Cartsburn Automated Self-Cleaning Trash Screen

Debris Removal Impact on Local Flood Risk Benefits

HERIOT WATT UNIVERSITY

Inverclyde council

Contents

1 Introduction

The Carts Burn is a local watercourse collecting urban stormwater runoff from a developed catchment of $0.24 km^2$. The watercourse connects the upstream small local Cartsburn reservoir ($1600 m^2$) to the River Clyde. The Carts Burn extends approximately 1500m from the upstream reservoir source to the River Clyde, with approximately 500m of over watercourse (location illustrated in Figure 1). The burn is partially culverted, with two significant stretches of large sub-surface rectangular box culvert and pipe culverts conveying flow beneath urban infrastructure (school, residential housing, commercial development and road infrastructure). The upstream culvert reach extends beneath the Lomond View Academy, a length of 355m, and connects the watercourse upstream of Upper Cartsburn Street to the lower open watercourse section south of Ingleston Street/Cartsburn Street. This culvert is a large concrete box culvert with a trash screen on the upstream inlet. The watercourse then flows at surface level between Clydeview Motors and Cartsburn Street prior to entering the downstream culvert reach. This second culvert conveys flow from the watercourse under the developed area of lower Ingleston to the discharge point at the River Clyde.

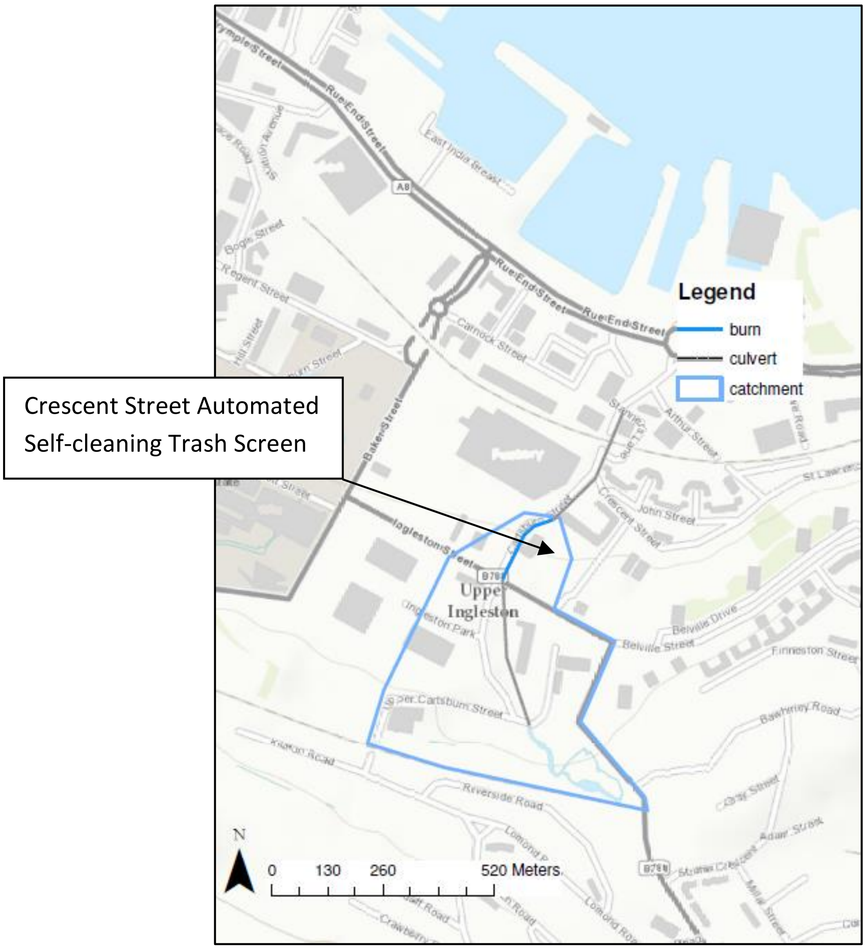


Figure 1. Carts Burn catchment and watercourse alignment

Cartsburn Street, from the junction with Crescent Street down to Main Street, has a history of flooding. Most recently, in 2011, this section of road flooded to an impassable depth (>0.3m) and inundated multiple properties along the east side and north of Cartsburn and Crescent Streets. Flood water surcharged over the culvert entrance at Crescent /Cartsburn Street junction, flowing overland through a vacant plot and down Cartsburn Street to the business district area adjacent Main Street (A8) (Figure 2).

