Task 4. Request for Proposals: Detecting and Quantifying Microplastics in Reservoirs

Task proposed by Dell Technologies

Task developed by Dell Technologies and NMSU Aquatic Ecology Department

Background

One of the primary challenges in mitigating microplastics pollution is the ability to detect and quantify microplastic particles in a large body of water. Your team is challenged to find a solution to this task that can be widely used for mitigation of microplastics in reservoirs.

Microplastics in Reservoirs

A 'reservoir' is defined as a large natural or artificial lake often used as a source of drinking water. Lebreton, el al., [1] found that dams, weirs, and other artificial barriers in freshwater systems catch and retain 65% of plastic waste before it can reach the oceans. By focusing microplastic mitigation efforts on reservoirs, we could make a significant positive impact on the presence of microplastics in our supplies of fresh water and reduce plastic pollution before it can be further distributed around the globe. Targeting reservoirs also proves a more tractable problem than attempting mitigation in the world's vast oceans.

Threat of Microplastics

Concern is on the rise for microplastics and nanoplastics in environmental media, including water, soils, and air. Microplastics have been found to alter human chromosomes, leading to infertility, obesity, and cancer [2]. Microplastics tend to accumulate in the gut of mammals, causing inflammation. Particles <150 microns are able to cross the mucous layer, and nanoparticles can penetrate into organs (liver, heart, lungs, reproductive organs, brain, etc.) [3]. In aquatic life, microplastics have been found to adversely affect the immune system, reproductive system, nervous system, and endocrine system [4].

Microplastics found in the environment have undergone degradation that affect their properties. They tend to have large specific surface area, low polarity, and be hydrophobic. These properties cause the them to attract and develop coatings of persistent organic pollutants (POPs) such as DDT, PCBs, PAHs, and BPA. The microplastics also develop coatings of PFAS, antibiotics, and heavy metals [4]. Environmental degradation can cause highly oxidized plastics to develop functional groups that further attract POPs and metals to their surfaces. All of these coatings are in much higher concentrations than found in ambient waters, indicating significant potential harm to the food web if microbiota ingest the coatings [5].

Characteristics of Microplastics in the Fresh-water Reservoir Environment

From a data set of 440 samples collected from 43 reservoirs worldwide, Guo et al. [6] determined that over 60% of microplastics in reservoirs are small-sized items (< 1 mm in diameter). The water and sediments in the reservoirs have been found to contain anywhere from 0.28 to almost 182,000 microplastic items/m^3, with an average of about 10,000 items/m^3.

Microplastic particle counts will underestimate the quantity of microplastics entering a body of water by 30-40% because ingestion of the particles by aquatic creatures is not accounted for in studies using water-filtration to count the number of microplastic items in the water. In addition, most research has focused on surface sampling, further causing underestimation of microplastics (see below).

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The most frequently identified polymer types in the 43 reservoirs studied are degraded PET (Polyethylene Terephthalate), PE (Polyethylene), and PP (polypropylene), with shapes being predominantly fibers and fragments, with a few pellet-shaped particles, and colors predominantly transparent and colorless, followed predominantly by blue, and then brown, white, black, and other colors. Each attribute listed above is ordered from highest to lowest frequency [6].

As noted earlier, microplastics found in the natural environment have almost always undergone degradation. The primary mechanisms for degradation are photo degradation and thermal-oxidative degradation. Degradation results in a chemical change in plastics, reducing their molecular weight, increasing the brittleness of their surface, and creating oxidative functional groups.

It is likely that most microplastics are created through degradation of larger plastic particles while on land, such as beaches. After they reach the aquatic environment, degradation significantly decreases due to reduced temperatures and reduced exposure to oxygen. In addition, in water, protective bio-films accumulate on the particles, further protecting them from degradation [3].

Reservoir Layers

Reservoirs in the temperate zone consist of three layers during the summer. The epilimnion is the top layer and consists of the warmest water. The middle layer is the metalimnion. It will be discussed in more detail below. The bottom layer is called the hypolimnion. It is consistently 4°C.

