2018 Project Abstract
For the Period Ending June 30, 2022

PROJECT TITLE: Assess and Develop Strategies to Remove Microscopic Plastic-Particle Pollution from Minnesota Water Bodies
PROJECT MANAGER: Lian Shen
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 04b as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

APPROPRIATION AMOUNT: $300,000
AMOUNT SPENT: $300,000
AMOUNT REMAINING: $0

<u>Sound bite of Project Outcomes and Results</u>

We performed a comprehensive study on the motions of microscopic plastic-particle in water flows. Extensive experiments utilizing innovative imaging techniques on laboratory apparatuses, assisted by state-of-the-art simulations on supercomputers, have been conducted. Valuable data have been collected and analyzed for addressing the plastic pollution in Minnesota water bodies.

<u>Overall Project Outcome and Results</u>

The amount of plastic waste in lakes and rivers is projected to increase, driven by the rise in plastics consumption. New federal and state legislation has banned the sale of certain products containing micro-beads, but thousands of tons of micro-plastic pollution are already in our waters, and will take thousands of years to biodegrade. The objective of this project is to utilize the advanced facilities at the St. Anthony Falls Laboratory to carry out a series of experiments, and use powerful computation simulations to investigate the motions of microplastics.

In this project, we have carried out extensive laboratory measurements of the motion of spherical and non-spherical particles (fibers and disks) in water channel flows. We also conducted the first-ever field measurements of particles transported on the water surface of a small river facility in the Outdoor StreamLab at the St. Anthony Falls Laboratory. Despite the constraints posed by COVID-19 on our research. We have obtained valuable measurement data. Extensive analyses have been performed on the measurement data. We discovered that fibers tend to orient mostly in the streamwise direction while disks maintain their symmetry axis quasi-normal to the water bottom. The fibers undergo strong tumbling near the bottom in response to the mean shear and turbulent fluid velocity fluctuations, whereas the disks wobble about their preferential bottom-normal orientation. In this project, we have also developed an advanced computer simulation method for the motions of plastic particles in water flows. Our simulation can capture particle-particle interactions and particle-flow interactions with unprecedented realism and accuracy. We conducted numerical experiments using a supercomputer to study the effect of breaking waves on the surfaces of lakes and rivers on the transport of microplastics. Using computer simulation, we have also revealed the relationship between microplastic's preferential orientation in water waves and particle shapes. We have also elucidated the microplastics transport process through comparing the motions of spherical particles, oblate particles. and a mixture of both particles to quantify their transport characteristics in water bodies.

Through the research in this project, we have substantially improved the abilities to assess, track, and develop methods to remove microscopic plastic particles that are dispersed and accumulating as pollution in Minnesota water bodies. We have obtained valuable experiment data by using high-speed video recordings to track 42 floating objects in an outdoor stream laboratory. We have measured the motions of floating objects of different shapes and sizes that correspond to the typical pieces of plastic litters found in rivers and lakes. We directly compared their motions to those of millimeter-sized spheres that follow the water surface flows. We discovered that larger objects spread faster on the surface of water. The above results obtained in this project are important for assessing and tracking the motions and fate of microscopic plastic pollutions in the Minnesota lake waters driven by wind-induced currents. The data and analyses are also valuable for devising effective sequestration strategies for plastic pollutions in Minnesota river waters using physical tracking and removal based on the surface water flow information because they revealed the relationship between plastic litter motions and river flow speed.

Project Results Use and Dissemination

In this project, substantial efforts have been put into sharing the knowledge gained from the research. The findings of this project were presented at national conferences, such as the annual meetings of the American Physical Society, Division of Fluid Dynamics and the Fall Meetings of the American Geophysical Union. A paper has been published in the Journal of Fluid Mechanics ("Experimental investigation of inertial fibres and disks in a turbulent boundary layer" by Lucia Baker and Filippo Coletti, vol. 943, A27), which is a leading journal in the field.

Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2018 ENRTF Work Plan (Main Document)

Date of Status Update: October 31, 2022

Final Report

Date of Work Plan Approval: 06/05/2018

Project Completion Date: June 30, 2022

PROJECT TITLE: Assess and Develop Strategies to Remove Microscopic Plastic-Particle Pollution from Minnesota Water Bodies

Project Manager: Lian Shen

Organization: University of Minnesota

College/Department/Division: St. Anthony Falls Laboratory

Mailing Address: 2 Third Avenue SE

City/State/Zip Code: Minneapolis, MN 55414

Telephone Number: 612-624-2022

Email Address: shen@umn.edu

Web Address: https://fluids.umn.edu
http://www.safl.umn.edu/

Location: Statewide

Total Project Budget: $300,000

Amount Spent: $300,000

Balance: $0

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 04b as extended by M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18

Appropriation Language: $300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to assess, track, and develop methods to remove microscopic plastic particles that are dispersed and accumulating as pollution in Minnesota water bodies. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18. ENVIRONMENT AND NATURAL RESOURCES TRUST FUND; EXTENSIONS. [to June 30, 2022]

I. PROJECT STATEMENT:

The amount of plastic waste in lakes and rivers is projected to increase, driven by the rise in plastics consumption (about 9% per year worldwide). New federal and state legislation has banned the sale of certain products containing micro-beads, but thousands of tons of micro-plastic pollution are already in our waters, and will take thousands of years to biodegrade. Scientific reports indicate that the Great Lakes, including Lake Superior, and the basin of rivers in Minnesota are polluted with billions of tiny pieces of plastic, and a 2016 report from the Friends of the Mississippi River found high concentration of micro-plastics in the river's sediment in Minnesota. These consists of mm-sized micro-beads and micro-fibers used for cleaning and personal care products or shed from clothing, which slip through the water treatment plants. The largest fraction consists of beads and fibers less than 1 mm in size, used as abrasives in products for household cleaning and personal care, but also shed from synthetic clothes during washing. These are small enough to slip through the water treatment plants. The plastic waste can also break down due to mechanical stresses and UV radiation, or agglomerate in larger flocks of various shapes and density. Such diverse structure of the particles makes it hard to predict their capability of floating or settling, and ultimately their fate. Also, because the motion of particles is influenced by the level of turbulent fluctuations in the water, plastic pollution will have a very different behavior in lakes versus streams. The plastic particles attract toxic substances (like Polychlorinated Bi-Phenyl), vector of invasive species, and enter the aquatic food chain with potentially severe consequences for the ecosystem and the population.

Micro-plastics are insidious because they come in various shapes and sizes, may agglomerate in larger flocks, and behave differently in streaming water versus still water. Because of these complexities, today it is unknown how far they travel in the waterways, how much they float or sink, and ultimately where they end up. Also, because the motions of particles are influenced by the level of turbulent fluctuations in the water, plastic pollution will have a very different behavior in lakes versus streams. Without a systematic data collection and advanced transport models, it is impossible to set up effective strategies to prevent or mitigate the environmental impacts. Indeed, presently there is no established method to limit micro-plastic impact once they enter the water system. We hypothesize that the fundamental understanding of the physical mechanisms governing micro-particle transport in recirculating and streaming water flows can enable the prediction of their fate, and therefore indicate effective removal strategy.

Using the unique facilities at the St. Anthony Falls Laboratory, we will carry out a series of laboratory and field measurements, which will inform and validate advanced computational models. In the laboratory, we will use water channel facilities. The computer simulations will use models that we have successfully used to tackle numerous flow and transport problems in marine and coastal environments. In the field, we will consider both the artificial water stream at St. Anthony Falls Lab and one Minnesota river. We will use multiple portable cameras to image the transport of plastic particles which we will release and collected at downstream locations. For each experiment, we will collect twice as many particles as we release, therefore the environmental impact will be negligible. Our capability of collecting data will be expanded by enlisting Minnesota citizen-scientists, who can provide information from the bodies of water they visit or live by, by sending picture/videos. For this purpose, we will develop a free mobile app from which quantify concentration and accumulation of micro-plastics at the time and location the message was sent.

II. OVERALL PROJECT STATUS UPDATES:

First Update January 31, 2019

We carried out laboratory measurements of the motion of spherical and non-spherical particles (fibers and disklets) saltating on the floor of a water tunnel. We were able to image both particle motion and fluid motion using small tracers. We also conducted first field measurements of particles transported on the water surface of a small river facility in our Outdoor Stream Lab at SAFL. We used computer simulations to investigate the water flows near the lake surfaces and at the bottoms of lakes and rivers. On the study of lake surfaces, we obtained extensive data on the water flows in the presence of waves. On the study of river and lake bottom flows, we also obtained data on the water motions in the benthic boundary layers at the bottom of the water column.