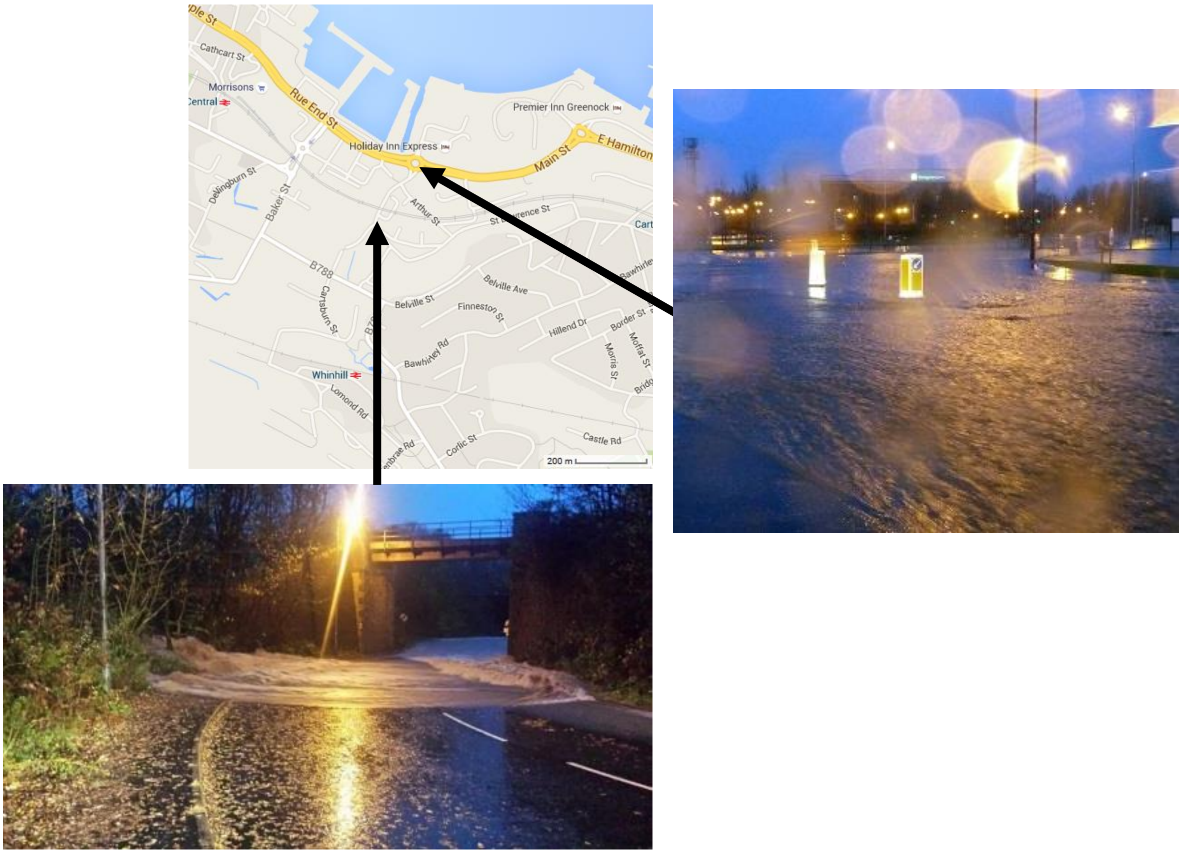


Figure 2: 2011 flooding of Cartsburn Road and the A8/Main Street

The known major cause of this localised but highly disruptive flooding is blockage of the lower Carts Burn culvert. During severe and extreme rainfall events, flood water conveyance down the Carts Burn becomes inhibited due to debris build up at the culvert entrance adjacent Crescent Street, limiting the free flow into and flood water volume conveyed by the lower culvert reach of the Carts Burn. As a result of this urban flood risk the lower culvert reach of the Carts Burn has been included in the Greenock Flood Protection Scheme.

Culvert blockage is a recognised cause of disruptive and damaging local flooding, resulting in increased flood frequency and lack of flood predictability within the urban environment.

The nature of this blockage (process and predictability) is not well established and is highly catchment specific. Influencing factors include physical debris characterisation, availability, mobility, transportability and structure interaction (Weeks and Rigby 2015). To minimise culvert blockage from urban refuse and woody debris, trash screens have become best practice in the UK (Wallerstein et al. 2013). While trash screens have been found to provide effective debris detainment (Blanc et al. 2014) maintenance and clearing of the screens is often difficult. For the screen to function effectively, it is necessary for debris build up prior to major rainfall events to be removed. Furthermore, during prolonged rainfall events, it may be necessary to remove debris build up on the screen to prevent localised flooding. Screen cleaning efficiency is often limited by access and weather conditions. As a result, automated self-cleaning trash screen technology has become available due to public agency and community need.

2 Design, installation and monitoring of the automated trash screen

The Greenock Flood Prevention Scheme made provision for an additional 300m of 1350mm diameter pipe and box culvert, following the existing lower Carts Burn culvert reach alignment. In addition to this further flow conveyance capacity, the installation of an automated self-cleaning trash screen was undertaken to minimise the ongoing and future flood risk due to culvert blockage.

In January 2015 the automated self-cleaning trash screen, designed by GJ Edwards Consulting Engineers Ltd in conjunction with Inverclyde Council and Transport Scotland, was installed at the Carts Burn culvert inlet at Crescent Street (shown in Figure 3). The grate is designed to current best standards, with screen bar spacing of 150mm and an inclined screen angle (Wallerstein et al. 2013). The trash screen extends 2m across and 3m high, over the entire existing culvert inlet.

Figure 3. Automated self-cleaning trash screen at Crescent Street culvert inlet.

The trash screen has been built with a forward/upstream facing arm than extends over the trash screen to collect detained debris. The debris collection arm is lowered and raised along two electrically powered screw mechanisms located on either side of the screen, negating the requirement for hydraulics. Using screw mechanisms to raise the debris collect arm allows significant weight to be lifted up and over the trash screen without risk of overloading. The screen is operated remotely, with a manual over-ride located at the physical trash screen. Cleaning can be set to occur periodically, as considered necessary prior to major rainfall events, or regularly to maintain a clear trash screen. The Carts Burn automated self-cleaning trash screen was set to self-clean twice per day.

3 Performance research

Heriot-Watt University undertook field research to study the efficiency and effectiveness of the designed automated self-cleaning trash screen. The aim of this research was to enhance current understanding of automated self-cleaning trash screen benefits on local flood risk and to provide field based evidence of the performance of these screens compared to traditional trash screens. The research was comprised of three elements:

- Analysis of the urban debris source, availability and transportation upstream of the automated trash screen and historically flooded area of Cartsburn Street and Main Street,
- Definition and analysis of the Carts Burn urban debris characterisation,
- Monitoring and reporting on the self-cleaning trash screen benefits on water level and flood risk.

Each of the research elements was addressed through field data collection and analysis. In conjunction with research specific activities, Hydro-Logic Ltd were commissioned to install a depth monitor within the culvert, downstream from the trash screen. This allowed continuous monitoring (15min time stepped) of the Carts Burn depth at the upstream extent of the culvert under Crescent Street. A time lapse camera was installed over trash screen and was programed to collect visual images of debris collection on the trash screen. As with the self-cleaning trash screen control, the camera and flow depth monitoring could also be controlled on command.

3.1 Self-cleaning screen benefits on water level and flood risk -Monitoring results

In conjunction with the installation of the automated self-cleaning trash screen, a remotely controlled camera and depth monitoring device were placed on the site. The camera was focused on the trash screen and was programed to take a minimum of two photographs of the trash screen per day. The camera was also automatically activated when any of the depth alarms were triggered, and a remote flow depth and visual monitoring provision was provided to request additional photographs whenever considered necessary.

The flow depth sensor was provided and installed by Hydro-Logic Ltd. The depth monitor was placed inside the culvert, a short distance downstream from the automated trash screen. The flow depth monitoring recorded water depths every 15 minutes, with additional depth recording during flood events. This information provision was provided remotely via a secure website, http://www.timeview2.net.

Water level and flood risk findings

The Carts Burn water level was monitored continuously over a year, from January 2015. The watercourse is fast flowing and steep, thus reacts quickly to rainfall within the catchment. The monthly rainfall varied from a maximum of 309mm (December 2015) down to 26mm (September 2015). Figure 4 illustrates the monthly rainfall and flow depth at the Cartsburn trash screen.

