2023 Lake Tahoe Clarity Report

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Prepared for the Tahoe Regional Planning Agency

Katie Senft (UC Davis), Yana Garcia (Secretary for Environmental Protection), California Governor Gavin Newsom and Lauren Sanchez (Senior Climate Advisor to the Governor) aboard the UC Davis TERC Research Vessel learning about Secchi disk measurements (June, 2024; photo credit: Charles Ommanney, Office of the Governor).

July 12, 2024

Executive Summary

Observations of lake clarity for the 2023 calendar year show the continuing trends of improving clarity conditions during the winter (December through March) months (**10th highest in the historical record and highest since 1983**) and deteriorating conditions during the summer (June through September) months (**5th lowest in the historical record**). The annual average decreased from 21.9 m in 2022 to 20.8 m in 2023 making it the **10th lowest observed annual average in the historical record** although the value appears level as a long term average

Observed high winter clarity (28.0 m) in 2023 is partly the result of complete lake mixing (turnover) observed in early March 2023. Deep water mixing plays a critical role in winter clarity as clearer bottom waters are mixed in with surface waters.

Observed low summer clarity (16.3 m) in 2023 primarily results from increased number of particles in the surface waters. These particles are being discharged from the watershed following the melting of the large snowpack received in 2023. This is exemplified by the rapid decrease in clarity in May 2023 when stream discharge from the watershed neared the maximum. Fine particles (1-6.73 µm in size) in streams around the basin are correlated with observed turbidity measurements.

Future research on lake clarity should focus understanding the processes associated with short- and long-term trends. Observed changes over the last decade in the zooplankton and phytoplankton communities are potentially playing a role in clarity. Particles resulting from microplastics may also be resulting in changes in water optical properties but are poorly understood at small sizes (e.g. <5 µm) in Lake Tahoe.

1. History of Clarity Measurements

Clarity is measured as the depth to which a 10-inch white disk, called a Secchi disk, remains visible when lowered into the water. In 2023, UC Davis scientists took 25 readings at Lake Tahoe's long-term index station (LTP station) and 13 readings from the mid-lake index station (MLTP) that were deemed acceptable. View the historic clarity readings from 1968-2023 at https://portal.edirepository.org/nis/mapbrowse?scope=edi&identifier=1340.

More than 80 organizations, including government agencies, nonprofits, and research institutions, are working collaboratively with scientists to improve Lake Tahoe's water clarity and ecological health under the Lake Tahoe Environmental Improvement Program, or EIP, which is one of the most comprehensive, landscape-scale restoration programs in the nation. EIP partners are helping meet TMDL reduction targets by reducing pollution through improved roadway maintenance and erosion control on roadways and private properties.

As reported in the 2022 Clarity Report, research over the last 25 years has established that the primary factor controlling lake clarity is the concentration of fine particles in the upper waters of the lake, in the approximate size range of 1-6 µm. These particles can be comprised of inorganic particles (e.g. fine silt or clay), particles associated with atmospheric deposition (e.g. wildfire smoke) or small phytoplankton (e.g. *Cyclotella*).

2. Annual and Seasonal Averages

In summary, the 2023 numbers from LTP reflect the trends observed for the last decade with improving winter clarity conditions and deteriorating summer clarity conditions. Although the annual average decreased slightly as compared to 2022, the value appears level as a long term average. Similar annual average results were observed at MLTP. These values are shown in **Table 1** (in meters) and **Table 2** (in feet).

Table 1: Summary of 2023 Secchi disk measurements (in meters)

Station_ID	Ave_Type	Avg.	Min	Max	SD	N	Note
Mid-lake	Annual	21.2	16.0	37.5	6.1	13	10th lowest in the historical record
Index	Annual	20.8	8.0	37.5	6.6	27	10th lowest in the historical record
	Winter	28.0	25.0	37.5	3.8	12	10th highest in the historical record, Highest since 1983 (29m)
	Summer	16.3	13.5	18.5	2.2	9	5th lowest in the historical record

Table 2: Summary of 2023 Secchi disk measurements (in feet)

Station_ID	Ave_Type	Avg.	Min	Max	SD	N	Note
Mid-lake	Annual	69.5	52.5	123	20.0	42.6	10th lowest in the historical record
Index	Annual	68.2	26.2	123	21.6	88.6	10th lowest in the historical record
	Winter	91.8	82.0	123	12.5	39.4	10th highest in the historical record, Highest since 1983 (29m)
	Summer	53.5	44.3	60.7	7.2	29.5	5th lowest in the historical record

Figures 1-3 show the Annual Averaged (January 2023-December 2023), Winter Averaged (December 2022- March 2023) and Summer Averaged (June 2023 – September 2023) time series respectively from 1968-2023 for the LTP station. The whiskers on each point indicate the standard deviation.

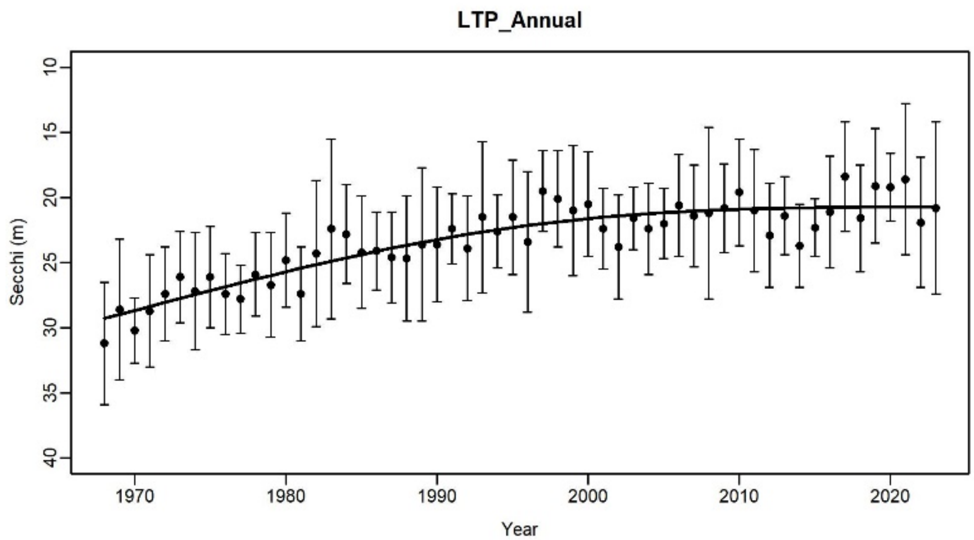


Fig. 1: Annual averaged Secchi disk measurements at the LTP Station. The value for 2023 was 20.8 ± 6.6 m (68.2 ± 21.6 ft).

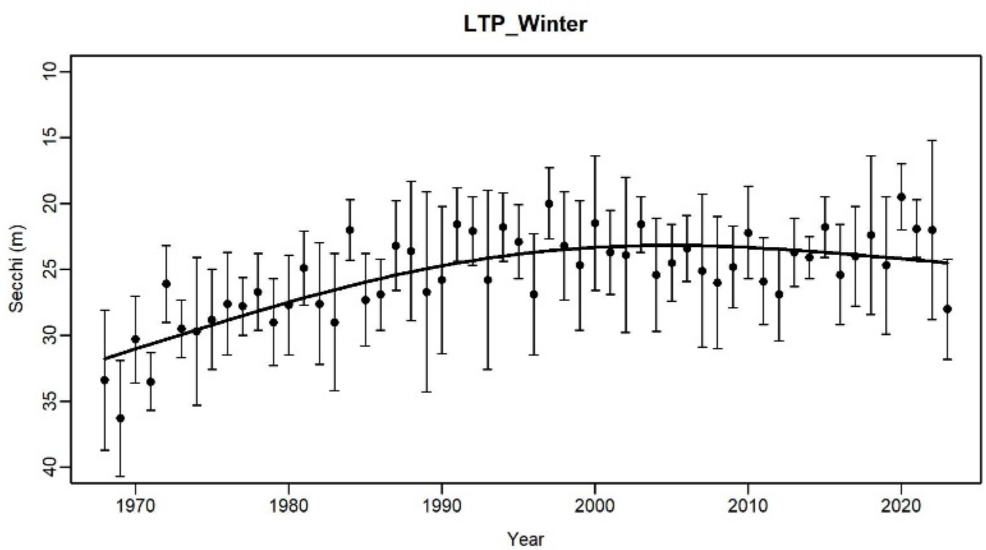


Fig. 2: Winter averaged Secchi disk measurements collected at LTP Station. The value for 2023 was 28.0 ± 3.3 m (91.8 ± 10.8 ft).

