EVALUATING MORE THAN PERFORMANCE – ASSET USE & LONGEVITY

Scott Perry – Contech Engineered Solutions
Michael Hannah – Stormwater360

ABSTRACT (300 WORDS MAXIMUM)

With increasing urbanization and redevelopment within the urban core there is a clear need for efficient and reliable stormwater treatment solutions. Limited available land space has been driving the demand for technology-based solutions and in some cases use of treatment trains to maximize net environmental benefit and protect stormwater treatment assets. To ensure proper vetting and selection of technologies and suitable applications, a detailed review and due diligence by engineers or regulators requires relatively consistent monitoring protocols and a review process. Resulting data from these evaluation programs and sometimes field observations are used to determine if the proposed treatment system achieves desired benchmark performance criteria.

Existing evaluation and approval programs have at times demonstrated limitations regarding the generation or examination and acceptance of data, real world experience and monitoring processes to determine the suitable design guidance and longevity. These limitations can lead to a reduced upfront capital expenditure, but a future pitfall for asset owners or managers. This can translate to long-lasting negative impacts on the asset’s life-cycle cost or environmental outcome.

This paper reviews monitoring and performance results of an innovative high surface area membrane-based stormwater filtration system to illustrate pollutant removal performance capability, and capacity. Contrasts to the more common monitoring methodologies are discussed, along with concepts to consider for expanding treatment system assessment with the focus on longevity indicators accounting for asset management.

KEYWORDS

Approval and Evaluation Programs, Assets, Monitoring, Longevity, Performance, Stormwater, Treatment Train

PRESENTER PROFILE

Based out of Buffalo, New York, USA, Scott Perry is a Certified Professional in Storm Water Quality (CPSWQ) who has worked in the water treatment industry for over twenty years, and is a Director within Contech Engineered Solutions. He has actively participated in several North American ASTM & ASCE stormwater technical committees, has served as a board member of the Stormwater Equipment Manufacturers Association (SWEMA), and has participated on multiple State-level technical regulatory committees across the United States.

1 INTRODUCTION

With increasing urbanization and redevelopment within the urban core there is a clear need for efficient and reliable stormwater treatment solutions. Limited available land space has been driving the demand for technology-based solutions and in some cases use of treatment trains to maximize net environmental benefit and protect the stormwater treatment assets. To ensure proper vetting and selection of technologies and suitable applications, a detailed review and due diligence by engineers or regulators requires relatively consistent monitoring protocols and a review process. Resulting data from these evaluation programs and sometimes field observations are used to determine if the proposed treatment system achieves desired benchmark performance criteria.

2 LIMITATIONS OF EVALUATION AND APPROVAL PROGRAMS

Existing evaluation and approval programs at times have demonstrated limitations regarding the generation or examination and acceptance of data, real world experience and monitoring processes to determine the suitable design guidance and longevity. These limitations have a high propensity to significantly impact an asset's maintenance frequency, associated life-cycle cost and net environmental benefit. Maintenance is inherent to all stormwater treatment practices. The inherent benefit to a well-designed treatment system is that it can account for variations in stormwater management, and strive to exceed a minimum time period between maintenance requirements. An additional benefit of a manufactured product is that once maintained the technology is then fully restored and put back into operation as originally designed, with the intent to obtain the highest level of pollutant removal performance.

As discussed in this paper, if limitations continue to be self-inflicted in treatment system approval programs, regulatory design guidance will be limited in scope. The end result often drives reduced upfront capital expenditure and future pitfalls for asset owners or managers to deal with excessive maintenance in the long-term. This occurrence translates to long-lasting negative impacts on the asset's life-cycle cost and likely a reduced net environmental outcome.