Second Update October 30, 2019
We have analyzed the large amount of data from the laboratory measurements and are using that to inform and validate computer models of particle transport in turbulent water flows. We carried out extensive field measurements of the motion of spherical and non-spherical particles (rods and disks) floating on the surface of the water in the Outdoor Stream Lab, a small outdoor river facility at SAFL. This allowed us to obtain detailed flow velocity as well as particle trajectories. We scanned the river bed and obtained a high-resolution reconstruction of it. This is now being set up to carry out computer simulations of the water flow and particle transport under the same conditions. We have also developed new computational capabilities that allows us to resolve the fluid dynamics around individual particles.

Third Update May 27, 2020
We have analyzed data from the Outdoor Stream Lab, a small outdoor river facility at SAFL, and we have characterized the motion of tracers floating on the water surface. We have successfully measured the mean velocity, root-mean-square velocity fluctuations, and turbulent diffusivity coefficients for a range of bulk velocities. We can therefore use this data to validate simulations of various level of sophistication, from time-accurate Large-Eddy Simulations (LES) to Reynolds-Averaged Navier-Stokes (RANS) models. We have also carried out laboratory measurements of the motion of non-floating particles saltating on the floor of a water flume, and for those too we have obtained mean velocity, root-mean-square velocity fluctuations, and turbulent diffusivity coefficients for a range of bulk velocities.

Fourth Update March 11, 2021
Because of the COVID-19, laboratories at the University of Minnesota have reduced operations. As a result, there were no experiments performed in the past period. Our laboratory research effort was mainly on the analysis of the experimental data collected previously. The dynamics of millimetric sphere-, rod- and disk-shaped plastic particles were studied through the quantification of particle trajectories and orientations. Meanwhile, substantial progress has been made in the computer simulation research. We conducted numerical experiments using supercomputers to study the breaking waves on the surfaces of lakes and rivers and their effects on the transport and distribution of the microplastics. We obtained extensive simulation data of breaking waves and bubbles including the velocity field, bubble sizes and numbers.

Project extended to June 30, 2022 by LCCMR 6/30/21 as a result of M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 18, legislative extension criteria being met.

Fifth Update October 7, 2021
We continued to analyze the data from the Outdoor Stream Lab. We conducted the hydrodynamic characterization of the flow using the rivers bathymetry and acoustic Doppler velocimetry measurements. We have also characterized the scales of the free surface turbulence using the tracer data for a range of bulk velocities in a suitable sub-region of the flow. Moreover, we used computer simulations to reveal the relationship between microplastic's preferential orientation in water waves and particle shapes.

Sixth Update January 31, 2022:
We continued to study the experiment results of the motions of negatively buoyant disks and fibers in turbulent flows. Our experiments were set up to faithfully address the transport of plastic particles in water, with the values of density ratio, major axis lengths, friction Stokes numbers, and friction Reynolds number carefully chosen. We investigated the translational and rotational motions of disks and fibers, as well as their concentration and dispersion, and compared the results with those of spheres of similar inertia. In our computer simulation study, we continued to investigate particle interactions, which are important for the transport of microplastics in water. We developed an advanced method to model particle-particle interactions and obtained satisfactory results.

Final Update October 31, 2022
We performed computer simulations to study the effects of the shape of plastic particles on their transport in water flows. We compared the motions of spherical particles, oblate particles. and a mixture of both particles to quantify their transport characteristics in realistic water bodies where the conventional point particle model is not applicable, and obtained valuable insights into the microplastics transport process. We also continued the analysis of the previous experiment on the motions of inertial fibers and disks in turbulent flows. We discovered that fibers tend to orient mostly in the streamwise direction while disks maintain their symmetry axis quasi-normal to the wall. The fibers undergo strong tumbling near the wall in response to the mean shear and turbulent fluid velocity fluctuations, whereas the disks wobble about their preferential wall-normal orientation. A paper by Lucia Baker and Filippo Coletti titled "Experimental investigation of inertial fibres and disks in a turbulent boundary layer" has been published in the Journal of Fluid Mechanics, a leading top journal in the field.

