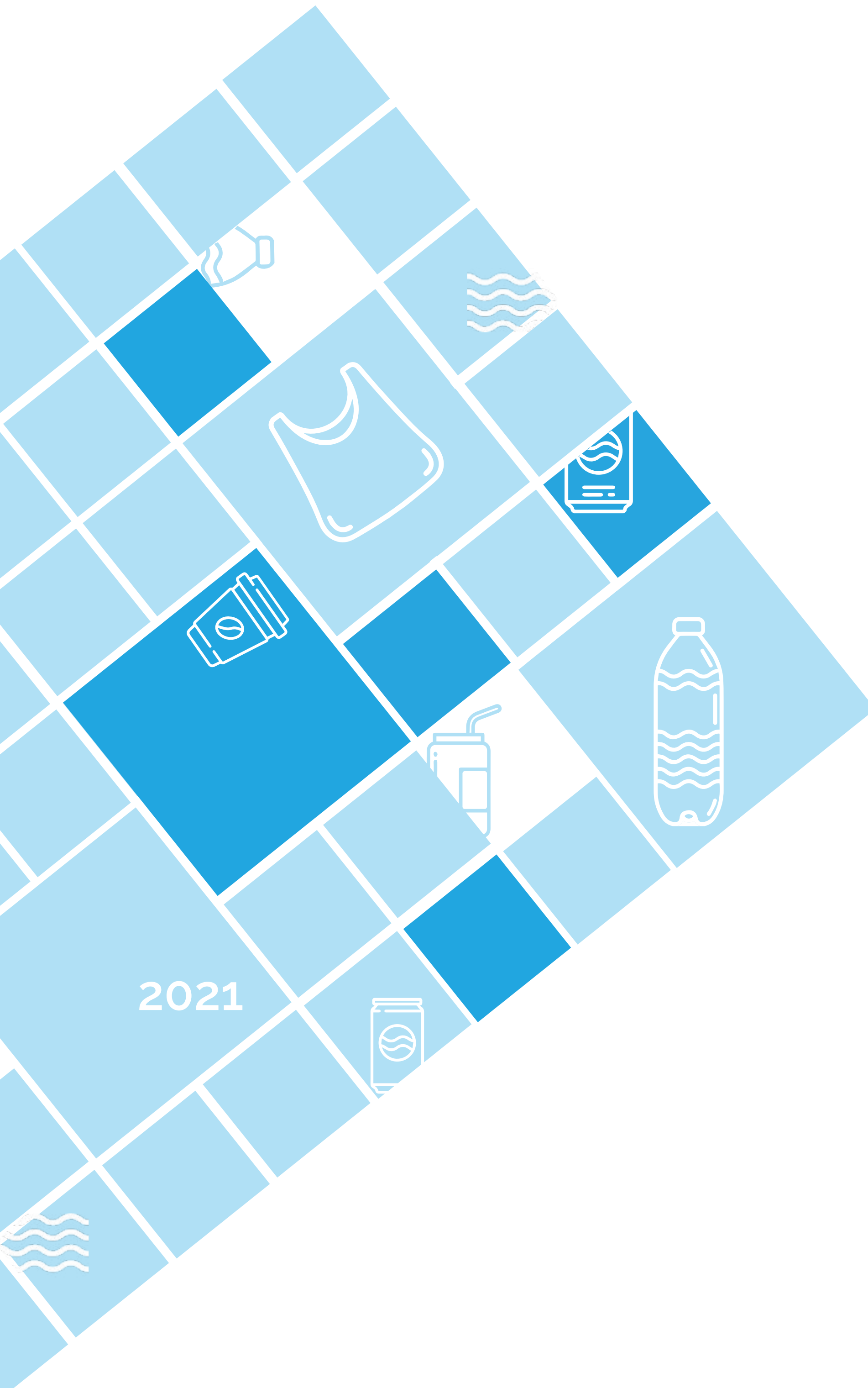
Plastic waste capture in rivers

An inventory of current technologies



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The Benioff Ocean Initiative, based in the Marine Science Institute at the University of California, Santa Barbara (UCSB) works to leverage science and technology to solve ocean problems and inspire the replication of these successes. The Initiative was founded in 2016 by a gift to UCSB from Marc and Lynne Benioff. Learn more at boi.ucsb.edu.

The Clean Currents Coalition is one of Benioff Ocean Initiative's flagship programs. The Coalition is a network of teams piloting different approaches to capturing plastic waste in river systems around the world to address one of the leading sources of plastic waste transport into the oceans. Several of the technologies featured in this document are being tested by Coalition member projects. Learn more at cleancurrentscoalition.org.

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Note about units

We use the metric system to report measurements, and the United States dollar (USD, $) to report currency.

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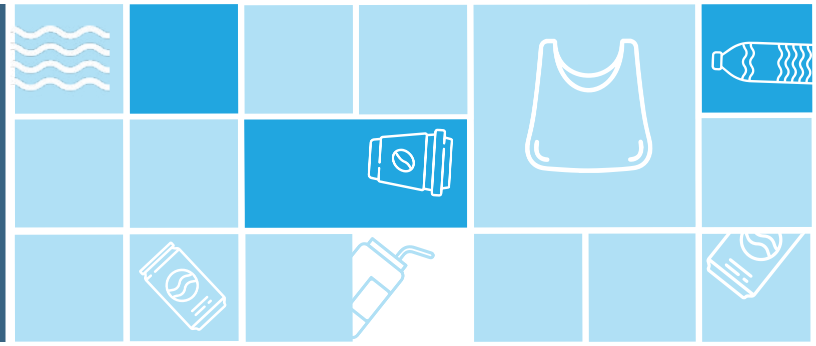

Executive Summary

Rivers serve as a major conduit of pollution, including plastic waste, into the oceans. An estimated 19 to 23 million metric tons (Mt) of plastic waste enter aquatic ecosystems (rivers, lakes, and oceans) every year, with between 0.8 and 2.7 Mt entering the oceans from rivers. The key role that rivers play in carrying waste from land to sea provides a strategic opportunity to turn off the tap of plastic waste into the oceans.

An estimated 19 to 23 million metric tons (Mt) of plastic waste enter aquatic ecosystems (rivers, lakes, and oceans) every year...

This paper offers an inventory of several prominent river plastic waste collection technologies operating in different river systems around the world. These range from passive devices such as booms, traps, and barriers that rely on river currents to concentrate debris, to integrated powered systems that actively capture or concentrate debris at high-volume sites, such as the Trash Wheel, the Bubble Barrier, and skimmer vessels. Several factors are considered in each technology profile, including technological characteristics (configuration, dimensions, maintenance requirements), cost, impact on the environment, and examples of applications. The information presented in this paper came from Benioff Ocean Initiative's experience leading the Clean Currents Coalition, a global network of organizations

Portoviejo River, Ecuador. Credit: Ichthion Ltd

Left to right: Trash trap in Lat Phrao Canal, Thailand. Credit: TerraCycle Global Foundation; Nairobi River cleanup, Kenya. Credit: Chemolex Company Ltd

piloting different technologies for capturing plastic waste in rivers; direct correspondence with technology developers; and internet research. As the Clean Currents Coalition program is ongoing and as we continue to learn more about strategies for capturing and preventing plastic waste in rivers and the oceans, we hope to continue to share more lessons learned.

The goal of this paper is to deliver an instructive and actionable tool to practitioners who wish to use technology to join the great global challenge of cleaning plastic waste from our rivers, and ultimately oceans. The authors recognize that capturing and cleaning up plastic waste is only one piece of a comprehensive strategy needed to prevent its leakage into the oceans, and wholeheartedly support efforts also aimed at policy change, reduction of production, consumer education and behavior change, and improved waste management capacity and technology.

The goal of this paper is to deliver an instructive and actionable tool to practitioners who wish to use technology to join the great global challenge of cleaning plastic waste from our rivers, and ultimately oceans.

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Borelle et al. 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369: 1515-1518.

Meijer et al. 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances 7: eaaz5803.

Introduction

The Problem

Rivers are the arteries of the planet. Like the blood vessels that deliver oxygen-rich blood throughout our bodies, rivers carry water and critical nutrients through terrestrial and aquatic ecosystems and into lakes and oceans. They shape and transform landscapes and promote life by offering innumerable ecosystem services such as drinking water for humans and animals; irrigation for agriculture; and recreation, cultural, and ceremonial sites.

But apart from transporting life-giving elements and providing invaluable ecosystem services, rivers also serve as a major conduit of pollution. An estimated 19 to 23 million metric tons (Mt) of plastic waste enter aquatic ecosystems (rivers, lakes, and oceans) every year. Of that total, 4.8 to 12.7 Mt of plastic waste flow into the oceans specifically, and 0.8 to 2.7 Mt of that is transported by rivers.

The Bubble Barrier in Westerdok Canal, Amsterdam. Credit: The Great Bubble Barrier

The Opportunity

The key role that rivers play in carrying waste from land to the oceans provides a strategic opportunity to turn off the tap of plastic waste into the oceans. In the oceans, plastics break down into smaller and smaller pieces (microplastics), and are transported by mixing and currents throughout the water column all the way to the deepest depths, making the possibility of capture extremely difficult to impossible. On the other hand, rivers are shallower and more contained, allowing for easier access to the debris they carry, and are relatively more controlled environments than the oceans, allowing for safer operating conditions.

Thanks to these advantages, technological systems that capture plastic waste in rivers are being deployed around the world. These systems generally seek to accomplish the same goal: to concentrate and capture plastic and other debris in rivers so it can be removed and properly disposed of. They range from

The key role that rivers play in carrying waste from land to the oceans provides a strategic opportunity to turn off the tap of plastic waste into the oceans.

simple, low-cost booms, barriers, and nets that are manually operated and maintained and passively rely on the river's current to concentrate the debris; to high-tech, high-investment electricity, hydrokinetic or solar-powered concentrators and conveyors. Today, these systems are designed, constructed, deployed, operated, and financed by a variety of entities worldwide, such as nonprofit organizations, tech start-ups, and governments.

