ENVIRONMENTAL TECHNOLOGY VERIFICATION TESTING FOR STORMWATER QUALITY IMPROVEMENT MEASURES IN AUSTRALIA

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ABSTRACT

The Clean Water Act administered in the United States of America by the USEPA has set a benchmark in terms of requiring general compliance against stormwater quality criteria. It has subsequently generated a demand for Low Impact Development (the US equivalent of WSUD) and proprietary treatment devices. To gain approval for use in some states, it is necessary for the Manufacturers to prove the performance of their device under a standard Environmental Technology Verification testing procedure (eg. NJCAT, TARP). Unlike the United States of America, Australia presently does not have any uniform testing protocol for stormwater treatment devices, whether manufactured or natural systems. As a result, manufacturers of proprietary devices can undertake individual testing of new products without consideration to actual field conditions, real pollutant concentrations or hydrological flow regimes. This creates a significant challenge to stormwater practitioners to then be able to compare alternatives. The US has been through several evolutions of ETV testing protocols over the last decade and gained some significant learnings. As the Stormwater Industry Association in Australia contemplates the introduction of a similar ETV program, we outline a protocol undertaken by Manly Hydraulics Laboratory to synthesise actual stormwater and test a product at full scale. The successes and failings of the protocol are outlined and recommendations for similar benchmark testing are made.

INTRODUCTION

As Water Sensitive Urban Design (WSUD) achieves more widespread use nationally much has been learned and researched by the stormwater community with regard to application, implementation, operation and maintenance. This research has historically focussed on the constructed natural options of wetlands and bioretention systems (biofilters). In many cases, the implementation of these natural systems is constrained by available land area, especially for retrofit situations. This constraint pushes designers to implement innovative solutions to achieve the desired water quality objectives. Adding to this is the fact that there is no single “magic bullet” option for every situation. These factors result in what has been commonly referred to as a “treatment train” solution, seen in the wastewater industry as primary, secondary and tertiary levels of treatment (Tchobanoglous et al., 2003).

The use of proprietary devices, in particular Gross Pollutant Traps (GPTs), to provide the primary treatment to stormwater has been in practice for more than a decade. Several Best Practice guidelines and papers conclude that the use of GPTs are an important part of the treatment train for protecting the downstream natural measures providing secondary and tertiary treatment (Engineers Australia, 2006, Hunter, 1999). For most of this duration, the value of this importance has been measured qualitatively through inspections undertaken during maintenance and selected quantitative analysis of the mass and characteristics of the pollutants removed. These qualitative and quantitative analyses were presented as evidence that the devices were performing their role adequately.

As the stormwater industry has grown and understanding has expanded, there has been a number of guidelines released attempting to provide selection guidance for stormwater designers. The CSIRO “blue book” (1999) provides a qualitative, “high, medium and low” rating for devices and other treatment measures based on published information at the time. Australian Runoff Quality guidelines (2006) provide some principles for selecting appropriate devices. Even with these respected references and others, the designer must choose from a range of products developed in Australia and internationally based predominantly on publicly available information. In many cases, the only publicly available, performance information available in Australia on proprietary devices, excluding the previous references, is that contained within sales collateral.

THE NEED FOR VERIFICATION PROGRAMS

A verification program is a multi-step process that provides entrants into the marketplace a streamlined, defined, benchmarking process. It also provides consumers in the market certainty regarding the new technology as measured against the benchmark (USEPA, 2010, ANCAP, 2010). Common examples in use in Australia include the Energy Efficiency Star Rating, the Water Efficiency Labelling Scheme (WELS), and the Australian New Car Assessment Program (ANCAP).

The WELS allows consumers and designers to select water fixtures, based on their rating, to control their water usage and ultimately have some control over the amount they pay for their annual water usage. The Energy Efficiency rating also provides customers with the ability to choose from similar products based on the amount of electricity the product uses and thereby manage their electricity costs and greenhouse gas emissions. The ANCAP scheme provides information to drivers regarding the safety of the vehicle so they can use that information in their decision making process where relevant.

