Effects of forest stand density reduction on nutrient transport at the Caspar Creek Watershed

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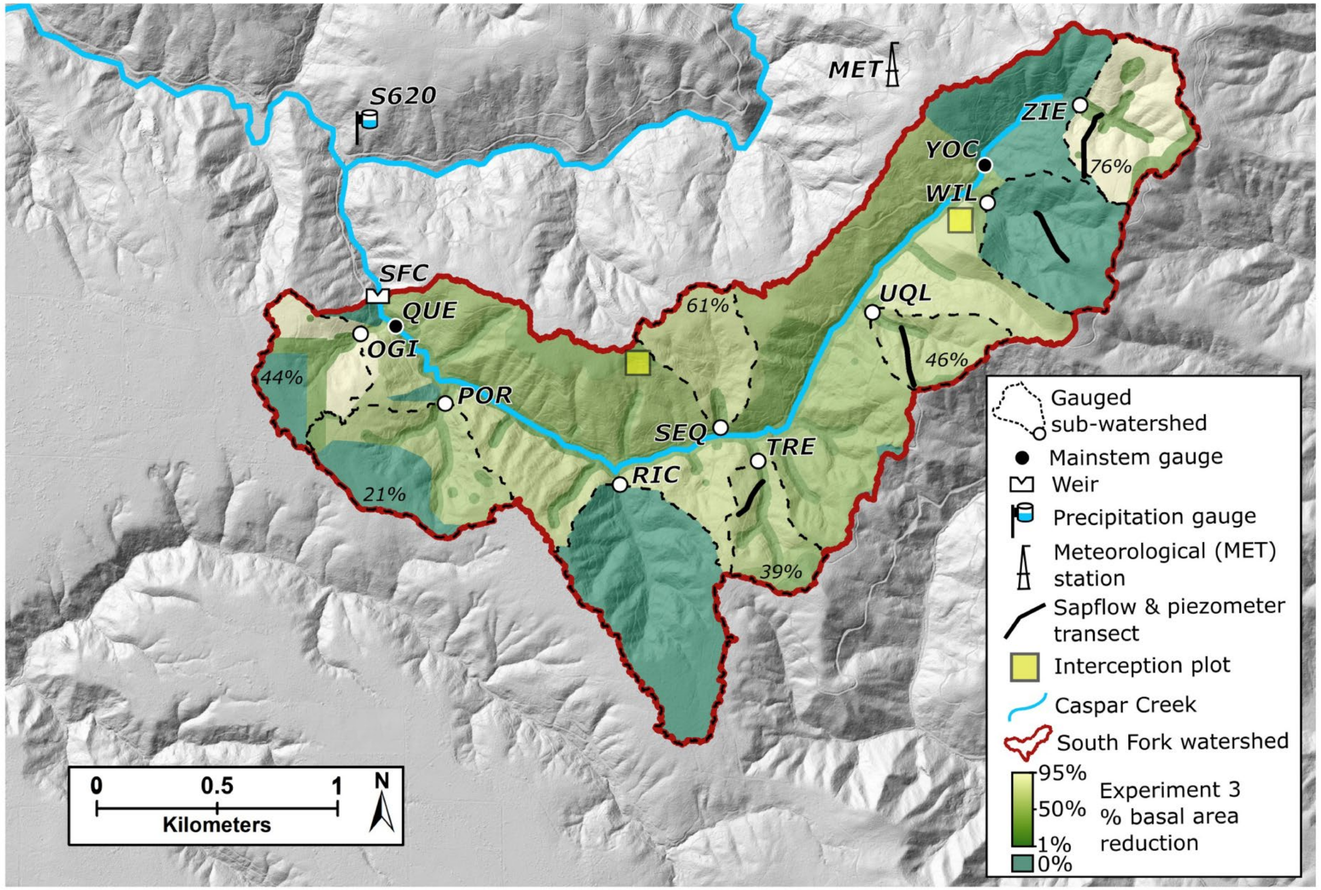
Research Objectives:

- Examine the effects of stand density reduction on the mass balance of:
- Stream water quality parameters and nutrient fluxes: EC, pH, turbidity, DOC, NO_3^-, NH_4^+, DON, TN, TP, PO_4^{3-}, (cations/anions: Mg2+, Ca2+, K+, Na+, Cl-, F^-, $SO_4$2-, Br^-)
  - 1) What are the temporal (pre- and post-harvest, water year, water year type, and season) variations and patterns of nutrient and base cation/anion fluxes from coast redwood forests?
  - 2) How do different stand density reductions change the patterns, concentrations and fluxes of nutrients and base cations and anions compared to pre-harvest conditions?
- Watershed comparison (7/2016-6/2020): South Fork main-stem and four gaged sub-watersheds (Williams, Treat, Uqlidisi, Ziemer)

Paired Watershed study

- Four gaged sub-watersheds and SFC outlet:
  - WIL (0% reduction in basal area),
  - TRE (35%),
  - UQL (55%),
  - ZIE (75%)
  - SFC (integrated signal, South Fork Caspar Creek outlet)



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Sampling

- samples were collected with ISCO 6712 automated samplers or manually by staff (grab samples)
- During storm events ISCO auto samplers collected samples on an hourly basis
- Sample selection: two samples on the rising limb, one near the peak, and two samples on the falling limb
- Monthly sampling in summer
- samples were collected in 125 ml HDPE bottles and stored in a refrigerator at 4 ºC until they were shipped on ice to UCD for laboratory analysis
- >2000 samples were collected in total

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Post-processing and statistical analysis

- Nutrient Load: $Load\left(\frac{kg}{ha}\right) = \frac{\sum_t^{t-1} Q_i * \frac{1}{2}(C_{t-1} + C_t)}{10^6} \frac{1}{A}$

  Q is discharge in L/day,
  A is the watershed area in ha

- ANOVA and Tukey's HSD (honestly significant difference) test at significance level $\alpha = 0.05$
- Tukey's HSD test mostly compared 5 groups (WIL, TRE, UQL, ZIE and SFC)
- Comparing 5 group results in 10 tests (A-B, A-C, A-D,… etc.)
- Deciding p-value: $\alpha_{test}/10 = 0.05/10 = 0.005$
- Any group that shares the same letter has no HSD

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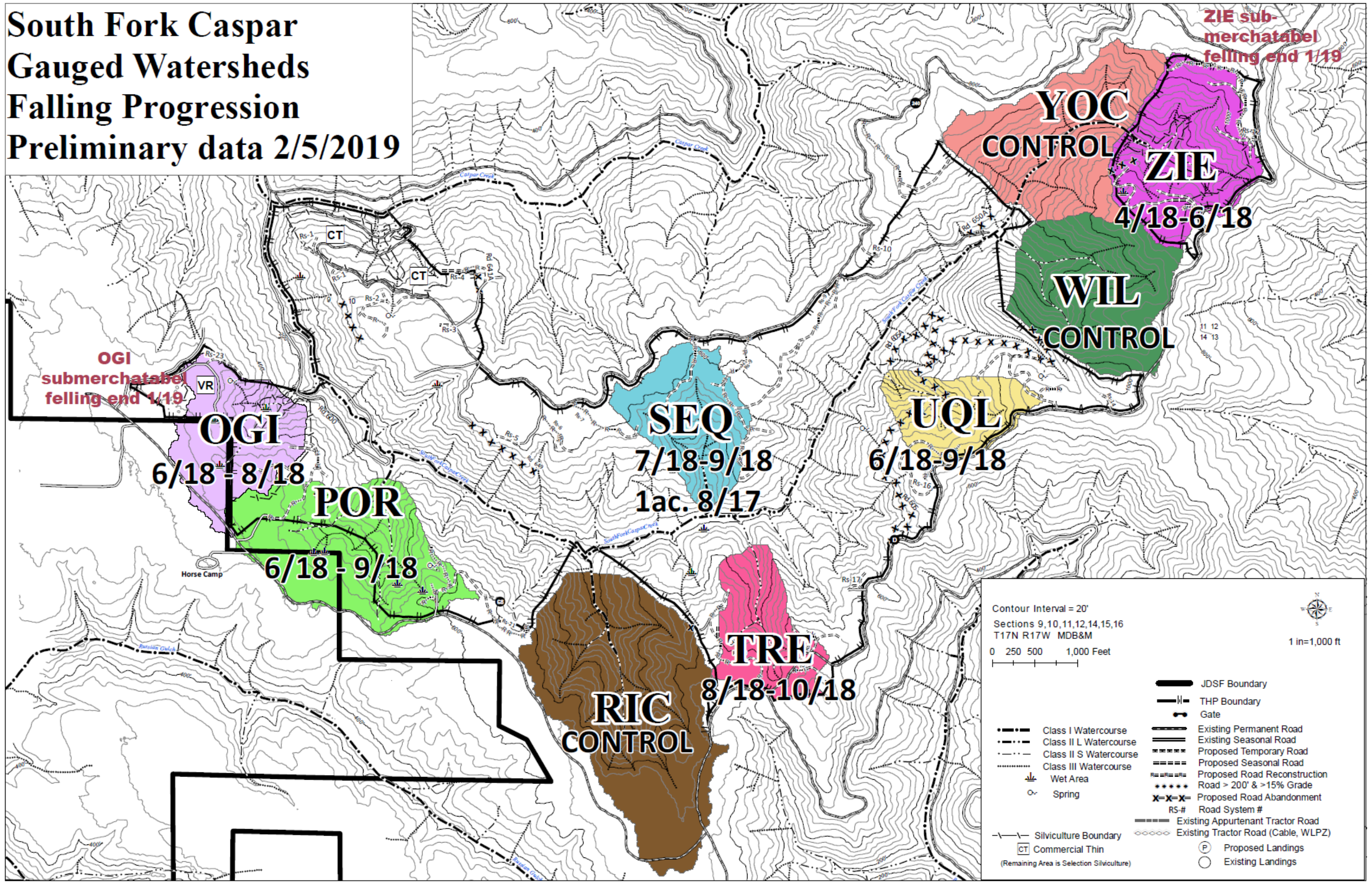
Comparison Periods

