TAHOE SCIENCE ADVISORY COUNCIL

MICROPLASTICS MEMORANDUM

OCTOBER 2024

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1. EXECUTIVE SUMMARY

Microplastics are a contaminant of emerging concern. The Tahoe Science Advisory Council convened the Microplastics Workgroup to assess the current state of knowledge of microplastics in the Tahoe Basin, highlight key data gaps, and recommend next steps. The workgroup focused on four main areas: microplastic sources, fate and transport, microplastic interactions with ecology and impacts to water quality, and regulatory/source controls to reduce microplastics entering Lake Tahoe.

The workgroup recommends (1) further assessing specific microplastic sources, (2) assessing microplastic transport, (3) evaluating the impacts of microplastics to lake clarity and drinking water, and (4) continued assessment of strategies to reduce plastic litter entering the environment.

2. GOAL OF DOCUMENT AND APPROACH

Microplastics are a contaminant of emerging concern around the globe (World Health Organization, 2019, 2022) and at Lake Tahoe (Nava et al., 2023). In response to growing awareness about plastics in the region, the Tahoe Science Advisory Council (Council) convened a working group (group) of local and regional experts to summarize and document microplastics and plastic pollution research in the Lake Tahoe Basin. Using available information, the group was charged with highlighting key information and data gaps, and with recommending next steps.

The group conducted its work over the course of one year and developed this memorandum to document its findings. The project was guided by the 2023 Lake Tahoe "Science to Action" conference proceedings, a targeted survey, and regular science community and stakeholder engagement. The conference provided space for science-management dialogue about microplastics and highlighted the need to summarize the state of the knowledge and prioritize future investment. An 11-question survey was circulated widely to researchers, monitoring groups, non-profits, and management communities to identify concerns and gauge interest in an assessment of microplastics in the Tahoe Basin. This effort included three participant groups to ensure broad engagement and provide insights into Lake Tahoe's microplastic issues: a Core Group, a broader Stakeholder Group, and Subject Matter Experts. At the end of the project, stakeholders were surveyed a second time to identify priorities moving forward.

2.1 DEFINITIONS

Microplastics

There are various definitions of microplastics and polymers (Hartmann et al., 2019). To ensure consistency with regional efforts this group uses the California State Water Resources Control Board definition of microplastics in drinking water (2020), which states that microplastics are "solid polymeric materials to which chemical additives or other substances may have been added, which are particles that have at least three dimensions that are greater than 1 nm and less than 5,000 micrometers (µm). Polymers derived in nature not chemically modified (other than by hydrolysis) are excluded." The term "nanoplastic" is used to describe the smaller size fraction of plastic material from <1 mm to >1 nm.

Polymer

A polymer is a "substance consisting of molecules characterized by the sequence of one or more types of monomer units. Such molecules must be distributed over a range of molecular weights wherein differences in the molecular weight are primarily attributable to differences in the number of monomer units" (California State Water Resources Control Board, 2020).

Plastic litter

The term "plastic litter" covers macroplastic items (plastic >5 mm in its longest dimension) that have been mismanaged and have entered the environment (Davidson et al., 2023).

3. Overview of Tahoe

The Lake Tahoe Basin is unique in its physical geography, environmental protection regulations, and population dynamics. Famous for its clear waters, Lake Tahoe is the second deepest lake in the United States (1,645 ft deep) (USGS, 2024) and is situated 1897 meters (6,224 feet) above sea level. With a long residence time of about 650 years (Goldman, 1988), Lake Tahoe has a relatively small watershed to surface area ratio, with a watershed of 813 km^2 (314 square miles) and a surface area of 497 km^2 (192 square miles) (Rowe et al., 2002). Lake Tahoe receives the most precipitation in winter from westerly orographic storms (Dettinger et al., 2004).

Designated as an Outstanding National Resource Water, Lake Tahoe is afforded stringent water quality protection requirements through Federal and State antidegradation policies. Lake Tahoe has been protected by a unique bi-state Compact and the bi-state Tahoe Regional Planning Agency (TRPA) since 1969 (Pub.L.96-551, 1980; TRPA, 2013). While sewage discharge and treated effluent are a common source of microplastics in other areas, the 1969 Porter Cologne Act mandated export of wastewater from the Lake Tahoe Basin starting in 1972 (SWRCB 2024).