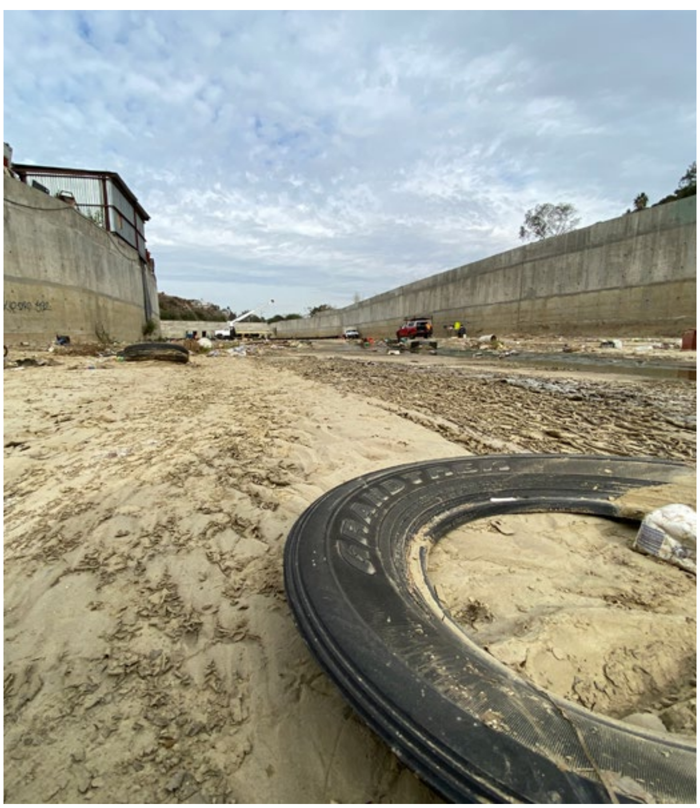
The Clean Currents Coalition is a network of teams operating in countries around the world to combat the flow of plastic waste from rivers to oceans. Supported by the Benioff Ocean Initiative at the University of California, Santa Barbara and The Coca-Cola Foundation, the Coalition is piloting innovative new technologies and reimagining pre-existing ones to capture plastic waste from polluted river systems around the world: Tijuana River in Mexico, Juan Diaz River in Panama, Portoviejo River in Ecuador, Kingston Harbour in Jamaica, Athi-Galana-Sabaki River in Kenya, Lat Phrao Canal in Thailand, Red River in Vietnam, and Citarum River in Indonesia. In addition to deploying these plastic capture technologies, the Clean Currents Coalition is collecting and using data to implement outreach and education campaigns to empower changes in human behavior, policy, and infrastructure to reduce the production and use of single-use plastics and improve waste management systems.

It is important to acknowledge this important point: the problem of plastic pollution is extremely complex. Cleaning up plastic in rivers specifically, and in the environment generally, is only one piece of a much more holistic set of solutions needed if we are to address this challenge globally. Tools that prevent plastics from entering waterways, such as stormwater filters, and those that capture plastics already in the oceans, such as The Ocean Cleanup's System 001, are important for capturing plastic waste along its entire aquatic journey. At a broader scale, we also need the development of systemic policy changes to curb plastic pollution (including improved waste management and producer responsibility); replacement of single-use plastics with cost-effective, functional alternatives; changes in personal and population-level use behaviors that reduce plastic demand; and improvements in plastic waste management and recycling. Only by combining the reduction of plastic production, improvement of waste management, and recovery of plastic waste from the environment can we drastically reduce total plastic emissions into the environment.

Cleaning up plastic in rivers specifically, and in the environment generally, is only one piece of a much more holistic set of solutions needed if we are to address this challenge globally.

Nairobi River, Kenya. Credit: Chemolex Company Ltd

Lat Phrao Canal trash trap, Thailand.
Credit: TerraCycle Global Foundation



Tijuana River, Mexico
Credit: WILDCOAST

This document is a product of the Benioff Ocean Initiative's work through the Clean Currents Coalition to fulfill a need for a compilation of the different plastic capture technologies that can be adapted to the diverse river systems and water bodies.

Paper Overview

The Clean Currents Coalition was conceived under the assumption that the only way to solve the global plastic problem is collaborative action and scalable solutions. Therefore, part of the Benioff Ocean Initiative's mission is to provide the public with the knowledge and lessons learned from experience with the experts and practitioners designing and implementing solutions to divert plastic waste from rivers. This document is a product of the Benioff Ocean Initiative's work through the Clean Currents Coalition to fulfill a need for a compilation of the different plastic capture technologies that can be adapted to the diverse river systems and water bodies. As the Clean Currents Coalition program is ongoing, we hope to continue to share more lessons learned over the course of the next few years.

The goal of this document is to deliver an instructive and actionable guide to practitioners who wish to join the great challenge of cleaning our rivers, and ultimately oceans, from plastic waste. This document focuses exclusively on river intervention technologies. For a larger, broader inventory of tools that can be implemented anywhere from households and urban waterways to rivers and oceans, visit the Plastic Pollution Prevention and Collection Technology Inventory from the Nicholas Institute for Environmental Policy Solutions at Duke University (https://nicholasinstitute.duke.edu/plastics-technology-inventory).

Because of the large disparity in river characteristics, such as depth, width, discharge, flow rate, seasonality, climate, pollution load, etc., effective technologies have to be adapted to these conditions. There is no one-size-fits-all solution. We profile several different categories of technologies, as well as some unique patented technologies, with the hope that practitioners will find the one that best fits their particular environmental and social conditions, as well as their budgets. Each profile is structured in the following way:

Overview
Brief description of the technology's structure and function

Energy Source
How the technology is powered, if at all (e.g., solar, fuel, passive)

Dimensions
Approximate size and configuration

Suitable Conditions
Types of environments and hydrological conditions to which the technology is known or anticipated to be best suited

Cost
Approximate example estimates of design, construction, and/or operation costs -- as available and for reference only[1]

Maintenance
Known or anticipated maintenance requirements

Environmental Impacts
Known or anticipated environmental impacts (physical and/or biological)

Strengths & Weaknesses
Comparative notable advantages and disadvantages

Applications
Real-world instances of technology testing or deployment

[1] Please note that costs may change and should be obtained directly from the product manufacturer or dealer.

Although the technological aspects of solving the plastic waste problem in rivers are key, there are several other important considerations of any potential intervention that are not covered in this document. First, although cleaning up plastic waste in rivers is critical to restoring ecosystem health, it is important to acknowledge and mitigate the potential for bycatch and habitat impacts during technology deployment. As these technologies are increasingly tested and deployed in the coming years, practitioners should monitor and evaluate impacts on organisms they may interact with. Important also to consider are stakeholder engagement and support (local governments, businesses, and communities), existing policies and regulations (including permitting), required infrastructure to properly manage captured waste, and added-value business plans. Each particular context will require a tailored approach that considers these factors in order to successfully implement a plastic capture strategy in rivers.

Matias Hernandez River, Panama. Credit: Marea Verde

Citarum River, Indonesia. Credit: Greeneration Foundation

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BOOMS

Overview

Booms are widely used to capture floating plastic and other debris in waterways. Booms use flotation structures, often with curtains suspended into the top of the water column, designed to capture buoyant materials. Booms can also be designed to absorb oils and grease. They are typically anchored to the shoreline and the riverbed downstream of one or more trash outfalls. The size of a boom can easily be customized based upon the size of the river and the expected volume of floating debris that can be carried by the river system. Material captured in a boom can be removed manually, with an excavator, conveyor, or a skimmer vessel.

Booms can be a component of other more complex waste capture systems, such as traps and trawlers. There is also the so-called "Biofence" that mimics the structure of a boom using upcycled bottles for flotation. Biofences are generally constructed of PET beverage bottles and netting.

The "Barrera o basura" ("B.o.B.") that was operated in the Matías Hernández River in Panama. Credit: Marea Verde

Booms in the Assi River in Varanasi, IN.
Credit: Renew Oceans

Energy Source

Passive (no energy source required)

Dimensions

Variable. Can come in a variety of sizes depending on the waterway, from small booms measuring 1m wide x 4m long to large booms measuring 4m wide x 15m long or more.

Maintenance

Proper anchoring is very important and should have a geotechnical engineer's assistance, and pilings or ground anchors should be used to secure the system. These should be inspected and maintained regularly. Continual manual collection of debris is also important, but highly labor intensive; boats, cranes, or conveyors might be used.

Cost

Costs will vary, but this is generally a low-cost option. For example, the Black Brute Boom made by Elastec ranges from USD $697 per 3m to $1,052 per 6.1m sections, and the optional 0.6m debris screen ranges from USD $275 per 3m to USD $507 per 6m section. Costs for Biofences made from upcycled materials are generally much lower.

Suitable Conditions

Booms represent a good option in smaller rivers or canals with relatively weak currents, especially where maintaining vessel navigability is not required and a boom can extend from one bank to the other. In the case of waterways that are utilized by small vessels or kayaks, the booms can be equipped with a flexible module that will allow them to pass above the booms.

Biofences do well in smaller rivers because they are lightweight and have low durability. Their ability to capture trash is maximized when spread across the width of a waterway.

Environmental Impacts

If the boom is not properly maintained and emptied regularly, the build-up of debris could have a negative impact on aquatic life. Submerged mesh netting extending below the boom may entangle fish, although it will vary according to net material (aluminum mesh netting better allows wildlife to flow underneath). Smaller organisms may also be affected but larger fish should be able to swim beneath.

Strengths

- Floating anchored system allows traps to rise and fall with changing water levels due to seasonal changes, rain, wind, and irregular current and flow rates
- Effective in capturing various types of floating debris at or near the surface without endangering or obstructing aquatic life
- Adaptable and modular, so it can easily be modified to suit different size waterways and waste volumes
- Can be locally constructed by metal fabricators worldwide, and so it can also be easily repaired or adapted for customized use
- Offers flexibility and mobility to avoid interference with residential/commercial boat traffic

Weaknesses

- In most cases, trash must be removed from the trap manually
- Does not extend deep into the water column to collect suspended litter
- May not capture debris across the entire width of the waterway
- Capture rates may be low when water levels or water movement are low

Elastec Brute Boom with debris screen in Los Laureles Canyon, tributary of the Tijuana River, MX.
Credit: WILDCOAST

Applications

WILDCOAST installed an Elastec Brute Boom at Los Laureles Canyon, Tijuana, Mexico. The boom consists of 8 HDPE floaters of 40 cm diameter and stuffed with expanded polystyrene. Each floater has a galvanized steel screen. The barrier is attached to concrete structures on the banks of the river through galvanized chains and galvanized steel shackles.

Marea Verde operated the "B.o.B" (Barrera o basura, translation: Barrier or garbage) on the Matías Hernández River, Panamá. The B.o.B. was originally just a boom, but was later reinforced with fencing to prevent debris spilling over or under the boom.

The Litterboom Project is installing large pipes in South Africa anchored across the rivers, which acts as a catchment for all surface-level plastics.

Plastic Fischer is installing its booms in rivers in Indonesia, India, and Vietnam, where the devices are well-suited to wide areas with low flow speeds.

The country of Guatemala installed 2 bio-fences in the Motagua River.