The Energy Rating and WELS schemes set out the verification process in an Australian Standard. A product can then be tested according to the Standard by a NATA registered laboratory, with the results submitted to the affiliated regulators for approval. The ANCAP scheme utilises "4 internationally recognised crash tests, undertaken by independent specialist laboratories." (ANCAP, 2010)

A similar scheme does not exist for environmental technologies in Australia. Thus, the research into stormwater treatment products, particularly, has often been conducted on an ad-hoc basis in response to needs at the time. The CDS product was researched by Monash University from 1995 through 1999 (Allison et al. 1998, Walker et al. 1999), and continues to be monitored in situ by MHL. The Humegard® product was researched by Swinburne University from 1997 through 2005 (Phillips, 1997, Chapman, 2000, Woods, 2004). The Ecosol RSF4000 product has been tested by University of South Australia and Avocet from 1997 to 2006. Constructed wetlands and bioretention systems have been studied by many Universities over the last decades (Greenway, 2000, Wong et al. 2000). Many other devices on the market have originated overseas and have been tested there. All of these test procedures have been different, based on varying briefs and different design criteria. The outcomes of these sometimes very extensive projects are answers to similar, but not comparable questions.

These test programs developed on an ad-hoc basis are substantially more expensive in cost and time than established test protocols. This is due to the iterations of testing needed to perfect the test methodology and determine the most appropriate method of analysis of results, as well as unnecessary testing that may not contribute to comparative analysis of devices. Thus the lack of guidelines not only results in a lack of verified information available to the industry, but is also a deterrent to vendors from implementing test regimes. Adding to the cost disincentive, there is a potential that the expected performance may not be met, while competitors may not have undertaken testing to verify their performance claims.

Despite this there are many benefits for vendors in verifying performance claims, it:

- Differentiates vendors from the competition and provides a distinct market advantage.
- Provides a specific and precise performance claim of the technology

- Provides the company with credibility to prospective buyers and reduces their risk in the procurement process.
- Compared to patenting and marketing costs, the verification cost is reasonable.
- Verified claims can be incorporated in to the patenting process.
- Verification demonstrates the commitment of the company to be fully transparent and accountable to stakeholders.
- An enhanced ability to attract investment.
- Verification aligns the company's business strategy with government policy and regulation.
- Minimises the possibility of criticism of installed devices

With no industry benchmark to follow, aside from historical research as a guide, there has been little comparative control over flow rates, sampling methodologies, number of sampling events, laboratory versus field studies, scaling methods, catchment types, pollutant loads and concentrations. This has resulted in comparisons for removal efficiency between studies at flow rates of 1L/s and 100L/s, and concentrations of 100mg/L and 1,000mg/L. As most stormwater professionals can attest, especially for water quality, it is much easier to demonstrate high removal efficiency for high concentration, low flow criteria than it is for low concentration, high flow criteria. It is for this reason that ETV programs exist.

EXISTING INTERNATIONAL ENVIRONMENTAL VERIFICATION PROGRAMS

In the United States of America, the USEPA administers the Clean Water Act. This Act provides a focus on Total Maximum Daily Loads (TMDL) for pollutants in stormwater runoff. An expansion of the National Pollutant Discharge Elimination System Phase II (Stormwater Regulations) also holds municipalities, in addition to private companies, responsible for discharges from their assets. Similar to the Queensland experience over the last 13 years since the introduction of the EPP(Water) 1997, municipalities in the US have been required to prepare Stormwater Management Plans for their catchments. A key difference in the US, is that the USEPA then monitors these catchments for compliance with the TMDLs, and more importantly, holds the Councils and private companies accountable through fines for breaches. Thus, there is a more urgent need to fully understand the efficiency of their stormwater treatment measures beyond a concept modelling stage. Naturally, verification of a measure's performance will increase its acceptance into the market, especially with regulators.