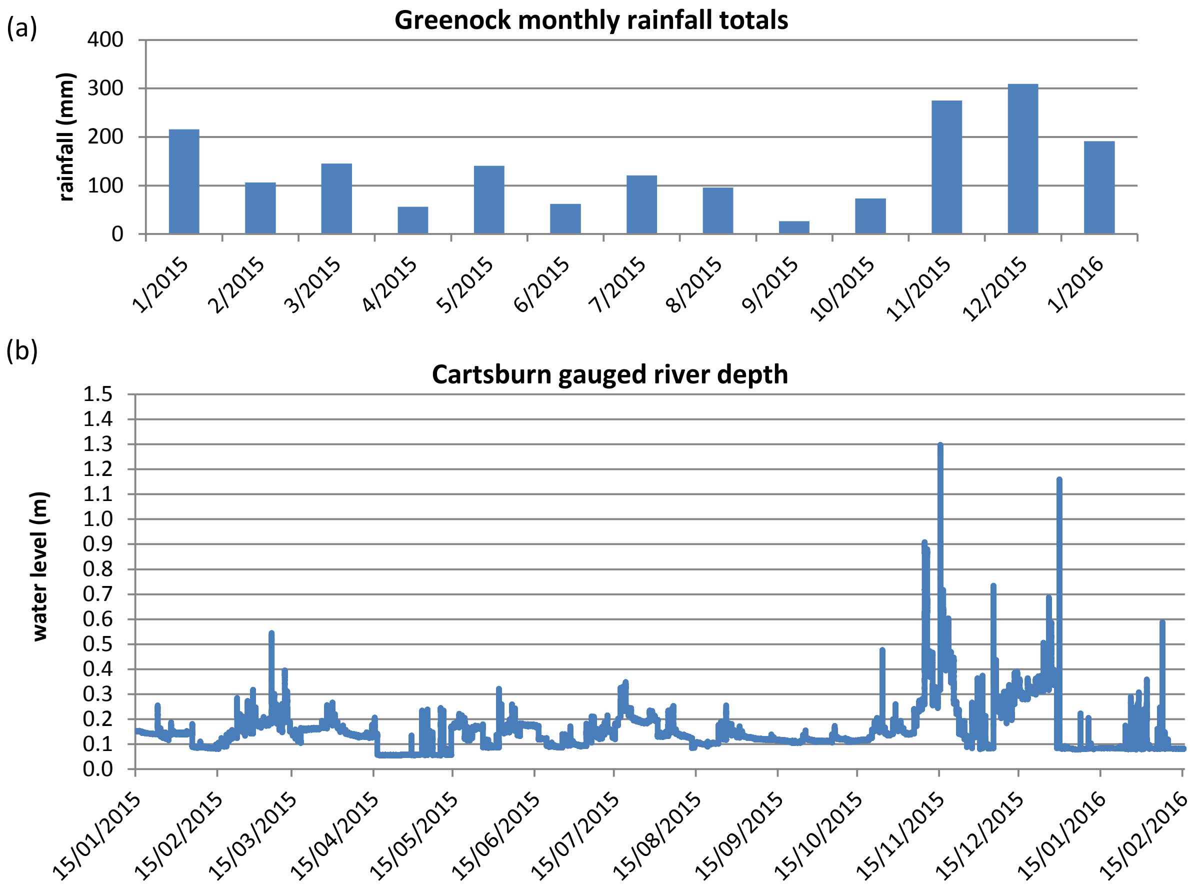
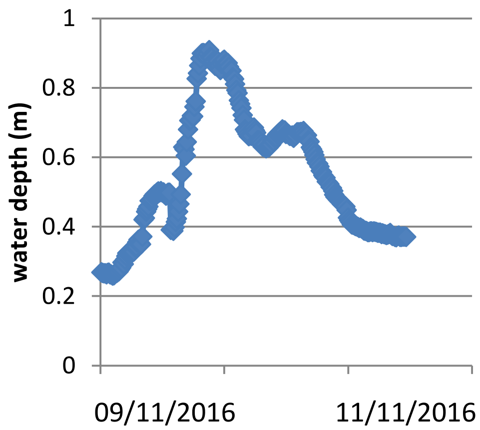


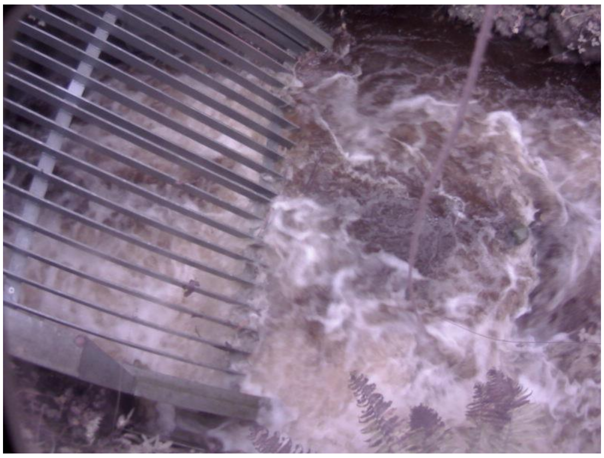
Figure 4. Crescent Street (a) monthly rainfall average (mm) and (b) culvert water depth (m).

There are four alarm station levels on the automated trash screen. These are located at 0.6m, 1.0m, 1.5m, and 2m above culvert invert level. The first alarm level, 0.5m, was triggered 6 times over the year, while the 2nd alarm (1.0m above invert) was triggered twice. The 3rd and 4th alarm levels were not reached within this 12 month period. The greatest flow depth at the Carts Burn automated grate over the entire 12 month period was 1.298m. This level was not recorded to caused any significant downstream localised urban flooding.

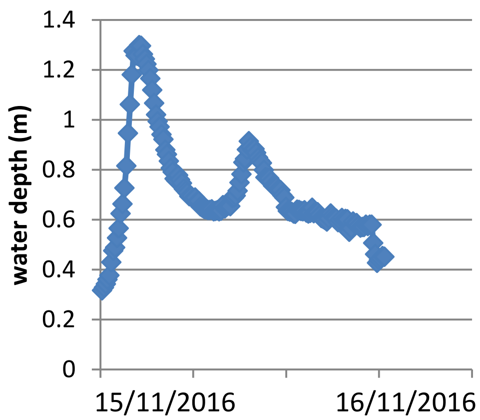
Review of the remote camera footage of the trash screed did not identify any significant debris build up resulting in any significant risk of exacerbating flooding downstream. Debris build up on the screen was maintained at a low level (<10% of the screen) throughout the monitoring period. The major flow events identified through the water depth record had been investigated to confirm this conclusion. The hydrographs, illustrating the flow depth as the trash screen, and the associated visual evidence of debris blockage, for the six (6) events which triggered the first alarm level are presented in Figure 5.

