United States Environmental Protection Agency

EPA/600/B-18/320 | October 2018
www.epa.gov/homeland-security-research

Evaluation of Stormwater Detention Basins to Improve Water Quality and Enable Emergency Response During Wide-Area Contamination Incidents

Office of Research and Development
Homeland Security Research Program

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EPA/600/R-18/320
October 2018

Evaluation of Stormwater Detention Basins To Improve Water Quality and Enable Emergency Response During Wide-Area Contamination Incidents

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Disclaimer

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development funded and managed the research described herein under contract EP-C-14-012 with APTIM Federal Services, LLC. It has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the view of the Agency. Any mention of trade names, products, or services does not imply an endorsement by the U.S. Government or EPA. The EPA does not endorse any commercial products, services, or enterprises.

The contractor role did not include establishing Agency policy.

Table of Contents

List of Tables

List of Figures

Abbreviations

A	cross-section area of the media chamber
a	cross-section area of the standpipe
Ag	silver
CFU	Colony Forming Units
cfs	cubic feet per second
Cs	Cesium
Cu	Copper
DRP	dissolved reactive phosphorous
E.coli	*Escherichia Coli*
EPA	Environmental Protection Agency
ft/min	feet per minute
GRO	gasoline range organics
ha	hectare
h_1	height of water at the beginning of time increment in inches
h_2	height of water at the end of time increment in inches
K	coefficient of permeability
km^2	square kilometer
lb	pound
M	million
Mn	manganese
N	nitrogen
NH_3	ammonia
NH3-N	ammonia-nitrogen
NHSRC	National Homeland Security Research Center
NO_3^-	nitrate
NO_2^-	nitrite
NOAA	National Oceanic and Atmospheric Administration
O&G	oil and grease
ORD	Office of Research and Development
P	phosphorous
PO_4-P	phosphate-phosphorous
PVC	polyvinyl chloride
$Q_{critical}$	Critical Flow
SD 1	Sanitation District No. 1 of Northern Kentucky
t	elapsed time increment
T&E Facility	Test and Evaluation Facility
TMS	Toyota Motor Sales
TN	total nitrogen
TP	total phosphorous
TPH	total petroleum hydrocarbons
TPH-DRO	total petroleum hydrocarbons diesel range organics

Acknowledgements

Contributions from the following individuals to the work described in the report are acknowledged: Radha Krishan, Greg Meiners, Don Schupp, Sue Witt, Nicole Sojda, LM Narasimman, and Gune Silva of APTIM Federal Services, LLC. Robert Hawley and Katie MacMannis of Sustainable Streams, LLC; Matt Wooten and Elizabeth Frye of Sanitation District 1 of Northern Kentucky; and Mark Jacobs of the Boone County Conservation District of Northern Kentucky.

Executive Summary

Detention ponds are stormwater management structures that temporarily collect runoff and then release a reduced flow to decrease the risk of flooding. The U.S. Environmental Protection Agency (EPA) National Homeland Security Research Center partnered with the Sanitation District No. 1 of Northern Kentucky and the Boone County Conservation District of Northern Kentucky to design and test detention pond outfall retrofit devices to determine the effectiveness of these devices in eliminating stream erosion, improving receiving stream water quality, and providing the capability to respond and mitigate wide area contamination incidents. Field studies for this project were performed at two locations in Hebron, KY - the Toyota Motor Sales distribution warehouse detention pond and the Boone County School District bus lot detention pond. Bench and field-scale pilot testing for this project were performed at the EPA's Test and Evaluation Facility in Cincinnati, OH.

Detention ponds are frequently used as a stormwater runoff best management practice to provide general flood protection, lessen extreme floods, and improve water quality. Contaminants could also enter the water bodies from the discharge of water used in cleanup or mitigation operations during homeland security events (such as biological, chemical, or radiological incidents). Concern for the intentional or unintentional contamination of water bodies have led to this report on the removal of contaminants within detention basin structures prior to discharge to surface water bodies or municipal wastewater treatment systems. Contaminated stormwater can be generated as a result of intentional incidents (e.g., terrorist attacks) as well as unintentional incidents (e.g., natural disasters, industrial spills, transportation accidents, etc.) from:

- Washdown activities involving chemical, biological, or radiological agents from indoor-outdoor areas;
- Water from decontamination activities such as extinguishing industrial fires; and
- Stormwater runoff during an incident or water infrastructure decontamination activities.

Field-scale, pilot-scale, and bench-scale tests were performed to evaluate the function of two innovative detention basin devices that can be quickly deployed to control stormwater contamination events within existing detention basin structures. The devices were designed with the intention of long-term stream water quality improvements by reducing scouring of stream beds, providing treatment of contamination that lead to stream impairment, and reducing the spatial extent of large volumes of contaminated water from wide area contamination incidents and mitigation efforts. A wide variety of media can be installed within the devices to remove the

targeted contaminants expected to be in the stormwater. The media evaluated include: gravel coated with an adsorptive media, switchgrass, granular activated carbon, natural zeolite, iron composite metals, and ferric oxide coated media. A summary of the results obtained from both field-scale and pilot-scale detention basin retrofit device evaluations to facilitate wide area water quality decontamination and control of stormwater runoff flow rates is as follows:

- A natural zeolite, switchgrass, ferric oxide powder, and coated gravel exhibited the best removal (> 90% removal) of cesium (radioactivity surrogate).
- Iron composite metal reduced *E. coli* (used as a bacterial contamination surrogate) levels by 8 logs followed by ferric oxide powder and natural zeolite (6 logs). Switchgrass exhibited an unexpectedly high removal capacity (4 logs).
- All the media exhibited > 72% removal of nitrogen and >56% removal of phosphorous which are typically related to harmful algal blooms in source waters.
- The media exhibited a wide range of permeability which reflects how quickly the treated water can exit the detention basin via the media. Most localities require detention basins to be emptied within 48 hours to prevent vector growth. The coated gravel, switchgrass, granular ferric oxide, activated carbon, and natural zeolite adequately allow flow to exit the detention basin within that time frame. The iron composite metal and sintered metal with copper may require an additional 24 hours whereas the ferric oxide powder and powdered reagent mix are not likely to be able to meet these flow requirements.
- Another practical consideration for the widespread use of media to treat contaminated stormwater is the cost. The ferric oxide powder was, by far, the most expensive media at $16.33/lb with switchgrass being the least expensive at $0.20/lb. The remaining media were primarily around $3.00/lb with none exceeding $5.00/lb.
- Full-scale installations of two variations of the detention basin retrofit prototype device demonstrated that outlet flow rates were maintained below $Q_{critical}$ (the flow rate at which erosion and down cutting of the receiving stream would begin) while doubling the detention time within the basin without causing flooding of the adjacent area.
- Post-retrofit detention basins safely detained storm events that exhibited more than twice the total precipitation and rainfall intensity of pre-retrofit storm events.

The selection of which media to use for the mitigation of a wide area incident or traditional stormwater runoff requires the consideration of multiple factors as described above:

1) Identify the contaminant causing impairment or requiring treatment.
2) Select the applicable media.
3) Identify the detention period required to keep the discharge below $Q_{critical}$. Narrow your selection of appropriate media.
4) Select the lowest cost media that meets the above requirements

The retrofit device does not disturb the existing ground cover or require additional excavation. It simply and cost-effectively optimizes the existing detention basin outlet to take greater advantage of the basin's existing storage capacity. The device can be fabricated and installed within days of an incident or as part of an emergency preparedness plan.

1.0 Introduction

The U.S. Environmental Protection Agency (EPA), Office of Research and Development (ORD), National Homeland Security Research Center (NHSRC) have partnered with the Sanitation District No. 1 of Northern Kentucky (SD 1) and the Boone County Conservation District of Northern Kentucky (BCCDKY) to design and test detention pond outfall retrofit devices to determine the effectiveness of these devices in eliminating stream erosion, improving receiving stream water quality, and providing the capability to respond and mitigate wide area contamination incidents. Field studies for this project were performed at two locations in Hebron, KY - the Toyota Motor Sales (TMS) distribution warehouse detention pond and the Boone County School District (BCSD) bus lot detention pond. Bench and field-scale pilot testing for this project were performed at the EPA Test and Evaluation (T&E) Facility in Cincinnati, OH.

1.1 The Effects of Urbanization on Stream Flow

Urbanization typically results in the replacement of land features where rainwater can infiltrate into the ground with impervious areas such as roads, parking lots, rooftops, driveways and sidewalks, and compacted soils. These impervious areas alter the natural hydrology of a watershed, leading to increased runoff volumes with more frequent, larger magnitude and shorter duration peak flows. The higher runoff volumes can, in turn, result in accelerated stream bank erosion, stream bed down cutting, and stream instability. These physical alterations to the stream channel negatively impact water quality (e.g., increased suspended solids), and, biological communities (through habitat disruption and/or loss). Further, these alterations can endanger infrastructure (e.g., drinking water/wastewater pipes, power lines, roads, bridges) located adjacent to streams necessitating costly repairs (Figure 1). The erosion of bridge supports, roads, and pipes (wastewater, chemicals) can cause a spill or incident directly. Erosion also increases the delivery of pollutants from the landscape to the stream. Pollutants commonly found in stormwater runoff include sediment, nutrients, pesticides, metals, organic pollutants, microorganisms, and oil and grease.

Figure 1 - Urbanization Causes Stream Degradation and Impacts Public Infrastructure

1.2 The Purpose and Design of Detention Ponds

In practice, detention ponds serve multiple purposes. The ponds help manage the excess runoff generated by constructed impervious surfaces such as roads, parking lots, and rooftops. To mitigate the adverse effects of urbanization on stormwater flow, detention ponds are frequently used as a stormwater best management practice (BMP) to provide general flood protection and lessen extreme floods. Detention ponds can also lessen downstream erosion by storing water for a limited period of a time. With the retrofitting of detention ponds, they can also be capable of incorporating water quality filtration media.

However, detention ponds do not remove all risk of flooding and downstream erosion. Thus, optimizing detention facilities to economically release runoff below the flow rate at which erosion and down cutting of the receiving stream begins for small and intermediate storm events would enable stormwater managers and sanitation districts nationwide to address multiple objectives, including hydromodification, water quality, and flooding issues within the watershed. When factoring in the economic benefits that more stable stream channels have on the life-extension of adjacent infrastructure (roads, bridges, and pipes), this approach has the potential for a high rate of return beyond that of water quality and habitat preservation.

A detention pond functions by allowing large flows of water to enter the pond, but it limits the outflow by having a small opening near the bottom of the structure. It is this outflow opening that can provide the filtration function when retrofitted with a filtration device and media.

1.3 Detention Basins as Containment and Mitigation Barriers for Homeland Security

Concern for the contamination of water bodies has led to this research on the removal of contaminants within detention basin structures prior to discharge of the contained water to surface water bodies or municipal wastewater treatment systems. Contaminated stormwater can convey pollutants that can contaminate water sources and have tremendous effects including loss of life, extensive contamination of infrastructure and environment, and fiscal strain from recovery and remediation efforts.

The contamination can arise from numerous sources. Chemical, biological, and radiological (CBR) contaminants could enter the stormwater infrastructure following an intentional (e.g., terrorist attacks) and unintentional (e.g., natural disasters, industrial spills, transportation accidents) incident from:

- Washdown activities involving chemical, biological, or radiological contaminants from indoor-outdoor areas
- Water from decontamination activities such extinguishing industrial fires, or
- Stormwater runoff during an incident or following decontamination activities.

The stormwater infrastructure pipes and basins incorporating strategically located multiple large detention basins could provide the volume necessary to contain and treat such amounts of contaminated water limiting the spatial extent of contamination. Such watershed assets (with retrofit devices) strategically located in a catchment area also contribute to the resilience of urban and suburban land use mitigating and containing wide area incidents. The use of various media has been considered as an effective and economical means for biological, chemical, and radiological contaminant removal. The adsorption or treatment potential of filtering media could enable the containment and removal of contaminants without generating environmentally large volumes of hazardous byproducts.

This approach may also be one of the most cost-effective investments in water quality and emergency response because of the abundance of traditional detention basins and their cumulative potential to be retrofitted toward a less erosive flow regime for channel stability, habitat, and ecosystem functionality. Detention basins are ubiquitous stormwater management facilities particularly in suburban areas that were developed as early as the 1980s (Hawley et al., 2017). For example, Figure 2 shows that in one approximately 36-square mile suburban watershed of Northern Kentucky with an average impervious cover of about 25%, there are an estimated 535 detention basins or an average of 1 detention basin per 18 hectare (ha). Using average values for basin size and present-day construction costs (Hawley et al., 2012b), the order-of-magnitude value of these assets is scaled to approximately $60 M, or an average of $600,000 in stormwater management assets per square kilometer within the watershed.

1.4 Research Objective

The objective of this research project is the development, deployment, and testing of a water quality treatment system/apparatus that can be integrated into existing stormwater detention basins as a retrofit device. The device design will utilize existing detention basin infrastructure to hold stormwater runoff and control the release rate of stormwater to prevent erosion using an orifice plate or by media that can also provide an effective and economical means for biological, chemical, and radiological contaminant removal. This research project also tested the adsorption or treatment potential of several such media materials with the goal of identifying low-cost materials that can be handled easily, deployed quickly, and can be customized to match the treatment needs of an impaired stream.

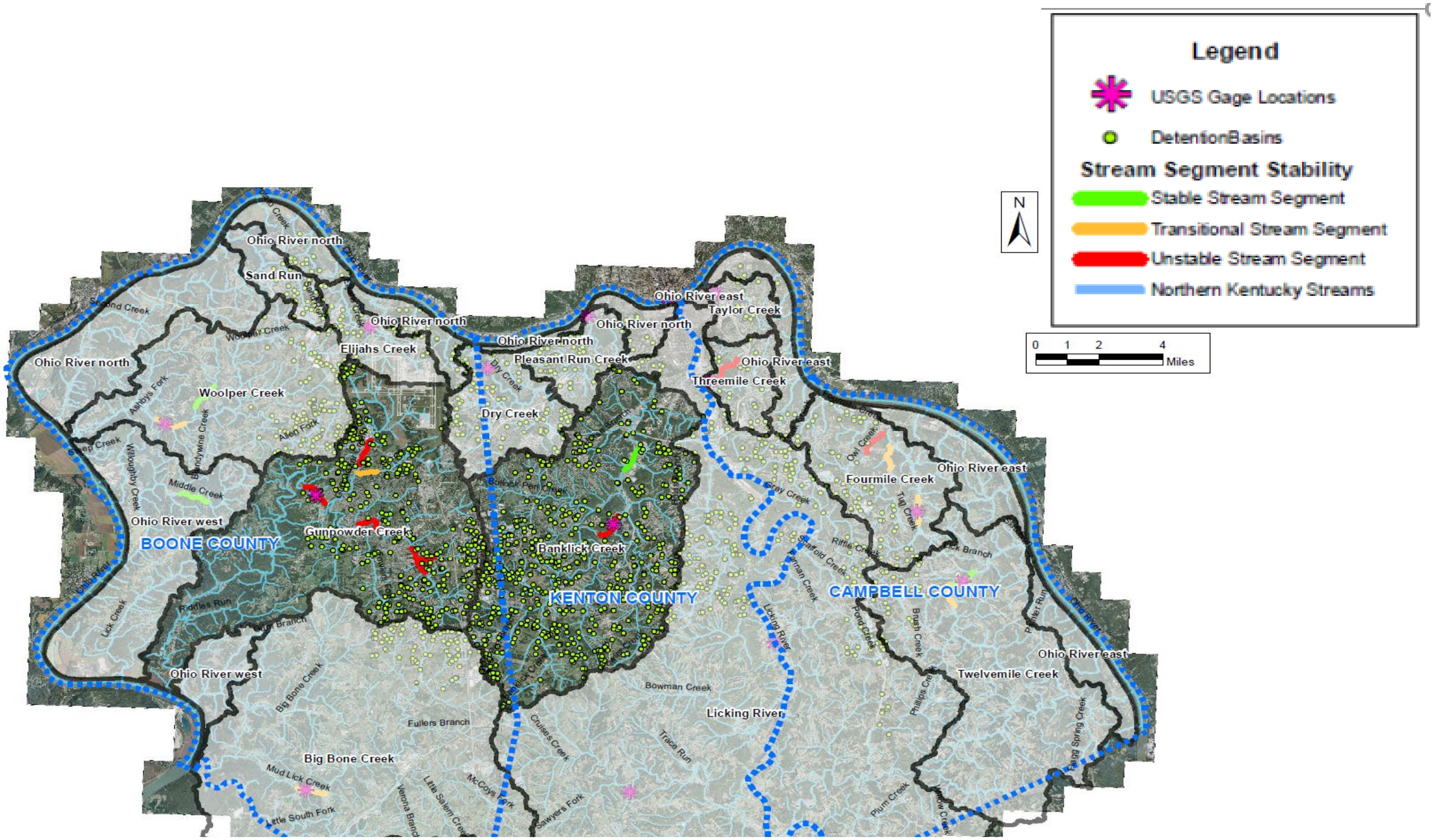

Figure 2 – Detention Ponds in Three Counties in Northern Kentucky

2.0 Detention Pond Retrofit Devices

Conventional stormwater management typically exacerbates channel erosion since BMPs designed for peak flow detention typically has little to no attenuating effect on 97-99% of the precipitation volume in a typical year (Emerson et al., 2003; Hawley, 2012). Runoff volumes above the critical flow ($Q_{critical}$) (the flow rate at which erosion and down cutting of the receiving stream would begin) for the mobility (erosion) of stream bed material (e.g., cobbles, gravel, sand) is both geomorphically and ecologically relevant (Poff, 1992; Townsend et al., 1997). Figure 3 graphically illustrates the typical year rainfall and recurrence probabilities for Northern Kentucky.