2.1 LABORATORY TESTING

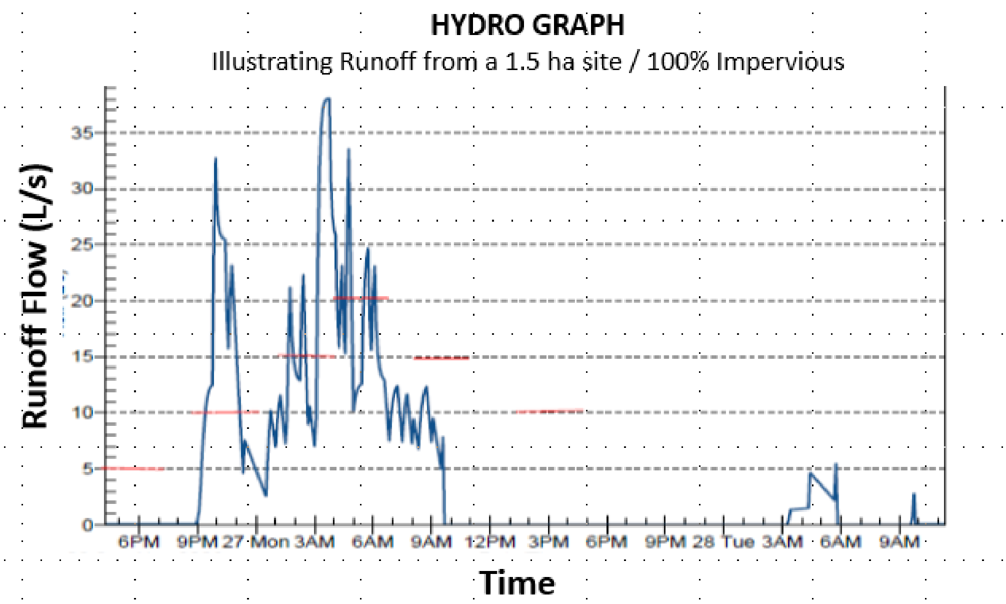
Evaluation and approval programs based on laboratory testing alone are best served for comparing technology performance versus each other, as opposed to determining how treatment systems will perform in real world conditions. Most laboratory test programs utilize test sediment mixed with clean water. The test sediment is often a specified ground silica gradation, or blends of ground silica with the intent to mimic a specific particle size distribution (PSD) as a surrogate for Total Suspended Solids (TSS). The ground silica particle's shape and density is largely uniform and entirely inorganic. These TSS characteristics do not exist in natural stormwater runoff and associated urban transported pollutant loads (Minton, 2011). Additionally, the ground silica surrogate TSS has no associated nutrients, heavy metals, organics or variations in other water chemistry parameters that can have a substantial impact on how treatment systems function, or fail.

The removal of particles by stormwater treatment systems is highly dependent on the particle size, shape, and specific gravity (Yingxia et al., 2005). Considering this and with the TSS surrogate being free of organics which function as binders, current laboratory testing programs ignore the real world impact or pollutant removal capability and maintenance frequency.

As an example a single variable such as particle density can begin to illustrate the limitations of determining approvals or design guidance based on laboratory testing. A common TSS surrogate used and specified for well recognized laboratory testing programs has a specific particle density of 2.65 (NJDEP, 2013). The specific gravity of particles transported by stormwater runoff identified by real world research vary from 1.1 (organics) to 2.86 (coarse sediments), (Karamalegos et al., 2005). If material has a specific gravity similar to water (close to 1.0) the material tends to float, and is difficult to settle. Material that has a higher specific gravity will have a higher tendency to settle. Floating particulate material may have a high potential to foul certain filtration devices, or may never be captured in other treatment devices. These aspects can be misinterpreted or largely ignored in today's common laboratory testing and evaluation programs. When comparing these types of scenarios to real world conditions, there are many aspects that begin to contribute to a negative asset outcome when solely relying on laboratory testing.

Another example is that laboratory testing is largely focused on TSS removal at specified steady-state flow rates. Technologies commonly have mechanisms intentionally built within that function on gravity and changes in flows during an event to help extend the time period between required maintenance. Steady-state flows are not typical in the real-world. An example comparing a typical real-world hydrograph versus a typical stead state laboratory flow rate can be observed in Figure 1. The implications of not having the real-world hydraulics occurring in a system during an evaluation in effect minimize the quick hydraulic changes that occur in a treatment system. For systems such as a membrane-filter relying on gravity-based backflushing based on these peak flow transitions, in effect are not properly evaluated. When only evaluating steady-state laboratory flows, systems that may have a tendency for pollutant release during quick flow transitions may also not be properly evaluated in comparison to real world conditions, over estimating performance capability.