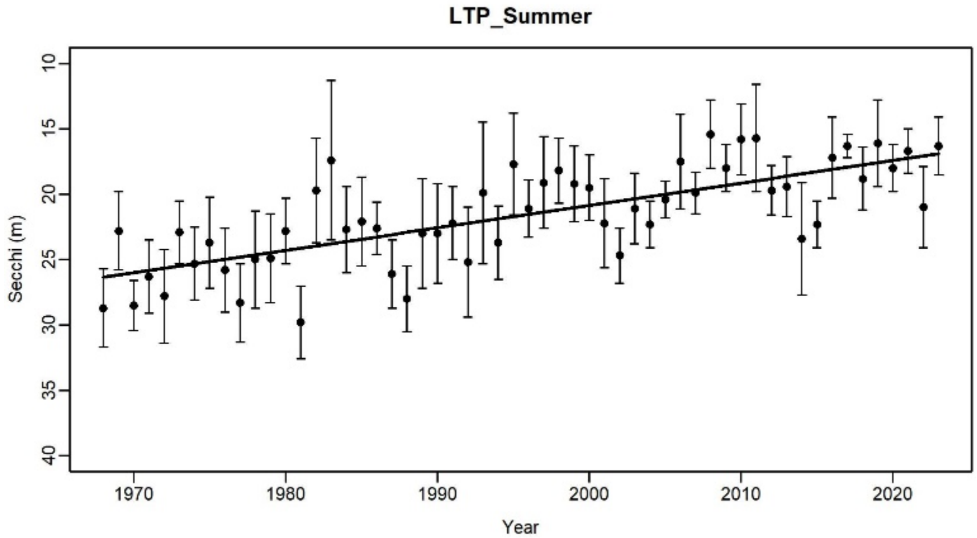


Fig. 3: Summer averaged Secchi disk measurements collected at LTP Station. The value for 2023 was 16.3 ± 2.2 m (53.5 ± 7.2 ft).

Compared to 2022, this represents a decrease in annual averaged values from 21.9 m to 20.8 m (-1.1 m), an increase in winter averaged values from 22.0 m to 28.0 m (+6.0 m) and a decrease in summer averaged values from 21.0 m to 16.3 m (-4.7 m).

3. Individual Measurements

Values are shown for the observation year (**Fig. 4** – blue solid circles) with values from the last 10 years shown for context (**Fig. 4** – gray solid circles).

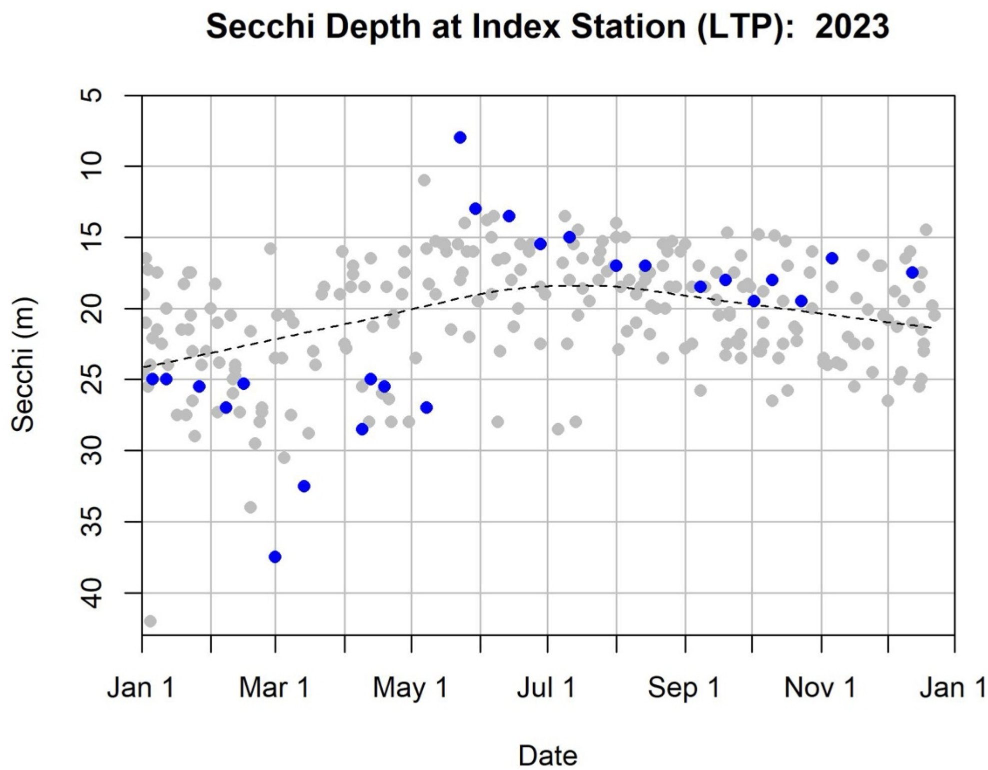


Fig. 4: Blue solid circles represent individual Secchi measurements at Index station (LTP) in 2023. Gray circles are those in last 10 years. Dashed line shows the averaged seasonal transition of Secchi in last 10 years (LOWESS fit).

Key observations from this plot include some individual record or near-record readings in Lake Tahoe occurring in 2023.

The minimum reading of 8 m (May 24, 2023) is the lowest ever recorded in the history of continuous Tahoe monitoring (since 1968). On this day, the field team remarked on how much greener the water appeared and that the zooplankton tows collected significant amounts of algae. A 'live' phytoplankton sample (an equal composite of water samples collected at 5 and 10 m water depth) was collected and analyzed by TERC using a light microscope 72h later. Observations of *Asterionella*, *Dinobryon*, *Staurastrum* and *Cosmarium* were recorded with these latter two species potentially contributing to the green color observed.

The highest reading of 37.5 m (March 2, 2023) is the twelfth highest in the historical record and the second highest in last 20 years after 42.0m (January 5, 2022). Full turnover occurred around February 26, 2023, and clearer water mixing from depth is a major driver of the high observed clarity.

The difference between maximum and minimum Secchi reading in a single year was 29.5 m and this is the third biggest difference recorded (highlighted below in **Table 3** and **Table 4**).

Table 3: Summary of top five years of biggest difference recorded (in meters)

Year	Secchi_Ave	Secchi_Min	Secchi_Max	Secchi_SD	Max-min difference
1983	22.4	8.5	38.5	6.9	30
1993	21.5	10	40	5.8	30
2023	**20.8**	**8**	**37.5**	**6.6**	**29.5**
2022	21.9	15.2	42	5	26.8
1989	23.6	14.5	41	5.9	26.5

Table 3: Summary of top five years of biggest difference recorded (in feet)

Year	Secchi_Ave	Secchi_Min	Secchi_Max	Secchi_SD	Max-min difference
1983	73.5	27.9	126.3	22.6	98.4
1993	70.5	32.8	131.2	19.0	98.4
2023	**68.2**	**26.2**	**123.0**	**21.6**	**96.8**
2022	71.8	49.9	137.8	16.4	87.9
1989	77.4	47.6	134.5	19.4	86.9

4. Particles Affecting Lake Clarity

Looking closely at the clarity values from 2018 – 2023 (**Figs. 5** and **6**), it appears that the rapid decrease in Secchi depth in May 2023 (highlighted in red – **Fig. 5**) corresponds to a rapid increase in lake particle concentrations in the 1-6.73 µm size range in the top 20 m of the water column (highlighted in red – **Fig. 6)**.