The initial goal of this research project was to develop simple devices that can reduce the cumulative erosive power in a receiving stream by restricting the more frequent storm events (up to the two-year storm) to be released below $Q_{critical}$ and achieving comparable flood control performance of the pre-retrofit configuration during larger and more infrequent events (5-, 10-, 25-, 50-, and 100-year events). The device should also improve water quality and be relatively easy to install, with minimal, if any need for heavy equipment. Due to the risks associated with a failure of the device during a large event such as the 100-year storm, the device should also minimize the reliance on moving parts to the extent possible, or have otherwise fail-safe controls to ensure adequate performance during flood events (i.e., incorporate overflow or other high-water relief methods). Furthermore, the device should be economical, with the design, materials, and installation on the order of ~$10,000 per detention basin, with potential opportunities for additional cost savings if using a utility's in-house staff for design and/or installation.

To meet these goals, two devices were designed and field tested:

- A prototype of the Detain H_2O (patent pending) retrofit technology installed at the Toyota Motor Sales distribution warehouse detention basin in Hebron, KY.
- A prototype of a modified Detain H_2O device with increased treatment capabilities installed at the Boone County School District Bus Lot in Hebron, KY.

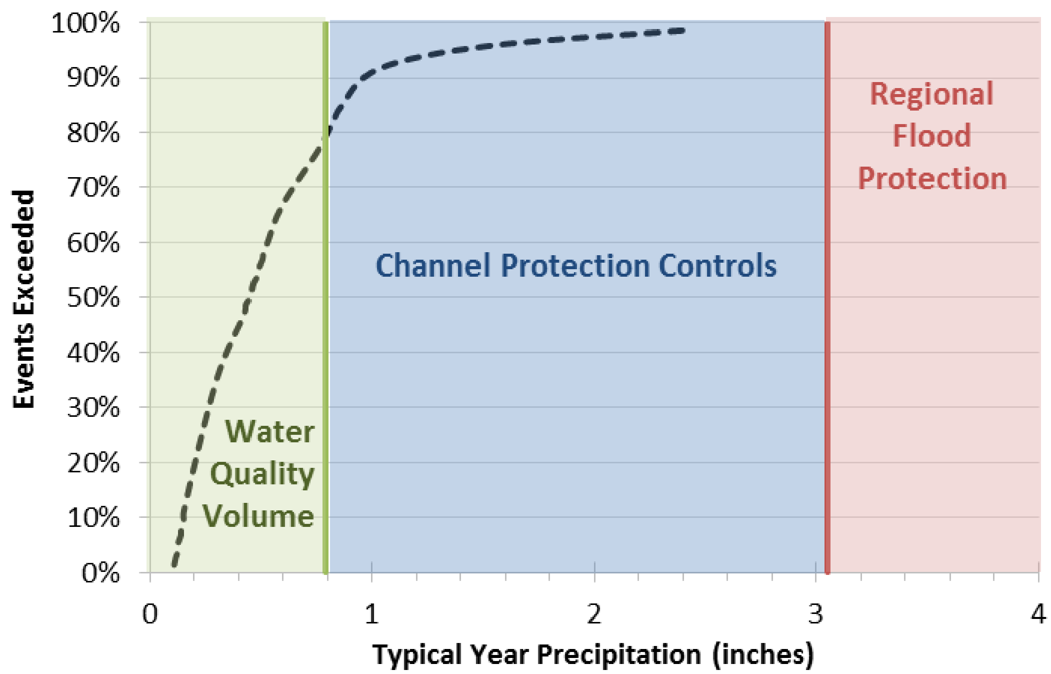

Figure 3 - Typical year rainfall and recurrence probabilities for Northern Kentucky

2.1 Detention Basin Design and Modifications

Until as recently as the last decade, detention basins were almost exclusively designed to meet flood protection criteria that typically involved managing stormwater runoff from new developments such that peak discharges did not exceed those of the predeveloped conditions for specific flood frequency recurrence intervals such as the 2-, 10-, 25-, 50-, and 100-year design storms (Roy et al., 2008, Clar et al., 2004). Because conventional development practices invariably create greater runoff volumes than predeveloped watersheds, the so-called "peak matching" strategy nearly universally results in prolonged durations of flows with relatively high magnitudes (Bledsoe, 2002). In many streams this results in increased durations of flows that exceed the $Q_{critical}$ for bed particle mobilization because $Q_{critical}$ can be considerably less than the two-year peak flow, particularly in streams with bed material composed of small cobbles, gravels, or sand (Rohrer and Roesner, 2006; Pomeroy et al., 2008; Hawley and Vietz, 2016). Indeed, conventional peak-matching designs can result in longer durations of flows that have the power to erode the streambed in such gravel and sand-dominated streams (Bledsoe, 2002). Furthermore, because the two-year flow tends to be the smallest discharge that conventional detention basins are optimized to control, these stormwater facilities tend to have little attenuating effects on more frequent precipitation events, with one study suggesting that up to 97% of the events in a typical year have essentially no attenuation (Emerson et al., 2003).

As a consequence of this design philosophy, lesser storms such as the 3-mo or 6-mo event that may not have caused stream erosion under predeveloped conditions may be amplified and discharged at rates that exceed $Q_{critical}$ under post-developed conditions. The cumulative effect is that conventional stormwater management policies tend to increase the frequency, duration, and/or magnitude of flows that exceed the threshold for stream channel erosion in developed watersheds (MacRae, 1997; Konrad and Booth, 2002; Rohrer and Roesner, 2006; Pomeroy et al., 2008). These policies have also failed to preserve other elements of the natural flow regime that can be important for stream integrity (Poff et al., 1997), with, for example, urban and suburban streams almost universally exhibiting flashier flow regimes than rural streams from the same hydroclimatic setting (Poff et al., 2006; Eng et al., 2013).

The widespread application of the peak-matching management strategy across North America has allowed numerous researchers to point to its ineffectiveness in protecting stream integrity — despite large investments in stormwater infrastructure, the biological, chemical, and physical integrity of streams in urban and suburban watersheds substantially departs from those in undeveloped watersheds (Booth, 2005; Walsh et al., 2005; NRC, 2009). For example, in developed watersheds with widespread incorporation of peak-matching control strategies, urban and suburban streams tend to have enlarged and more unstable channels with actively eroding banks and more homogenous habitat than those in rural watersheds (MacRae, 1997; Hawley et al., 2013a). These impacts have become so ubiquitous that "hydromodification," which among other types of hydrologic modification includes urban-induced flow amplification and associated channel erosion, is listed as the second most common source of impairment in U.S. rivers and streams (EPA, 2009).

Another consequence of this hydromodification impacts roads, power utilities, and water/sewer infrastructure that are commonly placed adjacent to and across streams. Urban-induced channel erosion, downcutting, and widening can necessitate repairs, stabilization efforts, impair water quality, and/or cause premature replacement/relocation. For example, using costs from Northern Kentucky, Hawley et al. (2013b) estimated approximately \$10,000, \$1,000, and \$350 per km^2-yr, in impacts to roads, sewers, and power utilities, respectively, that were attributable to channel erosion.

For these and other reasons, there is a growing consensus that more effective stormwater management is needed (Roy et al., 2008; NRC, 2009). This includes a need for more sustainable strategies that preserve stream integrity downstream of new developments as well as cost-effective strategies that begin to reverse the trajectories of degradation in previously developed watersheds. It follows that systematically retrofitting the ubiquitous, conventionally designed detention basins to minimize the extent of channel erosion in receiving streams would be beneficial to both the built and natural environment, would enable degraded streams to come into compliance with the Clean Water Act (CWA), and in addition, would provide an emergency response tool.

2.2 Benefits from Retrofit Devices

Future Federal or State stormwater regulations are likely to require some level of water quality improvement. In terms of water quality criteria, the Kentucky Division of Water currently requires a water quality volume approach in SD1's stormwater permit. In SD1's corresponding Rules and Regulations for new development, the first 0.8 inches of rainfall (the 80th percentile event) must pass through a water quality best management practice device before being discharged from the site. Theoretically, there may be some level of water quality improvement within a detention pond due to the stormwater being held promoting particle settlement and biological uptake. Data collected under this project indicate that typical detention ponds provide little detention time with stormwater passing quickly downstream for most storm events. Although the retrofit devices will increase the residence time and reduce sediment in the water column to some degree, there still exists the need to reduce dissolved water quality contaminants such as synthetic and volatile organic contaminants from roads, vehicles, and emission exhaust as well as pesticides and fertilizers from agricultural and residential application or chemicals from industrial, transportation, or nuclear incidents.

The retrofit design approach recognizes the role of the geomorphic setting in connecting watershed hydrology with stormwater infrastructure. For example, retrofitting a detention basin that exceeds $Q_{critical}$ approximately two to four times per year under a conventional design to a regime that does not exceed $Q_{critical}$ more frequently than once every two years would be a four-to-eightfold decrease in disturbance frequency. A retrofit strategy that restores a more natural disturbance regime may enable the transformation of an impaired aquatic community dominated by fast-lived multivoltine organisms (i.e. those producing two or more broods per year) to a more diverse community that included longer-lived species such as univoltine or semivoltine organisms (Townsend et al., 1997). It may also provide enough time for vegetation to successfully colonize recently deposited sediment at the toes of otherwise unstable streambanks, increasing the probability of a shift from an erosional state of channel evolution as described in the Channel Evolution Model (CEM) proposed by Schumm et al. (1984) to a recovered state of equilibrium.

Facilitating such changes to the flow regime that is stored, treated, and discharged from a conventionally designed detention basin does not necessarily require expensive regrading or additional excavation to make the storage volume larger. Indeed, retrofit strategies that are able to meet ecologically and geomorphically relevant hydrologic design goals within the limits of the existing facility have the potential to be much more cost-effective than those that require additional excavation. For example, even relatively minor earthwork, such as excavating the bottom ~0.9 m of soil and replacing it with amended soil media that promotes infiltration could cost ~$50,000 to $100,000 on a small basin draining ~6.5 ha, whereas simply reconfiguring the outlet control structure in the absence of additional excavation would be more likely to cost ~ $5,000 to $10,000 per basin. Furthermore, considering that these facilities are designed to have stormwater runoff directed to them during nearly every storm, approaches that require earthwork within the detention basin can create additional challenges by denuding existing vegetation ground cover, which not only requires reestablishment after construction but poses risks to water quality in terms of construction site sediment runoff. The scale of the problem as well as the abundance of conventional detention basins underscore the potential benefits of developing a simple, cost-effective strategy for achieving the retrofit performance goals (i.e., with limited funds for stormwater investments, low cost strategies have the potential to restore much greater stream lengths than higher costing alternatives). Stormwater treatment is not a new concept (Pitt et al., 1999) by large scale buried media vaults or regrading of the site which are very expensive and limited by site constraints and adjacent land use. The proposed retrofit device strategy does not disturb the existing ground cover or require additional excavation, but simply optimizes the existing outlet to take greater advantage of the basin's existing storage capacity and can be fabricated and installed within days of an incident. The retrofit device would also be available to serve as a washwater containment or treatment facility as part of a wide area emergency response mitigation effort.

2.3 Retrofit Device at Toyota Motor Sales Distribution Warehouse Detention Basin

The TMS Distribution Warehouse is located in Hebron, KY near the Cincinnati/Northern Kentucky International Airport (Figure 4). The site is a large Industrial Property of approximately 31 acres, with more than 52% impervious cover.

Figure 5shows the location on the retrofit installation in the detention pond. The device is comprised of an orifice plate that reduces the size of the outlet opening, thus reducing the flow rate exiting the detention basin (Figure 6 and Figure 7). The snorkel passively bypasses high levels of detained water from within the basin to prevent flooding under extreme storm events.

Figure 4 – Toyota Motor Sales Distribution Warehouse Site Vicinity Map

Figure 5 – Toyota Motor Sales Distribution Warehouse Detention Pond Showing Stormwater Inlets and Retrofit Device Location

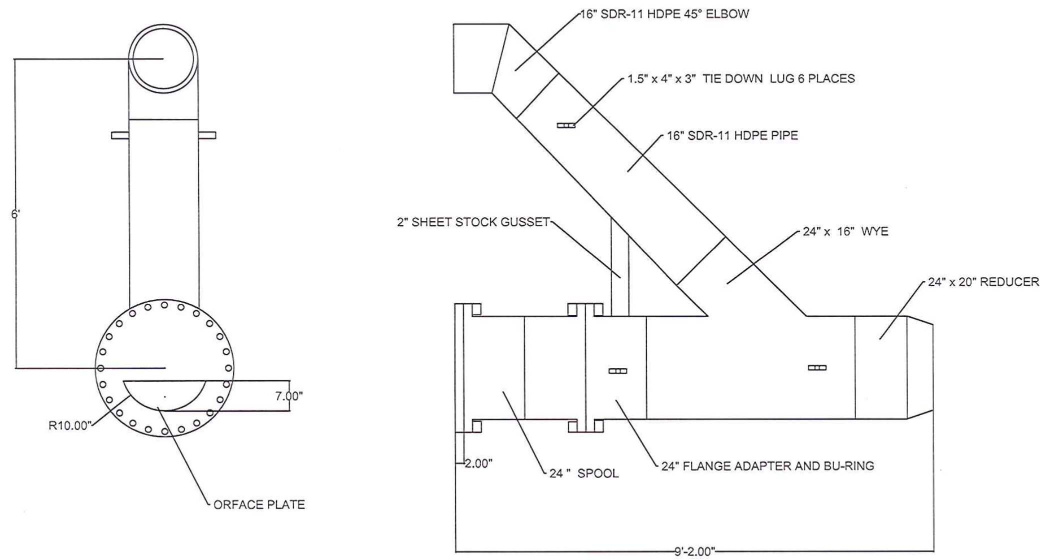

Figure 6 – Detention Pond Retrofit Device Schematic

Figure 7 – Before and After Photographs of Outlet Structure with Retrofit Device Installed

2.4 Retrofit Device Installed at Boone County Schools Bus Lot Detention Basin

The BCSD Bus Lot is located in Hebron, KY and also near the Cincinnati/Northern Kentucky International Airport (Figure 8). The site is a large paved impervious area where school buses are parked when not in use. The parking lot also includes a 2,000-gallon diesel tank for fueling the buses. Figure 9Figure 8 shows the location of the retrofit installation in the detention pond.

Figure 10 shows the new retrofit device designed for this location. The device consists of a base structure with three flanged inlet openings capable of accepting a 4-inch PVC pipe. A solid or perforated PVC pipe 3 feet in length or longer can then be filled with an appropriate media and attached to these flanges. The center opening is fitted with a float attached to a flapper valve. This opening allows a variable volume to pass depending on the level of water in the basin thus modulating the length of time water stands in the detention basin. Finally, the device includes an overflow to avoid flooding should the rate of water flow through the other openings in the device prove to be too slow. The center float valve can be replaced with another pipe containing media based on the circumstances of the installation. Figure 11 shows the device outfitted with perforated PVC pipes containing media. Figure 12 shows the stormwater outflow structure before and after the installation of the retrofit device.