Lake Tahoe hosts about 2 million unique visitors and 15 million "visitor days" per year (Official Visitors Bureaus, 2024) and is home to 56,000 year-round residents (United States Department of Transportation, 2022). Direct human interaction with the lake itself generally occurs in summer, when swimming, fishing and boating are most popular.

4. Prior and Current Microplastic Research and Monitoring at Lake Tahoe

4.1 Peer-Reviewed Scientific Studies (External)

Nava et al. 2023

The study measured plastic particles >250 mm across 38 lakes and reservoirs from around the globe using standardized sampling methods (horizontal net trawls with mesh sizes ranging from 50 to 300 µm, no less than 50 m^3 of water filtered for each trawl). This work showed that lakes with urbanized watersheds and lakes with high surface areas and long residence times are at risk of microplastic pollution. The study found Lake Tahoe had microplastic concentrations of 5.4 particles per m^3 the third most contaminated waterbody studied. Measured plastic particles were primarily fragments followed by other shapes and filaments, predominantly clear, black or white in color, and comprised of polypropylene followed by polyethylene.

Study Limitations

- The study entailed "snapshot" type sampling that does not reflect temporal or spatial variability.
- The study focused on plastics >250 µm, neglecting smaller microplastics.
- The study focused on floating plastics and did not collect samples below the surface.

Davidson et al. 2023

The study investigated plastic litter from Lake Tahoe's lakebed using self-contained underwater breathing apparatus (SCUBA) at a 30 ft depth. Litter from each dive transect was brought to the surface and characterized by litter type. Each litter category was then weighed and counted. The top plastic litter found was in the "other" category (plastic litter that did not fall in another category), followed by food containers, bottles <2 L, plastic bags, and toys. The top three polymers most frequently detected in the litter polyvinyl chloride, polystyrene/expanded polystyrene, and polyethylene. On average, 83±49 items per kilometer were found on the lakebed.

Study Limitations

- Only a subset of dive transects were studied.
- The dive transects were spatially limited (Nevada only).
- Much of the litter was categorized as "other" plastic, making it difficult to attribute the material source.

4.2 Scientific Reports (Not Peer Reviewed)

Gjeltema et al. 2023

Sampling was conducted monthly along ~3km transects using horizontal net trawls with mesh size of 335 µm both at the surface and at 15 m depth. On average, the study found 306,000 (SD 417,012) microplastic particles per km^2 at the surface and 0.043 (SD 0.04) microplastic particles per km^3 at 15 m depth. For the surface tows more microplastic particles per km^2 were observed in the spring than the winter or fall, suggesting a potential relationship with runoff. Polyester, polypropylene, and polyethylene were the most identified plastics.

The study also analyzed municipal water for microplastics from Incline Village and Edgewood pumphouses. Approximately 7 to 10 L of water were collected per sampling event and the water was filtered onto 10 µm polycarbonate filters. There were a total of 4 sampling events. On average, 0.044 plastic particles per liter were found.

Study Limitations

- Horizontal net trawls study only captured plastics >335 µm.
- Only one location for the surface tows was conducted, therefore spatial variability was not studied.

- Small sample volumes (municipal water sampling)
- Lack of information on blank corrections (municipal water sampling)

Lake sediments were also studied, but conclusions could not be drawn from the study as a more robust sampling is required. Asian Clams were studied, and while the authors did identify polypropylene, conclusions could not be drawn without more robust sampling.