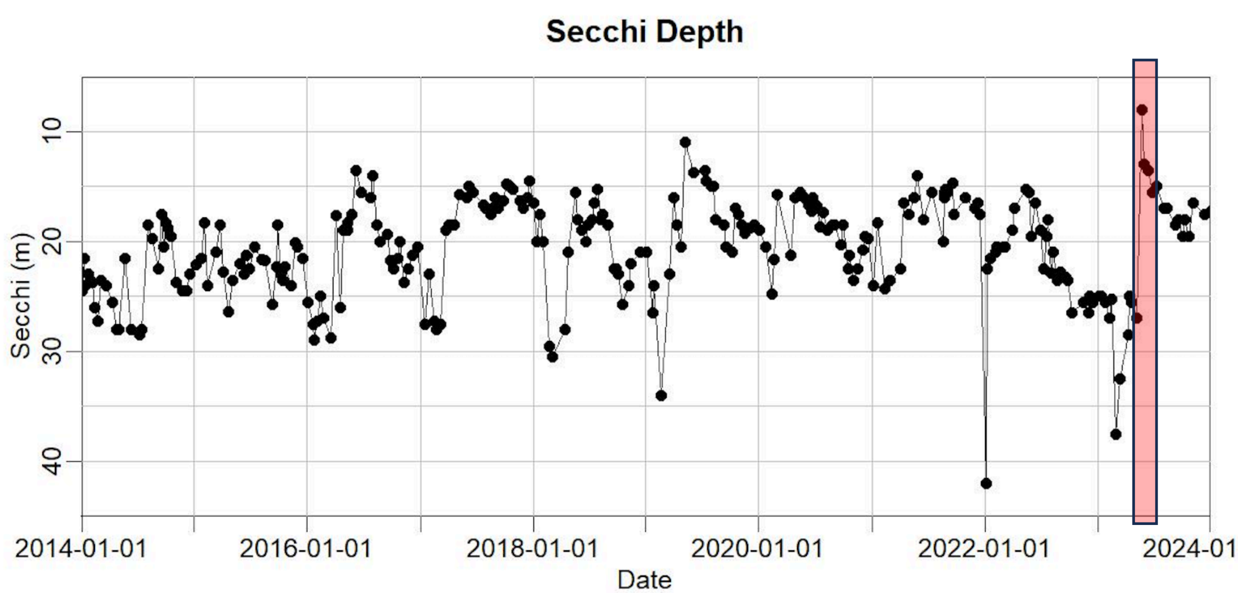


Fig. 5: Secchi measurements (in m) at Index station (LTP) from 2018 – 2023. The rapid decrease in clarity recorded on May 24, 2023, is highlighted in red for reference.

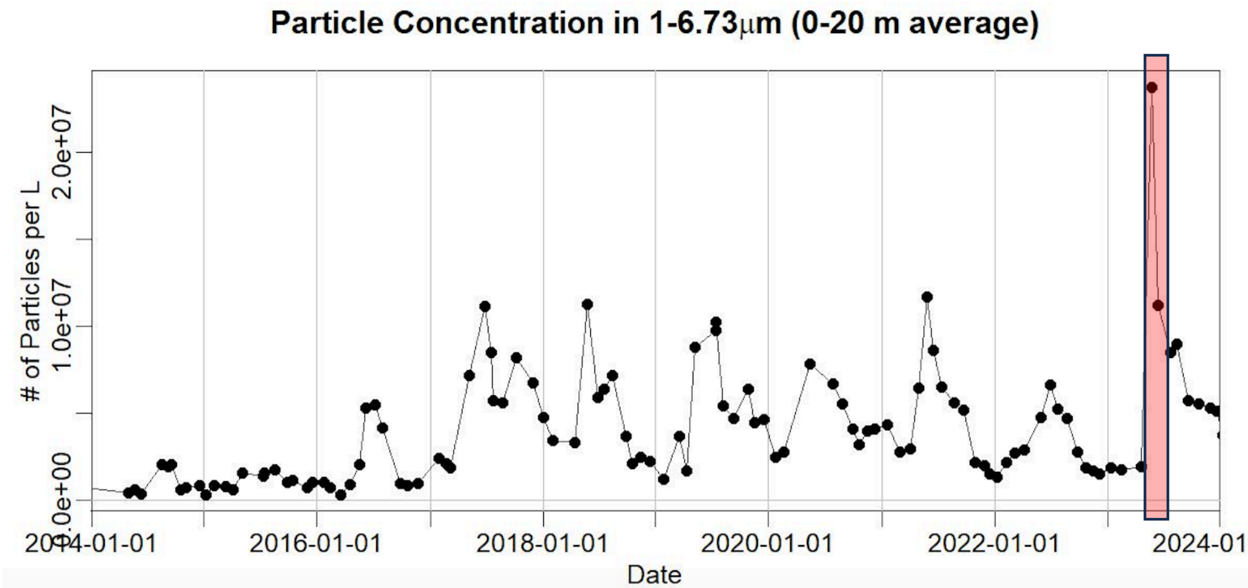


Fig. 6: Particle concentrations at Index station (LTP) from 2018 – 2023. The rapid increase in particles recorded on May 24, 2023, is highlighted in red for reference.

The concentration of 2.4 x 10^7 particles / L on May 24, 2023, was the highest ever recorded since valid measurements began in 2008. This value is double the previously recorded high value of 1.2 x 10^7 particles / L on June 23, 2020.

Receiving >100 cm of precipitation (**Fig. 7**), 2023 was a wet year similar to 2019 but not abnormally wet (e.g. 2017). Annual averaged streamflow from Blackwood Creek (**Fig. 8**) displays similar results. Blackwood Creek is the closest observation station to LTP and was chosen as a proxy for other streams in the drainage.

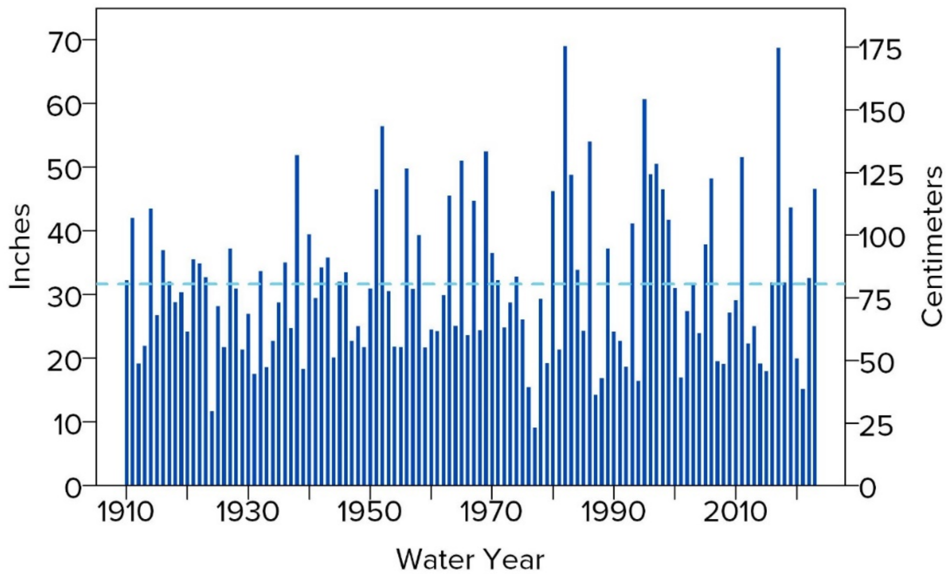


Fig. 7: Observed precipitation at Tahoe City from 1910 – 2023.

