

# Mapping Groundwater Discharge Areas to the Los Angeles River, USA Using Hydrochemical and Isotopic Tracers

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**Abstract**—Groundwater discharge can play a critical role in sustaining dry-weather flow and influencing water quality in heavily urbanized river systems. The Los Angeles River, the largest urban river in Southern California, is now largely sustained by recycled water from municipal wastewater plants; however, projected reductions in wastewater discharge and urban runoff may increase the relative importance of groundwater contributions to baseflow and river chemistry. This study evaluates groundwater discharge to the Los Angeles River and selected tributaries using hydrochemical and isotopic tracers to characterize spatial variability in total dissolved solids (TDS), nitrate-N ( $\text{NO}_3\text{-N}$ ), selenium, and stable water isotopes ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ). Groundwater seepage, springs, and weepholes were mapped through field reconnaissance, and 173 groundwater samples were collected from five reaches and two tributaries, Arroyo Seco and Laguna Channel. Results show spatial variability in groundwater chemistry. TDS ranged from 145 to 5558 mg/L, with elevated values in the Upper Los Angeles River, Arroyo Seco, and Laguna Channel.  $\text{NO}_3\text{-N}$  concentrations reached 25.9 mg/L in upstream reaches, indicating anthropogenic inputs. Selenium concentrations reached 70  $\mu\text{g/L}$  in upstream reaches and were usually below 15  $\mu\text{g/L}$  in other areas studied. Stable water isotopes indicate meteoric signatures with downstream enrichment consistent with mixing between local groundwater and imported water recharge. These findings demonstrate that groundwater discharge remains a persistent and chemically significant component in parts of the Los Angeles River system. As recycled water discharges decline and channel restoration expands, identifying groundwater discharge zones and associated water quality risks is essential for effective river management, ecological restoration, and protection of aquatic habitat.

**Keywords**—groundwater seepage, groundwater-surface water interactions, channelization, anthropogenic inputs, water quality, urban rivers, Los Angeles River

## I. INTRODUCTION

Groundwater contributions to streamflow are in many cases critically important for sustaining the perennial flow of streams and governing the quality of their stream waters. In urban areas, groundwater can be an important source for controlling stream flows and water quality, and these groundwater discharges are important to understand so that urban streams can be better managed. In Los Angeles, the largest urban stream is the Los Angeles River, which extends 82 km (51 miles), beginning upstream in the San Fernando Valley in Southern California and flowing southward into the Pacific Ocean at Long Beach [1]. The Los Angeles River drains a watershed of approximately 2,160  $\text{km}^2$  (834  $\text{mi}^2$ ) with both urbanized and natural land cover and crosses fourteen cities (Fig. 1) [2].

The Los Angeles River has been heavily modified from its natural course through channelization for flood control and

urban development, resulting in mostly concrete-lined reaches and few unlined sections remaining [3]. Previous studies have suggested that groundwater seepage may contribute to dry-weather flow conditions in the Los Angeles River, although flows are largely dominated by treated wastewater effluent during dry periods [4]. Recent studies indicate that dry-weather streamflow in the Los Angeles River is dominated by effluent discharge from treated wastewater reclamation plants (WRPs), with additional contributions from groundwater upwelling and storm drain discharge from urban dry-weather uses [5]. Despite extensive research on Los Angeles River water quality, groundwater contributions remain insufficiently characterized, particularly in engineered channels where their magnitude, spatial variability, and transport of nutrients, trace elements, and dissolved solids are often overlooked in hydrologic assessments [6].

The goals of this paper are to:

- Evaluate groundwater contributions to the Los Angeles River and tributaries and determine TDS, sulfate, chloride, nitrate-N, ammonia-N, orthophosphate, selenium, and stable water isotopes added through groundwater discharge
- Characterize the groundwater chemistry and spatial variability of groundwater
- Determine where groundwater discharges to the Los Angeles River and its major tributaries
- Determine the potential influence of groundwater discharge on river water quality and the ramification of upwelling groundwater to overall watershed management

## II. LITERATURE REVIEW

Groundwater-surface water interactions in the Los Angeles Basin have been widely investigated through regional hydrogeologic characterization and numerical modeling, providing a robust framework for understanding basin-scale hydrologic processes. Land cover data used to characterize watershed conditions in this study were obtained from publicly available datasets including National Land Cover Database (NLCD) 2021 [7], while watershed boundaries and Los Angeles River spatial datasets were compiled from the Los Angeles County Department of Public Works [8] and the City of Los Angeles GeoHub [9].

Regional groundwater modeling studies of the Los Angeles Coastal Plain demonstrate that streamflow, groundwater extraction, and artificial recharge are dynamically linked within a complex, multi-aquifer system composed of alluvial

and basin-fill deposits overlying low-permeability bedrock. Paulinski *et al.* [10] developed a basin-wide groundwater simulation model that quantified major components of the groundwater budget and flow system, demonstrating sensitivity of groundwater storage and discharge to pumping, artificial recharge, and imported water supply. Similarly, Reichard *et al.* [11] applied three-dimensional groundwater flow and optimization modeling to the Central and West Coast Basins, demonstrating that groundwater gradients and

flow paths are strongly controlled by aquifer stratigraphy, hydraulic gradients, and both natural and engineered subsurface barriers. Baseline groundwater quality conditions in the Coastal Los Angeles Basin have been characterized by Fram and Belitz [12], who documented significant spatial variability in total dissolved solids (TDS), nitrate-N, and trace elements, demonstrating that groundwater chemistry reflects the combined influence of aquifer lithology and anthropogenic inputs.

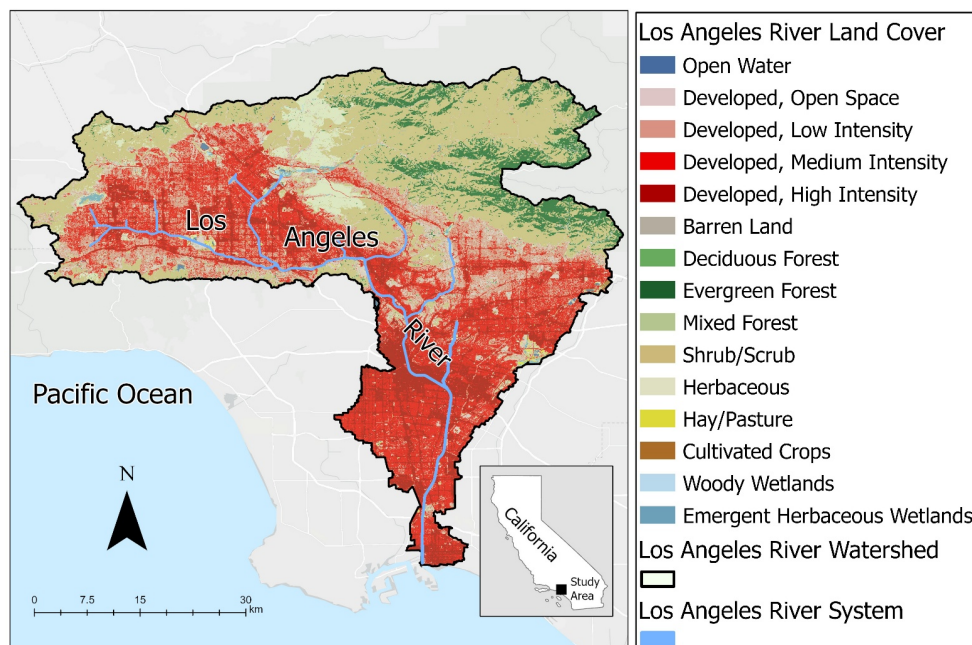


Fig. 1. Los Angeles River watershed land cover showing National Land Cover Database (NLCD) 2021 data [8], with watershed polygon data from Los Angeles County Public Works and the City of Los Angeles GeoHub [9, 10].

Within this hydrogeologic context, the Los Angeles River has evolved into an engineered, effluent-dominated system in which dry-weather flow regimes and water quality are strongly influenced by wastewater management infrastructure. The One Water LA 2040 LA River Flow Study [13] characterizes dry-weather flow in the Los Angeles River as a combination of treated wastewater effluent, groundwater upwelling, and urban runoff, with wastewater reclamation plant discharges representing the dominant source in many reaches. Complementing these findings, Stein *et al.* [14] demonstrate that ecological flow conditions in the Los Angeles River are governed by the combined influence of effluent-derived flows and natural groundwater contributions, underscoring the importance of maintaining baseflow to support aquatic habitat. Additional work by the Southern California Coastal Water Research Project (SCCWRP) [15] demonstrates that environmental flow thresholds in the Los Angeles River are influenced by the combined effects of managed discharges and natural hydrologic inputs, including groundwater-derived baseflow. Hydrologic and water-quality modeling studies have also evaluated tradeoffs between maximizing water reuse and sustaining in-channel ecological conditions. These studies show that changes in wastewater reclamation plant (WRP) operations propagate through the river system by altering temperature, nutrient concentrations, and dissolved solids in downstream reaches [5], highlighting the interconnected nature of water management decisions and riverine ecosystem response.

This managed flow system is undergoing a significant transition driven by changes in regional water management practices. Current wastewater discharges to the Los Angeles River are estimated to be on the order of approximately 32–38 cubic feet per second (cfs), with future projections indicating substantial declines as recycled water is increasingly diverted for urban irrigation, groundwater recharge, and other non-discharge uses [13]. Planning analyses suggest that baseflow contributions from WRPs may decrease markedly over the coming decades under expanded water reuse scenarios. Concurrently, widespread adoption of drought-tolerant landscaping, improvements in irrigation efficiency, modernization of municipal water systems, and increasing water costs are expected to reduce incidental dry-weather runoff. As a result, dry-weather flows, which are dominant for much of the year in Southern California, are anticipated to increasingly reflect groundwater discharge as wastewater inputs and urban runoff decline.