The USEPA's ETV program "*develops test protocols and verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment*". It has been operational since 1995 and provides a credible source of performance data for market-ready products such that purchasers, vendors, regulators and the public can evaluate environmental technologies. "*The ETV is a voluntary program operated as a public/private partnership, mainly through cooperative agreements between EPA and private, non-profit research institutes called ETV verification organisations. ETV currently operates six verification centres that test and evaluate the performance of environmental technology in all environmental media—air, water, and land*" (2010). The program develops a test protocol that each market entrant must comply with. Results of the testing (undertaken by experienced consultants or research houses) are presented to the verification centre in a Verification Report for confirmation of the performance claims. Testing must be performed in both the laboratory and field according to defined procedures, time limits and event numbers (Bachhuber et al. 2002).

Given the spatial and climatic variation across the United States, several of the individual states felt that the USEPA ETV protocol required further refinement and so the Technology Assessment Reciprocity Partnership (TARP) protocol and Technology Assessment Protocol – Ecology (TAPE) were developed. The TARP protocol is endorsed by California, Massachusetts, Maryland, New Jersey, Pennsylvania, and Virginia meaning that any claims verified under the TARP protocol will generally be accepted by all States. The endorsement states that the partners agree to:

> *"1. Address technology review and approval barriers in policy and regulations that do not advance knowledge of a technology's performance or recognize innovative approaches to meet environmental protection goals;*
>
> *2. Accept the performance tests and data, and acknowledge the approval results of a partner's review of a technology demonstration, as appropriate, in order to reduce subsequent review and approval time;*
>
> *3. Increase expertise in the applications and advantages of technologies that may have superior environmental and economic benefits for controlling stormwater pollution;*
>
> *4. Use the Protocol, as appropriate, for state-led initiatives, grants, and verification or certification programs where the objective is to document performance efficiency and cost of best management practices;*
>
> *5. Share technology information with potential users in the public and private sectors using existing state supported programs; and*
>
> *6. Monitor and evaluate the results of using this Protocol, and periodically review and revise the Protocol to maintain its viability." (TARP, 2003)*

The TARP protocol focuses predominantly on field testing, but will assess and verify laboratory data as well where presented. It provides a defined process to be followed and details a procedure for the number of sampling events, sampling methods, selecting the field location, determining a representative data set and identifying appropriate storm events to sample.

In Washington, the Department of Ecology (WDoE) TAPE program differs slightly by giving emerging technologies a "Use Designation". For example, a new product seeking to enter the market provides the WDoE performance data and receives, or is denied, a Pilot Use Level Designation (PULD). This allows the product to be installed and tested according to the TAPE protocol over a period of time. Once the field test data is verified by WDoE, it receives a General Use Level designation (GULD). If the test data provided to WDoE were not compliant with the TAPE protocol, then the product is granted a Conditional Use Level designation (CULD) (WDoE, 2008).

The German Construction Institute (DIBt) has released draft Admission principles for stormwater treatment systems (2010) outlining a required testing protocol so that regulatory authorities and designers can be confident that the devices will treat road runoff to a standard suitable for infiltration. The TRITECH ETV is a broader scheme that covers all environmental products in the European Union. In Canada, there is the ETV Canada to give their authorities and consumers certainty surrounding performance claims. Bangladesh even has its own program.

Despite the international lead and an evident desire by designers and authorities in Australia for transparent, uniform testing and verification, an Australian ETV program remains to be initiated. In this void manufacturers and designers must attempt to satisfy the desire without clear direction.

DEVELOPMENT OF AN AUSTRALIAN ETV TEST PROTOCOL

Humes® engaged Manly Hydraulics Laboratory (MHL) to undertake the equivalent of an ETV protocol on one of their new product prototypes. Test programs by other authorities around the world were reviewed to determine the best method of device testing, with the most robust methods found to conducted in the USEPA ETV, TARP testing and ETV Canada. As the brief was to identify the product performance for TSS, TN and TP, it was necessary to develop a test program to target these pollutants. Research in Australia, however, presents particle size distributions (PSD) in Australia lower than those identified by the USEPA (Lloyd & Wong, 1999, Ball & Abustan, 1999, Drapper, 2001) as shown in Figure 1 below.