4.3 Current Monitoring for Microplastics and Plastic Litter in the Tahoe Basin

- In collaboration with UC Davis, the Tahoe Water Suppliers Association is currently updating its plan to quarterly monitor four domestic water facilities in the Lake Tahoe Basin. The monitoring is scheduled for some time in 2024.
- As part of California Senate Bill 1422, the State Water Board will sample the North Tahoe Public Utility District water supply for microplastics during Phase I of the statewide monitoring program. Microplastics will be monitored at the point at which water enters the treatment facility.
- Municipal Stormwater Permitting requires the City of South Lake Tahoe, Placer County, and El Dorado County to monitor litter over 5mm on streets and in stormwater conveyances (California Regional Water Quality Control Board and Lahontan Region, 2018).
- Desert Research Institute (DRI) is currently monitoring microplastics in snow from the Sierra Nevada. Sampling occurred from 2022 to 2024 at ~7 sites across the Tahoe Basin. DRI is also currently monitoring microplastics in the Truckee River, downstream of Lake Tahoe. Sampling also occurred from 2022 to 2024 for the Truckee River, two times per year.
- University of Nevada Reno (UNR) is incubating (Spring 2024) different plastic types in Lake Tahoe to assess biofilm formation, ecosystem production, community dark respiration, and influences on nitrogen, phosphorus, organic carbon, and oxygen in water.
- The League to Save Lake Tahoe has implemented two litter monitoring programs since 2014. Volunteer crews adopt areas/zones (beaches as well as neighborhoods) and regularly collect litter in their adopted area. The League also hosts cleanups throughout the Tahoe Basin (e.g., 5 beach sites on July 5th) including a collaboration with EcoClean Solutions (since 2022), which uses a litter sifting robot to collect litter at 9 locations twice annually on the shore zone. Litter programming includes count, weight, and categorization by item type (e.g., balloons, plastic cups, straws, metal cans, etc.).
- Clean Up the Lake (CUTL) has been monitoring submerged litter in Lake Tahoe. In 2022, they completed a circumnavigation of the 0 to 25-foot depth. CUTL has also performed additional projects at 30 litter hotspots around the lake's circumference and 60 deep dive surveys at depths of 35 to 70 feet off each hotspot. Litter data collected includes counts, weights, photos, and documentation of litter types across 77 categories (e.g., aluminum cans, plastic bottles, etc.). Also see Harrold et al. (2021) and Clean Up the Lake (2024).

4.4 FINDINGS AND RECOMMENDATIONS FOR FUTURE RESEARCH AND MONITORING

- Future microplastic studies in the Tahoe Basin should use accepted, peer reviewed methods. Prioritizing these methods will aid in data comparability and the possibility of long-term monitoring analysis.
- Published methods for monitoring microplastics in Lake Tahoe include Nava et al. (2023) for measuring lake surface water for microplastics >250 mm and Davidson et al. (2023) for measuring submerged plastic.
- We acknowledge that prior studies likely do not encompass future monitoring needs. We also recommend the development of robust methods for nanoplastic monitoring. The group recommends consulting Cowger et al. (2020) and Co-Editors-in-Chief (2024) for additional details on developing robust monitoring approaches. Considerations include, but are not limited to:
    - Follow best practices published in the peer-reviewed literature (Brander et al., 2020; Moore et al., 2020) and by the California State Water Board (Wong and Coffin, 2021).
    - Design the sample collection and analysis approach to address the monitoring goals.
    - Correct for blank contributions and calculate method limit of detection and limit of quantification.
    - Identify polymer types by spectroscopic or mass-based approaches.
    - Report size range of quantifiable particles.
    - Follow recommended reporting guidelines for all studies (Cowger et al., 2020).
    - Collect a statistically robust sample size.
    - Categorize temporal and spatial variation (e.g., temporal or spatial replication of sample collection).
    - Develop a Quality Assurance Project Plan (QAPP) (US EPA, 2015) for studies.
    - Compare with previous methods and findings in Lake Tahoe.

5. WHAT IS KNOWN AND UNKNOWN OF MICROPLASTICS IN THE TAHOE BASIN?

This following provides a general summary of the current state of knowledge to provide background information to inform future priorities.

5.1 SOURCES OF MICROPLASTICS

Table 1 provides a first order estimate of the known or expected sources of microplastics to Lake Tahoe. The list is not exhaustive. Table 1 provides an assessment of each source using three criteria: (1) documented occurrences in Lake Tahoe (e.g., through scientific studies), (2) likely occurrence due to widespread source throughout the region, (3) the occurrence is likely very large (e.g., >1 ton).