Under this evolving hydrologic regime, it is essential to identify locations of groundwater discharge, characterize groundwater quality, and evaluate the persistence of these inputs as other flow sources decline. This information is particularly important in river reaches targeted for restoration, where engineered channel linings may be modified or removed to reestablish more natural conditions. In such settings, groundwater discharge can influence channel stability, sediment transport, vegetation establishment, and long-term ecological function. Understanding groundwater inputs is therefore both a scientific and practical requirement

for effective river management and restoration.

Stable isotopes of hydrogen and oxygen provide robust tools for distinguishing between imported water, local recharge, groundwater discharge, and recycled water sources within complex urban hydrologic systems. Craig's Global Meteoric Water Line (GMWL) [16] defines the linear relationship between  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  in meteoric waters, while Kendall and Caldwell established isotope hydrology frameworks [17], and Clark and Fritz [18] provide the theoretical and applied basis for identifying recharge sources, evaporative enrichment, and mixing processes in complex hydrologic systems. Applications of environmental tracers in Los Angeles County demonstrate that isotopic and geochemical signatures can be used to track the fate and transport of recycled water, including its migration into downgradient groundwater and surface water systems [19]. Additional studies have demonstrated that nitrate isotopes ( $\delta^{15}\text{N}$ – $\delta^{18}\text{O}$ – $\text{NO}_3^-$ ) can be used to differentiate wastewater-derived nitrate from other anthropogenic and natural sources, providing a robust framework for identifying nutrient sources under variable flow conditions [20].

Previous research identifies total dissolved solids (TDS) and nitrate as key indicators of groundwater quality, reflecting the combined influence of natural geochemical processes and anthropogenic inputs, while major ions such as sulfate and chloride contribute substantially to TDS through mineral dissolution, oxidation, and human activities [21]. Nutrients such as ammonia-N and orthophosphate occur naturally through biogeochemical cycling but are often elevated in urban systems due to wastewater discharge, fertilizer application, and urban runoff [22]. Elevated orthophosphate concentrations in groundwater used for public supply have been documented across California, reflecting both natural and anthropogenic influences on water quality [23]. Understanding groundwater contributions to streamflow requires integrated approaches that combine channel mapping, hydrochemical characterization, and evaluation of groundwater recharge sources. These methods allow groundwater-derived baseflow to be distinguished from wastewater effluent and enable attribution of observed spatial patterns in TDS, nitrate, and selenium to specific geologic units and water management practices. This study provides a first comprehensive mapping, spatially resolved evaluation of groundwater discharge zones along the Los Angeles River, including lined channel reaches, and assesses associated groundwater chemistry using major ions, nutrients, trace elements, and stable water isotopes.

### III. MATERIALS AND METHODS

#### A. Purpose of Study

This study focuses on direct groundwater seepage, springs, and weepholes along five reaches of the Los Angeles River and two tributaries. These locations were identified through months of field reconnaissance that delineated groundwater baseflow zones that had not been previously characterized. Parameters commonly cited as water-quality concerns in the Los Angeles River include Total Dissolved Solids (TDS), sulfate ( $\text{SO}_4$ ), chloride (Cl), nitrate-N ( $\text{NO}_3\text{-N}$ ), ammonia-N ( $\text{NH}_3\text{-N}$ ), orthophosphate ( $\text{HPO}_4$ ), and selenium [20–22]. To ensure consistency across study sites, these parameters are

reported uniformly throughout this paper. Stable water isotopes were included in the analytical suite to evaluate water provenance and distinguish groundwater derived from internal basin processes from water imported to the Los Angeles Basin, including supplies from Owens Valley, the Colorado River, and the Sacramento–San Joaquin Delta. By integrating TDS,  $\text{SO}_4$ , Cl,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_3\text{-N}$ ,  $\text{HPO}_4$ , selenium, and stable water isotopes with spatially explicit sampling, this study identifies persistent groundwater discharge zones, characterizes their general geochemical signatures, and evaluates their potential importance under future reduced flow conditions. Within the context of declining wastewater discharges, expanding water reuse, and planned river restoration, this work provides a foundation for understanding how groundwater will influence the hydrology, water quality, and ecological function of the Los Angeles River in coming decades.

#### B. Field Methods

Extensive field mapping was conducted to determine area of groundwater seepage in the Los Angeles River and its tributaries. This was accomplished by walking the channel and observing groundwater flow through weepholes, seepages, and leakage through cracks in concrete lining.

Once field mapping was done, groundwater samples ( $n = 173$ ) were collected from five reaches along the Los Angeles River and from two tributaries. Sampling began from upstream to downstream across the Upper Los Angeles River, Glendale Narrows, and Lower Los Angeles River. The two tributaries included in the study are Arroyo Seco and Laguna Channel (Fig. 2). Groundwater samples from the Upper Los Angeles River were collected during two periods: May–August 2022 and May 2024–February 2025. Samples from the remaining reaches were collected monthly between March 2024–March 2025.

At each site, field parameters including temperature, and electric conductivity (EC) were measured using portable meters. Groundwater along the Los Angeles River channel, where seepage was observed, was collected using grab samples in 500-mL HDPE bottles rinsed three times with sample water, leaving 2.5 cm of headspace to prevent bubbles. Tributary samples were collected using a combination of grab sampling and a bailer, following the same rinsing and headspace procedure. Stable water isotope samples were collected in 50-mL conical tubes, ensuring no headspace.

Surface water samples ( $n = 10$  stations) were collected using grab or composite methods depending on field conditions and channel width. Surface water samples were analyzed using the same field and laboratory methods as groundwater samples. Surface water samples were used to characterize upstream and downstream surface water chemistry and to evaluate groundwater contributions by comparing surface water and groundwater chemistry.

The study reaches at Upper Los Angeles River, Glendale Narrows, Lower Los Angeles River, Arroyo Seco and Laguna Channel varied in type of groundwater seepage infrastructure across different hydrology and geologic conditions, including unlined and lined channel sections, influence from treated wastewater effluent and dry-weather urban runoff. A summary description is provided with the pertinent details along each reach.

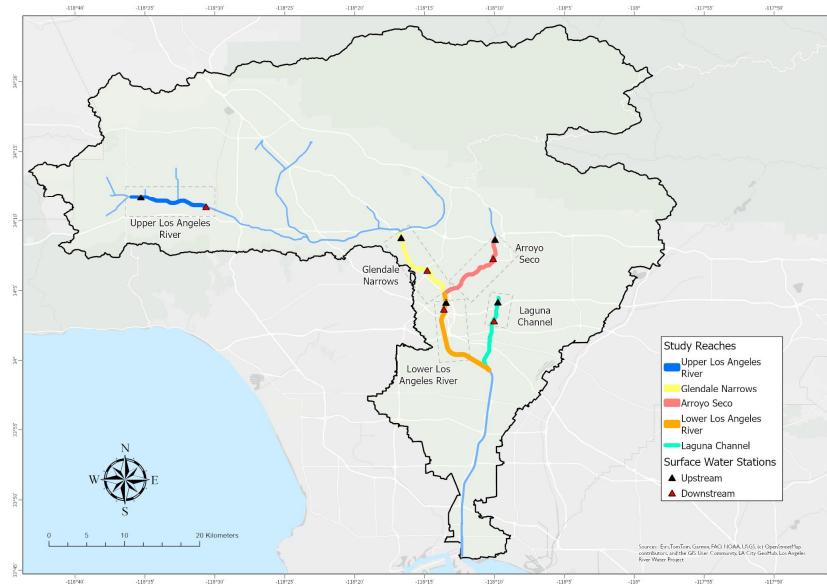
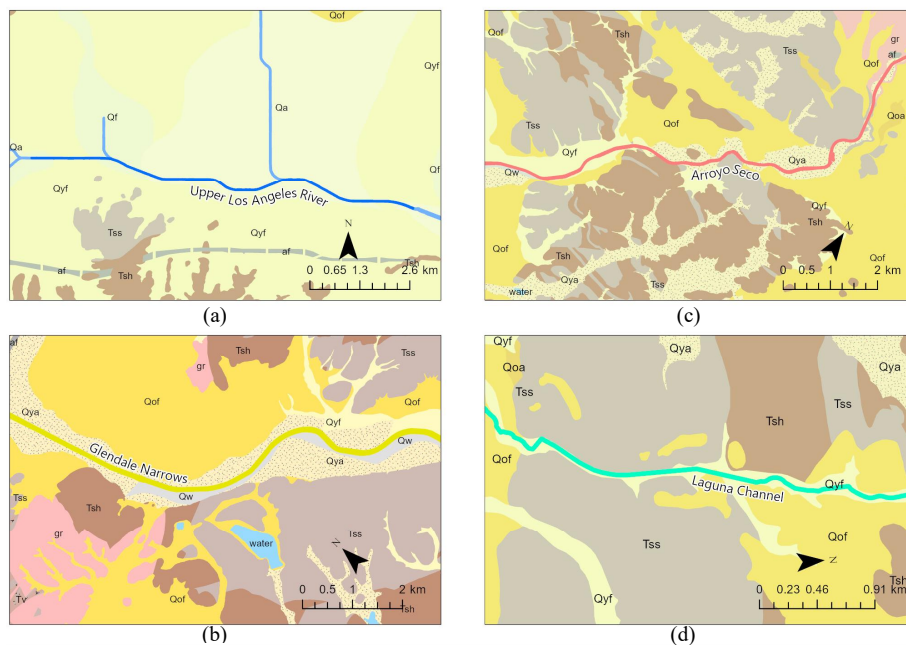


Fig. 2. Study area map illustrates the five study reaches of the Los Angeles River from upstream to downstream: Upper Los Angeles River, Glendale Narrows and Lower Los Angeles River. Tributaries: Arroyo Seco and Laguna Channel. Spatial data were obtained through Los Angeles County Public Works [9] and the City of Los Angeles GeoHub [10].



