Hydrodynamics of Litter Study

Final Report

Report for Parks Victoria

December 2023

Prepared by: Streamology Pty Ltd
Level 1,753-755 Nicholson Street
Carlton North VIC 3054
www.streamology.com.au
ACN: 600 641 370

Client Contact: Personal Information

Consultant Contact: Personal Information

Cover image: Bandalong litter trap in the Yarra River, July 2023, Streamology.

Document Status

Version	Doc Type	Reviewed By	Approved By	Date Issued
V01	Draft	Personal Information		06/11/2023
V02	Final	CLA	CLA	11/12/2023

Executive Summary

Parks Victoria is actively working on litter management in the Yarra and Maribyrnong Rivers. The October 2022 floods damaged the existing litter traps located along both waterways, many requiring repairs or replacement. This study focussed on assessing the performance of the existing and alternative litter trap designs and locations, identifying issues and improvements for litter management.

The study was conducted in three stages. Stage 1 involved a detailed investigation of the hydrodynamic conditions of the lower Yarra and Maribyrnong Rivers to understand how litter moves through the waterways and how effective the existing litter traps are. Results indicated that Yarra River traps are located such that they trap a significant amount of floating litter (>50%), while for the Maribyrnong, only one of them (Flemington Racecourse) performed relatively well (30%) with trap location identified as one of the main factors affecting performance.

In Stage 2, modelling results were evaluated further to assess possible changes in the location of litter traps to improve their performance and opportunities for alternative litter management devices. As identified in Stage 1, trap location is a key determiner of success, and relocating existing traps can significantly increase performance, especially in the Maribyrnong River. A wide range of alternative litter management devices were investigated, and compared in terms of their effectiveness, technical suitability, impacts and costs. In general, the effectiveness and feasibility of different trap management devices was related to the type of litter the device targets (e.g., small or large) and where they can be located (e.g., constraints such as access or power). Conveyor belt systems are effective to trap large quantities of medium to large litter types but have a high implementation and maintenance cost. Other alternatives, such as the Bubble Barrier, are more effective for smaller litter types, and can extend across the entire width of the waterway, have high implementation costs but lower maintenance costs.

Building on the outcomes of the previous stages, Stage 3 assessed how combinations of different devices could be deployed to target a wide range of litter sizes and device capacity in both the lower Yarra and Maribyrnong Rivers. The scenario comparison showed how litter management requires an integrated approach, combined with knowledge of the targeted litter types, sources and pathways.

Acknowledgement of Country

Aboriginal cultural landscapes form the core of Victoria’s network of parks and reserves and have been modified over many thousands of years of occupation. They are reflections of how Aboriginal people engage with their world and experience their surroundings and are the product of thousands of generations of economic activity, material culture and settlement patterns. The landscapes we see today are influenced by the skills, knowledge and activities of Aboriginal land managers. Parks Victoria acknowledges the Traditional Owners of these cultural landscapes, recognising their continuing connection to Victoria’s parks and reserves and ongoing role in caring for Country.

Acknowledgement of Funding

This project is funded by the Victorian Government, through funding from the Australian Government.

contents

1. **INTRODUCTION** **1**

1.1. Overview **1**

1.2. Scope & reporting **1**

2. **STAGE 1 HYDRODYNAMIC STUDY** **2**

2.1. Objectives **2**

2.2. Methodology **3**
2.2.1. Hydrodynamic models 3

2.3. Outcomes **6**
2.3.1. Yarra River litter traps 6
2.3.2. Maribyrnong River litter traps 8
2.3.3. Performance issues 10

2.4. Suggested improvements **11**

3. **STAGE 2 OPTIONS TO IMPROVE LITTER MANAGEMENT** **12**

3.1. Objectives **12**

3.2. Methodology **12**

3.3. Outcomes **13**
3.3.1. Existing traps performance improvements 13
3.3.2. Review of alternative litter trap designs 15
3.3.3. Conveyor belt systems review and feasibility analysis 19
3.3.4. MCA of shortlisted options 23

4. **STAGE 3 INTEGRATED PROGRAM DEVELOPMENT** **30**

4.1. Objectives **30**

4.2. Methodology **30**
4.2.1. Base case 31
4.2.2. Scenarios 33

4.3. Outcomes **37**

5. **SUMMARY OF FINDINGS AND RECOMMENDATIONS** **41**

5.1. Performance issues and improvements **41**

5.2. Conveyor belt systems feasibility and implementation analysis **42**

5.3. Integrated litter management programs **42**

5.4. Complementary works **43**

6. **ATTACHMENTS** **44**

ATTACHMENT 1: HYDRODYNAMIC MODELLING REPORT **44**

ATTACHMENT 2: PRODUCT REVIEW SPREADSHEET **45**

ATTACHMENT 3: MCA **45**

1. Introduction

1.1. Overview

Parks Victoria is the Waterway Manager of the lower reaches of the Yarra and Maribyrnong Rivers. They have actively worked on litter management in these waterways for over 20 years. The flood events in October 2022 damaged the existing litter traps with significant impacts on those traps located in the Maribyrnong River. All three traps on the Maribyrnong River required repair or replacement following the floods. However, due to constraints such as water depths and river traffic, there are limited opportunities to alter the location of the current litter traps or add additional litter traps to the system.

This study aimed to assess the performance of the Yarra and Maribyrnong litter traps and identify improvements. The improvements could be in the form of alterations to the current trap system or the development of the next generation of litter traps and devices. In addition, the study also assessed whether the hydrodynamic conditions, litter types and quantities, and movement patterns in the project area are suited to the existing type of litter traps.

1.2. Scope & reporting

This report summarises the three stages of this project.

- Stage 1 was a detailed investigation of the hydrodynamics of the lower Yarra and Maribyrnong Rivers, assessing how litter moves through the system and the performance of the existing litter traps.
- Stage 2 built upon the learnings of Stage 1 to evaluate changes to litter trap locations to improve their performance, as well as a desktop investigation of a wide range of alternative technologies for managing litter in river systems. The various systems were compared based on their effectiveness in removing different types of litter, their technical suitability for application to the lower Yarra and Maribyrnong Rivers, potential impacts, and costs (implementation and maintenance).
- Stage 3 then extended the outcomes of Stages 1 and 2 to develop a series of litter management scenarios, which incorporated a range of litter trap systems to optimise Parks Victoria's ability to manage litter in these rivers.

Each stage of the project is summarised in this report, with further technical details provided as Attachments.

2. **Stage 1 Hydrodynamic Study**

2.1. Objectives

The objectives of Stage 1 were:

1. Illustrate the inflows and movements of litter and river surface water on the two rivers.
2. Assess the suitability and effectiveness of the current litter trap design and locations.
3. Identify the main reasons for litter loss from existing litter traps on the Maribyrnong River.

For this analysis the litter trap performance on both the Maribyrnong and Yarra Rivers were assessed in order to understand why the Yarra River sites perform better than the Maribyrnong sites. This also assisted in setting the performance criteria for the evaluation of the traps and other devices in Stages 2 and 3.

The existing litter traps are a Bandalong type system which is a floating device that uses large polyethylene pipes for buoyancy and is held in place at a strategic location along the waterway by chains (Figure 1). They have outspread collector booms to intercept floating litter and guide it towards a one-way gate into the trap where it is kept until removal. A polyethylene side skirt beneath the water line prevents debris escaping under the main floats[1].

Figure 1. Bandalong litter traps along the Yarra River (30/07/2023).

[1] Bandalong International (2023). https://www.bandalong.com.au/bandalong-litter-trap.html.

2.2. Methodology

Stage 1 involved the collection of field data (bank information, bathymetric data, current speed data), trap performance (time lapse cameras) to inform the modelling of the hydrodynamic conditions in both rivers. Once the data was collected, models were setup and used to simulate flow and litter conditions in the rivers using a novel particle tracking approach.

The general steps in Stage 1 are summarised in Figure 2 below, while a summary of the hydrodynamic modelling method is also provided.

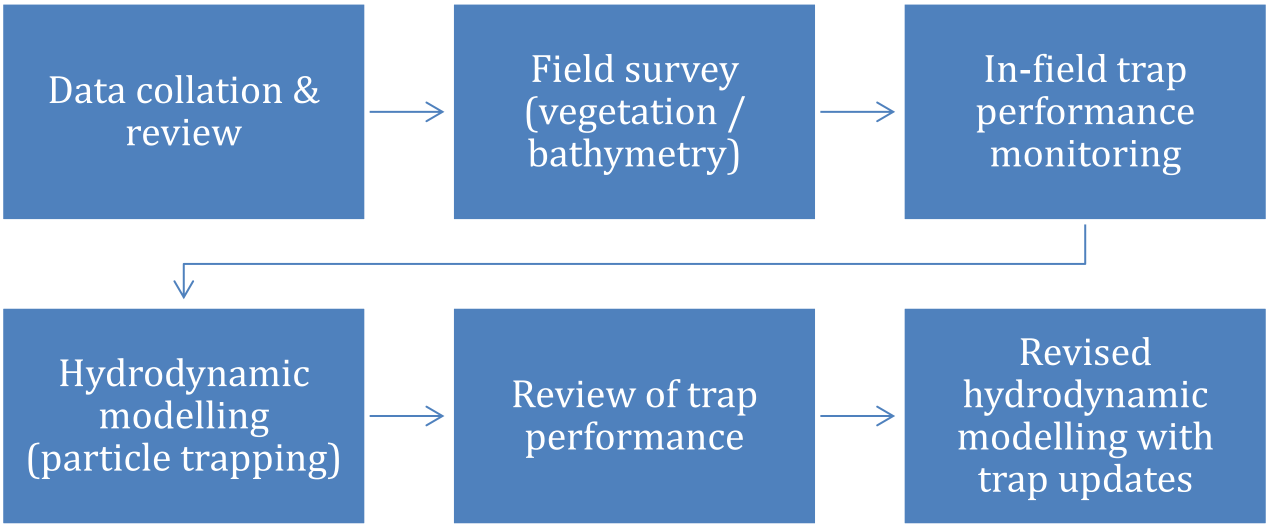


Figure 2. Summary of steps undertaken in Stage 1.

2.2.1. Hydrodynamic models

Hydrodynamic models were developed for the Yarra and Maribyrnong Rivers using the industry standard Delft3D software. The model grids included 25 and 16 grid cells respectively across the width of the Yarra each river channel to enable a detailed representation of the flow velocity and how is varies across the channel. Features in the river such as bridge piers were explicitly included as they can alter the flow pattern and influence litter movements. A detailed modelling report is included in Attachment 1.

The models were calibrated against measured water level and (limited) velocity data. Two simulation conditions were applied:

- Typical river and tidal flows (i.e., low flows based on 8th to 15th July 2022)
- Higher river flow conditions (based on the October 2022 flood hydrograph shape but with the peak flows scaled down so that flows remain in-channel).
- Both conditions were run without (base case) and with litter traps.

Litter traps were included in the model based on their general dimensions and by blocking surface flows to enable them to "capture" litter. The modelled traps included were (Figure 3 and Figure 4):

- Yarra River: 6 sites - Federation North Wharf (11), Sandridge North (13) and South (14), South Wharf Exhibition (15), Webb Bridge North (17) and South (16).

- Maribyrnong River: 3 sites - Edgewater Marina (1), Flemington Racecourse (2) and Dynon Bridge (3).

The movement of litter was simulated by the release of model particles at the upstream boundary of each model. These floating particles then move with the currents and their paths were tracked for the duration of the simulation. The results were analysed to assess how many litter particles were "captured" in each litter trap and the overall pattern of litter movements to inform potential new locations or improvements for Stage 2.