Figure 1: Example Hydrograph versus Steady State Flow



2.2 FIELD TESTING

Strong, globally recognized field evaluations offer the best potential opportunity to gain the highest level of insight on how a treatment system will perform in real world conditions, over the long-term. There are areas for improvement with these monitoring programs and associated regulatory infrastructure to ensure the life-cycle value of the asset is maximized.

A common drawback raised is that field evaluations and approval programs are most often based on a single test site, with only one set of real world conditions. This scenario is largely due to the high cost and amount of time required to conduct a single, in-depth field monitoring evaluation. Well recognized technology field evaluation programs (TARP, 2001, NJDEP, 2009, TAPE, 2011) typically carry significant requirements to monitor performance for a minimum number of qualified storm events. For a storm event to qualify there needs to be adequate rainfall depth with a sufficient antecedent period between storms. Some field test protocols are evolving toward inclusion of more event qualification criteria. For example some have considered setting influent concentration limits on specific pollutants in an effort to increase consistency in the data sets gathered for increased system comparability. The combination of these parameters and requirements, coupled with the complexity of field monitoring typically drive a year-long monitoring period, if not longer. The length of time required to obtain enough qualified events often encompasses monitoring through seasonal changes including hydrologic rainfall intensities and volumes, land use changes and resulting variation in pollutant loads. Other less scientific provisions have been included by regional bodies as requirements to help ensure storm events are not specifically selected, or that enough data is obtained to help push more consistency into monitoring and approval programs. Often sufficient random variance exists within a 15 to 20 storm event field monitoring program to offset most concerns and generate a suitable statically valid data set for evaluation.

A monitoring requirement that would be beneficial to include into a field program is monitoring of both flow and driving head (water elevations) using pressure transducers. This is especially the case for unit processes that include filtration or infiltration, and volume-based systems such as retention, detention or run-off reduction. Quantifying water elevations and resulting flow can clearly illustrate positive or negative impacts on a system's performance over the course of the monitoring period, and during given events. A 25 storm monitoring period which took place on a membrane-based filter evaluated both the peak and median water elevations using transducers, and resulting flow as illustrated in Table 1. The value of this monitoring data, specifically reviewing the median and peak water elevations versus the design parameters and flow rates over the 25 event period provides a solid indication that maintenance was not yet required for this treatment system during the evaluation period.

As a filter is loaded with more and more sediment, fouling or occlusion of the filtration surface or filtration bed will occur. The higher the flow rate per filtration surface area, or flux rate across a filter medium, the higher the propensity to clog, impact or occlude the filter. Ways to offset this are to; increase the filtration surface area, reduce the flow rate or segregate captured pollutants from the filter medium. Inevitably sediment impacting, clogging or occluding the filtration surface or infiltration medium will occur. As a result the required driving head to achieve the same treatment volume or flow rate will increase. Eventually the driving head or water elevation required to achieve the designed treatment rate exceeds the bypass level or elevation. This scenario is a key indication of maintenance being required on the asset. By monitoring the treatment systems' water elevations throughout the monitoring period more data driven insight can be obtained regarding system performance and behavior over a range of conditions, and the potential need for maintenance.

Table 1: Membrane-based Filter monitoring Head versus Flowrate

Event Date	**Median head of filter system**	**Peak head of filter system**	**Filter system Treatment Flow Rate**	**% of Design Treatment Flow**
	(mm)	**(mm)**	**(L/s)**	**(%)**
28-May-10	40	158	4.29	34
16-Jun	108	198	5.36	43
21-Jun	170	251	7.44	59
30-Jun	51	395	9.15	72
15-Jul	147	429	13.25	105
1-Aug	194	531	14.26	113
6-Aug	146	306	6.81	54
7-Aug	116	311	8.26	65
23-Aug	37	116	1.26	10
12-Sep	53	157	3.85	30
26-Sep	37	63	0.44	4
27-Sep	30	399	10.91	87
4-Nov	78	171	3.53	28
16-Nov	45	173	1.77	14
5-Jan-11	61	298	7.38	58
10-Jan	38	204	3.34	26
25-Jan	83	175	4.10	32
7-Feb	138	309	2.21	18
9-Mar	69	184	3.15	25
28-Mar	85	153	1.01	8
30-Mar	177	398	5.62	44
20-Apr	117	163	3.28	26
14-May	108	499	7.51	60
6-Jun	16	167	1.58	12
27-Jun	143	426	3.34	27

Additionally, quantifying the total mass pollutant load transported by the runoff, and captured by the treatment system during the monitoring period can also be a beneficial piece of data. This information can then be used and applied by the regulatory approval body to establish suitable design requirements. In order to protect the asset the established design requirements must go beyond evaluating hydraulics and approved flow rates by determining the appropriate filtration capacity or unit size based on expected mass pollutant load. Approval and established design criteria from real world experience that accounts for the mass pollutant load as a key design parameter will provide better asset protection, and lead to reduced life-cycle cost.