AlphaMERS has installed floating barricades that carry debris to the riverbank for manual or mechanical collection across cities in India.

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FENCES, SCREENS & BARRIERS

Overview

This category comprises solutions based on the installation of fences, screens, or barriers that trap plastic and other waste. These have similar characteristics to booms but differ structurally and can be constructed of various materials, such as chain-link fencing, reinforcing bar ("rebar"), or plastic mesh net.

Blue Barriers by Sea Defence Solutions (SEADS) are designed to divert floating waste towards the riverbank. Credit: SEADS

The Azure system by Ichthion Ltd will use a barrier and a conveyor belt to capture plastics in rivers. The first device is being deployed in the Portoviejo River, Ecuador. Credit: Ichthion Ltd

Energy Source

Passive (no energy source required)

Dimensions

Fully adaptable to river location.

Maintenance

If debris accumulates along the fence or barrier, it must be manually emptied frequently enough to prevent a blockage.

Cost

A basic fence may cost a few thousand USD. The Nash Run Trash Trap near Washington, DC, USA cost $2,000 for the initial build and an additional $2,700 for repairs, modifications, and maintenance.

Sea Defence Solutions' Blue Barriers have the following cost structure: 50 m wide river - $166,000; 100 m wide river - $309,000; 200 m wide river - $605,000.

Suitable Conditions

Should be installed in rivers with flow rates that are sufficiently low such that they do not pose a threat to dismantling the structure.

Environmental Impacts

A fence or screen that extends from the river surface to the bottom of the riverbed may prevent movement of larger aquatic organisms. Sea Defence Solutions' Blue Barriers are designed such that fish will be able to continue their transit beneath and between the barriers.

Strengths

- Modular barrier structures can be configured to allow vessels to pass through with only a slight variation in direction
- Structures can capture debris across the entire width of the river
- Fences and screens can be low cost

Weaknesses

- Some fence structures do not allow for the passage of vessels or especially large debris
- The size of debris captured is dependent upon the mesh size of the fence or screen material
- Blockages may cause flooding of the surrounding riverbank

The Nash Run Trash Trap was installed in the Anacostia River near Washington, DC, USA in 2009.

Chemolex Company Ltd has installed five fences in the Nairobi and Ngong Rivers, Kenya. Waste is removed with a mechanical conveyor. Credit: Chemolex Company Ltd

Applications

The **Nash Run Trash Trap** was installed in the Anacostia River near Washington, DC, USA, and was 100% effective at capturing plastic beverage bottles, take-out food packaging, and bags.

Sea Defence Solutions' (SEADS) **Blue Barriers** are expected to collect 100% of suspended waste under ideal conditions.

Chemolex Company Ltd has installed fences at several locations on the Nairobi and Ngong Rivers in Kenya. Plastic and other debris are removed from the fence by a mechanical electricity-powered conveyor.

The **Azure** system by **Ichthion** is an enhanced barrier designed for preventing river plastic waste from reaching marine environments. As of May 2021, it is being deployed in the Portoviejo River, Ecuador.

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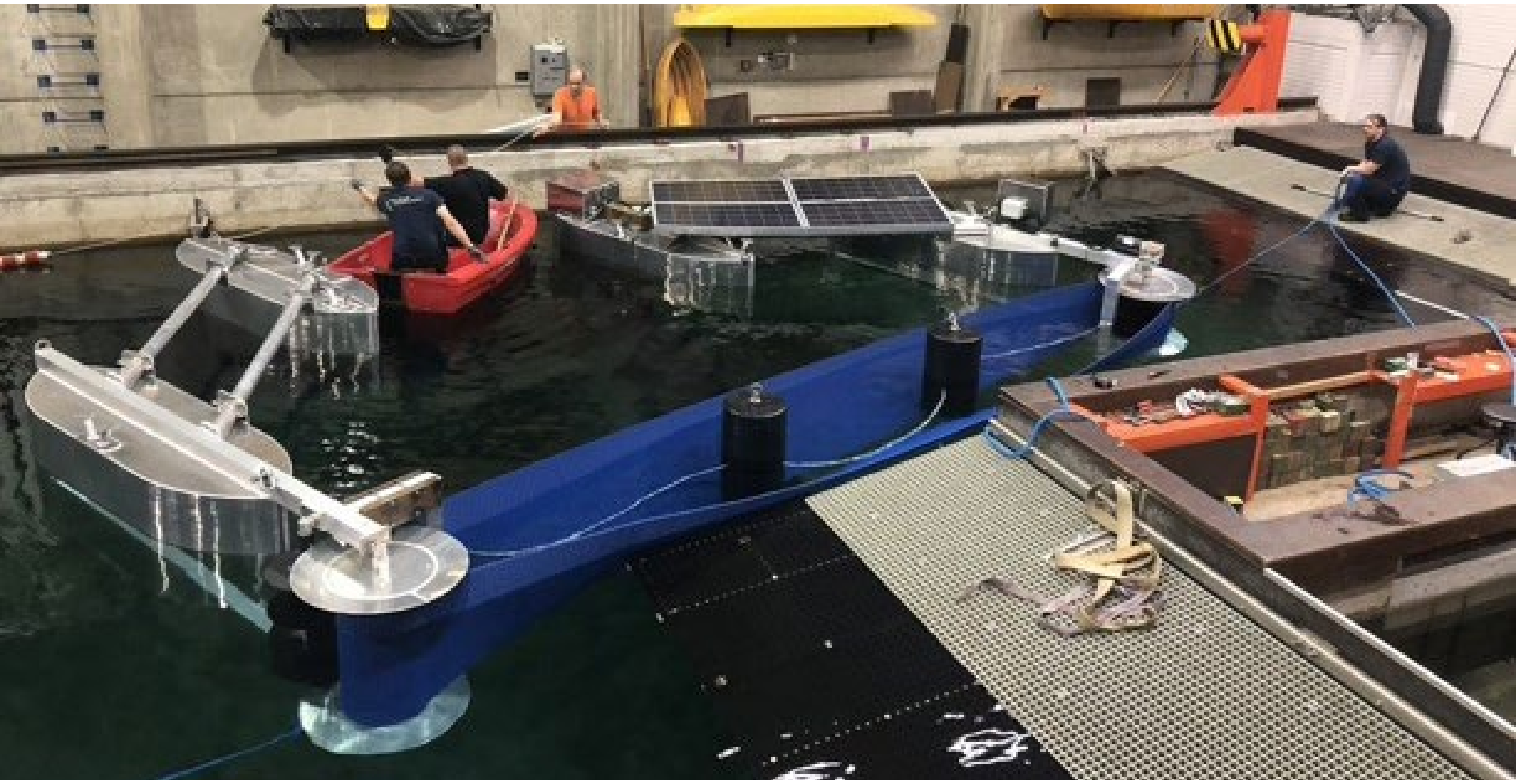
ROTATING MODULES

Overview

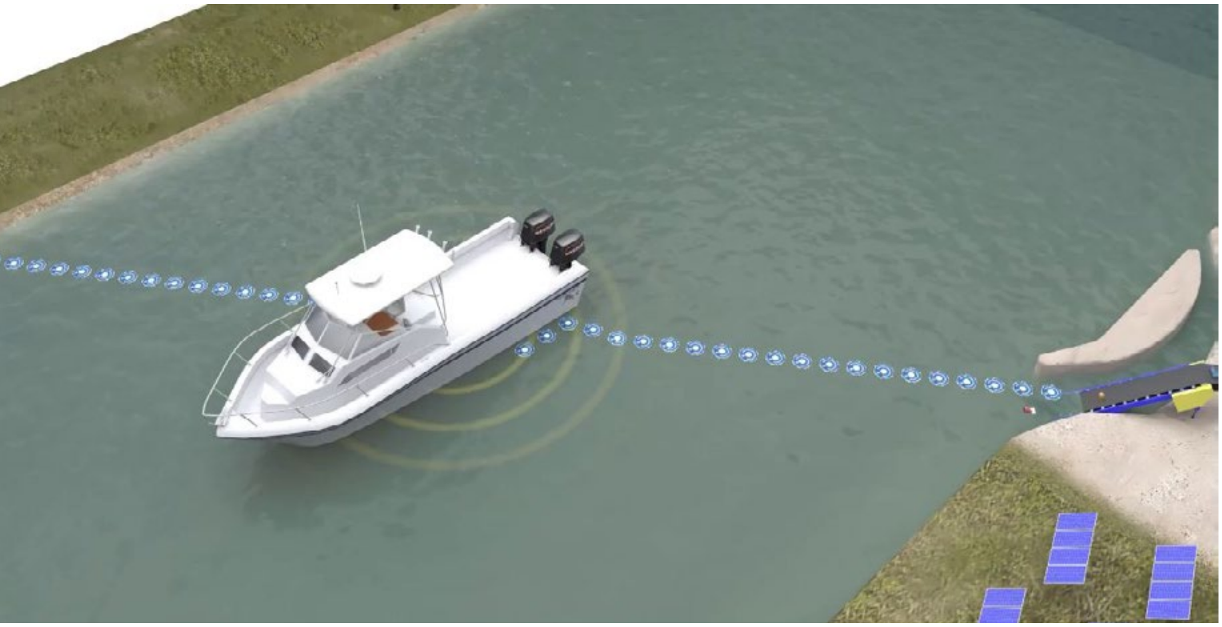
This category comprises technologies that use rotating concentration modules to divert the river waste to a collection site. We identified two primary technologies in this category:

The River Cleaner created by RiverRecycle consists of active concentration modules placed along the river to guide the plastic and other waste to one side, followed by an automatic collection wheel that lifts the waste out of the river. The system is designed to capture 20-100t of waste per day, and collect all waste larger than 1.5cm floating within 1m depth.

The River Cleaning System, created by River Cleaning, is a series of rotating modules positioned diagonally on the course of the river that intercepts plastic waste and transports it to a storage and extraction area at the river bank.



The River Cleaner by RiverRecycle at the testing facility. Credit: RiverRecycle



The River Cleaning System by River Cleaning is a series of floating devices, positioned diagonally on the course of the river, that intercept and transport plastic waste to the river bank. Credit: River Cleaning

Energy Source

The river current rotates the concentrator modules. Other power sources may be required for the waste extraction.

Dimensions

The modular design allows for adjustability to river size and conditions.

Maintenance

The systems are designed to be modular so any damage is limited to individual units that can be easily repaired or replaced. Debris will need to be removed manually or automatically from the collection site along the river bank.

Cost

Construction costs of the River Cleaner are estimated at $120,000, with operating costs of $22,000 per year.