In the metalimnion, the temperature changes at least 1°C/meter. Thus, the water density gradient is strongest here, favoring the accumulation of particles (e.g., algae, microplastics etc.) within this layer. Supporting this, Guo, et al. [6] reported that for a study in which all three layers were sampled, the highest number of microplastic items were found to be in the metalimnion.

Interestingly, a large number of studies that quantify the presence of microplastics in reservoirs collect their samples by skimming the top of the water with a fine filter, resulting in an underestimation of microplastic quantities during the summer months.

With the change in weather during spring and fall, the reservoir temperature stratification becomes unstable, the entire reservoir will turn over, and the same water temperature will exist at the bottom and the top of the reservoir. Thus, although microplastics are found at all depths in the world's reservoirs, the best strategy for quantifying maximum amounts of microplastic particles, and of eliminating microplastics from a reservoir, will be during the summer in the metalimnion.

Needs in Microplastics Research

The three most pressing research issues for microplastics in reservoirs are 1) detection and quantification, 2) treatment and capture, and 3) developing microplastic particles for use in research.

Solving the detection and quantification issue is the first step needed before treatment can be addressed. Your team is challenged to develop a detection/quantification solution that can be used in field studies of reservoirs to detect and quantify microplastics in real time or near-real time. There are a few detection systems on the market, but cost or ease of use limit their practicality in field work.

The third research challenge addresses the issue of weathering and degradation of microplastics for use in research. When found in nature, microparticles and microfibers have experienced weathering, oxidation, UV exposure, saline environments, mineralization, biotic fouling, etc. Therefore, one cannot simply grind primary plastics into small particles and expect them to have the same properties as microplastics found in nature. For the purpose of this task, WERC will address issue #3 by creating laboratory-weathered microplastic particles and sharing samples with each registered team.

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Problem statement
Your team is challenged to design a portable process or device to detect and quantify microplastics in real time or near-real time (as quickly as possible, with target of 30 minutes). It is expected that the device will be used on lakes and reservoirs, and thus must fit in a small watercraft and, if needed, the power supply must be portable.

It is assumed that your detection device will depend on traditional grab-sampling methods of collecting water and bringing it to the surface to be analyzed. However, if your team has a solution that can address in situ microplastics detection by some other means, you are welcome to demonstrate it.

Your bench-scale designs will be tested with a synthetic solution of aged microplastics, bacteria, algae, and bentonite clay, with water having a pH of 8.0 and salinity 700 mg/L* (conductivity ~ 100 µmho/cm^2). See "Bench-scale Demonstration" for more details about the preparation of the synthetic solution.

Design requirements
Your proposed design should provide specific details and outcomes outlined below.

- Develop a portable method of detecting and quantifying microplastics for a reservoir.
- Provide a process diagram illustrating all components of your design and their functions.
- The device shall be capable of detecting microplastics in the range of 5000 – 50,000 items/m^3.
- The device shall provide a result in real time or near-real time (target of 30 minutes).
- The device shall distinguish between the microplastics and other particulate matter in the synthetic sample.
- Teams are cautioned to ensure that microplastics from the air or containers do not contaminate the bench-scale processes.
- Business Plan: Include: *(List subject to change—watch FAQs.)*
    - Costs, cost-recovery structure, recovery rate, and schedule.
    - Level of profit to show viability to a prospective lender (as an indication of ability to pay off a loan needed to set up the manufacturing process).
    - Projected sales forecast, market potential, potential market share.
    - Reduction in the marginal cost of each device as manufacturing progresses over successive years (to reflect economies of scale: i.e., the cost of manufacturing a single car is $50M, but the cost of manufacturing 5M cars is $30,000 each).
    - Note that, although your team is required to submit a business plan, most tasks require a Techno-Economic Analysis (TEA) rather than a business plan. The business plan is important to this task because your team will be building a marketable, manufacturable product, requiring different parameters for the economic analysis. Should you decide that a TEA is more appropriate for your design solution, contact us for implementation guidelines.
    - Teams are advised to create a multi-disciplinary team by inviting a business major to help draw up economic plans for full-scale implementation of your designs.
- Address any intangible benefits of the selected treatment process.
- To be considered for the WERC P2 Award, in a separate section of the report (titled "Pollution Prevention"), document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project.
- Address safety aspects of handling the reservoir water (natural or synthetic), plastic particles, and any final/waste products. Safety issues for the full-scale design should be addressed in the written report. Safety issues for the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

