Stormwater Management: Peak Flow Attenuation System.

A new approach to Low Impact Design

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ABSTRACT

This paper introduces a patented peak flow attenuation system that reduces a development's peak runoff rates to pre-development levels.

The Resource Management Act 1991 (RMA) does not permit an adverse effect on the environment from the discharge of water-to-water. The greatest erosive effect results from a watercourse's peak flow. Runoff from impervious surfaces increases peak flow, accelerating riparian erosion and deposition. Current Low Impact Design (L.I.D.) methods for land development have been shown to achieve lower than expected levels of compliance with required standards.

Three case studies of Auckland subdivisions using L.I.D. demonstrated an average 11.3% reduction in peak discharge rate when compared to conventional subdivision. For the same case studies, the peak flow attenuation system model achieved a 100% reduction.

The peak flow attenuation system includes energy dissipation that reduces discharge velocity mitigating watercourse erosion and damage to riparian ecology. This system maximises the potential of any residential, commercial or industrial development while satisfying L.I.D. and RMA requirements. The attenuation system features low maintenance, a small footprint, enhanced environmental performance and significant financial benefit and should appeal to the wider engineering community.

KEYWORDS

stormwater management, detention chamber,
Low Impact Design (L.I.D.), stormwater attenuation.

PRESENTER PROFILE

Anthony Muir is a qualified civil engineering technologist, architectural designer, weathertight specialist, and trade certified carpenter with 30 years experience in the construction and land development industry; this provides unique interdisciplinary background. With a passion for research and development, Anthony holds several patents for products and systems used within the construction industry.

1 INTRODUCTION

A primary goal of stormwater management is to reduce a development's peak runoff rate to pre-development levels. This paper introduces a patented peak flow attenuation system that achieves this goal for any selected storm event.

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In the natural environment, most channels are continuously adjusting due to varying bank stability and fluctuating sediment supply. Nature, in the form of climatic changes, earthquake and storm inducing sediment, provides streams and rivers with a varying environment that affects rates of erosion and deposition. Natural bank erosion is beneficial to the ecology of waterways, providing numerous habitats for flora and fauna which contributes to ecological diversity (Watson & Basher, 2006).

A storm event contains a measured depth of rain falling over a given amount of time. A design storm of a given return period is typically embedded within a longer-term storm event and features as a burst of intense rainfall, which causes rapid runoff (Coombes et al., 2002). Creek and pipe flow depth and velocity increase quickly in response to this runoff.

A developed site's area of impervious surface further increases the runoff, creating an unnaturally large stormwater peak discharge. Coombes et al., (2002) asserts that the greatest detrimental contributor to streambed erosion and aquatic life is the peak flow generated during significant storm events.

New Zealand legislation, the Resource Management Act 1991 (RMA), clearly states no activity is to effect the environment in an adverse manner, regardless of any form of permission to do so. An artificially increased peak flow rate causes erosion with adverse effects to stream ecology and is therefore a non-permitted activity. A disregarded, or inadequate, stormwater management program creates ongoing potential for prosecution.

Low Impact Design (L.I.D.) techniques are well established, both in New Zealand and internationally. Auckland Council have summarised their hydrologic mitigation targets as "mimicking the predevelopment runoff hydrograph, including flow rates, total runoff volumes, and runoff timing." It is recognised that smaller storm events, occurring several times per year, may have significant effect on channel erosion (Auckland Council, 2013). Management of the peak stormwater runoff rate is a critical aspect of the L.I.D. process.

Mitigation techniques include large detention storage of rainwater runoff, which are often expensive using valuable land, and infiltration methods. Infiltration has serious limitations, especially for developed land, requiring significant geotechnical investigation. Significantly, Eason et al (2004) determined changes to development practices to reduce environmental impacts must be at least cost-neutral.

2 BACKGROUND

2.1 THE RESOURCE MANAGEMENT ACT (1991)

The RMA promotes the sustainable management of natural and physical resources. Sustainable management includes managing the development of natural and physical resources in a way that enables society to provide for their needs while avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Specifically, the RMA states no person may discharge any contaminant or water into water unless there is no effect on the environment. The Environment Court or enforcement officer may issue an enforcement order or abatement notice prohibiting any action that is likely to have an adverse effect on the environment and may also require a person to avoid, remedy or mitigate any likely adverse effect on the environment.