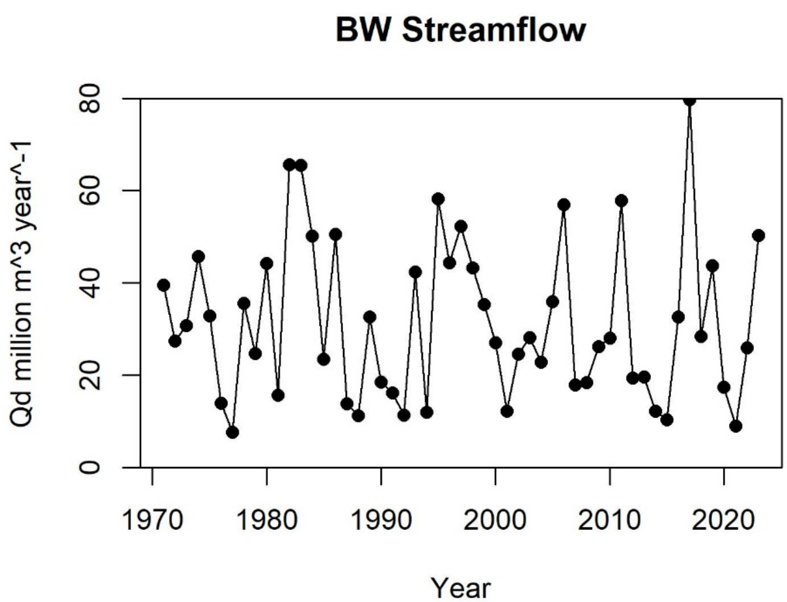


Fig. 8: Observed streamflow in Blackwood Creek from 1970 – 2023.

Observations of instantaneous streamflow (**Fig. 9**), turbidity (**Fig. 10**) and particle count (**Fig. 11)** for Blackwood Creek show 2023 to be a significant year for turbidity and increased particles in the 1-6.73 µm size range.

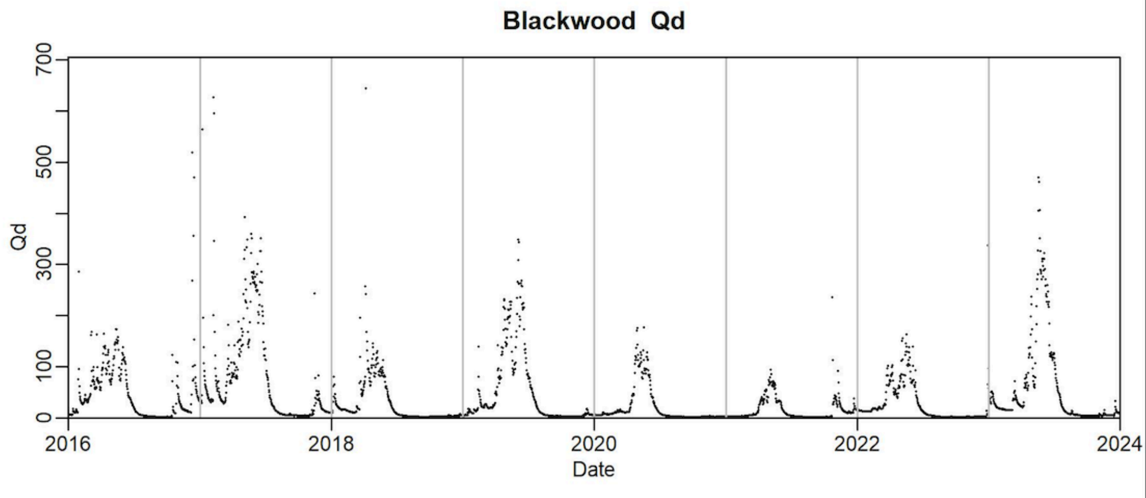


Fig. 9: Observed instantaneous streamflow (cfs) in Blackwood Creek from 2016 – 2023.

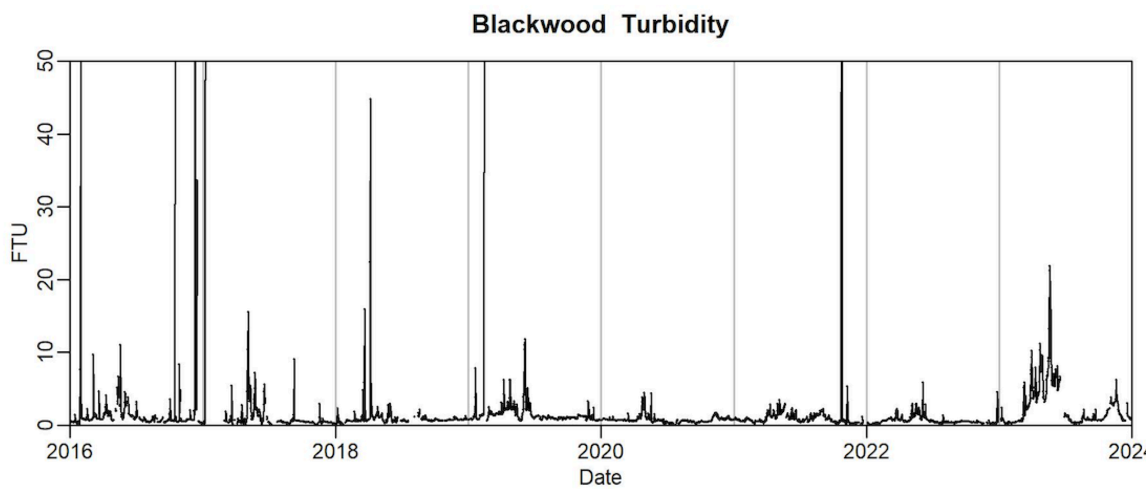


Fig. 10: Observed turbidity (FTU) in Blackwood Creek from 2016 – 2023.

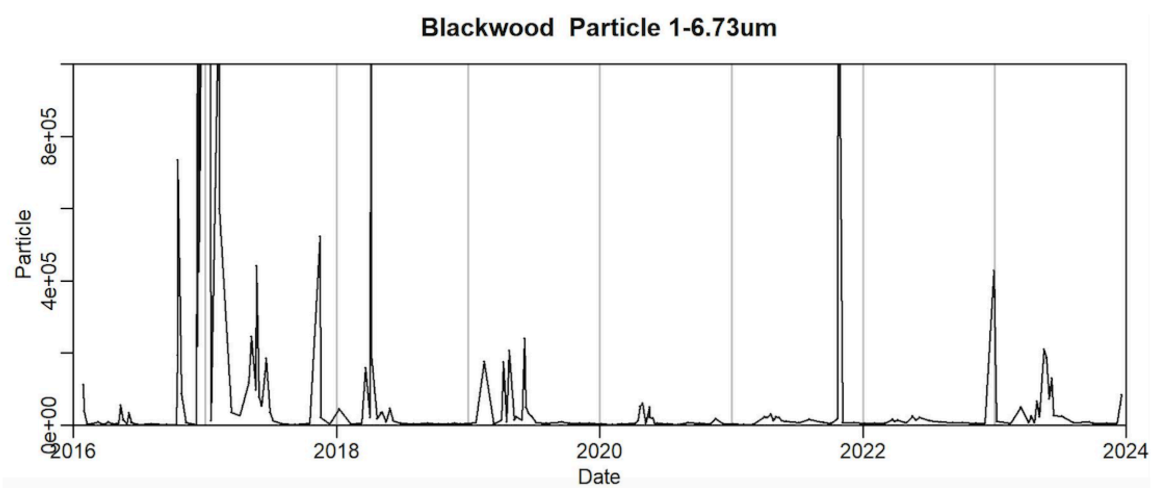


Fig. 11: Observed number of particles in the 1-6.73 μm size range in Blackwood Creek from 2016 – 2023.