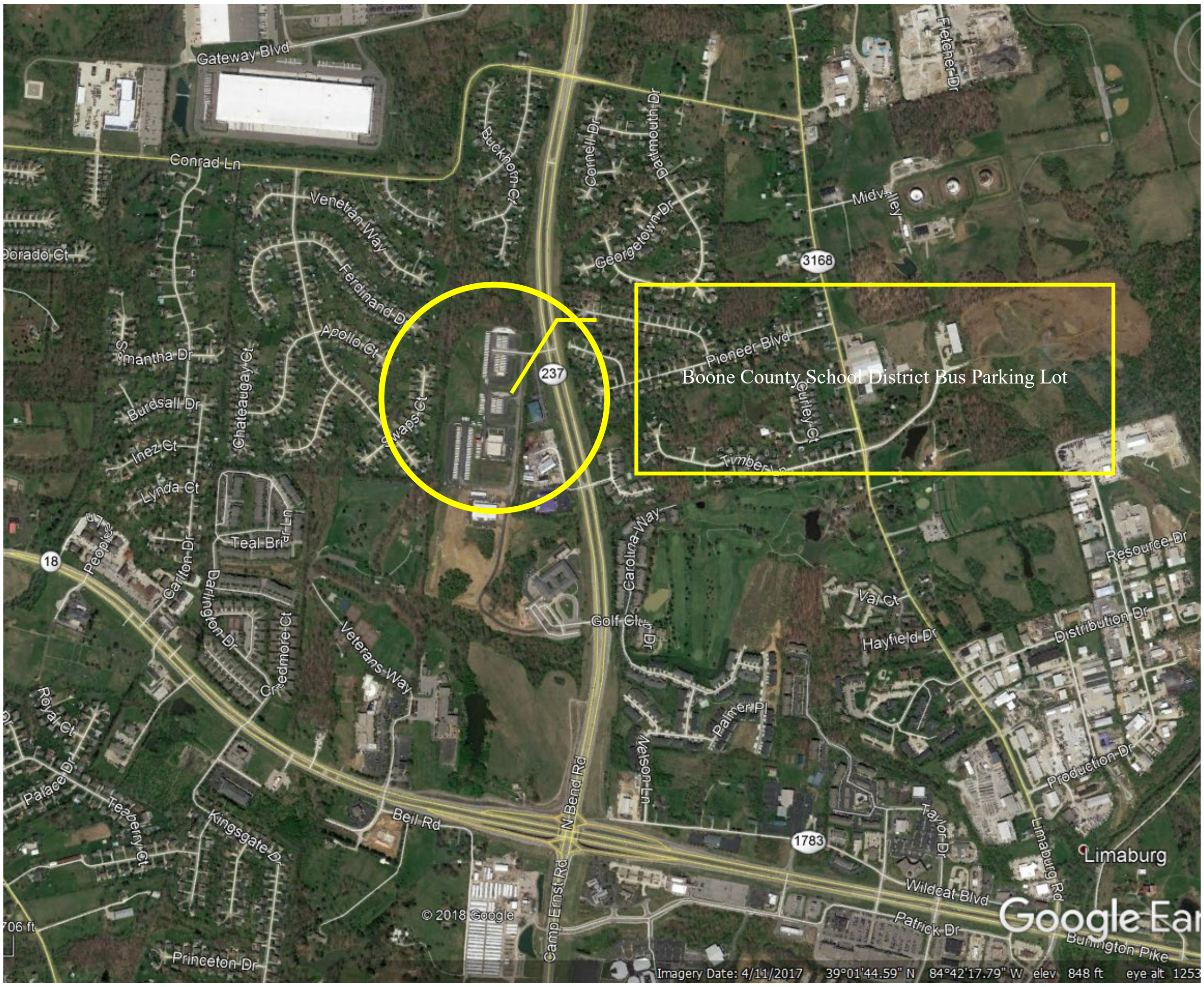

Figure 8 – Boone County School District Bus Lot Detention Pond Site Vicinity Map

Figure 9 – BCSD Bus Lot Detention Pond Showing Stormwater Inlets and Retrofit Device Location

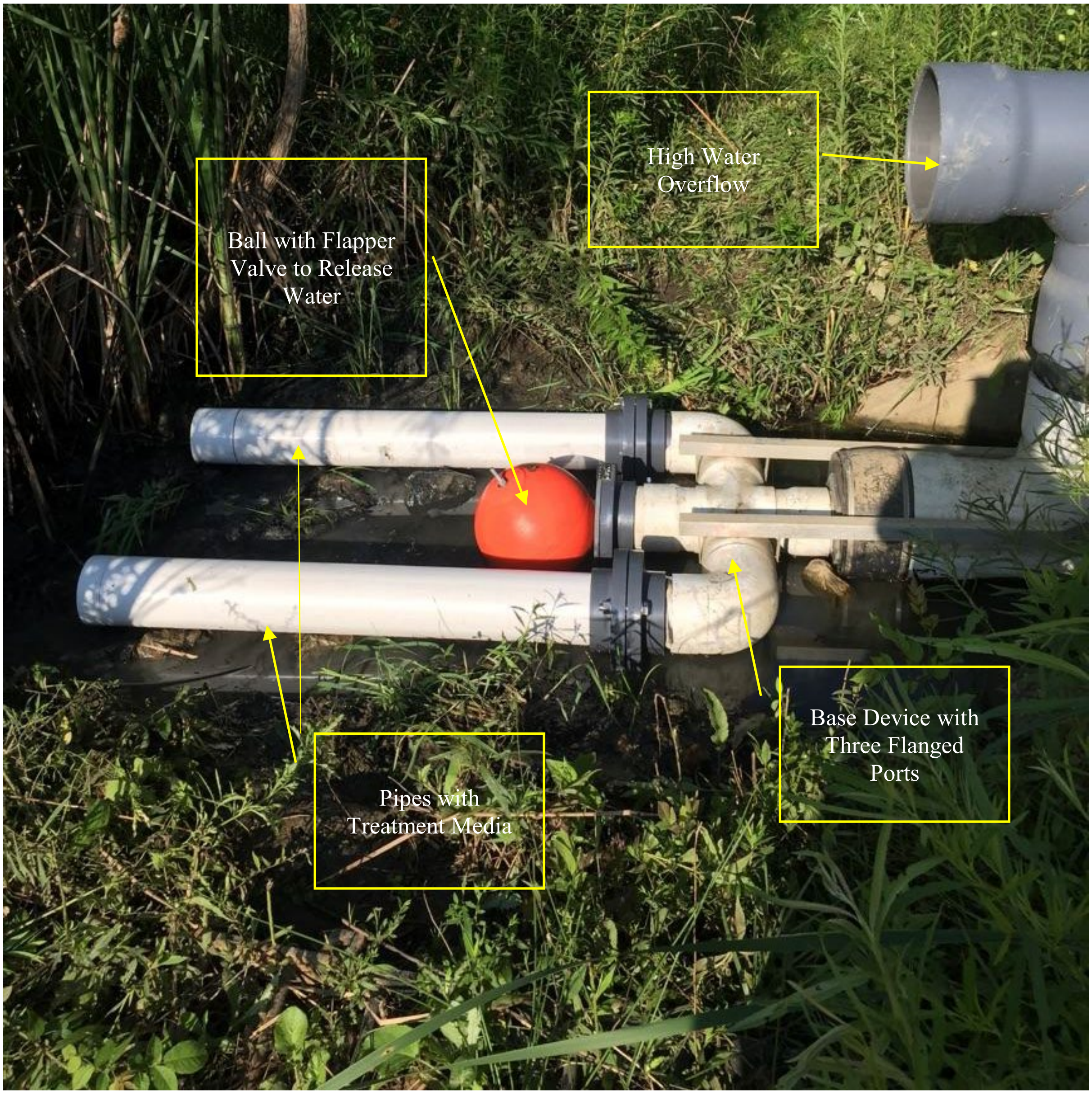

Figure 10 – Modified Detain H_2O Device installed at the BCSD Bus Parking Lot

Figure 11 – Modified Detain H_2O Device with Perforated Pipes Containing Media

 

Figure 12 – Before and After Photographs of BCSD Detention Pond Outlet Structure with Retrofit Device Installed

3.0 Contamination Treatment for Homeland Security Incidents

The detention basin retrofit devices are effective in reducing the outflow rates below the flow-critical values to reduce downstream erosion of the channel bed and bank and reduce the spatial extent of contaminated stormwater. These units are also capable of incorporating water quality filtration media. Stormwater will not only be temporarily detained, but multiple stormwater pollutants (e.g., nutrients, pesticides, microorganisms, and roadway runoff) will be mitigated as well. During emergency response mitigation/recovery efforts for biological, chemical, or radiological contaminated water could be fully retained within a detention basin by retrofit devices that to treat all the water for discharge, disposal, or further treatment at a wastewater treatment plant. Potential filtration media range from natural products such as mulch, switchgrass, sand, and gravel to various grades of granular activated carbon and other manufactured media designed for specific classes of contaminants. Additionally, for a more expeditious evaluation of water quality filtration media relative to real-world flow rates, pressures, and contact times, a pilot-scale experimental apparatus was constructed at the EPA T&E Facility.

3.1 T&E Media Testing Apparatus

3.1.1 Pilot-Scale Stormwater Detention Basin Simulation

An experimental system was installed at the T&E Facility to simulate a stormwater basin and associated detention basin retrofit device as shown in Figure 13 through Figure 16. The experimental device was intended to simulate the field installation while enabling controlled flow rate and media performance evaluations.

The flow rate through the pipe was initially determined as a function of pressure (10 ft. of water maximum pressure) with no restriction (media) in the outlet pipe. The flow/pressure control valves were then gradually closed to reduce the pressure in the pipe while the flow rate was recorded. Following the generation of the flow rate vs. pressure curve, treatment media was inserted into the Test Media section of the pilot-scale device. Different types of media detailed in Section 3.2 were evaluated in this experimental system. Flow rate vs. pressure curves (10 ft. of water maximum pressure) were generated for each of the media in the same manner as the initial testing.

The system is capable of testing two types of media (or run a duplicate test simultaneously). The parameters to be measured during the tests are the following:

- Flow rate
- Pressure
- Influent/effluent water quality

The flow rate and the pressure were measured for each retrofit media. The flow meter is a Toshiba (Tokyo, Japan) 3-inch magmeter (Model No. 335-379 80) and the pressure gauge is an analytical gauge.

For each test, the pressure was initially set at 10 ft. of water and the flow rate was measured. The pressure was then reduced using the flow/pressure control valves, and the flow rate measured when the pressure and flow stabilized for 15 minutes.

Each media was packed into a 4-inch by 48-inch pipe designed to serve as the vessel to hold the media during flow simulations (essentially the same size as the Bus Lot media installation). Prior to testing for removal of contaminants, the flow rate through the system was evaluated to estimate the percent occlusion provided by each device by utilizing a falling-head permeability test in which a known volume of water flowed through the selected media housed within a perforated pipe with a calculated equivalent cross-sectional area.

Figure 13 - Pilot-Scale Testing Showing Storage Tanks

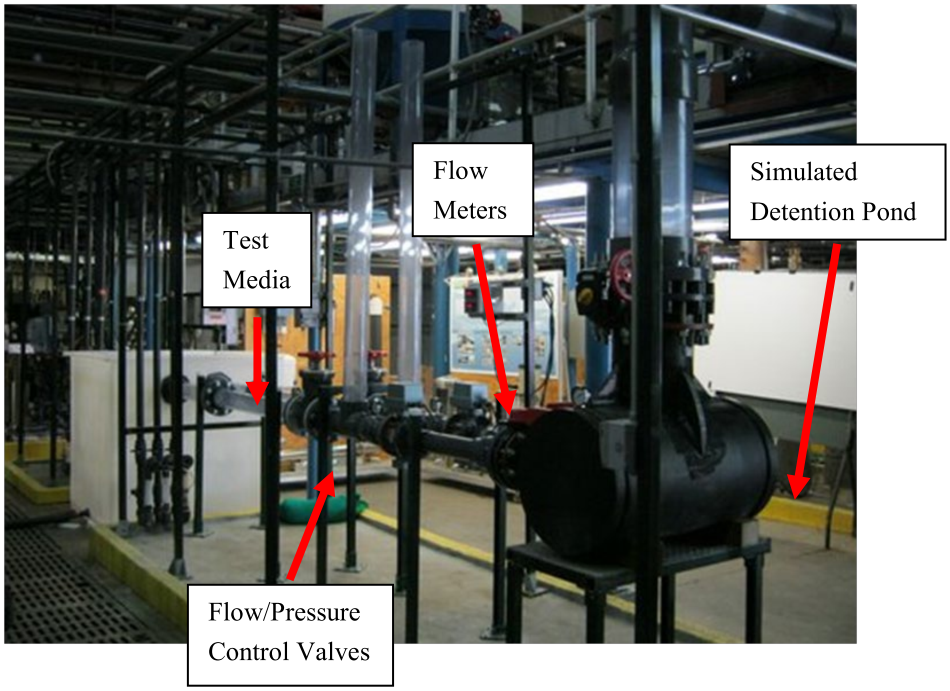

Figure 14 - Pilot-Scale Testing Unit Showing Test Media

Figure 15 - Pilot-Scale Test Media Chamber Containing Coated Gravel

Figure 16 - Switchgrass Sock Tested in Pilot-Scale Apparatus

3.1.2 Bench-Scale Apparatus for Media Testing

Figure 17 shows the bench-scale burette testing apparatus for media that could not be tested in the pilot-scale apparatus either because insufficient quantities of the test media were available or because the permeability was too low such that the flow rate could not be practically measured in the falling head tests.

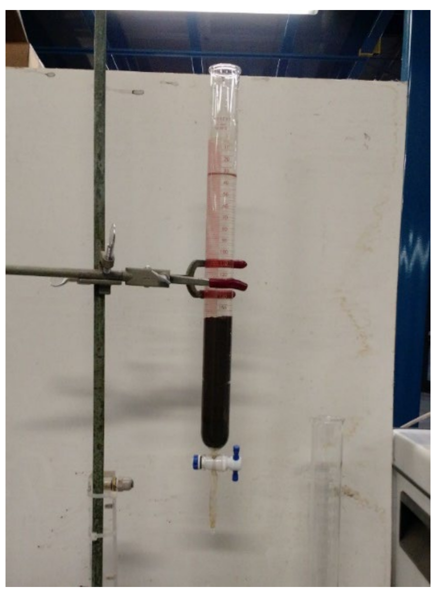

Figure 17 - Bench-Scale Testing Unit.

3.2 Media Tested at the T&E Facility

The generic contaminants tested to determine the adsorption/absorption potential of different media included:

1) Petroleum hydrocarbons in the diesel range (C_{10}-C_{20}),
2) Motor oil,
3) Nitrogen (N) and Phosphorus (P) containing soluble fertilizer (Scott's Miracle Gro),
4) *Escherichia Coli (E. coli)*, and
5) Cesium (Cs), a surrogate for radioactive material.

The tested media are shown in Table 1 which also shows the apparatus used to test each media as well as the contaminants that are assumed to be targeted by each media. The media-contaminant combinations for testing were based upon the applicability of the respective media for removing various contaminants and thus not all media were evaluated for all contaminants.

Table 1 – Media Tested at the T&E Facility

Media	Description	Target Contaminants	Apparatus
Reference - 1.5" Rock	Reference - 1.5" Rock	Baseline Reference	Pilot Test
Osorb	#4 gravel coated with an organo-silica adsorptive media from ABS Materials, Wooster, OH	Oil & Grease Nutrients (N &P)	Pilot Test
Switchgrass	Switchgrass, chopped into ~6inch strips and placed in a mesh sock. From BEG Group, Cambridge, OH	Nutrients (N&P) Oil & Grease Radioactive compounds	Pilot Test
Activated Carbon	Filtrasorb® 400 Granular Activated Carbon placed in a sock. From Calgon Carbon, Moon Township, PA.	Oil & grease Nutrients (N&P) Organic compounds Radioactive compounds	Pilot Test
Clinoptiolite	Microporous arrangement of silica and alumina tetrahedral. Natural Zeolite from Bear River Zeolites, Preston, Idaho.	Metals	Pilot Test
CleanIt LC Plus	Iron composite metal with high internal porosity placed in a sock. From Hoganas Environment Solutions LLC, Cary, NC.	Metals	Burette
CleanIt CU	A sintered metal with silver and copper disinfectant media placed in a sock. From Hoganas Environment Solutions LLC, Cary, NC.	Bacteria	Burette
Coarse E33	Iron oxy hydroxide powder coated media from AdEdge Water Technologies, Atlanta, GA.	Metals (e.g., arsenic) Bacteria	Pilot Test
Granular E33	Granular Ferric Oxide media from AdEdge Water Technologies, Atlanta, GA.	Metals (e.g., arsenic) Bacteria	Burette
Powdered Rembind	Mix of activated carbon, aluminum hydroxide from Tersus Environmental, Wake Forest, NC.	Organic	Pilot Test and Burette

N - nitrogen; P - phosphorus

Influent concentrations of each contaminant/contaminant source for a typical media test are outlined in Table 2 and Figure 18 shows the preparation of a contaminant solution. Each contaminant was mixed either separately or as a mixture in tap water dechlorinated using granular activated carbon (GAC) water to achieve the specific contaminant concentration. Due to the low solubility of diesel, a pre-prepared petroleum diesel saturated water was used to obtain influent solution based on Total Petroleum Hydrocarbon Diesel Range Organics (TPH-DRO) concentration. The proposed influent concentrations for fertilizer and diesel were based on TN and TPH concentrations, respectively. Respective concentrations of fertilizer and Cs were prepared by mixing both components in water. *E. coli* influent solution of 10^6 CFU/100 mL was prepared by mixing 40mL of stock *E. coli* at 10^{11} CFU/100 mL grown at the T&E facility in a nutrient broth at 37°C into 40 L of dechlorinated tap water. Two gallons of motor oil (Mobil SAE 10W-30) purchased from Walmart was mixed with 18 gals of water to achieve the desired influent concentration of 15 mg/L. In order to prepare a solution of TPH, 1 part of commercially purchased diesel from a local fuel station was mixed with 9 parts of water and the resultant mixture was stirred for 24 hours (Irwin 1997). This diesel-saturated water (drained from the bottom of the separator funnel) typically resulted in a solution containing 20 mg/L of TPH. Grab samples of each influent solution (Petroleum diesel, Motor oil, Fertilizer, Cs and *E.coli* in water) were analyzed to verify the application rates (Table 2).

Table 2 – Contaminant Concentrations for Tests at the T&E Facility

Contaminant Sources	Types of Contaminants	Proposed Influent Concentration (mg/L)
Petroleum diesel	TPH	0.5
	DRO	As measured as a component of TPH
	GRO	As measured as a component of TPH
Motor Oil	O&G	15
Miracle-gro fertilizer	TN	25
	NH_3	As measured as a component of fertilizer
	NO_3^-	As measured as a component of fertilizer
	NO_2^-	As measured as a component of fertilizer
	TP	As measured as a component of fertilizer
	DRP	As measured as a component of fertilizer
Cs	Cs	0.1
E. coli	*E. coli*	10^6 CFU/100 mL

The water used for the falling head tests was spiked with various contaminants so that the same tests could also be used to estimate contaminant removal in accordance with Table 2. The prepared influent solution was transferred into the water tower to conduct the falling head test. These tests, designed to evaluate the flow rate through the system to estimate the percent occlusion provided by each device, utilized a known volume of water that flowed through the selected media housed within the test apparatus with a calculated equivalent cross-sectional area.