Existing User Rights are defined within the RMA. Any activity that has been legally established and is occurring prior to any form of development taking place is the permitted baseline for the development. With respect to stormwater runoff, the existing peak rate of discharge occurring from an undeveloped site for any given storm event determines the sites permitted post-developed peak flow.

The RMA requires the preservation of a flow paths natural character – creek, stream, river and no adverse effect on the environment as society discharges water to water.

2.2 REGIONAL COUNCILS AND TERRITORIAL AUTHORITIES

Since 2000, both Auckland Regional Council and Christchurch City Councils have developed Stormwater Management Guidelines (ARC, 2000, 2008) (CCC, 2012) for various methods of low impact design including stormwater detention. These guidelines outline methods to combine detention with some measure of water treatment, usually in the form of infiltration where the water and any contaminants are directed into the ground. Recent research concludes that large-scale infiltration of stormwater runoff is not recommended unless adequate site investigation is undertaken. Specific requirements include; site soil conditions, slope gradients, proximity to other structures and areas that recharge aquifers (New York Department of Environmental Conservation, 2010). There are very few, if any, guidelines limiting infiltration as a practice in New Zealand.

2.3 LOW IMPACT DESIGN (L.I.D.)

Low impact design attempts to maintain the original hydrological cycle for a post-development site. The most significant aspect of L.I.D. is to have a developed sites stormwater runoff not affect downstream characteristics (ARC, 2000).

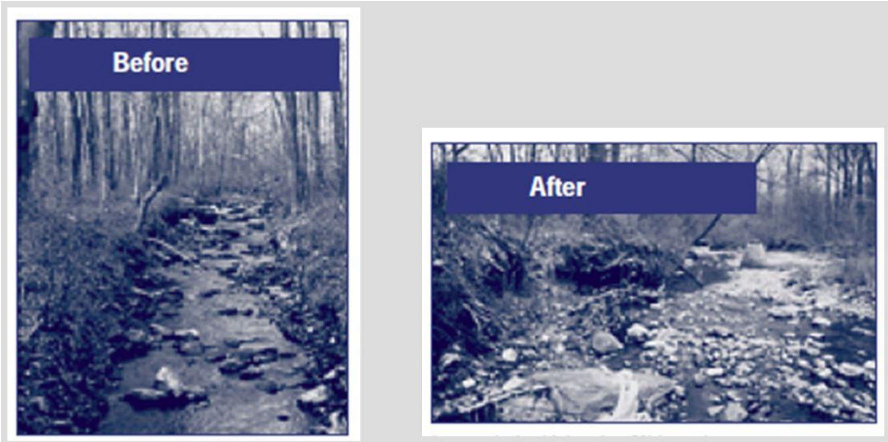
Increased peak rate of runoff is one of the greatest concerns for developed subdivisions (ARC, 2000). The immediate effect on the downstream environment due to increased peak flow is well documented and includes; flooding, rapid streambed and bank erosion, turbidity and sediment deposits, all adversely effecting stream ecology (ARC, 2000).

An overview of Hydrologic Mitigation Targets identified peak flow control as a well-established method of reducing the downstream effects of large storm events. While channel forming flows are not limited to large events, lesser flows cause less erosion. The duration of a critical flow above a critical magnitude causes greater sediment transportation (Auckland Council, 2013). It may be necessary to establish a critical magnitude prior to L.I.D. design in locations where soil types are prone to easy transport.

Technical Publication 124 (ARC, 2000) compares the cost and runoff performance for three subdivisions in the Auckland area. The predevelopment characteristics are compared with those of a normal subdivision and an L.I.D. subdivision. While swales, other filtration techniques, and flow slowing methods are employed within the L.I.D. case study, their performance relies on a reduction of the area to be developed, resulting in a significant reduction in section size. The study states, the reduced section size may result in buyer resistance. With a reduced development area, L.I.D. efficiency provided minimal improvement to outfall peak flow rates, providing at best 14%, averaging 11.3%, efficiency when compared to a standard type subdivision.