Study Areas within Los Angeles River

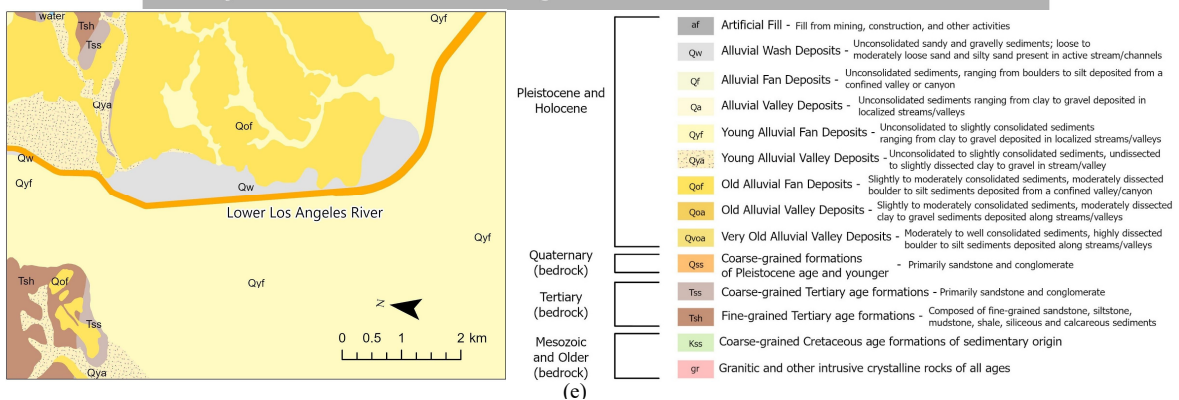


Fig. 3. Geologic map of the study areas within Los Angeles River and tributaries: (a) Upper Los Angeles River, (b) Glendale Narrows, (c) Arroyo Seco and (d) Laguna Channel and (e) Lower Los Angeles River, modified from the California Geological Survey Special Report 217 [24] and Los Angeles County Public Works [9].

C. Upper Los Angeles River

The upper reach is located above the Sepulveda Dam,

extending from the western side of the Sepulveda Recreation Area and ending at Canoga Ave, located at the cusp where

Bell Creek and Arroyo Calabasas tributaries feed into the Los Angeles River (Fig. 2). The geology of this reach is dominated by Quaternary alluvial deposits composed of sand, silt, and gravel in the San Fernando Valley as shown in Fig. 3(a) [24]. The sedimentary bedrock on the south side of the river includes Tertiary marine units including the Monterey and Topanga formations. Artificial fill can be seen in portions of the reach and is outlined in grey, parallel to the Los Angeles River. Groundwater in the Upper Los Angeles River area enters the channel as seepage through cracks and weepholes in the concrete lining, as shown in Fig. 4.



Fig. 4. Groundwater seepage through the concrete lining in the Upper Los Angeles River.

#### D. Glendale Narrows



(a)



(b)

Fig. 5. Groundwater seepage through cracks in the concrete-lined channel at the Glendale Narrows reach (Los Feliz): (a) upstream east side; (b) downstream west side.

This reach includes both lined and unlined sections of the channel influenced by treated effluent from the LA-Glendale Water Reclamation Plant, urban runoff, and shallow groundwater seepage (Fig. 2). Groundwater is present in two sections, upstream adjacent to the Rio de Porciuncula Picnic Area and downstream below the LA-Glendale WRP, where

groundwater seepage can be observed from both the east and west side of the channel (Fig. 5). Further downstream, irrigation from Los Feliz Golf course and urban runoff from surrounding residential areas contribute to water quality inputs at the groundwater stations on both sides of the channel. The geology in this area reveals small sections of Monterey Formation present along the Los Angeles River characterized by thin-bedded siliceous shale with white weathering [25]. Westward away from the Los Angeles River exposes granitic rock forced groundwater upwelling and flowed downstream between Griffith Park and Glendale. Adjacent to the Santa Monica fault, the Middle Topanga Formation and volcanic rocks are present depositing basaltic volcanic rocks containing mafic minerals such as augite and olivine (Fig. 3(b)). Weathering along the west side of the channel introduces iron and manganese to groundwater discharging along the west channel, leading to reducing conditions, in contrast to higher nitrate-N concentrations observed along the east channel side.

#### E. Arroyo Seco



Fig. 6. Lower Arroyo Seco – Below the Colorado Bridge, the picture captures the drop-off marking the start of the channelized reach where groundwater seeps in through weepholes, French drains, and cracks in the concrete.

The Lower Arroyo Seco is the 11.3 km (7 mi) of groundwater reach that drains into the Los Angeles River below the Colorado Bridge (Fig. 2). This part of Arroyo Seco is heavily modified with extensive diversion, interruption, and channelization. However, groundwater upwelling continues to provide a significant contribution to streamflow that is enriched in nitrate, selenium, and sulfate. Geologically, the Lower Arroyo Seco lies within a structurally complex transition zone characterized by interbedded sedimentary and crystalline rocks. Bedrock units include the Miocene-age Topanga Formation, composed primarily of sandstone and conglomerate, overlying older granitic basement rocks such as quartz diorite (Fig. 3(c)). Topanga Formation outcrops can still be observed along portions of the lower reach, particularly below La Loma Rd Bridge, where road cuts expose well-cemented sandstone and pebble conglomerates

(Fig. 6). Below the Raymond Fault, the geologic setting transitions into the Monterey Formation, which consists of Miocene sandstone, siliceous shale, and micaceous silty shale and siltstone [26]. Structural features such as the Raymond and Eagle Rock faults strongly influence topography, groundwater flow, and the connectivity between geologic units controlling functions like infiltration capacity, groundwater recharge, and potential contaminant migration [27]. Together, these hydrologic and geologic factors shape the lower reach, whose groundwater-surface water interactions play a defining role in both streamflow dynamics and contaminant transport.

#### F. Laguna Channel



Fig. 7. Main study area in Laguna Channel showing year-round flow consistent with groundwater discharge.

Laguna Channel, also referred to as Luguna Channel in older literature, is a drainage channel found adjacent to the I-710 freeway at its northern end in the City of Alhambra (Fig. 2). The structure of this channel is mainly concrete lined with small sections of unlined channel presenting near the section adjacent to California State University, Los Angeles (Fig. 7). Laguna Channel's year-round flow is believed to be derived from natural, groundwater flow and is notably supplemented by urban runoff during wet seasons. Its location provides an important pathway for nutrients, metals, and other water constituents to flow directly into the Lower Los Angeles River. Laguna Channel also shares similar geologic characteristics with the Lower Arroyo Seco below the Raymond Fault. The western side of the tributary is underlain by the Monterey Formation composed of white weathering siliceous shale interbedded with silty shale. Southward the channel lithology transitions into the Fernando Formation of Pliocene age, consisting of marine claystone covered by non-marine sandstone and conglomerate with surrounding Quaternary alluvial deposits of silt, sand, and gravel (Fig. 3(d)) [26]. The marine and alluvial units influence groundwater chemistry along the Laguna Channel where shallow groundwater flow and weathering contribute to

elevated nitrate-N concentrations resulting from urban inputs.

#### G. Lower Los Angeles River

The Spring St. area is one of the only places along the Lower Los Angeles River reach from Downtown Los Angeles to Long Beach where groundwater seepage was observed (Figs. 2 and 8). This reach is located within an industrialized area surrounded by the Downey Recreation Area, warehouses, and a rail yard. Samples collected along a 3.2 km (2 mi) stretch of the river show that  $\text{NO}_3\text{-N}$  concentrations in the groundwater were below detection limits at the northern end of the study area but increased towards the southern. Iron concentrations were detected through the reach and increased downstream, with manganese following a similar trend but at lower concentrations. Iron and manganese are consistent with weathering of geological formations surrounding the river in this reach as shown in Fig. 3(e), as well as contributions from historical or ongoing industrial activities. Overall, the Lower Los Angeles River geologic characteristics are similar to those observed in Laguna Channel. Along the southwestern side of the Los Angeles River, groundwater flows through the Monterey Formation and Quaternary alluvial deposits. Structural features such as the Elysian Park Anticline occur upstream of groundwater sampling locations and downstream transitions into oil bearing units and the Fernando Formation [26]. The geologic and structural setting of this downstream reach influences groundwater chemistry and its transport within the urban river system.



Fig. 8. Weephole (S-Spring St.-WH4) at the southern end of the sampling area along the Lower Los Angeles River, illustrating groundwater seepage observed in this reach.