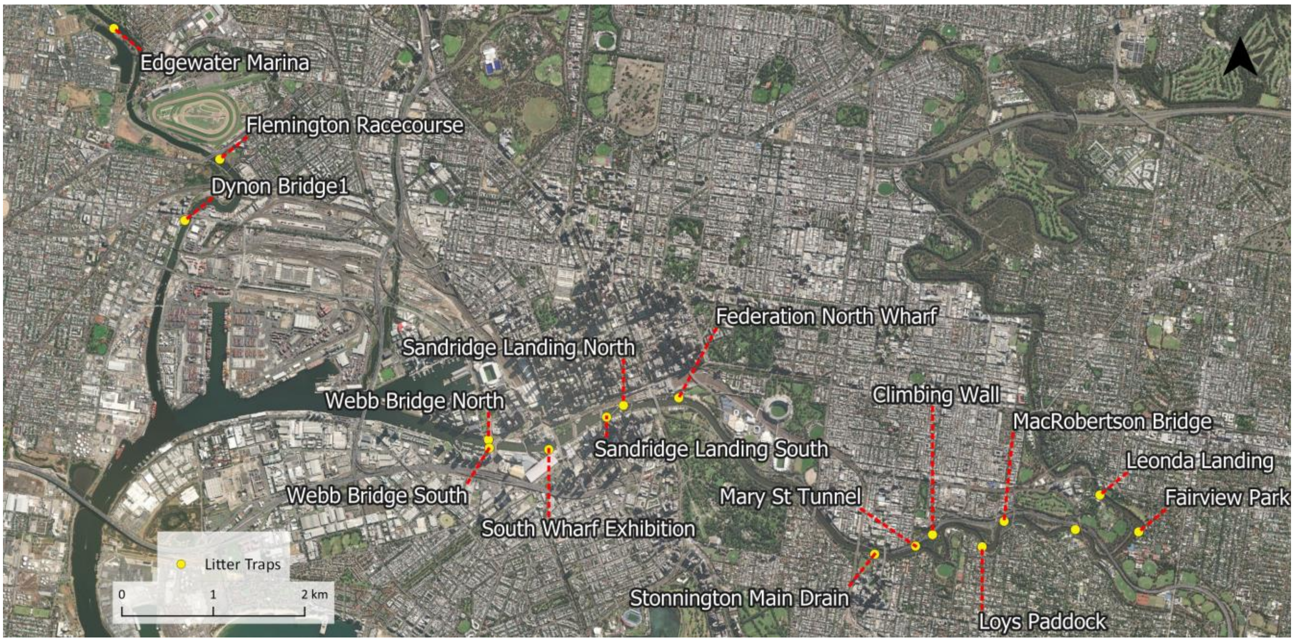
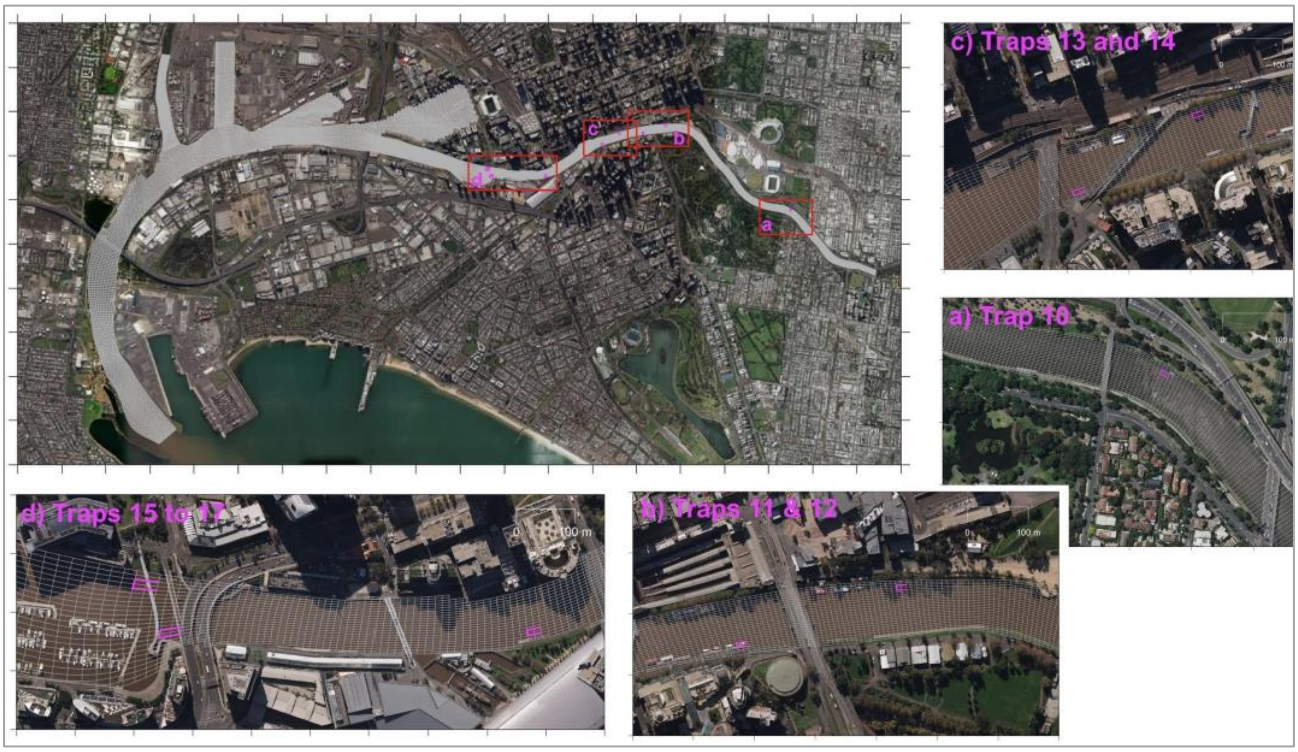


Figure 3. Location of existing litter traps along the Yarra and Maribyrnong Rivers.



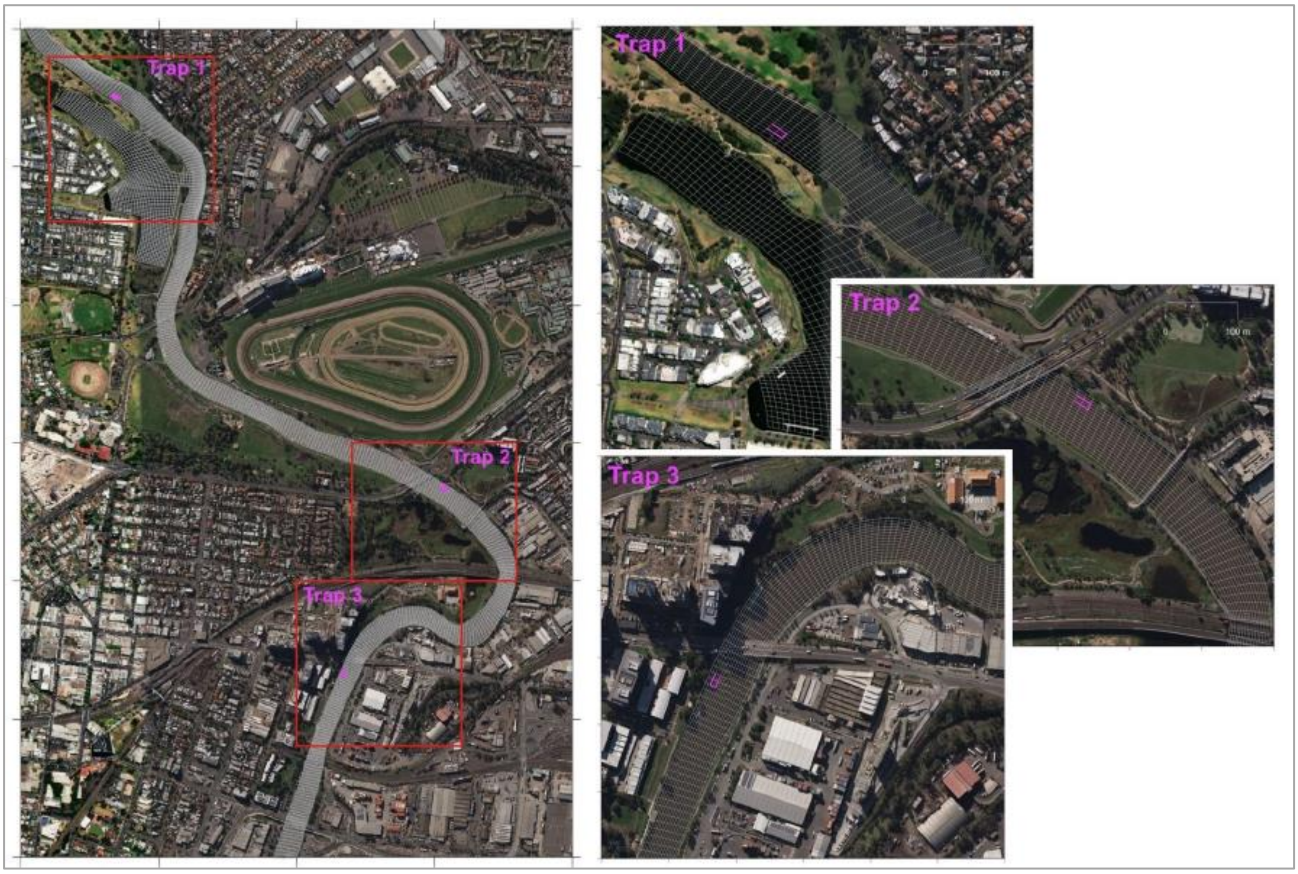


Figure 4. Model grid for the existing litter trap locations at the Yarra River (above) and Maribyrnong River (below).

2.3. Outcomes

2.3.1. Yarra River litter traps

Flow conditions

Flow conditions for the Yarra River were described as:

- Currents vary spatially across the channel, with highest speeds in the centre (0.4 to 0.5 m/s) reducing towards the banks (<0.3 m/s).
- Bridge piers blocked the flow and modified the flow patterns.
- Current speeds at the litter trap locations ranged from 0.2 m/s to 0.5 m/s under typical conditions but increased to 0.75 to 1.75 m/s in the higher flow conditions scenario.
- River flows were dominant in terms of current speed and duration under both typical and high flow scenarios.

Litter movements

Overall, the litter tracks are well distributed across the channel, meaning that that most of the existing litter trap locations should be successful in intercepting litter. Specifically:

- Around trap 14 (Sandridge South) there are slightly more litter tracks along the northern side of the channel compared to the southern, although the tracks are uniformly distributed across the channel (Figure 5).
- The distribution is similar between typical and high flow conditions.
- Trap 11 was predicted to be the most effective, with it predicted to capture 19% and 27% of the particles released during the typical and high rainfall conditions respectively.
- Trap 17 (Webb Bridge North) shows the lowest performance in trapping litter because of a flow eddy at the downstream of the Webb Bridge and the pedestrian bridge (Figure 6).

Overall, the results indicated that the Yarra River traps modelled captured between 65% and 69% of the floating litter particles released, with the majority captured by Traps 11, 13 and 16.

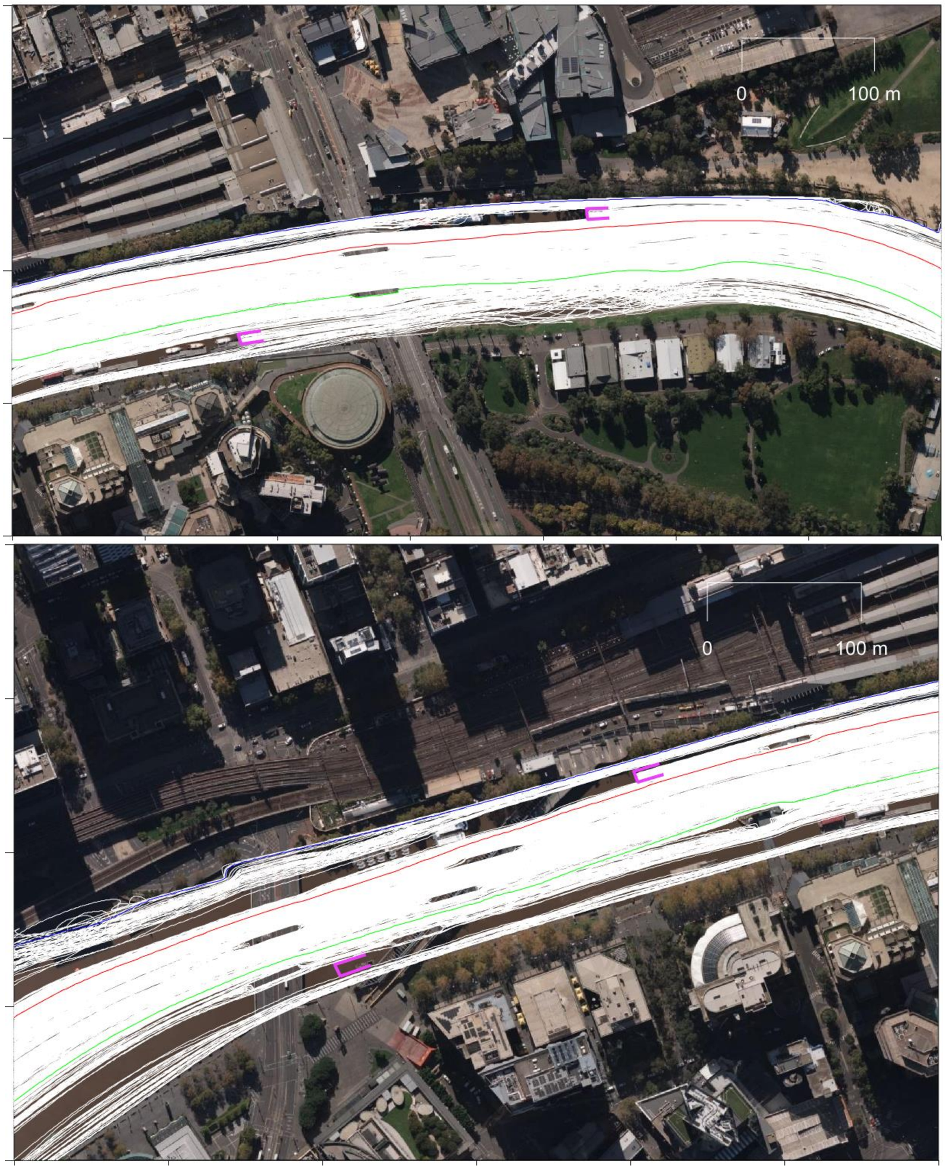


Figure 5. Litter tracks (white) along the Yarra River under typical flow conditions, with example individual tracks shown in blue, red and green. Litter traps are represented with magenta rectangles.