A grab sample of the effluent water (after passing through the media) was collected at the water discharge port 30 seconds after the initiation of the falling water head test. Each contaminant and each media were tested in duplicate.

It is important to maintain a similar coefficient of permeability and contact time among media for a better comparison of contaminant adsorption. To achieve a similar coefficient of permeability, media was packed in the test media pipe or in the burette. After determining the coefficient of permeability of respective media, dechlorinated tap water was run as a control test prior to running contaminated water through the media. Influent and effluent samples were collected from both control and contaminated water tests to determine the adsorption capacity.

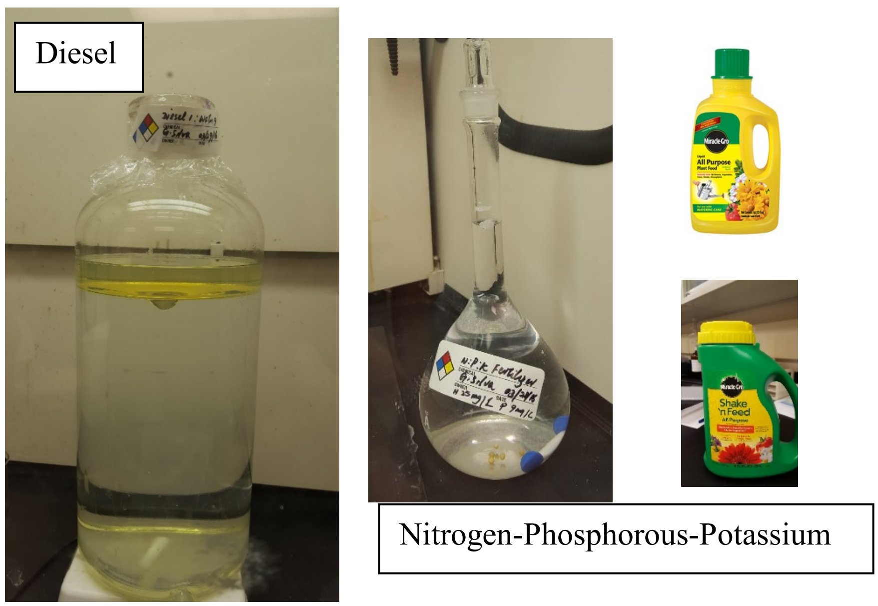

Figure 18 – Contaminants Preparation for Use in Media Testing

3.3 Permeability Estimates from Media Testing

The permeability for the falling head tests were computed using the equation:

$K = (aL/At) \ln (h_1 / h_2)$

Where:
K = coefficient of permeability [feet/minute (ft/min)]
a = cross-sectional area of the standpipe (ft^2)
L = Length of media chamber (ft)
A = cross-sectional area of the media chamber (ft^2)
t = elapsed time increment (min)
h_1 = height of water at the beginning of time increment [inches (in)]
h_2 = height of water at the end of time increment (in)

Table 3 shows the results for each media in descending order of permeability as well as a calculation of drainage time versus the reference media. The ‘time to drain’ is an important factor in that most localities (under normal operation) require detention basins to hold water no longer that 48-72 hours to reduce the potential for mosquito or other vector growth. Thus, as an example, if a basin requires 1 hour to drain through a media bed of rock, that same basin will require 6 hours to drain if switchgrass was uses as the media.

The ‘time to drain’ also represents the relative permeability of each media. As seen in Table 3, media with larger particles (such as coated gravel) have high permeability whereas powdered material exhibits a high resistance to water flow (i.e., low permeability). The Rembind media, which is marketed as a soil amendment for the adsorption of organic compounds, proved to be practically impermeable.

Table 3 – Results of Falling Head Tests for Each Media Type

Media	Generic Reference	K		Time to Drain (vs. Reference)/ Relative Permeability	Apparatus
Reference - 1.5" Rock	Reference - 1.5" Rock	28.90	ft/min	1	Pilot Test
Osorb	Coated Gravel	11.55	ft/min	3	Pilot Test
Switchgrass	Switchgrass	4.82	ft/min	6	Pilot Test
Granular E33	Granular Ferric Oxide	0.89	ft/min	32	Burette
Activated Carbon	Activated Carbon	0.68	ft/min	43	Pilot Test
Clinoptiloite	Natural Zeolite	0.63	ft/min	46	Pilot Test
CleanIt LC Plus	Iron composite metal	0.44	ft/min	66	Burette
CleanIt CU	Sintered Metal with Cu	0.39	ft/min	74	Burette
E33	Ferric Oxide Powder	0.15	ft/min	193	Pilot Test
Powdered Rembind	Powdered Reagent Mix	Very small		Very Long	Pilot Test

Acronyms: ft, foot; K, coefficient of permeability; min, minute

3.4 Contaminant Treatment Performance for Tested Media

Table 4 shows the performance of each media for the removal of challenge contaminants. The data shows that the tested media performed well for the removal of nutrients and radioactivity. Media geared towards the removal of microorganisms also performed well.

Figure 19 shows the correlation of Nitrogen and Phosphorous removal. Clinoptiolite demonstrated the highest removal of both nutrients although most media performed well in this regard.

Figure 20 illustrates the performance of media in removing bacterial contamination (with *E. coli* as the surrogate). The CleanIt LC Plus performed the best, but the copper-based CleanIt CU demonstrated the lowest disinfection percentage. Switchgrass exhibited an unexpectedly high removal capacity.

Figure 21 shows the performance of each media in removing radioactivity as represented by Cesium. Clinoptiolite, switchgrass, and Osorb performed the best for these tests.

Table 4 – Results of Contaminant Testing for Each Media Type

		Nutrients				Radioactive	Bacteria
Parameter		**Total N**	**NH_3-N**	**Total P**	**PO_4-P**	**Cesium**	**E. coli**
Media Description	**Description**	**% Removal**	**% Removal**	**% Removal**	**% Removal**	**% Removal**	**Log Removal**
Osorb	Coated Gravel	90.0	78.0	100.0	86.0	92.0	0.0
E33	Ferric Oxide Powder	76.0	78.0	100.0	98.0	94.0	6
Switch Grass	Switchgrass	92.0	76.0	64.0	90.0	94.0	4
Activated Carbon	Activated Carbon	94.0	76.0	90.0	84.0	80.0	4
Clinoptiolite	Natural Zeolite	94.0	80.0	88.0	86.0	96.0	6
Granular E33	Granular Ferric Oxide	66.0	74.0	100.0	100.0	NT	2
CleanIt CU	Sintered Metal with Cu	72.0	78.0	56.0	54.0	NT	2
CleanIt LC Plus	Iron Composite Metal	80.0	80.0	100.0	100.0	NT	8

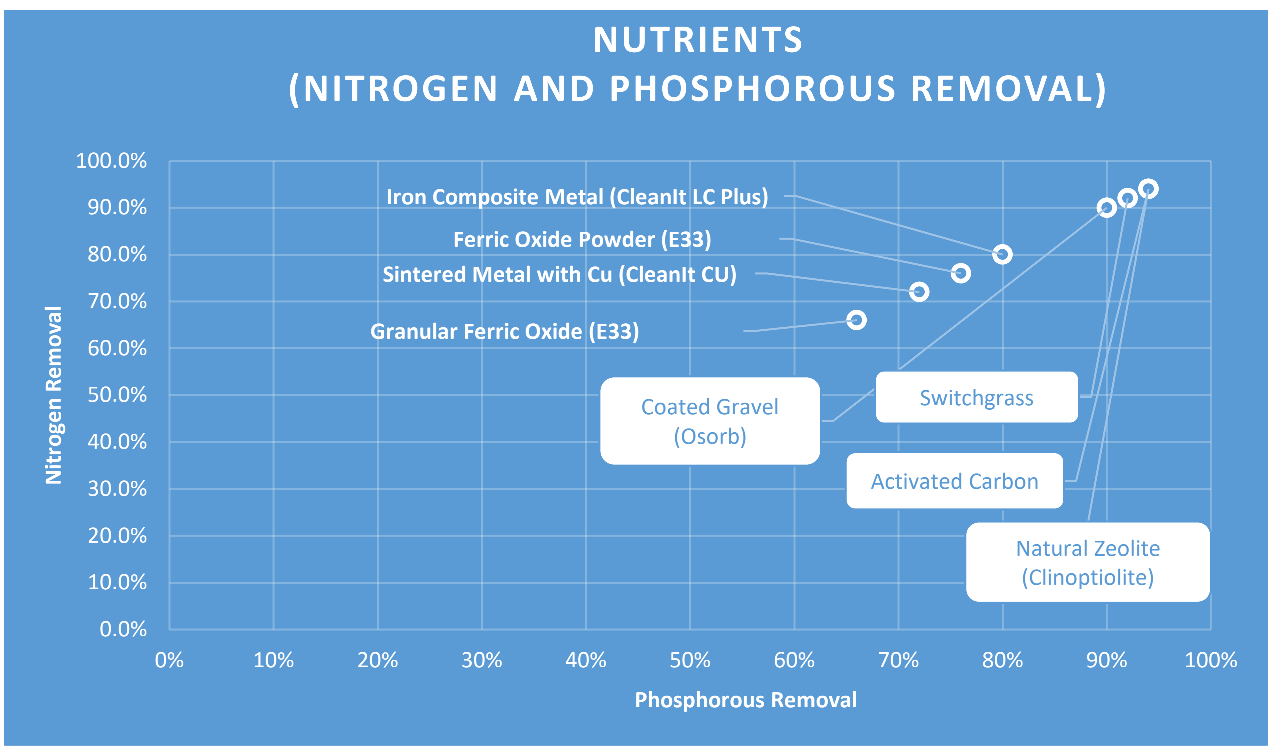

Figure 19 – Correlation of Nitrogen and Phosphorous Removal

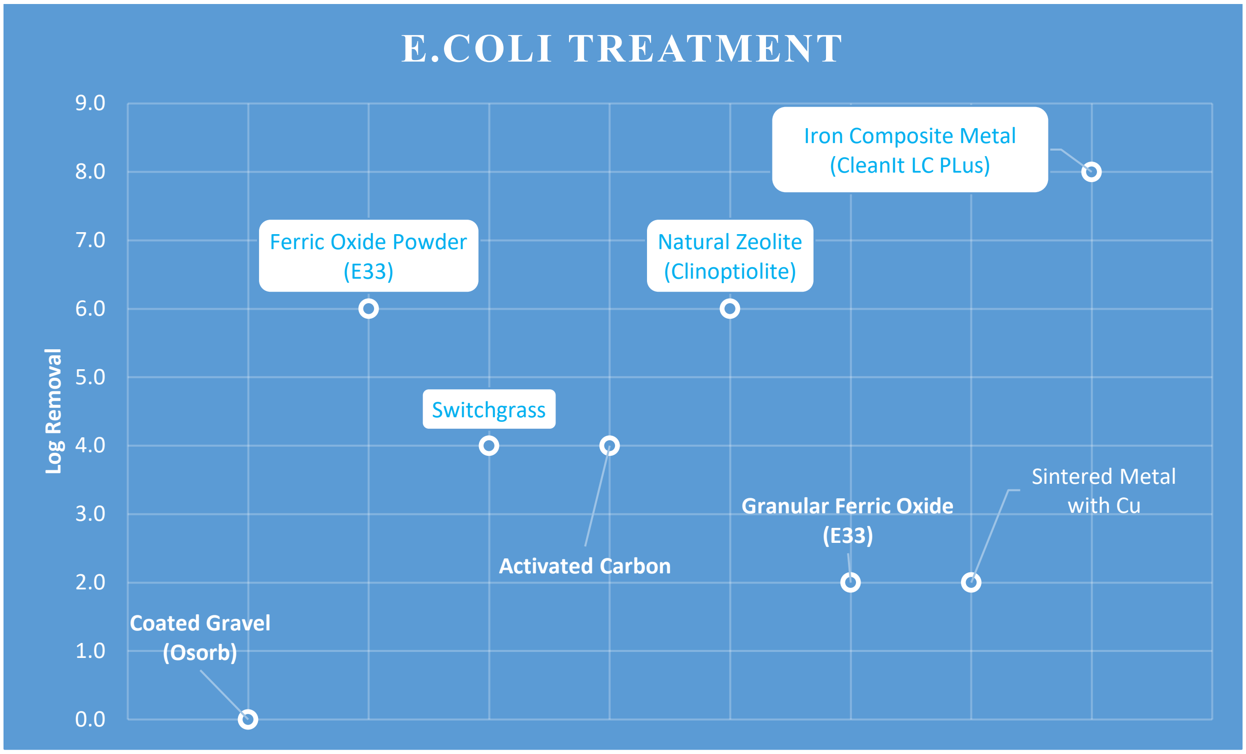

Figure 20 – E. coli Removal for Each Media

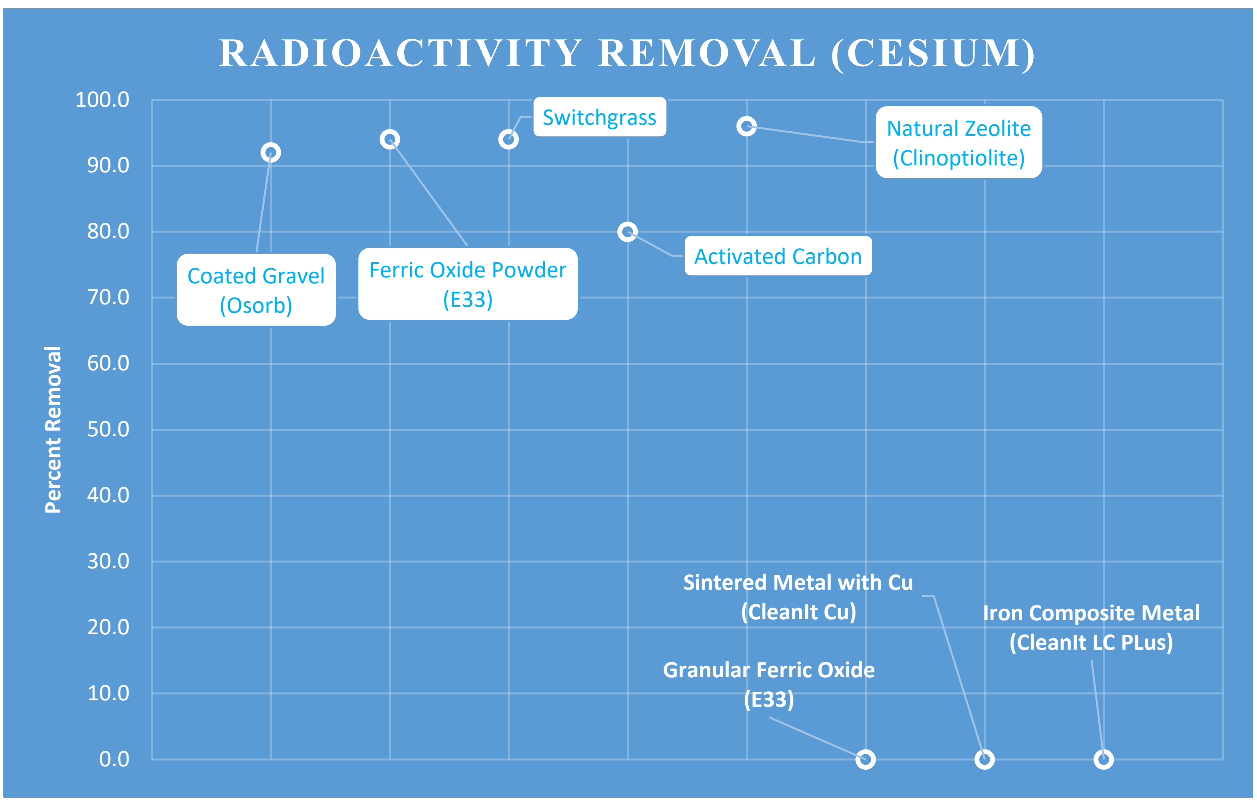

Figure 21 – Radioactivity Removal for Each Media

3.5 Costs and Selection Criteria for Media

Table 5 presents the costs for each tested media. There is a wide range in costs ranging from the cheapest (Switchgrass) at $0.20/lb to E33 at $16.33/lb. Thus, the selection of media for a specific application should be examined through the following criteria:

1) Identify the contaminant causing impairment or requiring treatment (as part of an emergency preparedness plan).
2) Select the appropriate media from Table 4 and from charts such as Figure 22 (which shows the total phosphorous removal versus the permeability).
3) Identify the detention period required to keep the discharge below $Q_{critical}$. Select appropriate media from Table 3.
4) Use Table 5 to determine the lowest cost media that meets other requirements for treatment.

Future research will identify the expected time the various media will perform well until needing to be replaced. Media contaminated with dangerous contaminants would have to be disposed appropriately. Figure 23 shows the correlation between permeability and cost. This graph can also help in visually identifying the cost-effectiveness of each media depending on the retention desired.