Event 1: 09/11/2015

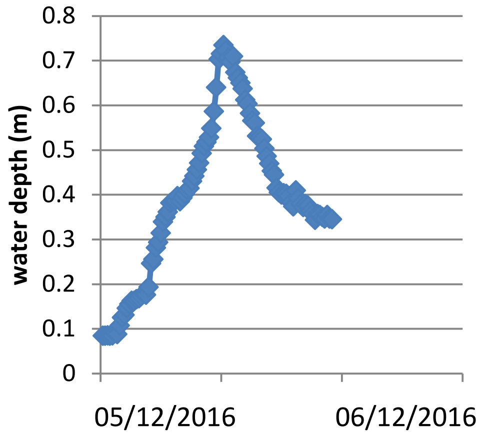


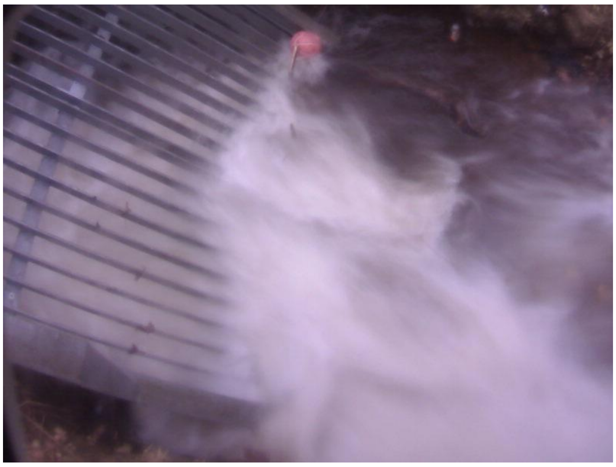


Event 2: 15/11/2015

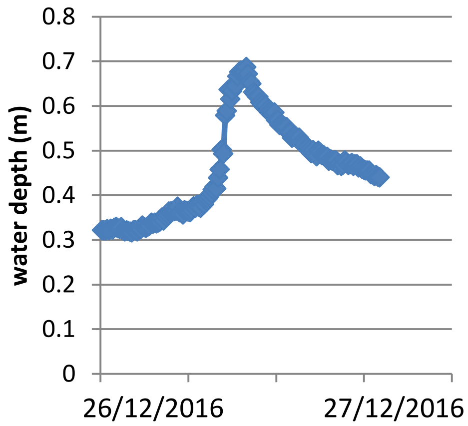


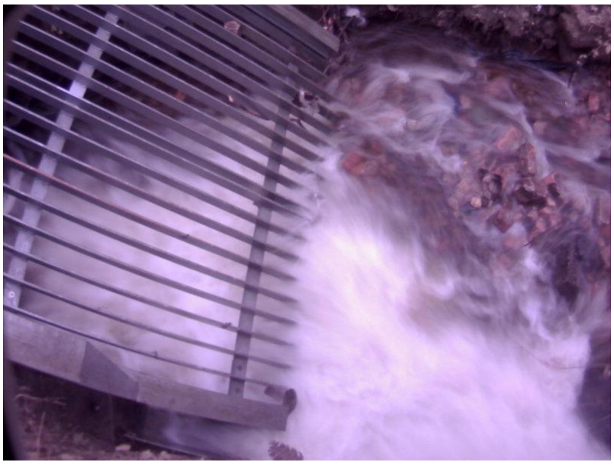
Event 3: 05/12/2015



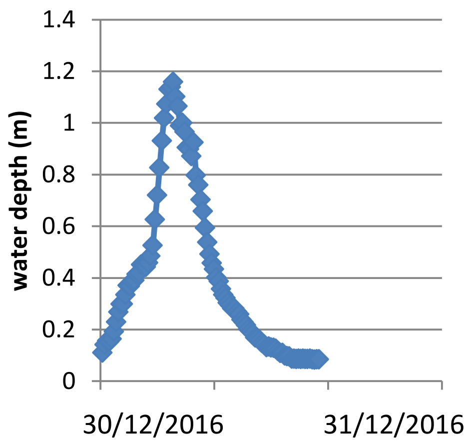


Event 4: 26.12.2015





Event 5: 30.12.2015



Event 6: 07/02/2016

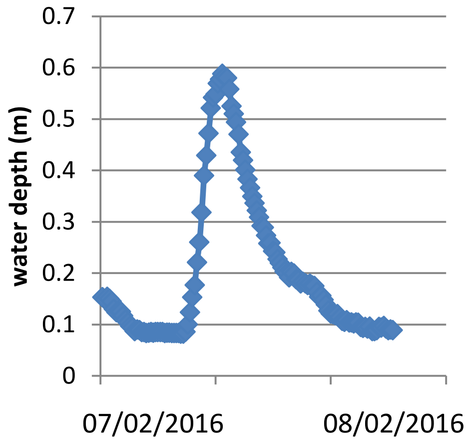


Figure 5. Water level (m) hydrographs and corresponding screen visual monitoring (photographs) for the 6 events recorded to exceed 0.5m in flow depth.

Each of these 6 flow events show a rising and falling hydrograph that follows a smooth curve (Figure 5) and not the severe rise or fall change flow depths associated with a blockage forming or clearing at the screen. Comparing the visual monitoring of these time periods it is seen that the automated trash screen is generally unencumbered by urban debris. Thus any debris that does build up on the screen is managed (cleaned off) and no long term build-up or peak flood exacerbation of blockage has been found over the monitored year. The automated self-cleaning trash screen is highly effective in maintaining a limited level of debris is retained on the screen for any extended period, and prevents the high flood risk debris build-up that causes exacerbated urban flooding downstream.

Over the 12 month monitoring period, 80% for the recorded flow depths were between 0.05 -0.20m, illustrating the base flow water depth for this reach of the Carts Burn. The base flow level illustrated in April-May 2015 was consistently 0.05-0.06m in depth. Minimal rainfall occurred during this period. The second extended low rainfall period occurred in September 2015 and then for a short period in January 2016. The base flow level illustrated during these latter periods is 0.08-0.1m. This is a key finding for the ongoing management of this trash screen. Over the 8 months (between April 2015-January 2016) the morphological change in the Carts Burn at this location was approximately 0.5m (build-up of rocky debris in front of the trash screen and within the culvert) resulting in a base flow water level increase of 0.03m (in the culvert). This finding was confirmed through camera footage, illustrated in Figure 6.

Figure 6. January 2015 (commencement of the study) and February 2016 (cessation of the study) photographs illustrating bed level change.