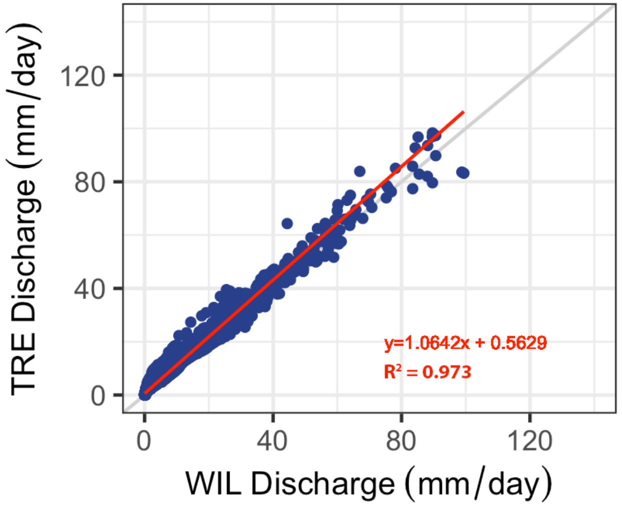
- Nutrient analysis is based on yarding periods for statistical analysis
- Hydrologic calculations use felling dates (to account for reduced plant uptake)

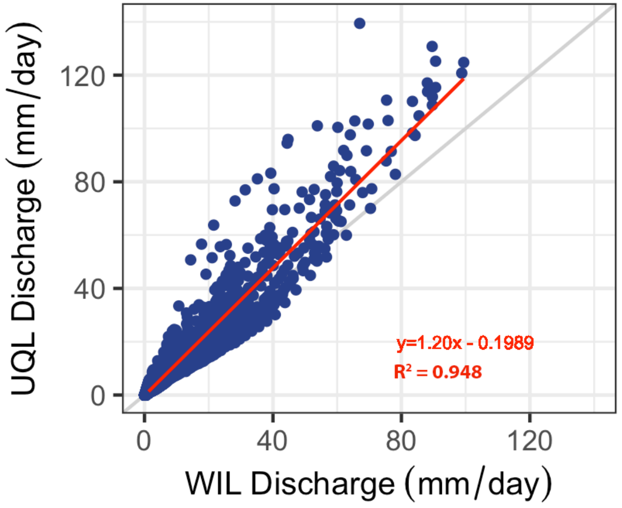


Comparison Periods

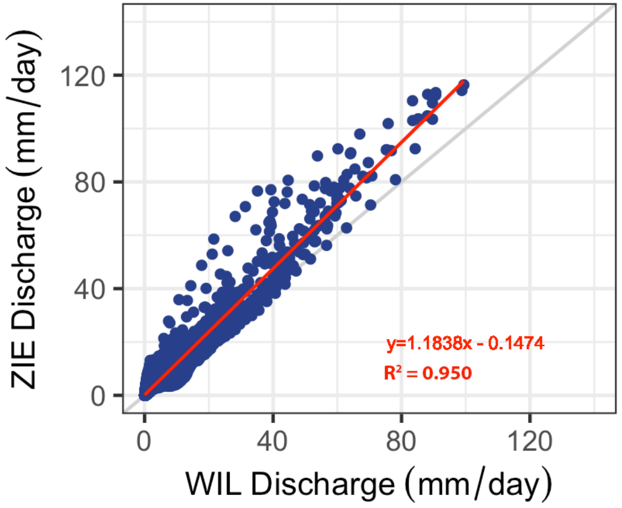
- Pre- and post-yarding: time period is specific to each sub-watershed,
  SFC & WIL: pre: 8/15 - 4/18 , post: 5/18 - 6/20
  TRE, UQL, ZIE: pre: 8/15 - 7/18 , post: 8/18 - 6/20
- Wet and dry years: wet: HY17, HY19, dry: HY18, HY20
- Hydrologic years: 2017, 2018, 2019, 2020
- seasons within the pre- and post-yarding periods (e.g. pre-yard spring seasons vs. post-yard spring seasons); and
- seasons of wet and dry years (e.g. dry-year winter seasons vs. wet-year winter seasons)

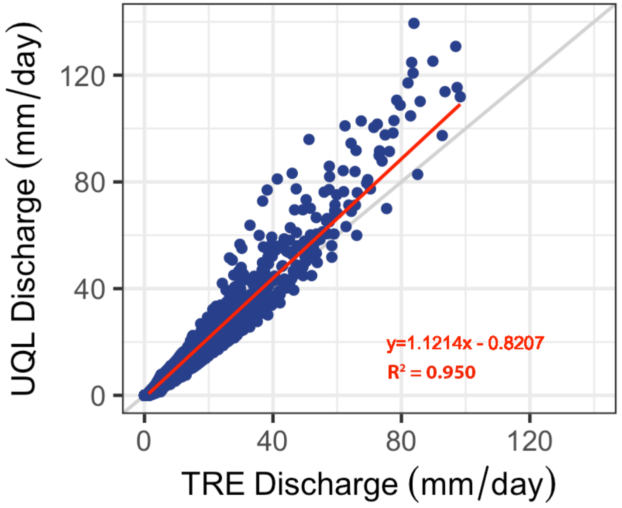
Paired watershed assumption

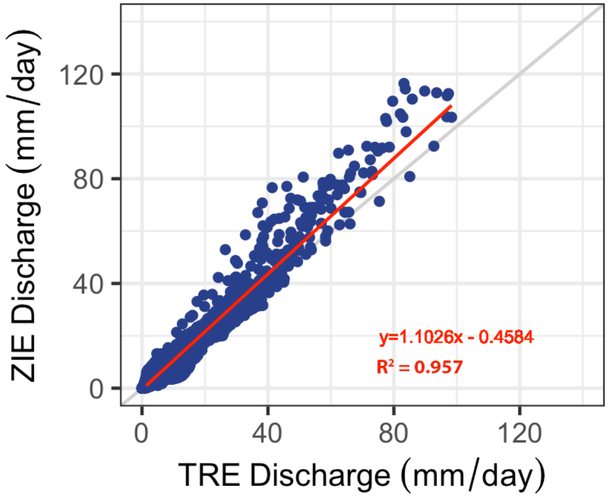


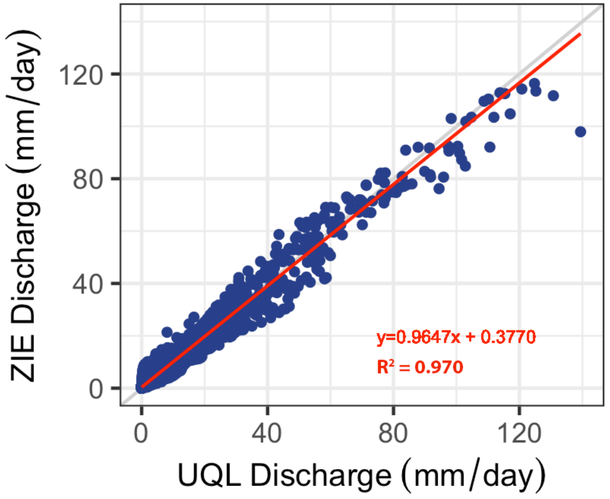


- Comparison of discharge prior to harvest to determine if watersheds behave similarly
- Discharge in TRE, UQL, and ZIE is greater than in WIL by about 6.4% (TRE), 18% (ZIE) and 20% (UQL)









Paired watershed assumption

Sub-watershed ID	Reduction %	Average slope (%)	% difference to WIL
SFC*	TBD	60	18.0
WIL*	0	51	0.0
TRE*	35	47	7.9
UQL*	55	49	4.0
ZIE*	75	43	14.9

* Sub-watershed outlets intensively monitored for stream water chemistry analysis.