Table 1. Potential microplastic sources. Blue shading indicates priorities for region specific action. Orange shading indicates priorities for region specific research. Green shading indicates more research is needed to confirm or deny our current understanding.

Source	Sub-source (Examples only, not exhaustive)	Tahoe Specific Rationale	Known Occurrence in Tahoe	Likely Wide spread	Likely Very Large (>1 ton)
Consumer Goods	Cigarette butts	Widely found from study in region (Davidson et al., 2023).	Yes	Yes	Yes
Consumer Goods	Nearshore litter breakdown	Widely found by study in region (Davidson et al., 2023).	Yes	Yes	Yes
Clothing	Dryers	Every home has a dryer, direct input to the atmosphere of microfibers (Kapp and Miller, 2020).	Yes	Yes	Yes
Rubber	Car tires	High residential and tourist auto traffic, likely high prevalence of tire wear particles. Note: some may be captured by stormwater Best Management Practices (Tamis et al., 2021).	Yes	Yes	Yes
Roads	Road particles/ asphalt	Roadway construction accounts for a large mass of material produced and is known to be made of toxic materials, some would call road particles microplastics (Vogelsang et al., 2019).	Yes	Yes	Yes
Roads	Paint	All roads painted, stormwater Best Management Practices may be capturing some of the road particles. (Gaylarde et al., 2021)	No	Yes	Yes
Boating	Bottom paint	Boat paint is commonly found in microplastic samples where boat paint is used (Turner et al., 2022).	No	Yes	Yes
Stormwater Infrastructure	Piping/erosion control materials Best Management Practices such as plastic netting, plastic sandbags, and other erosion control materials that are in direct contact with stormwater	No studies to date	No	Yes	Yes

Table 1. Potential microplastic sources. Blue shading indicates priorities for region specific action. Orange shading indicates priorities for region specific research. Green shading indicates more research is needed to confirm or deny our current understanding (continued).

Source	Sub-source (Examples only, not exhaustive)	Tahoe Specific Rationale	Known Occurrence in Tahoe	Likely Wide spread	Likely Very Large (>1 ton)
Construction/ Conservation Activities	Lake-front construction and conservation (e.g., tarps, packaging, fencing/mesh, rebar caps, nail connectors, expansion nails and associated shreds, rubber coating [plastic-dip type])	Pier construction is directly in the Lake and adjacent to it. Best Management Practices use plastic adjacent to waterways to prevent erosion (Prasittisopin et al., 2023).	No	Yes	Yes
Clothing	Washing machines	Wastewater effluent not discharged to the Lake, also no known biosolid application (Domagalski et al., 2021).	No	No	No
Clothing	Recreation fragmentation	Lots of recreation in Lake Tahoe, synthetic clothing shedding likely prevalent but probably much less than what is released by dryers (Forster et al., 2023).	No	Yes	No
Rubber	Bike tires	No specific research on bike tire wear. Limited volume.	No	No	No
Rubber	Shoe rubber	Everyone wears shoes with synthetic soles (Lee et al., 2022).	No	Yes	No
Boating	Sewage release	Wastewater disposal is prohibited by state law (TRPA, 2019).	No	No	No
Boating	Fiberglass fragmentation	Probably low, boats made to prevent reduce shedding of the hull, shed paint instead.	No	No	No
Boating	Pier materials	Recent spill of Styrofoam from an old pier indicates this infrastructure may be aging (Anguiano, 2024).	Yes	Yes	No
Boating	Ropes	Unclear how prevalent degradation of ropes is compared to other synthetic textiles but certainly ropes are used on boats (Napper et al., 2022).	No	Yes	No
Boating	Fishing gear	Only hook and line fishing is allowed. Fishing lines are often lost to the environment (Cai et al., 2022).	No	Yes	No
Cosmetics	Microbeads	This is banned nationwide (FDA, 2022).	No	No	No

Table 1. Potential microplastic sources. Blue shading indicates priorities for region specific action. Orange shading indicates priorities for region specific research. Green shading indicates more research is needed to confirm or deny our current understanding (continued).