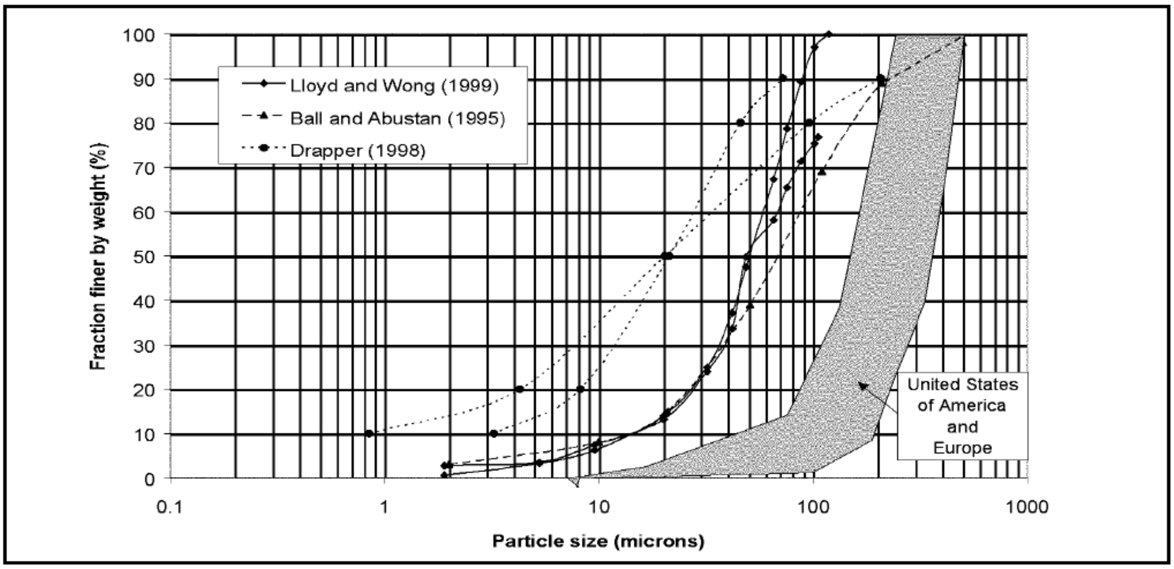

Figure 1. Comparison of Particle Size Distribution of suspended solids collected from overseas and Australian road and highway runoff - Extract from Wong (2000)

Table 1. Synthetic Stormwater Pollutant Concentrations

Pollutant	Target Concentration (mg/L)	Australian Range of Pollutant Concentration (mg/L) (after Engineers Australia, 2006)
TSS	250 – 350	20 – 1,000
TP	0.3 – 0.4	0.12 – 1.6
TN	1 – 2	0.6 – 8.6

In refining the protocol, MHL also improved the selection of the TSS surrogate to ensure that the PSD was close to that used in the MUSIC software. Also in keeping with the Australian research data on urban runoff concentrations, the influent was designed to provide the following concentrations (Table 1) referenced in MUSIC. To make the synthetic stormwater as representative of real world conditions as practicable, the nutrient concentrations were created with a target makeup of 50% dissolved and 50% particulate fractions.

The prototype was connected to a test rig that pumped the synthetic stormwater at a known rate. The pollutants were mixed into a slurry in a hopper and then injected into the main supply pipe with a progressive cavity pump capable of maintaining a constant flow over a range of pipe pressures. Samples were collected upstream and downstream of the prototype according to the residence time and test flow rates. Analysis of the samples was undertaken by NATA registered laboratories.

TRIALS AND TRIBULATIONS

The greatest challenge in this validation protocol was the selection of a suitable synthetic stormwater mixture. Target concentrations for Nitrogen, Phosphorous and Suspended Solids were taken from ARQ guidelines (as referenced above), and through several iterations of generating synthetic stormwater mixture and laboratory testing, finally was within guideline ranges. However, the target particle size distribution provided in MUSIC is a single distribution rather than an envelope and achieving that precise PSD is impossible in practice, yet can be a critical factor in determining the performance efficiency.