- Discharge in TRE, UQL, and ZIE is greater than in WIL by about 6.4% (TRE), 18% (ZIE) and 20% (UQL)
- differences cannot be explained by the watershed slope or watershed area since WIL has the largest watershed slope (51%) and largest watershed area (26.5 ha)
- Differences likely related to aspect, precipitation and storage of watersheds

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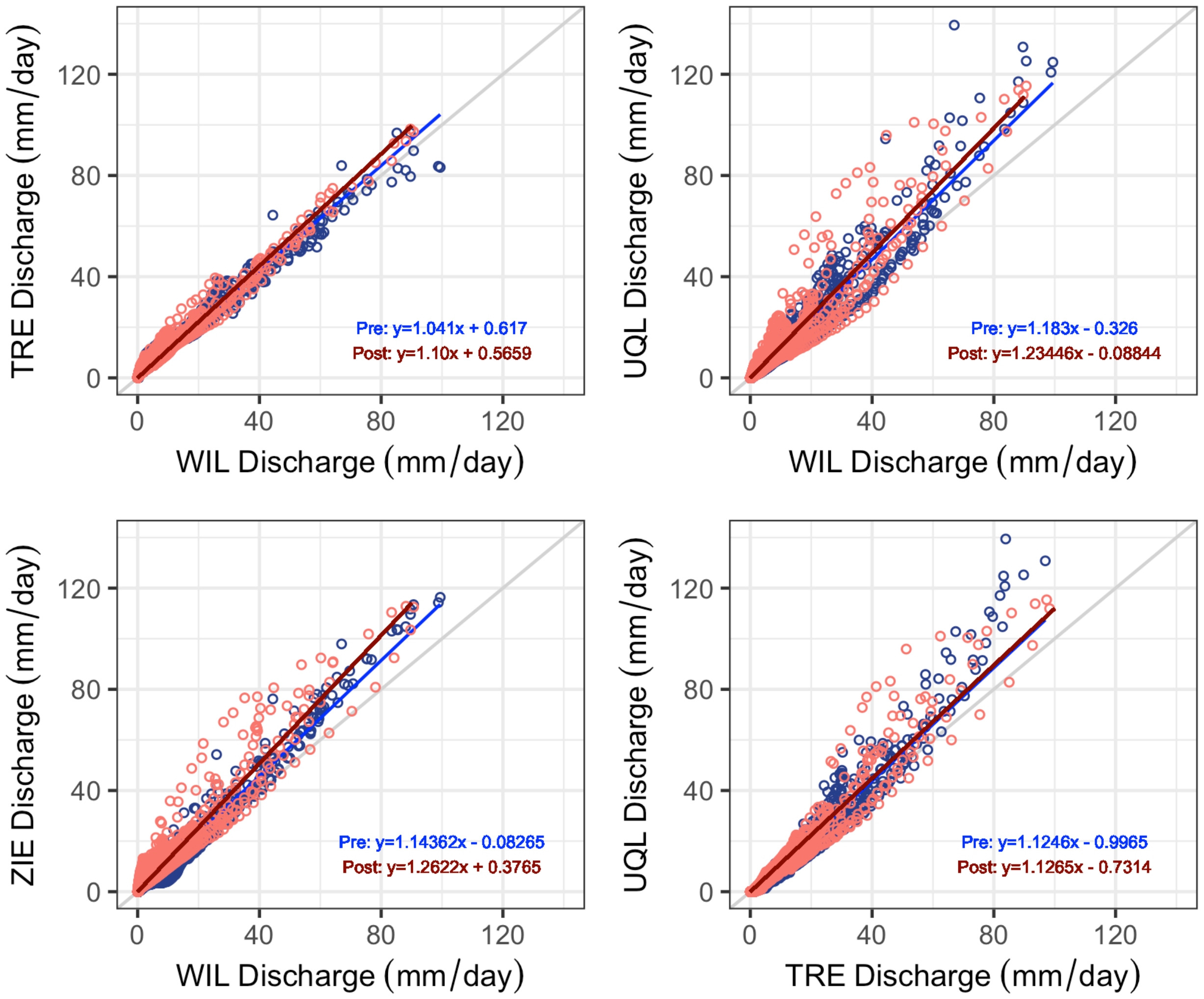
Effects of forest stand density
reduction on hydrology

Hydrologic comparison (pre vs post)

		Precip. (mm)	
HY17	b	1632	Wet
HY18	a	947	Dry
HY19	b	1372	Wet
HY20	a	534	Dry



- Daily water yield in TRE, UQL and ZIE increased by 5.9%, 5.2% and 11.8%, respectively in the post-felling season
- TRE and UQL showed similar increases while ZIE showed most pronounced increase in flow
- Average daily flow in ZIE increased by 11.8% compared to WIL, by 7.3% compared to TRE, and by 6.2% compared to UQL

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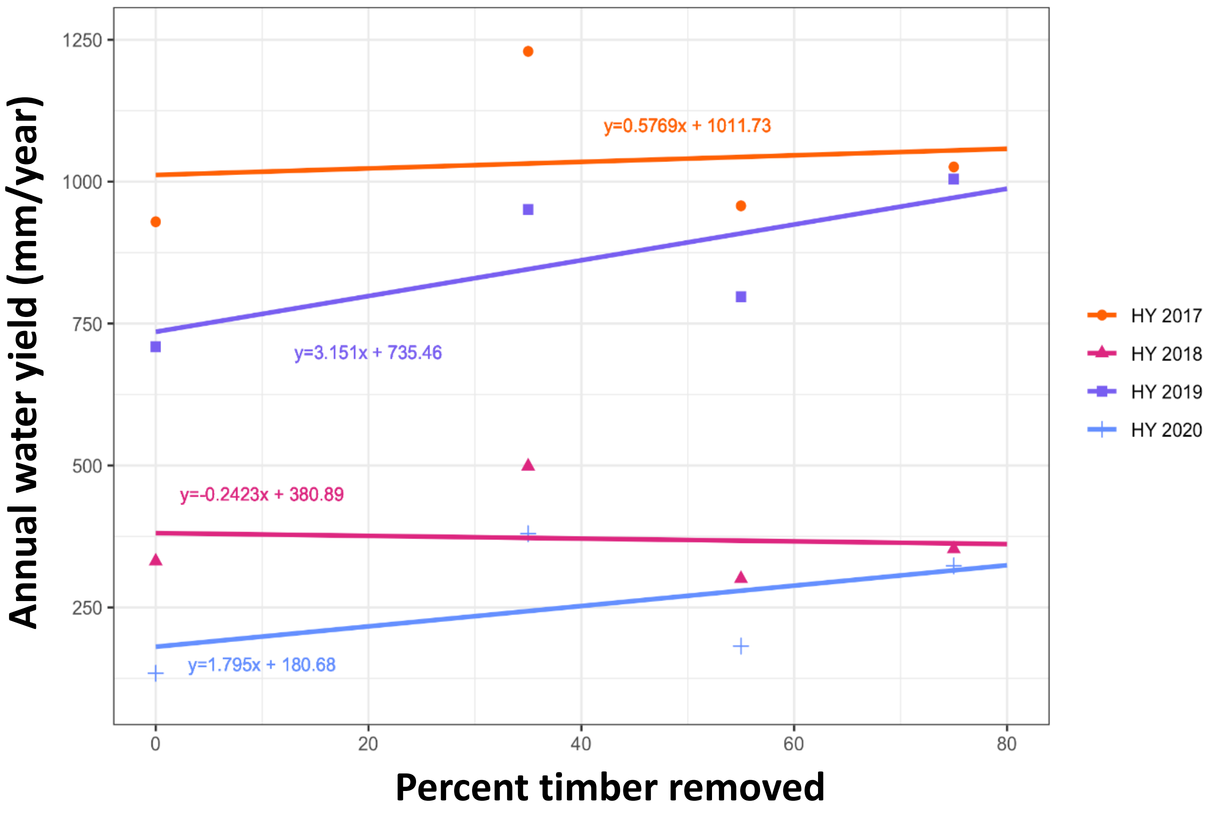

- All sub-watersheds and SFC had comparable water yields in HY2017 and HY2018
- Water yield in ZIE (75%) was 300 mm higher than in the control WIL in HY2019
- A regression of percent timber removed vs. annual water yield showed an average increase of 31.5 mm per 10% timber removed in HY2019 and an increase of 17.9 mm per 10% timber removed in HY2020