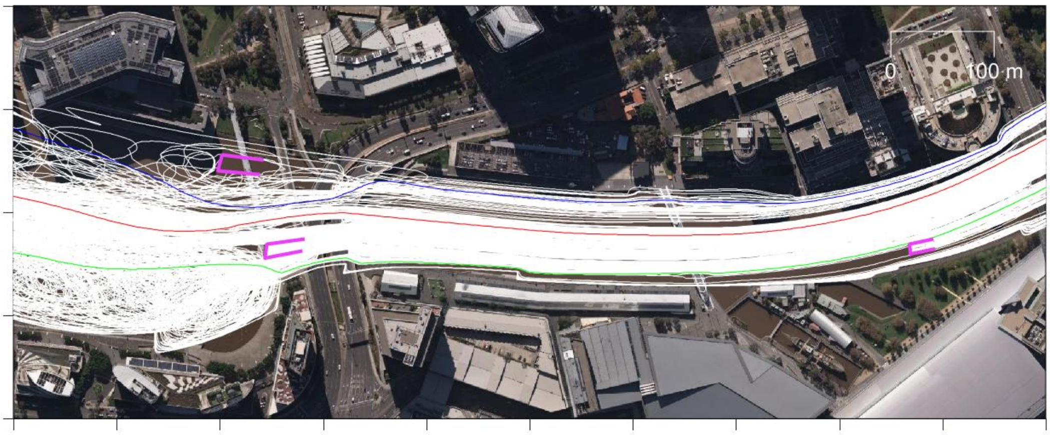


Figure 6. Litter tracks (white) along the Yarra River section near Webb Bridge under typical flow conditions, with example individual tracks shown in blue, red and green.

2.3.2. Maribyrnong River litter traps

Flow conditions

Flow conditions for the Maribyrnong River were described as:

- Currents were relatively uniform across the channel but varied along the channel.
- Current speeds are relatively low under typical conditions (0.2 m /s to 0.5 m/s) but increased to 1.0 m/s in the higher flow conditions scenario.
- River flows were dominant in terms of current speed and duration at all three sites, but the currents did have periods of flow in the upstream direction at low speeds.

Litter movements

The performance of the litter traps was more variable than the Yarra River sites, with fewer litter particles trapped in general. Specifically:

- Traps 1 and 3 are predicted to capture very few floating particles during typical conditions (<2% of particles released) compared to Trap 2 (30% of particles released). Trap 2 is predicted to catch almost a third of all litter particles released (30%).
- Trap 1 (Edgewater Marina) - during typical conditions the litter particle tracks are predominantly moving along the centre of the channel and northern bank, while the litter trap is located on the southern bank (Figure 7). This pattern strengthens under higher flows with no litter movements into to around the existing litter trap location.
- Trap 2 (Flemington Racecourse) - under both typical and high flow conditions there are more litter particle tracks on the centre and northern bank of the channel where the litter trap is located (Figure 8).
- Trap 3 (Dynon Bridge) - during typical conditions the litter particle tracks are predominantly moving along the eastern side of the channel, while the litter trap is located on the western bank. This trap did not capture particles under either condition (Figure 9) and may perform better in capturing litter inputs close to the trap or if strong wind conditions alter the surface currents.

Figure 7. Litter tracks (white) along the Maribyrnong River section near Edgewater Marina under typical flow conditions, with example individual tracks shown in blue, red and green.

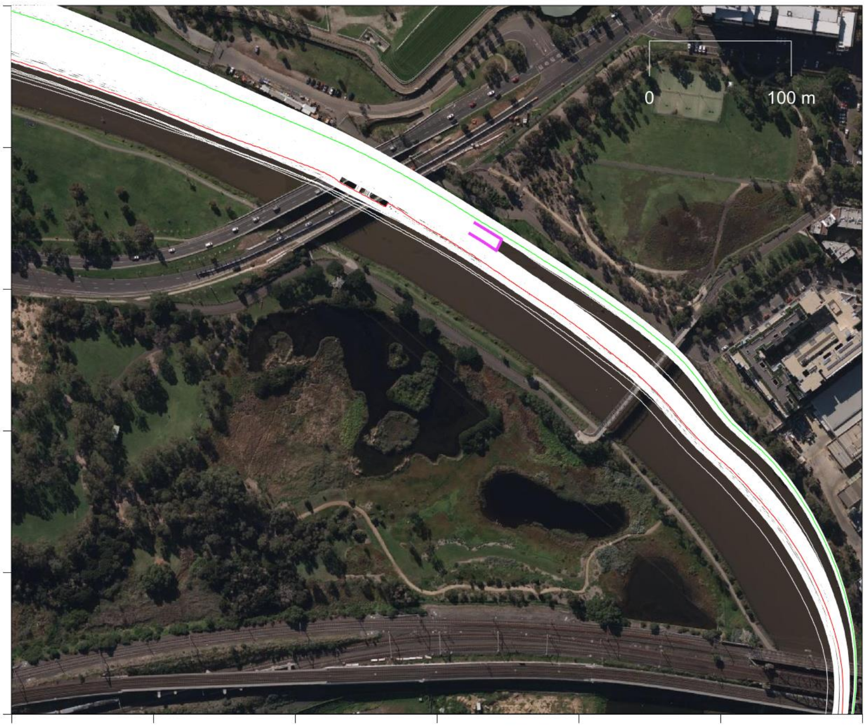


Figure 8. Litter tracks (white) along the Maribyrnong River section near Flemington Racecourse under typical flow conditions, with example individual tracks shown in red and green.

Figure 9. Litter tracks (white) along the Maribyrnong River section near Dynon Bridge under typical flow conditions, with example individual tracks shown in red and green.

2.3.3. Performance issues

The current litter traps are all Bandalong type devices which operate by capturing litter floating at or near the surface. Ideally the litter remains in the trap and can be physically removed.

The litter traps in the Yarra River are all located such that they trap a significant proportion (>50%) of the litter passing along the reach. The performance of Trap 17 is affected by the eddy produced by the Webb Bridge.

For the Maribyrnong, only Trap 2 (Flemington Racecourse) performed relatively well in all simulations, but even this trap was not as effective as the Yarra River sites. Trap location is the main factor affecting their performance e.g., Traps 1 and 2 were clearly bypassed by most particles released.

In terms of the release of litter once captured, the following performance issues were identified:

- Slack water or upstream tidal flows during low river flow conditions can move litter out of the traps in the Maribyrnong River. These conditions are less common at the Yarra River trap sites.
- The exact mechanisms for loss of litter have not been confirmed but appears to be due to opening of the gate at the entrance to the traps when there are upstream currents. This

could be the result of litter/debris forcing the gate open or becoming stuck under the gate keeping it open or lifting it above the water surface.

The following observations were made from the time lapse videos deployed on the litter traps on both rivers:

- Site 17 Yarra River (Webb Bridge North), the entrance appears to open at times with a lot of litter movement within the trap. This may be the result of the more variable currents in this location.
- Site 16 Yarra River (Web Bridge South), a piece of wood is seen blocking the entrance.
- Site 3 Maribyrnong River (Dynon Bridge), the litter moves upstream and downstream within the trap and later in the video the entrance appears to be slightly open.
- Site 2 Maribyrnong River (Flemington Racecourse), the trap performance was impacted by large wood in the river which submerges the trap along the left side for a period. The gate was also observed not to be working properly. The left side of the trap appeared to be often underwater.

2.4. Suggested improvements

Overall, the main factors influencing litter trap performance were:

- The trap location relative to the surface currents within the river, with better performance when the currents were more uniform across the channel.
- Shorter duration slack water or upstream tidal currents which limits the potential for litter to exit the trap through the entrance.
- Large debris can get jammed in the traps, affecting the opening mechanism.

Improvements to the litter trap locations and configurations were then analysed in the models for Stage 2.

3. Stage 2 Options to improve litter management

3.1. Objectives

The objectives of Stage 2 were:

1. Evaluate improvements to the existing litter trap based on outcomes from Stage 1.
2. Review and assess alternative litter interceptor design collaboratively with Parks Victoria to determine the most feasible options.
3. Review and assess alternative conveyor belt systems.

The results of Stage 1 identified that the location of the existing litter traps was a significant influence on their performance on both the Maribyrnong and Yarra Rivers and provided insight into what performance criteria were important when evaluating alternative litter interceptor designs.

3.2. Methodology

Stage 2 involved the re-evaluation of the existing litter traps within the Yarra and Maribyrnong Rivers using the hydrodynamic model. The suggested improvements from Stage 1 were incorporated in the models and changes to litter trap performance were assessed. In parallel a detailed review was undertaken of a range of alternative litter traps/devices, including conveyor belt systems.

Based on the updated modelling and the review, the most feasible options for implementation by Parks Victoria were identified and a multicriteria analysis approach used to compare these different systems. The general steps in Stage 2 are summarised in Figure 10.

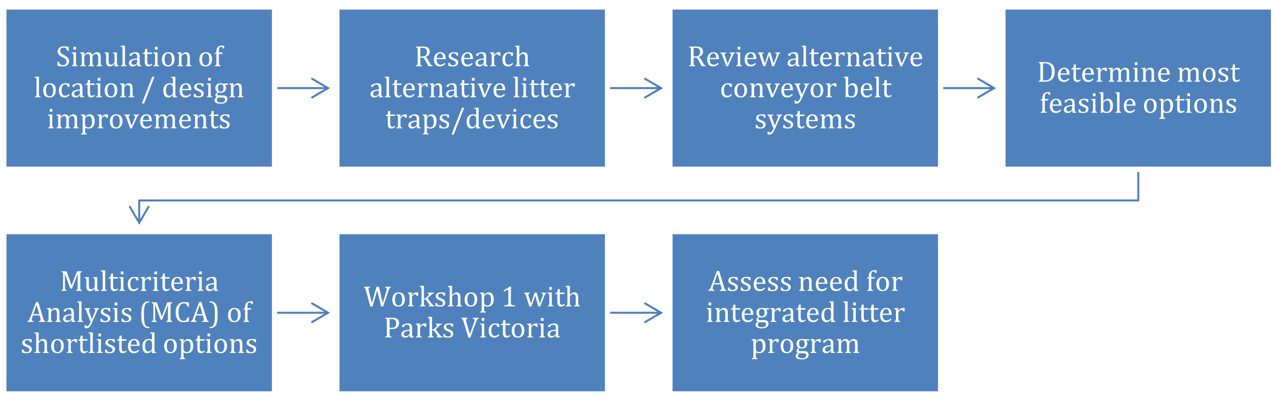


Figure 10 Summary of steps undertaken in Stage 2.

3.3. Outcomes

3.3.1. Existing traps performance improvements

The suggested improvements to the location and configuration of the existing litter traps were incorporated into the hydrodynamic model and the improvement to the performance of the traps was re-evaluated. The outcomes are briefly discussed below, while further detail is provided in Attachment 1.