Table 5 – Costs for Each Media Type

Media	Generic Reference	K		Apparatus	Cost/lb
Osorb	Coated Gravel	11.55	ft/min	Pilot Test	$2.92
Switchgrass	Switchgrass	4.82	ft/min	Pilot Test	$0.20
Granular E33	Granular Ferric Oxide	0.89	ft/min	Burette	$16.33
Activated Carbon	Activated Carbon	0.68	ft/min	Pilot Test	$3.02
Clinoptiloite	Natural Zeolite	0.63	ft/min	Pilot Test	$2.12
CleanIt LC Plus	Iron composite metal	0.44	ft/min	Burette	$2.72
CleanIt CU	Sintered Metal with Cu	0.39	ft/min	Burette	$5.00
E33	Ferric Oxide Powder	0.15	ft/min	Pilot Test	$16.33
Powdered Rembind	Powdered Reagent Mix	Very small		Pilot Test	$4.44

Acronyms: ft, foot; K, coefficient of permeability; lb, pound; min, minute

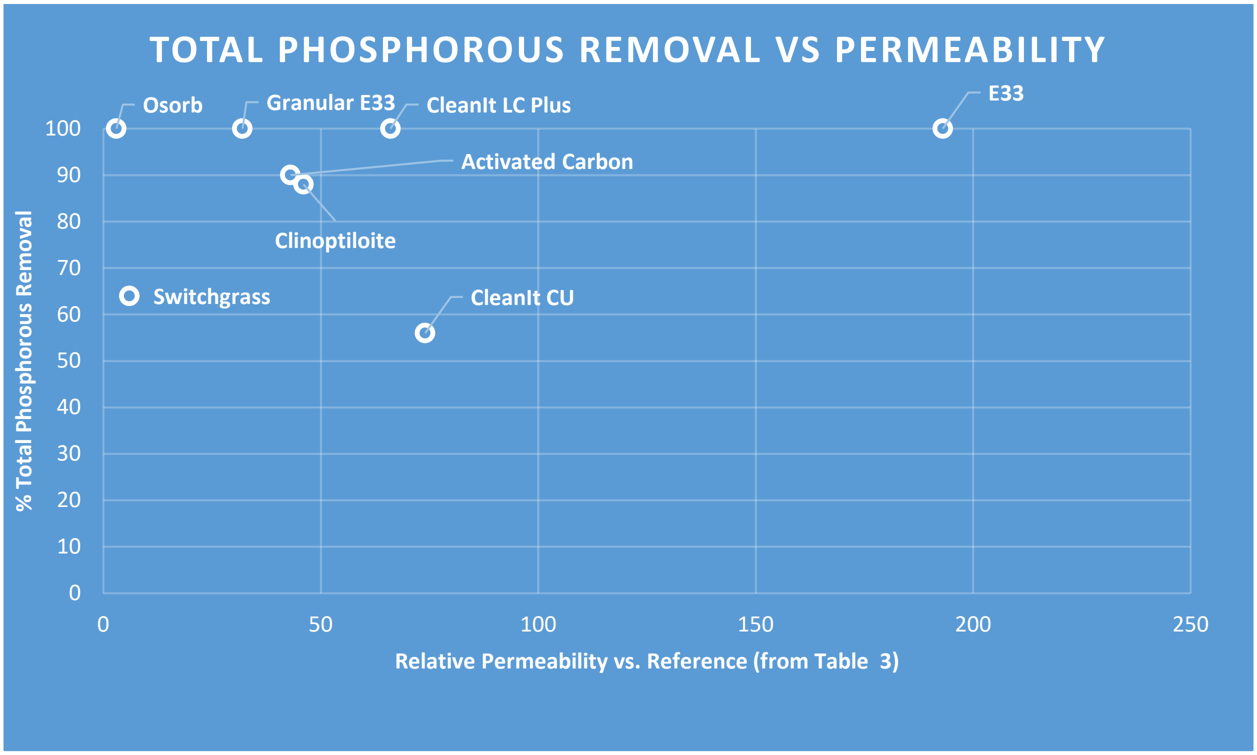

Figure 22 – Total Phosphorous Removal vs. Permeability

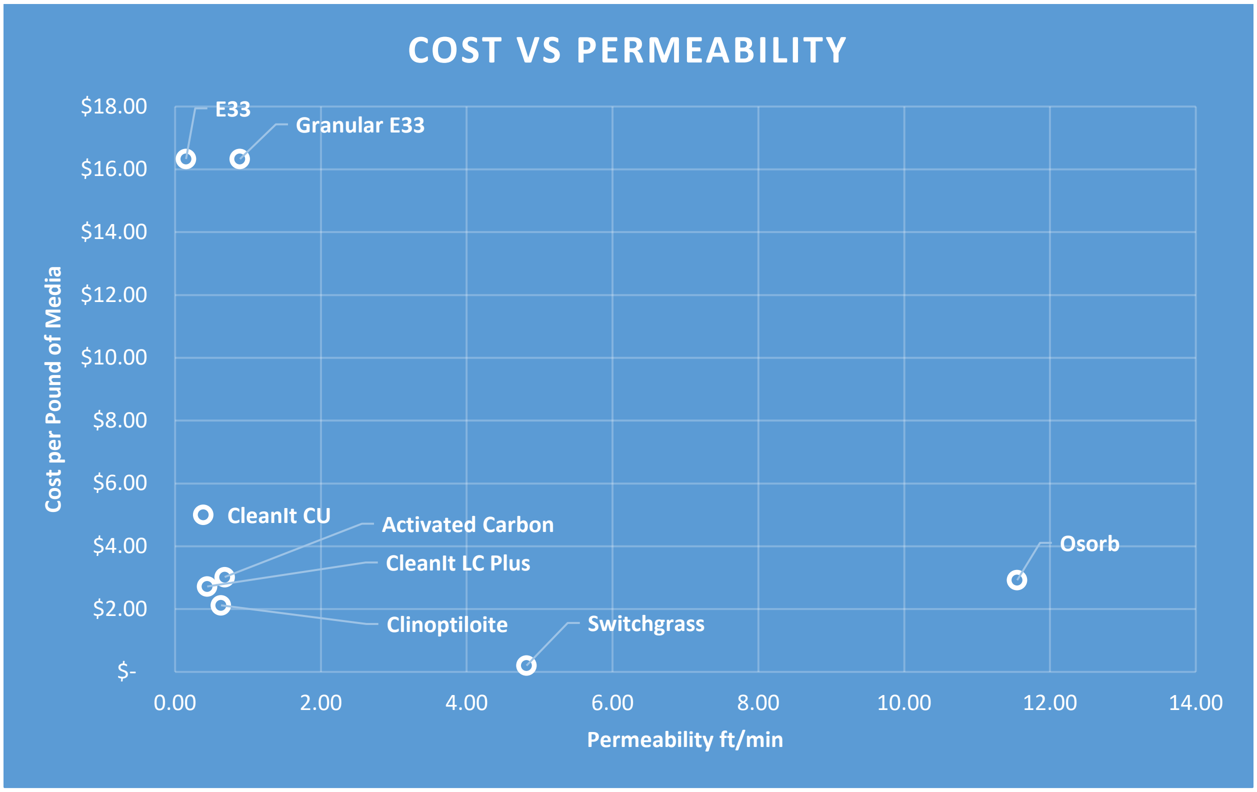

Figure 23 – Cost of the Media vs. Permeability of Media

4.0 Performance Monitoring of Detention Basin Devices

4.1 Performance Monitoring of TMS Detention Basin Retrofit Device

Monitoring of the retrofit performance of the Detain H2O device was conducted using a suite of time-series data including:

(1) time-series photographs of basin stage;
(2) outflow and inflow pipe discharge (via area-velocity meters); and
(3) rain gages

Figure 24 shows the TMS detention basin with devices installed to monitor the performance of the system. Trail cameras were mounted to capture photographs at 10-minute intervals of the inlet and the outlet of the system. A staff gage was mounted at the inlet to the retrofit device to provide a scale (in feet) for the photos (Figure 26).

Flow into the detention basin included two pipe inlets and one swale, along with direct precipitation and local drainage. The outflow of the basin was routed through a network of staged pipes that were connected to a single 81-cm-diameter outflow pipe on the downstream side of the berm. The basin was designed for flows greater than the 100-year design event to discharge through a concrete spillway. Three pipe-flow meters (ISCO model 2150) were donated to the project by Teledyne ISCO and recorded measurements at 15-min intervals. Figure 25 shows one of the ISCO gauges installed at an inlet location. The gauges were installed according to the manufacturer's specifications and data were downloaded and processed using their software (Flowlink® 5.1, Teledyne ISCO, Lincoln, Nebraska) and protocols. These data are typically considered to have precision of ~2%, with the exception of extremely low flows, which go unrecorded due to minimum depths that are required for accurate area-velocity measurements to register. Access to monitoring equipment was limited by project funding phases and by the timing of equipment donations; equipment was deployed as it became available. The initial pipe monitoring deployment included installations on the downstream side of the 81-cm outflow pipe and on one of the two inflow pipes to the basin. When the third gauge became available, the second inflow pipe was also gaged. All other inputs into the basin, including the swale and local drainage remained ungauged.

Data were screened for outliers, and values that were determined to be erroneous, such as points that were recorded during data downloads when the transducers were out of the water, were systematically removed. An ISCO 4150 Flow Logger, also from Teledyne ISCO, was installed at the site and collected incremental rainfall at 10-min intervals. Hourly precipitation data from a NOAA station located at the Cincinnati/Northern Kentucky International Airport, which was less than about 2 km away from the site, served to validate the site data.

Figure 27 shows the retrofit device under high water conditions. This photograph shows the device holding back water within the containment basin thus utilizing a greater volume of the existing infrastructure.

Table 6 presents the pre- and post-retrofit peak outflow for two comparative precipitation events and demonstrates that the peak outflow is similar up to a doubling of rainfall thus demonstrating significant detention within the basin.

Figure 28 shows the pre- and post-retrofit flows for similar precipitation events. The pre-retrofit event (October 31, 2013) had a smaller peak rainfall intensity (1 in/h) but larger peak discharge [6 cubic feet per second (cfs)] than the post-retrofit event (April 2, 2014, peak intensity 1.2 in/h, peak discharge 5.3 cfs). The post-retrofit event also received more than twice the total rainfall than the pre-retrofit event (2 inches compared 0.9 inches), adding to the weight of evidence of the restrictive effect of the retrofit device.

A detailed depiction of the post-retrofit event from June 4, 2014 is provided in Figure 29 with corresponding real-time photographs that highlight the 3 hours of ponding that was induced by the retrofit device, resulting in a prolonged release of a peak discharge that was over five times less than the peak inflow (3.88 ft3/s compared to 20.5 ft3/s).

In summary, the post-retrofit events had greater rainfall depths, peak intensities, and shorter durations than the pre-retrofit events, but were discharged at less than or equal to the peak discharge of the pre-retrofit events.

Figure 24 – TMS Detention Basin Retrofit Device Monitoring Devices

Figure 25 - ISCO Flow Monitoring Gauge Installed at Stormwater Detention Basin Inlet

Figure 26 – TMS Detention Basin Retrofit Device with Staff Gauge (in feet) for Camera Scale

Figure 27 - Detention Basin Retrofit Device Under High Water Conditions

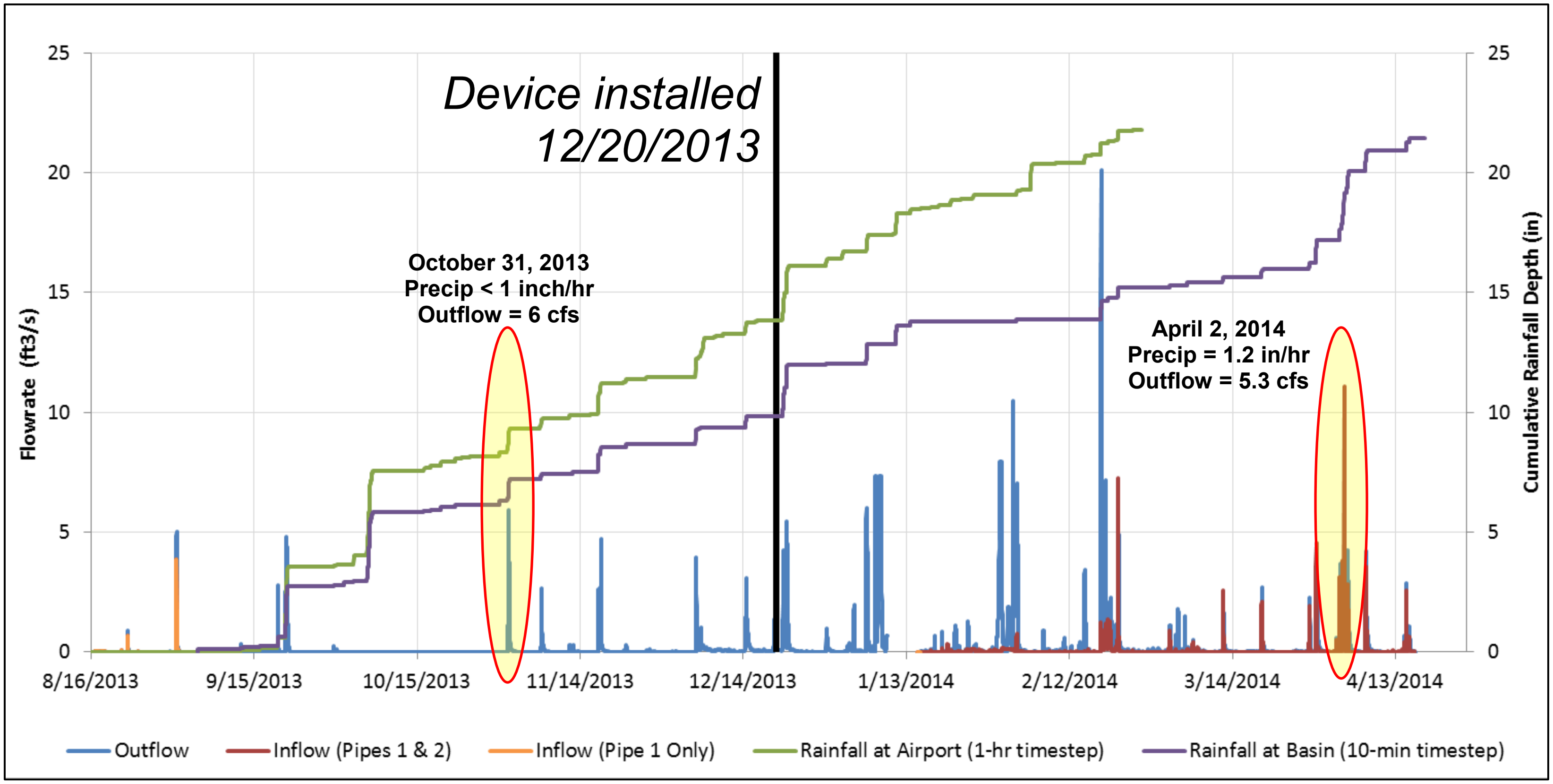

Figure 28 - Pre- and Post-Retrofit Outflow for Similar Precipitation Events

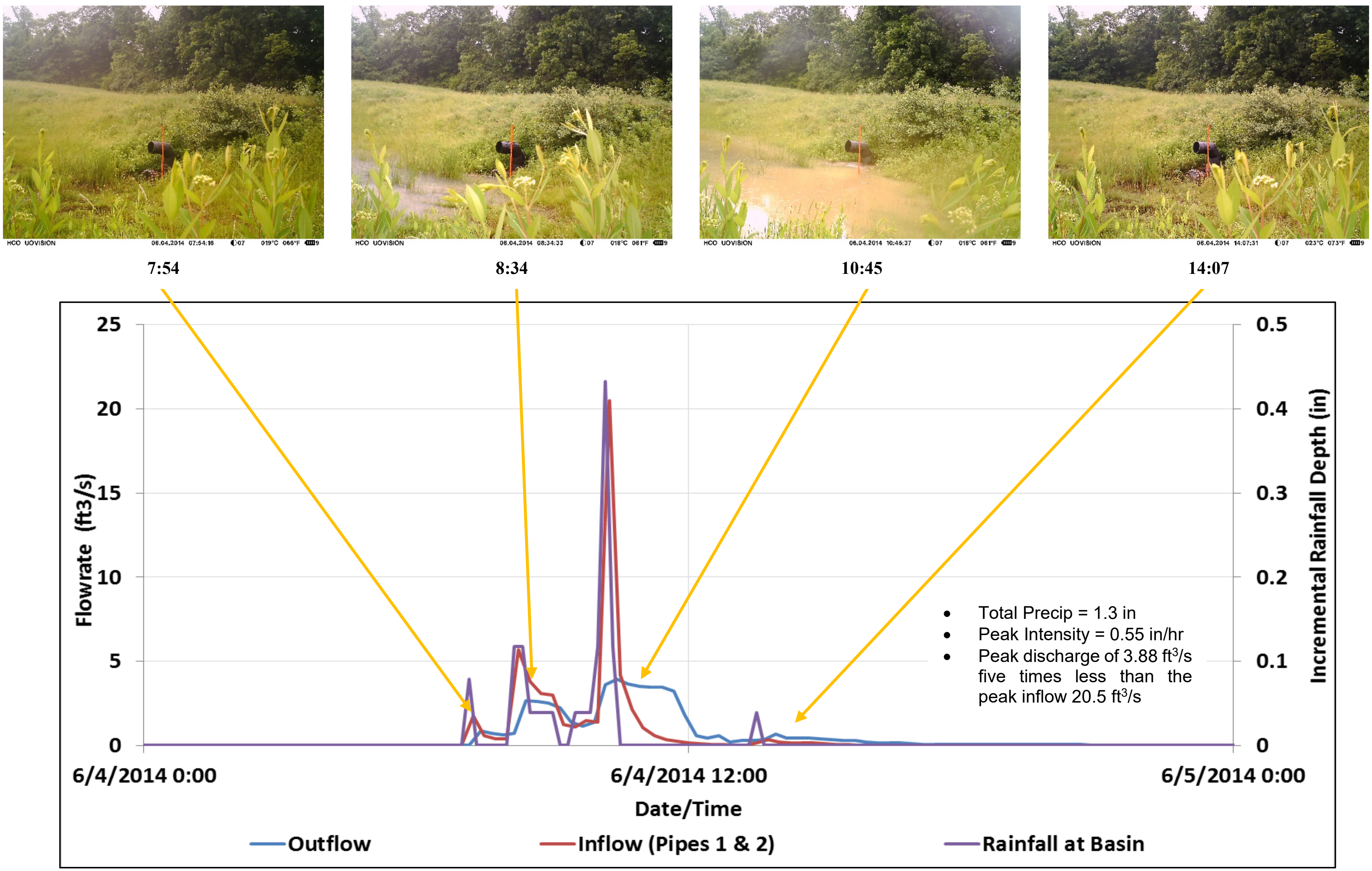

Figure 29 - June 4, 2014 Post-retrofit Event with Hydrograph and Associated Photographs Indicating a Clear Increase in Basin Storage and Restriction of the Outflow due to the Full Submergence of the Restricted Low-Flow Pipe Outlet

Table 6 – Comparison of Pre- and Post-Retrofit Peak Outflow for Measured Precipitation Events

Pre- or Post-Retrofit Precipitation Event (date)	Total Precipitation (in)	Peak Precipitation Intensity (in/hr)	Peak Inflow (ft^3/sec)	Peak Outflow (ft^3/sec)
Pre-Retrofit (October 31, 2013)	0.9	0.94	Not Measured	6.0
Post-Retrofit (April 3, 2014)	2.0	1.18	11.1	5.3
Pre-Retrofit (December 5, 2013)	0.6	0.94	Not Measured	4.0
Post-Retrofit (June 4, 2014)	1.3	2.6	20.5	4.0

Acronyms: hr, hour; ft, feet; in, inch(es); sec, second

4.2 Performance Monitoring of BCSD Detention Basin Retrofit Device

There were no flow monitoring devices installed at this location and so the performance of this device was approximated using photographs from onsite cameras. Cameras were placed at the inlet and at the outlet of the device and the water levels were estimated from photographs taken at an interval of 10 minutes.