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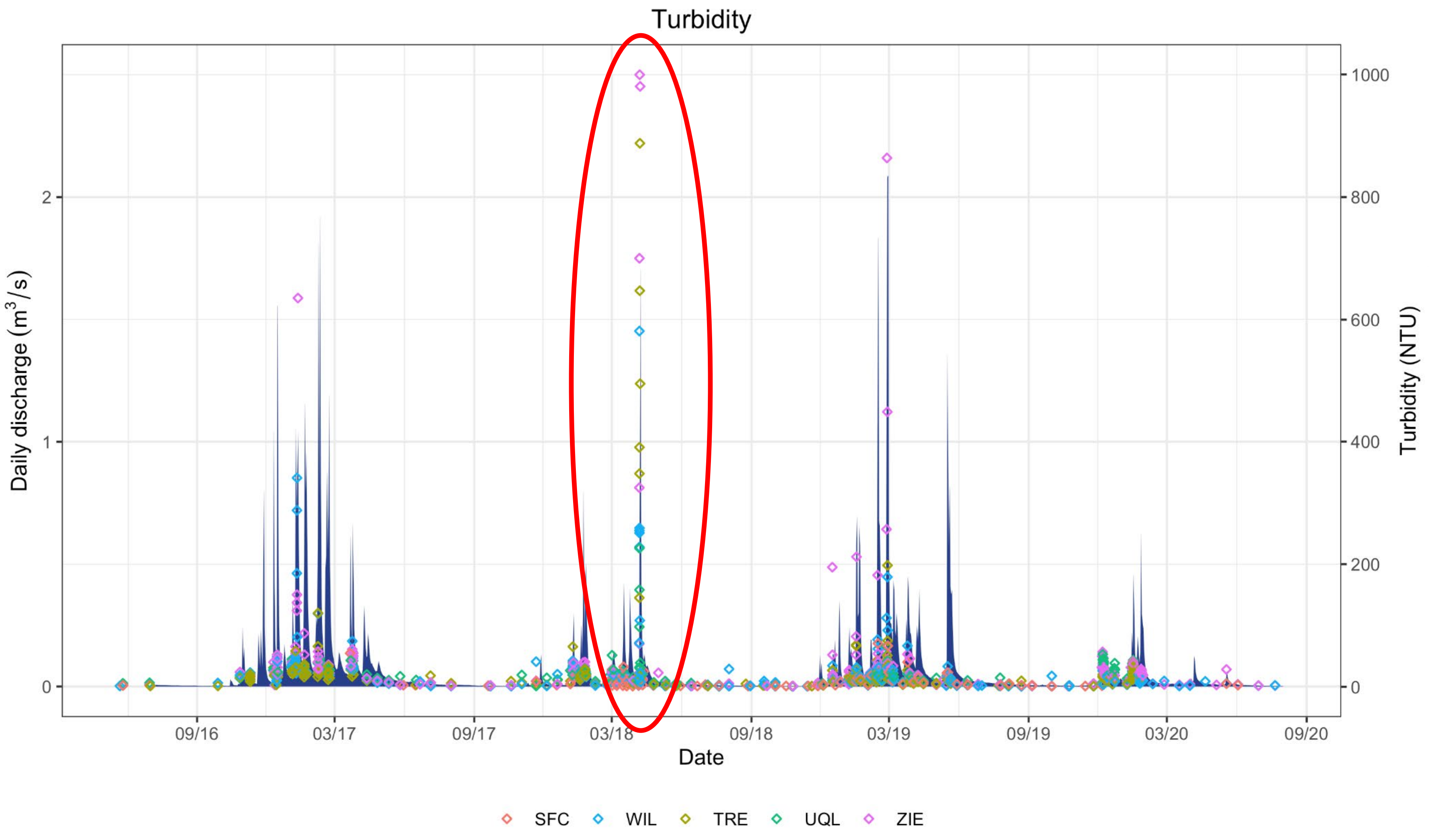
Water chemistry

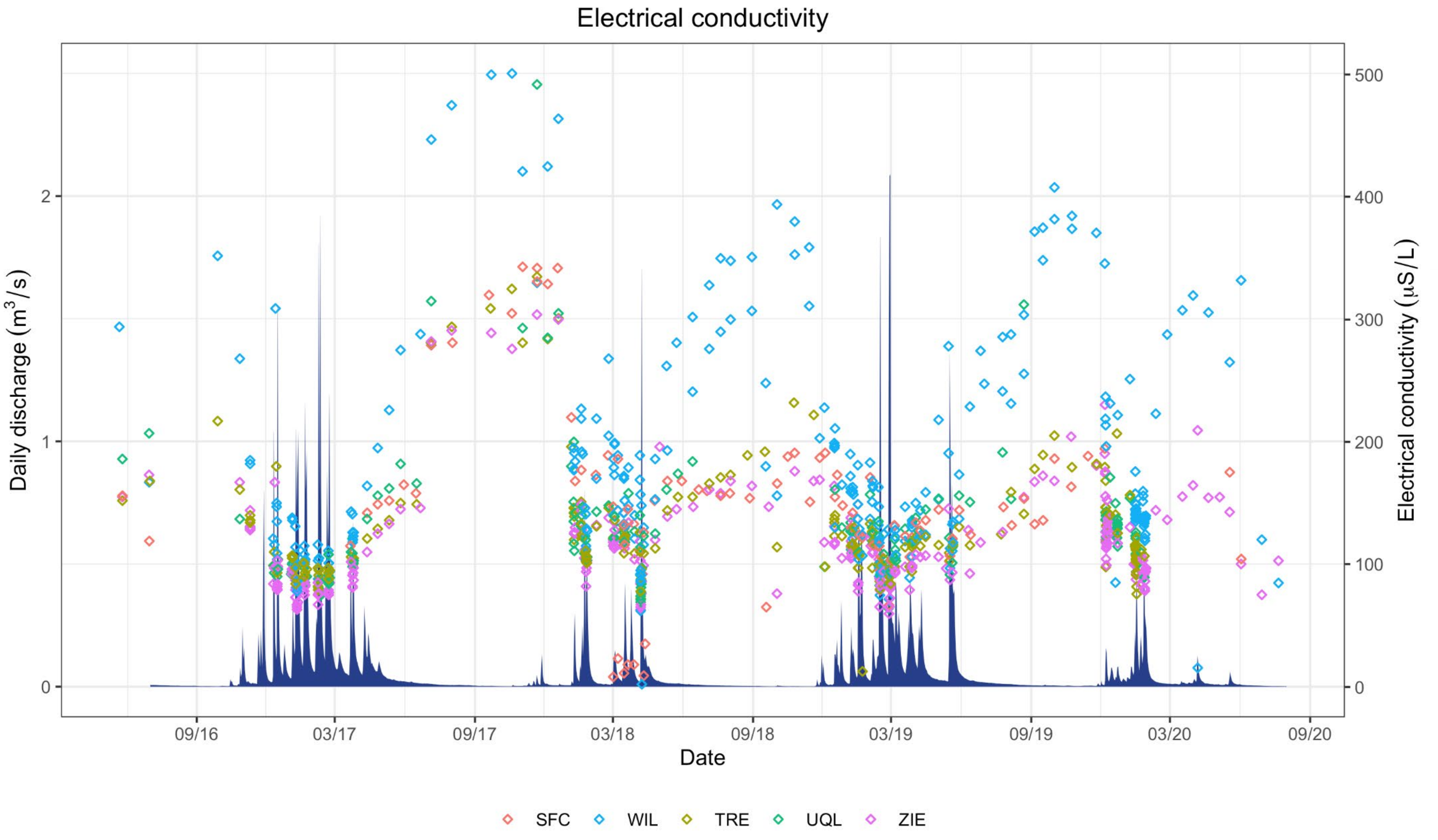
Pre- vs. post-yarding comparison - Turbidity

- highest in all four sub-watersheds on April 6, 2018 after receiving 114.5 mm of rainfall within 24-hours
- post-harvest mean winter turbidity was significantly higher in ZIE and 4-fold the turbidity measured at SFC