Suitable Conditions

Requires a current to rotate the modules. The modular design can be implemented to ensure that the river stays navigable at sites with both aquatic life and vessels.

Environmental Impacts

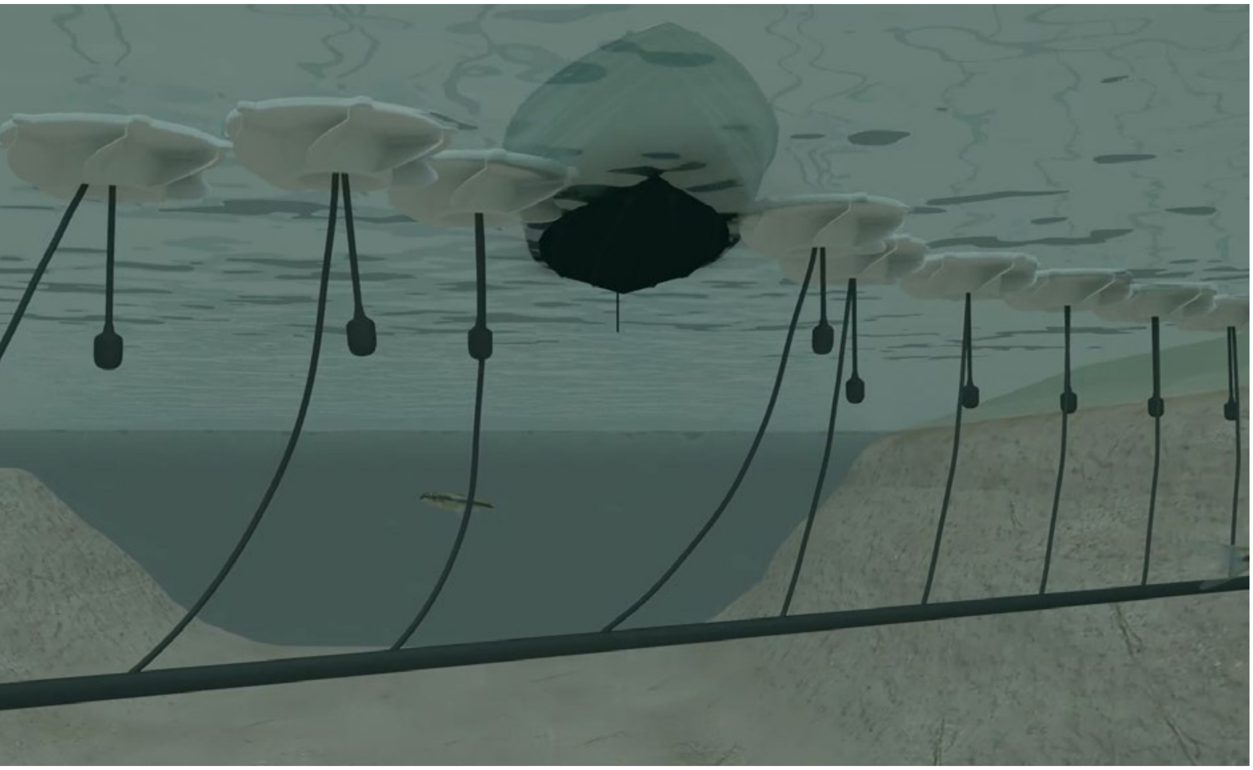
The River Cleaning System claims to allow fish to swim past the modules and proposes to use a device that will deter fish from entering the extraction area.

Strengths

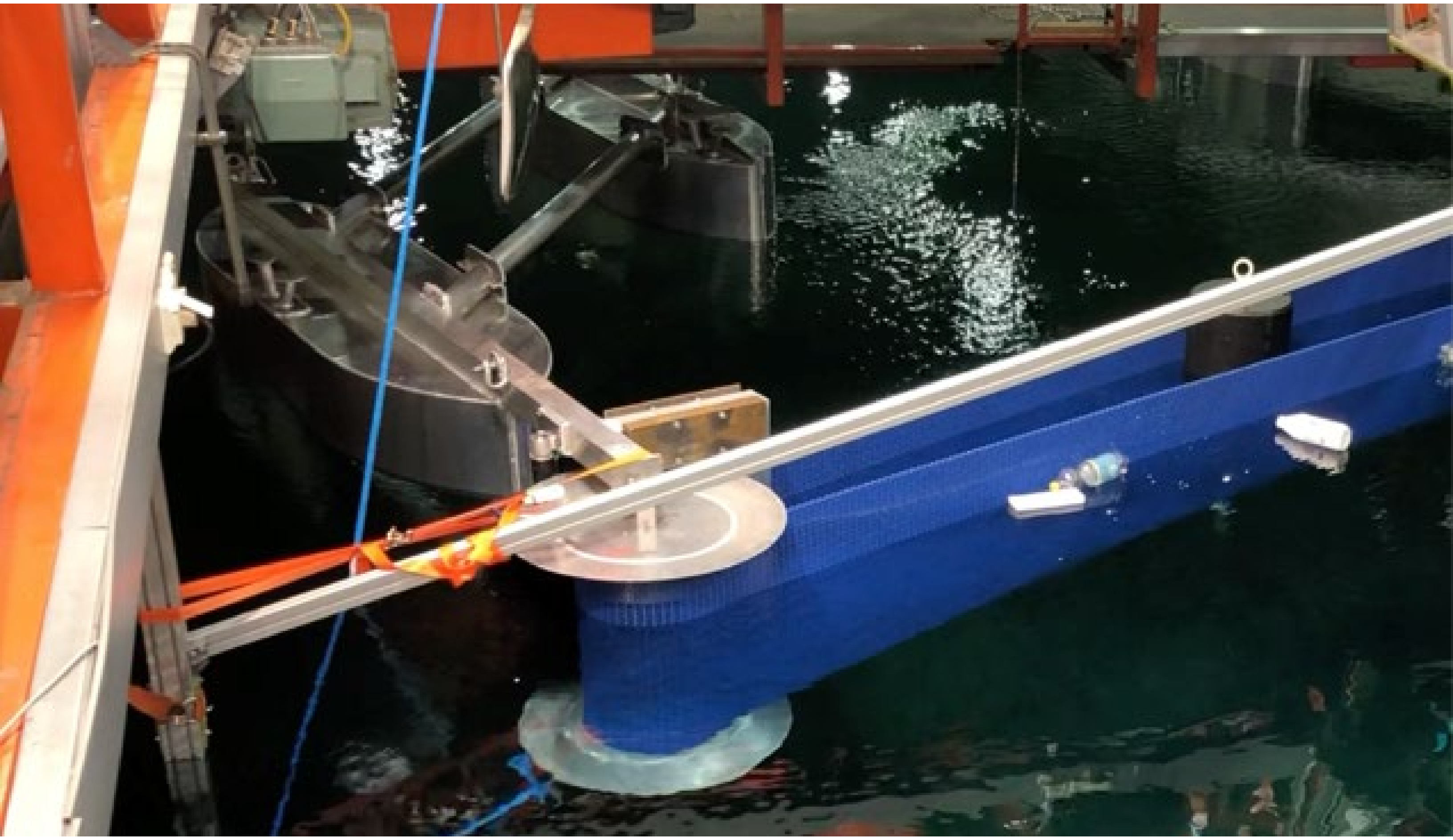
- Continuous autonomous operation
- Modular and scalable to meet the requirements of each location
- Relatively easy to install and dismantle to anticipate drastic changes in river volume
- Concentrators ensure a constant flow of waste and avoid accumulation
- Low risk of breaking or being submerged by heavy currents relative to rigid barriers
- Malfunctions are limited to the individual module units rather than the entire system

Weaknesses

- Does not collect submerged debris
- Relies on a relatively strong and consistent current to operate



The modules of the River Cleaning System allow for the passage of vessels, moving back into place following displacement by passing vessels. Credit: River Cleaning



Close-up of the River Cleaner rotating module. Credit: RiverRecycle

Applications

A partnership between **RiverRecycle** and **Greeneration Foundation** has plans to install the **River Cleaner** in the Citarum River, Indonesia.

As of April 2021, **River Cleaning** is in the fundraising stage of deploying its first international **River Cleaning System.**

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TRAPS

Overview

River trash traps usually consist of two out-stretched boom arms anchored and attached to a collection trap. The boom arms funnel floating debris into the trap and may have attached nets to better capture debris floating just below the water's surface. River traps are designed to float in waterways, capturing litter by using the current to guide debris into the trap. To increase mobility and ease of maintenance, the device can be designed with a detachable metal collection trap. River trash traps are usually made up of aluminum and high-density polyethylene (HDPE) and capture litter as it floats downstream. Trash removal might be done with a lift-out basket, a conveyor belt, transporting the device to shore, or by boat, among other options that best fit the specific needs of the project.

Trash trap on the Song Hong (Red River) in Nam Dinh, Vietnam, operated by the Centre for Marinelife Conservation and Community Development (MCD) and Ocean Conservancy. Credit: Ocean Conservancy and MCD

Trash trap in the Lat Phrao Canal in Bangkok, Thailand operated by TerraCycle Thai Foundation. Credit: TerraCycle Global Foundation

Energy Source

Passive (no energy source required)

Dimensions

Small traps can be 1.5m x 4m with 3m collection boom arms, and weigh approximately 275kg. Large traps can be 4m x 9m and weigh approximately 450kg.

Maintenance

The trap must be manually cleaned out continuously or transported for servicing. An example from the TerraCycle Global Foundation's application in Thailand estimated maintenance costs at around USD $6,000 per year. Other estimates were as high as $27,000 to $30,000 per year.

Cost

Project costs vary based on the type of trash trap installed. Relatively simple designs could allow for low costs of construction, ranging between USD $10,000 to $15,000 per device. However, more complex designs, such as the Bandalong Litter Traps in Washington, DC, have costs associated with designing, building, and installing the trap ranging from $50,000 to $100,000. The Brute Bin by Elastec has a price of USD $12,150 for the small bin (2.4m x 3.7m), and $19,200 for the large bin (2.4m x 6m).

Suitable Conditions

Trash traps are better for waterways with high rainfall, faster flow rates, and variable water levels. This design can be placed in various types of waterways and trap floating debris, primarily plastics, which are most commonly found in urban waterways.

Environmental Impacts

Low anticipated impacts on wildlife compared to other technologies. Wildlife can pass through the floating trash trap unharmed, and in some cases the traps have been reported to serve as habitat for riparian wildlife.