A field monitoring evaluation was conducted on an 1829 mm diameter, four cartridge high surface area membrane-based filter (JF6-3-1) by the Nevada Department of Transportation (NDOT) as seen in Photograph 1. The additional monitoring conducted between maintenance cycles illustrates the benefits of quantifying the total mass pollutant load captured by a treatment system. The 0.25 hectares drainage area comprised of roadway runoff from SR 431 in Washoe County, Nevada experiences an average daily traffic (ADT) rate of 5,400. The material captured by the filter was assessed on September 23, 2015 in conjunction with maintenance activities performed by the NDOT. The assessment involved the following activities: filtration cartridge pollutant removal analysis, calculation of settled material found inside of the treatment system at differing locations and the collection of settled material samples from the treatment systems' sump for quantification and pollutant capture analysis.

Photograph 1: 1829 mm diameter, four cartridge membrane-based filter (JF6-3-1) being maintained in 2013 by the Nevada Department of Transportation (NDOT).

With the JF6-3-1, the high surface area membrane-based cartridges are comprised of eleven tentacles, which are easily disassembled by hand for ease of rinsing off sediment buildup and restoring as illustrated in Photograph 2. Tentacles were removed and restored using the tentacle rinse ring cleaning tool as seen in Photograph 3. Rinsate and pollutants associated with the cleaning of the membrane tentacles were collected separately and quantified to determine the dry mass, and then analyzed. Composite samples of the settled material were also collected from the systems' sump.

From March 2013 to September 2015, there was a two and half-year period of operation between maintenance events. During this time the treatment system revealed a net pollutant capture mass of 651 kg of material (1,002 kg/ha/yr). This equates to 163 kg of sediment captured per membrane-based cartridge by this treatment system, which exceeds the manufacturer's design limits for mass sediment design basis by over a factor of 3, illustrating the robustness of the treatment system from an asset management standpoint.

Photograph 2: JF6-3-1 membrane based cartridges

Photograph 3: Tentacles Removed and Restored with Rinse Ring

Based on further analyses 5% (14.8 kg) of the mass was found attached to the membrane-based filter cartridges, and 95% (280.5 kg) of the mass was located on the system' sump floor of the system indicating successful backflushing operation. Additional sediment depth measurements found that 32% of the mass was located within the perimeter of the separation skirt, and 63% of the mass was located outside the perimeter of separation skirt. The maintenance indicator for this treatment system is a sump sediment depth of 305 mm. The average depth of consolidated mass located outside the perimeter of the unit's separator skirt and inside the perimeter of the separator skirt was observed to be 357 mm and 229 mm respectively. Particle size analysis of materials indicated that the material attached to the membrane filter cartridges and located inside the perimeter of the separator skirt had higher percentages of silt and clay sized particles. Analysis of the captured solids confirmed the removal of Zinc (0.125 kg total, and 0.192 kg/ha/yr) and Copper (0.025 kg total, and 0.038 kg/ha/yr).

2.3 COMBINING FIELD AND LAB-BASED EVALUATIONS

Another potential concept to quantify the need for maintenance is combining aspects of a laboratory evaluation with a full field monitoring period. An example of this combined approach was applied to a membrane-based filter treatment system, 1219 mm diameter (JF4-2-1).

The JF4-2-1 treatment system consisted of three 1,372 mm long, high-surface area membrane-based cartridges in total. Each cartridge consisted of 35.4 square meters of membrane filtration surface area. Two cartridges were hi-flo cartridges, each with a design flow rate of 5.0 L/s, and one draindown cartridge with a design flow rate of 2.5 L/s. These values translate to a design membrane filtration flux rate (flow per unit surface area) of 0.14 L/sec/m^2 for the hi-flo cartridge and 0.07 Lps/m^2 for the drain down cartridge.

