Evolving Headwater Stream Resiliency: Modeling Surface Water Trends Across the San Bernardino National Forest to Support Sustainable Water Resources Management

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Abstract

High quality water resources are essential to sustaining ecological and human health, however, less focus has centered on watershed landscape and climatic impacts to headwater streams. The San Bernardino National Forest (SBNF) in Southern California contains numerous perennial headwater streams that serve both the Santa Ana and Mojave River Basins as well as recreational streams and lakes utilized by locals and tourists alike. Using a teacher-scholar model, undergraduate and graduate research assistants collaborated with faculty to monitor surface water quality at 10 sites across the SBNF including headwater streams entering Silverwood Lake, Lake Gregory and Lake Arrowhead. In situ sampling for temperature, pH, conductivity, flow, turbidity, nitrate (NO3-), ammonium (NH4+), and dissolved oxygen with lab based assessments for E col., total coliform and enterococci were conducted during the dry and wet seasons. Results indicate that multiple water quality metrics exceeded federal, state and regional regulatory requirements simultaneously during both seasons suggesting that both the climatic and variable anthropogenic characteristics of mountain watersheds may be adversely impacting the longitudinal quality of water resources across the hydrological network. This is of paramount concern because water impairment in these headwater streams could potentially affect the social, economic and environmental characteristics of communities across varying spatial scales. Results also highlight the complexities of headwater management as streams traverse multiple jurisdictional boundaries as well as opportunities for public education and outreach aimed at collectively supporting community and environmental resiliency.

Background

- Extensive literature highlights ***human-environmental contributions to surface water impairments*** with less attention centered on the physicochemical quality of headwater streams located in semi-arid regions where water resources are limited (Alford et al. 2016; Arnold and Gibbons 1996; Cahoon et al. 2006;Edwards et al. 2015; Huang et al. 2013; Mallin et al. 2009; Schueler 1994; Shaw et al. 2014; St-Hilaire et al. 2015; Tong and Chen 2002; UNH 2020, USFS 2020; Wallace and Eggert 2015)
- ***Headwater streams*** serve as the beginning and collectively the largest percentage of stream miles across the hydrologic network providing numerous environmental (i.e. nutrients, habitat, thermal refuges), socio-cultural (i.e. drinking water, irrigation, food) and economic (i.e. fishing, hunting, manufacturing, agricultural) benefits (Edwards et al. 2015; EPA 2011, EPA 2020; UNH 2020).
- Across the United States, headwater streams account for 53 percent of total stream miles, however, ***only 19 percent of all stream miles have been assessed.***
- In ***arid to semi-arid climates***, such as the southwestern US, ***perennial headwater streams*** are essential because they provide surface water resources for human and ecological activities during seasonal dry periods that are typically void of precipitation events (EPA 2019; Wallace and Eggert 2015).
- Of growing concern to recreational, natural resources, and public health agencies is the ***excessive input of nutrients*** (i.e. NO3-, NH4+) and ***bacteria*** that support harmful algal blooms (HABs) (i.e. cyanobacteria), eutrophication (i.e. excessive nutrients), and hypoxic conditions (i.e. low dissolved oxygen) within waterways.
- These conditions cause a ***multitude of public and ecological health issues*** including skin irritations, respiratory issues, gastroenteritis infections, and liver damage in humans and the bioaccumulation of cyanotoxins in aquatic species (Bello et al. 2017; Butcher & Covington 1995; CAWQ 2020b; He et al. 2011; Manganelli et al. 2012; WHO 1999).
- During ***warmer seasons***, when recreational waters are in high demand, higher water temperatures and the presences of excessive nutrients in waterways lower dissolved oxygen (DO) levels needed to support aquatic species leading to widespread fish kills and creating conditions favorable for HAB outbreaks (Burger et al. 2003; Burkholder et al. 2001; DPH 2019; Gandhi et al. 2017; Marion et al. 2017; Matuszak et al. 1997; Missaghi et al. 2017; WND 2019).
- Such conditions require agencies to issue ***public health advisories*** leading to ***waterways closers*** in an effort to protect the public from consuming toxic fish and coming into contact with impaired waterways.

