Evaluating Barrier Inlet Screens to Capture Debris and Improve Roadside Drainage Infrastructure

Évaluation des grilles d'entrée de barrage pour la capture des débris et l'amélioration des infrastructures de drainage en bordure de route

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RÉSUMÉ

Les bouches d'égout des barrages routiers sont sujettes à l'obstruction par les débris de la chaussée, ce qui crée des risques pour la sécurité et nécessite un entretien intensif pour assurer un drainage efficace des abords de la route. Cette étude a évalué les performances de sept modèles de grilles pour bouches d'égout, dont quatre propriétaires et trois non propriétaires, installés à 24 bouches d'égout dans l'Ohio (États-Unis) et suivis en temps réel pendant deux ans à l'aide de capteurs à faible coût. Au cours de l'étude, les grilles ont empêché l'entrée de 123 kg de débris dans le réseau d'égouts pluviaux. Ces débris étaient principalement composés de sédiments, de végétation et de plastique. Les grilles non brevetées se sont avérées plus performantes que les modèles brevetés : elles nécessitent un entretien moins fréquent (en moyenne tous les 125,8 jours contre 75,7 jours), sont plus faciles à installer et s'adaptent à toutes les bouches d'égout, même celles dont les dimensions varient en raison de l'usure. Des essais sur le terrain des techniques d'entretien ont révélé que l'association d'un compresseur d'air à une balayeuse de voirie à air régénératif constituait l'approche la plus efficace et la plus économe en ressources, tandis que les balayeuses seules se sont avérées insuffisantes pour les volumes importants de débris. Ces résultats soulignent le potentiel des nouvelles grilles d'entrée d'eau comme composante de l'infrastructure de drainage routier afin d'améliorer la fiabilité du drainage, la sécurité routière et l'impact environnemental en aval.

ABSTRACT

Highway barrier inlets are prone to clogging from roadway debris, creating safety hazards and requiring labor-intensive maintenance to maintain effective roadside drainage. This study evaluated the performance of seven barrier inlet screen designs, four proprietary and three non-proprietary, installed at 24 inlets across Ohio, USA and monitored in real-time over a two-year period using low-cost sensors. A total of 123 kg of debris was blocked from the storm sewer by the screens during the study, which was primarily comprised of sediment, vegetation, and plastic. The non-proprietary screens outperformed proprietary designs, requiring less frequent maintenance (on average, every 125.8d versus 75.7d, respectively), easier installation, and universal fit to barrier inlets with non-uniform dimensions due to wear over time. Field testing of maintenance techniques revealed that pairing an air compressor with a regenerative air street sweeper was the most effective and resource-efficient approach, while street sweepers alone were inadequate for heavy debris loads. Findings highlight the potential for novel barrier inlet screens as a component of highway drainage infrastructure to improve drainage reliability, roadway safety, and downstream environmental outcomes.

KEYWORDS

Barrier inlet screens; highway drainage infrastructure; litter collection; real-time monitoring; road maintenance

1 INTRODUCTION

Highway drainage systems are critical for maintaining safe and efficient transportation networks, yet they are highly susceptible to clogging from roadway debris. Materials ranging from fine sediment and vegetation to large anthropogenic items such as hubcaps, tires, lumber, and plastic bottles are routinely deposited and influenced by enviornmental factors, traffic patterns, and vehicular accidents (Winston et al. 2023). When these materials enter stormwater inlets, they obstruct flow, reduce hydraulic capacity, and increase the risk of ponding on travel lanes which poses significant safety hazards for motorists. Barrier inlets, unobstructed 10cm x 3m openings in concrete median walls along divided highways which efficiently route runoff to centerline sewers, are common elements of highway drainage infrastructure in Ohio, USA. Their standard geometry, directly connected and impervious drainage areas, and proximity to fast-moving traffic make them particularly vulernable to debris accumulation and clogging, resulting in ponded water encroaching into travel lanes. Clogged barrier inlets can result in the blockage of hundreds of linear meters of centerline sewers; traditional maintenance efforts (e.g., vacuuming storm sewers) are labor intensive, expose workers to challenging maintenance operations and safety concerns, and require extended lane closures (Green et al. 2019). Consequently, transportation agencies have explored preventive strategies to intercept debris before it enters the storm sewer system. Screening devices for barrier inlets, intended to reduce maintenance frequency, improve road safety, and improve environmental outcomes by preventing debris from entering receiving streams, have emerged as a promising solution; however, questions remain regarding their hydraulic performance, durability, and cost-effectiveness when deployed at scale (Elzarka et al., 2020).