Through the research in this project, we have substantially improved the abilities for assessing and tracking and helped the development of methods for removing microscopic plastic particles that are dispersed and accumulating as pollution in Minnesota water bodies. We have obtained valuable experiment data by using high-speed video recordings to track 42 floating objects of different shapes and sizes in an outdoor stream laboratory. We have measured the motions of centimeter-sized discs and rods, which correspond to the typical pieces of plastics found in rivers, and directly compared them to the motions of millimeter-sized spheres that follow the surface flow. We discovered that larger discs and rods spread faster on the surface of water. Our experiments were performed in a channel with meanders that model the natural river environments faithfully. The above results obtained in this project are important for assessing and tracking the motions and fate of microscopic plastic pollutions in the Minnesota lake waters driven by currents. The data and analyses on the relationship between plastic litter motions and river flow speed are also valuable for devising effective sequestration strategies for plastic pollutions in Minnesota river waters that use physical tracking based on the surface water flow information.

Amendment Request as of January 3, 2023

The total project budget is $300,000. The amount spent is $300,000. The balance is $0. In the sub-categories of the budget, there were small differences between the budget and expenditure as a result of the execution of the project, while the total is matched exactly. To make each sub-category also matched exactly, we request to adjust the personnel (wages and benefits) budget from $291,500 to $291,523, the equipment/tools/supplies budget from $1,500 To $1,370, and the capital expenditures over $5,000 budget from $6,000 to $6,107. The above adjustments were slight compared to the budgets, and the total amount of the project remains the same.

Amendment Request Approved as of February 2, 2023

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Perform laboratory measurements of plastic particle traveling in flowing water systems

Description:
This activity will develop foundational understanding of how plastic particles of different shape and size travel, float, and/or settle in streaming water under well-controlled laboratory conditions. Large flumes and water tanks at the St. Anthony Falls Laboratory will be used, reproducing a wide range of regimes occurring in natural water bodies. Tested particles will include plastic beads and fibers from commercially available products, which will be imaged while floating and settling using high-speed, high-resolution cameras

ENRTF BUDGET: $ 121,804

Outcome	Completion Date
1. Characterize micro-plastic transport in lab for varying particle type	June 2019
2. Characterize micro-plastic transport in lab for varying streaming water conditions	June 2020
3. Derive general relationship between transport velocities and physical parameters	January 2021

First Update January 31, 2019

In the past period we carried out measurements of the motion of spherical and non-spherical particles (fibers and disklets) in a water tunnel, using Particle Image Velocimetry. The particles were slightly heavier than water and therefore were saltating on the floor of the tunnel. We were able to image both particle motion and fluid motion using small tracers.

We also conducted first field measurements of particles transported on the water surface of a small river facility in our Outdoor Stream Lab at SAFL, using Particle Tracking Velocimetry We were able to measure thousands of particle tracks, which gave access to detailed flow fields. The particles were small enough to be considered tracers.

Second Update October 30, 2019

We have analyzed the large amount of data from the laboratory measurements and are using that to inform and validate computer models of particle transport in turbulent water flows. We carried out extensive field measurements of the motion of spherical and non-spherical particles (rods and disks) floating on the surface of the water in the Outdoor Stream Lab. We so obtained detailed flow velocity as well as particle trajectories, which we are now using to devise strategies for particle sequestration. We scanned the river bed and obtained a high-resolution reconstruction of it.

Third Update May 27, 2020

We have analyzed data from the Outdoor Stream Lab, a small outdoor river facility at SAFL, and we have characterized the motion of tracers floating on the water surface. We have successfully measured the mean velocity, root-mean-square velocity fluctuations, and turbulent diffusivity coefficients for a range of bulk velocities. We have also carried out laboratory measurements of the motion of non-floating particles saltating on the floor of a water flume, and for those too we have obtained mean velocity, root-mean-square velocity fluctuations, and turbulent diffusivity coefficients for a range of bulk velocities.

Fourth Update March 4, 2021

Because of COVID-19, the University of Minnesota has reduced operations in laboratories. As a result, there were no more experiments performed in the past period. Our research effort was mainly on the analysis of the data collected previously. The dynamics of millimetric sphere-, rod- and disk-shaped plastic particles in a saltation-suspension regime were studied in a turbulent boundary layer. Simultaneous, time-resolved flow fields, particle trajectories, and particle orientations were quantified using particle image velocity and particle tracking velocimetry in a paddlewheel-driven water channel. Statistics of particle velocity, particle acceleration, and fluid velocity interpolated at particle locations were computed to investigate particle interaction with the fluid turbulence and with the wall.