Early iterations showed input concentrations of nutrients and sediment were within guidelines, but the suspended sediments were strongly skewed towards very small particles. A close inspection of the pre- and post-treatment PSD revealed a very strong removal of particles above 30-60μm, with very small particles remaining. Furthermore, the bulk of the nutrient load was delivered through liquid fertiliser with nutrients dissolved or in a form creating TSS with a particle diameter less than 10μm. An adjustment was made to the synthetic stormwater mixture to more closely match the distribution used by MUSIC, as well as a change to a solids based nutrient load (worm castings). At the same time a change in the dosing technique from batch loading in a large tank, to in-line dosing. This resulted in a more accurate representation of actual stormwater.

The method of performing the particle size analysis (PSA) was also reviewed, with the discovery that sonication was being used to suspend the sediment during analysis, with the possibility of attrition (breaking down of particles) occurring. An alternative method of suspension was subsequently employed to analyse the final results and ensure that the PSA results were representative of the sediment load during testing. The results of the prototype tests are presented in Figure 2.

The issue of particle size distribution is particularly difficult to address as the sediment load can be highly variable from location to location, so published results may not apply equally to different installations. In addition, the sediment load can be temporally variable as an urban development matures, through seasonal changes, ENSO cycles, and other natural and anthropogenic forces. So the specification of a representative synthetic stormwater needs to address this variability even before issues of reliably creating a synthetic mixture are addressed.

Testing from one device to another under laboratory conditions may not be consistent if the composition of the synthetic stormwater is not consistent. Pollutants used in testing are generally soils and other gardening products, which can be highly variable from one supplier to another, and from batch to batch. Waters that have identical PSD, nutrient and sediments loads, may provide different test results if the form of the nutrients is different. A test program with dissolved nutrients may deliver very different results to one with coarse humus-based nutrients. Ensuring consistency of synthetic stormwater across all test programs is a major challenge to the development of an ETV protocol.