While this is a base flow increase is small, 0.03m, it is occurring due to geomorphological change in the channel and this will result in a significant loss of conveyance capacity over time. The cause of the channel geometry change is clearly visible, resultant from rocky debris deposition in front of the trash screen grate. The Carts Burn is a fast flowing watercourse and the large rock/boulder conveyance capacity of this water is therefore high. Thus rocky debris from the influencing reach of the Carts Burn (close to the automated trash screen) is being conveyed to the downstream obstruction point (the trash screen itself). Furthermore, the conversion of the watercourse from an open waterway to a culvert at Crescent Street has resulted in a significant watercourse bed slope change. The Carts Burn has a steep bed slope, including numerous small cascades. The Crescent Street culvert links this steep watercourse to the River Clyde and has a shallow grade. Due to this change the watercourse bed slope the entrance to this culvert would naturally act as a rocky debris deposition zone. However, the installation of the automated self-cleaning trash screen at this point has exacerbated this rocky deposition, as seen by the build-up of rocky debris along the front of the grate in Figure 11. Though continuous monitoring of the water depth and trash screen by remote sensors and camera equipment, the importance of rocky debris management on the Carts Burn has been clearly illustrated. While the automated trash screen does remove some large rocky debris from the screen (35 boulders/bricks over 3 months) the self-cleaning mechanism is not designed for rocky debris removal. It is recommended that future placement of trash screens take rocky debris deposition into consideration and provide either: i) a rocky debris deposition zone upstream from the trash screen, in an area that is easily accessible for clearing; ii) place the trash screen on a watercourse reach with a stable and continuous stream bed slope; or, allowing sediments to pass under the screen .

3.2 Debris source, availability and transportation

Experimental evidence has illustrated that urban woody debris is transported from a nominal distance upstream from a culvert, in given flow events (Allen et al. 2014). The transport of urban woody debris to a culvert, and the associated risk of culvert blockage from this transported material, has been tested using tagged artificial material in laboratory and field environments (Blanc et al. 2013, Allen et al. 2014). Previous urban woody debris transport analysis has been conducted across open channel watercourse reaches. The Carts Burn incorporates the complexity of both an upstream open channel, culvert and upstream traditional style trash screen. Thus, to establish the source of urban woody debris arriving at the automated trash screen artificial debris release experiments were undertaken.

Artificial debris was constructed from wooden dowel. Three of lengths and diameters were used, mimicking the natural woody debris found on the banks of the Carts Burn upstream from the screen. Three sets of artificial woody debris were constructed, to allow debris release from three separate specific locations upstream from the automated trash screen.

Research undertaken across Belfast by Wallerstein and Arthur (2012) has provided an insight into the key forms of urban debris that becomes detained and causes blockage at urban culverts. In conjunction with leaves, sticks and other woody debris (forming over 70% of the culvert blockage material on Belfast screens) the second key debris type was found to be plastic material (up to 20%) (Wallerstein and Arthur 2012). While larger woody debris tends get trapped against the trash screen due to its length or size, small debris causes significant flood risk from blockage when it builds up on and around these larger debris items. Small debris, such as leaf litter and plastic bags, become trapped on the trash screen as a result of this larger, 'blockage instigator' debris, creating a matt of smaller debris across the trash screen that is impermeable. This smaller debris could pass through the trash screen if there was no previously detained debris in its path, thus causing no blockage risk. However, when blockage instigator debris is detained on the trash screen, this smaller debris becomes a significant blockage and flood risk.

To evaluate whether plastic material caused significant impact to Carts Burn trash screen blockage, and to establish how far urban plastics (primarily plastic bags) travelled through this watercourse, a range of biodegradable, colour coded bags were included in the debris release. Table 1 provides and overview of the artificial debris created and released across the 3 locations.

Release location	Woody debris				Plastic bags*	
	colour	diameter	length	number	colour	number
1	yellow	25mm	150mm	20	blue	20
		15mm	300mm	20		
		25mm	500mm	20		
2	orange	25mm	150mm	20	green	20
		15mm	300mm	20		
		25mm	500mm	20		
3	red	25mm	150mm	20	red	20
		15mm	300mm	20		
		25mm	500mm	20		

* All plastic bags used in this experiment were certified biodegradable (potato flour)

Table 1. Artificial debris for source testing on the Carts Burn

The urban debris, outlined in Table 1, was released at the point upstream from the automated grate. Release location 3 was at the upstream extent of the Carts, downstream from the reservoir outlet (680m upstream from the automated trash screen). Release location 2 was positioned at the inlet to the first culverted section of the Carts Burn (540m upstream from the trash screen), along Upper Cartsburn Street. This culvert has a traditional trash screen across the culvert entrance. All artificial debris was released downstream of the traditional trash screen to emulate transport of material that had transitioned through to the culvert. The final release location (release location 1) was at the discharge point of the upstream culvert, where the Carts Burn returned to open channel flow (190m upstream from the trash screen). Artificial debris was release from the Ingleston Street overpass of this culvert outlet (illustrated in Figure 6).

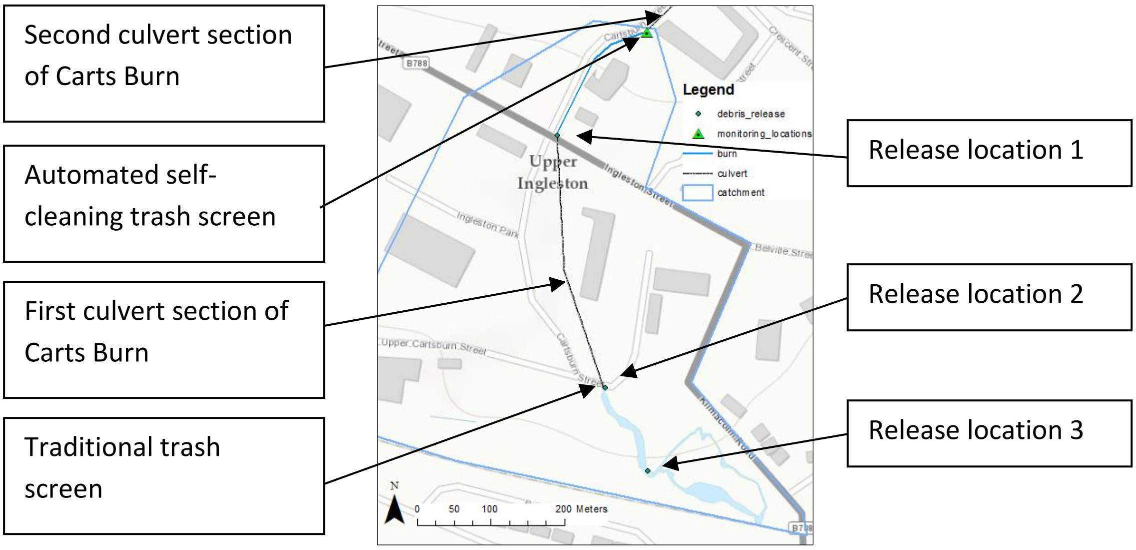


Figure 6. Debris release locations

Tracking of both woody and plastic debris was passive, through visual monitoring of the automated trash screen at Crescent Street and review of the material removed from the grate by the debris collection arm. Debris arriving at the trash screen was detected using the camera, reviewed daily. The debris removed from the trash screen by the debris removal arm was inspected monthly and the artificial debris detained and removed was recorded. Debris was released in October and was monitored until the end of January.