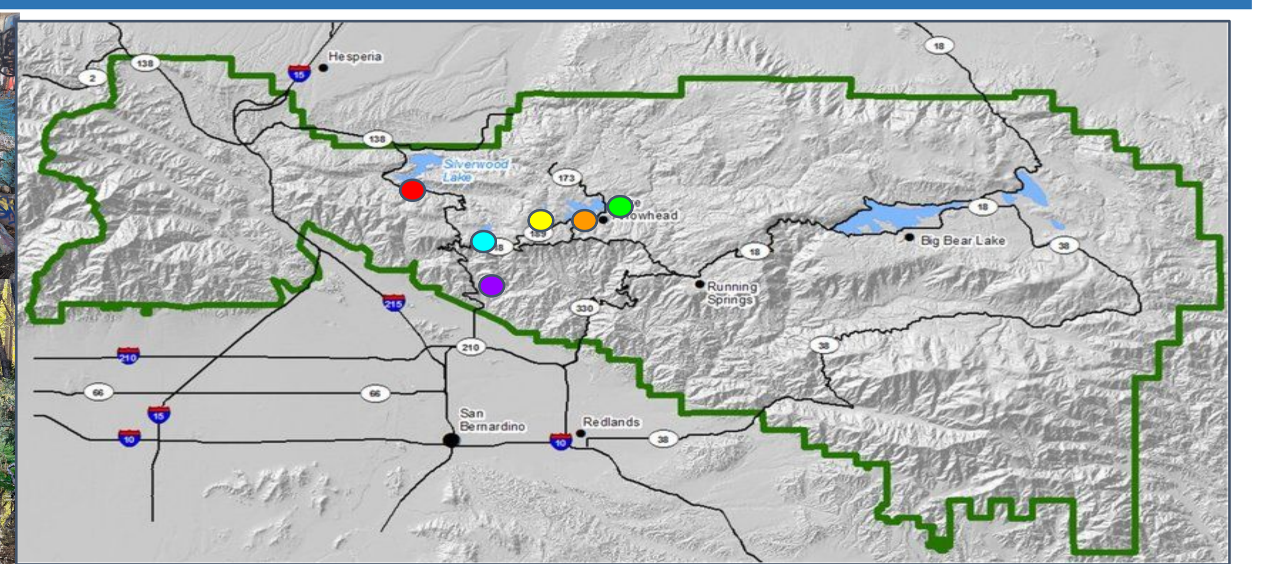
Methods

CSUSB undergraduate and graduate student research interns funding by the CSU WRPI USDA Grant assisted with monitoring efforts including watershed landscape assessments (i.e. GIS), climatic data and in situ and lab water quality assessments. Waterman Creek served as a pilot monitoring location during 2018-2019. Water quality was monitored *in situ* for ammonium (NH4+, mg/L), conductivity (μS/cm), dissolved oxygen (DO, mg/L), pH, nitrate (NO_3^-, mg/L), turbidity (NTU), and water temperature (°C) using ion selective electrode probes and a Vernier Labquest 2 monitor. Additional grab samples were collected, immediately placed on ice, and transported to California State University at San Bernardino to test for total coliform (TC, cfu/100mL), and Escherichia coli (E. Coli, cfu/100mL). Grab samples were collected in 1 (L) brown opaque HDPE plastic bottles that were acid washed using EPA protocols (EPA 2003). individual sampling events and the means of samples were compared to federal, state and regional water quality objectives and standards to determine the frequency in which samples met or exceeded these requirements as outlined in Table 1.

Table 1. Water Quality Criteria Include the EPA Recreational Criteria for *E. coli*, Lahontan Region Objectives for DO and pH, and Hooks Creek Objectives for NO_3^- and TDS.
Source: CWT, 2004; EPA, 2018, 2019b; WB, 2002; WQCP, 2015

Water Quality Metric	Criteria/Objective	Source
Temperature	<25°C	CA State Water Board Objectives
Dissolved Oxygen (DO)	>4 mg/L	CA State Water Board, Lahontan Region Objectives
pH	6.5-8.5	CA State Water Board, Lahontan Region Objectives
Turbidity	<100 NTU	CA State Water Board Objectives (Fact Sheet)
Conductivity	150-500 Range <336 μS/cm (Average)	EPA Criteria (Range) CA State Water Board Objectives (Average)
Nitrate (NO3-)	0.8-2.5 mg/L	San Bernardino Mountains Hooks Creek Objectives
Ammonium (NH4+)	0.02-0.4 mg/L	EPA Aquatic Life Criteria
Total Coliform	1,000 cfu/100mL	CA State Water Board Objectives
E. coli	<126 cfu/100mL	EPA Recreational Criteria

San Bernardino National Forest



Waterman Canyon Stream Monitoring:
WC1 Waterman Canyon Western Headwater Tributary and Catchment. Includes the highest percentages of impervious surfaces and shrub scrub land in this study area. **WC2** Waterman Canyon Eastern Headwater Tributary and Catchment. Included the highest percentages of forest and closest percentages of shrub scrub and impervious surfaces.
Lake Gregory Shoreline Monitoring:
LG1 swimming recreation in the southwestern shore drains commercial and residential land uses, **LG2** fishing recreation south central shore drains primarily residential land uses, and **LG3** fishing recreation eastern shore drains primarily residential land uses.
Lake Arrowhead Stream Tributary Monitoring:
Three tributaries. Two monitoring sites along Little Bear Creek **(LBC1 LBC2)** containing mixed forest, commercial and residential land uses - southwestern shore. One monitoring site along Burnt Mill Creek **(BMC)** draining mostly residential with some commercial land uses along the south shore and Orchard Creek **(OC)** draining all residential land uses along the estern shore.
Seeley Creek Stream Tributary Monitoring:
Tributary draining the Valley Of Enchantment shrub scrub, residential, evergreen and commercial land use types. Converges with Mill Creek downstream and enters Silverwood Lake.