Source	Sub-source (Examples only, not exhaustive)	Tahoe Specific Rationale	Known Occurrence in Tahoe	Likely Wide spread	Likely Very Large (>1 ton)
Cosmetics	Glitter	Not used at the amount of other sources, very rare in the environment.	No	No	No
Cosmetics	Nail paint	Not used in nearly the amount of other sources (Chen et al., 2022).	No	No	No
Celebrations	Fireworks	Only really on 4th of July and Labor Day from what we can tell (Visit Lake Tahoe, 2019; Devereux et al., 2022).	No	No	No
Celebrations	Confetti	Not many studies on this specifically. Unclear how significant.	No	No	No
Celebrations	Balloons	Mylar becoming illegal (Schlepp, 2023). In general, large scale balloon releases are no longer happening.	No	No	No
Agriculture		Negligible amount of agriculture in the watershed, mostly illicit indoor marijuana, no known major plastic applications.	No	No	No
Landscaping	Sandbags	Difficult to find data on this.	No	No	No
Landscaping	Weed whacker string	Likely small in comparison to other sources even within landscaping category (Luo et al., 2022).	No	No	No
Landscaping	Plastic sheeting	Where used is known to be used in large amounts (Steinmetz et al., 2016).	No	Yes	No
Landscaping	Faux flowers	No studies to date.	No	No	No
Landscaping	Astroturf	Being put in more often, made up of very toxic plastic forms, very mobile and can transport to waterways (van Kleunen et al., 2020).	No	No	Yes

5.2 FINDINGS AND RECOMMENDATIONS FOR MICROPLASTIC SOURCES

- There are many potential sources of microplastics to Lake Tahoe and little quantification of actual sources.
- Based on best professional judgement, the top microplastics sources are likely: road debris, dryers, recreational activities, litter, and construction/conservation debris.
- Future study is needed to better refine source estimates.
- Tahoe specific research is needed to better understand other potential sources to inform our collective understanding of how plastics move through the environment and future management actions.

5.3 FATE AND TRANSPORT OF MICROPLASTICS INTO THE LAKE

Microplastics can be directly introduced to the Lake (e.g., boats, piers, ropes to tie up boats, recreation) or enter the Lake through activities on the lakeshore (e.g., fireworks, landscaping, improper disposal). Litter/microplastics can also be transported to the Lake via other processes, summarized in Table 2. To our knowledge, there has been no assessment in the Tahoe Basin of the known microplastic transport mechanisms summarized in Table 2.

Table 2. Summary of transport mechanisms of microplastics to Lake Tahoe.

Transport Mechanism	Tahoe Specific Details	Pathway to Lake	Prior Research at Tahoe	Relevant Citations (not Tahoe specific)
Atmospheric Transport	The primary wind direction in the Tahoe Basin is west/southwest and therefore regions upwind from Tahoe may serve as a potential source of microplastics.	Direct deposition, or to adjacent areas.	None	Microplastics have been found in remote regions in the United States (Brahney et al., 2020).
Waterways and Overland Flow	With rainfall and snowmelt, microplastics/litter may be transported to nearby waterways.	Waterways that flow into the Lake may be a source.	None for microplastics, for other pollutants see (Maurer et al., 2008).	Factors such as particle size, shape, density can influence transport (Koutnik et al., 2021).
Groundwater	Microplastics can infiltrate into groundwater.	There is some groundwater input to the Lake, but minor.	None	Microplastics can infiltrate into groundwater (Koutnik et al., 2022).
Stormwater	Stormwater is discussed in section 6.5.	Both treated and untreated stormwater enters the Lake.	None	Stormwater treatment may remove microplastics (Österlund et al., 2023). See section 6.5

5.4 FATE AND TRANSPORT OF MICROPLASTICS IN THE LAKE

Once in Lake Tahoe, microplastics can be transported through a variety of mechanisms with several ultimate fates, summarized in Table 3.

Table 3. Summary of transport mechanisms and fate of microplastics in Lake Tahoe.