Fifth Update October 7, 2021

We continued to analyze the data from the Outdoor Stream Lab and have characterized the scales of the free surface turbulence using the tracer data for a range of bulk velocities in a suitable sub-region of the flow. We have found that the tracer's behavior on the free surface is consistent with the classic phenomenology of homogeneous three-dimensional turbulence in terms of the velocity and acceleration single-point and two-point statistics.

Sixth Update January 31, 2022

We continued to study the experiment data of the behavior of negatively buoyant disks and fibers in a turbulent boundary layer. The regime is relevant to the transport of plastic particles in water, with density ratio close to 1, major axis lengths approximately 50, friction Stokes numbers nearly 10, and friction Reynolds number 620. The translational and rotational motion, as well as concentration and dispersion, were studied in detail through comparison with those of spheres of similar inertia.

Final Update October 31, 2022
We continued the analysis of previous experiment data of inertial fibers and disks in turbulent flows. We found that disks and fibers both oversample high-speed fluid near the wall, in agreement with particle-resolved numerical simulations. Fibers tend to orient mostly in the streamwise direction while disks maintain their symmetry axis quasi-normal to the wall. This alignment is more stable for disks than for fibers: the latter undergo strong tumbling near the wall in response to the mean shear and turbulent fluid velocity fluctuations, whereas the former wobble about their preferential wall-normal orientation.

ACTIVITY 2: Perform computer simulations of micro-plastic transport processes in fluvial environments
Description:
We will incorporate the findings of Activity #1 into an advanced numerical model to simulate the transport of particles through stagnant, circulating, and streaming water. The relationship for the particle transport velocities as function of flow regime and particle characteristics will be implemented in our high-resolution computer model, for which we will be using the super-computer capabilities available at the St. Anthony Falls Laboratory and at the Minnesota Supercomputing Institute. After validating the model for idealized conditions that replicate the laboratory experiments, we will use the real topography and volume flow rates of the Outdoor Stream Lab and one Minnesota river.

ENRTF BUDGET: $ 132,051

Outcome	Completion Date
1. Validate computational simulations of particle transport against lab measurements	June 2020
2. Perform predictions of the transport of plastic particles in real river settings.	January 2021
3. Identify locations of accumulations enabling effective strategies for removal	June 2021

First Update January 31, 2019
In the past period, we used computer simulations to investigate the water flows near the lake surfaces and at the bottoms of lakes and rivers. This study is important for the understanding of the motions of microplastics in aquatic environments. Water surface and water bottom are two important regions for the study of the fate of microplastics. On the study of lake surfaces, we have obtained extensive data on the water flows in the presence of waves, which is an important factor to consider in the natural environment of Minnesota in the presence of winds. On the study of river and lake bottom flows, we have also obtained substantial data on the water motions in the benthic boundary layers at the bottom of water column.

Second Update October 30, 2019
The real topography and volume flow rates of the Outdoor Stream Lab have been incorporated in a numerical model, which will be run to reproduce the water flow and particle motion, and validated against the field measurements. This is now being set up to carry out computer simulations of the water flow and particle transport under the same conditions. We have also developed new computational capabilities that allows us to resolve the fluid dynamics around individual particles. This leverages large clusters of supercomputers in order to capture the physics over an exceptionally large range of scales (from the particle to the river).

Third Update May 27, 2020
We are using the measurements in both the Outdoor Stream Lab and the laboratory flume to validate numerical simulations obtained at matching regimes based on the computational platform previously developed. In

particular, we are seeking to match the mean velocity, root-mean-square velocity fluctuations, and turbulent diffusivity coefficients for a range of bulk velocities.

Fourth Update March 4, 2021
We conducted numerical experiments using supercomputers to study the breaking waves on the surfaces of lakes and rivers. Understanding the breaking waves and the bubbles created by the wave breaking is important in this project because they have significant effects on the transport and distribution of the microplastics. For example, in the wave breaking process, the strong wave motion breaks the wave surface and brings the microplastics near the lake surface downward into a deeper region. Moreover, the bubbles created by the breaking waves rise up to the wave surface due to buoyancy, during which process they bring the microplastics inside the lake water to the lake surface. In the research of this period, we obtained extensive data of breaking waves and bubbles including the velocity field, bubble sizes and numbers. We have also interpreted the data using the fluid dynamic fundamental theory.