Barrier inlets are installed along Ohio's divided highways in regions with markedly different climatic conditions and traffic patterns which create complex and site-specific challenges for maintaining inlet functionality. Long-term field monitoring data to quantify the performance of barrier inlet screens under real-world conditions is non-existent, as previous evaluations have largely relied on short-term observations or laboratory simulations (Elzarka & Meduri, 2020; Green et al., 2019). However, the unique, space-constrained environment of barrier inlets (i.e., the center of divided highways) coupled with the safety risks posed by prolonged ponding on high-speed roadways demand a unique monitoring approach to quantify the performance of these devices.

This study addresses this knowledge gap by: (1) conducting market research of commercially available barrier inlet screens and designing a suite of novel, non-proprietary screens, (2) installing and monitoring of 24 screens across Ohio over a 2yr period in real-time using an ensemble of low-cost sensors, and (3) evaluating maintenance techniques to ensure the long-term effectiveness of these screens as part of highway drainage infrastructure.

2 METHODOLOGY

Three clusters of eight barrier inlets along interstate highways in Cleveland (41.602454°N, 81.438716°W), Columbus (39.9034°N, 83.0279°W), and Cincinnati (39.2735°N, 84.3545°W), Ohio, USA were evaluated in this study. Areas with known debris accumulation issues were selected for the research, and clusters of closely located barrier inlets were prioritized to ensure the screens were exposed to similar rainfall and traffic patterns. Following a review of commercially available products, four proprietary screens were selected for field monitoring. These screens were custom built to fit the dimensions of each inlet and contained features ranging from simple oval-shaped openings to retractable hinges and louvered flanges. In addition, three non-proprietary screens were developed from long-lasting materials (steel) and intended to universally fit all barrier inlets without complex installation procedures (Figure 1). Each screen was tested in triplicate (i.e., one screen was installed per cluster of eight barrier inlets in each city); the final inlet in each city remained unscreened to serve as experimental controls. Installation time and a qualitative rating of installation difficulty for each was recorded.

Given the study locations were separated by a distance of 400km along with the need for rapid responses to drainage issues in close proximity to high-speed traffic, ultrasonic depth sensors paired with internet-connected microcontrollers were developed to remotely monitor roadside ponding levels in real-time (Figure 1). The sensors were mounted to custom fabricated assemblies affixed to the top of the barrier wall to measure ponding depth in front of each barrier inlet. Wildlife cameras were used to photo-document debris movement during rain events. Tipping bucket rain gauges were installed to record rainfall measurements. Ponding depth at the inlet was used to monitor debris accumulation on the barrier inlet screen. Because of the safety risks to passing motorists, maintenance (i.e., debris removal) was performed when ponding spread within 30cm of the travel lane; an automated messaging system was used to facilitate rapid debris removal and restore drainage capacity.

Debris removed from the barrier inlet screens was weighed and oven dried at 100°C for 72hr to determine the wet weight, dry weight, and moisture content of the sample. Dried material was separated into subcategories: gravel, plastic, wood, metal, glass, natural vegetation, paper, fabric, sediment, and material passing a 2mm sieve.