Transport Mechanism	Tahoe Specific Details	Prior Research at Tahoe	Relevant Citations (not Tahoe specific)
Vertical Transport	Prior research at Tahoe shows that microplastic concentrations decrease with water depth.	(Gjeltema et al., 2023)	This is supported by observations in other lakes (Liu et al., 2020). Settling of microplastics can be impacted by particle size, shape, and density (Koutnik et al., 2021).
Thermal Stratification	Thermal stratification occurs in Tahoe and may impact transport/settling.	None.	Other reservoirs with thermal stratification (Zhang et al., 2023).
Surface Currents	Surface currents in Tahoe could be an important transport process for floating plastics.	Surface concentrations of microplastics in Tahoe have been measured (Gjeltema et al., 2023; Nava et al., 2023).	Surface currents can impact the distribution of microplastics (Deng et al., 2022).
Tahoe City Dam	Tahoe's dam may impact transport and settling.	None.	Some studies indicate dams can trap and retain microplastics (Yan et al., 2021; Liu et al., 2022), but other studies are less clear (Watkins et al., 2019; Dhivert et al., 2022).
Sedimentation	One study assessed microplastics in Tahoe's sediment but was inconclusive.	(Gjeltema et al., 2023)	High abundance in sediments compared to in the water column has been observed (e.g., Martin et al., 2022).
Consumption by Biota	One study assessed microplastics in Asian Clams from Tahoe but was inconclusive.	(Gjeltema et al., 2023)	See section 6.4 for additional details
Truckee River	Dam operations may impact the export of microplastics to the Truckee River.	None, however, see section 5 for ongoing monitoring.	Dams may impact downstream transport, but studies are not clear (Watkins et al., 2019; Yan et al., 2021; Dhivert et al., 2022; Liu et al., 2022).
Drinking Water	Drinking water has been studied but was inconclusive.	(Gjeltema et al., 2023) and see section 5 for ongoing monitoring.	California Water Board is leading efforts to study drinking water in California (California Water Board, 2024).

5.5 Impacts to Drinking Water

One important fate of microplastics in Lake Tahoe is in drinking water. Filtration is the most common water treatment method, and it is notable that there are six water treatment systems in the Tahoe Basin with exemptions that allow them to operate without any type of filtration. Filtration exemption is a rare status, issued to only a handful of the 100,000+ public water systems. Consequently, there is great interest in maintaining the filtration exemptions in the Tahoe Basin that allow purveyors to deliver uncommonly high-quality drinking water without filtration. Research on the concentration of microplastics in drinking water intakes in Lake Tahoe is ongoing by the State of California, and preliminary data suggest low concentrations (Gjeltema et al., 2023), however, current studies suggest a minimum recommended volume of 500L for treated drinking water based on expected abundance (Koelmans et al., 2019), which is much greater than the prior Tahoe study.

5.6 Findings and Recommendations for Fate and Transport of Microplastics

- There is little information about the many potential transport mechanisms of microplastics to Lake Tahoe.
- The primary transport mechanisms of microplastics to Lake Tahoe are likely: waterways/overland flow in urban environments, atmospheric deposition, and stormwater in urban environments.
    - These transport mechanisms should be studied further to inform future mitigation actions.
- Future investments should prioritize robust studies on microplastics and nanoplastics in drinking water in the Tahoe Basin.

5.7 Microplastics and Ecology

Once plastics enter Lake Tahoe, they can interact with the ecology of the Lake. Table 4 summarizes the potential impacts on various aspects of Lake Tahoe's aquatic ecosystem. For more information on of microplastics and the environment, please consider Wang et al. (2023).