Yarra River

For the Yarra River the focus was on efficiency improvements for the existing litter traps and exploring new types of traps.

- Moving Trap 17 to upstream of the Webb Bridge improved its litter trapping performance from 1% to 19%. The blue example litter particle track in Figure 11 shows how the litter tracks can be influenced by the eddy from the bridge.

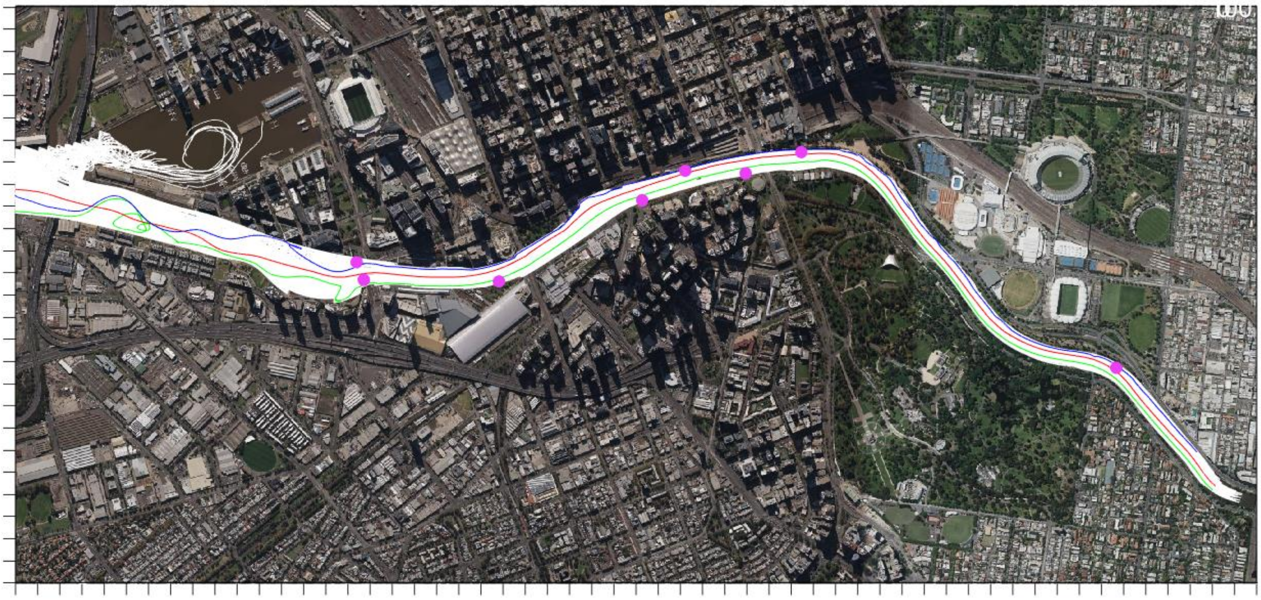


Figure 11. View of the litter trap locations along the Yarra River (pink dots) with the litter tracks of all the particles released (white) along with example individual tracks in blue, green and red.

- Extending the booms on the litter traps to the nearest riverbank, resulted in 10% more litter being captured during typical conditions, but very little difference during high rainfall conditions. The performance of some downstream traps decreased because more litter was captured upstream so there was less transported and therefore available for capture.

- A bubble barrier type litter trap device was included in the model. This alternative litter interceptor design is discussed further in the next section; however, it acts to direct litter towards the banks of the river and increases the overall litter capture by 9% during both typical and high rainfall conditions. Most of the additional litter was captured by Trap 16 (Webb Bridge South).

Maribyrnong River

For the Maribyrnong River sites, location was identified as the biggest influence on performance and the focus was on relocating the existing traps to improve performance. Figure 12 shows the location of the existing litter tracks along with the litter particle tracks. A boom type arrangement which extends the litter trap to the adjacent bank was also incorporated.

Figure 12. View of the litter trap locations along the Maribyrnong River (pink dots) with the litter tracks of all the particles released (white) along with example individual tracks in blue, green and red.

- Moving Trap 1 so that it is opposite of Trap 3, but upstream of the Dynon Bridge, increases its performance from 1% to 19% for typical conditions.
- Extending the boom from the relocated Trap 1 so that it reaches the riverbank significantly increases its performance, from 19% to 70% during typical conditions and 15% to 77% during high rainfall conditions.
- Extending the boom of Trap 2 so it reaches the riverbank results in an increase in the effectiveness of Trap 2 of 31% to 59% in typical conditions, but a slight reduction during high rainfall conditions, as the additional surface blockage slightly diverts the upstream flow away from the trap.

Overall, the results showed that altering the location of the existing litter traps can significantly improve their performance on the Maribyrnong River.

3.3.2. Review of alternative litter trap designs

A literature review and product search were conducted to collect and review information on alternative litter trap designs. The search covers a total of 24 alternative designs that are being used both in Australia and the rest of the world. The findings are presented in a spreadsheet format (Attachment 2) which allows to review and compare their feasibility for different applications, technical requirements, and costings.

Table 1 summarises information on designs or products that were considered most relevant to the scope of this study and most feasible to implement in both rivers. Photographs or sketches of each design together with a feasibility summary are included in the spreadsheet (Attachment 2).

Table 1. Literature review/product search results – Summary of most feasible options for MCA

Design	Type of design	How it works	Size/scalability	Performance	Technical requirements	Feasibility of design		Costs		
						Pros	Cons	Cost of device	Maintenance costs	Manufacturer
Mr. Trash Wheel	Conveyor belt large scale	Semi-autonomous large scale trash interceptor that is placed at the end of a river or outfall. Using containment booms captures litter flowing down the river and funnels it to the belt. Can stop oil licks.	Containment booms and funnels, booms have 2 ft (0.6 m) skirt (underwater litter). Conveyor belt is very strong (captures tires, mattress, trees). 14 ft (4.3 m) water wheel, powers rakes and conveyor. Skip bin on separate floating barge.	Can collect up to 17.2 m3 of litter. Solar panels can produce 2,500 watts of electricity.	Solar and hydro powered, must be tailored to the river. The trash wheel works well in medium to large rivers due to its size. Ideal conditions include a relatively small range in water level, low to medium flow rates, low to medium vessel traffic, and accessibility for onshore transfer of bin.	Can withstand storms (durability). Picks up mostly large litter types. Can operate in tidal waterways. Reusable refuse containers (skip bins instead of nets), reducing operational cost. Renewable power source, visually appealing and low maintenance.	Large size, fixed position Might disturb navigation. Low to medium flow range and water level change. Requires boat to retrieve trash dumpster from water. Patented technology.	Between USD Commercial Information K for device and installation. Commercia estimated (AUD).	Up to Commercia per year, based on drainage size, not including tipping fees for skip bins. $600/ton.	International manufacturer: Invented and constructed by Clearwater Mills, LLC http://www.clearwatermills.com/ MrTrashWheel@WaterfrontPartnership.org
The Rise - DESMI	Conveyor belt mid-scale	Electrically powered system designed to guide floating litter and debris for easy on-land recovery with perforated belt designs (double belt system).	Made in marine grade aluminium and buoyancy is created by high abrasion resistant pontoons. *Rise A Series*: dual electrically driven belt systems to load material away from water on an angled belt in a left or right direction. *Rise S Series*: electrically driven belt lifts debris out of water draining free water by gravity (up to 9m transport length).	Both models: 3,500 kg/hr recovered waste.	Electrically powered, requires space onshore for skip bins and truck access.	Can withstand storms (durability). Easy to assemble and operate. The angled belt is counter balanced making the transport of waste material safe and easy. Waste is recovered on-land, reducing maintenance costs of boat servicing.	Requires electricity to operate. On-land bins should be covered to avoid wind/storms/fauna.	Commerc from pers.comms with PV[2].	Comme K/y for maintenance (estimated from Geoff trial data) and Comi K/y in electricity usage cost. Total of $62 K/y.	Process Pumps (Aust) Pty Ltd. Unit 5 / 385 Dorset Road, Boronia, Victoria Melbourne (Head Office) Australia Phone: +61 03 9762 9222 Fax: +61 03 9762 9233 E-mail: Personal I [at] processpumps.com.au
ARC 2nd Generation – Ocean Crusaders	Conveyor belt mid-scale	Autonomous conveyor belt vessel (not yet developed). Floating debris is captured by two floating boom arms and guided towards the conveyor belt guiding litter to a skip bin (on	Medium sized conveyor belt system (1.5 m wheel), with 1 large skip bin on separate barge or on land (dual belt system for this option). Bigger belt and pontoons than Geoff prototype.	NA - estimated higher than Geoff prototype.	Space on land needed: 5m2 flat space with access for a skip bin truck to back up to the skip. The belt will be covered with solar panels and the drive would be incorporated with the conveyor. Anchored to bottom of river permanently with sea piles, preventing	Relatively resistant to large rainfall events. Has remote monitoring capability. Renewable power source, visually appealing and low maintenance.	Not yet built or trialled. Not yet decided if on land recovery will be the best option, boat servicing required if not. Fixed to bottom makes it less adaptable/flexible to manage and move around.	Commercial Infor K, dual belt (on land recovery) additional Commercial Inf K.	Similar to Geoff (prototype) Comme K/y.	Ocean Crusaders in Queensland, Australia.

[2] This cost seems underestimated as aluminum costs are high and, for its dimensions, it was initially estimated in Commercial Inform Costs are estimated to be similar to the 2nd Generation of ARCs by Ocean Crusaders.

Design	Type of design	How it works	Size/scalability	Performance	Technical requirements	Feasibility of design		Costs		Manufacturer
						Pros	Cons	Cost of device	Maintenance costs	
		separate barge or on land), monitored by cameras. Powered by solar panels.			movement and increasing efficiency.					
Bandalong Boom Systems	Containment boom	Floating litter deflection and capture system that can be installed fully or partially across a waterway, or in conjunction with a Bandalong Litter Trap	The floating boom sections are coupled together, capturing floating litter and debris in a centralized location and preventing it from floating further downstream. The Bandalong Boom System can be custom designed to suit the specific site conditions of each location. Each boom is manufactured from exceptionally strong high-density polyethylene (HDPE) to ensure lasting durability.	NA	Only chains and anchors required to hold the system in place, can be located below ground.	Suitable for most waterways. Has litter removal service.	Not very resistant to floods. May not capture litter deep in water column. Capture rates are low with low flows. If the boom is not properly maintained and emptied regularly, the build-up of debris could have a negative impact on aquatic life (fish entanglement).	Approx. Commerci	Depending on the site approx. Comme /additional ft	Bandalong International, can be manufactured in Australia.
The Waste Shark	Litter drone	Drone that can vacuum litter from the water surface to collect in basket under the catamaran. The Waste Shark returns to its home base on the coast/bank whenever the basket is full.	Dimensions: L: 161cm H:46cm Width 114cm. Weight: 45 kg. There are 2 types: Manual and Autonomous (computer managed).	It takes 1 hour to fill the collection basket. Up to one-ton waste removal per day (per unit). Up to 160 litres (43 gallons) per deployment.	Radio-controlled guidance 3km range/ 5km range. Requires batteries.	Removable basket cartridge for easy disposal Onboard POV operator camera Live data-capable - real-time water health quality data/depth	Storm or flood resistance is unclear. Compact size, low collection capacity. Manual type needs supervision and manual servicing. Does not trap suspended litter. Uses batteries.	Commercial infor (includes portable flight case and annual data connectivity for 24/7 communication with device)	Minimal, may require battery and oil changes, lubrication.	Manufactured by Drone Solution Services, Singapore.
The Shoreliner	Litter trap	The Shoreliner is a capture and recycling system by TAUW, solely making use of water and wind flows. Fixed litter trap design.	Similar to existing Bandalong litter traps. Can be tailored to every river condition.	NA	Fixed to the riverbank.	Removes macro and micro plastics in surface water. Has been successfully used in Italy (Taranto), can be tailored to different settings.	Only removes litter on surface. Changing flow directions? Capture rates al low with low flows. Requires manual emptying.	NA	NA	Manufactured in Rotterdam by TAUW.