Results & Discussion

*Observed Majority Dry Season Exceedances +Observed Majority of Samples Exceedances Wet Season
*+ Samples Exceedances Observed Both Season

Table 2. 2018-2019 Waterman Canyon Creek Tributary Sampling Site Exceedances

Sampling Site	Ammonium (NH4+) mg/L	Nitrate (NO3-) mg/L	Total Coliform (TC) cfu/100mL	E. coli (EC) cfu/100mL
WC1	**49%, +** n=34	**94%, +** n=35	**62%, *** n=23	5%, * n=37
WC2	**54%, +** n=37	**85%, +** n=39	**46%, *** n=37	8%, * n=37

Note: WC1 means. medians and individual sampling events did not exceed regulatory standards for DO, Temperature, Conductivity, and Turbidity; pH did not exceed 13%.
WC2 means, medians and individual sampling events did not exceed regulatory standards for DO, and temperature. Conductivity exceeded 5%, turbidity 8% and pH 3% of sampling events.

Table 3. 2019-202 Seeley Creek Sampling Site Exceedances

Sampling Site	Ammonium (NH4+) mg/L	Nitrate (NO3-) mg/L	Total Coliform (TC) cfu/100mL	E. coli (EC) cfu/100mL
SC	**50%, +** n=28	**58%, *+** n=29	**64%, *** n=14	17%, * n=17

Note: No means, medians, or individual sampling events that exceeded regulatory standards for temperature, and conductivity standards. pH exceeded 41% of sampling periods.

Table 4. 2019-2020 Lake Gregory Shoreline Sampling Site Exceedances

Sampling Site	Ammonium (NH4+) mg/L	Nitrate (NO3-) mg/L	Total Coliform (TC) cfu/100mL	E. coli (EC) cfu/100mL
LG1	**61%, *+** n=42	31%, + n=42	**50%, *** n=24	9%, * n=24
LG2	**46%, +** n=47	**40%, +** n=47	33%, * n=27	3, *+ n=27
LG3	**41%, +** n=48	37%, + n=48	33%, * n=27	0% n=27

Note: No sampling locations had means, medians or individual sampling events that exceeded regulatory standards for turbidity. Conductivity, DO, and temperature did not exceed 10% of sampling events and pH did not exceed 38% of sampling events.

Table 5. 2019-2020 Lake Arrowhead Tributary Sampling Site Exceedances

Sampling Site	Ammonium (NH4+) mg/L	Nitrate (NO3-) mg/L	Total Coliform (TC) cfu/100mL	E. coli (EC) cfu/100mL
LBC1	24%, + n=37	10%, *+ n=37	22%, + n=22	**45%, *+** n=22
LBC2	**28%, +** n=38	**38%, *+** n=38	**37%, +** n=24	33% n=24
BMC	**22%, +** n=40	5%, *+ n=40	4% n=25	4% n=25
OC	**26%, +** n=38	15%, * n=38	13% n=23	8% n=23

*Note: No sampling locations had means, medians or individual sampling events that exceeded regulatory standards for temperature, conductivity, DO, pH and turbidity.

Conclusions

- Frequent monitoring of headwater streams and recreational waters that contribute to downstream water resources is vital to developing comprehensive water resource management plans that protect water resources across multiple geographical scales and variable landscapes.
- Monitoring efforts and adequate reporting can be complicated by streams traversing multiple jurisdiction boundaries (i.e. regional, county, local).
- Many resource agencies have large geographical boundaries resulting in a one size fits all approach to water resources management that is inadequate when streams travers diverse ecological settings (i.e. mountains to valley and ocean).
- Nutrients and bacteria that may contribute to HABs were observed to be elevated and exceeding regulatory standards year round, in both wet and dry seasons throughout the study sites.
- Variability in the extent to which NH4+ and NO3- exceed regulatory standards in the wet season at Seeley Creek, Waterman and Lake Gregory sampling sites.
- Lake Arrowhead tributaries all experienced higher NH4+ in the wet season, with Little Bear Creek sites also having higher total coliform in the wet season, and NO3- noted to be high throughout the study period.
- Generally, bacteria tends to be higher in the dry season when recreational and drinking water resources are in high demand.
- Infrastructure is highly variable with watersheds in the Seeley Creek, Lake Gregory and Little Bear drainage areas with a mixture of primarily on septic with a smaller number of commercial buildings on sewer.
- Watershed stakeholders should be more informed about the extent to which landscape characteristics and climatic patterns influence the longitudinal physicochemical quality of water resources to mitigate impacts to human and ecological health across the hydrological network.

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