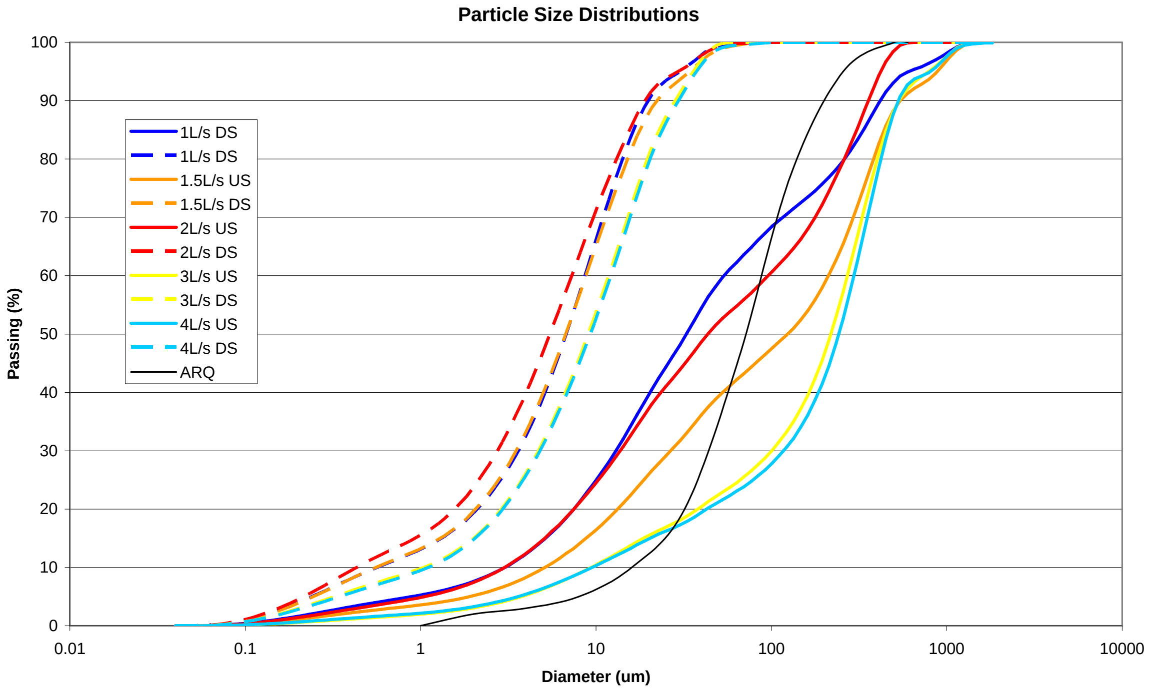

Figure 2 Prototype test results for particle size distribution pre- and post-treatment, with the guideline distribution as given by MUSIC.

The final program of testing used to validate the product's water quality performance was the result of a concerted effort to achieve accurate, verifiable, repeatable performance results in the absence of an Australian protocol for ETV. After completing the test program, we are confident that the protocol satisfies these criteria and should be considered as the protocol for all prototype testing in Australia.

RESULTS

Water quality performance testing under this detailed protocol produced repeatable, reliable results with very few outliers. These results would be considered indicative of a worst case scenario as constant flows were maintained through the prototype. In the field, a hydrograph and thus a pollutograph will occur. For this reason, the authors consider it is necessary that second stage evaluation (field testing) is vital for any ETV to calibrate any results returned in the laboratory.

Table 2. Prototype Pollutant Removal Efficiency

Pollutant	Removal Efficiency (EMC)
Total Suspended Solids	62%
Total Phosphorous	73%
Total Nitrogen	14%

HYDRAULIC TESTING

Hydraulic testing provides vital information about the device under extreme flow conditions, outside the design treatable flow range. Bypass flows allow the device to sustain high flows without damage to itself or the broader drainage network, and to maintain free flow through the system up to the design bypass limit. Hydraulic testing can only readily be performed in laboratory conditions.

The parameter to be determined from the hydraulic testing is the k-value, this is to be used by practitioners in numerical modelling and the design of stormwater systems. The formulation for the head loss of a hydraulic unit is:

$$\underbrace{h_{In} + \frac{p_{In}}{\rho g}}_{PressureHeadUS} + \underbrace{\frac{v_{In}^2}{2g}}_{VelocityHeadUS} = \underbrace{h_{Out} + \frac{p_{Out}}{\rho g}}_{PressureHeadDS} + \underbrace{\frac{v_{Out}^2}{2g}}_{VelocityHeadDS} + HL$$

With the k-value given by

$$k = \frac{2g(HL)}{v^2}$$

where:

h_{In} and h_{Out} is the elevation of the flow in metres at the inlet and the outlet respectively

p_{In} and p_{Out} is the pressure at the inlet and the outlet respectively (Pa)

ρ is the density of the water (997 kg m^{-3})

g is the acceleration due to gravity (9.81 m s^{-1})

v_{In} and v_{Out} is the velocity at the inlet and outlet respectively (m s^{-1})

HL is the head loss (energy lost in the system).
v is the flow velocity to be used in the k-value calculation
US and DS are Upstream and Downstream respectively

The *k*-value is calculated from a series of tests, by plotting head loss against velocity head ($v^2/2g$), and determining the slope of the least squares linear fit. It is very sensitive to the velocity in the calculation. The derivation of the k-value this is complicated in the product where differing pipe conditions at the inlet (pipe full conditions) and outlet (free surface conditions), lead to different velocities. The inlet pipe must be full and surcharged to drive flow through the device, whereas the outlet pipe will be free surface flow for all correctly installed systems. This results in different velocities, and so different possible values for head loss coefficient. To be consistent with other treatment devices the free surface flow was chosen.