Design	Type of design	How it works	Size/scalability	Performance	Technical requirements	Feasibility of design		Costs		Manufacturer
						Pros	Cons	Cost of device	Maintenance costs	
The Great Bubble Barrier	Bubble barrier	Bubble screen from the bottom of waterway to water surface. Upward current brings floating litter to the surface where it is guided to a litter trap. The bubble screen originates from pumping air through a pipe that's fixed on the bottom of the waterway.	The Bubble Barrier covers the entire width and depth of the waterway. The bubble curtain is created by a perforated tube anchored to the bottom of the waterway where air is pumped through. An electric compressor supplies the air for the Bubble Barrier (placed in an insulated container onshore). The catchment system retains litter until removal.	86% of test materials were successfully caught. Total capacity of trap is 700 kg. 85 kg/month in Amsterdam.	Electric compressor needs connection to electricity grid and a container for protection (8 -20 ft, to accommodate a 400 V air compressor). Antifouling self-sinking (anchored) hose EPDM enforced with steel cable. Ideal for rivers up to 230 m and for flows up to 1.0 m/s, and up to 9 m depth. Initial feasibility study of waterway is included in design phase.	Does not affect fish movement or boat traffic (in comparison to conveyors, traps and booms). Catches litter with a size range of 1 mm to 1 m, all types and shapes of objects. Can be worked with other systems (i.e., existing traps) as complement. Bubble hose is self-purging and low maintenance. Designed to resist 10 years.	Can't catch larger litter over 1 m. Flow velocities above 1 m/s have not been tested yet. Patented technology.	Commercial Informatio Euros. Estimated in Commercia based on river width and depth.	Maintenance is mainly to the air compressor, once or twice a year, due to change in filters. Approx cost is under 20 K/y. Electricity cost estimated in 5 K/year. Total of $ 25 k/y.	The Great Bubble Barrier, Amsterdam.
River Cleaning System	Rotating modules	Round floating modules, positioned diagonally on width of river, anchored with flexible lines to a rail at the bottom. As modules spin, intercept litter and move it to the riverbank, into a trap.	Depending on river size and strength of current it can be tailored to any river. Devices are solid and able to come in contact with any boat types.	Efficiency level measured at 85% (Italy). Collect all waste larger than 1.5cm floating within 1m depth.	Requires a current to rotate the modules.	Self-powered, autonomous 24/7, allows navigation. Scalable, easy to install and dismantle. Malfunctions are limited to individual modules rather than entire system. Adjusts to changes in water level.	Relies on river flow direction and consistent flows to operate. Does not collect submerged debris (over 1 m depth). Microplastics (under 1.5 cm) not intercepted.	Commercia for implementation	Weekly ordinary maintenance is extremely reduced Failures are limited to individual units, allowing fast repairs and substitutions. Commerci year in maintenance.	River Cleaning, Cassola, Italy

3.3.3. Conveyor belt systems review and feasibility analysis

Within the review of the alternative designs, a range of conveyor belt systems were included to analyse the feasibility of the designs to be implemented in the Yarra and Maribyrnong Rivers. The information gathered from a range of sources[3] resulted in a total of 5 conveyor belt systems which were included in the feasibility analysis. In parallel to this review, Parks Victoria has been undertaking a field-based feasibility assessment of conveyor belt systems and so we have provided a targeted summary of these systems here.

Conveyor belt systems are autonomous or semi-autonomous litter interceptor devices, usually placed at the downstream reach of a river or waterway to prevent litter entering the ocean. Using containment booms or barriers, they capture litter from the water column and direct it to a large, medium or small conveyor belt which finally directs litter into a dumpster/bin, commonly on a separate barge or on land. There are several conveyor belt systems currently being used in Australia and the rest of the world. It was agreed that for the MCA they would be broken down by size and, in turn, the type and quantity of litter they target to trap in the river.

The details for each conveyor belt system are found in Attachment 2 and summarised below.

Large scale conveyor belt systems: Mr. Trash Wheel and The Interceptor Original

One of the emblematic conveyor belt litter interceptors worldwide is the **Mr Trash Wheel**, launched in 2014 in Baltimore, USA. This is a semi-autonomous interceptor that collects debris at a single point in the Baltimore harbour using containment booms to capture litter flowing in the water and then funnels it through the conveyor belt to a dumpster with 17 m^3 capacity on a separate barge. The conveyor and water wheel are mounted on a floating platform held in place by pilings. The system is powered by river currents and solar energy, producing up to 2,500 watts of electricity. Long booms and submerged skirts funnel waste into the dumpster, that when full, is taken on the barge to an incinerator plant. There are four Trash Wheels now operating in Baltimore (Figure 13).

Figure 13. Mr Trash Wheel in Baltimore Harbour (left) launched in 2014, and Gwenda (middle) the newest addition to the group of 4 (right).

[3] Manufacturer information, brochures, interviews/personal communications, previous experience or testing done by Parks Victoria (traps and Geoff ARC), and a previous review that contains an inventory of current technologies: Benioff Ocean Initiative (2021). Plastic waste capture in rivers: An inventory of current technologies.

Strengths	Weaknesses	Feasibility summary
• Durable • High capture potential, especially of large litter types (over 22,000 kg/d of solid waste) • Uses renewable power sources • Can be used in tidal environments • Low manual servicing labour	• Large size and fixed position, can disturb navigation • Mostly traps surface water litter • Requires boat servicing • High initial capital costs • High maintenance costs if parts are damaged • Patented technology	**Service connection**: Solar and hydro powered. **Space requirements**: Onshore transfer of dumpster/bins. **Resilience of materials**: High, can withstand high flows and storms. **Agreements/approvals**: Needed, can disturb navigation. **Potential suppliers**: Patented technology by Clearwater Mills. **Cost range**: High.

The **Interceptor Original** is another a large-scale conveyor belt technology by the Ocean Cleanup. It 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 (50-100 cm submerged and 20 cm above water) towards the pontoon, which is a steel catamaran moored with anchors/piles and chains to the riverbed. The debris flows through the centre of the catamaran towards an extraction conveyor belt. A secondary conveyor belt ensures debris is distributed evenly among 6 dumpsters on the same boat (50 m^3 capacity, 24 m long), enabling maximum capacity utilization of the system. The distribution is fully automated, using sensors to log the amount of litter 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 (Figure 14).

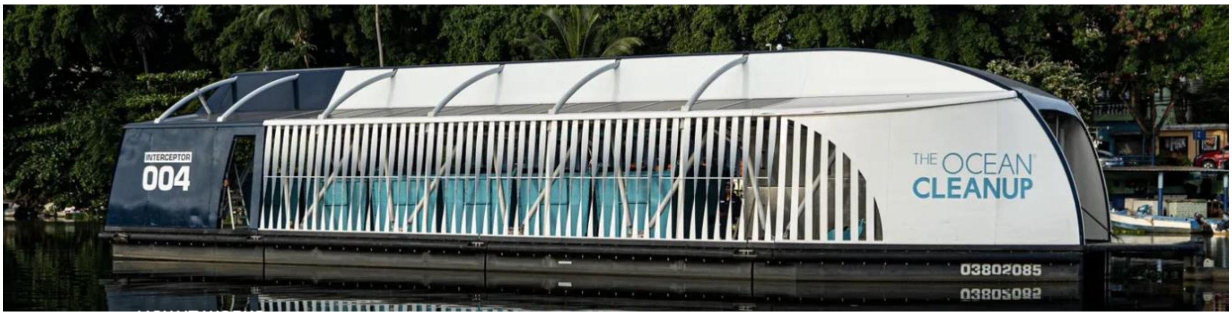


Figure 14. The Interceptor Original (The Ocean Cleanup).

Strengths	Weaknesses	Feasibility summary
• Durable • Energy neutral • High capture potential, especially large litter types (over 100,000 kg/d of litter) • Optimal for heavily polluted rivers as it can store litter for long time • Onboard electronic monitoring system and remote dashboard	• Large size and fixed position, can disturb navigation • Depends on flow conditions • Mostly traps surface water litter • Requires on land servicing (space requirement) • High initial capital costs • High maintenance costs • Patented technology	**Service connection**: Solar powered. **Space requirements**: Onshore transfer of 6 dumpster/bins. **Resilience of materials**: High, can withstand high flows and storms. **Agreements/approvals**: Needed, can disturb navigation and requires space on land. **Potential suppliers**: Patented technology by The Ocean Cleanup. **Cost range**: High.

Mid-scale conveyor belt systems: The Rise (DESMI) and 2nd Generation of ARCs (Ocean Crusaders)

The Rise by DESMI is an automated, electrically powered mid-scale conveyor belt litter interceptor that guides floating litter and debris using long booms towards a dual belt system with on-land recovery (to a left or right position), requiring space onshore for skip bins and truck access. It is a modular design, made in marine grade aluminium and the buoyancy is provided by abrasion resistant pontoons. It can trap approximately 3,500 kg/hour of litter and can be found in two versions, A Series (dually electrically driven belt) or S Series (electrically driven belt with up to 9-meter transport length to a waste collection point).

Figure 15. The Rise - DESMI

Strengths	Weaknesses	Feasibility summary
• Durable • High capture potential for medium litter types (Between 20cm - 1m) • On land recovery reduces servicing costs	• Requires electricity • Requires space onshore for skip bins and truck access • Booms can disturb navigation • Mostly traps surface water litter	**Service connection**: Requires electricity. **Space requirements**: Onshore placement of bins and access roads. **Resilience of materials**: High, can withstand high flows and storms. **Agreements/approvals**: Probably required for land recovery. **Potential suppliers**: Process Pumps, Melbourne. **Cost range**: Middle.

The **2nd Generation of ARCs** (Automatic River Cleaners) being developed by the Ocean Crusaders in Queensland, following the prototype version currently being trialled in the Yarra and Maribyrnong Rivers (Geoff the River Cleaner, shown in Figure 16) is another mid-scale conveyor belt technology that could be available soon. As opposed to the DESMI Rise, this conveyor belt vessel would be autonomous and fully solar powered, with a 1.5 m wheel conveyor belt and a large skip bin on a separate barge (bigger than the prototype) with an optional version with a dual belt system for on-land recovery (requiring a 5m^2 space on land with truck access). The 2nd Generation of ARCs would be anchored to the bottom of the river permanently with sea piles, preventing movement and increasing efficiency.

Strengths	Weaknesses	Feasibility summary
• Durable • Solar-powered • Acceptable capture potential for medium and small litter types (1m and smaller) • On land recovery option would reduce boat servicing costs	• Not yet built or trialled • Requires space onshore for skip bins and truck access for on land option • Booms can disturb navigation • Mostly traps surface water litter • Fixation to bottom could reduce adaptability/ flexibility to changing conditions	**Service connection**: Not required. **Space requirements**: Onshore placement of bins and access roads for on land option. **Resilience of materials**: Unknown, but will be higher than prototype. **Agreements/approvals**: Probably required for fixed position in river land recovery option. **Potential suppliers**: Ocean Crusaders, Queensland. **Cost range**: Middle.

Small scale conveyor belt systems: 1st Generation of ARCs (Ocean Crusaders)

A small-scale conveyor belt prototype called Geoff the River Cleaner managed by Parks Victoria is currently being trialled in Melbourne rivers (Figure 16). It was placed on the Yarra River first, then moved to the Maribyrnong and now will be going to the Moonee Ponds Creek for a further 6 months in early November. It was built by Ocean Crusaders with pontoons found during clean ups and designed the conveyor belt wheel (0.85 m) around those pontoons. The mid-scale 2nd Generation ARC will be designed so the pontoons fit the bigger belt, not the other way around.

Figure 16. Geoff the River Cleaner – 1st Generation of ARCs by Ocean Crusaders on trial on the Yarra River (30/07/2023).

Strengths	Weaknesses	Feasibility summary
• Solar-powered • Acceptable capture potential for medium to small litter types (20cm and smaller)	• Not resistant to storms or high flows • Requires regular boat servicing and maintenance, elevating costs • Booms can disturb navigation • Mostly traps surface water litter	**Service connection**: Not required. **Space requirements**: Not required. **Resilience of materials**: Low. **Agreements/approvals**: Not required. **Potential suppliers**: Ocean Crusaders, Queensland. **Cost range**: Middle.

Strengths	Weaknesses	Feasibility summary
	• Yarra River trial suggests efficiency is reduced with low flows	

3.3.4. MCA of shortlisted options

Shortlisted options

From the information collated and reviewed in the previous stage, the most feasible options were shortlisted for the MCA. From the total of 24 alternative designs reviewed, 11 were selected to determine the most feasible options to include in the MCA (Table 2).

Table 2. Feasibility considerations analysed to shortlist alternative designs for MCA.