2.4 STORMWATER MANAGEMENT

A small increase to a catchments impervious surface can have devastating effects on downstream characteristics as shown in photograph 1 (Credit Valley Conservation, 2010). It is recognised that the greatest detrimental contributor to streambed erosion and aquatic life is the peak flow rate generated during significant storm events (Coombes et al., 2002).



Photograph 1: The effect of a 25%increase to a catchments impervious surface area. (Credit Valley Conservation, 2010) (Ministry of the Environment, Canada. 2003)

A design storm of a given return period is typically imbedded within a longer-term storm event and features as a burst of intense rainfall (Coombes et al., 2002). Existing detention systems generally route the total runoff through their chambers rather than focusing on the damaging intense rainfall burst. This requires the system to display considerable redundancy, detaining large volumes of runoff occurring at a relatively low flow rate. The pre-burst rainfall increases the required size of a standard detention chamber.

Current detention systems include pond construction, which fluctuate in level as storm events contribute to its volume. These are large, using valuable land and feature health risks especially when incorporated close to residential developments. They are expensive to construct and incur a very high maintenance cost (Ira, Vesely & Krausse, 2008). Current legislation requires they are fenced to maintain public safety.

Underground detention comes in two forms; a simple chamber with a slow release discharge or a chamber used without a base to promote rapid infiltration of the stormwater into the soil. Both of these systems are large as they detain both the pre and post design storm rainfall along with the intense storm event. As mentioned, large rapid infiltration of stormwater to the soil must be undertaken with extreme care. Significantly, concrete chambers have the smallest carbon footprint of these systems (Filshill & Martin, 2011).

Stormwater management often segregates and treats stormwater runoff through flow-splitting devices such as first flush interception (CCC, 2012).

2.5 PRINCIPLES OF WATERCOURSE EROSION

Watercourse erosion is a natural phenomenon. Stream competence and capacity are a function of the stream’s energy derived from the flow volume and velocity. As the flow increases, the potential energy available to move particles increases. The speed of erosion is also dependant on the characteristics of the bank soil structure, with light, small, less bound particles easier to remove. It is natural for a stream to occasionally realign its path, moving across its floodplain during periods of high or prolonged rainfall, and experience water levels to rise more rapidly in catchments having larger areas of impermeable surfaces (Blaschke et al., 2009).

Erosion is a natural effect, and only excessive, rapid or reduced erosion should be seen as an indication of RMA noncompliance. Therefore, waterway erosion is expected, occurring to maintain an ecological balance.

Developed land contains areas of impervious surface such as roads, buildings and site development that shed rainwater at greater volumes and at a greater speed than the pre-developed land. Ideally, post-development site stormwater runoff will have similar if not identical peak flow rates and volumes of the pre-developed site. Without any form of intervention, a developed site's discharge will have greater peak flow volumes causing increased velocity, turbulence and subsequently erosion to its discharge watercourse. Uninhibited flows create significant detrimental affects to the downstream environment, bank undermining, deposition and bed widening as shown in photograph 2.

Photograph 2: Stream displaying effects of increased runoff and channel erosion.

If the developed flow is piped to a municipal stormwater system, an increased flow rate may overload the existing network causing widespread flooding. Without adequate stormwater management, this high volume, high velocity, flow is a burden on the environment.

2.6 WATERCOURSE FLOW REDUCTION

Currently, most if not all, territorial authorities require stormwater management to limit the post-development two and ten-year design storm peak discharge to the predevelopment peak discharges for those events. If there are existing flood issues downstream, a post-development discharge equivalent to a one hundred year design storm peak discharge of the pre-developed discharge may be necessary (ARC, 2003).

2.7 LIMITATIONS FOR L.I.D. INFILTRATION

A reduction in peak runoff rate has been identified as being of significant benefit to stream ecology and is therefore an important aspect of L.I.D.. While some aspects of rainwater infiltration may have merit, especially in treatment of water quality, it has little benefit in reducing peak runoff flow occurring as a mid storm rain burst. While infiltration has a benefit for water quality, internationally and nationally, the disposal of large volumes of stormwater using infiltration techniques is becoming less desirable (Moore & Darragh, 2013). The potential effect of increased soil water content on soil bearing capacity and slope stability can have dire consequences. Significant issues may arise for sloping sites, sites with modest clay content and areas of aquifer recharge (New York Department of Environmental Conservation, 2010).