#### H. Laboratory Methods

Groundwater samples were stored and analyzed for  $\text{SO}_4$ , Cl,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_3\text{-N}$ , and  $\text{HPO}_4$  at the Environmental Geochemistry Laboratory at California State University Los Angeles using HACH DR6000 UV-VIS Spectrophotometer following USEPA method 375.4( $\text{SO}_4$ ) and 9251 (Cl), EPA Method 353.2 ( $\text{NO}_3\text{-N}$ ), 350.1 ( $\text{NH}_3\text{-N}$ ), and 365.1 ( $\text{HPO}_4$ ). Samples selected for selenium analysis were chosen based on

conductivity measurements and spatial trends within each reach. These samples were collected unfiltered and unacidified and sent to Weck Laboratories, Inc., where they were filtered and preserved. Sample preparation followed EPA 200.2 and selenium was analyzed using EPA Method 200.8.

Groundwater discharge contributes to TDS in the Los Angeles River and tributaries. Specific conductivity was used to estimate TDS because complete ionic composition data were not available for all samples. Therefore, a standard conductivity TDS conversion factor was used to estimate TDS concentrations for this study using Eq. (1) [28]:

$$\text{TDS (mg/L)} = \text{Specific Conductivity } (\mu\text{S/cm}) \times 0.67 \quad (1)$$

Stable water isotope analysis of oxygen and hydrogen ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) were conducted at the Environmental Isotope Laboratory at the University of Arizona in Tucson, following analytical procedures described in [22].

Data from all fields and laboratory analysis were screened and evaluated using standard hydrochemical data processing procedures followed. Quality control included checks of data entry accuracy, acceptable analytical ranges, and replicate consistency. Values below quantification limits were assigned one-half the detection limit for plotting and summary statistics. For example, nitrate-N values below the 0.23 mg/L  $\text{NO}_3\text{-N}$  quantification limit were assigned 0.115 mg/L  $\text{NO}_3\text{-N}$  for plotting and averaging purposes.

Groundwater chemistry data were organized by study reach and screened using standard hydrochemical data interpretation methods. Statistical summaries and graphical analyses were used to determine spatial patterns across study reaches, using box plots. Data processing, maps, and boxplots were created using R, Microsoft Excel and ArcGIS Pro. Complete data processing details are provided in the referenced publication.

#### IV. RESULT

TDS,  $\text{SO}_4$ , Cl,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_3\text{-N}$ ,  $\text{HPO}_4$ , and selenium demonstrated spatial variability across the five reaches of the study area (Table 1). Sample sizes varied by parameter due to analytical limitations per location: TDS ( $n = 173$ ),  $\text{SO}_4$  ( $n = 151$ ), Cl ( $n = 144$ ),  $\text{NO}_3\text{-N}$  ( $n = 156$ ),  $\text{NH}_3\text{-N}$  ( $n = 156$ ),  $\text{HPO}_4$  ( $n = 156$ ), and selenium ( $n = 73$ ).

Table 1. Summary statistics for all groundwater chemistry parameters and stable isotope values (min, max, mean, median)

Parameter	n	Min	Max	Mean	Median
TDS (mg/L)	173	145	5558	1104	1077
$\text{SO}_4$ (mg/L)	151	8	950	357.2	320
Cl (mg/L)	144	18.8	517	154.7	127.7
$\text{NO}_3\text{-N}$ (mg/L)	156	0.115	25.9	5.05	4.27
$\text{NH}_3\text{-N}$ (mg/L)	156	0	1.53	0.099	0.0075
$\text{HPO}_4$ (mg/L)	156	0.034	2.98	0.150	0.075
Se ( $\mu\text{g/L}$ )	73	0.2	70	9.26	6.1
$\delta^{18}\text{O}$ (‰)	85	-9.7	-5.7	-7.59	-7.3
$\delta^2\text{H}$ (‰)	85	-72.8	-36.3	-53.56	-50.8

n varies by reach.

All stable water isotope values are reported in Vienna Standard Mean Ocean Water (VSMOW).

Boxplots were used to visualize the distribution of groundwater chemistry across the five study reaches. The box represents the interquartile range (IQR) with the median

shown as a central line, whiskers extending to values within 1.5 times IQR and points beyond this range plotted as outliers (Fig. 9).

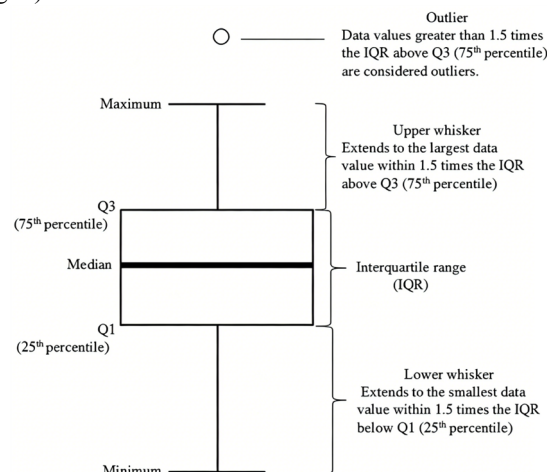


Fig. 9. Diagram showing the components of a boxplot.

#### A. Total Dissolved Solids

Fig. 10 displays TDS ( $n = 173$ ) ranged from 145 mg/L to 5558 mg/L, with the lowest values occurring in the upstream reach of the Upper Los Angeles River and moderately increasing downstream. Laguna Channel showed the highest TDS and a high average of 1960 mg/L. In contrast, the Lower Los Angeles River had the lowest average TDS at 758.4 mg/L. The Upper Los Angeles River TDS levels were consistent between the 1<sup>st</sup> (1098.1 mg/L) and 3<sup>rd</sup> (1394.8 mg/L) quartile. Glendale Narrows mean 993.1 mg/L while Arroyo Seco average 1082.0 mg/L both show wider TDS distributions in groundwater seepage. Overall, the boxplot revealed TDS increasing in the middle reach by the tributary of Laguna Channel.

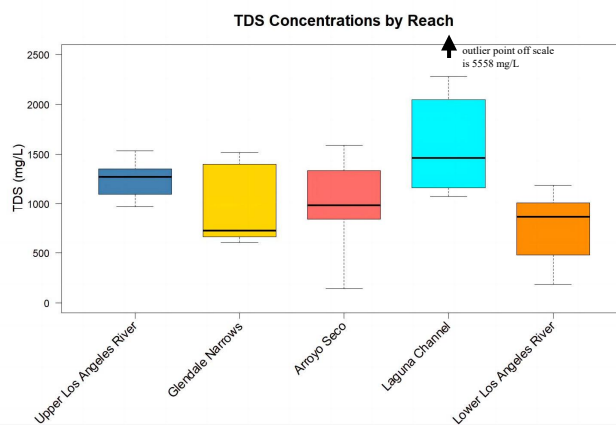


Fig. 10. Boxplots of TDS concentration in groundwater by study reach. Sample sizes are  $n = 28$  (Upper Los Angeles River),  $n = 52$  (Glendale Narrows),  $n = 69$  (Arroyo Seco),  $n = 9$  (Laguna Channel), and  $n = 15$  (Lower Los Angeles River).

#### B. Sulfate

Fig. 11 boxplot shows sulfate concentrations ( $n = 151$ ), ranging from 8 to 950 mg/L across all reaches. Average sulfate concentration in groundwater varied spatially with the highest value observed in Laguna Channel (551.4 mg/L), Upper Los Angeles River (469.8 mg/L), Arroyo Seco (380.2 mg/L), Glendale Narrows (260.0 mg/L), and Lower Los Angeles River (237.4 mg/L). The Upper Los Angeles River and Arroyo Seco show the widest concentration ranges

compared to the other reaches.

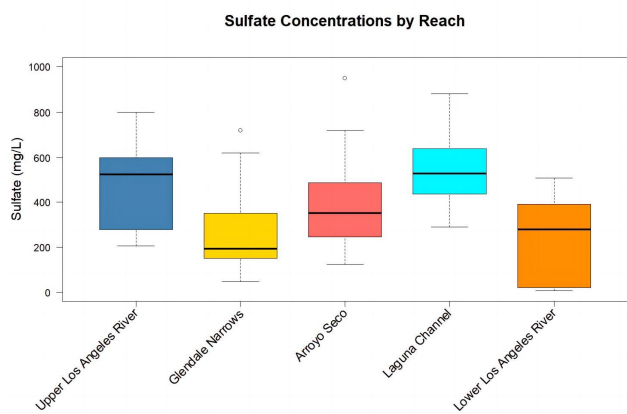


Fig. 11. Boxplot of sulfate concentration in groundwater by study reach. Sample sizes are  $n = 28$  (Upper Los Angeles River),  $n = 43$  (Glendale Narrows),  $n = 59$  (Arroyo Seco),  $n = 7$  (Laguna Channel), and  $n = 14$  (Lower Los Angeles River).

### C. Chloride

In Fig. 12, chloride concentrations ( $n = 144$ ) were elevated in Glendale Narrows with an average of 173.4 mg/L and highest 517.0 mg/L. The lowest chloride average concentration was observed in the Lower Los Angeles River 66.5 mg/L and lowest value of 18.8 mg/L. The average concentration across all other reaches ranged from Upper Los Angeles River (120.9 mg/L), Arroyo Seco (160.0 mg/L), and Laguna Channel (213.4 mg/L).