Debris source and transport findings

The cumulative number or artificial debris items arriving at and detained on the automated self-cleaning trash screen is presented in Table 2. It can be seen that very few artificial debris items arrived at the trash screen.

Debris item description	Monitored location	Release location	Cumulative number or items
Plastic bag – blue	In removed debris	1	7
	On/passing through the trash screen		9
Plastic bag – green	In removed debris	2	0
	On/passing through the trash screen		10
Plastic bag – red	In removed debris	3	0
	On/passing through the trash screen		6
Woody debris - yellow	In removed debris	1	1 (500mm)
	On/passing through the trash screen		7

Woody debris - orange	In removed debris	2	1 (500mm)
	On/passing through the trash screen		1
Woody debris - red	In removed debris	3	0
	On/passing through the trash screen		1

Table 2. Artificial debris arriving or detained at the automated trash screen over the monitoring period

The number of released debris items arriving at the trash screen was low, less than 40% plastic bags (no. 32); 10% woody debris (no. 17). Greater than half of the artificial debris released into the Carts Burn was not transported to the trash screen. This strongly indicates that the woody and plastic debris arriving at the trash screen is provided by the lower reach of the burn, directly upstream from the trash screen. Release location 1 was 190m upstream from the screen. While the greatest proportion of artificial debris collected off the trash screen was from release location 1 (89%), the quantity of debris actually arriving at the screen was very small. This illustrates that the key reach of the Carts Burn that may require urban debris maintenance and management is shorter than 190m (distance upstream from the automated trash screen) and that debris removal and management further upstream from Ingleston Street may provide significant flood risk benefit.

Daily automated cleaning of the trash screen has notably reduced the quantity of woody debris detained at the screen. The automated self-cleaning trash screen effectively removed the blockage instigator debris, allowing the smaller material to pass through the trash screen without causing blockage or flood risk. While the number of debris items conveyed to the screen is small, the majority of the material passed through the screen rather than becoming part of a debris jam or build up. Research presented in the ‘Supplementary technical note on understanding blockage risk’ (Wallerstein and Arthur 2013) illustrates a Gaussian curve distribution of significant debris delivery to a trash screen (Figure 7.)

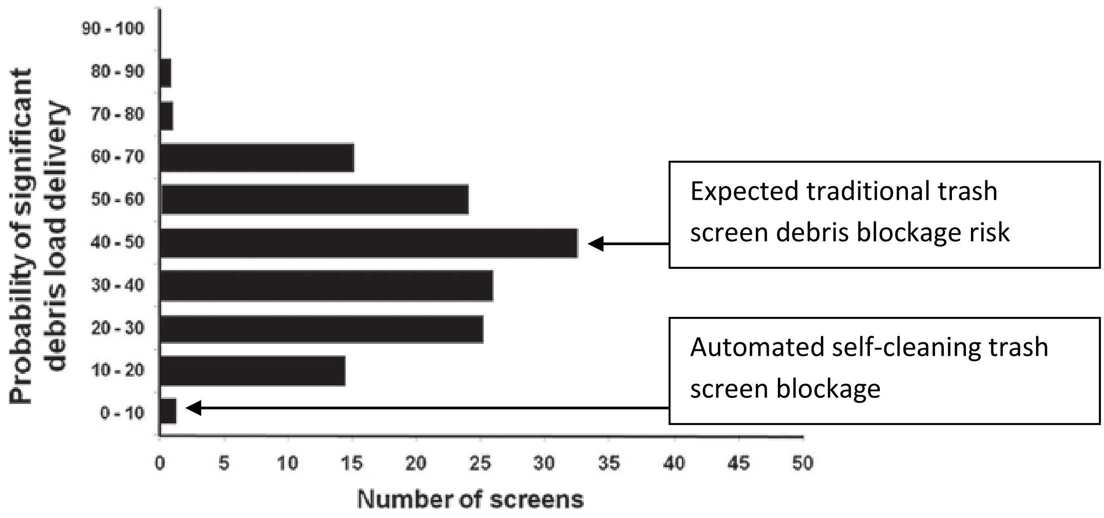


Figure 7. The number of screens lying in 10% probability of delivery classes (Wallerstein and Arthur 2013, p24, Figure 3.2).

This technical note illustrates that a traditional trash screen has a 50% probability of significant debris delivery. Significant debris delivery is defined as a quantity of debris material that causes >10% blockage of the trash screen, thereby having the potential to exacerbate the predictability and level of flood risk (Wallerstein and Arthur 2013). On review of the automated trash screen debris build up over the monitoring period, the extent of screen blockage was not seen to exceed 10%. If no automated cleaning had occurred during the monitoring period, it is expected that this trash screen would have conformed to the technical note findings. Therefore, it can be concluded that daily cleaning of this screen has significantly reduced the level of debris build up on this trash screen, allowing smaller (artificial) debris to be conveyed through the screen without causing increased flood risk.

3.3 Detained debris characterisation

Trash screens are designed to detain urban debris (woody, plastic and other material) at the inlet of the associated culvert, to prevent debris blockage inside the culvert infrastructure. However, as illustrated in past research and field studies, the trash screens themselves often become blocked causing high risk localised urban flooding. The material that makes up a debris blockage on a trash screen is very catchment specific (Wallerstein and Arthur 2012), but is noted to comprise of a range of large and small woody debris, leaf matter and urban refuse. The larger debris items provide structure to the debris blockage, allowing smaller debris to become lodged against the screen rather than pass through.