Fifth Update October 7, 2021
We examined the tracer microplastics in canonical wave motions. In the simulation, microplastics were treated as tracer particles with spheroid shapes. The spheroids we considered using this model cover a wide range of shapes, and they represent the microplastics in the real water environment well. We focused our study on the orientation of the microplastic particles under wave motions.

Sixth Update January 31, 2022
We continued to investigate particle interaction process, which is essential to the transport of microplastics in water. We developed a method to model particle-particle interactions. Collisions between particles are modelled by a linear spring-dashpot system. The Adaptive Collision Time Model is employed to calculate the contact force. We performed extensive tests and found satisfactory performance.

Final Update October 31, 2022
Considering that the shape of plastic particles plays an important role in the fluid-particle interactions, we performed numerical simulations of particle transport for spherical particles, oblate particles and a mixture of both particles. These numerical tools enable us to quantify the motions of plastic particles in realistic water flows where the conventional point particle model is not applicable, providing further insights into the microplastics transport process.

ACTIVITY 3: Collect field data and engage citizen-scientists
Description:
We will perform field measurements of plastic particles transport, in the same water bodies investigated by numerical simulations in Activity #2. We will place plastic particles of known size and shape (as used in laboratory experiments and computer simulations) and image them with multiple cameras at various downstream stations. We will use few tens of particles per type, which we will collect with trawls at the downstream locations. After comparing with the simulations, we will use the validated computational tool to provide general guidelines to predict transport and fate of the various particle types. These will be tested through the particle release/collection process. Our capability of collecting data will be greatly expanded by enlisting Minnesota citizen scientists. This will be facilitated by diffusing a free mobile app with which any user can send images and videos from which quantify concentration and accumulation of micro-plastics at the time and location the message was sent.

ENRTF BUDGET: $ 46,145

Outcome	**Completion Date**
1. Measure micro-particle transport in real river settings.	June 2020
2. Validate computational simulations of particle transport against field measurements	January 2021

3. Increase public awareness by engaging citizen scientists using mobile app	June 2021

First Update January 31, 2019
The activity has not begun yet.

Second Update October 30, 2019
The activity has not begun yet.

Third Update May 27, 2020
The activity has not begun yet.

Fourth Update March 11, 2021
The activity has not begun yet. Because of COVID-19, the University of Minnesota has restrictions on laboratories and field work.

Fifth Update October 7, 2021
No activity to report because of the restriction by COVID-19.

Sixth Update January 31, 2022:
No activity to report because of the restriction by COVID-19.

Final Update October 31, 2022
Due to constraints of COVID-19, we analyzed the experiment data of inertial fibers and disks in a turbulent boundary layer and the outdoor streamlab instead, which resembles the natural riverine setting closely and serves the same scientific goal of studying the transport of plastic particles in natural environment. We discovered that the translational and rotational accelerations of fibers and disks indicate that, despite the nominal relaxation times being similar, the disks are slower than the fibers in responding to wall turbulence. For both, wall contact causes strong and intermittent tumbling. The concentration profiles follow the Rouse-Prandtl theory over a limited portion of the boundary layer, deviating near the wall and in the outer region. This is largely due to the non-uniform settling velocity, which decreases steeply approaching the wall for all particle types. This is, in turn, a consequence of the reduced particle diffusivity, which closely matches the profile of the eddy viscosity.

IV. DISSEMINATION:

Description:
The scientific and societal outcomes of the proposed projects will be a prediction tool on the transport of micro-plastics in Minnesota rivers and lakes, which can be used by State agencies. The collected data will be shared with federal and state agencies through a user-friendly web interface, providing guidelines to wisely allocate resources to remove the pollution and mitigate the ecologic impacts. Additionally, we will hold virtual workshops to help agency members familiarize with the tools developed in this project. The research findings will be disseminated through presentations, and local media outlets, and will be leveraged in educational efforts including the SAFL outreach program towards middle school students from Native American tribes in northern Minnesota.

First Update January 31, 2019

Second Update October 30, 2019
A paper was published in the Journal of Fluid Mechanics based on the first laboratory measurements supported by this project.