5. Future Approaches to Understanding Lake Clarity

5.1 Evolving Background Conditions

Collected LISST-100X (an instrument using a scattering transmissometer measuring particles from 1-250 µm) vertical profiles at LTP from 2013 – 2020, show the total volume concentration (over the top 150 m) and the integrated total volume concentration (taken over the top 120 m) transitioning in 2015 through 2017 (**Fig. 12**). Since then, conditions have been relatively constant with intermittent spikes in the integrated total volume concentration that could be correlated with episodic events (e.g. run-off) in the catchment (McInerney, 2024). Similar trends are observed in the results from the Liquilaz (**Fig. 13**) for the same period.

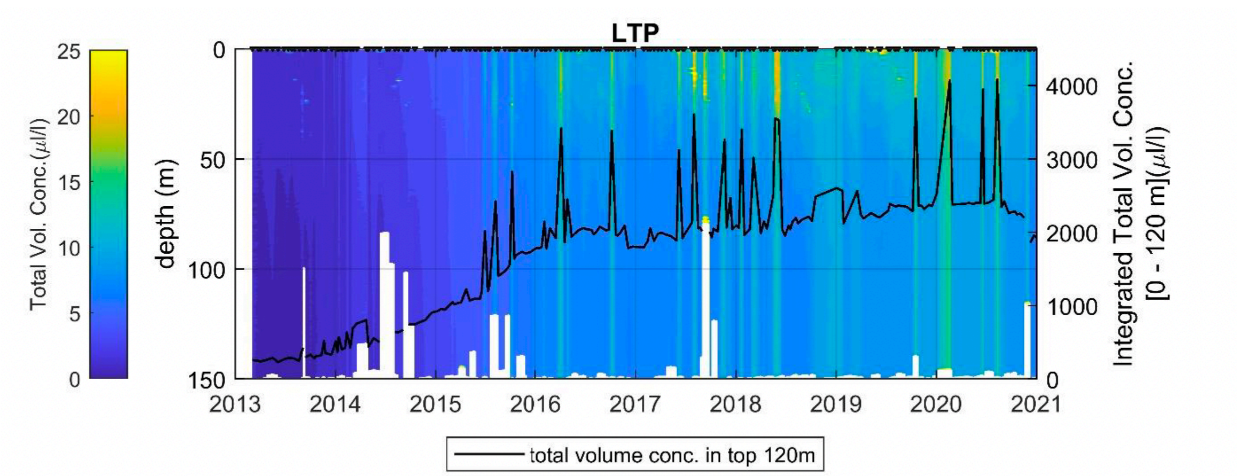


Fig. 12: Suspended particle volume concentration at LTP from LISST-100x profiles. Right axis: integrated total volume concentration integrated over 0 – 120 m depth.

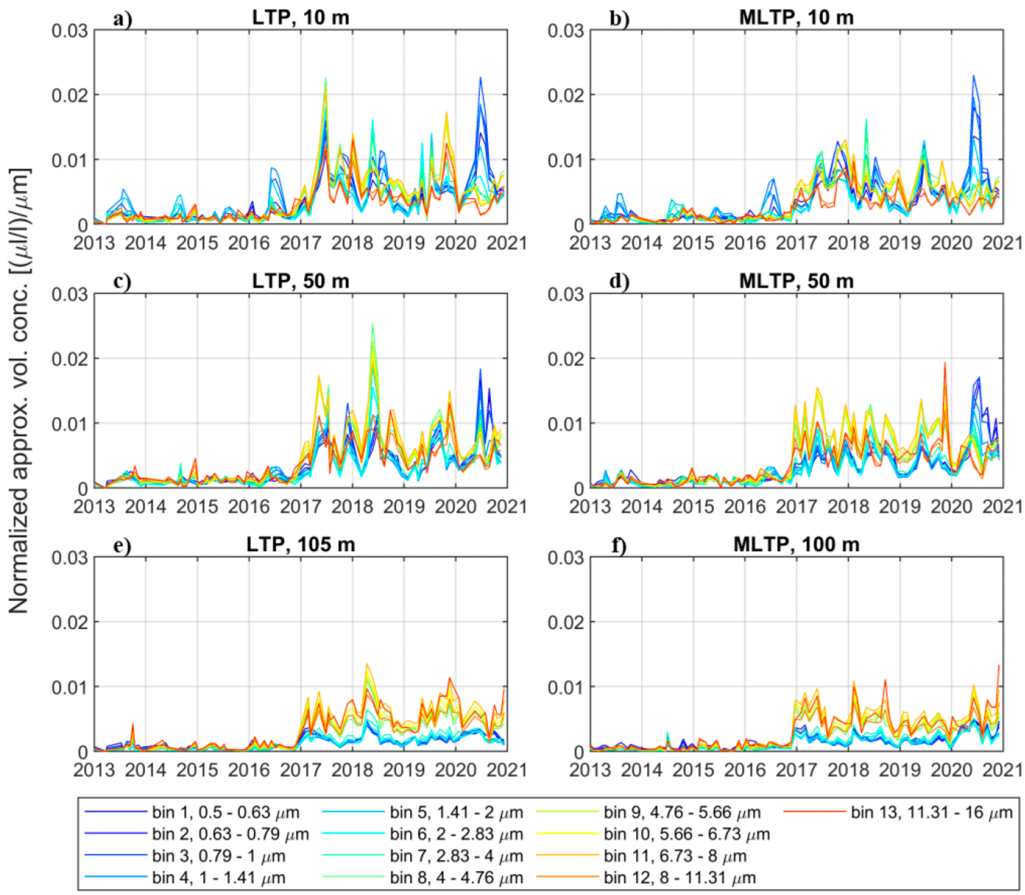


Fig. 13: Estimate of particle concentration normalized by bin width for small particles at 10, 50, and 100 m at LTP and MLTP stations.

To understand these evolving conditions UC Davis will be installing a Wirewalker system (https://www.delmarocean.com/) in 2024 to make continuous observations in the lake. This system is powered by wave energy to move up and down through the lake.

5.2 Changes in the Zooplankton Community

In recent years, much attention has been made to the role of *Mysis* in Lake Tahoe. While their relative contribution to on clarity will not be discussed here, it important to note that the decline in population numbers seen and reported in the 2022 Clarity Report have begun to show a slight recovery in early 2023 (**Fig. 14**). It should be noted that the numbers don't extend until the end of 2023 because there are still being analyzed by an external laboratory. There also appears to be a significant shift in both the cladoceran and copepod numbers which have not been seen in the last decade (**Fig. 15)**. This represents a change to the central trophic levels of the ecosystem and will require continued monitoring to quantify the long-term impacts on lake water quality.