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Bench Scale Demonstration

Bench-scale demonstrations will serve to illustrate the design considerations listed above. The bench-scale apparatus should demonstrate a portable process or device that can be used to detect and quantify microplastics in a reservoir in real- or near-real time (target of 30 minutes).

In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation, but shall not be substitutes for the bench-scale demonstration.

For the bench-scale demonstration at the contest, teams will be provided with up to 18 liters (5-gallon container) of room-temperature synthetic solution containing (*subject to change – watch FAQS*):

- Laboratory-prepared microplastics described below.
  - Size: will vary between 50 and 100 microns in diameter.
  - Composition: may include a distribution of aged PET, PE, and/or PP.
  - Texture: may include a distribution of fibers, fragments, and pellets.
  - Color: may include transparent and/or blue.
  - Concentration: between 5,000 and 50,000 items of microplastics per m^3 of water (representative of values collected in the world's reservoirs [6]).
  - Aging: The microplastic particles will have undergone a laboratory aging process:
    - Minimum of one month of sun-spectrum lighting, including UV and heat.
    - Second month of aging will add water, bacteria, and algae.
- The microplastics will be suspended in water at room temperature with
  - pH 8.0*
  - salinity 700 mg/L* (conductivity ~ 100 µmho/cm^2)
  - Other particles: The provided samples will contain a quantity of bacteria (~1 micron), algae (~3 microns), and 200-mesh bentonite clay (~74 microns)

  *Values typical of Lake Mead [7].

  Note that the oxygen content will depend on the status of the bacteria and algae. Turbidity will be a function of the density of the microplastics, bacteria, algae, and clay particles.
- Teams will not know ahead of time the exact concentration, compositional distribution, or textural distribution of the items in the water.
- WERC may opt to test the team's devices multiple times using varying concentrations of synthetic solution or water containing no known microplastics.

Pre-contest Bench-scale Testing

Samples of the synthetic solution will be shipped upon request to teams in early January for use in bench-scale testing prior to the contest. Send your mailing address to werc@nmsu.edu to request the sample.

Reporting Bench-scale Testing Results

At the bench-scale demonstration in April, your team will report the concentration of microplastics detected in the synthetic solution in terms of items per m^3.

Analytical Testing Techniques

Your team's detection and quantification values will be compared with the quantity of each component mixed into the original synthetic solution.

30% Project Review
Suggested submission date: Feb. 6, 2023
Final submission date: February 24, 2023

An engineering "30% Project Review" reviews the engineering firm's preliminary design and aspects of a project with a client. It provides the client an opportunity to suggest modifications for inclusion in the final design. The goal is to define the scope of the project, present a project schedule, report progress to date to meet the final deadline, and determine fatal flaws, if any.

For the design contest, the review should not exceed four pages. Submit the project review as soon as possible to allow time for revisions after receiving feedback. You are allowed to change your plans after submitting the Project Review. Although the review is not scored, your team will receive feedback from the judges for improving your project. (The higher the quality of your review, the more help you will get from the judges.)

At a minimum, the review must include:

- **A brief description of your project:** One bulleted list outlining: goals, planned solution to the problem, and any anticipated drawbacks.
- **A project schedule:** schedule for completion of the contest solution, including progress to date.
- **Process Diagram** illustrating all components of your design and their functions.
- **Table of Contents** planned for the technical report (place topics in order, one line per topic).