Third Update May 27, 2020
A second paper was submitted in the Journal of Fluid Mechanics based on the laboratory flume measurements supported by this project. Results were also presented at the meeting of the American Physical Society – Division Fluid Dynamics, held in November 2019 in Seattle, WA.

Fourth Update March 11, 2021
Lucia Baker and Filippo Coletti gave a virtual presentation entitled "Effects of shape on microplastic particle–fluid–wall interaction and transport in a turbulent boundary layer" at the American Geophysical Union Fall Meeting in December, 2020.

Fifth Update October 7, 2021
Henri Sanness Salmon completed his Master's Degree thesis entitled "Effect of shape and size of the transport of particles over the turbulent free surface of a natural stream" and gave a presentation on August 24, 2021. The thesis is archived in the library of University of Minnesota.

Sixth Update January 31, 2022
Lucia Baker and Filippo Coletti submitted a manuscript titled "Experimental investigation of inertial fibres and disks in a turbulent boundary layer" to the Journal of Fluid Mechanics for publication.

Final Update October 31, 2022
After being reviewed and a revision, the paper by Lucia Baker and Filippo Coletti titled "Experimental investigation of inertial fibres and disks in a turbulent boundary layer" has been published in the Journal of Fluid Mechanics, which is a top journal in the field.

V. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview: See attached budget spreadsheet

Explanation of Capital Expenditures Greater Than $5,000: Six portable digital cameras will be used to record presence and motion of plastic particles at various locations along the considered river. This is the bare minimum number of cameras needed to document the presence and traveling velocity of particles over a significant river segment. The imaging resolution and frame rate need to be sufficient to detect the particles and track their speed. Commercial cameras with such capabilities are listed at about $1,000.

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: 8,528	Divide by 2,080 = TOTAL FTE: 4.1

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:

Enter Total Estimated Personnel Hours: N/A	Divide by 2,080 = TOTAL FTE: N/A

B. Other Funds: N/A

VI. PROJECT PARTNERS: N/A

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The scientific and societal outcomes of the proposed projects will be a powerful tool to reduce plastic water pollution, in that it will inform state agencies on where and how to remove harmful micro-plastics from our waters. The collected data will be shared with federal and state agencies through a user-friendly web interface, providing guidelines to wisely allocate resources to remove the pollution and mitigate the ecologic impacts. The information will be used to inform consumers' choice, support legislative action, and influence corporate responsibility, ultimately preserving the aquatic ecosystem and population of Minnesota. Further funding to extend the scope of this work will be sought through the National Science Foundation, the U.S. Geological Survey, and the National Institutes for Water Resources, which all supports annual call for proposals to focus on water quality problems.

VIII. REPORTING REQUIREMENTS:

- **The project is for 4 years, will begin on July 1 2018, and end on June 30 2022.**
- **Periodic project status update reports will be submitted January 31 and June 30 of each year.**
- **A final report and associated products will be submitted between June 30 and October 31, 2022.**

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
D. Research Addendum (internally peer-reviewed by U of M specialists)

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2018 Budget Spreadsheet

Project Title: Assess and Develop Strategies to Remove Microscopic Plastic-Particle Pollution from Minnesota Water Bodies

Legal Citation: M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 04b
Project Manager: Lian Shen
Organization: University of Minnesota
College/Department/Division: St. Anthony Falls Laboratory
M.L. 2018 ENRTF Appropriation:
Project Length and Completion Date: 4 years, June 30, 2022
Date of Report: October 31, 2022

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	**TOTAL BUDGET**	**AMOUNT SPENT**	**TOTAL BALANCE**
BUDGET ITEM			
Personnel (Wages and Benefits)	$291,523	$291,523	$0
1 graduate student at 50% FTE for 3 years; 1 postdoctoral fellow at 100% FTE for 2 years; 1 technician at 12.5% FTE for three years; previous PI Filippo at 5% FTE for 3 years; PI Lian Shen at 3% for 3 years.			
Equipment/Tools/Supplies	$1,370	$1,370	$0
Supplies for laboratory and field measurements			
Capital Expenditures Over $5,000	$6,107	$6,107	$0
Portable cameras for particle imaging			
Travel expenses in Minnesota	$1,000	$1,000	$0
Field deployment on a river in Minnesota			
COLUMN TOTAL	**$300,000**	**$300,000**	**$0**