Strengths

- Floating anchored system allows traps to rise and fall with changing water levels due to seasonal changes, rain, wind, and irregular current and flow rates
- Effective in capturing various types of floating debris at or near the surface without endangering or obstructing aquatic life
- Adaptable and modular, so it can easily be modified to suit different size waterways and waste volumes
- Can be locally constructed by metal fabricators worldwide, and so it can also be easily repaired or adapted for customized use
- Offers flexibility and mobility to avoid interference with residential/commercial boat traffic

Weaknesses

- In most cases, trash must be removed from the trap manually
- Does not extend deep into the water column to collect suspended litter
- May not capture debris across the entire width of the waterway
- Capture rates may be low when water levels or water movement are low

The CirCleaner by Noria Sustainable Innovators in Rotterdam, the Netherlands, funnels plastic debris into the trap where it is lifted out of the water with a small water wheel. Credit: Noria Sustainable Innovators

Applications

TerraCycle Thai Foundation operates three trash traps in the Lat Phrao Canal to reduce the amount of marine plastics entering into the Chao Phraya River through the interconnected canal systems of Bangkok, Thailand.

Ocean Conservancy and **The Centre for Marinelife Conservation and Community Development (MCD)** designed and operates trash traps constructed of local materials in the Song Hong ("Red River") in Nam Dinh, Vietnam.

Noria Sustainable Innovators have deployed the **CirCleaner** trash trap in Rotterdam, the Netherlands. Plastic debris is lifted out of the water with a small water wheel.

Clear Rivers (Recycled Island Foundation) have implemented traps in Rotterdam the Netherlands; Brussels, Belgium; and Ambon, Indonesia.

The Groundwork Anacostia River D.C. (GWARDC) introduced the **Bandalong Litter Trap** to the Anacostia River in Washington DC. The trap is installed on Watts Branch Creek, a tributary of the Anacostia River.

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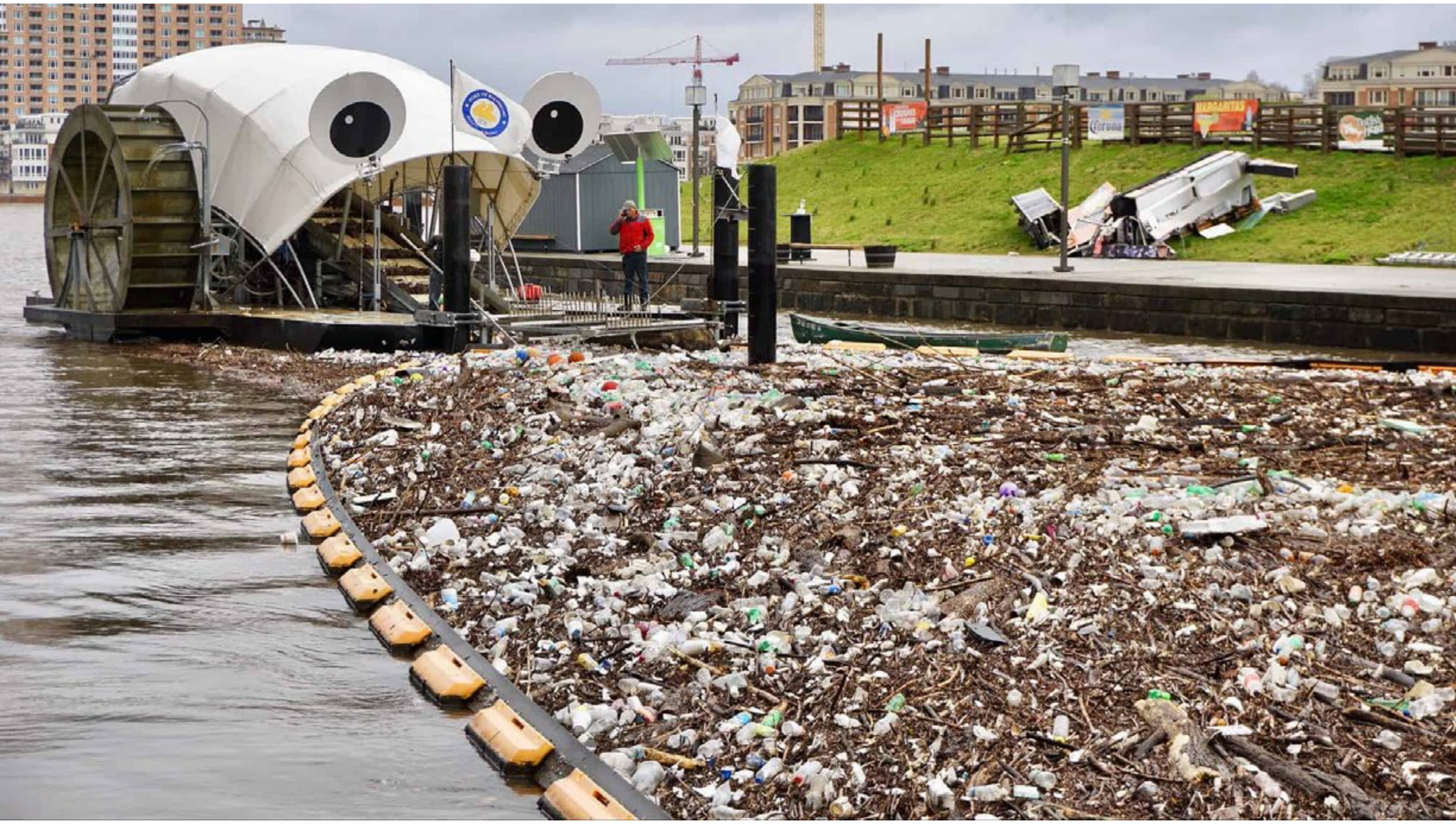
TRASH WHEEL

Overview

The trash wheel is a solar- and hydro-powered system that pulls floating debris from the water. Water currents concentrate debris captured in the containment booms into the rotating rakes and conveyor, which transports and deposits the debris into a dumpster barge. The conveyor and water wheel are mounted on a floating platform held in place by pilings, and the dumpster is on a separate barge that is transported by a service vessel to a transfer point for disposal. The patented trash wheel technology was invented by John Kellett of Clearwater Mills LLC in the USA.



Mr. Trash Wheel™ in Baltimore Harbor, Maryland, US. Credit: Waterfront Partnership of Baltimore

Energy Source

Solar and hydromechanical power drive a water wheel that powers the conveyor and rakes.

Dimensions

The flagship model, Mr. Trash Wheel™, at Jones Falls River in the Baltimore Harbor is 15m x 7m. The size of the device can be adapted to the specific waterway; for example, Captain Trash Wheel℠ is smaller and at the mouth of a fairly small creek.

Maintenance

Trash wheel dumpsters need to be offloaded and emptied when full, usually via a transfer vessel. However, it requires little to no regular manual labor, except for repairs.

Cost

The capital costs of the Mr. Trash Wheel™ in Baltimore Harbor were $800,000, with maintenance costs of $600/ton (varies by location due to distances, disposal fees, and volume). The capital costs of the smaller Captain Trash Wheel℠ were $400,000, with total operations and maintenance costs of $18,000/year.

Suitable Conditions

The trash wheel works well in medium to large rivers due to its size, but can also be scaled to smaller waterways. Ideal conditions include relatively small range in water level, low to medium flow rates, low to medium vessel traffic, and accessibility for onshore transfer of dumpster.

Environmental Impacts

The conveyor belt technology contains slow-moving rotating forks which allow the trash wheel to skim the surface of waters without entangling wildlife.

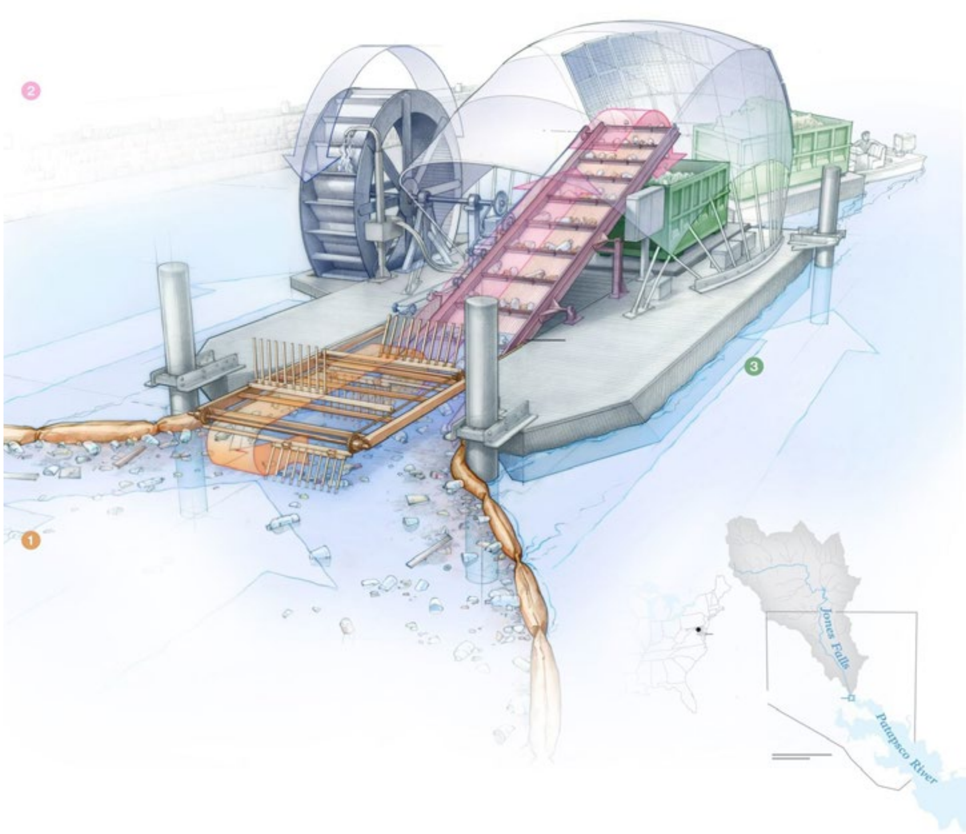
Strengths

- High capture potential, capable of capturing more than 22,000 kg of solid waste per day
- 90% capture rate in both normal and storm conditions
- Uses renewable power sources
- Visually appealing
- Low manual labor to operate

Weaknesses

- High initial capital costs and maintenance costs
- Requires boat to retrieve trash dumpster from the water
- Patented technology

Below: Professor Trash Wheel℠ at Harris Creek in Baltimore Harbor, Maryland, US. Credit: Waterfront Partnership of Baltimore
Right: Schematic of Mr. Trash Wheel™. Credit: National Geographic



Applications

The **Waterfront Partnership of Baltimore** operates four trash wheels (Mr. Trash Wheel™, Professor Trash Wheel℠, Captain Trash Wheel℠, Gwynnda the Good Wheel of the West℠) at different locations in Baltimore, Maryland, US

Marea Verde Panama is developing an adapted version of Mr. Trash Wheel™ to deploy near Panama City, Panama

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INTERCEPTOR

Overview

The Interceptor™ is an integrated floating plastic extraction system that consists of a solid barrier to catch and concentrate debris towards a conveyor belt fitted onto a floating pontoon. The barrier concentrates floating debris (50-100cm submerged and 20cm above water) towards the pontoon, which is a steel catamaran moored with anchors/piles and chains to the riverbed. The debris flows through the central channel of the catamaran towards an extraction conveyor belt. A secondary conveyor belt ensures debris is distributed evenly among 6 dumpsters, enabling maximum capacity utilization of the system. The distribution is fully automated, using various sensors to log the amount of debris extracted and distributed across the dumpsters. When the barge is completely full, an alert is sent to the local operators to come and remove the barge, bring it to the side of the river, and empty the dumpsters. Two design generations of the Interceptor™ are in use today; the first machines of a third generation are expected to be deployed in summer 2021.