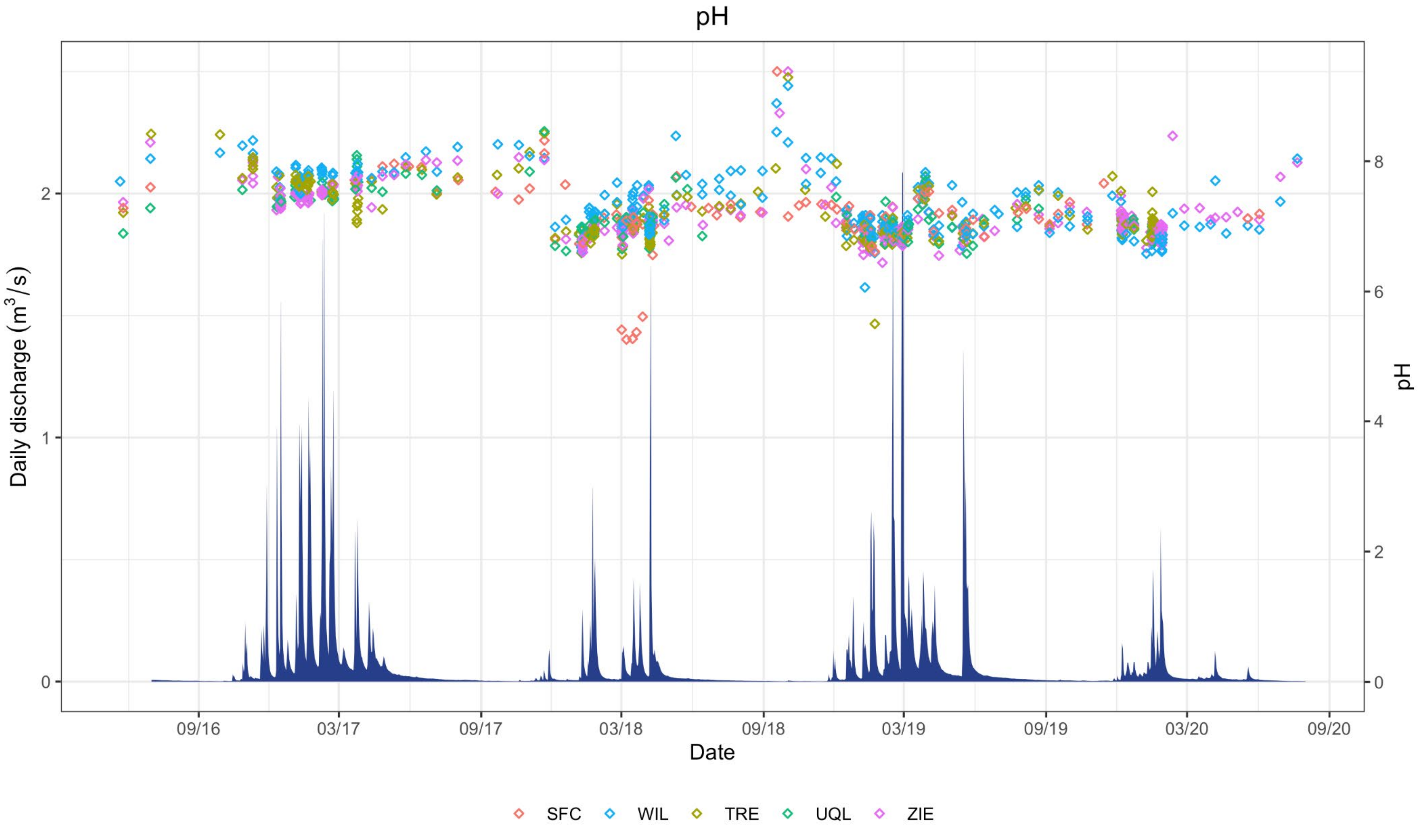
Pre- vs. post-yarding comparison - EC

- EC in WIL was 100-200 µS/cm higher → deeper flow pathways and longer residence times
- EC was higher during dry years than during wet years
- Exceptionally high EC in summer 2017 (flushing of deeper flow paths from wet year?)



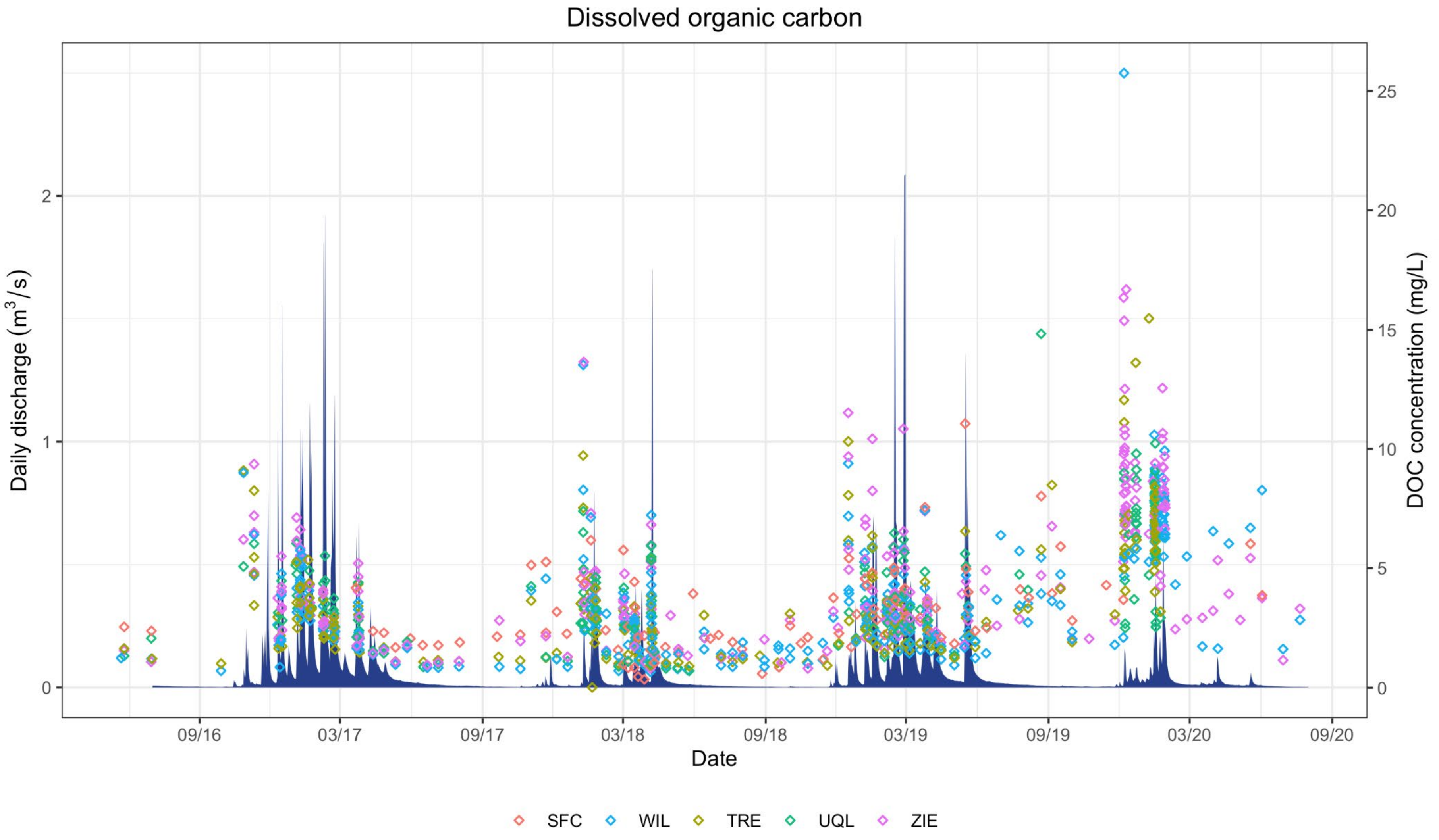
Pre- vs. post-yarding comparison - pH

- declining trend over the 4-year study period, possibly indicating higher amounts of organic-matter-rich runoff contributing to streamflow
- pH lower in winter when runoff has more contact time with organic-rich soil; lower during summer when baseflow dominates



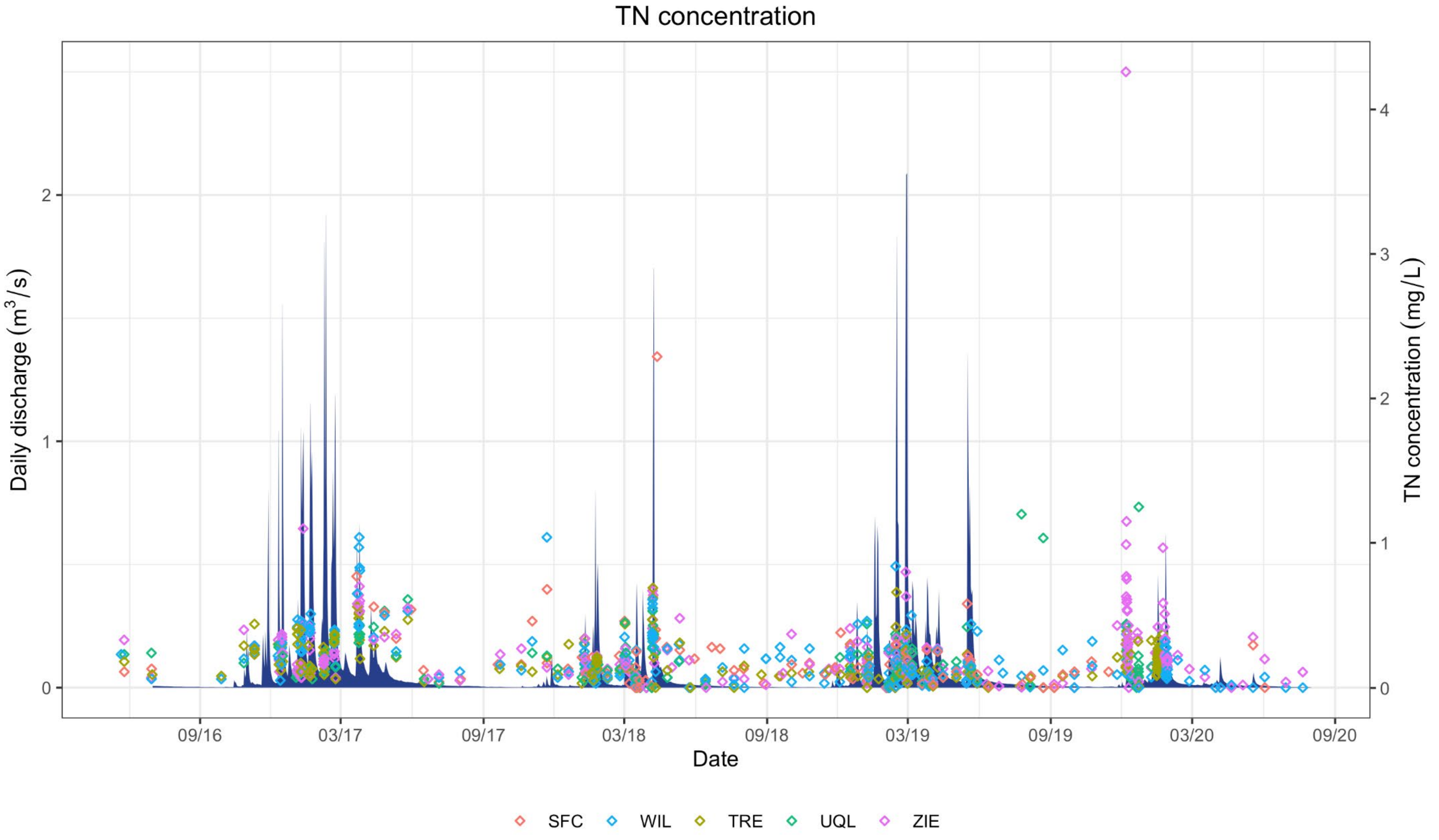
Pre- vs. post-yarding comparison - DOC

- Post-harvest increase in DOC expected but timing depends on organic matter decomposition and C mineralization
- Clear increase post-harvest, particularly in ZIE
- DOC nearly doubled in HY20 (dry year)
- Summer of 2019 and 2020 elevated in DOC