Figure 30 shows a rainfall event on May 11, 2015 that occurred before the retrofit device was installed. Figure 31 shows the time series photographs of the fall of water level following this event as well as the time required for the water level to fall as a percentage of the maximum height of the water level. The photographs demonstrate that approximately 60 minutes was required for the detention basin to drain.

Figure 32 shows a rainfall event on July 29, 2015 that occurred after the retrofit device with media in perforated pipes was installed. Figure 33 shows the time series photographs of the fall of water level following this event as well as the time required for the water level to fall as a percentage of the maximum height of the water level. The photographs demonstrate that approximately 120 minutes was required for the detention basin to drain thus doubling the time from the pre-install drainage time again demonstrating significant detention within the basin.

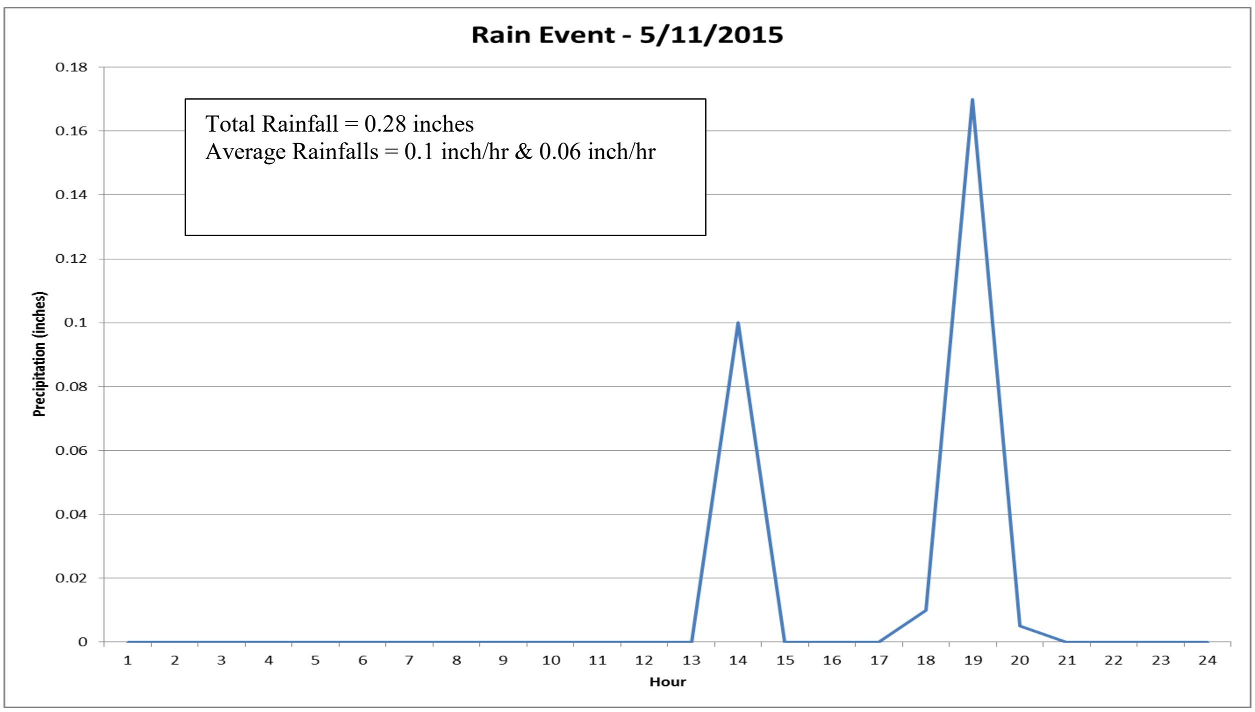

Figure 30 – Pre-install Rainfall Event on May 11, 2015 and Maximum Height of Water Level

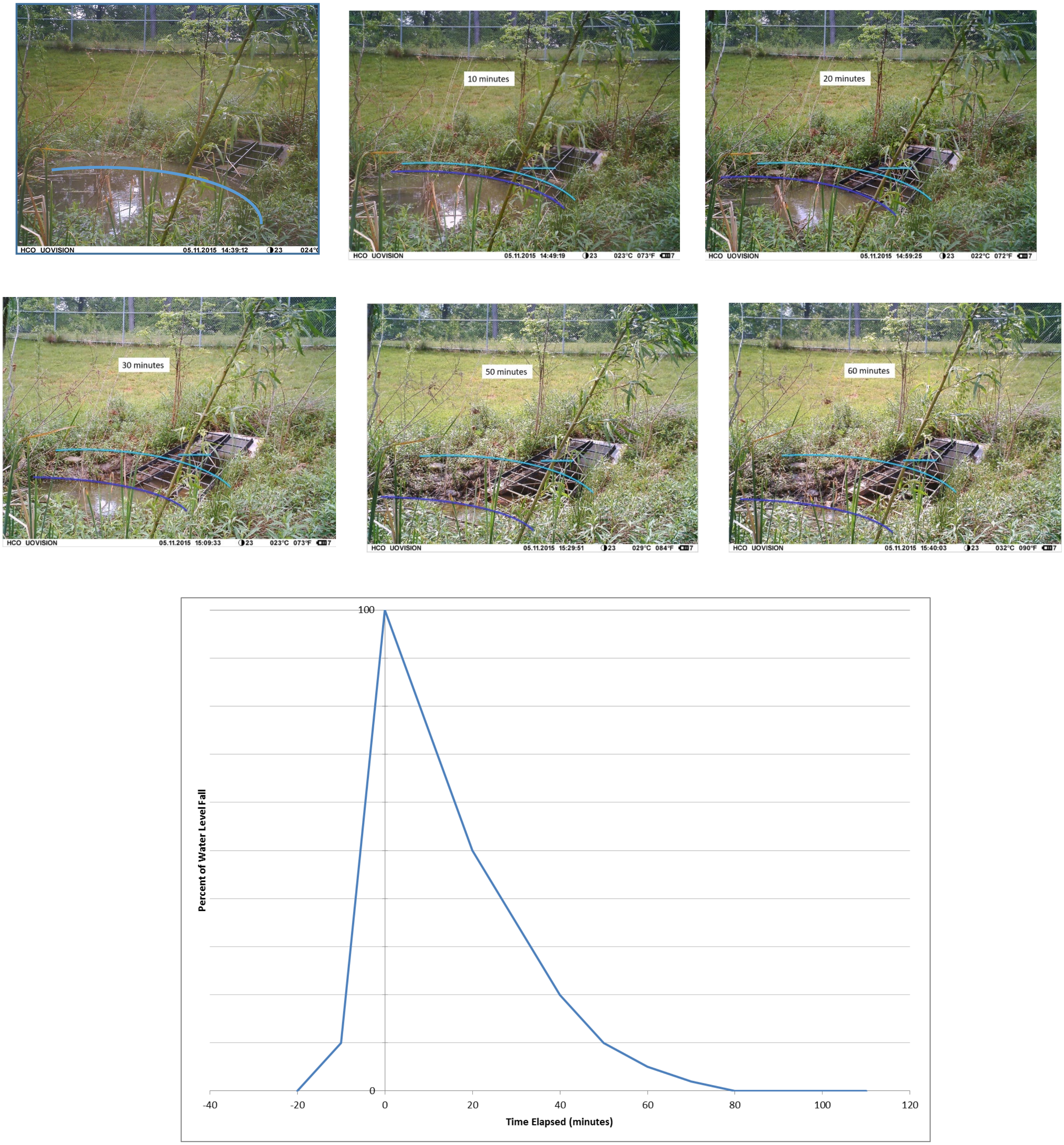

Figure 31 – Time Series Showing Estimated General Fall of Water Level Following May 11, 2015 Rain Event

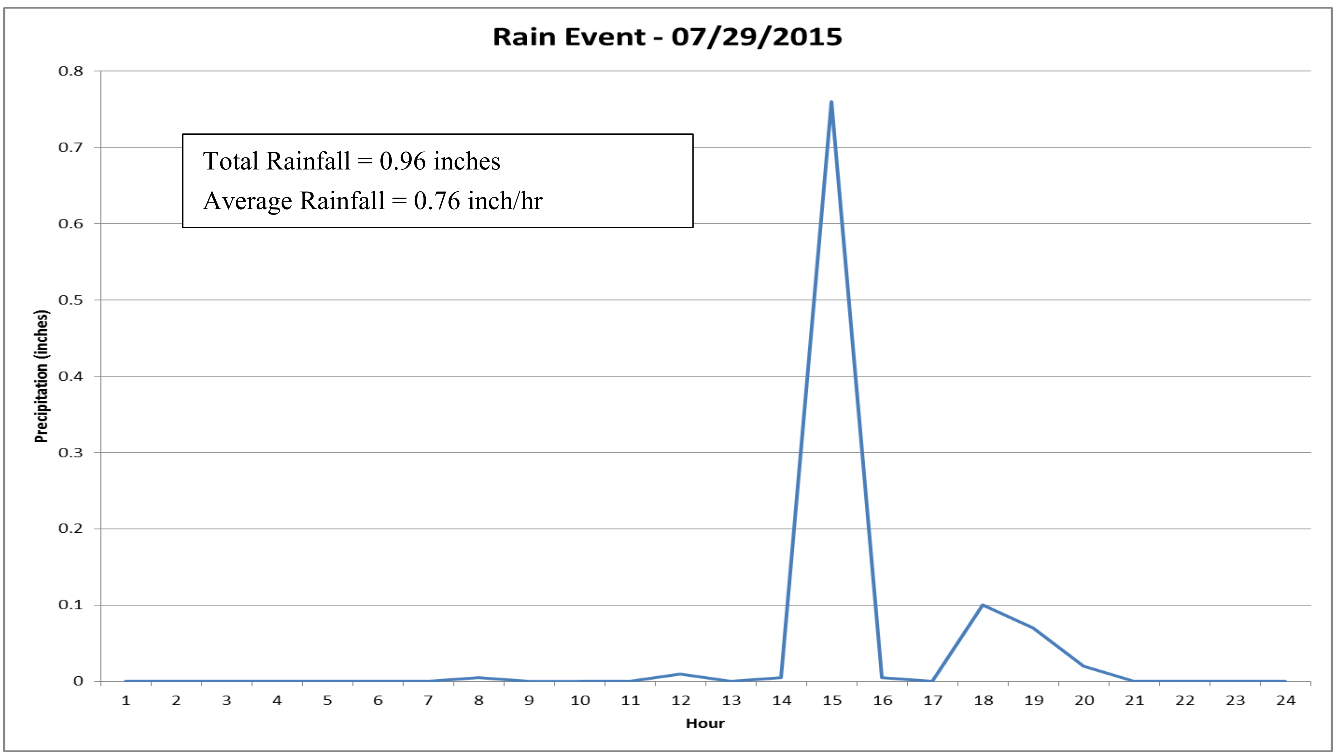

Figure 32 – Post-Retrofit Install Rainfall Event on July 29, 2015 and Maximum Height of Water Level

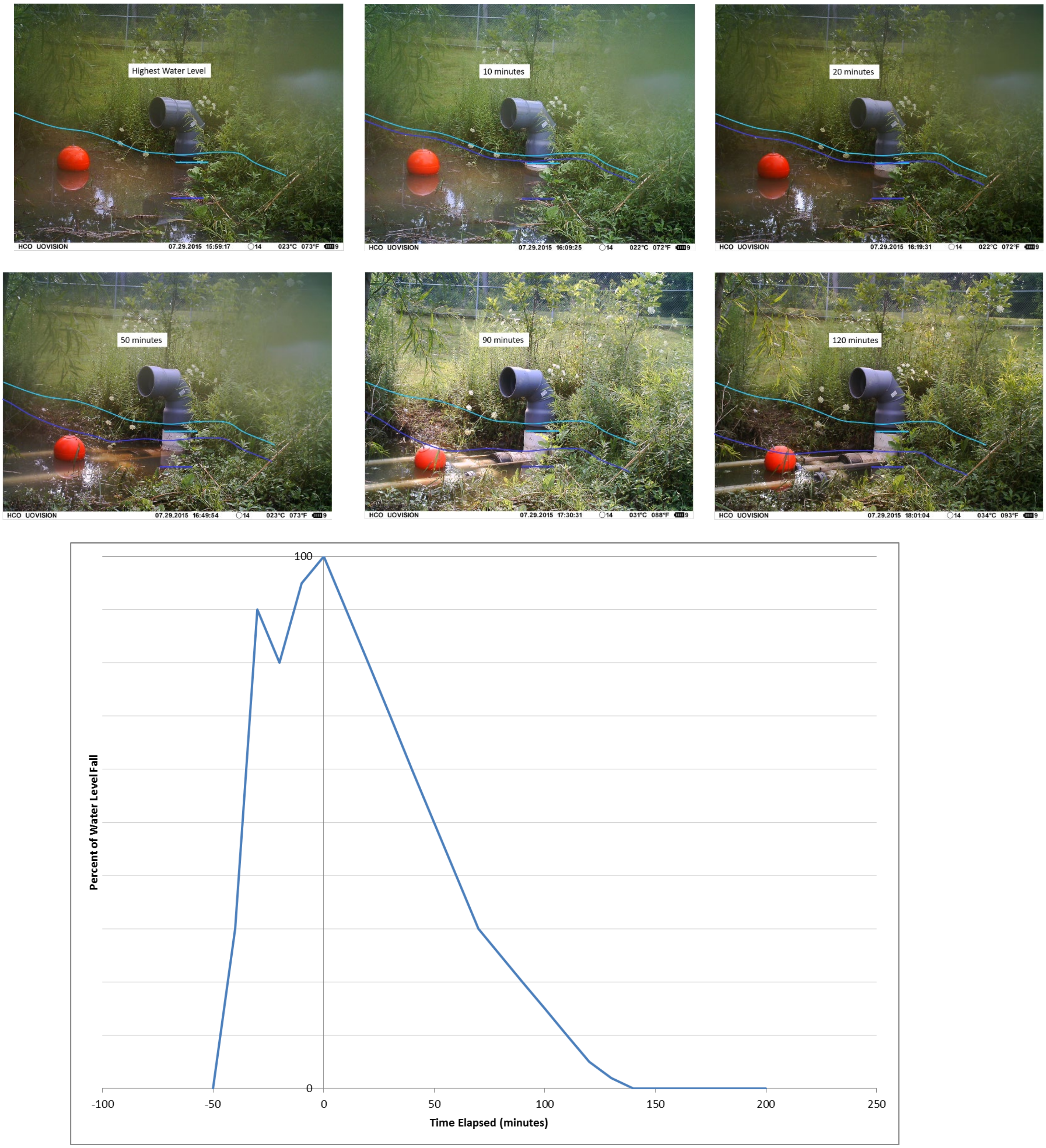

Figure 33 – Time Series Showing Estimated General Fall of Water Level Following July 29, 2015 Rain Event

4.3 Measure Plugging of Media in the Field Using Falling Head Tests

A concern for detention devices equipped with media is the potential rate at which the media can blind and slow down the water flow sufficiently to cause excessive detention volumes and overflow conditions. This data is also useful to determine the meantime between maintenance events which, in turn, would determine operating costs. The media chambers from the unit at the BCSD detention basin shown in Figure 34 was removed after nearly two years of operation and brought back to the T&E Facility as shown in Figure 35. The media chamber was then placed in to a 5,000-gallon tank though a device fabricated to fit over the manhole as shown in Figure 36. The valve was then opened and the time for the fall of the height of water was measured for comparing with the baseline. Figure 37 shows the graph of the height of water versus time for one falling head test. The calculated permeability from this test was 56.9 ft/min versus a permeability of 11.55 ft/min calculated at the T&E Facility. The higher permeability in this test is reflective of the perforated pipe used as the media chamber (i.e., the water has a shorter flow path through the media). This falling head test demonstrates that even after two years in the field, there is no noticeable plugging in the system.