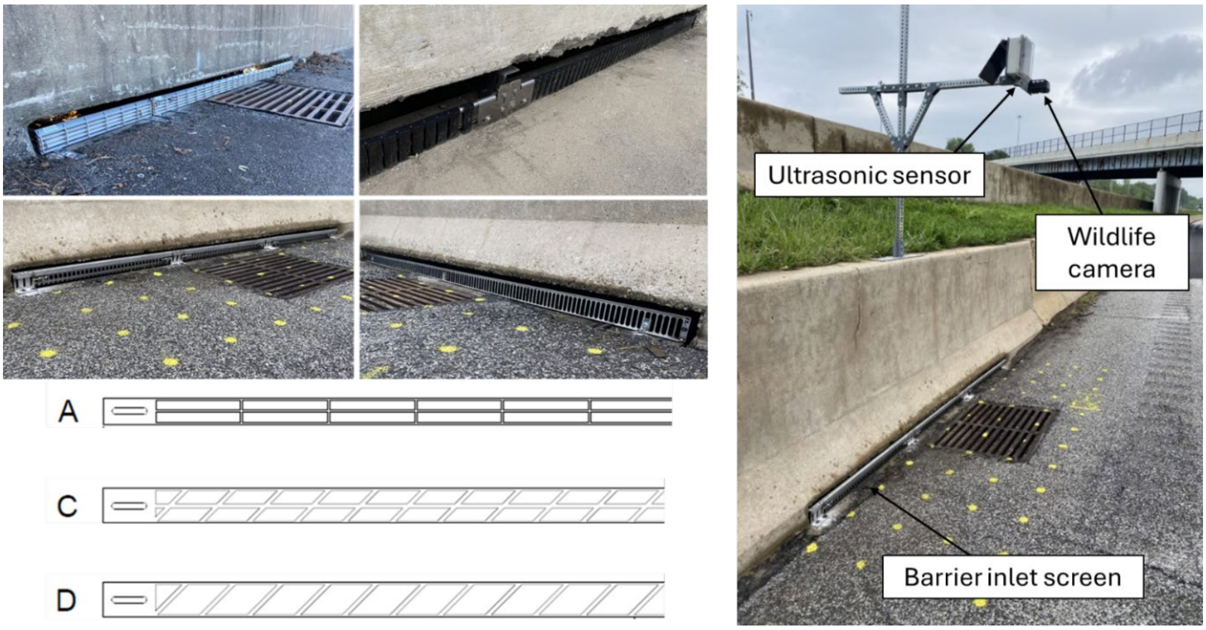

Figure 1: Photos of four proprietary barrier inlet screens (upper left), design of non-proprietary screens (lower left), and field monitoring apparatus designed for real-time monitoring of roadside ponding depth (right).

Four barrier inlet maintenance techniques were evaluated at the culmination of field monitoring. Standard roadside maintenance practices (i.e, use of a regenerative air street sweeper) were coupled with (1) a tow-behind air compressor, (2) a pressure washer, and (3) use of hand tools (e.g., shovels, rakes, brooms) intended to loosen debris adhered to the barrier inlet screen ahead of the street sweeper. Techniques were evaluated based on time required for maintenance, debris removal effectiveness, and resilience of each barrier inlet screen to the mechanical debris removal methods tested in the field.

3 RESULTS AND DISCUSSION

Debris collection thresholds were triggered 13 times during the monitoring period, all from barrier inlets in Columbus, indicating site-specific factors such as road design, traffic density, and climate influenced debris generation and clogging. Though debris was observed in all locations, greater longitudinal slopes and larger barrier inlet openings (i.e., due to damage from snow plows) likely mitigated excessive ponding at the Cincinnati and Cleveland study areas, respectively. In total, 123kg of debris was removed from the screens, with an average moisture content of 35.8% and a 91-day interval between maintenance triggers. Debris samples were primarily composed of sediment (61%), natural vegetation (12.7%), and plastic waste (7.7%). Inlets at sag points (i.e., those which received runoff from both sides of the inlet) required maintenance approximately twice as often as on-grade inlets (64d versus 123d) and had higher debris loading rates (0.14 vs. 0.09 kg/d), suggesting these locations should be the focus of targeted maintenance programs. An example of a hyetograph and hydrograph leading to debris blockage as well as the composition of debris removed from the barrier inlet screen is shown in Figure 2.

Performance differences between proprietary and non-proprietary screens were evident. Maintenance of the proprietary screens was required nine times during the study compared to five instances for the non-proprietary screens. On average, maintenance intervals of the non-proprietary screens were 50.1 days longer (125.8d) compared to the proprietary screens (75.7d). Debris samples from the proprietary screens contained more sediment (mean 66.6%) than the non-proprietary screens (48.5%), indicating the smaller opening sizes of the proprietary screens (Figure 1) were blocked more rapidly by small particles. Small sediment entering the storm sewer is often acceptable given the low clogging risks of smaller particles in pipes. Overall, non-proprietary screens required maintenance less frequently in all inlet configurations compared to proprietary screens. Further, the universal fit and simple installation of the non-proprietary screens were benefits.