Using clean potable water in the laboratory, this JF4-2-1 treatment system had flow rate and head loss measured on a fresh set of unused, new cartridges as seen in Photograph 4. As a secondary step, this same treatment system was then employed in the field for a 25 storm event monitoring evaluation adhering to the Technology Acceptance and Reciprocity Partnership (TARP, 2001) field test protocol and New Jersey Department of Environmental Protection field test protocol (NJDEP, 2009).

Photograph 4: JF4-2-1 treatment system – New Cartridges lab tested

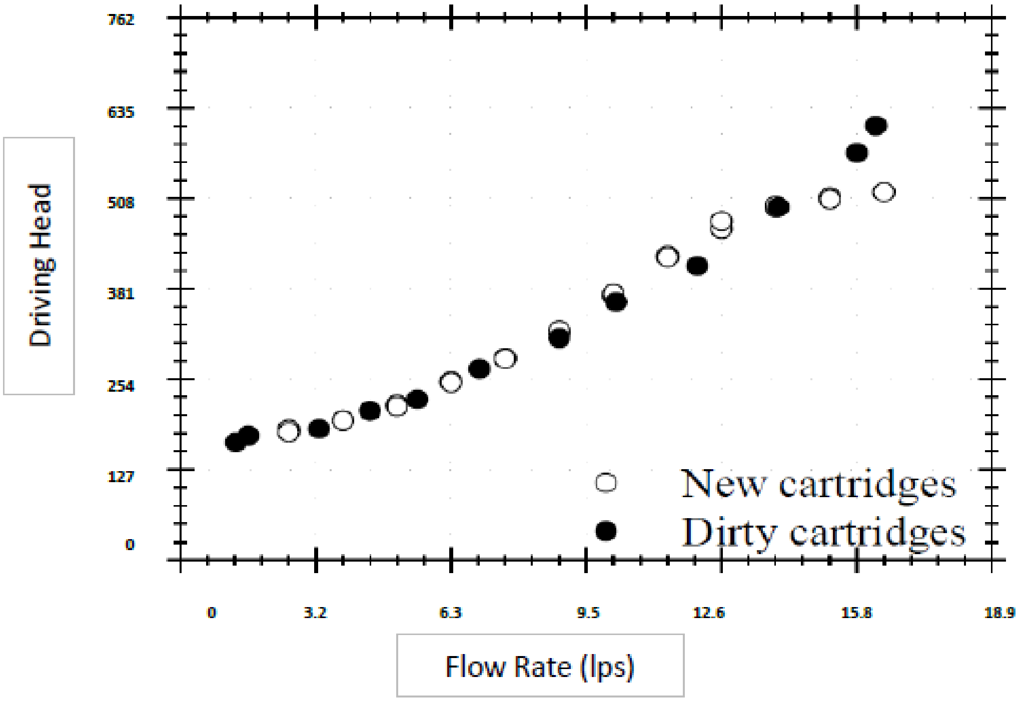
Over the range of the 25 events monitored the treatment system was exposed to varying TSS loads, and a cumulative total of over 75 kg of mass. The TSS was a combination of sediments and organics with a ranging influent concentrations from a low of 25 mg/L to a high of 261 mg/L, with a D_{50} particle diameter ranging as low as 32-microns to as high as 263-microns. After the full field study was concluded, which consisted of quantifying median pollutant removal performance of; TSS – 89%, Total Phosphorus – 59%, Total Nitrogen – 51%, Total Copper – 90%, Zinc – 70%, Lead – 81% and Chromium – 36% and Turbidity – 85%, the treatment system was then returned to the laboratory for further evaluation.

The third step was taking this same JF4-2-1 treatment system, with its dirty cartridges partially occluded after 25 storm events, back to the laboratory for further evaluation. Using potable water as seen in Photograph 5, the JF4-2-1 treatment system had flow and head loss measured again on the same dirty cartridges previously exposed to pollutant loading from 25 storm events.