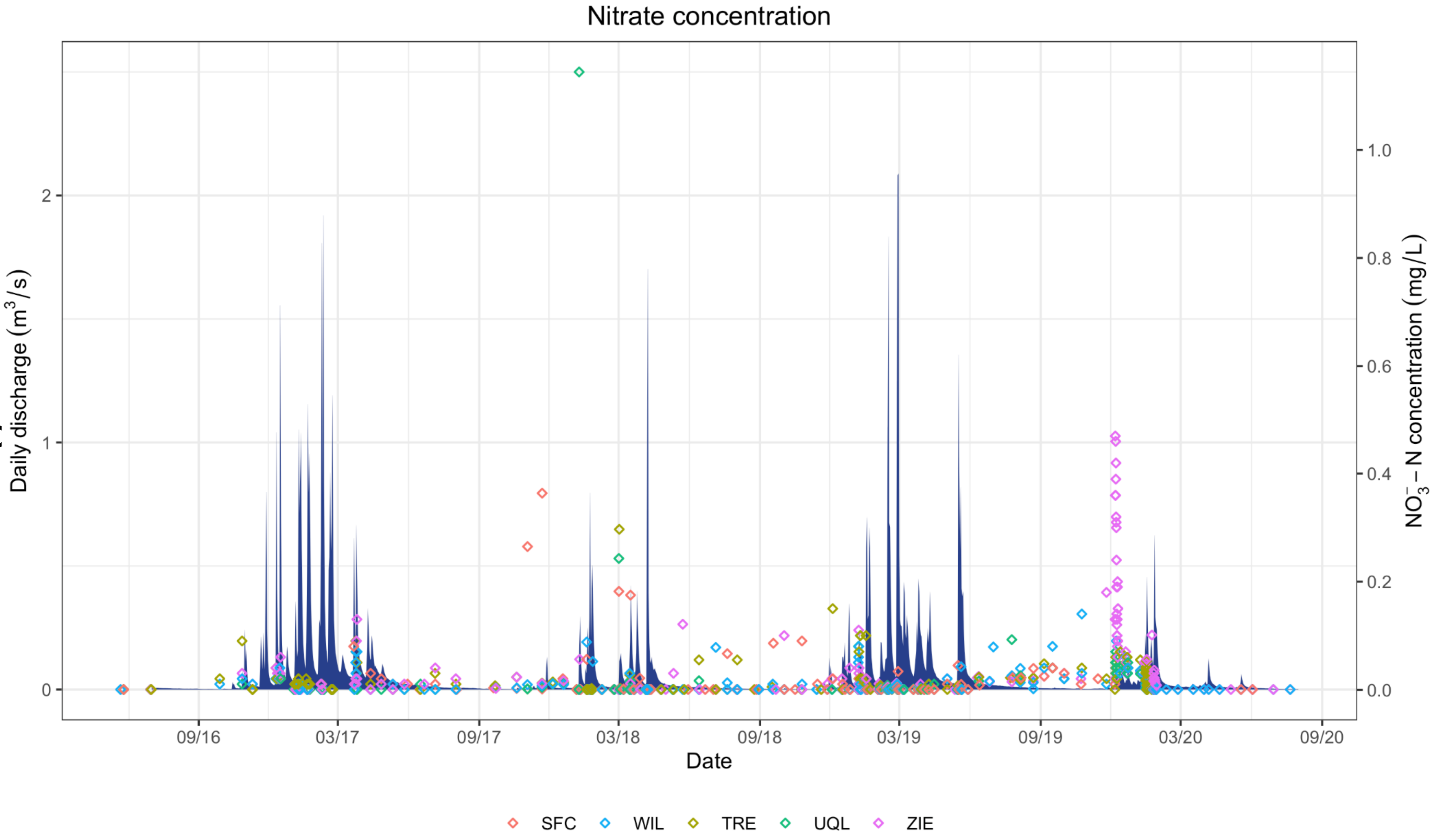
Pre- vs. post-yarding comparison - TN

- High TN during storm events of wet years, and during fall flush of dry years
- TN higher in UQL and ZIE post-harvest
- TN higher in all treatments in HY19 & HY20
- Mineralization and nitrification of organic-N to inorganic ammonium, nitrate



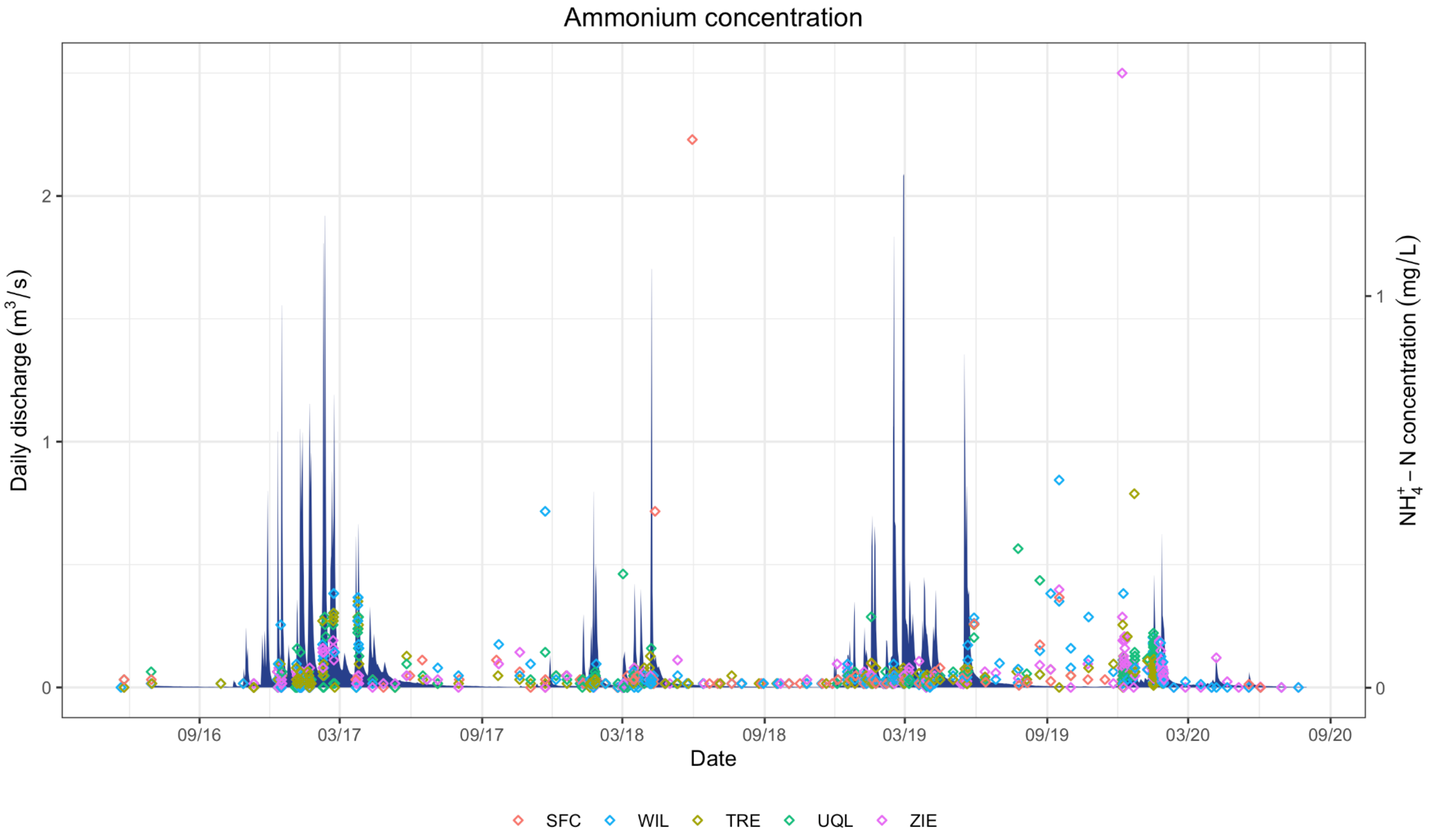
Pre- vs. post-yarding comparison – NO_3^-

- NO_3^- was near detection limit and showed similar trends to NH_4^+
- NO_3^- increase highest in 2nd year post-harvest
- NO_3^- mainly produced by soil microbes. 1st year after harvest high organic matter created high C:N ratios and immobilization of organic N