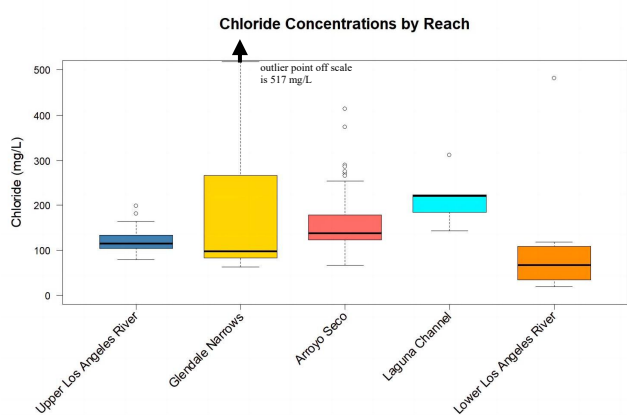


Fig. 12. Boxplot of chloride concentration in groundwater by study reach. Sample sizes are  $n = 21$  (Upper Los Angeles River),  $n = 43$  (Glendale Narrows),  $n = 59$  (Arroyo Seco),  $n = 7$  (Laguna Channel), and  $n = 14$  (Lower Los Angeles River).

### D. Nitrate-N

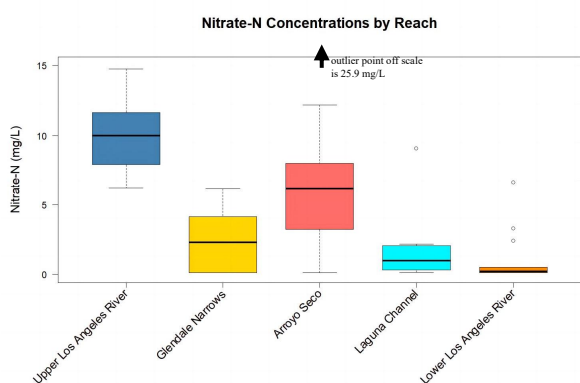


Fig. 13. Boxplot of nitrate-N concentration in groundwater by study reach. Sample sizes are  $n = 28$  (Upper Los Angeles River),  $n = 46$  (Glendale Narrows),  $n = 59$  (Arroyo Seco),  $n = 9$  (Laguna Channel), and  $n = 14$  (Lower Los Angeles River).

As shown in Fig. 13,  $\text{NO}_3\text{-N}$  concentrations ( $n = 156$ ) varied across the five reaches with the highest values located upstream in the Upper Los Angeles River average 9.95 mg/L in Fig. 10. A single measurement was observed in Arroyo Seco 25.9 mg/L, providing a wider spread in the reach. Both the Upper Los Angeles River and Arroyo Seco displayed higher  $\text{NO}_3\text{-N}$  concentrations compared to the other reaches. In contrast,  $\text{NO}_3\text{-N}$  levels decreased downstream, with Glendale Narrows average 2.54 mg/L and Laguna Channel and the Lower Los Angeles River ranging between 1.96 mg/L and 1.06 mg/L.

### E. Ammonia-N

As shown in Fig. 14,  $\text{NH}_3\text{-N}$  concentrations ( $n = 156$ ) were highest in Laguna Channel reaching a maximum of 1.53 mg/L. In contrast, groundwater from the Upper Los Angeles River, Glendale Narrows, and Arroyo Seco reaches mean were below the method detection limit 0.0075 mg/L. However, one groundwater sample in the Lower Los Angeles River reach measured 1.37 mg/L and the mean 0.170 mg/L.

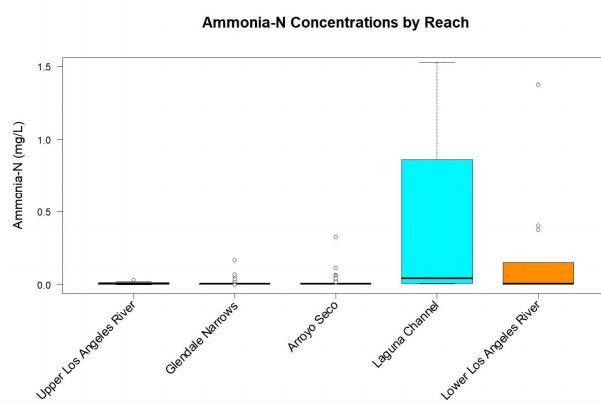


Fig. 14. Boxplot of ammonia-N concentration in groundwater by study reach. Sample sizes are  $n = 28$  (Upper Los Angeles River),  $n = 46$  (Glendale Narrows),  $n = 59$  (Arroyo Seco),  $n = 9$  (Laguna Channel), and  $n = 14$  (Lower Los Angeles River).

### F. Orthophosphate

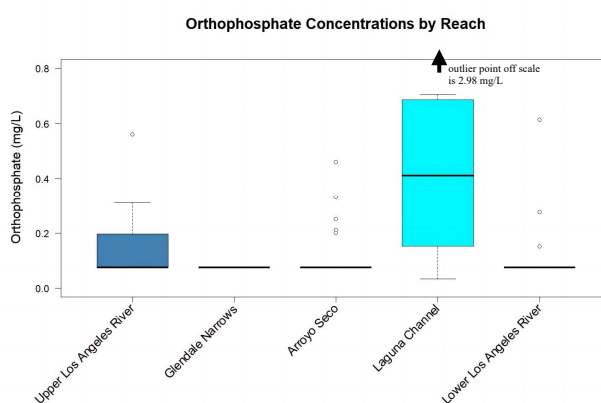


Fig. 15. Boxplot of orthophosphate concentration in groundwater by study reach. Sample sizes are  $n = 28$  (Upper Los Angeles River),  $n = 46$  (Glendale Narrows),  $n = 59$  (Arroyo Seco),  $n = 9$  (Laguna Channel), and  $n = 14$  (Lower Los Angeles River).

In Fig. 15, orthophosphate concentrations ( $n = 156$ ) was highest in Laguna Channel mean of 0.633 mg/L and elevated concentration at 2.98 mg/L. Groundwater from the Glendale Narrows, Arroyo Seco, and Lower Los Angeles River reaches average concentration below the method detection limit 0.075 mg/L for orthophosphate. Upper Los Angeles River concentration elevated value at 0.560 mg/L.

### G. Selenium

Fig. 16 shows selenium concentrations ( $n = 73$ ) varied across the five reaches with the highest average concentration located in Arroyo Seco 70  $\mu\text{g/L}$  and lowest in Glendale Narrows 6.10  $\mu\text{g/L}$  shown in Fig. 15. Both Upper Los Angeles River and Arroyo Seco have higher selenium levels compared to the other reaches. In contrast, Glendale Narrows and Laguna Channel have lower average selenium concentrations in groundwater samples between 2.42  $\mu\text{g/L}$  and 2.78  $\mu\text{g/L}$ . The Lower Los Angeles River displayed a wider range of selenium values, overall concentrations remained lower than those observed in Upper Los Angeles River and Arroyo Seco.

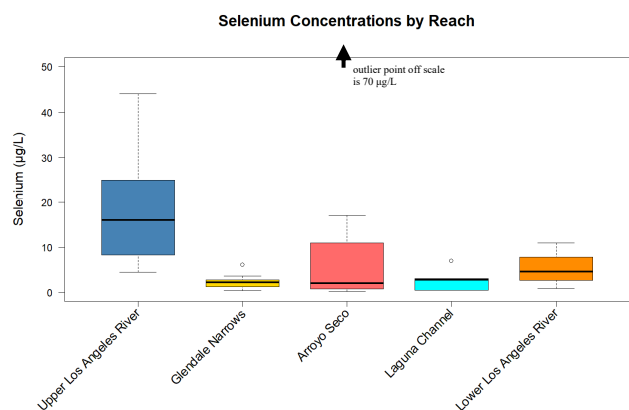


Fig. 16. Boxplot of selenium concentration in groundwater by study reach. Sample sizes are  $n = 19$  (Upper Los Angeles River),  $n = 10$  (Glendale Narrows),  $n = 35$  (Arroyo Seco),  $n = 5$  (Laguna Channel), and  $n = 4$  (Lower Los Angeles River).

### H. Groundwater-Surface water Hydrochemistry Summary

In areas where groundwater discharge was mapped, we sought to evaluate what is the influence of groundwater baseflow on river chemistry. Upper and lower stream stations were selected, and groundwater samples were collected between upstream and downstream stations (Figs. 2 and 17).

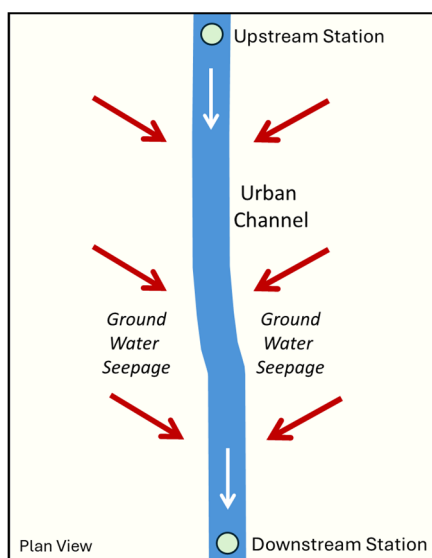


Fig. 17. Conceptual diagram of the sampling design along the Los Angeles River showing upstream and downstream surface water sampling locations and groundwater sites located in between where groundwater seepage discharges into the river channel.

Surface water chemistry is presented first followed by groundwater chemistry. Groundwater-surface water

hydrochemistry varied across the Los Angeles River and tributaries, including the Upper Los Angeles River, Glendale Narrows, Arroyo Seco, Lower Los Angeles River, and Laguna Channel (Tables 2–6).