Figure 34 – Media Chamber at BCSD Installation After Two Years of Operation

Figure 35 – Media Chamber Retrieved from BSCD Installation After Two Years

Figure 36 – Manhole Adapter to Insert Media Chamber in 5000 Gallon Tank

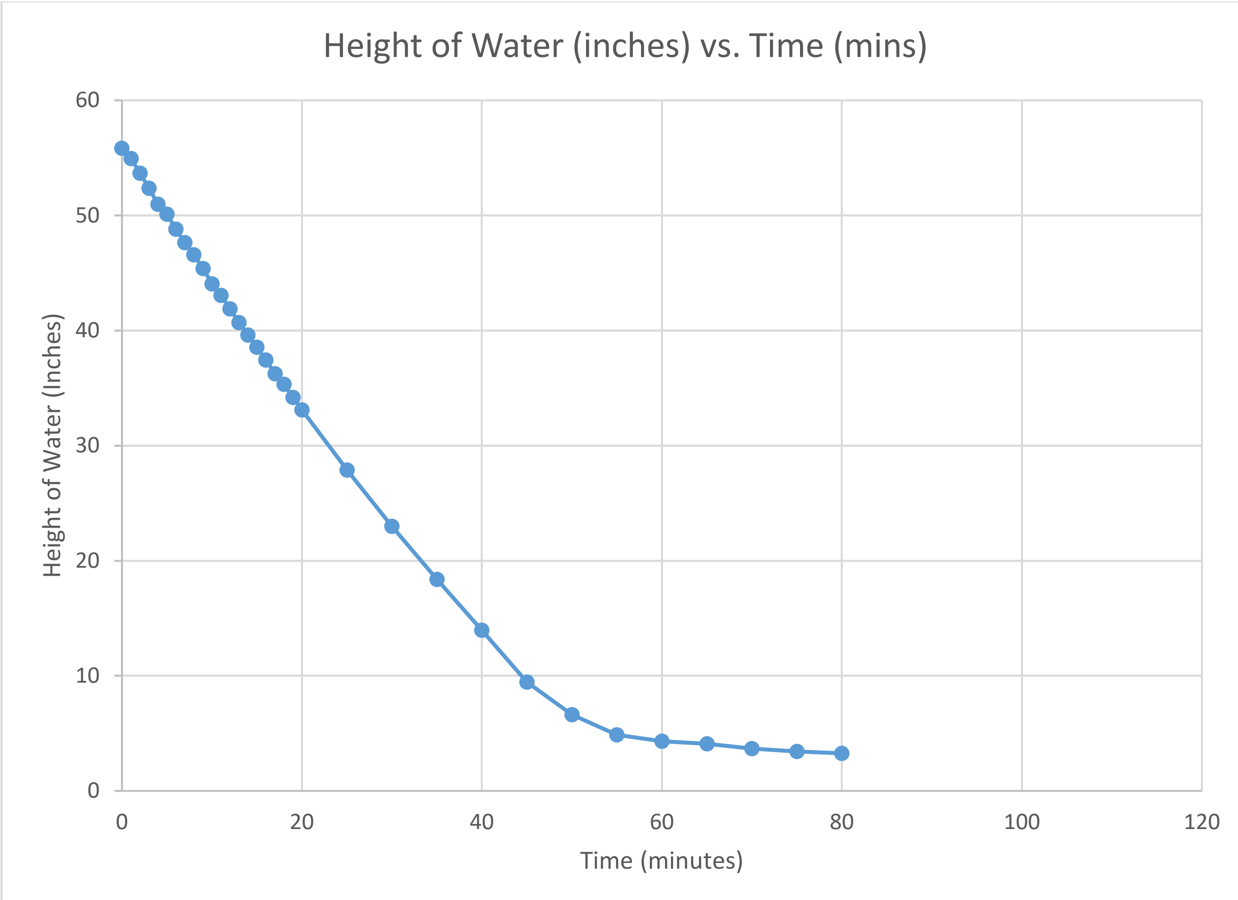

Figure 37 - Height of Water versus Time for Falling Head Test

5.0 Data Quality Assurance/Quality Control

5.1 Quality Metrics (QA/QC)

Instruments/equipment were maintained in accordance with the EPA ORD Policies and Procedures Manual, Section 13.4 *Minimum Quality Assurance (QA)/Quality Control (QC) Practices for ORD Laboratories Conducting Research*. The quality metrics for this study are summarized below and shown in Table 8.

5.2 QA/QC Acceptance Criteria

5.2.1 Accuracy

Percent Recovery was calculated using the following equation:

For controls:

$$\%R = \left(\frac{M}{K}\right) * 100$$

For matrix spike:

$$\%R = \left(\frac{X_s - X_u}{K}\right) * 100$$

Where,
R = percent recovery
M = Measured analyte concentration
K = Known analyte/spike concentration
Xs = Measured concentration of analyte in spiked sample
Xu = Measured concentration of analyte in un-spiked sample

5.2.2 Precision

<u>Duplicates- Relative Percent Difference (RPD):</u>

The RPD between duplicate samples was calculated as follows:

$$RPD = \frac{|D_1 - D_2|}{(|D_1 + D_2|)/2} * 100$$

Where,
RPD = relative percent difference
D1 = first sample value
D2 = second sample value (replicate)

<u>Replicates- Relative Standard Deviation (RSD):</u>

The RSD between replicates was calculated as follows:

$$RSD = \left(\frac{S}{\acute{y}}\right) * 100$$

Where,
S = standard deviation
ý = Mean of the replicates

5.3 Data Analysis, Interpretation, and Management

5.3.1 Data Reporting

Sample analytical data were obtained from instruments, notebooks, and log sheets as appropriate. Data that were not generated electronically will be entered into Microsoft Excel spreadsheet for subsequent evaluation. All data were compiled into a comprehensive Excel spreadsheet for submission.

All results were reduced to the appropriate reporting units by the analyst performing the test. The reporting units for each analysis are summarized in Table 7. Results for replicates were reported as means.

Table 7 – Reporting Units by Analyte

Analyte	Unit
DRO	mg/L
GRO	mg/L
O&G	mg/L
TN	mg/L
NH_3	mg/L
NO_3^-	mg/L
NO_2^-	mg/L
TP	mg/L
DRP	mg/L
Cs, Ag, Cu, Mn	mg/L
E. coli	CFU/100 mL

5.3.2 Data Validation

Calculations were carried out on a computer and were checked initially by the analyst for gross error and miscalculation. The calculations and data entered into computer spreadsheets were checked by a second analyst for accuracy. QC parameters from instrumental methods satisfied the stated criteria (see Tables 9, 10, and 11) or analyses were repeated. Instrumental and experimental replication and blanks assessed whether the methodologies used were valid. When the aforementioned repeated analyses were not possible, data were qualified. Additional data review was performed by WA leader prior to report preparation.

Comprehensive details of sample collection, sample analysis, QA/QC requirement and data review/validation can be found in EPA approved QAPPs entitled “Evaluation of Media for Treatment of Contaminated Water” and “Detention Pond Retrofit Technology”.

Table 8 – Quality Metrics and Criteria by Analyte

Parameter/Method	QC Checks	Frequency	Acceptance Criteria
TN Hach Method 10208	Ongoing precision and recovery (OPR)	One per batch	80-120%
	Matrix Spike/Matrix Spike Duplicate	One per batch	70-130% ≤20% RPD
TP Hach Method 10210	Ongoing precision and recovery (OPR)	Prior to sample analysis	80-120%
	Matrix Spike/Matrix Spike Duplicate	One per batch	70-130% ≤20% RPD
NH_3 Hach Method 10205	Ongoing precision and recovery (OPR)	One per batch	80-120%
	Matrix Spike/Matrix Spike Duplicate	One per batch	70-130% ≤20% RPD
($NO_3^- + NO_2^-$) EPA Method 300.1	Initial calibration	Once per sequence, after initial calibration check or continuing calibration check failure, or whenever fresh eluent is prepared	Initial calibration needs to be verified with an initial calibration check and the QCS
	Initial calibration check	Analyzed immediately after the calibration curve	±25 % of true value (QL to 10x QL) ±15% of true value (>10x QL)
	Quality control sample (QCS)	After initial calibration	±15 % of true value
	Instrument Performance Check (IPC)	One per batch	0.8-1.15
	Continuing and end calibration check	After every 10 samples	±25 % of true value (QL to 10x QL) ±15 % of true value (Greater than 10x QL)
	Laboratory reagent blank (LRB)	After every 10 samples and at the end	<MDL
	Surrogate	With each calibration and sample	Recovery of 90-115%

Table 8 – Quality Metrics and Criteria by Analyte (Continued)

Parameter/Method	QC Checks	Frequency	Acceptance Criteria
Metals (Cs, Ag, Cu, Mn) EPA Method 6010C	Initial calibration	Prior to each batch of analysis or after ICV failure	Second order curve $r^2 \geq 0.998$
	Initial calibration verification (ICV)	After initial calibration	±10 % of the analytes true value
	Low-level initial calibration verification (LLICV)	After initial calibration	±30 % of the analytes true value
	Calibration Blanks (ICB & CCB)	Following ICV (ICB) and following each continuing calibration verification (CCB)	< low-level calibration standard (QL)
	Continuing calibration verification (CCV)	CCV after every 10 samples and at the end of the sample batch	±10 % of the analytes true value for CCV
	Method Blank (MB)	One per batch of sample preparation	< low-level standard concentration (QL), or < 10% of the lowest sample concentration for each analyte in a given preparation batch, whichever is greater
	Laboratory control sample (LCS)	One per batch of sample preparation	For liquid, ±20 % of the analytes true value; For solid (commercially prepared), manufacturer's established acceptance criteria
	Matrix Spike (MS)/ Matrix Spike Duplicate (MSD)	One per sample matrix	±25 % of the analytes true value for MS and 20% RPD for MSD
	Laboratory duplicate	One per batch	≤20% RPD for sample values

Table 9 – QA/QC Summary for Ammonia, Total Nitrogen and Total Phosphorus Analysis

Media Tested	Standard Check		Matrix Spike Recovery		
	Measured	Recovery	Recovery 1	Recovery 2	RPD
Ammonia					
E33	10.3	103	105	105	0
Osorb	10.6	106	115	113	2
Switch Grass	10.1	101	106	106	0
Granular Activated Carbon	10.2	102	101	101	0
Clinoptiolite	9.89	99	97	96	1
E33 and CleanIt	9.94	99	96	96	0
Total Nitrogen					
E33 and Osorb	11.5	115	130	122	6
Switch Grass	11.4	114	121	121	0
Granular Activated Carbon	9.72	97	133	106	23
Clinoptiolite	10	100	99	94	5
E33 and CleanIt	9.55	96	99	96	3
Total Phosphorus					
E33	2.98	99	104	103	1
Osorb	3	100	89	89	0
Switch Grass	3.02	101	47	46	2
Granular Activated Carbon	3.01	100	59	41	36
Clinoptiolite	3.05	102	71	70	1
E33 and CleanIt	3.03	101	102	97	5

Table 10 – QA/QC Summary for Anions Analysis

Samples from E33 media evaluation		Anions in mg/L				Surrogate % Recovery	Criteria
		NO_2	NO_3	PO_4	DCAA		
ICB		ND	ND	ND	4.71	94.2	90-115 %
Calibration Standards	0.2 mg/L	0.14	0.18	0.13	4.75	95	90-115 %
	0.5 mg/L	0.39	0.49	0.44	4.89	97.8	90-115 %
	2 mg/L	2.16	2.32	1.93	4.51	90.2	90-115 %
	5 mg/L	4.97	4.8	5.04	4.73	94.6	90-115 %
	10 mg/L	9.96	9.79	10.15	5.26	105.2	90-115 %
	20 mg/L	20.01	20.11	19.94	5.6	112	90-115 %
QCS	Measured	1.12	1.13	1.14			
	Actual	1	1	1.5			
	% Recovery	112	113	76.00			
	Criteria	85-115 %	85-115 %	85-115 %	4.56	91.2	90-115 %
ICV 0.2 mg/L	Measured	0.22	0.153	0.125			
	Actual	0.2	0.2	0.2			
	% Recovery	110	76.5	62.5			
	Criteria	75-125 %	75-125 %	75-125 %	4.64	92.8	90-115 %
ICV 0.5 mg/L	Measured	0.44	0.52	0.46			
	Actual	0.5	0.5	0.5			
	% Recovery	88	104	92			
	Criteria	75-125 %	75-125 %	75-125 %	4.64	92.8	90-115 %
LRB		ND	ND	ND	4.97	99.4	90-115 %
E33- Con1 - Blank 1- Inf		ND	0.21	0.337	4.87	97.4	90-115 %
E33- Con1 - Blank 1- Eff		ND	0.38	ND	4.55	91	90-115 %
E33- Con1 - Test 1- Inf		ND	2.17	11.25	4.94	98.8	90-115 %
E33- Con1 - Test 1-Eff		ND	0.65	ND	4.94	98.8	90-115 %
E33- Con1 - Blank 2- Inf		ND	0.25	0.34	4.94	98.8	90-115 %
E33- Con1 - Blank 2- Eff		ND	0.39	ND	4.84	96.8	90-115 %
E33- Con1 - Test 2- Inf		ND	2.05	11.36	4.85	97	90-115 %
E33- Con1 - Test 2-Eff		ND	0.58	ND	4.54	90.8	90-115 %
E33- Con1 - Test 2-Eff (DUP)		ND	0.69	ND	4.67	93.4	90-115 %
LFB (Blank + 2 mg/L spike)		2.07	1.99	ND	4.53	90.6	90-115 %
LFM		2.06	3.97	12.95	4.77	95.4	90-115 %
ECV 10 mg/L	Measured	9.93	9.93	10.39	5.73	114.6	90-115 %
	Actual	10	10	10	-		
	% Recovery	99.3	99.3	103.9	-		
	Criteria	85-115 %	85-115 %	85-115 %	-		
LRB		< 0.2	ND	< 0.2	4.86	97.2	90-115 %

Table 10 – QA/QC Summary for Anions Analysis (continued)

Samples from Switch Grass media evaluation		Anions in mg/L NO$_2$	NO$_3$	PO$_4$	DCAA	Surrogate % Recovery	Criteria
ICB		ND	ND	nd	4.553	91.06	90-115 %
Calibration Standards	0.2 mg/L	0.229	0.218	0.131	4.62	92.4	90-115 %
	0.5 mg/L	0.464	0.487	0.347	4.649	92.98	90-115 %
	2 mg/L	1.931	2.022	1.86	4.69	93.8	90-115 %
	5 mg/L	4.964	4.964	5.089	4.964	99.28	90-115 %
	10 mg/L	10.209	10.036	10.332	5.228	104.56	90-115 %
	20 mg/L	19.925	19.99	19.856	5.47	109.4	90-115 %
QCS	Measured	1.106	1.004	1.493			
	Actual	1	1	1.5			
	% Recovery	110.6	100.4	99.53			
	Criteria	85-115 %	85-115 %	85-115 %	4.526	90.52	90-115 %
ICV 0.2 mg/L	Measured	0.238	0.21	0.21			
	Actual	0.2	0.2	0.2			
	% Recovery	119	105	105			
	Criteria	75-125 %	75-125 %	75-125 %	4.57	91.4	90-115 %
ICV 0.5 mg/L	Measured	0.504	0.462	0.426			
	Actual	0.5	0.5	0.5			
	% Recovery	100.8	92.4	85.2			
	Criteria	75-125 %	75-125 %	75-125 %	4.546	90.92	90-115 %
LRB		ND	ND	ND	4.54	90.8	90-115 %
SG- Con1 - Blank 1- Inf		ND	0.41	2.412	4.743	94.86	90-115 %
SG- Con1 - Blank 1- Eff		ND	3.368	13.736	4.895	97.9	90-115 %
SG- Con1 - Test 1- Inf		ND	ND	32.325	5.275	105.5	90-115 %
SG- Con1 - Test 1-Eff		ND	0.401	0.343	4.887	97.74	90-115 %
SG- Con1 - Blank 2- Inf		ND	0.256	4.868	4.993	99.86	90-115 %
SG- Con1 - Blank 2- Eff		ND	3.473	14.353	4.674	93.48	90-115 %
SG- Con1 - Test 2- Inf		ND	ND	8.242	4.576	91.52	90-115 %
SG- Con1 - Test 2-Eff		ND	0.434	1.458	4.983	99.66	90-115 %
SG- Con1 - Test 2-Eff (DUP)		ND	0.314	1.194	4.639	92.78	90-115 %
LFB (Blank + 2 mg/L spike)		2.05	2.062	2.036	4.753	95.06	90-115 %
LFM		2.796	2.488	6.633	5.03	100.6	90-115 %
ECV 10 mg/L	Measured	10.548	10.27	10.651	5.285		
	Actual	10	10	10	-		
	% Recovery	105.48	102.7	106.51	-		
	Criteria	85-115 %	85-115 %	85-115 %	-	105.7	90-115 %
LRB		< 0.2	ND	< 0.2	4.504	90.08	90-115 %