Aerial view of Interceptor 004™ in Santo Domingo, Dominican Republic. Credit: The Ocean Cleanup

The conveyor belt of Interceptor 002™ in Klang River, Malaysia. Credit: The Ocean Cleanup

Energy Source

Solar power for the onboard conveyor belts, lights, sensors, and data transmission.

Dimensions

Approximately 24m long, 8m wide, and 5m tall.

Maintenance

Similar to the trash wheel, the dumpster barge needs to be offloaded and emptied when full, for which it will send a signal to the operators. However, it requires relatively little regular manual labor, except for repairs.

Cost

Approximately USD $669,000 for manufacture (transportation, installation, barriers, operations, and maintenance excluded)

Suitable Conditions

Best suited for waterways that are compatible with the device's large size, and that have consistent flow throughout the year (rather than seasonal rivers).

Environmental Impacts

Impacts are expected to be low; the conveyor belt is slow-moving to prevent adverse impacts to wildlife.

Strengths

- The Interceptor can store up to 50m³ of trash before needing to be emptied, so it can operate continuously in highly polluted rivers without human interaction for long periods of time
- At optimal efficiency, its capacity is up to 100,000kg of waste per day
- Onboard electronic monitoring system and remote monitoring dashboard

Weaknesses

- High initial capital costs and maintenance costs
- Requires boat to retrieve trash dumpster from the water
- Patented technology

The Interceptor™ uses a solid barrier to catch and concentrate debris towards a conveyor belt fitted onto a floating pontoon. Santo Domingo, Dominican Republic. Credit: The Ocean Cleanup

Applications

As of November 2020**, The Ocean Cleanup** had installed Interceptors in Jakarta, Indonesia; Klang, Malaysia; Santo Domingo, Dominican Republic; and Can Tho, Vietnam.

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BUBBLE BARRIER

Overview

The Bubble Barrier is a curtain of air bubbles created by pumping compressed air through a perforated tube made of PVC which is placed on the bottom of the waterway. The perforated tube is reinforced with a steel cable, and is attached to the bottom with steel or (recycled) concrete blocks. This system not only stops floating plastic but also brings plastic in suspension to the surface. The plastic debris is concentrated towards a catchment system along the side of the waterway. The Bubble Barrier was created by The Great Bubble Barrier, a Dutch startup company.

The Bubble Barrier creates a barrier to stop plastics from flowing past, while allowing fish and ships to pass through unimpeded. Westerdok Canal, Amsterdam, the Netherlands. Credit: The Great Bubble Barrier

Energy Source

The Bubble Barrier uses a compressor to force the air that creates the bubble curtain. The length of the Bubble Barrier has a significant influence on the necessary energy usage.

Dimensions

The Bubble Barrier in river IJssel in Netherlands extends 200m across the river.

Maintenance

Debris will need to be removed after being concentrated into the catchment area. The perforated tube may need to be occasionally cleared of biofouling.

Cost

Depends on the local conditions, but may range from $400,000 to $1,200,000.

Suitable Conditions

The Bubble Barrier can be placed in various rivers and canals. The organization's goal is to place Bubble Barriers in urban and industrial areas, which are known to have a high rate of plastic litter. It's also important to consider the bottom topography of the river to make sure the tube can be laid appropriately.

Environmental Impacts

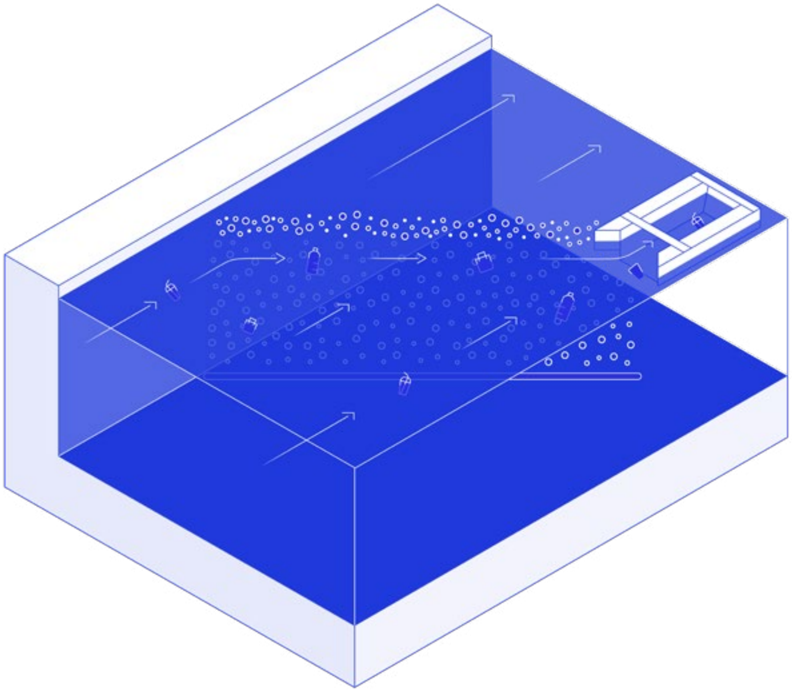
Most species are able to pass through the Bubble Barrier. A fish passage is incorporated into each design, either under the catchment system or under the bubble tube itself.

Strengths

- Is estimated to capture up to 86% of total waste
- Operates continuously
- Extends the entire width and depth of a river or canal, while allowing fish and ships to pass
- Increases the oxygen within the water
- Is easily scalable in both large rivers and small canals

Weaknesses

- Patented technology
- Few real-world applications to date



Above: The Bubble Barrier is a curtain of air bubbles created by pumping compressed air through a perforated tube anchored to the bottom of the waterway. Credit: The Great Bubble Barrier

Right: The Bubble Barrier uses the natural flow of the river to divert debris into a catchment system. Credit: The Great Bubble Barrier

Applications

As of November 2020, **The Great Bubble Barrier** has piloted the Bubble Barrier in the IJssel River, the Netherlands. The first full-scale Bubble Barrier was implemented in Westerdok Canal in Amsterdam, the Netherlands in 2019.

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SKIMMER VESSELS

Overview

Skimmer vessels are human-operated boats designed specifically for collecting floating debris. Debris is brought on board the vessel with moving screens on a conveyor belt system, or by lowering large nets into the water. They almost always require companion equipment, including a shore conveyor for unloading, a truck for disposal, and a trailer for land transport. Skimmers are used primarily in lakes, harbors, and bays and are usually custom made to meet site-specific challenges.

The WasteCleaner 92 by Efinor collects solid and liquid waste, with a capacity of 1200kg for solid waste such as plastics and 4000L for liquid waste such as oil. Credit: Efinor

The Omni Catamaran by Elastec is a versatile aluminum work boat that offers a variety of waterway maintenance and marina service applications, including collecting floating debris.
Credit: Elastec

Energy Source

Variable, but most commonly standard boat fuel or electric.

Dimensions

Variable, ranging from approximately 7m x 3m (e.g., Elastec Omni Catamaran, Efinor Waste Cleaner 66, Alpha Botas MC 202, or Water Witch Versi-Cat) to much larger vessels, such as the 70m x 50m Sea Cleaners Manta, which is designed to operate in the ocean.

Maintenance

Maintenance costs typical of a boat must be considered in addition to maintaining and emptying the parts used for debris capture and removal. However, mechanized equipment for unloading debris can greatly reduce the need for manual labor.

Cost

The Omni Catamaran from Elastec has a unit price of USD $81,000, with a litter basket sold separately for $9300. The Versi-Cat Trash Skimmer with a gasoline motor has a unit price of $55,000-65,000. The Versi-Cat Trash Skimmer with electric drive has a unit price of $68,000-77,000.

Suitable Conditions

Mostly operating in coastal and ocean waters, but also in riverways with navigable conditions.

Environmental Impacts

Generally low impact because specific hotspots of debris may be targeted. Will depend on the selectivity of the collection technology used by the vessel and the fuel consumption efficiency.

Strengths

- Versatile and maneuverable
- Can target specific areas for specialized cleanup purposes
- Low environmental impact by avoiding sensitive areas

Weaknesses

- Relatively high costs of trash collection
- Requires human operation (non-autonomous)
- Collection capacity is limited by vessel size

The Versi-Cat Trash Skimmer Boat by Water Witch collects floating and semi-submerged litter, debris and aquatic vegetation from the water surface into a removable basket, which can be lifted and tipped directly into a skip or shore side receptacle for disposal. Credit: Water Witch

Applications

Elastec offers several vessel options, including the Omni Catamaran and the Kvichak MARCO Boom skimmer, also used for oil spills.

Water Witch has several vessel options, including the Versi-Cat Trash Skimmer, which allows floating and semi-submerged debris to collect between the hulls and is available in an all-electric, zero-emissions model.

Efinor Sea Cleaner has several options for vessels, including the Waste Cleaner 66, 83, and 92. The cleaners capture solid and liquid pollution, and a microplastic collecting net can be added using double flow technology.

Alpha Boats has several options for vessels, including the MC202, 402, and 502 in barge and pontoon layouts. The articulating vertical wing capture system delivers debris to a front pick-up conveyor.