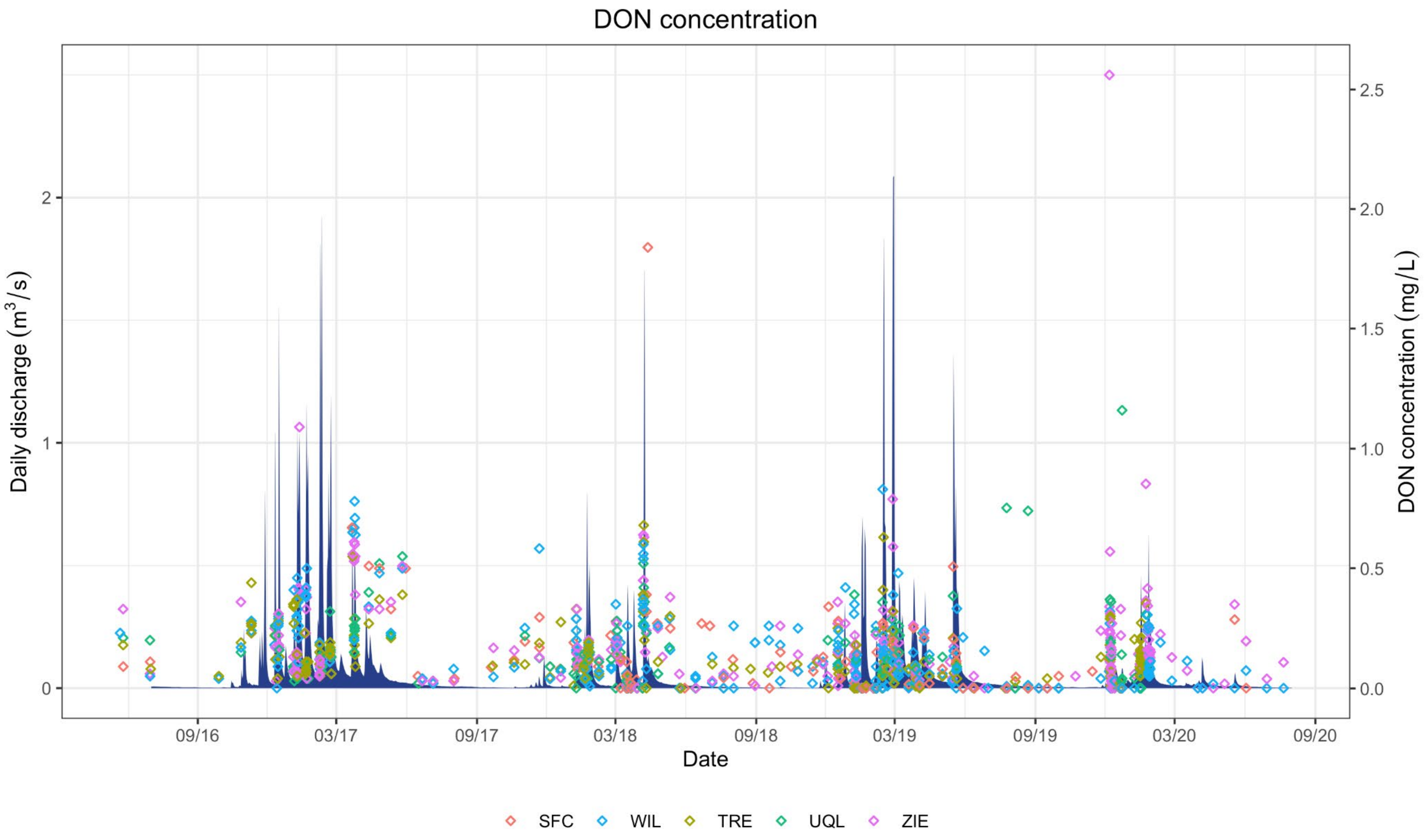
Pre- vs. post-yarding comparison – NH_4^+

- NH_4^+ was near detection limit and shows similar trends to TN
- NH_4^+ makes up ~20% of TN
- organic matter input, reduced vegetation uptake, increased mineralization of soil organic N, and N fixation
- Increase in stream N transformation (e.g. algal production)



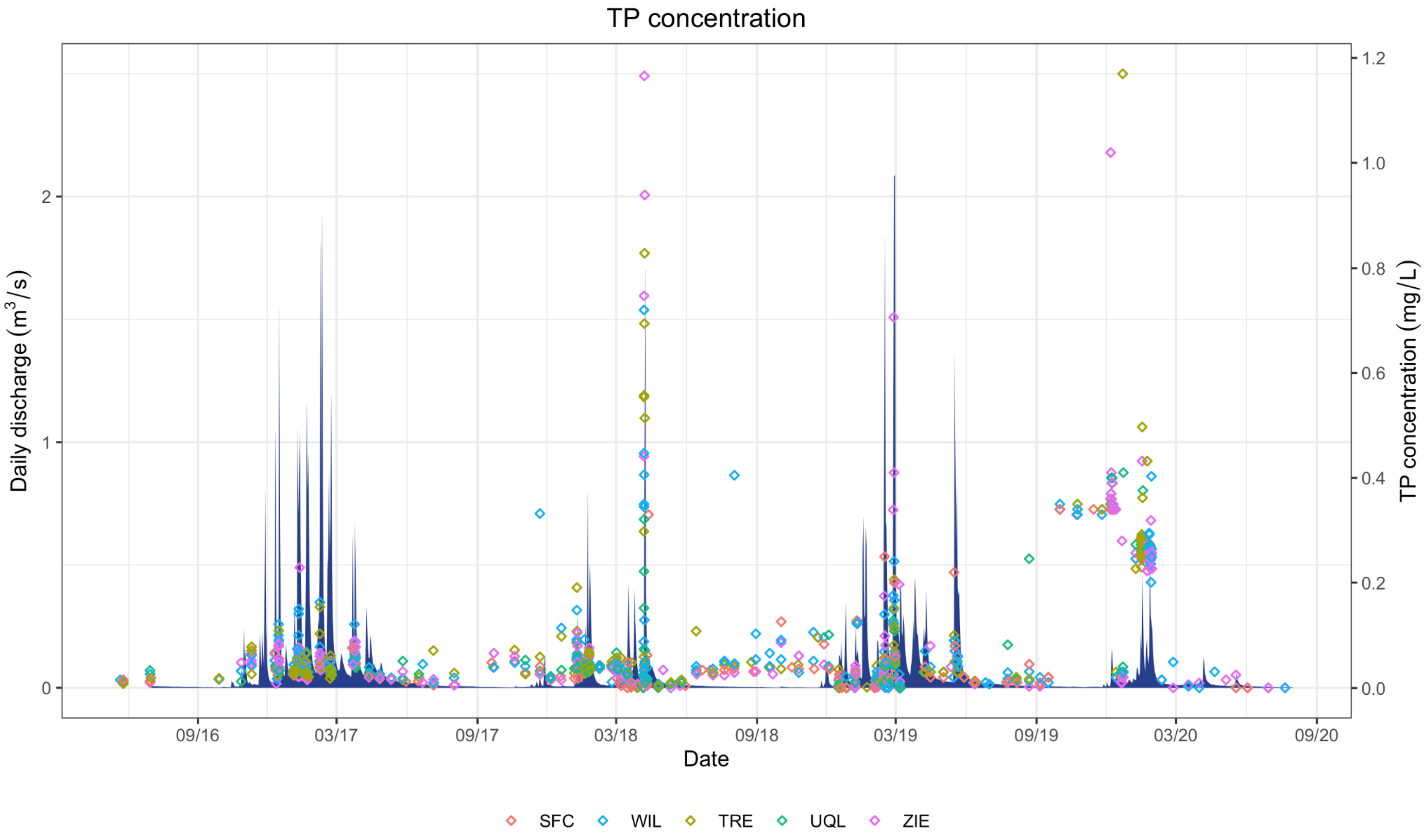
Pre- vs. post-yarding comparison – DON

- DON makes up ~80% of TN
- elevated during storm events and peaked late in the rainy season during wet years (early during dry years)
- DON elevated in UQL and ZIE post-harvest



Pre- vs. post-yarding comparison – TP

- TP overall was very low but higher during dry years and lower during wet years
- clear relationship to flow and geogenic sources (e.g. mineral weathering)
- HY18, HY19 increased influx of suspended sediments and particulate phosphorus into streams