Through this field research, the hypothesis that daily or regular cleaning of a trash screen would remove these larger debris items, thus reducing the overall debris blockage build up, was tested through debris monitoring and characterisation. The larger debris items, often woody material but also comprised of shopping trollies, couches/couch cushions etc. (Wallerstein et al. 2013), were named 'blockage instigator' debris, due to the initiating influence of this material on significant trash screen debris build up. Through field monitoring of the debris type and size, detained and removed from the automated trash screen, insight into the influence of screen cleaning on debris build up and blockage instigator debris removal has been achieved.

Debris characterisation findings

Over three months, from the release of the artificial debris (October 2015) until January 2016, all debris detained on and removed from the trash screen was collected on site. Debris that the automated self-cleaning trash screen removed was characterised to determine what type, and how much, debris the self-cleaning mechanism was removing from the screen. The debris collected on the screen over this monitoring period has been categorised and is presented in Figure 8.

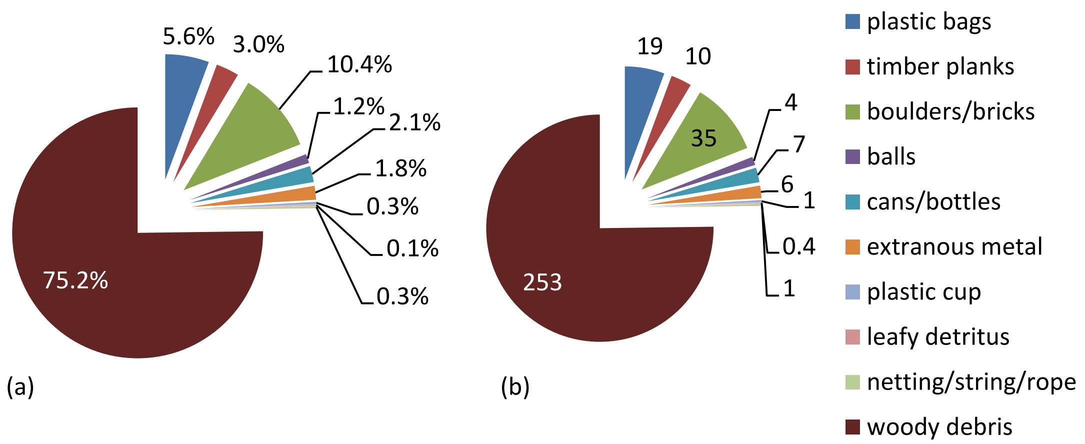


Figure 8. Composition of debris removed from the automated trash screen during the monitoring period of the total (a) number of items (b) and percentage. The leafy detritus is presented as a m^3 volume.

The primary debris type collected by the automated self-cleaning trash screen was woody debris. This concurs with the debris characterisation information presented in the CIRIA guidance (Wallerstein et al 2013). The second notable debris type was boulders/bricks. Review of the remotely controlled camera feed identified notable boulder brick and large rock debris movement in front of and on to the trash screen (photographs provided in Appendix 1). It is acknowledged that the screen is designed to detain woody and urban debris rather than rock material, and the illustration of this self-cleaning mechanism to remove rocky debris is unexpected and beneficial.

The woody debris collected off the trash screen was measured for both length and circumference. The majority of the woody debris was small in circumference (40mm), ranging from 10mm to 450mm. The range and frequency of debris circumference follows a Gaussian curve (Figure 9), with the majority of debris material being between 30-80mm in circumference.

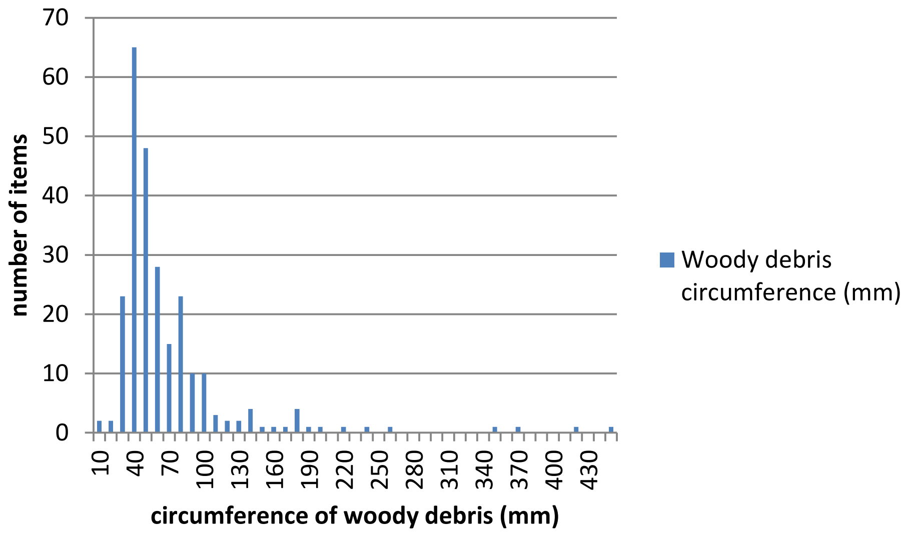


Figure 9. Distribution of woody debris circumference size (mm)

It can therefore be concluded that the woody debris conveyed within the influential reach of the Carts Burn was small in circumference. It is notable that the majority of the woody debris removed from the trash screen has a circumference that is smaller than the width between the trash screen bars. Woody debris causing debris build up on the trash screen is therefore not primarily large tree sections but smaller broken branches. The circumference or diameter of the woody debris is not the limiting factor in woody debris detention on the trash screen, as debris detained on the screen was generally smaller in diameter than the distance between the trash screen bars.

The length of all detained woody debris was measured and tabulated. In total, 253 woody debris items were collected on the screen, and removed by the automated self-cleaning mechanism, over the 3 month monitoring period. Figure 10 presents the woody debris lengths for material detained and removed from the automated trash screen.

