



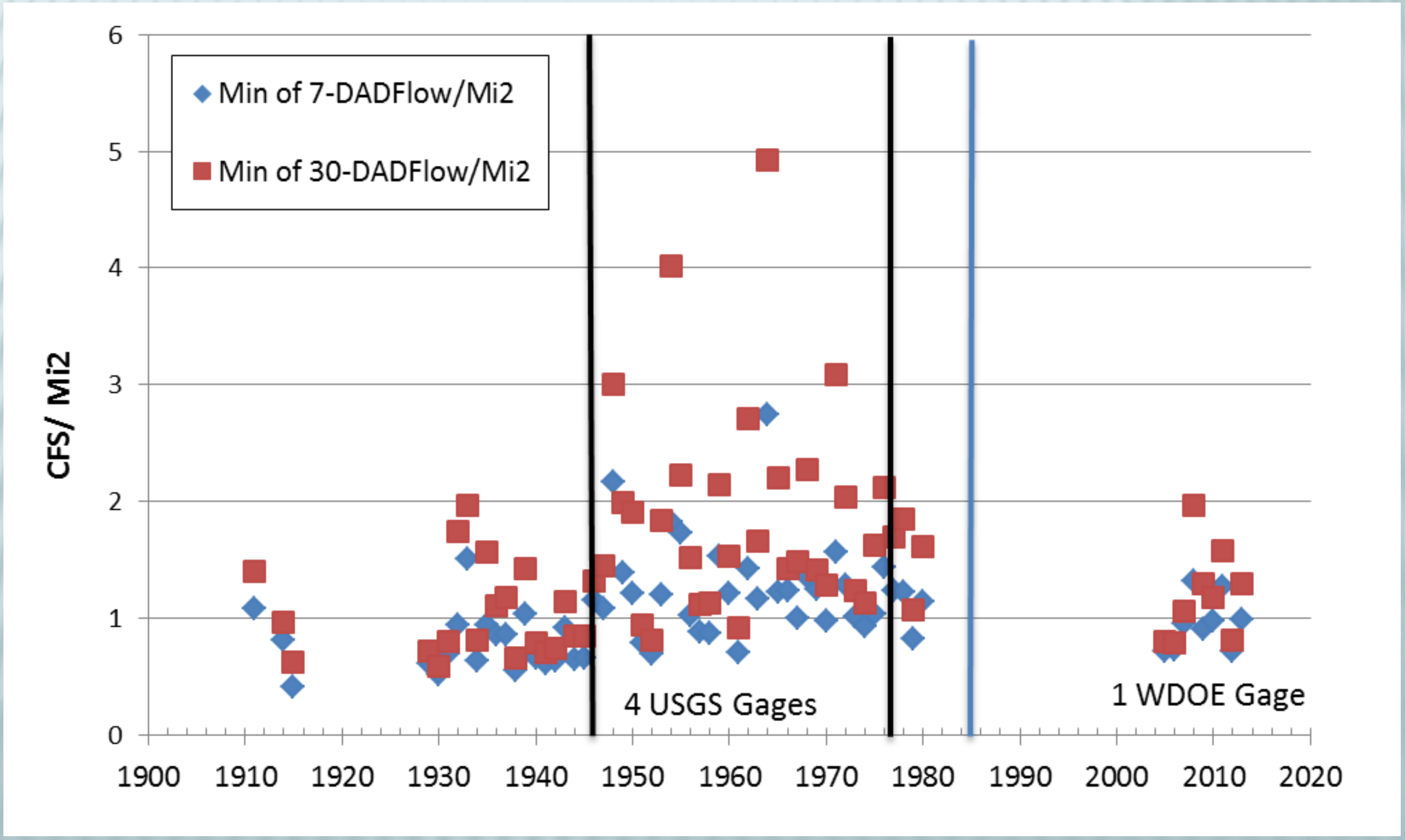
- Kruskall-wallis
- Non-parametric
- ANOVA
- H (2, N=27) =10.9
- p =.0042

Squire Creek – 2 gages, same location –



SOUTH FORK STILLAGUAMISH FLOW

- 5 SF gages standardized to drainage area (cfs/mi2)



PILCHUCK CREEK – 2 GAGES/ 2 LOCATIONS