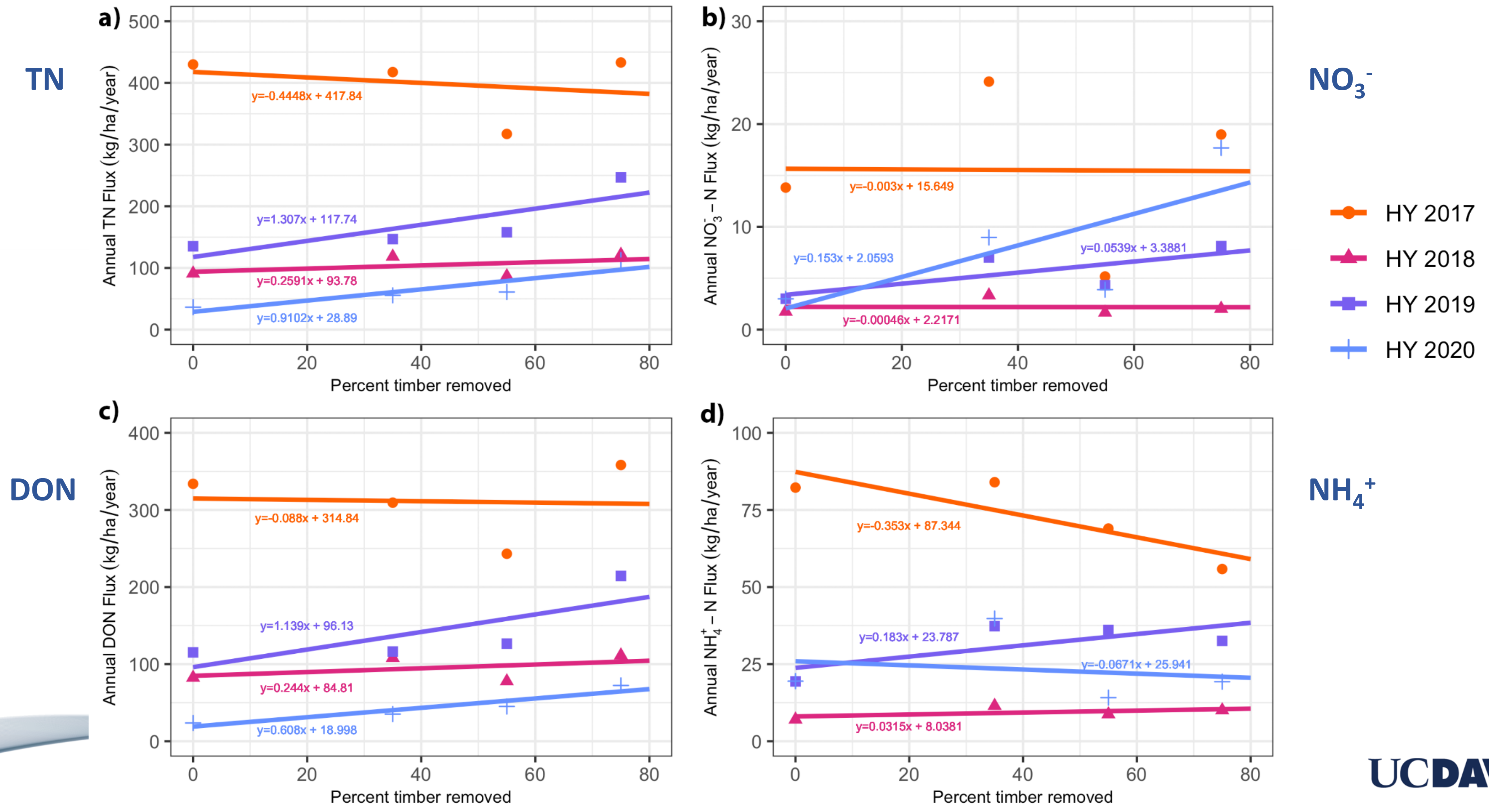


Elemental fluxes

HY17 created largest N flux

		DOC	TN	NO_3^--N	$NH4^+$-N	DON	TP	PO_4-P
		Elemental Flux (kg/ha/period)						
SFC	pre-yard	1923.96	234.52	18.32	28.41	197.93	21.32	13.47
	post-yard	5411.26	234.85	8.12	31.89	201.72	95.35	11.78
WIL	pre-yard	5010.21	520.49	15.57	89.19	415.91	104.36	20.29
	post-yard	3890.24	172.08	6.00	38.99	139.36	75.26	16.05
TRE	pre-yard	6204.51	536.08	27.47	95.49	417.47	151.22	23.22
	post-yard	5342.94	202.41	15.98	77.07	151.50	125.13	30.50
UQL	pre-yard	6222.11	404.07	6.83	77.73	320.91	78.50	9.16
	post-yard	5631.23	218.84	8.20	50.19	171.68	111.75	15.06
ZIE	pre-yard	6205.22	549.16	20.18	65.28	465.65	190.44	10.82
	post-yard	8222.22	364.98	26.64	52.47	290.80	191.89	20.64

Pre- vs. post-yarding comparison – elemental fluxes



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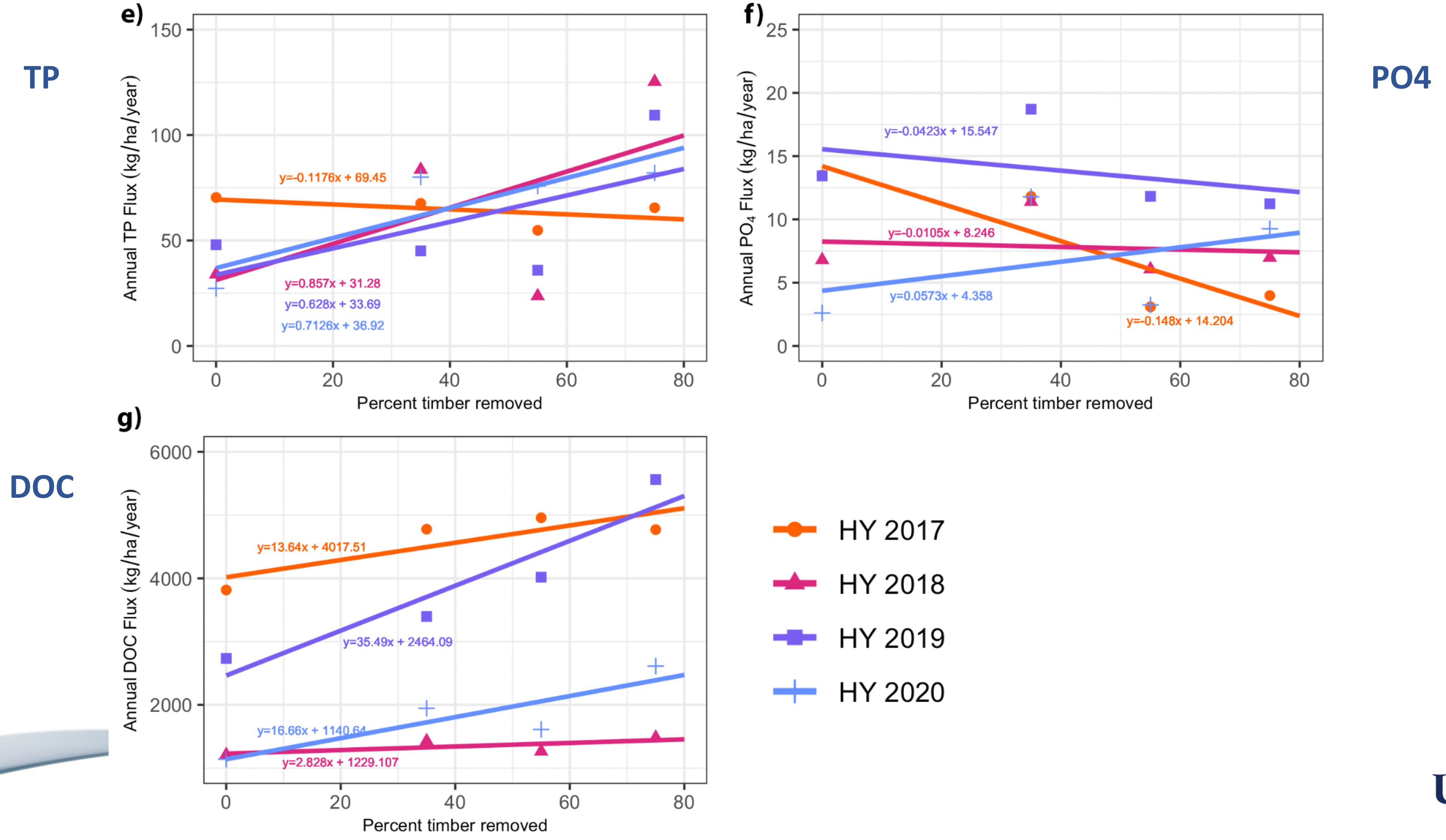
Pre- vs. post-yarding comparison – elemental fluxes



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Conclusions

- Water yield increased post-harvest at an avg. rate of ~31.5 mm/yr and 18 mm/yr for every 10% of timber removed in HY2019 and HY2020
- Clear increase in DOC and TP post-harvest (increased availability and transport of biomass, organic matter and suspended sediment from the harvested areas
- TN, DON flux largest during HY2017 (wettest year)
- Clear increase in DON, NO_3^- and NH_4^+ with percent timber removed in HY19 (and HY20)
- Fluxes of N, P and C from treatment watersheds were generally 1.3 to 9 times greater than those in control; result of both increased solute concentrations (e.g. DOC, TP, DON) and increased water flux

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Liz Keppeler, Forest Service Staff and the Field Crew at the PSW Research Station in Fort Bragg

CAL FIRE

The Redwood League

Questions?

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