Table 4. Potential impacts of microplastics on Lake Tahoe's ecosystem

Ecologic Mechanism	Tahoe Specific Details	Prior Research at Tahoe	Relevant Citations (Not Tahoe Specific)
Biofilms on Plastic and their Ecology	Different environmental gradients may result in different biofilm diversities. The plastic biofilms may then be ingested by organisms (Li et al., 2022).	See section 5 for ongoing monitoring.	Most of the peer-review literature on this topic focuses on laboratory studies (Li et al. 2022). Studies show the biodiversity of biofilms (Barros and Seena, 2021; Nava et al., 2024) and impact on ecosystems (Nava and Leoni, 2021).
Biofilms on Plastic and Impact to Water Quality	The biofilm community types may impact the cycling of nutrients and greenhouse gases. Quantifying how microplastics enhance or modify nutrient and greenhouse gas cycling may be important.	None, however, see section 5 for ongoing monitoring.	If heterotrophic bacteria dominate the communities on plastics, then dissolved oxygen decreases, and carbon dioxide or methane production can increase (Troost et al., 2018).
Plastics can Absorb Chemicals or Contribute Chemicals	Plastics can adsorb chemicals, transporting them to other parts of the watershed or to organisms. Plastics can also contribute chemicals to the environment.	None	Studies show microplastics adsorb metals (Godoy et al., 2019). A byproduct of tire degradation is toxic to coho salmon (Tian et al., 2021).
Clarity	It is unlikely that microplastics play a major role in controlling offshore clarity.	None	The concentration of microplastics in Lake Tahoe (Nava et al., 2023; Gjeltema et al., 2023) is low relative to the overall concentration of living and nonliving particles in the water column.
Ingestion	Microplastics can be ingested by an organism with potential impacts to the environment and the organism.	The study of microplastics in biota from Tahoe was inconclusive (Gjeltema et al., 2023).	Microplastics may interfere with zooplankton's ability to ingest algal particles (Pan et al. 2022). Microplastic concentrations might increase with the size of organisms and may increase with the trophic feeding positions (Garcia et al. 2021).
Other Impacts to Biota	Impacts at the cellular, organismal, population, or community level from microplastics in Lake Tahoe is unknown.	None	Additional research is needed on the impacts of microplastics and nanoplastics to biota (Wang et al., 2023).

5.8 Findings and Recommendations for Microplastics and Ecology

- Research documenting the effects of microplastics and nanoplastics on various aspects of freshwater ecosystem traits (e.g., biota health, water quality, clarity, nutrient, algal growth, and carbon cycles) is still in its infancy and nonexistent for Lake Tahoe.
- Carbon cycling may influence the flow of material energy into the food web, affecting organisms and emissions of greenhouse gases.
- While microplastics are relatively low in abundance today in Lake Tahoe based on current research, impacts may be observed in the future with increases in concentrations.
- Studies are needed on microplastic and nanoplastics and their relationship to ecological health, cycling of nutrients, and plastic derived chemicals.

5.9 Regulatory Controls of Microplastics in the Tahoe Basin

The management of microplastics in the environment often involves two broad strategies: source control and clean-up (Picó and Barceló, 2019). Source control strategies aim to stop or minimize the introduction of microplastics into the environment in the first place. Clean-up strategies involve removing plastics and/or microplastics that are already present in the environment. The tables below categorize what is currently known about the effectiveness of both strategies.

Table 5. Source control methods for plastic regulation.

Measure	Tahoe Specific Details	Prior Research at Tahoe	Relevant Citations (not Tahoe specific)
Regulation	The City of South Lake Tahoe and Truckee have implemented various plastics bans.	The effectiveness of these bans reducing plastic input to the Tahoe environment is unknown.	Bans reduce plastic use (Diana et al., 2022).
Enforcement	There are litter laws in the Tahoe Basin.	None	Effective enforcement of anti-litter laws, including penalties and fines, has been shown in the literature to reduce littering incidents (Townsend et al., 2019).
Market-based incentives	A bottle deposit on the CA side encourages recycling. South Lake Tahoe requires a minimum of a 10-cent charge for each reusable plastic or recycled paper bag.	None	Market-based incentives, such as charging for plastic bags have been shown to be effective in reducing use (Jakovcevic et al., 2014; Nishijima and Nakatani, 2023).
Convenience of recycling and disposal	Much of Tahoe has comingled recycling. Trash receptacles in Tahoe need to be bear proof.	None	Studies have shown that design and placement of trash receptacles influence utilization (Portman and Behar, 2020; Rossi et al., 2023).