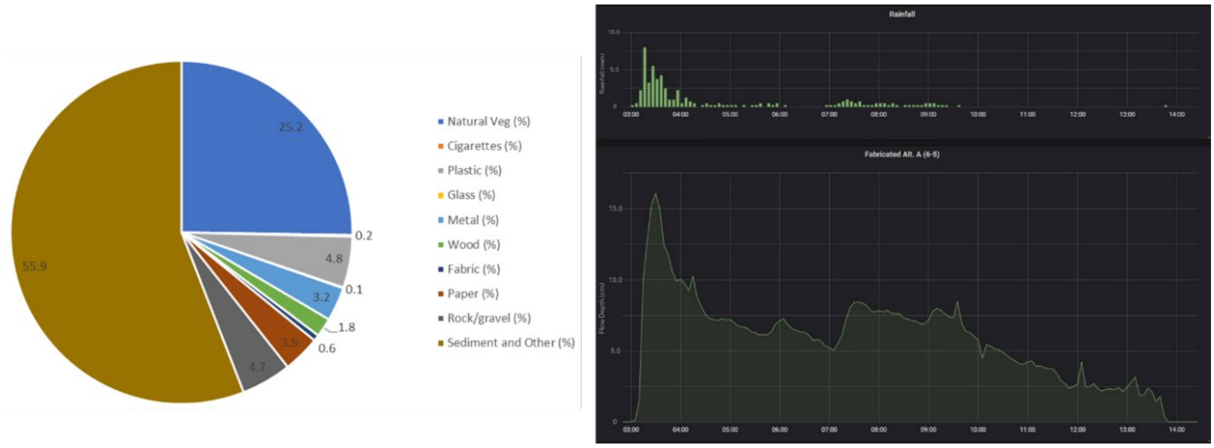

Figure 2: Debris sample composition (left) and hyetograph/hydrograph (right) collected from non-proprietary screen during a 56mm rain event.

Alternative maintenance techniques combined with a regenerative air street sweeper were highly effective at clearing debris from barrier inlet screens, achieving complete removal (i.e., 0% clogging) in all cases and imparting minimal damage to the screens. Maintenance using the street sweeper alone, the current standard of practice for roadside management in the state, did not effectively loosen debris from the barrier inlet screens, indicating the benefits of the alternative maintenance techniques tested. The frequency of debris removal affected the time required for maintenance, as the street sweeper alone remained effective when clearing inlets with minimal debris accumulation. While maintenance measures tended to be equally effective, resource needs varied: the air compressor technique required extra crew and equipment, while the pressure washer required a water supply and longer setup time, and the use of hand tools was labor-intensive and introduced safety risks to maintenance crews. Based on performance and feasibility, the air compressor paired with regenerative street sweeping was determined to be the most effective maintenance technique. Street sweeper systems with integrated air compressors may be beneficial to reduce maintenance demands and personnel needs for large-scale implementation and maintenance of barrier inlet screens.

4 CONCLUSIONS

This study demonstrates that barrier inlet screens can significantly reduce pipe clogging and improve drainage performance and environmental outcomes on divided highways, though their effectiveness is highly dependent on screen design characteristics and site-specific conditions. Field monitoring revealed that inlets located in relative low points in the roadway require more frequent maintenance, underscoring the need for targeted debris removal in these areas. Non-proprietary screens outperformed proprietary designs in terms of maintenance intervals and ease of installation, offering a practical and cost-effective solution for implementation at large scales. While all maintenance techniques effectively removed debris without damaging barrier inlet screens, pairing an air compressor with a regenerative air street sweeper emerged as the most efficient approach, particularly when integrated into purpose-built equipment to minimize labor and resource demands. These findings provide actionable guidance for transportation agencies seeking to enhance roadway safety and operational efficiency through preventive, low-cost additions to drainage infrastructure on highways.

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