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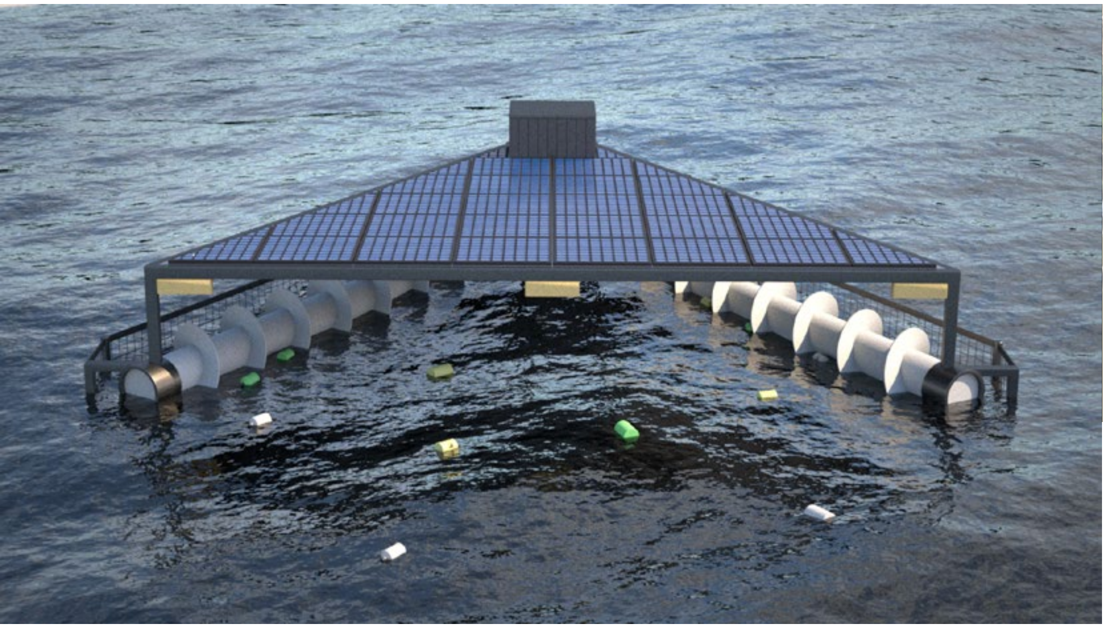
UNMANNED SKIMMERS

Overview

This category comprises all skimmer vessels that are capable of navigating and collecting waste without the presence of humans on board, but can be remotely monitored via shore-based operations. Some of these technologies are programmed to target and collect waste autonomously, while others can be remotely controlled to target waste.

The WasteShark by RanMarine is an autonomous surface vessel that is modelled after the whale shark and produces zero greenhouse gas emissions. Credit: RanMarine



The Marine Debris Collection System by DeltaSea is designed for collecting plastics and other marine debris from coastal areas, river deltas, lakes, and open ocean environments. It uses Archimedes Helicoid elements to create a self-buoyant and self-propelling system.
Credit: DeltaSea

Energy Source

Some technologies operate on fully autonomous energy harvesting (e.g., solar, wave), while others require external energy sources (e.g., batteries, fuel).

Dimensions

Variable sizes range from compact devices (e.g., WasteShark measuring 2m x 1.5m) to larger vessels (e.g., autonomous Kvichak MARCO Boom skimmer measuring 9.5m x 3m).

Maintenance

In most cases, devices must be manually emptied. According to DeltaSea, the maintenance cost for the Marine Debris Collection System is minimal and includes oil changes, lubrication, etc.

Cost

The base price for a DeltaSea Marine Debris Collection System unit is $60,000 (includes gas-driven hydraulic drives and a remote hand-held control device). The base price for the WasteShark is $20,200 (includes a portable flight case and annual data connectivity for 24/7 communication with the device).

Suitable Conditions

Although many of these devices were first designed for chemical or oil spill cleanup in the ocean, they are adaptable to solid waste cleanup in rivers. The relatively compact size of many models allows this technology to be adapted to rivers of various sizes.

Environmental Impacts

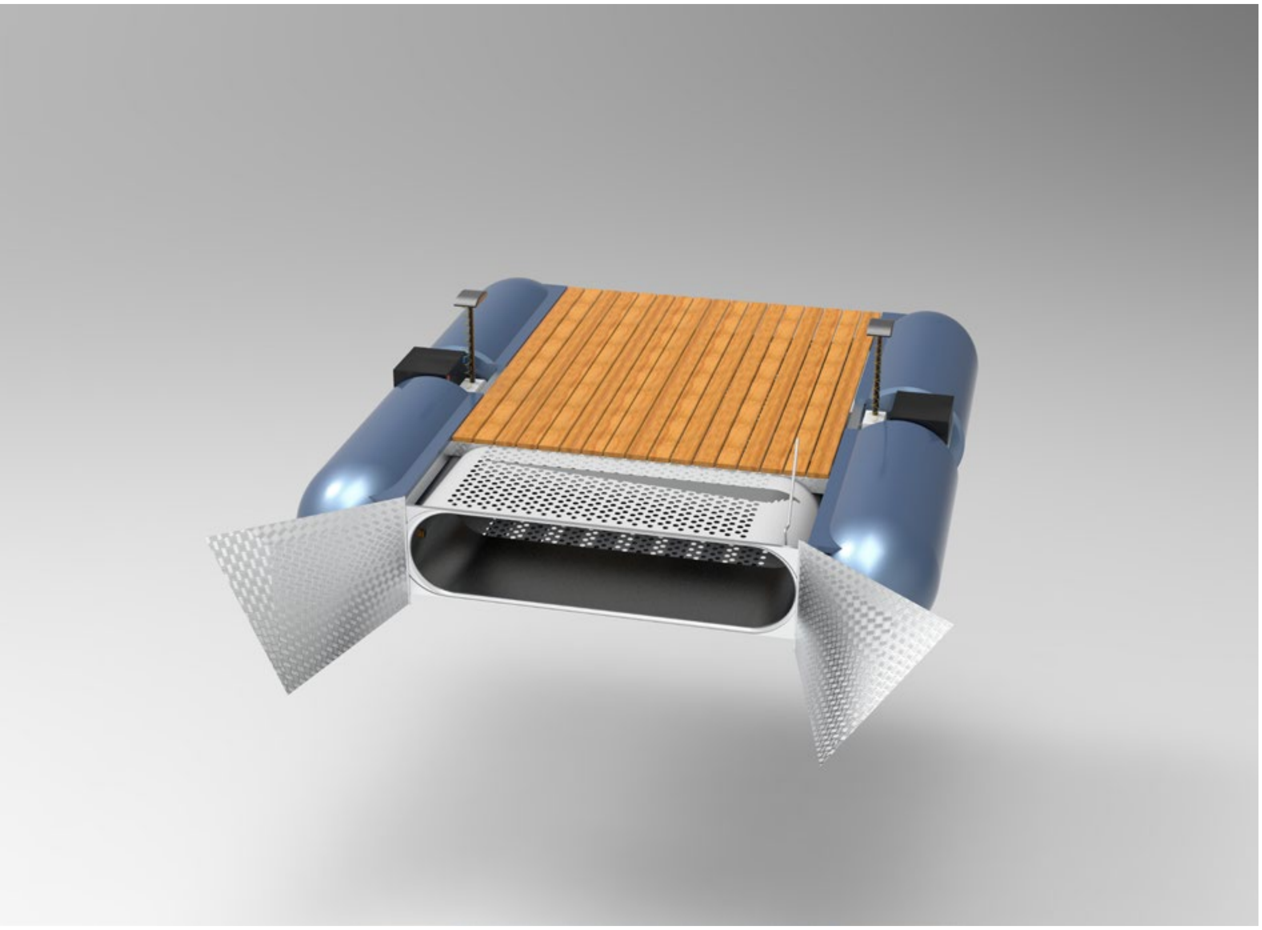
There are no apparent significant environmental impacts from these devices. The focus on the surface prevents interference with underwater life, and mobility avoids interference with other vessels (if supervised).

Strengths

- Some devices have onboard monitoring systems, such as operator cameras, data sensors (e.g., temperature, pH, conductivity, dissolved oxygen, depth, turbidity) and GPS
- Flexibility of movement can target debris in concentrated or hard-to-access areas
- Autonomous operations can collect debris based on pre-programmed routes without oversight

Weaknesses

- Relatively low collection capacity due to compact size
- Most need manual assistance for unloading the waste
- Non-autonomous remotely-controlled operations require constant direction and oversight



The A1100, of the AWARE series by DESMI, is a remote controlled mobile unit designed to allow a free flow of trash into the waste collection bag supported by a floating platform mounted with four pontoons. Credit: DESMI

Applications

Sea Machines Robotics created an autonomous control system aboard a **Kvichak MARCO Boom skimmer** that is owned and operated by the Marine Spill Response Corporation in Portland, Maine, USA

RanMarine's WasteShark autonomously cleans plastics, bio-waste, and other debris from waterways while collecting data with an onboard monitoring system

DESMI AWARE are remote-controlled electrical mobile units that consist of a floating platform mounted with four pontoons

DeltaSea Marine Debris Collection System is powered by solar and wave energy, has an onboard monitoring system, and can also be used for cleaning of oil and chemical spills. DeltaSea expects to have the technology available in 2021

ORCA-TECH has self-driving vessel models **SMURF20, TITAN60,** and **ELFIN**, which have been deployed in 20 cities around the world

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PUMPS & VACUUMS

Overview

Primarily designed for cleaning up oil and other chemical spills in marine environments, these pumps can also be successfully applied to plastic waste capture in rivers. Some of them are capable of adapting to different environments, such as the ORCA, while others are designed with more specific purposes, such as the Seabin; we will focus this profile primarily on these two model technologies.

The Seabin by the Seabin Project is a stationary electric skimmer that catches marine debris, including bottles, bags, cigarette filters, microplastic, and oil films; it captures on average 1.5 tons of trash per year. Credit: The Seabin Project

The Enviro Buggy by #SeaTheBiggerPicture Ocean Initiative and Matriarch Generic Engineering as seen cleaning a beach in Cape Town, South Africa, can also be adapted to clean along riverbanks..
Credit: Jay Caboz

Energy Source

Require external energy source. For example, Seabin requires AC power, either 110v or 220v. Power consumption is 2.5amps at 500 watts.

Dimensions

Varied. For example, the Seabin is 0.5 m diameter and 1.8 m height, weighing 55 kg. The ORCA is a multi-component system and is much larger, weighing nearly 1500 kg.

Maintenance

Varied. For Seabin, the catch bag can hold up to 20kg of marine debris and should be checked twice daily and emptied as needed. A non-toxic and highly durable anti-foul system reduces the cleaning to once every 6-8 weeks depending on the location.

Cost

Varied. The Seabin costs $3,825 and has an operating cost of approximately $3 per day. In open ocean environments, the ORCA can cost nearly $300,000, but may be less expensive in an enclosed bay or other protected waterway.