The downstream velocity is further complicated by its dependence on the slope of the downstream pipe (or upstream pipe in other treatment devices). Steeper slopes will provide a higher downstream velocity and thus a lower *k*. In testing the product a single slope was selected based on installation guidelines provided by **Humes®**.

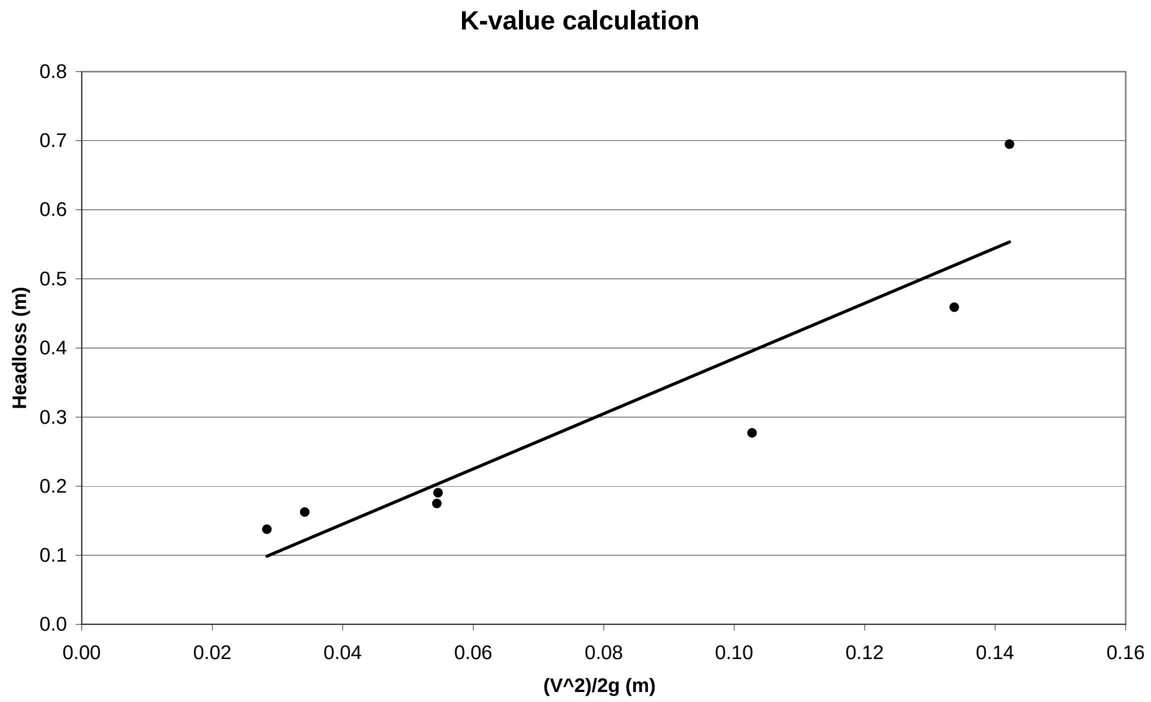

Figure 4 Hydraulic performance of the prototype in bypass conditions. The slope of the line of best linear fit gives the k-value, for this device it is 4.0.

CONCLUSIONS AND RECOMMENDATIONS

This paper identifies that there is a clear need for an Australian ETV protocol and program. Many international examples of ETV exist that could be readily adopted and translated for Australian conditions. The use of existing laboratory test results could be considered as a Stage 1 PULD benchmark followed by Stage 2 testing in the field to demonstrate performance before granting a GULD verification.

MHL has developed a test protocol that has proven to be repeatable, robust, compliant with MUSIC PSD and observed Australian stormwater concentrations and consider it to be suitable as a benchmark for future prototype laboratory testing for the validation of stormwater treatment devices.

Implementing this test protocol on the prototype supplied by **Humes®,** demonstrated laboratory removal efficiencies of 62% TSS, 73% TP and 14% TN. The hydraulic performance concluded a headloss factor (k) of 4.0. Field testing is recommended to verify these results in-situ but was not the subject of this research.

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