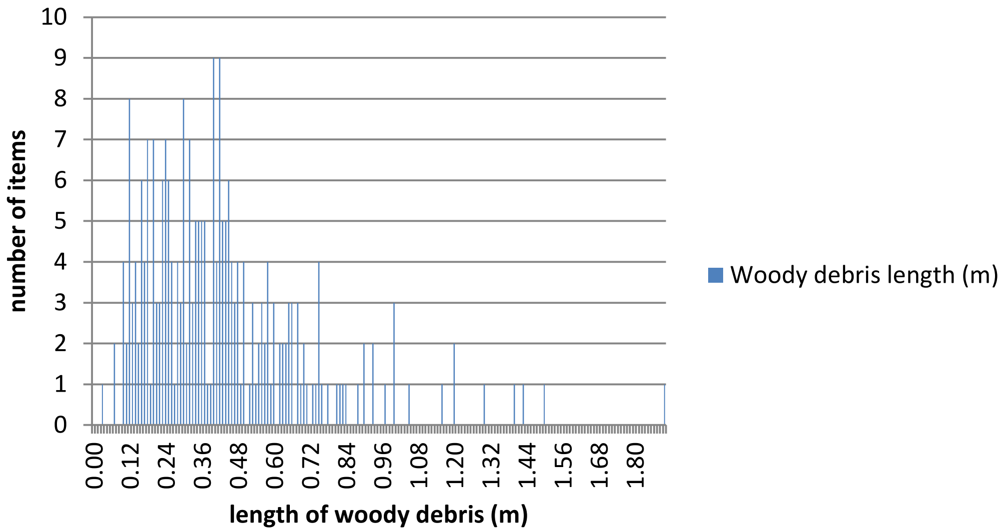


Figure 10. Distribution of woody debris length (m)

Woody debris extended from 0.03m to 1.9m in length, with the 50% of the debris ranging between 0.1-0.45m. The most prevalent woody debris lengths were 0.4-0.42m, slightly longer than the distance between two trash screen bar spacings. In total, 66% of the woody debris removed from the trash screen was longer than 0.3m, and 90% was greater than 0.15m in length (the distance between trash screen bars). These results suggest that the woody debris length that acts to instigate debris blockage is potentially only slightly longer than the trash screen bar spacing (for the Carts Burn). It is hypothesised that through regular self-cleaning, the quantity of small woody debris (<0.15m length) detained on the trash screen has decreased. Further analysis of the trash screen functionality is required to confirm this, however there is a notable lack of very short debris in the removed material (10% of removed woody debris was ≤ 0.15m length). This suggests that through regular cleaning, this trash screen is functioning to detain the longer woody debris items that would otherwise cause blockage within the culvert, but is allowing the smaller low blockage risk woody debris to be conveyed into and through the culvert.

The watercourse channel is over 1.5m wide upstream from the automated trash screen. The screen and culvert are approximately 1.5m in width. During the monitoring period only two (2) items of debris of 1.5m or greater length were detained and removed by the trash screen. Without the use of a trash screen, these woody items could have instigated serious blockage within the culvert. The use of a trash screen therefore prevented the culvert blockage risk, moving the flood risk to the screen location. Had this long and large woody debris been left at the culvert entrance on the trash screen, these would have caused notable screen blockage, detaining smaller woody debris, leafy detritus and plastic debris on the screen. Through implementation of the automated self-cleaning mechanism in this trash screen, these blockage instigators – the long woody debris, have been removed in a timely manner, preventing long term debris build-up and trash screen blockage and thus reducing the local flood risk to the predicted (SEPA flood map) level.

4 Key findings and recommendations

The automated self-cleaning trash screen installed at Crescent Street on the Carts Burn has been monitored throughout 2015. The results of flow depth, debris build up and self-cleaning flood influence have illustrated that the self-cleaning screen provides multiple benefits to the watercourse management and local flood risk. This research has also illustrated that the reach of key concern, for bank and watercourse maintenance, is close to the trash screen rather than the full length of the Carts Burn watercourse.

Key findings from the monitoring and research undertaken across Carts Burn are:

- The self-cleaning trash screen is effective in removing debris that is detained on the screen in a timely manner.
- Debris build up on the screen was maintained at a low level (<10% of the screen) throughout the monitoring period.
- Regular trash screen cleaning results in limited debris build up, which in turn reduces the flood risk and unpredictability of flooding resulting from culvert/screen blockage.
- The woody debris detained and removed from the trash screen is moderate in length. Much of the debris is longer than the screen bar width, illustrating that trash screen cleaning. allows the small, low risk woody debris to pass through the screen while detaining the longer and larger debris that may otherwise cause culvert blockage downstream.
- Regular removal of this larger debris, the instigator sticks, results in limited general debris build up on the screen over any extended period.
- Notable rocky debris build up occurred in front of the trash screen. This screen is capable of removing some rocky debris that falls in/onto the screen- an unplanned benefit.
- The sharp change channel slope at the location of the trash screen results in significant rocky debris deposition. The positioning of the trash screen appears to have exacerbated this, with acknowledgement that the deposition would have otherwise occurred within the culvert and potentially caused blockage.

Key recommendations from the monitoring and research are:

- Design and consideration of large rocky debris in future automated self-cleaning trash screen design.
- Trash screens should ideally be located on watercourse reaches where there is limited to no change in watercourse bed slope.
- Careful consideration of trash screen positioning is necessary to ensure rocky debris deposition and build up is not increased. Where location of a trash screen at a culvert entrance necessitates the screens location at a change in watercourse slope, an upstream rocky debris deposition zone should be constructed. This would allow the debris to be detained and removed prior to the trash screen.

The Carts Burn automated self-cleaning trash screen is highly effective in preventing urban debris build up on the screen. As a result, high low events occurring over the 2015-2016 monitoring year have not been worsened by trash screen blockage. Furthermore, by undertaking regular screen cleaning, the quantity of small woody debris is small and the overall trash screen debris build up as been low. The automated trash screen has been found to be effective in managing urban debris build up and removal in a fast flowing urban watercourse.

Appendix 1: Debris removed by the automated self-cleaning trash screen (October 2015-January 2016)

1) Woody debris

2) Timber planks

3) Cans, bottles, extraneous metal, balls

4) Leafy detritus

5) Boulders/bricks

6) Plastic bags

Appendix 2: Automated Self-Cleaning Trash Screen design drawings

References

Allen, D., Arthur, S., Haynes, H. and Wallis S.G. (2014) Influences and drivers of woody debris movement in urban watercourses, Science China Technological Sciences, 57(8), 1512-1521.

Blanc, J. (2013) Analysis of the impact of trash screen design on debris related blockage at culvert inlets, unpublished thesis, Heriot-Watt University, Scotland.

Blanc, J., Wallerstein, N.P., Arthur, S. and Wright, G. (2014) Analysis of the performance of debris screens at culverts. In Proceedings of the Institution of Civil Engineers-Water Management, 167(4), 219-229).

Wallerstein, N. and Arthur, S. (2012) Predicting and managing flood risk associated with trash screens at culverts, FRMRC2, Heriot-Watt University, Scotland.

Wallerstein, N., Arthur, S. and Blanc, J. (2013) Culvert design and operation guide supplementary technical note on understanding blockage risks, CIRIA, London.

Weeks, W. and Rigby E. (2015) Blockage of Hydraulic Structures: Blockage Guidelines, Engineers Australia, ACT.

HERIOT WATT UNIVERSITY

Inverclyde council