Table 10 – QA/QC Summary for Anions Analysis (continued)

Anions results from Granular Activated Carbon Media evaluation		Anions in mg/L NO₂	NO₃	PO₄	DCAA	Surrogate % Recovery	Criteria
ICB		ND	ND	<0.2	4.553	91.06	90-115 %
Calibration Standards	0.2 mg/L	0.22	0.214	0.179	4.64	92.8	90-115 %
	0.5 mg/L	0.497	0.513	0.404	4.729	94.58	90-115 %
	2 mg/L	1.92	2.018	1.946	4.828	96.56	90-115 %
	5 mg/L	5.032	5.038	5.147	4.533	90.66	90-115 %
	10 mg/L	10.081	9.898	10.037	4.759	95.18	90-115 %
	20 mg/L	19.966	20.035	19.962	5.251	105.02	90-115 %
QCS	Measured	0.901	0.961	1.584	4.519	90.38	90-115 %
	Actual	1	1	1.5			
	% Recovery	90.1	96.1	105.6			
	Criteria	85-115 %	85-115 %	85-115 %			
ICV 0.2 mg/L	Measured	0.238	0.172	0.161	4.569	91.38	90-115 %
	Actual	0.2	0.2	0.2			
	% Recovery	119	86	80.5			
	Criteria	75-125 %	75-125 %	75-125 %			
ICV 0.5 mg/L	Measured	0.472	0.491	0.508	4.547	90.94	90-115 %
	Actual	0.5	0.5	0.5			
	% Recovery	94.4	98.2	101.6			
	Criteria	75-125 %	75-125 %	75-125 %			
LRB		ND	ND	< 0.2	4.853	97.06	90-115 %
AC- Con1 - Blank 1- Inf		ND	0.176	5.881	5.103	102.06	90-115 %
AC- Con1 - Blank 1- Eff		ND	ND	2.6	4.929	98.58	90-115 %
AC- Con1 - Test 1- Inf		ND	2.398	18.343	4.61	92.2	90-115 %
AC- Con1 - Test 1-Eff		ND	ND	2.756	4.925	98.5	90-115 %
AC- Con1 - Blank 2- Inf		ND	ND	1.178	5.638	112.76	90-115 %
AC- Con1 - Blank 2- Eff		ND	ND	0.629	5.552	111.04	90-115 %
AC- Con1 - Test 2- Inf		ND	2.377	14.526	4.542	90.84	90-115 %
AC- Con1 - Test 2-Eff		ND	ND	2.233	5.188	103.76	90-115 %
AC- Con1 - Test 1- Inf (dup)		ND	2.317	18.722	5.039	100.78	90-115 %
LFB (Blank + 2 mg/L spike)		2.234	1.983	2.095	5.239	104.78	90-115 %
LFM		3.673	2.194	12.724	5.695	113.9	90-115 %
ECV 10 mg/L	Measured	10.688	9.992	10.361	5.315	106.3	90-115 %
	Actual	10	10	10	-		
	% Recovery	106.88	99.92	103.61	-		
	Criteria	85-115 %	85-115 %	85-115 %	-		
LRB		< 0.2	ND	< 0.2	4.53	90.6	90-115 %

Table 10 – QA/QC Summary for Anions Analysis (continued)

Vial #	QA/QC summary for Anions analysis E33 and CleanIt media samples		NO_2	NO_3	PO_4
#3 - 8	Calibration Range		0.2 - 20.0	0.2 - 20.0	0.2 - 20.0
#3 - 8	Calibration Correlation		0.9974	0.9987	1
9	Variable conc QCS 1:20	# Recovery	1.0805	0.9925	1.4253
	Quality Control Standard / 2nd Source Standard Sec 9.2.2	Prep. Conc.	5.00	5.00	5.00
		% Recovery	22%	20%	29%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%
10	0.2 mg/L anions ICS	# Recovery	0.1897	0.2015	0.1815
	Calibration Verification Sec 10.5 and Instrument Performance Check Solution Sec 9.3.3	Prep. Conc.	0.20	0.20	0.20
		% Recovery	95%	101%	91%
		Acceptable Range	75 - 125%	75 - 125%	75 - 125%
			PGF is 0.809		
11	LRB	# Recovery	n.a.	n.a.	n.a.
	LRB Sec 9.3.1	Acceptable Range	<0.044	<0.040	<0.036
12	LFB 2 mg/L	Validate	2.0314	1.9541	2.0457
	Lab Fortified Blank Sec 9.3.2	Fort. Conc.	2.00	2.00	2.00
		% Recovery	102%	98%	102%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%
19	E33-C1-Ts2-Eff	Replicate 1	4.5826	1.22	n.a.
20	E33-C1-Ts2-Eff LD	Replicate 2	4.5829	1.1964	n.a.
	Sample Replicates / QAPP requirement	RSD%	0%	2%	NA
		Acceptable Range	<10%	<10%	<10%
19	E33-C1-Ts2-Eff	Replicate 1	4.5826	1.22	n.a.
21	E33-C1-Ts2-Eff LFM	Fortified Sample	6.4802	3.093	1.7031
	Lab Fortified Matrix Sec 9.4.1	# Recovery	1.898	1.873	1.703
		Fort. Conc.	2.00	2.00	2.00
		% Recovery	95%	94%	85%
		Acceptable Range	75 - 125%	75 - 125%	75 - 125%
23	LRB	Blank	n.a.	n.a.	n.a.
	LRB Sec 9.3.1	Acceptable Range	<0.044	<0.040	<0.036
24	20.0 mg/L anions CCV	# Recovery	20.1644	19.8907	19.6492
	Calibration Verification Sec 10.5	Prep. Conc.	20.00	20.00	20.00
		% Recovery	101%	99%	98%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%
30	ClCU-C1-Ts2-Eff	Replicate 1	n.a.	0.1108	4.3896
31	ClCU-C1-Ts2-Eff LD	Replicate 2	n.a.	0.0792	4.4149
	Sample Replicates / QAPP requirement	RSD%	NA	33%	1%
		Acceptable Range	<10%	<10%	<10%
30	ClCU-C1-Ts2-Eff	Replicate 1	n.a.	0.1108	4.3896
32	ClCU-C1-Ts2-Eff LFM	Fortified Sample	1.9483	1.7332	6.2602
	Lab Fortified Matrix Sec 9.4.1	# Recovery	1.948	1.622	1.871
		Fort. Conc.	2.00	2.00	2.00
		% Recovery	97%	81%	94%
		Acceptable Range	75 - 125%	75 - 125%	75 - 125%

Table 10 – QA/QC Summary for Anions Analysis (continued)

35	LRB	Blank	n.a.	n.a.	n.a.
	LRB Sec 9.3.1	Acceptable Range	<0.044	<0.040	<0.036
36	LFB 2mg/L	Validate	2.028	1.978	1.7766
	Lab Fortified Blank Sec 9.3.2	Fort. Conc.	2.00	2.00	2.00
		% Recovery	101%	99%	89%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%
37	10.0 mg/L anions CCV	# Recovery	10.3685	9.8536	9.8739
	Calibration Verification Sec 10.5	Prep. Conc.	10.00	10.00	10.00
		% Recovery	104%	99%	99%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%
42	ClLC-C1-Ts2-Eff	Replicate 1	n.a.	n.a.	n.a.
43	ClLC-C1-Ts2-Eff LD	Replicate 2	n.a.	n.a.	n.a.
	Sample Replicates / QAPP requirement	RSD%	NA	NA	NA
		Acceptable Range	<10%	<10%	<10%
42	ClLC-C1-Ts2-Eff	Replicate 1	n.a.	n.a.	n.a.
44	ClLC-C1-Ts2-Eff LFM	Fortified Sample	1.9776	1.7478	0.6711
	Lab Fortified Matrix Sec 9.4.1	# Recovery	1.978	1.748	0.671
		Fort. Conc.	2.00	2.00	2.00
		% Recovery	99%	87%	34%
		Acceptable Range	75 - 125%	75 - 125%	75 - 125%
45	E33-C1-Bl1-Eff 1:10	Replicate 1	8.4796	2.1134	n.a.
46	E33-C1-Bl1-Eff 1:10 LFM	Fortified Sample	10.3019	3.8775	1.455
	Lab Fortified Matrix Sec 9.4.1	# Recovery	1.822	1.764	1.455
		Fort. Conc.	2.00	2.00	2.00
		% Recovery	91%	88%	73%
		Acceptable Range	75 - 125%	75 - 125%	75 - 125%
48	LRB	Blank	n.a.	n.a.	n.a.
	LRB Sec 9.3.1	Acceptable Range	<0.044	<0.040	<0.036
49	5.0 mg/L anions CCV	# Recovery	5.1123	4.894	4.7043
	Calibration Verification Sec 10.5	Prep. Conc.	5.00	5.00	5.00
		% Recovery	102%	98%	94%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%
47	E33-C1-Bl2-Eff 1:10	Replicate 1	7.9212	1.8571	n.a.
50	E33-C1-Bl2-Eff 1:10 LFM	Fortified Sample	9.8027	3.8426	1.7406
	Lab Fortified Matrix Sec 9.4.1	# Recovery	1.882	1.986	1.741
		Fort. Conc.	2.00	2.00	2.00
		% Recovery	94%	99%	87%
		Acceptable Range	75 - 125%	75 - 125%	75 - 125%
51	LRB	Blank	n.a.	n.a.	n.a.
	LRB Sec 9.3.1	Acceptable Range	<0.044	<0.040	<0.036
52	2.0 mg/L anions CCV	# Recovery	2.0262	1.914	1.6609
	Calibration Verification Sec 10.5	Prep. Conc.	2.00	2.00	2.00
		% Recovery	101%	96%	83%
		Acceptable Range	85 - 115%	85 - 115%	85 - 115%

Table 11 – QA/QC Summary for Cesium Analysis

Sample ID	Sample Type	Mean Conc (µg/L)	Expected Result	Recovery/ Result	Acceptance Criteria
Cal Zero	Zero	0.0000	0.00		
Standard 1	Cal	20	20.00	Abs= $.00001C^2$ X .00256C r=0.9999	r2>0.998
Standard 2	Cal	40	40.00		
Standard 3	Cal	60	60.00		
LRB	LRB	-0.2400	0.00	-0.24	<20ppb (QL)
40ppb ICV	ICV	46.1700	40.00	115%	±10%
40ppb QCS	QCS	48.6000	40.00	122%	±20%
40ppb LFB	LFB	42.9200	40.00	107%	±25%
AC-Con1-Blank1-Inf	Sample	7.8500			
AC-Con1-Blank1-Eff	Sample	2.3400			
AC-Con1-Test1-Inf	Sample	50.9200			
AC-Con1-Test1-Eff	Sample	8.0900			
AC-Con1-Blank2-Inf	Sample	0.7600	0.00	0.76	<20ppb (QL)
AC-Con1-Blank2-Eff	Sample	0.7600	40.00	2%	±10%
AC-Con1-Test2-Inf	Sample	52.7900			
AC-Con1-Test2-Eff	Sample	11.8400			
AC-Con1-Test2-Eff LD	LD	11.2800	%RPD=	4.84%	≤20%RPD
AC-Con1-Test2-Eff LFM	LFM	55.1700	40	108%	±25%
LRB	LRB	1.9900	0.00	1.99	<20ppb (QL)
40 ppb CCV	CCV	40.1100	40.00	100%	±10%
SG-Con1-Blank1-Inf	Sample	2.5800			
SG-Con1-Blank1-Eff	Sample	1.2000			
SG-Con1-Test1-Inf	Sample	44.8200			
SG-Con1-Test1-Eff	Sample	2.3400			
SG-Con1-Blank2-Inf	Sample	1.7600			
SG-Con1-Blank2-Eff	Sample	1.1100			
SG-Con1-Test2-Inf	Sample	1.0500			
SG-Con1-Test2-Eff	Sample	1.4900			
SG-Con1-Test2-Eff LD	LD	1.0300	%RPD=	36.51%	≤20%RPD
SG-Con1-Test2-Eff LFM	LFM	1.2600	40	-1%	±25%
Cal Zero	Zero	0.0000			
Reslope	Cal	40.0000	40	96%	±25%

Table 11 – QA/QC Summary for Cesium Analysis (continued)

Sample ID	Sample Type	Mean Conc (µg/L)	Expected Result	Recovery/ Result	Acceptance Criteria
Cal Zero	Zero	0.0055	0.00		
Standard 1	Cal	0.0458	20.00	Abs= $.00002C^2$ X .00182C r=0.9999	r2>0.998
Standard 2	Cal	0.1041	40.00		
Standard 3	Cal	0.1833	60.00		
LRB	LRB	1.5200	0.00	1.52	<20ppb (QL)
40ppb ICV	ICV	31.5800	40.00	79%	±10%
40ppb QCS	QCS	48.0500	40.00	120%	±20%
40ppb LFB	LFB	44.0900	40.00	110%	±20%
BRZ-Con1-Blank1-Inf	Sample	4.9800			
BRZ-Con1-Blank1-Eff	Sample	2.7800			
BRZ-Con1-Blank2-Inf	Sample	0.5900			
BRZ-Con1-Blank2-Eff	Sample	-1.0800			
BRZ-Con1-Test1-Inf	Sample	102.0100			
BRZ-Con1-Test1-Eff	Sample	1.5200			
BRZ-Con1-Test2-Inf	Sample	97.4400			
BRZ-Con1-Test2-Eff	Sample	2.0200			
BRZ-Con1-Test2-Eff LD	LD	1.0300	%RPD=	64.92%	≤20%RPD
BRZ-Con1-Test2-Eff LFM	LFM	26.2500	40	61%	±25%
LRB	LRB	0.8800	0.00	0.88	<20ppb (QL)
40ppb CCV	CCV	44.1500	40.00	110%	±10%

6.0 Summary and Conclusions

Stormwater detention basins are nearly ubiquitous infrastructure, particularly in areas that were developed since the 1980s. It follows that systematically retrofitting these extensive stormwater management facilities would be beneficial to both the built and natural environment as well as provide an additional emergency response tool for mitigation and decontamination of wide area contamination incidents such as a nuclear accident, terrorist attack, industrial spill, or transportation accident. This study examined the cost and performance of multiple types of media to remove a radiological surrogate, nutrients, and bacteria as well as ensure that flows within a stormwater application do not violate flood protection requirements. The media evaluated include: gravel coated with an adsorptive media, switchgrass, granular activated carbon, natural zeolite, iron composite metals, and ferric oxide coated media. A summary of results are as follows:

- A natural zeolite, switchgrass, ferric oxide powder, and coated gravel exhibited the best removal (> 90% removal) of cesium (radioactivity surrogate).
- Iron composite metal reduced *E. coli* (used as a bacterial contamination surrogate) levels by 8 logs followed by ferric oxide powder and natural zeolite (6 logs). Switchgrass exhibited an unexpectedly high removal capacity (4 logs).
- All the media exhibited > 72% removal of nitrogen and >56% removal of phosphorous which are typically related to harmful algal blooms in source waters.
- The media exhibited a wide range of permeability which reflects how quickly the treated water can exit the detention basin via the media. Most localities require detention basins be emptied within 48 hours. The coated gravel, switchgrass, granular ferric oxide, activated carbon, and natural zeolite adequately allow flow to exit the detention basin within that time frame. The iron composite metal and sintered metal with copper may require an additional 24 hours whereas the ferric oxide powder and powdered reagent mix are not likely to be able to meet these flow requirements.
- Another practical consideration for the widespread use of media to treat contaminated stormwater is the cost. The ferric oxide powder was by far, the most expensive media at $16.33/lb with switchgrass being the least expensive at $.20/lb. The remaining media were primarily around $3.00/lb with none exceeding $5.00/lb.
- Full-scale installations of two variations of the detention basin retrofit prototype device demonstrated that outlet flow rates were maintained below $Q_{critical}$ while doubling the detention time within the basin without causing flooding of the adjacent area.
- Post-retrofit detention basins safely detained storm events that exhibited more than twice the total precipitation and rainfall intensity of pre-retrofit storm events.

The selection of which media to use for the mitigation of a wide area incident or traditional stormwater runoff requires the consideration of multiple factors as described above:

1) Identify the contaminant causing impairment or requiring treatment.
2) Select the applicable media.
3) Identify the detention period required to keep the discharge below $Q_{critical}$. Narrow your selection of appropriate media.
4) Select the lowest cost media that meets the above requirements.

Future research will investigate the longevity and the time to breakthrough of the various media and optimizing the retrofit design to facilitate the replacement of the media. Greater guidance on the location and type of retrofit is needed to provide a targeted response. For example, for "transportation", a retrofit of a highway detention pond should be able to completely capture the complete contents of tanker truck. An industrial watershed serviced by rail cars should have detention to complete capture of a tanker car, or cars. This could be for any potentially harmful liquid product. For a wide area contamination, there is a need for quickly deployable systems that can be installed to totally prevent outflows and facilitate treatment to minimize the spatial extent of contamination.

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