Designs	Feasibility considerations					
	Service connection	On shore space requirements	Resilience of materials	Agreements / approvals	Local suppliers	Cost range
Mr Trash Wheel						
DESMI Rise						
1st Gen ARC - Ocean Crusaders						
2nd Gen ARC - Ocean Crusaders						
Existing litter traps and booms - Bandalong						
The Shoreliner - TAUW						
Alternative traps and booms - Urban Asset Solutions						
The Aquadrone - Clean Solutions						
The Waste Shark						
The Great Bubble Barrier						
River Cleaning Rotating Modules						

Considering feasibility, quantity and quality of information collected and having a range of technologies to compare, the 9 options included in the MCA were:

1. Large-scale conveyor belt - Mr Trash Wheel
2. Mid-scale conveyor belt with on land recovery - DESMI Rise
3. Small-scale conveyor belt prototype - 1st Gen Ocean Crusaders (Geoff)
4. Existing litter traps - Bandalong
5. Alternative litter traps - The Shoreliner
6. Complementary boom system - Bandalong / Urban Asset Solutions
7. Litter drone - Waste Shark
8. Bubble curtain - The Great Bubble Barrier
9. Rotating modules - River Cleaning System

Categories, criteria, and scoring

The MCA was conducted in a spreadsheet format and can be found in Attachment 3. A range of categories and criteria were set for the MCA to be able to compare the effectiveness, technical feasibility, impacts on values and costs between the 9 options. The weightings amongst categories were kept equal (Table 3). The MCA was conducted in collaboration with Parks Victoria during

Workshop 1 with one iteration after gaining further insights to adjust to the needs of the study (15/08/2023).

Table 3. MCA Categories and criteria.

Category	Criteria ID	Criteria	Description
Effectiveness	Eff.1	Hydrodynamic conditions	Suitability to the hydrodynamic conditions (flow velocity and direction under typical conditions)
	Eff.2	Movement patterns	Suitability to flow movement patterns
	Eff.3	Large-sized litter types (Over 1 m): logs, tires, chair, bikes	Suitability to trap large-sized litter types
	Eff.4	Medium-sized litter types (Between 20cm - 1m): bottles, bags, helmets, balls, medium macroplastics	Suitability to trap medium-sized litter types
	Eff.5	Small-sized litter types (Under 20cm): styrofoam, degraded macroplastics, cigarette butts, candy wrappers, straws, cups, microplastics, small macroplastics	Suitability to trap small-sized litter types
	Eff.6	Quantity of litter	Suitability to trap large volumes of litter (capacity)
Technical feasibility	Tech.1	Technical feasibility	Technically feasible to use in the river without constraints
	Tech.2	Flexibility/Adaptability	Can be easily adapted to river conditions with suitable effort level
	Tech.3	Flow resistance of materials/device	Flow resistance of materials to storms and high flow events (consider if extra anchors or piles needed)
	Tech.4	Optimal size of design features and space requirements	Total dimensions and size of design features (i.e., conveyor belt, dumpster, booms, etc) are suitable for river conditions and litter types
	Tech.5	Suitable locations	Availability of suitable locations within the river, proximity to wharf or infrastructure for litter removal
	Tech.6	Agreements or approvals	The design of the device involves reaching agreements or need for approvals from other organisations or authorities
Impact on values	Val.1	Environmental/Sustainability	Its implementation and maintenance do not pose a negative impact on the environment or sustainability
	Val.2	Social	Its implementation and maintenance are acceptable to local community and stakeholders
	Val.3	Cultural	Its implementation and maintenance are acceptable to the Traditional Owners
Costs	Cos.1	Capital investment	Implementation cost
	Cos.2	Ongoing costs and maintenance	Maintenance cost of structures/parts, operation

The ratings (scores) used to assess the different options ranged from Highly acceptable (5) to Unacceptable/ ineffectual (-5) as shown in Table 4 below.

Table 4. Ratings used for the MCA

Standard	Scores
Highly acceptable	5
Very acceptable	4
Acceptable	3
Modest	2
Neutral/modest	1
Neutral/poor	-1
Poor	-2
Very poor	-3
Exceptionally poor	-4
Unacceptable/ineffectual	-5

Results

The general results and ranking of options indicate that the most cost-effective option to improve litter management would be to include a complimentary boom system to all existing litter traps in both rivers, followed by adding a small-scale conveyor belt, then a mid-scale conveyor belt, then introducing rotating modules, drones, bubble curtain and, finally, a large-scale conveyor (Table 5). However, as these results aggregate all values for the different categories and criteria equally (i.e., costs, effectiveness, technical requirements) a deeper analysis is needed as every technology has a different purpose making direct comparison difficult.

When categories are broken down and analysed according to specific criteria for effectiveness (i.e., trapping different litter types), technical feasibility (flexibility/adaptability, flow resistance), environmental impacts and costs (Table 6), the different options can then be ranked accordingly in a finer scale (Table 7). This provides further insights into which one could work best for different purposes and environments. The same exercise was conducted with a focus on conveyor belt systems described in Section 3.3.2 above (Table 8 and Table 9).

Table 5. MCA general aggregated results and ranking

	Option	Weighted score				Positive Score	Negative Score	Net score	Rank
		Effectiveness	Technical	Impact on values	Cost				
1	Existing litter traps - Bandalong	1.00	3.98	3.67	5.00	14.14	-0.50	13.65	2
2	Complimentary boom system - Bandalong/Urban Asset Solutions	-0.33	4.65	3.33	5.00	15.31	-0.33	14.98	1
3	Alternative litter traps - The Shoreliner	0.66	4.65	3.67	4.00	13.82	-0.83	12.99	3
4	Conveyor belt large - Mr Trash Wheel	3.98	1.99	3.67	-2.00	9.81	-2.17	7.64	9
5	Conveyor belt middle (on land recovery) - DESMI Rise	3.82	2.66	3.00	2.00	11.47	0.00	11.47	5
6	Conveyor belt small - Geoff the River Cleaner prototype Ocean Crusaders	1.83	3.15	4.00	3.00	12.31	-0.33	11.98	4
7	Bubble barrier - The Great Bubble Barrier	3.49	2.32	3.33	0.50	11.14	-1.50	9.64	8
8	Rotating modules - River Cleaning System	2.16	2.49	3.33	2.50	10.98	-0.50	10.48	6
9	Litter drone - Waste Shark	2.32	2.99	3.67	1.50	11.14	-0.66	10.48	7

Table 6. MCA results for specific effectiveness, technical feasibility, impacts and cost criteria for all options

Devices	Effectiveness - litter types/quantity			Technical feasibility		Impacts on values	Cost	
	Large-sized	Medium-sized	Small-sized	Flexibility/ adaptability	Flow resistance	Environment/ sustainability	Implementation	Maintenance
Existing litter traps - Bandalong								
Trap w/ boom system - Bandalong/Urban Asset Solutions								
Alternative litter traps - The Shoreliner								
Conveyor belt large - Mr Trash Wheel								
Conveyor belt mid (on land) - The Rise DESMI								
Conveyor belt small - Geoff the River Cleaner								
Bubble curtain - The Great Bubble Barrier								
Rotating modules - River Cleaning System								
Litter drone - Waste Shark								

Table 7. Ranking of options for specific effectiveness, technical feasibility, impacts and cost criteria for all options

Criteria			Options ranking
Effectiveness - litter types/quantity	Large-sized litter types (Over 1 m): logs, tires, chair, bike	1	Large-scale conveyor (Mr Trash Wheel)
		2	Mid-scale conveyor (DESMI Rise)
		3	Traps + Booms / Bubble barrier
	Medium-sized litter types (Between 20cm - 1m): bottles, bags, helmets, balls, medium macroplastics	1	Traps + Booms
		2	Mid-scale conveyor (DESMI Rise) / Large-scale conveyor (Mr Trash Wheel)
		3	Bubble Barrier
		4	Rotating modules / Drone (Waste Shark)
	Small-sized litter types (Under 20cm): styrofoam, degraded macroplastics, cigarette butts, candy wrappers, straws, cups, microplastics	1	Bubble Barrier
		2	Traps + Booms
		3	Small-scale conveyor (Geoff) / Rotating modules
Technical	Flexibility/adaptability	1	Traps + Booms
		2	Litter drone
		3	Small-scale conveyor (Geoff) / Rotating modules
	Flow resistance of materials/device	1	Large-scale conveyor (Mr Trash Wheel) / Bubble barrier
		2	Traps + Booms / Conveyors/Rotating modules
Impacts on values	Environment/sustainability (energy/fuel requirements, fish passage, birds)	1	Small-scale conveyor (Geoff)
		2	Traps + Booms / Rotating modules
Cost	Implementation	1	Traps + Booms
		2	Small-scale conveyor (Geoff)
		3	Mid-scale conveyor (DESMI Rise) / Rotating modules
		4	Litter drone
		5	Bubble Barrier / Large-scale conveyor (Mr Trash Wheel)
	Maintenance	1	Traps + Booms
		2	Rotating modules / Bubble barrier
		3	Small and mid-scale conveyor (Geoff / DESMI Rise)

Table 8. Results for specific effectiveness, technical feasibility, impacts and cost criteria for conveyor belts

Devices	Effectiveness - litter types/quantity			Technical feasibility		Impacts on values	Cost	
	Large-sized	Medium-sized	Small-sized	Flexibility/ adaptability	Flow resistance	Environment/ sustainability	Implementation	Maintenance
Conveyor belt large - Mr Trash Wheel								
Conveyor belt large -The Interceptor Original Ocean Cleanup								
Conveyor belt (mid) on land - The Rise DESMI								
Conveyor belt (mid) - 2nd Generation Ocean Crusaders								
Conveyor belt small - Geoff the River Cleaner prototype								

Table 9. Ranking of options for specific effectiveness, technical feasibility, impacts and cost criteria for conveyor belts

Criteria		Options ranking	
Effectiveness - litter types/quantity	Large-sized litter types (Over 1 m): logs, tires, chair, bike	1	Large-scale conveyors (Mr Trash Wheel / Interceptor Original)
		2	Mid-scale conveyors (DESMI Rise / 2nd Gen Ocean Crusaders)
	Medium-sized litter types (Between 20cm - 1m): bottles, bags, helmets, balls, medium macroplastics	1	Mid-scale conveyors (DESMI Rise) / Large-scale conveyors (Mr Trash Wheel)
		2	Large-scale conveyors (Mr Trash Wheel / Interceptor Original)
		3	Small-scale conveyor (Geoff)
	Small-sized litter types (Under 20cm): styrofoam, degraded macroplastics, wrappers, straws, cups, microplastics	1	Small-scale conveyor (Geoff)
		2	Mid-scale conveyors (DESMI Rise / 2nd Gen Ocean Crusaders)
Technical	Flexibility/adaptability	1	Large-scale conveyor (Interceptor Original)
		2	Small-scale conveyor (Geoff)
	Flow resistance of materials/device	1	Large-scale conveyors (Mr Trash Wheel / Interceptor Original)
		2	Mid-scale conveyors (DESMI Rise / 2nd Gen Ocean Crusaders)
Impacts on values	Environment/sustainability (energy, fish passage, birds)	1	Mid-scale conveyor (Ocean Crusaders)
		2	Small-scale conveyor (Geoff)
Cost	Implementation	1	Small-scale conveyor (Geoff)
		2	Mid-scale conveyors (DESMI Rise / 2nd Gen Ocean Crusaders)
		3	Large-scale conveyors (Mr Trash Wheel / Interceptor Original)
	Maintenance	1	Mid-scale conveyors (DESMI Rise / 2nd Gen Ocean Crusaders)
		2	Small-scale conveyor (Geoff)
		3	Large-scale conveyors (Mr Trash Wheel / Interceptor Original)

Results for the comparison between all options indicate that:

- The **effectiveness** of designs varies with different litter types. The best options to trap larger litter types are large and mid-scale conveyor belt systems, followed by existing litter traps with boom systems in place. All options trap medium sized litter within acceptable to very acceptable scores; however, the traps with booms outperform the others. For small sized litter types, the best performing option is the bubble barrier.
- **Technical feasibility** concerns, specifically flexibility/adaptability results show traps and booms are the most adaptable option and can be moved or adjusted to different river conditions with suitable effort level. Options that are fixed to the bottom or side of the waterway are less flexible, such as The Shoreliner traps, large and mid-sized conveyor belt systems, and the bubble barrier. For ability to withstand high flows, the best options are Mr Trash Wheel and the bubble barrier.
- The **environmental/sustainability impacts** of most options are overall low, with acceptable and highly acceptable scores. The best options are traps and booms, small conveyor belt systems (off grid) and the rotating modules. The options that require energy or batteries to operate, and their maintenance could pose an impact to the environment or fauna, are the larger conveyor belt systems, the bubble barrier, and the drone.
- **Costs** of implementation are highest for Mr Trash Wheel, followed by the bubble barrier and the drone. The cheapest option are traps and booms, and small and mid-scale conveyor belts and the rotating modules in the middle. Maintenance costs, however, are low for traps and booms and the bubble barrier, followed by the mid-scale conveyors, rotating modules, and drones. Mr Trash Wheel has the highest maintenance cost.