In the Upper Los Angeles River (Table 2), surface water chemistry changed drastically between upstream and downstream locations. TDS, sulfate, and chloride concentrations decreased downstream with TDS decreasing from 1752 mg/L to 1389 mg/L (~21%), sulfate from 900 to 615 (~32%), and chloride from 260 to 159 mg/L (~39%). In contrast, nutrient concentrations increased downstream, with nitrate-N rising from 0.8 to 2.2 mg/L and ammonia-N increasing from 0.04 to 0.16 mg/L. Orthophosphate was below detection limits upstream but measured at 0.15 mg/L downstream, while selenium increased from 2.9 to 10.0  $\mu\text{g/L}$  (~245%).

Average groundwater seepage concentrations entering the channel had an average TDS of 1325 mg/L, sulfate of 504.2 mg/L, chloride of 119.7 mg/L, nitrate-N of 10.3 mg/L, ammonia-N of 0 mg/L, orthophosphate of 0.2 mg/L and selenium of 22.7  $\mu\text{g/L}$ .

In Glendale Narrows (Table 3), surface water chemistry showed upstream to downstream locations where TDS increasing from 679 to 721 mg/L (~6%) and sulfate from 200 to 196 mg/L (~2%) and chloride from 126 to 114 mg/L (~9%) decrease. Nutrients concentration showed nitrate-N increasing from upstream to downstream 1.6 mg/L to 2.7 mg/L (~69%) while ammonia-N increased from 0.027 to 0.05 mg/L and orthophosphate at 0 mg/L, and selenium increased from 1.9 to 2.0  $\mu\text{g/L}$  (~5%).

Average groundwater seepage concentration entering the channel had a TDS of 1027 mg/L, sulfate of 325 mg/L, chloride of 175 mg/L, nitrate-N at 2.5 mg/L, ammonia-N of 0 mg/L, orthophosphate below detection limit, and selenium of 1.9  $\mu\text{g/L}$ .

In Arroyo Seco (Table 4), upstream to downstream surface water had an overall increase for TDS, sulfate and chloride concentrations. TDS increasing from 534 to 933 mg/L (~75%), sulfate from 91 to 290 mg/L (~219%), chloride from 107 to 186 mg/L (~74%). Nutrients revealed elevated nitrate-N concentration from 0.6 to 2.3 mg/L (~283%) and a decrease in ammonia-N from 0.092 to 0.02 mg/L (~78%) and orthophosphate from 0.16 to 0.08 mg/L (~47%), and selenium had no net change from upstream to downstream surface water remained at 0.2  $\mu\text{g/L}$ .

Average groundwater seepage concentration in this tributary had higher concentration in all parameters than surface water. TDS of 1183 mg/L, sulfate of 415 mg/L, chloride of 219 mg/L, nitrate-N of 3.9 mg/L, orthophosphate of 0.785 mg/L, and selenium of 0.5  $\mu\text{g/L}$ . Ammonia-N concentration in groundwater was the only nutrient lower than surface water of 0.0205 mg/L.

In Laguna Channel (Table 5) surface water chemistry revealed elevated concentrations in TDS, sulfate and chloride from upstream and downstream locations. TDS increased from 878 to 1369 mg/L (~56%), sulfate from 270 to 500 mg/L (~85%), and chloride from 122 to 244 mg/L (~100%). Nutrients increased in ammonia-N from 0.027 to 0.053 mg/L (~96%), in contrast to a decrease in nitrate-N from 7.6 to 4.6 mg/L (~39%) and orthophosphate from 0.386 to 0.246 mg/L (~36%).

Average groundwater seepage entering this tributary

showed elevated TDS concentrations of 3918 mg/L with nutrients ranging from nitrate-N of 1.4 mg/L, ammonia-N of 0.056 mg/L, and orthophosphate of 0.36 mg/L. Selenium was not analyzed and major ions were not measured for groundwater seepage at the upstream and downstream locations.

In the Lower Los Angeles River (Table 6), minor changes were observed between upstream and downstream surface water chemistry. TDS increased from 718 to 781 mg/L (~9%), sulfate from 230 to 248 mg/L (~8%), and chloride from 131 to 139 mg/L (~6%). Nutrient concentrations showed minimal variation, with ammonia-N and orthophosphate remaining relatively unchanged, while nitrate-N increased from 1.6 to 1.8 mg/L (~13%). Selenium was not analyzed for upstream surface water sample in this reach.

Average groundwater seepage concentration entering the channel had an average TDS of 678 mg/L, sulfate of 212 mg/L, chloride of 133 mg/L, and nutrients

concentration of nitrate-N 2.5 mg/L, ammonia-N 0.0827 mg/L and orthophosphate 0.115 mg/L. Selenium concentration of 7.8 µg/L.

These collective results show that several rivers and tributary reaches exhibit substantial upstream to downstream percentage changes in TDS, sulfate, chloride, nitrate-N, and selenium coincident with groundwater seepage contributions, whereas channel segments at Glendale Narrows and Lower Los Angeles River, receiving wastewater discharges, show relatively minor upstream to downstream percentage changes. This reflects groundwater inputs along these two reaches that represent 10% or less of the combined discharge.

Table 2. Summary of Groundwater-surface water Hydrochemistry in the Upper Los Angeles River

Reach	Water Type	Date	TDS (mg/L)	SO <sub>4</sub> (mg/L)	Cl (mg/L)	NO <sub>3</sub> -N (mg/L)	NH <sub>3</sub> -N (mg/L)	HPO <sub>4</sub> (mg/L)	Se (µg/L)
Upper Los Angeles River - Upstream	SW	5/1/2022	1752	900	260	0.8	0.04	<0.15	2.9
Upper Los Angeles River - Groundwater Seepage (Avg)	GW	5/1/2022-8/3/2022	1325	504.2	119.7	10.3	<0.015	0.2	22.7
Upper Los Angeles River - Downstream	SW	6/15/2022	1389	615	159	2.2	0.16	0.15	10.0

\*Values below the method detection limit (0.015 mg/L) were assigned 0.075 mg/L (½ MDL) for summary statistics.

Table 3. Summary of Groundwater-surface water Hydrochemistry in Glendale Narrows

Reach	Water Type	Date	TDS (mg/L)	SO <sub>4</sub> (mg/L)	Cl (mg/L)	NO <sub>3</sub> -N (mg/L)	NH <sub>3</sub> -N (mg/L)	HPO <sub>4</sub> (mg/L)	Se (µg/L)
Glendale Narrows - Upstream	SW	9/13/2024	679	200	126	1.6	0.027	<0.15	1.9
Glendale Narrows - Groundwater Seepage (Avg)	GW	9/13/2024	1027	325	175	2.5	<0.015	<0.15	1.9
Glendale Narrows - Downstream	SW	9/13/2024	721	196	114	2.7	0.050	<0.15	2.0

\*Values below the method detection limit (0.15 mg/L) were assigned 0.075 mg/L (½ MDL) for summary statistics.

Table 4. Summary of Groundwater-surface water Hydrochemistry in Arroyo Seco

Reach	Water Type	Date	TDS (mg/L)	SO <sub>4</sub> (mg/L)	Cl (mg/L)	NO <sub>3</sub> -N (mg/L)	NH <sub>3</sub> -N (mg/L)	HPO <sub>4</sub> (mg/L)	Se (µg/L)
Arroyo Seco - Upstream	SW	7/26/2024	534	91	107	0.6	0.092	0.16	<0.4
Arroyo Seco - Groundwater Seepage (Avg)	GW	7/26/2024	1183	415	219	3.9	0.0205	0.785	0.5
Arroyo Seco - Downstream	SW	7/26/2024	933	290	186	2.3	0.020	<0.15	0.2*

\*Non detected values (<0.4 µg/L) were assigned a value of 0.2 µg/L (½ MDL) for summary calculation.

Table 5. Summary of Groundwater-surface water Hydrochemistry in the Laguna Channel

Reach	Water Type	Date	TDS (mg/L)	SO <sub>4</sub> (mg/L)	Cl (mg/L)	NO <sub>3</sub> -N (mg/L)	NH <sub>3</sub> -N (mg/L)	HPO <sub>4</sub> (mg/L)	Se (µg/L)
Laguna Channel - Upstream	SW	11/14/2024	878	270	122	7.6	0.027	0.386	NA
Laguna Channel - Groundwater Seepage (Avg)	GW	4/30/2024-7/24/2025	3918	NA	NA	1.4	0.056	0.360	NA
Laguna Channel - Downstream	SW	11/14/2024	1369	500	244	4.6	0.053	0.246	NA

NA = Not Analyzed.

Table 6. Summary of Groundwater-surface water Hydrochemistry in the Lower Los Angeles River

Reach	Water Type	Date	TDS (mg/L)	SO <sub>4</sub> (mg/L)	Cl (mg/L)	NO <sub>3</sub> -N (mg/L)	NH <sub>3</sub> -N (mg/L)	HPO <sub>4</sub> (mg/L)	Se (µg/L)
Lower Los Angeles River - Upstream	SW	9/16/2024	718	230	131	1.6	<0.015	<0.15	NA
Lower Los Angeles River - Groundwater Seepage (Avg)	GW	6/19/2024-7/31/2024	678	212	133	2.5	0.0827	<0.15	7.8
Lower Los Angeles River - Downstream	SW	7/31/2024	781	248	139	1.8	<0.015	<0.15	2.6

NA = Not Analyzed.

\*Values below the method detection limit (0.015 and 0.15 mg/L) were assigned ½ MDL (0.0075 and 0.075 mg/L) for summary statistics.