Experimental Safety Plan (ESP)
The ESP outlines your team's plans for safely operating your bench-scale demonstration at the contest. This document is submitted in February (see dates below). Instructions are provided in the team manual. The Team Leader, or a designated team member, shall attend a mandatory short course that outlines the ESP process. Teams will not be able to run a bench-scale demonstration if the ESP is not received by the deadline. Your team should follow your school's safety procedures while conducting tests prior to attending the contest.

Evaluation Criteria
Each team is advised to read the 2023 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in the manual, there are five events: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale apparatus, a poster presentation, and a Flash Talk. Criteria used by the judges in evaluation of these five components are described in the Team Manual.

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: Guidelines | werc.nmsu.edu

Your response to the problem statement will include consideration of the following points specific to this task.

- Potential for real-life implementation, including portability, ease of use, length of time required to obtain results, affordability, expected reliability, and maintainability.
- Thoroughness and quality of the process diagram.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- The results of your bench-scale demonstration. In particular, reasonable detection and quantification of microplastics in the synthetic sample.
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs online).

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Short Courses

WERC is offering two short courses:

- ***Mandatory:*** Preparing the Experimental Safety Plan. The Team Leader, or a person assigned by them, must attend the course prior to submitting the ESP (and before February 20, 2023).
- ***Optional:*** Environmental Health and Safety (EH&S). The course is designed to prepare teams to complete the EH&S portion of their technical report. Course fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration information. Individuals who complete the course can earn a digital badge to add to their professional development portfolio.

Dates, Deadlines, FAQs (*dates subject to change—watch website FAQs*)

- Today: Email us to let us know you are interested in this task. We will contact you with breaking news.
- Opening mid-December, 2022: Optional Course: WERC Safety and Environmental Topics. Live— See website & Team Manual for more information.
- Opening mid-December, 2022: Mandatory Course: Preparing the Experimental Safety Plan February 20, 2023: deadline for attending. On-demand—See website & Team Manual for information.
- February 6 - 24, 2023: Preliminary Report due.
- February 6 - 24, 2023: Experimental Safety Plan (ESP) due.
- April 5, 2023: Technical Report due
- Weekly: Check FAQs weekly for updates:
  - Task-specific FAQs: 2023 Tasks/Task FAQs
  - General FAQs: 2023 General FAQs
- All dates or task requirements are subject to change. Check FAQs for updates online.

References

[1] Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., Reisser, J., 2017. River plastic emissions to the world's oceans. Nat. Commun. 8, 15611. https://doi.org/10.1038/ncomms15611.

[2] Sharma, S., Chatterjee, S. 2017. Microplastic pollution, a threat to marine ecosystem and human health: a short review. 2017. Environ Sci Pollution Research 24, 21530–21547. https://doi.org/10.1007/s11356-017-9910-8.

[3] Hirt N., Body-Malapel M. 2020. Immunotoxicity and intestinal effects of nano- and microplastics: a review of the literature. Part Fibre Toxicol. 2020 Nov 12;17(1):57. doi: 10.1186/s12989-020-00387-7. PMID: 33183327; PMCID: PMC7661204.

[4] Vo H.C., Pham M.H. 2021. Ecotoxicological effects of microplastics on aquatic organisms: a review. Environ Sci Pollut Res Int. 2021 Sep;28(33):44716-44725. doi: 10.1007/s11356-021-14982-4. Epub 2021 Jul 5. PMID: 34226995.

[5] Anthony L. Andrady. 2011. Microplastics in the marine environment. Marine Pollution Bulletin Volume 62, Issue 8. 1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030.

[6] Guo, Z., Boeing, W.J., Xu, Y., Borgomeo, E., Mason, S.A. and Zhu, Y.-G. 2021. Global meta-analysis of microplastic contamination in reservoirs with a novel framework. Water Research 207 (2021) 117828. doi: 10.1016/j.watres.2021.117828.

[7] USBR. Colorado river interim surplus criteria draft environmental impact statement. Chapter 3. Affected environment & environmental consequences. Chapter_3.05.pdf (usbr.gov)