The overall results from Stage 2 indicate that a combination of different litter trap systems could be implemented to optimise litter trapping for all litter types within both the Yarra River and Maribyrnong River. This type of integrated litter management program, together with more detailed information on the costings (investment, operation, and maintenance), effectiveness and agreements for the shortlisted alternative options are discussed in Stage 3.

4. Stage 3 Integrated program development

4.1. Objectives

To maximise the type and amount of litter that can be collected across both rivers, an integrated program of different litter trap devices and locations was developed for Stage 3.

The analysis considered:

1. The best functional designs and design requirements including existing infrastructure and litter interceptors (traps, booms, small-scale conveyor belt prototype) and the shortlisted alternative designs.
2. A hierarchy of options that includes a range of litter trap devices using a whole of river approach for the Yarra and Maribyrnong Rivers.

The results of Stage 1 and 2 were combined for this analysis.

4.2. Methodology

Stage 3 involved setting up a base case (existing conditions) for litter management in both rivers, and then a series of options scenarios, focussed on maximising litter reduction. These scenarios were then compared the base case to identify constraints and opportunities for Parks Victoria's litter program. An overview of the approach is provided in Figure 17.

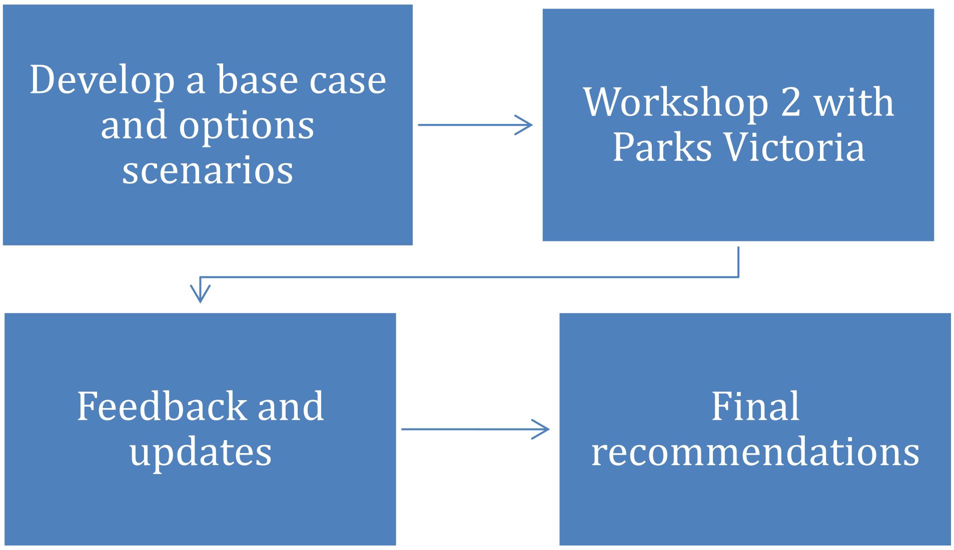


Figure 17. Summary of steps undertaken in Stage 2

The scenario assessment built upon the previous stages, by integrating all the information collected and extending the feasibility analysis for both existing and alternative options. The rationale and assumptions used to build the base case (existing litter traps and booms) and the different scenarios (using a combination of alternative designs) are summarised below.

For the base case:

- Using existing infrastructure and litter traps and booms available.
- Existing river conditions (under typical hydrodynamic conditions) and recommendations provided in Stage 1 contained in the Numerical Modelling Assessment PCS (2003) are in place: all litter traps have boom systems extended from the trap to the riverbank and are located following the recommendations.
- Effectiveness, technical feasibility and impacts of devices obtained from MCA scores.

For the scenarios:

- Stormwater drain and pit locations considered to place alternative designs (where available - CBD area).
- Space requirements (including road access) and landownership considered to determine the level of agreements/approvals (with preference in placement on Crown Land and Council Land, if available[4]).
- Sections of the river without litter traps.
- Effectiveness of devices derived from MCA scores.
- Implementation cost accounts for the cost of the individual device and installation, and maintenance cost covers servicing and operation[5]. All costs are included in Attachment 2.

4.2.1. Base case

The base case for both the Yarra and Maribyrnong Rivers is shown in Figure 18. For the Yarra River, it consists of 14 Bandalong litter traps with booms. The Webb Bridge North trap is located upstream of the bridge with booms extended from the trap to the riverbank (+ 10% more litter being captured)[6]. For the Maribyrnong River, it includes 3 Bandalong litter traps, with Dynon Bridge trap moved and placed opposite to the former Edgewater Marina trap (+19% effectiveness). Booms for all traps are extended to the riverbank (+70% effectiveness).

[4] Obtained from the Property layer in https://mapshare.vic.gov.au/mapsharevic/.
[5] Including parts, yearly servicing, and energy usage (kWh consumption estimate according to the product description and Commercial Information cost in Victoria assuming 24 hrs of operation). Does not include the emptying of skip bins or the transportation of the recovered litter to the final destination.
[6] PCS (2033). Numerical Modelling Assessment (Attachment 1).

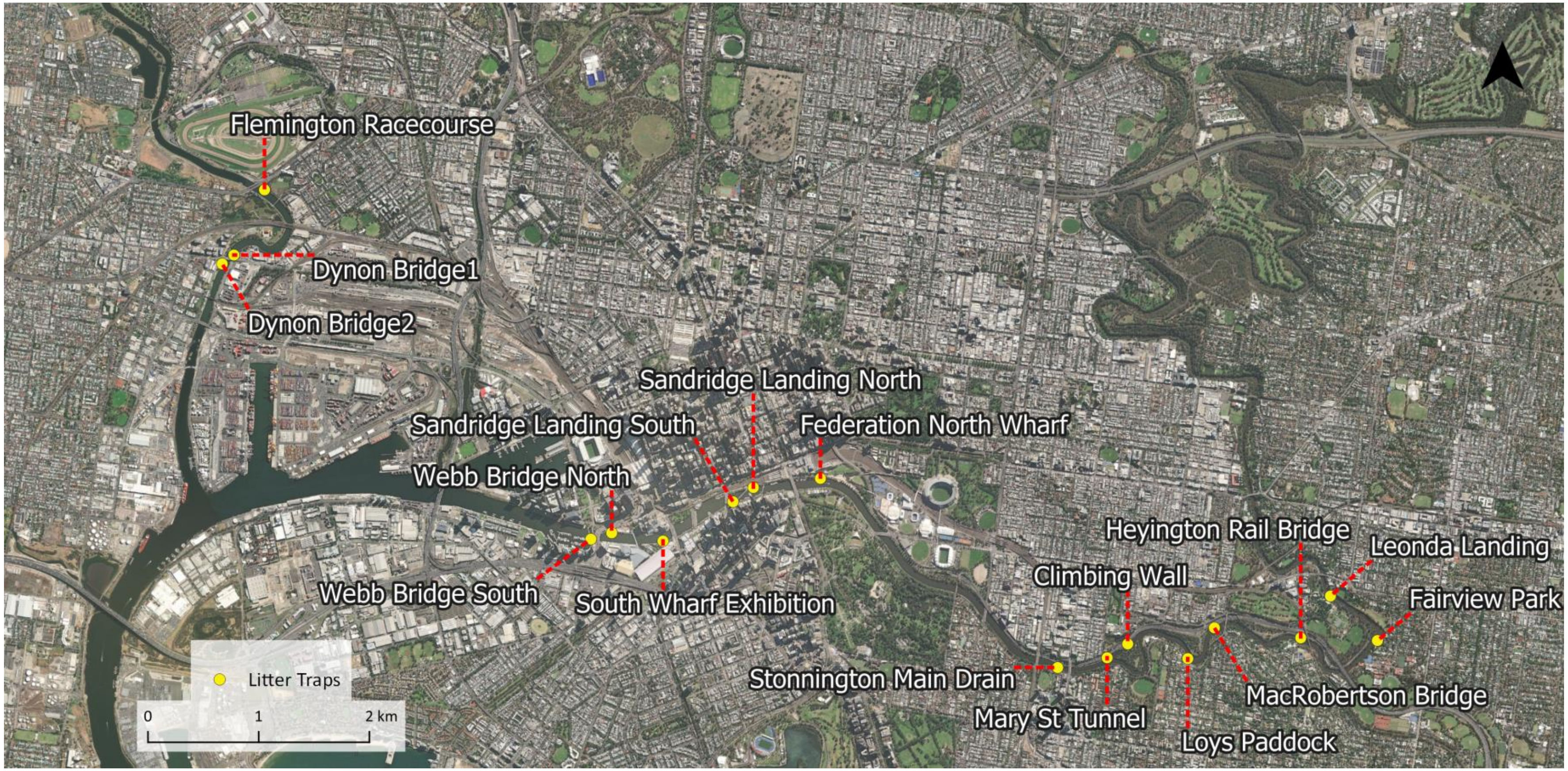


Figure 18. Base case for the Yarra and Maribyrnong Rivers.

4.2.2. Scenarios

Yarra River Scenarios

- **Scenario 1**: 10 Bandalong litter traps and booms + 1 bubble barrier[7] (Figure 19).

Figure 19. Yarra River - Scenario 1: 10 litter traps and booms, and 1 bubble barrier.

[7] Placement of bubble barrier following PCS (2023). Numerical Modelling Assessment (Attachment 1). Crown Land on right bank is available (energy connection and road access).

- **Scenario 2**: 8 Bandalong litter traps and booms + 1 bubble barrier + 1 mid-scale conveyor belt (DESMI Rise)[8] (Figure 20).

Figure 20. Yarra River - Scenario 2: 8 litter traps and booms, 1 bubble barrier, 1 mid-scale conveyor belt.

[8] Placement of conveyor belt on council land (Stonnington) downstream from Stonnington Main Drain (on-land recovery, energy connection, road access).

- **Scenario 3**: 8 Bandalong litter traps and booms + 1 bubble barrier + 1 mid-scale conveyor belt (DESMI Rise) + 1 large-scale conveyor belt (Mr Trash Wheel)[9] (Figure 21).

Figure 21. Yarra River - Scenario 3: 8 litter traps and booms, 1 bubble barrier, 1 mid-scale conveyor belt + 1 large scale conveyor belt.

[9] Placement of the large-scale conveyor is on council land (City of Melbourne) on the south bank at Bolte Bridge as this is the limit of the litter management area of the council and requires on land servicing (road access).

Maribyrnong River Scenarios

- **Scenario 1**: 2 Bandalong litter traps and booms + 1 mid-scale conveyor[10] (Figure 22).
- **Scenario 2**: 1 Bandalong litter trap + 1 bubble barrier[11] (Figure 22).

Figure 22. Maribyrnong River Scenario 1 (left) and Scenario 2 (right).

[10] Placement of conveyor belt on Crown Land under Footscray Road Bridge, downstream from a stormwater drain on left bank (on-land recovery, energy connection, road access).
[11] Placement of bubble barrier also on Crown Land under Footscray Road Bridge as the electric compressor and protection container must be placed on land and would require energy connection and road access.

4.3. Outcomes

The scenario comparison for the Yarra River is summarised in Figure 23 and for the Maribyrnong River in Figure 24, showing the differences in effectiveness, technical feasibility, environmental impacts, costs, and approvals between the different combinations of litter interceptors. The breakdown of costs per device and scenario is summarised in Table 10 (and further detailed in Attachment 2, Costings).