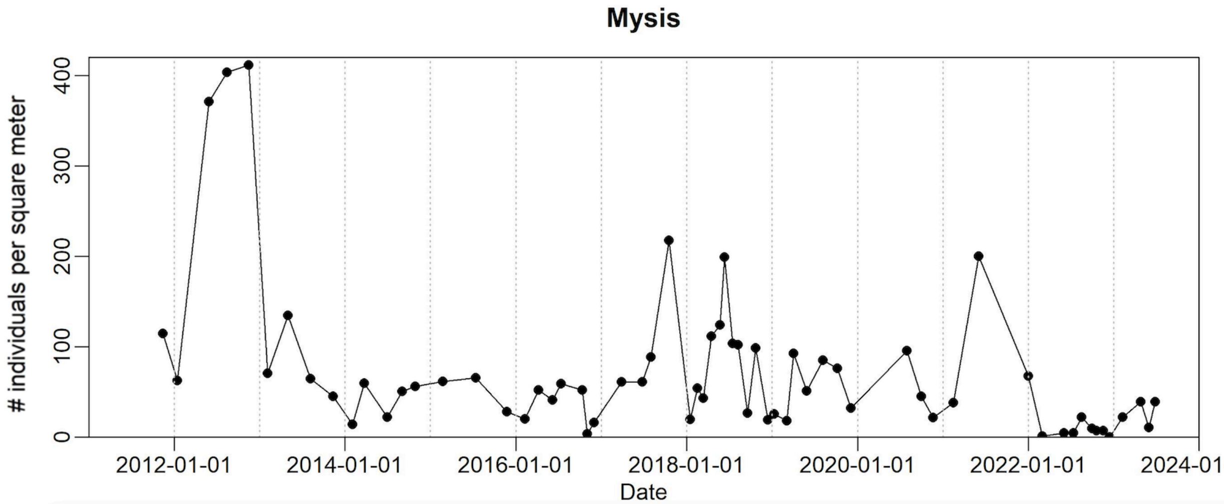


Fig. 14: Mysis density in Lake Tahoe from December 2012 to June 2023.

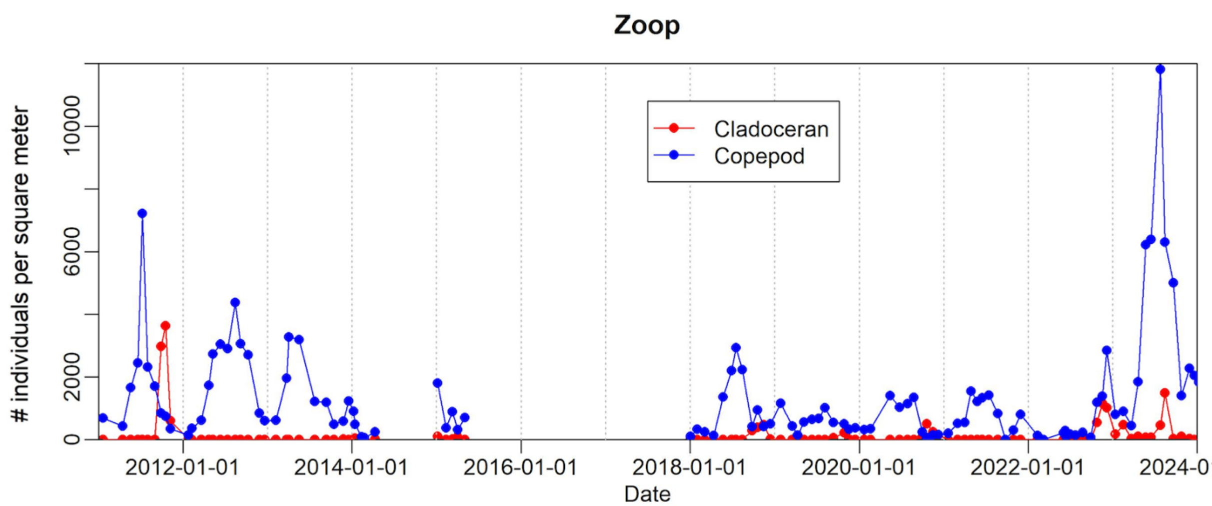


Fig. 15: Cladoceran and copepod densities in Lake Tahoe from December 2012 to December 2023.

5.3 Changes in the Phytoplankton Community

In addition to changes in the zooplankton community over the last several years are changes to the phytoplankton assemblage. Since 2017 there has been a significant shift in the dominant phytoplankton species (**Fig. 16**). While *Cyclotella* is still present, which is known to impact clarity (e.g. Winder et al., 2009), there has been a notable increase in the *Synedra* population. While these diatoms are significantly larger (40 – 100 µm) than *Cyclotella* (5 – 7 µm), they may also be playing a role in the continued reduction in clarity during the summer months (McInerney, 2024).

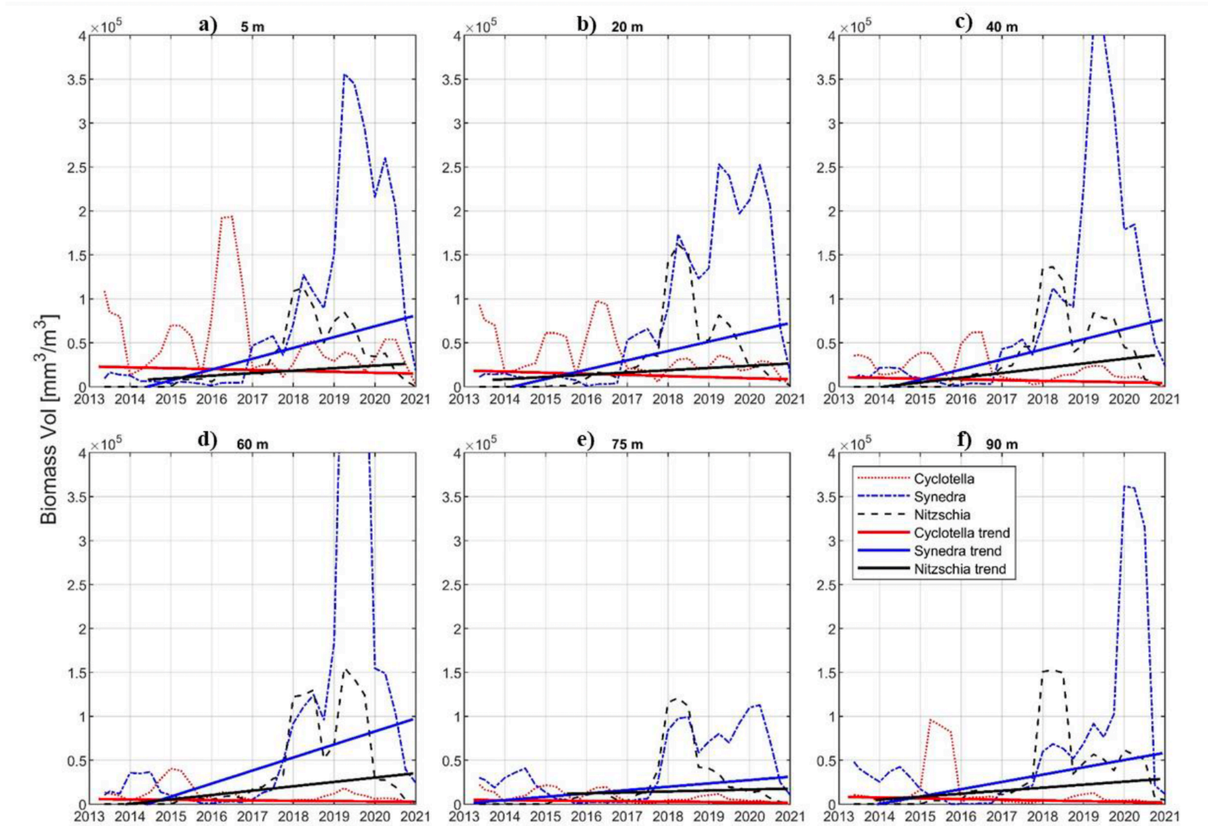


Fig. 16: Biomass volume (from cell counts) of dominant genus *Cyclotella* (red), *Synedra* (blue), and *Nitzschia* (black), at a) 5 m, b) 20 m, c) 40 m, d) 60 m, e) 75 m, and f) 90m.