Table 5. Source control methods for plastic regulation (continued).

Measure	Tahoe Specific Details	Prior Research at Tahoe	Relevant Citations (not Tahoe specific)
Incentives	Not currently implemented in Tahoe.	None	This is a relatively understudied area of research.
A mix of voluntary and regulatory approaches	The League to Save Lake Tahoe Blue Beaches program uses both approaches. Infrastructure, education, and enforcement mechanisms are emphasized along with novel methods to capture plastic materials under the sand.	None	Using both approaches may be more effective (Prata et al., 2019) at reducing littering.
Education	Take Care campaign includes messaging designed to educate and promote proper disposal of litter. UC Davis Tahoe Environmental Research Center (TERC) has a display about litter/microplastics. The League to Save Lake Tahoe is also opening an education center.	Many educational opportunities exist in Tahoe, additional research on effectiveness may be of interest.	Studies emphasize the importance of educational campaigns in fostering a change in behavior toward littering (Willis et al., 2022).

Table 6. Methods for removing plastics

Measure	Tahoe Specific Details	Prior Research at Tahoe	Relevant Citations (Not Tahoe Specific)
Stormwater Management	Stormwater Best Management Practices already implemented in Tahoe may be effective at removing micro and nanoplastics.	No study on Best Management Practices and micro or nanoplastics has been done.	Rain gardens were effective at entraining >90% of microplastics (Werbowski et al., 2021). Bioretention cells have also been demonstrated to retain microplastics from urban stormwater (Smyth et al., 2021).
Clean-Up	Many cleanups occur in Tahoe.	See section 5 for ongoing monitoring. Coordination of litter data between Tahoe groups organizing cleanups would increase the impact of clean ups.	Smaller fragments often escape clean-up efforts (Loizidou et al., 2018). Clean-up efforts enhance educational opportunities (Almosa et al., 2022).
Microplastic/ Litter Removal from Waterways	None	None	Innovative technologies are now being developed to remove microplastics from waterways (e.g., https://polygonesystems.com/ or https://www.mrtrashwheel.com/technology/)

5.10 Findings and Recommendations for Regulatory Controls of Microplastics

- Additional research is needed to assess stormwater Best Management Practices effectiveness in capturing microplastics and nanoplastics.
- The region should work towards coupling education and marketing campaigns, with policies and programs to curb the use of plastics in the region and encourage appropriate disposal of plastics that are used.
- The mix of local controls and regulations in the region provides a unique opportunity to assess the efficacy of individual polices. This heterogeneity could be used to design experiments on how the existing education campaigns can be coupled with infrastructure design and/or enforcement that could then provide insight into which combination of factors works best in the Tahoe Basin.
- Review of the potential sources of microplastics to Lake Tahoe and their likely magnitude (Table 1) in concert with the intersection of regulatory opportunities should be assessed to address potential opportunities for high impact.

6. Summary of Future Priorities

Each of the previous sections outline the current state of knowledge and recommendations for future actions. The project team surveyed stakeholders following the assessment and offers the following summary of priority research and monitoring topics:

6.1 Sources

Future studies should focus on the breakdown of plastic litter, construction/construction erosion materials, stormwater, road particles/asphalt, and rubbers from car tires to better assess these potential sources to the Lake. There is also interest in better quantifying the magnitude of plastics emitted from clothes dryers.

6.2 Impacts

To better understand the effect of microplastics on the ecosystem, future research should investigate the impacts on specific biota (e.g., bioaccumulation in Tahoe relevant species) and on the broader impacts to Lake Tahoe’s ecology. Importantly, there is consensus on the need to study the effect smaller microplastics (<5 μm) and nanoplastics may have on Lake Tahoe’s clarity and drinking water.

6.3 Control

The workgroup supports ongoing implementation, tracking, and evaluation of methods to reduce plastic litter entering the environment. Such practices include education, increased convenience of litter disposal, and increased policies to reduce plastic usage and littering. The group also recommends targeted study on the effectiveness of established stormwater treatment methods at removing micro and nanoplastics from stormwater.

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