Photograph 5: JF4-2-1 treatment system – Dirty Cartridges lab tested

Combining both the laboratory and field evaluation as a means of monitoring the technology allowed for a hydraulic response (driving head versus flow rate) graph to be produced comparing new cartridges versus dirty cartridges as illustrated in Figure 2. The hydraulic response through the high surface area membrane-based cartridges after 25 storm events was consistent, indicating the asset was far from requiring maintenance.

Figure 2: Cartridge Hydraulic Response (clean versus partially occluded)



2.4 REAL WORLD EXPERIENCES

Many approval programs have omitted establishing acceptance of a stormwater treatment system, proprietary or non-proprietary based on real world in the field experience. There is an opportunity here that stakeholders may be missing. The community and regulatory body could choose to implement multiple field trial systems to evaluate from an asset's inspection and maintenance point of view. By getting hands-on experience and involving more stakeholders to gain real world experience there would likely be opportunity to avoid long-term issues, which cannot be always be identified on paper.

Implementing this practice would offer multiple benefits to all stakeholders in the short and long-term. The first benefit would be that design engineers would be driven to size and design these systems or treatment trains accounting for more than hydraulics, i.e. maintenance implications. Right-sizing of a treatment system or implementing a treatment train based on the site type and expected mass pollutant load would be a likely outcome assuming there was a known expectation that the real world maintenance frequency would impact the long-term approval basis.

Another benefit is stakeholder groups would have multiple opportunities to inspect and maintain these treatment systems. That process would provide ample opportunity for owners or regulators to identify system accessibility benefits or concerns, while also creating a platform to begin to quantify inspection and maintenance cost. The feedback may have use in determining how systems are designed or physically arranged.

An example of involving multiple stakeholder groups to review technologies, and at times evaluate systems in the field prior to approval does occur in Montgomery County, Maryland. Being a densely populated 1,000,000 person community within the heart of the impaired Chesapeake Bay watershed, Montgomery County has very strict stormwater treatment regulations, maintenance and access guidelines. When evaluating technologies for consideration of approval, over twenty stakeholders come together to collaborate with the New Products Committee. Personnel from several County Departments, private maintenance companies, and local engineering firms are represented during the thorough review and evaluation process.

It is not uncommon for products to be modified prior to approval. Examples have included restricting approval to specific model sizes, requiring access points to be increased in size or number, and forcing the use of trolley systems in systems to allow for the ability to lift and remove sealed filtration cartridges weighing well over 100 kg to as high as 180 kg. Often the changes are centered on system accessibility for inspection and maintenance to adapt to County specific requirements, all associated with the County's focus on the real world approach and concerns around asset life-cycle cost.

Accounting for these hands-on, real world scenarios of proprietary or non-proprietary assets is largely not yet included in laboratory or field monitoring or regulatory approval programs. Adopting these types of approaches could have a substantial impact on the asset's long-term viability and life-cycle cost.

2.5 DESIGNING FOR THE POLLUTANT LOAD

From stormwater research conducted globally, pollutant loads are known to significantly vary based on site type, land use and average daily traffic loads (ADT) (Horner and Skupien, 1994, ARC 2003). Pollutant load variance when not accounted for in the design and sizing of treatment systems can have significant impacts on an asset's maintenance frequency and ultimately net environmental benefit. Regulatory design guidelines, acceptance, and treatment system approvals largely focus on requirements such as runoff volume treated or approved treatment flow rates, but tend to ignore the key parameter, pollutant load capacity.

Establishing pollutant load capacity of a treatment system based on real world monitoring to determine adequate design, and time periods in-between maintenance cycles is often not accounted at the regulatory approval level. This parameter should be better understood as a component of the monitoring program and then factored into the approval process, and used to establish approval guidelines.

Some programs such as the most recent New Jersey Department of Environmental Protection (NJDEP) approval processes have established pollutant load capacity limits. In the case of the NJDEP there is an assumed annual sediment capacity of 224 kg per hectare per year (200 pounds of sediment per acre per year), which is then translated into a maximum allowable impervious drainage area per cartridge for filtration technologies.

There was good intention of this approval process, however over the past several years as the NJDEP program changed there is now apparent flaws. The first issue as discussed above is that the current NJDEP program is now entirely based on laboratory testing. The program requires use of ground silica test sediment in clean water, which falsely determines a technology's sediment pollutant load capacity. This ignores all the real-world impacts of organics, and variations in sediment transported in runoff which can significantly alter pollutant load capacity.