5.4 Microplastics

A factor in lake clarity that remains a relative unknown is the role of microplastics. A recent paper by Koestner et al. (2024) demonstrated how the aqueous suspension of microplastics changes the inherent optical properties of freshwater and seawater. Recent work by UC Davis (Gjeltema et al., 2023) found that Lake Tahoe had nearly double the microplastic concentration (# / km^2) of other North American lakes surveyed from literature in larger size classes (e.g. 335 µm).

Breaking down the composition of the plastic types sampled resulted in observations of three main classes (polyethylene, polypropylene and polyesters; **Fig. 17**).

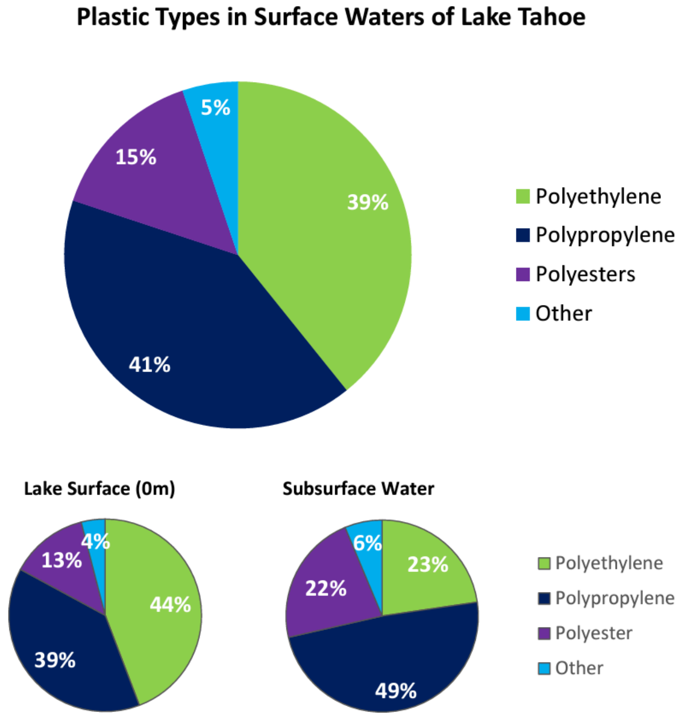


Fig. 17: Synthetic polymer (plastic) types of confirmed microplastic particles collected from surface and subsurface waters of Lake Tahoe (Gjeltema et al., 2023).

Collected samples were sieved to only yield particles greater than 335 μm, which is much larger than the size classes known to affect clarity (1 – 6 μm); however, observed concentrations of these larger size classes followed a similar seasonal trend (**Fig. 18**) as the particles being measured using the Liquilaz. Partitioning the relative contribution from natural and anthropogenic (e.g. microplastics) sources is necessary for future work.

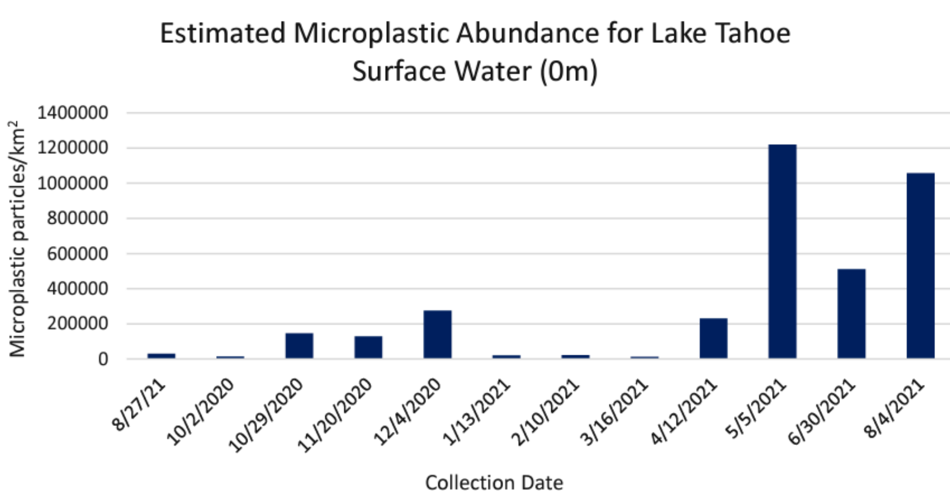


Fig. 18: Estimated microplastic particle abundance (> 335 μm) in the surface water of Lake Tahoe during the period of August 27, 2020, to August 4, 2021 (Gjeltema et al., 2023).

6. Conclusions

The results from the 2023 calendar year showed improvement in winter lake clarity and a decrease in summer lake clarity (as compared to 2022). High winter clarity for 2023 was related to an overturning event in February 2023. Low summer clarity for 2023 was related to observed high particle counts in the upper waters after a relatively high run-off year.

Understanding shifting physical and ecological conditions in Lake Tahoe is critical to understanding the long-term trends in the data. Future areas of lake clarity research should be focused on understanding the implications of ongoing changes to the zooplankton and phytoplankton communities and the addition of microplastics to the lake.

In addition to ongoing monitoring, the citizen science app run by UC Davis TERC scientists in collaboration with the League to Save Lake Tahoe and the Desert Research Institute is an effective tool for tracking changes and alerting new issues as they arise. This app can be downloaded here: https://tahoe.ucdavis.edu/citizen-science.

7. Acknowledgements

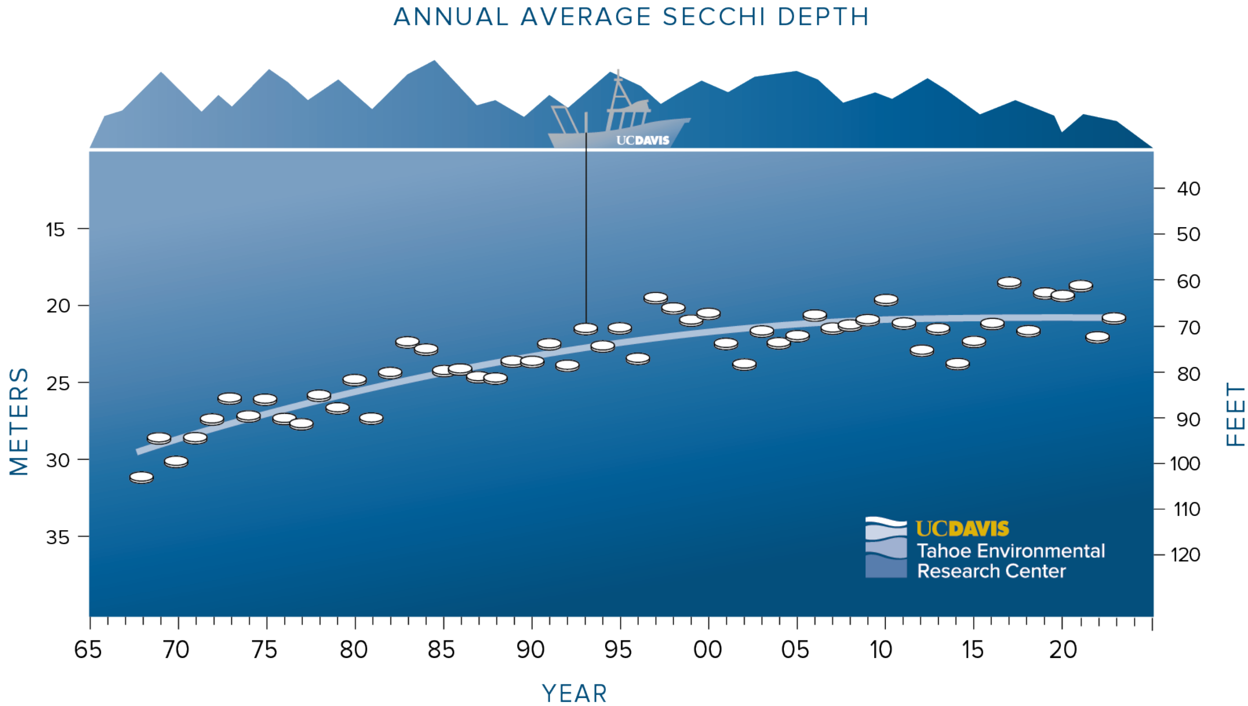
We acknowledge and thank the following TERC scientists:

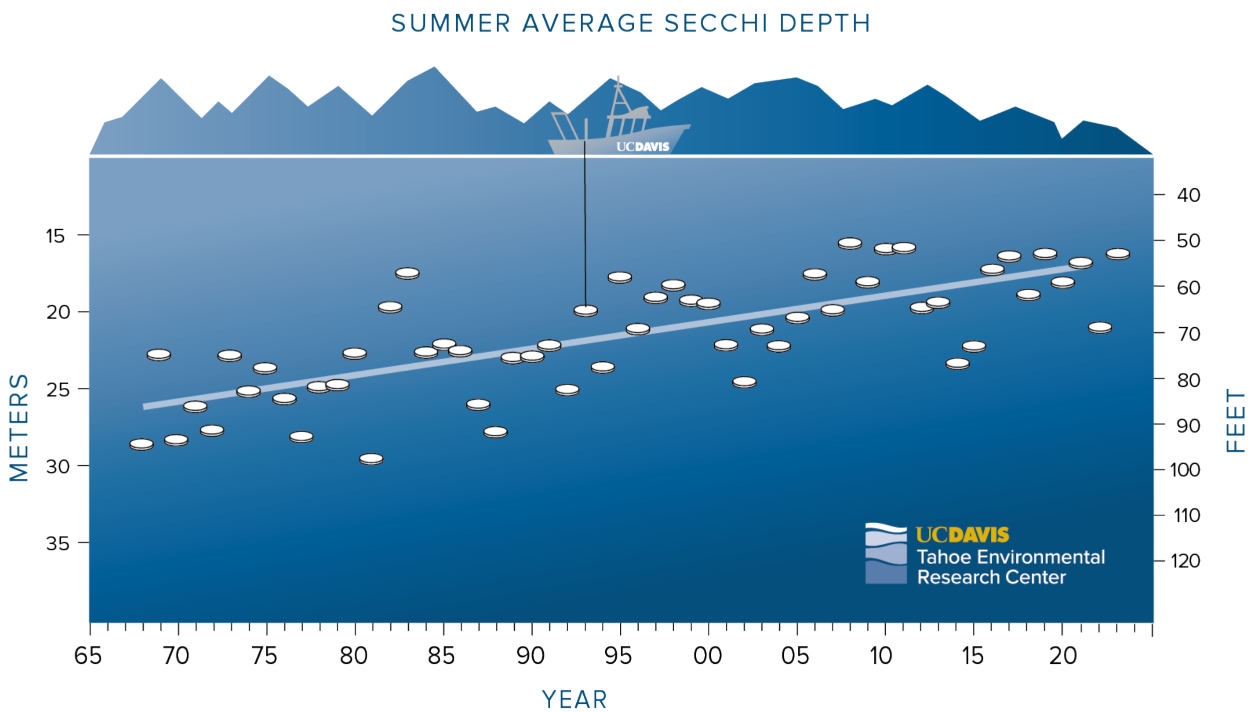
Field data collection (Brant Allen, Katie Senft, Brandon Berry, Michael Cane, Raph Townsend, Erik Young and Aaron Vanderpool)
Physical data analysis – Alicia Cortes and Sergio Valbuena
Particle size analysis – Aaron Vanderpool
Phytoplankton enumeration and identification – Lidia Tanaka
Zooplankton enumeration and identification – Katie Senft
Microplastics data (Katie Senft, Steven Sesma, Jenessa Gjeltema)

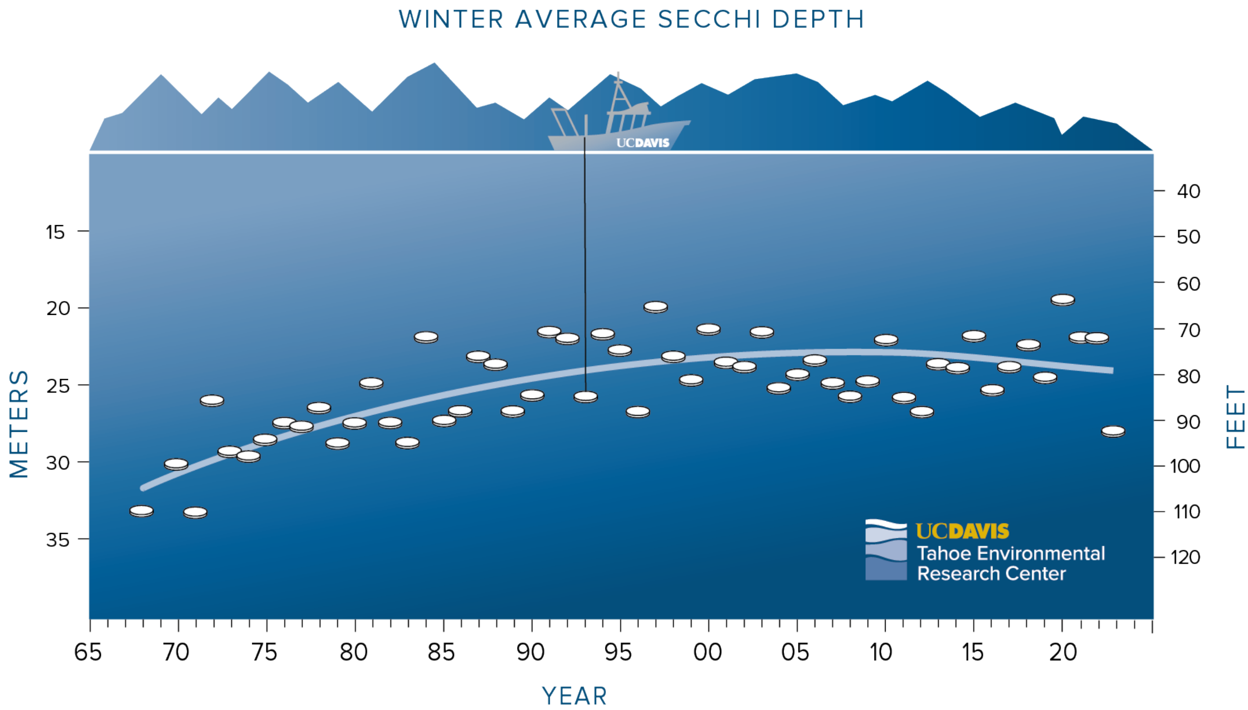
8. References

1. Gjeltema, J., Senft., K. Lang, J., Sesma, S. and Schladow, G. (2023). To Sink or Swim: A Snapshot Evaluation of the Fate and Types of Microplastics in Lake Tahoe. A Report to the Nevada Division of Environmental Protection.
2. Koestner, D., Foster, R., El-Habashi, A., & Cheatham, S. (2024). Measurements of the inherent optical properties of aqueous suspensions of microplastics. *Limnology and Oceanography Letters*.
3. McInerney, J. (2024). Capturing Spatial and Temporal Variability in Lake Processes with Autonomous Underwater Gliders (Doctoral dissertation, University of California, Davis).
4. Winder, M., Reuter, J. E., & Schladow, S. G. (2009). Lake warming favours small-sized planktonic diatom species. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1656), 427-435.

Appendix A – Public Release Secchi Charts



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