### I. Stable Water Isotopes

Stable water isotopes for groundwater samples show an isotopic separation between Upper Los Angeles River and Glendale Narrows to Lower Los Angeles River (Fig. 18). Upper Los Angeles River has lighter water molecules that are reflected in the more negative (depleted) values of the Global

Meteoric Water Line (GMWL) ranging between

-9.8 to -7‰ δ18O and -71.7 to -64.5‰ δ2H. In contrast, enriched isotopes are reflected in the heavier range where majority of the downstream reaches from Glendale to Lower Los Angeles River have a cluster and overlapping of isotope values ranging from -8 to -6‰ δ18O and -60 to -40‰ δ2H.

These different ranges are due to different water provenance, with elaboration in the analysis of results section.

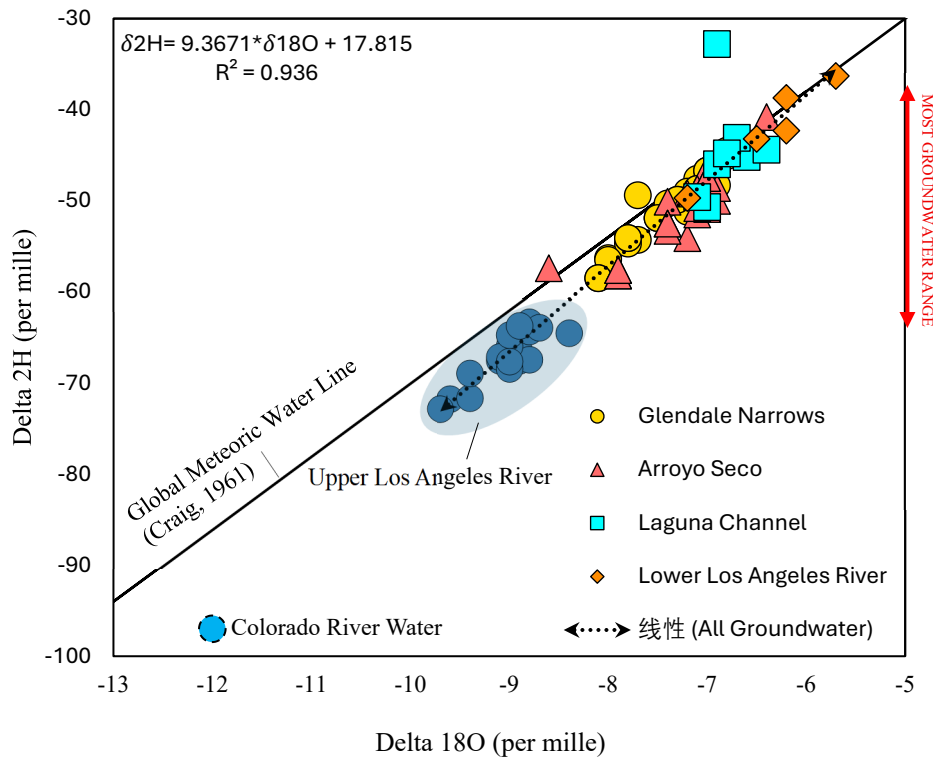


Fig. 18. Groundwater stable isotopes ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) of groundwater samples across study reaches. The isotopic composition of Colorado River water ( $\delta^{18}\text{O} \approx -12\text{‰}$ ,  $\delta^2\text{H} \approx -97\text{‰}$ ) reported values [12].

J. Analysis of Results

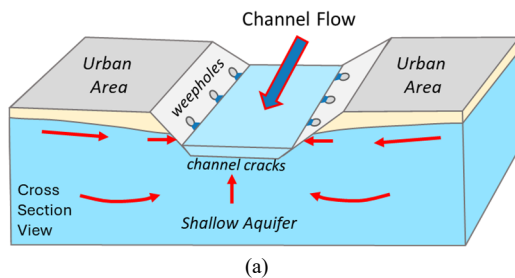


Fig. 19. Groundwater-surface water interactions in the Los Angeles River: (a) Cross section of the Los Angeles River shows channel flow direction and groundwater seepage locations along the concrete lining within a shallow aquifer; (b) groundwater seepage along the concrete lining located in the Upper Los Angeles River.

Urbanization along the Los Angeles River has substantially altered natural groundwater recharge processes by reducing infiltration through widespread impervious surface cover (Fig. 19(a)) [29]. As a result, groundwater

recharge in many parts of Los Angeles River Watershed is increasingly dependent on anthropogenic inputs, including imported water, irrigation return flow, stormwater capture, leaky sewer and water pipes, seepage through unlined channel segments (Fig. 19b), and tributary inflows. The groundwater chemistry data presented in this study demonstrate pronounced spatial variability among the five river reaches, reflecting differences in hydrogeologic setting, channel engineering, land use, and underlying geology. Distinct longitudinal patterns in TDS, sulfate, chloride, nitrate-N, ammonia-N, orthophosphate, and selenium concentrations (Figs. 10–16) indicate that both natural geochemical processes and anthropogenic influences control groundwater discharge to the Los Angeles River (Tables 2–6).

Spatial differences in TDS concentrations closely reflect the underlying geology and the degree of groundwater-surface water interaction along the Los Angeles River corridor (Fig. 10). Elevated TDS concentrations observed in the Upper Los Angeles River, Arroyo Seco, the western side of the Glendale Narrows, and the Laguna Channel indicate substantial groundwater contributions derived from contact with marine sedimentary strata of the Monterey, Topanga, and Pico Formations. These formations consist primarily of marine shales, sandstones, and siltstones that readily contribute dissolved solids to groundwater through prolonged water-rock interaction. Dissolution of marine derived salts and associated mineral phases contributes to the consistently higher salinity observed in these reaches.

Boxplot distributions show that median and upper quartile TDS values are highest in reaches where groundwater discharges intersect or is hydraulically connected to these marine formations. Shallow or exposed Monterey–Topanga–Pico strata along tributary valleys and river margins facilitate

direct groundwater inflow to the channel, including where channel lining exists or is absent or discontinuous. These geologic controls dominate the observed TDS patterns in upstream and tributary reaches. In contrast, lower TDS concentrations observed in the eastern Glendale Narrows and Lower Los Angeles River reflect differences in rock and sediment provenance and hydraulic conditions. These downstream reaches are underlain predominantly by coarse alluvial deposits derived from granitic and metamorphic rocks of the San Gabriel Mountains. These lithologies are characterized by low solubility and contribute relatively small, dissolved solids loads to groundwater. Extensive concrete channelization in these reaches controls groundwater–surface water exchange to cracks, weepholes, and dewatering appurtenances [30]. Consequently, lower TDS values downstream reflect primarily geologic composition with sediment minerals consisting mostly of low-solubility igneous and metamorphic rock derivatives.

Similarly, boxplot distribution of groundwater sulfate and chloride demonstrate spatial variability from the Upper Los Angeles River to downstream of the Lower Los Angeles River (Figs. 11-12). Elevated sulfate concentrations are observed more in the Upper Los Angeles River, Arroyo Seco, and Laguna Channel reaches suggesting a strong influence from groundwater mixing with marine sedimentary formations. In contrast, Glendale Narrows had the lowest sulfate range and a wider range of chloride concentrations. The Lower Los Angeles River had a wider distribution of sulfate but low chloride concentrations. The spatial variability of these ions suggests groundwater chemistry is highly influenced by the geology along the Los Angeles River and tributary inputs.

Nitrate-N concentrations exhibit spatial patterns that in some cases parallel those of TDS, with the elevated concentrations in the Upper Los Angeles River and Arroyo Seco and decreasing values downstream (Fig. 13). Arroyo Seco samples ranged from <0.115 to 25.9 mg/L as  $\text{NO}_3\text{-N}$ , with maximum concentrations exceeding the U.S. Environmental Protection Agency Maximum Contaminant Level of 10 mg/L for drinking water [31]. Boxplots indicate higher medians and broader interquartile ranges in upstream and tributary reaches, reflecting spatially variable but persistently elevated nitrate loading to groundwater discharging to the river. The Arroyo Seco watershed overlies the Raymond Groundwater Basin and includes areas of dense residential development, historical septic system use, fertilizer application, and urban runoff [32].

Although a Superfund site is present at the Jet Propulsion Laboratory along upper Arroyo Seco, available documentation indicates that nitrate contamination within Arroyo Seco is not directly associated with the JPL CERCLA site [32]. Instead, nitrate sources are more plausibly linked to legacy septic systems, landscape irrigation, urban runoff, and historical agricultural practices. In the upper San Fernando Valley, much of the nitrate likely reflects residual nitrogen from agricultural activities that occurred prior to widespread urbanization beginning in the 1950s [33]. Nitrate stored in the vadose zone and shallow groundwater continues to be mobilized during recharge events, contributing to elevated concentrations decades after agricultural land use declined. The spatial coincidence of elevated nitrate and elevated TDS indicates mixing between anthropogenically affected

groundwater and naturally mineralized groundwater derived from marine sedimentary formations. Downstream reductions in nitrate concentrations in groundwater are consistent with areas of the city that have been urban for much longer, with no history of irrigated agriculture using synthetic nitrogen fertilizer.

Similar nitrate-N concentrations between surface water samples in Glendale Narrows and the Lower Los Angeles River suggest that surface water chemistry in these reaches is dominated by treated effluent inputs with limited influence from groundwater discharge, however, groundwater seepage is likely to become increasingly important as treated wastewater input decreases.

Ammonia-N and orthophosphate in groundwater were consistently low across the study area which limited the ability to identify clear spatial trends (Figs. 14 and 15). However, groundwater at the Laguna Channel tributary reach exhibited relatively higher concentrations of these nutrients suggesting that nutrient levels in this tributary may be influenced by industrial and urban discharges.