Suitable Conditions

Varied. ORCA works on land as well as in marine and riverine environments. The Seabin is designed to be installed in marinas, yacht clubs, ports and any other calm water body. It could be applied in rivers with relatively lower flow rates. In calm conditions, the Seabin has a 50m collection radius, but in windy or tidal conditions it relies on its strategic positioning for the wind and current to bring the marine litter to its location.

Environmental Impacts

Because these technologies rely on suction, marine life may be drawn into the systems.

Strengths

ORCA

- Operates in terrestrial and marine environments
- Able to recover large volumes using its Universal Hatch Cover™
- Versatile with multiple environmental applications

Seabin

- Affordable
- Autonomous
- Continuously catches everything floating in the water from plastic bottles and microplastics to paper, oil, fuel and detergent

Weaknesses

ORCA

- High cost
- Requires manual operation
- Marine life may be suctioned into the hose mouth, but may be safely removed from the receiving tank

Seabin

- Low collection capacity

A Seabin prior to deployment in a harbor.
Credit: The Seabin Project

Applications

The **Seabin V5** moves up and down with the range of the tide collecting all marine debris. Water is sucked in from the surface with a submersible water pump capable of displacing 25,000 liters per hour, and passes through a catch bag inside the Seabin. The water is then pumped back into the waterway leaving marine debris trapped inside the catch bag. The Seabin fleet removed a total of 1,316 kg of marine debris from Sydney Harbor in one month.

The **ORCA™ (Oil Refuse Cleaning Apparatus)** is a multi-purpose environmental recovery system that captures a wide range of pollutants and other refuse from both land and water. It has been used to clean up oil spills in Singapore.

SHORVAC is a robotic vacuum cleaner with a handheld sifting shovel that is used to remove plastic debris on land along coastal environments.

The **Enviro Buggy** from #SeaTheBiggerPicture and Matriarch Generic Engineering vacuums and sieves macroplastics and microplastics from sand on shorelines.

The ORCA™ (Oil Refuse Cleaning Apparatus) is a multi-purpose environmental recovery system that uses powerful vortex technology to generate wind speeds of up to 180 kph to suction debris. Credit: ORCA

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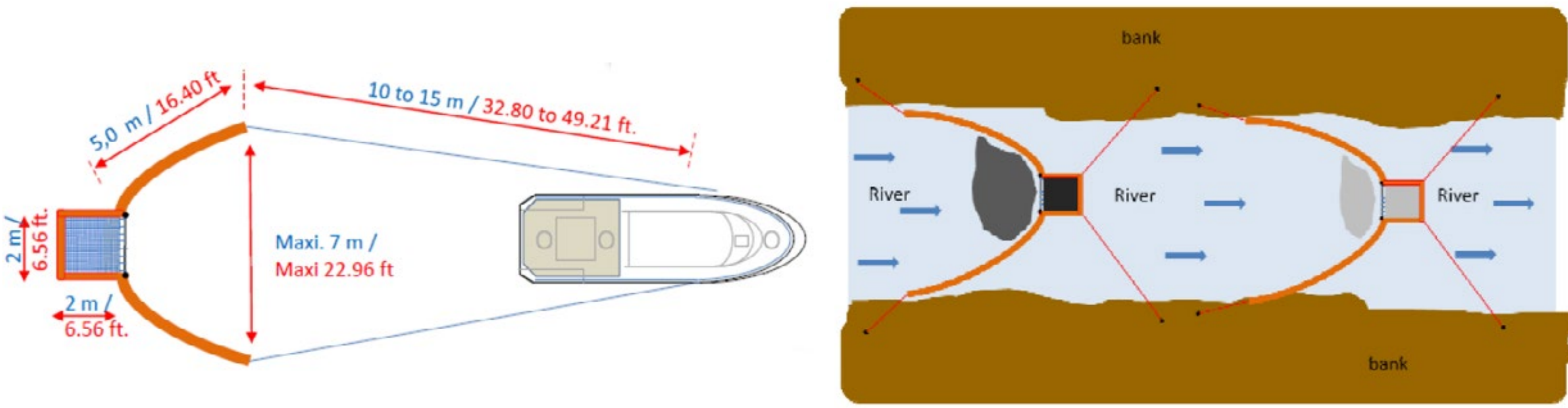
TRASH TRAWLS

Overview

Trash trawls, also called “trash catchers”, are usually inflatable and made of neoprene and a fine mesh filter net that collects litter. It is usually towed by a vessel and is most often used in oceans, but may also be towed or anchored in rivers.

More specialized trash trawling systems, such as the “manta trawl”, are primarily used for microplastic sampling in oceans and other waterways for research purposes, but could potentially be used for capturing microplastics in rivers.

The Trash Catcher by Waste Free Oceans is designed to be towed by a fishing vessel. Credit: Waste Free Oceans



Schematic of Waste Free Oceans' small trawler towed behind a vessel and anchored in a river. Credit: Waste Free Oceans

Energy Source

Towed behind a vessel or anchored to a riverbed or riverbank.

Dimensions

Trawls come in variable sizes. Waste Free Oceans' small net is 7 m long x 7 m wide, weighing 200 kg, and the large net is 20 m long x 21 m wide, weighing 650 kg. The 5 Gyres Manta Trawl is 1.5 meters wide with a 3 m long fine-mesh net. The mouth of the Manta Trawl is 60 cm wide, with two 45 cm floating wings on either side.

Maintenance

Maintenance can be high for larger trawls if cranes must be used to transport and empty the full nets. If the trawl is stored properly it can be reused multiple times; if punctured, repair may be difficult.

Cost

Costs can depend on size and materials and typically range from $20,000 to $50,000. There may be additional costs for training and installation.

Suitable Conditions

Trawls do well in open waters and oceans where they are pulled along the surface by boats to maximize trash capture. Nets may fill quickly in heavily polluted areas and would need access to cranes to move large volumes of waste. Anchoring in a river may require consideration of the river substrate, riverbank structure, and current speeds.

Environmental Impacts

Depends on the net mesh size. The net may trap surface organisms and smaller fish, possibly disrupting the ecosystem.

Strengths

- Trawl design and size can be adapted to the size of the river and amount of available plastic debris
- Portable and versatile; may be transported and used in different waterways in the same region

Weaknesses

- High maintenance and transportation costs
- Capture volume is limited by the size of the net
- Not well-tested in rivers; may not be durable and permanent anchoring may pose challenges

The Manta Trawl allows Save The Bay's Waterkeepers to collect microplastics from surface water in Narragansett Bay. Credit: Save the Bay - Narragansett Bay

Applications

Waste Free Oceans have applied their **Trash Catcher** trawler in association with fishermen from different places around the world.

Save the Bay's Waterkeepers use a **manta trawl** to collect and study microplastics from surface waters of Narragansett Bay, US.

5 Gyres has resources for the public about how to build **manta trawls** and **high-speed mini trawls.**

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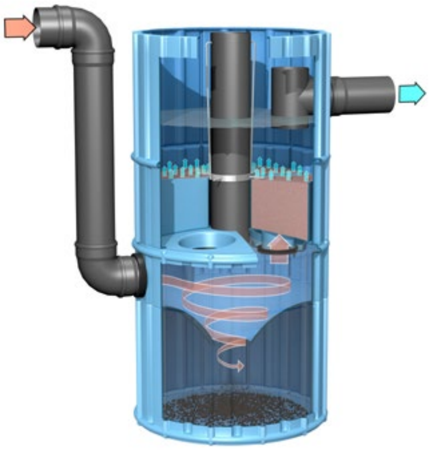
OTHER URBAN SOLUTIONS

Overview

This broad category includes technologies that are designed specifically for urban drainage infrastructure, such as storm drains, pipes, and culverts. Particularly in areas with heavy trash loads in urban runoff, these technologies can be effective and efficient. Most make use of various combinations of screens, filters, cages, and nets installed at drain inlets or outlets, or in-line with pipes.

The StormX Half Pipe by Storm Water Systems, Inc. in Carrollton, Texas. Credit: Storm Water Systems, Inc.



Bottom right: The Wing-Gate™ by United Storm Water, Inc. is a storm drain curb inlet cover that prevents debris from entering storm drains during the dry season, while opening automatically during specific water flow conditions to prevent street flooding.
Credit: United Storm Water, Inc.

Top left: A hydrodynamic separator, which is a flow-through structure with a settling or separation unit that removes sediments, floatables, and other pollutants.
Credit: Sustainable Technologies Evaluation Program;
Top right: Exploded view of the Original Gutter Bin by Frog Creek Partners, which is installed in a storm grate with a hinged access hatch for easy servicing. The Mundus Bag water filter removes various pollutants, including trash, microplastics, sediment, and oils.
Credit: Frog Creek Partners

Energy Source

Passive (no energy source required)

Dimensions

Variable. Generally can be custom sized

Maintenance

Varied. In some cases, occasional manual cleaning and repairs may be sufficient; in other cases, vacuum trucks and other trash removal equipment may be required.

Cost

Variable. Retrofitting existing storm water systems can be relatively inexpensive, but technologies requiring significant engineering and construction, such as hydrodynamic separators, can be quite expensive.

Suitable Conditions

Various urban settings

Environmental Impacts

Urban technologies may generally present relatively lower environmental risks than river-based technologies because of lack of exposure to wildlife and separation from natural waterways.

Strengths

- Prevent plastic waste from entering natural waterways
- More "upstream" intervention relative to river-based technologies
- May capture all debris within a give size class, relative to river-based technologies which generally capture floating debris only
- Can be retrofit or built into new structures

Weaknesses

- Generally smaller scale than river-based technologies and may require high replication to have a comparable impact

Applications

Frog Creek Partners has several products, including the **Original Gutter Bin**, the **Drop Inlet Filter**, and the **Channel Filter System**, all of which use the patented Mundus Bag water filter to remove trash, microplastics, sediment, oil, grease, and heavy metals.

Storm drain curb inlet covers are manufactured by several companies, such as the **Wing-Gate™** by **United Storm Water, Inc**. Screens prevent debris from entering the storm drain system and keep it on the street so it can be swept up manually or by street sweepers.

StormX by **Storm Water Systems, Inc**. is an end-of-pipe netting system that can be installed at the mouth of a sewer overflow or a drainage system. The net captures pollutants as small as 5mm, and built-in overflows allow heavy runoff to flow unimpeded.

The **CDS hydrodynamic separator** by **Contech** is a flow-through structure that uses swirl concentration and continuous deflective separation to screen, separate, and trap trash, debris, sediment, and hydrocarbons from stormwater runoff.

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