Overall, results indicate that:

- Effectiveness to trap litter increases when a range of devices that target different litter types are combined; however, costs and approvals could also increase.
- The planning and positioning of alternative designs should consider the specific litter types to target and the river conditions of that reach, as well as how these integrate to the whole of river system or catchment.
- Mid-scale conveyor belt systems trap a broader range of litter types than other technologies (intercepting medium to large litter best); however, they trap mostly surface litter and are fixed to a unique position in the river. They have high implementation and maintenance costs.
- The bubble barrier is very effective trapping smaller litter types (mostly medium to small and microplastics) and covers the entire width of the waterway. They have a slightly higher implementation cost[12] (in comparison to a mid-scale conveyor belt system such as the DESMI Rise / 2nd Gen ARC Ocean Crusaders) but lower estimated maintenance costs (see Table 10 for details).
- Approvals needed to implement alternative designs increase as the combination of litter interceptors cover larger sections of the river and require space, access roads for litter recuperation and transportation, and energy connections.

[12] Including all stages and parts (compressor and litter capture/removal system).

Scenario	Effectiveness - litter types/quantity			Technical		Impacts on values	Cost		Agreements
	Large-sized	Medium-sized	Small-sized	Flexibility/ adaptability	Flow resistance	Environment/ sustainability	Implementation	Maintenance (per year)	Agreements/ approvals
Base case									
14 Bandalong litter traps and booms	*acceptable*	*very acceptable*	*acceptable*	*very acceptable*	*modest*	*very acceptable*	Commercial Informa	Commercial In	*Not needed*
Scenario 1									
10 Bandalong litter traps and booms 1 Bubble Barrier	*acceptable*	*very acceptable*	*highly acceptable*	*acceptable*	*very acceptable*	*acceptable*	Commercial Inforr	Commercial Inf	*Council / MW*
Scenario 2									
8 Bandalong litter trap and boom 1 mid-scale conveyor* 1 Bubble Barrier	*very acceptable*	*very acceptable*	*highly acceptable*	*acceptable*	*very acceptable*	*acceptable*	Commercial Informa	Commercial Inf	*2 Councils / MW*
Scenario 3									
8 Bandalong litter trap and boom 1 mid-scale conveyor 1 large-scale conveyor 1 Bubble Barrier	*highly acceptable*	*highly acceptable*	*highly acceptable*	*acceptable*	*highly acceptable*	*acceptable*	Commercial Informat	Commercial In	*2 Councils / MW / Port*

*The implementation and maintenance costs presented are inclusive of a DESMI Rise. The scenario costs inclusive of a 2nd Generation ARC Ocean Crusaders are Commercial Inforr for implementation, and Commercial Inforr for yearly maintenance (lower, as there would be no electricity usage).

Figure 23. Scenario comparison for the Yarra River.

Scenario	Effectiveness - litter types/quantity			Technical		Impacts on values	Cost		Agreements
	Large-sized	Medium-sized	Small-sized	Flexibility/ adaptability	Flow resistance	Environment/ sustainability	Implementation	Maintenance (per year)	Agreements/ approvals
Base case									
3 Bandalong litter traps and booms	*acceptable*	*very acceptable*	*acceptable*	*very acceptable*	*modest*	*very acceptable*	Commercial Inform	Commercial	*not needed*
Scenario 1									
2 Bandalong litter traps and booms 1 mid-scale conveyor belt*	*very acceptable*	*very acceptable*	*acceptable*	*acceptable*	*acceptable*	*acceptable*	Commercial In	Commercial In	*Council / MW*
Scenario 2									
1 Bandalong litter trap and boom 1 Bubble Barrier	*acceptable*	*very acceptable*	*highly acceptable*	*acceptable*	*very acceptable*	*acceptable*	Commercial Infor	Commercia	*Council / MW*

*The implementation and maintenance costs presented are inclusive of a DESMI Rise conveyor. The scenario costs inclusive of a 2nd Generation ARC Ocean Crusaders are Commercial In for implementation, and Commercial for yearly maintenance (lower, as there would be no electricity usage).

Figure 24. Scenario comparison for the Maribyrnong River.

Table 10. Summary of costs per individual device and scenario.

Device/Scenario	Implementation cost ($ K AUD)	Maintenance cost ($ K/y AUD)		Yarra River		Maribyrnong River	
		Operation	Energy	Implementation	Maintenance	Implementation	Maintenance
Bandalong traps	Commercial Information		0	840	42	180	9
Bandalong booms			0	196	42	42	9
Mr Trash Wheel			0	600	175	0	0
DESMI Rise			2[4]	70	80.6	70	80.6
2nd Gen ARC Ocean Crusade			0	450	60	450	60
Bubble Barrier (BB)			9[5]	590	37.7	590	37.7
Scenarios							
Base case				1,036	84	222	18
Yarra River Scenario 1				1,330	97.7	0	0
Yarra River Scenario 2				1,252[6]	166.3[8]	0	0
Yarra River Scenario 3				1,852[7]	341.3[9]	0	0
Maribyrnong River Scenario 1				0	0	218[10]	92.6[11]
Maribyrnong River Scenario 2				0	0	664	43.7

[1] Pers. comms. with PV, potentially underestimated as costs likely be similar to the 2nd Gen ARC Ocean Crusaders (see Table 1).

[2] Estimated based on river width and depth (in consultation with BB provider). It includes all stages and parts (litter capture/removal system).

[3] Estimated from ARC Ocean Crusaders Prototype (Geoff the River Cleaner) maintenance costs spreadsheet provided by PV.

[4] Cost estimated including 2 x 0.5 kW belts (on-land recovery), Commercial Ir kWh (energy cost in Victoria), 24 hrs operation, 1 year.

[5] Cost estimated including a 400 V Kaeser air compressor (for a mid-range BB suited to Yarra/Maribyrnong Rivers), 4 kWh, Commercial Inf kWh, 24 hrs operation, 1 year.

[6] Cost would increase to Commercial Inf with 2nd Gen ARC Ocean Crusaders (more realistic for a mid-scale conveyor belt system).

[7] Cost would increase to Commercial In with 2nd Gen ARC Ocean Crusaders (more realistic for a mid-scale conveyor belt system).

[8] Cost would drop to Commercial Inf with 2nd Gen ARC Ocean Crusaders (no energy cost involved).

[9] Cost would drop to Commercial Inf with 2nd Gen ARC Ocean Crusaders (no energy cost involved).

[10] Cost would increase to Commercia with 2nd Gen ARC Ocean Crusaders (more realistic for a mid-scale conveyor belt system).

[11] Cost would drop to Commer with the 2nd Gen ARC Ocean Crusaders (no energy cost involved).

5. **Summary of findings and recommendations**

5.1. Performance issues and improvements

The litter traps in the Yarra River outperform the litter traps in the Maribyrnong River, mainly under typical river conditions. From the hydrodynamic study (Attachment 1) and outcomes of Stage 1, the main factors found to influence litter trap performance in the Yarra and Maribyrnong Rivers were:

- Location of traps relative to the surface currents within the river, with better performance when currents are uniform throughout the river channel.
- Changes in flow direction (tidal currents) which affects the retention of litter in the trap.
- Large debris that can affect the operation of the litter traps.

The relocation of some of the traps, therefore, could improve performance and increase the effectiveness in trapping litter (i.e., moving the Webb Bridge North trap on the Yarra River upstream of the Webb Bridge to improve from 1% to 19% performance by avoiding the eddy from the bridge). Also, extending the booms towards the riverbanks could improve performance under typical conditions. For the Maribyrnong River, the relocation of Trap 1 and boom extension of Trap 2 increases the effectiveness significantly (from 19% to 70% and 31% to 59%, respectively).

Stage 2 reviewed and assessed alternative litter interceptor designs to determine the most feasible options to improve litter management in both rivers. A total of 24 alternative designs were reviewed (Attachment 2). The most feasible options were then shortlisted for the Multicriteria Analysis to deepen the analysis and comparison between the options using specific criteria to measure effectiveness, technical feasibility, impacts on values and costs (Attachment 3). Results, when broken down by criteria, show:

- Large-scale conveyor belt systems are more effective to trap large-sized litter types and quantities, followed by mid-scale conveyor belts.
- Traps with boom systems are effective to trap medium-sized litter types, also followed by mid-scale conveyor systems.
- The bubble barrier is the most effective option to trap smaller types of litter and microplastics, followed by traps with booms.
- Traps and booms are the most adaptable device and the one with less impacts on the environment, together with small-scale conveyor belt (or off grid conveyors).
- Large conveyor belt technologies and the bubble barrier are the most resistant or durable option, resisting high flows and storm events.
- Traps with booms would be the cheapest option to implement and maintain. The most expensive technology is the large-scale conveyor (Mr Trash Wheel / Interceptor Original), followed by the bubble barrier; meanwhile the bubble barrier and the rotating modules have a lower maintenance cost (and cover the entire width of the waterway).

5.2. Conveyor belt systems feasibility and implementation analysis

Within Stage 2, a review of the feasibility of the 5 different conveyor belt technologies was conducted, indicating:

- They are effective for a range of litter types but are usually placed at the downstream reach of a river to avoid litter entering the ocean.
- All require large boom systems that potentially could disturb navigation or other activities in the river.
- Durability and resilience of materials vary from larger scale technologies to smaller scale technologies. Larger scale technologies are usually fixed to the riverbed to avoid movements and increase effectiveness.
- Amongst common strengths are they can be used in tidal environments, can be off grid, have high potential to capture large amounts of medium to large litter types, could require less approvals if they do not disturb navigation or fauna and local suppliers are available.
- Common weaknesses are they trap mostly surface water litter, require regular boat servicing, high initial capital cost, and could have high maintenance cost if parts are damaged with storm or high rainfall events.

5.3. Integrated litter management programs

The best functional designs (existing and alternative) were combined to explore how to optimise the amount of litter collected in both rivers through the development of a base case (current situation) and option scenarios.

For the Yarra River, the effectiveness of the litter management program to capture a wide range of litter types can be improved by adopting a combination of different litter trap technologies. However, this is dependent on the number, type and placement of devices, and the costs. There is also likely to be an increased need for agreements or approvals.

If we assume the overarching objective for the integrated litter management program for the Yarra River is to capture the widest range of litter types possible, then the most effective option to complement the existing network of Bandalong litter traps would be:

- Install a bubble barrier system and reduce the number of existing Bandalong litter traps in the CBD as presented in Scenario 1. This would improve the ability of the litter program to trap medium to small litter types and microplastics in the lower (and most urbanised) reach of the river without extensively increasing costs (approx. 30%).
- Any existing Bandalong litter traps removed, depending on the budget available for servicing and maintenance, could be redeployed further upstream where there are currently no other devices, and positioned downstream from main stormwater drains (i.e., upstream of Leonda Landing).
- This option assumes the recommendations for improving the existing litter trap locations and configuration (e.g. booms) are undertaken at the same time.

For the Maribyrnong River, the existing Bandalong litter traps can be effective if placed in suitable locations, as demonstrated in the hydrodynamic modelling. To further enhance the litter management program, as with the Yarra River, the following options are recommended to complement the Bandalong litter traps, assuming the Bandalong litter traps are moved to the recommended locations:

- Install a mid-scale conveyor belt type system to improve capture of medium to larger sized litter types and which can operate over variable flow velocities and movement patterns, provided the system is physically moved as flow conditions change. Some conveyor systems do not work as effectively with low flows or without being powered.

or

- Install a bubble barrier to improve capture of medium to small sized litter and microplastics and which can operate over variable flow velocity conditions. As the bubble barrier is installed across the full width of the waterway the direction of flow is not as significant an operational factor as for conveyor belt systems which are in a specific location.

- Costs, space requirements, agreements and impacts between both options assessed were similar (considering the 2nd Gen ARC by Ocean Crusaders), with the conveyor belt having a lower implementation cost but a slightly higher maintenance cost.

Overall, the scenario comparison detailed in Section 4.2 showed how litter management for both rivers requires an integrated approach, based on the agreed litter management objectives such as which litter types are to be targeted, their sources, and pathways.

5.4. Complementary works

As well as the recommended enhancements to the litter interceptors described previously, we recommend the following complementary works:

- A catchment study to understand the most problematic litter types, sources, and pathways to optimise litter trap systems and locations.
- Collaboration with other river and litter related authorities and community (MW, LGAs, Friends of groups), similar to the *Chain of Ponds - Transforming the Moonee Ponds Creek* collaboration, with the aim of achieving strategic and coordinated litter action across the Yarra and Maribyrnong catchments to reduce end-of-line litter burdens.

6. **Attachments**

Attachment 1: Hydrodynamic Modelling Report

Attachment 2: Product review spreadsheet

In spreadsheet (digital) format.

Attachment 3: MCA

In spreadsheet (digital) format.