The second issue is that for all approvals and site designs the State of New Jersey assumes that only 224 kg of sediment will be transported in runoff per hectare per year to all treatment systems. When comparing the assumed, fixed parameter of 224 kg/ha/yr to well establish TSS loading from global stormwater research this creates an issue. As research indicates, depending on site type, mass sediment loading ranges from 60 kg/ha/yr to up to 1369 kg/ha/yr (ARC, 2003). When not accounting for the TSS loading and land use variable in system or treatment train design, there inherently can be significant deviation. This practice could easily result in over sizing or worse yet under sizing by over 600%.

To put this in perspective, if one was to utilize NJDEP's approval basis for sediment capacity universally and apply a treatment system on a heavily loaded commercial site or roadway, the asset's maintenance frequency could easily move from a desired minimum 12-month interval to a required two months interval.

3 CONCLUSIONS

Existing well recognized stormwater treatment evaluation and approval programs have inherent limitations in respect to monitoring processes, real world experience and design practices related to providing suitable design guidance and longevity. If not addressed, these limitations have high potential to translate to long-lasting negative impacts on the asset's life-cycle cost, and likely a reduced net environmental outcome.

There are several suggested areas to improve and enhance stormwater treatment evaluation and approval programs to avoid these existing limitations, such as;

- Acknowledging that laboratory testing is best served for comparison of technology's performance versus each other, as opposed to determining how treatment systems will perform in real world conditions.

- When conducting field monitoring, include measurements of both flow and driving head (water elevations), especially for filtration or infiltration, and volume-based systems such as retention, detention or run-off reduction to help understand the system's behavior and maintenance requirements.

- Quantifying the total mass pollutant load transported by the runoff, and captured by the treatment system during the monitoring period provides a beneficial piece of data. Approval programs should include pollutant load capacity of a treatment system based on real world monitoring to determine adequate design guidelines.

- Involving various stakeholders in the approval process and hands-on experience on maintenance of treatment systems can be an opportunity to avoid long-term issues that impact the assets accessibility and long-term maintainability.

By mitigating the limitations discussed in existing or new evaluation and approval programs, upfront capital cost may increase slightly, however asset owners would avoid system pitfalls at a reduced life-cycle cost, with an improved overall environmental outcome.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Nevada Department of Transportation, Contech Engineered Solutions and John Pedrick for contributions.

REFERENCES

Auckland Regional Council (ARC), 2003, 'Stormwater management devices: Design guidelines manual 2003, Technical Publication # 10, *ARC online publication (2003).*

Horner, R., and J.J. Skupien, 1994, *‘Fundamentals of Urban Runoff Management: Technical and Institutional Issues’*, Terrene Institute, Washington D.C.

Karamaelgos, A., M. Barrett, D. F. Lawler, and J.F Malina, (2005) ‘Particle Size Distribution off highway runoff and modification through stormwater treatment, *CWR On-line Report 01-10*, Center for Research in Water Resources, University of Texas, Austin, Texas.

Minton, G. (2011) ‘*Stormwater Treatment’,* 3rd Edition, RPABook, pg. 41 – 56.

New Jersey Corporation for Advanced Technology (NJCAT) Verification, Jellyfish Filter, *NJCAT On-line publication* (2012).

New Jersey Department of Environmental Protection (NJDEP) Protocol for Total Suspended Solids Removal Based on Field Testing Amendments to TARP Protocol Dated August 5, 2009, Revised December 15, 2009, *NJDEP On-line publication* (2009).

New Jersey Department of Environmental Protection (NJDEP) Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device, *NJDEP On-line publication* (2013).

State of Washington, Department of Ecology, Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies, Technology Assessment Protocol – Ecology (TAPE), August 2011 revision of Publication no. 02-10-037, Publication no. 11-10-061, TAPE *On-line publication* (2011).

The Technology Acceptance Reciprocity Partnership (TARP) Protocol for Stormwater Best Management Practice Demonstrations, TARP updated July (2001).

Yingxia, L., Sim-Lin, L., Masoud, K. and Stenstrom, F. (2005) 'Particle Size Distribution in Highway Runoff' *Journal of Environmental Engineering*, ASCE, 131, 9, 1267-76.