In contrast, TDS, nitrate-N, and selenium provide stronger tracers for evaluating the groundwater spatial variability in the study.

Selenium concentrations display pronounced spatial variability that is primarily controlled by geology (Fig. 16). Elevated selenium concentrations in the Upper Los Angeles River and Arroyo Seco are consistent with groundwater flow through marine sedimentary units, particularly the Monterey, Topanga, and Modelo Formations, which contain selenium bearing minerals associated with organic rich marine shales. Observed concentrations ranged from <0.2 to 70  $\mu\text{g/L}$ , exceeding typical natural groundwater background levels [34]. Data in Table 4, represents a very short reach of Arroyo Seco that flows across rocks with limited selenium contribution to groundwater and surface water, however. This reach of Arroyo Seco was selected for evaluating TDS controls primarily.

The semi-arid climate of southern California enhances selenium mobilization by promoting oxidative weathering of marine shales and rich organic sediments, increasing selenium solubility and transport in groundwater [35]. Outcrops and shallow subsurface exposures of the Monterey Formation near the river corridor provide direct geologic sources for selenium enriched groundwater discharging to surface waters. Boxplots indicate that the highest selenium medians and extreme values occur in reaches where groundwater interacts with this marine unit. Topanga and Pico Formations are coarser textured marine clastics and do not contain as much selenium as Monterey Formation. Additionally, low selenium concentrations observed in surface water suggest dilution, mixing, and possible uptake processes across the reaches.

Although anthropogenic inputs cannot be entirely excluded, the strong spatial correspondence between elevated selenium, elevated TDS, and marine sedimentary geology indicates that natural geologic processes dominate selenium loading to the Los Angeles River (Fig. 20). Lower selenium concentrations observed downstream are consistent with limited contact with selenium bearing formations due to predominance of low selenium alluvial sediments derived from granitic and metamorphic source rocks in the San Gabriel Mountains.

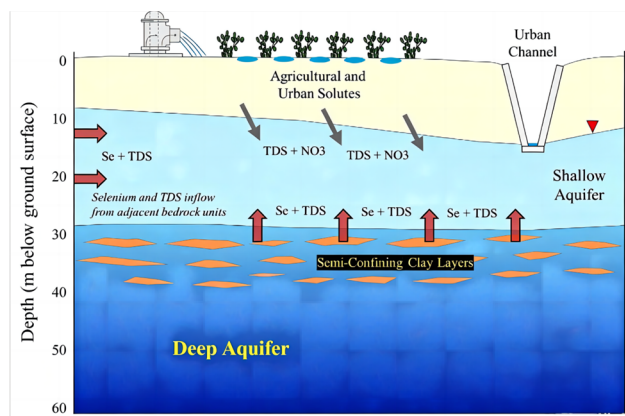


Fig. 20. Cross section of groundwater depth and sources of selenium, TDS, and nitrate in the shallow aquifer adjacent to the urban channel.

Stable water isotope data ( $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ) provide additional information on groundwater–surface water interactions and recharge sources [36] across the Los Angeles River system (Fig. 18). Most samples plot at or near the Global Meteoric Water Line (GMWL), indicating dominantly meteoric groundwater recharge and limited evaporative enrichment prior to infiltration [17]. The regression slope of 9.36 ( $R^2 = 0.936$ ) further supports meteoric groundwater recharge rather than a strong evaporative trend. Systematic spatial differences in isotopic composition reflect contrasting recharge sources and water management histories among the river reaches [37].

Groundwater and surface water samples from the Upper Los Angeles River, which drains the San Fernando Valley, cluster in an isotopically lighter space with isotopic signatures associated with imported water and lighter regional groundwater [38]. The more depleted isotopic compositions are consistent with recharge derived from higher elevation precipitation sources, where temperature-dependent fractionation produces isotopically lighter rainfall, as well as contributions from managed recharge of imported water supplies and long-term importation of water [39]. The San Fernando Valley has a long history of dependence on imported water following completion of the Los Angeles Aqueduct in 1913, which conveyed water from the Owens Valley and eastern Sierra Nevada. Over time, additional imported supplies became available through the Colorado River Aqueduct and the State Water Project, which delivers water originating from the Sacramento–San Joaquin Delta [38]. These imported sources are isotopically lighter than locally derived precipitation and have been widely used for municipal supply and large-scale irrigation within the San Fernando Valley.

Historically, imported water was applied extensively across the valley floor for agricultural production and later for municipal use and landscape irrigation, resulting in substantial recharge to the underlying aquifers through infiltration and return flow. As a result, imported water has constituted a large fraction of the recharge volume to the San Fernando Basin for more than a century. The long-term use and recharge of these imported supplies have substantially influenced groundwater storage and composition in the basin, and the isotopic signatures observed in groundwater discharging to the Upper Los Angeles River reflect this legacy of managed recharge and imported water dependence

[40].

In contrast, samples from the Arroyo Seco, Laguna Channel, and portions of the Glendale Narrows plot closer to the isotopic range expected for locally derived meteoric recharge. These reaches drain smaller foothill and mountain catchments along the San Gabriel Mountains and local foothills, where groundwater systems historically relied more heavily on locally sourced precipitation recharge [41]. Many of these surrounding upland areas were historically used for grazing and other low-intensity land uses and did not experience the same degree of large-scale irrigation with imported water that characterized the San Fernando Valley. Consequently, groundwater recharge in these other areas below the Upper Los Angeles River area have been more strongly influenced by local meteoric inputs, with imported water becoming a more significant component only in later decades.

Slight enrichment in some Arroyo Seco samples suggests localized evaporation or soil–water interaction prior to recharge. Some evaporation of Upper Los Angeles River water probably derives from transit through reservoirs and aqueducts from imported water sources. Mixing trends evident in Fig. 18 indicate active exchange between imported and locally recharged groundwater.

## V. CONCLUSION

This investigation represents the first comprehensive, spatially explicit study to systematically map groundwater discharge zones along the Los Angeles River and its major tributaries and to evaluate the associated groundwater chemistry using integrated hydrochemical and isotopic tracers. Previous studies have acknowledged the presence of groundwater contributions but have not provided reach-scale mapping of seepage locations, particularly along lined channel segments. By linking observed discharge locations to geologic settings, land use history, and water-management infrastructure, this study provides a unique and valuable framework for understanding how groundwater currently influences dry-weather flow and river water quality, and how that influence is likely to evolve under future conditions of declining wastewater discharge and expanded river restoration.

Collectively, the spatial patterns in TDS, sulfate, chloride, nitrate-N, ammonia-N, orthophosphate, selenium, and stable water isotopes indicate that groundwater discharge to the Los Angeles River is not chemically uniform. Instead, groundwater quality varies by reach in response to geology, land use history, imported water management, and engineered channel conditions. As wastewater discharges decline and dry-weather flows increasingly reflect groundwater contributions, these spatial differences may exert greater influence on river water quality.

Elevated TDS and selenium concentrations in upstream and tributary reaches reflect groundwater interaction with marine sedimentary formations, whereas downstream reaches underlain by granitic derived alluvium exhibit lower concentrations due to lithologic controls from both rocks and minerals. Nitrate patterns reflect legacy agricultural inputs and urban sources that persist in groundwater systems long after land use changes. Stable isotope data provides the framework needed to interpret these chemical patterns by

distinguishing imported water dominated recharge from locally derived meteoric recharge.

These findings indicate that future management and restoration of the Los Angeles River will require consideration of groundwater inputs as well as groundwater quality. Restoration strategies that increase groundwater–surface water connectivity without accounting for geologic and legacy contaminants may increase constituent loads during dry-weather. Conversely, identifying reaches where groundwater discharge is persistent and chemically favorable may provide opportunities for sustainable baseflow enhancement and ecological restoration.

Further work is needed to refine understanding of groundwater–surface water interactions and associated water-quality impacts along the Los Angeles River. Future studies should incorporate higher-frequency temporal sampling to better capture seasonal variability in groundwater discharge and constituent concentrations, particularly during transitions between wet and dry-weather conditions. Expanded use of isotopic tracers, including nitrate isotopes and additional redox-sensitive elements such as iron, manganese, molybdenum, and vanadium, would improve discrimination between natural geologic sources and anthropogenic inputs of nutrients and trace elements. Quantitative mixing analyses and reach scale mass loading estimates are also needed to more explicitly evaluate the proportional contribution of groundwater to river flow and constituent loads under declining wastewater discharge scenarios. In addition, targeted monitoring in restoration reaches where channel lining is modified or removed would help assess how increased groundwater connectivity influences water quality and ecological conditions. Addressing these gaps will be essential for anticipating future water quality outcomes as river management, water reuse, and restoration strategies continue to evolve.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest.

#### AUTHOR CONTRIBUTIONS

Conceptualization, B.H.; literature review, D.M., B.H.; methodology, M.G.R., T.J.R., J.K.M., C.S.R., B.H.; investigation, M.G.R., T.J.R., D.M., J.K.M., C.S.R., B.H.; formal analysis, M.G.R., T.J.R.; data curation, M.G.R., T.J.R., J.K.M., B.H.; visualization, M.G.R., T.J.R.; writing-original draft, M.G.R., D.M.; writing-reviewing & editing, B.H., M.G.R., T.J.R., D.M.; supervision, B.H.; project administration, B.H.; funding acquisition, B.H., M.G.R., T.J.R. All authors have read and agreed to the published version of the manuscript.

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