Figure 1 shows the reduction in soil bearing capacity as a soil becomes saturated.

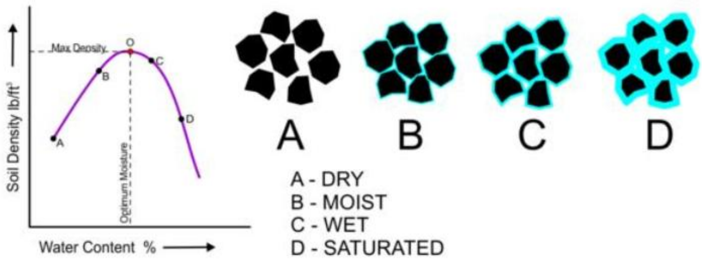


Figure 1: Soil density/bearing capacity vs. water content

Often developed land has subsequent design criteria requiring removal of surface water to a drainage system as quickly as possible to reduce rainwater infiltration. Thereby maintaining the soil structural properties and bearing capacity (Connell Wagner, 2002). New York State provides guidance that has very particular requirements when infiltration is to be considered as a L.I.D. approach, of which several are itemised below (New York Department of Environmental Conservation, 2010).

- *Infiltration practices cannot be located on ground with natural slopes greater than 15% max.*
- *Underlying soils shall have infiltration rates of at least 12.5mm/hour*
- *Soils shall have a clay content of less than 20% and a slit/clay content of less than 40%*
- *Infiltration practices cannot be located in fill soils*

These limitations are well founded in civil engineering practice and soil mechanic principles.

> "The rainfall intensity also has a marked effect on the slope factor of safety. The higher the intensity of the rainfall, the higher is the infiltration rate into the soil, hence the lower is the factor of safety against slope instability" (Bujang, Faisal and Low, 2006).

3 PEAK FLOW ATTENUATION SYSTEM

The RMA defines a clear legal requirement, requiring development not to affect the environment. The post-developed peak flow rate was identified as the single most important aspect of L.I.D. and therefore the controlling parameter for any new method or technique.

Reducing a site's developed peak runoff rate to predevelopment levels requires some stormwater detention. Observation of an existing traditional type detention chamber confirmed significant storage capacity was in use during a storms initial low intensity rainfall when detention was not necessary. During the early stage of a storm event, the flow from a developed site is lower than the pre-developed site's peak efflux. Therefore, this early storm event flow can bypass the storage device thereby reducing the required design volume of the chamber without adverse effect on the environment, provided that energy dissipation is constructed at the discharge point.

TP124 provided environmental and financial comparison between the Peak Flow Attenuation System and both conventional and L.I.D. subdivision design for the three Auckland case studies.

3.1 PEAK FLOW ATTENUATION SYSTEM DESCRIPTION

The Peak Flow Attenuation System combines specific flow control, 1.35m diameter detention chambers and energy dissipation. The system provides the same, or reduced, peak flow rate and outfall velocity evident from the pre-developed land. The system is constructed using readily available materials, 1350mm diameter rubber ring joint concrete pipe, manhole risers and comes with a flexible design method to suit all development area sizes and environments. It is able to be designed for any selected design storm.

This form of detention system can be less than 25% the size of a standard detention system and produces a selected peak flow rate often equal to or less than the site's natural peak runoff for any design storm. Multiple detention chambers provide a solution for different ARI storm events for any given site. The discharge from the developed site is a piped flow and therefore has greater velocity than an undeveloped site as its runoff flows over ground. Therefore, the accelerated flow must have its velocity reduced by the energy dissipater at the pipe outlet. Existing pipes discharging to a watercourse would benefit from attenuation and/or energy dissipation.

3.2 PEAK FLOW ATTENUATION SYSTEM PROCESS

Stormwater drainage collects the catchment runoff from the site in the normal manner. Once collected this volume enters stage one: a typical manhole structure (figure 2). The manhole has no haunching. The flow entering the manhole exists via a plate orifice sized to enable a predetermined bypass flow. This bypass flow has a volume of 70 – 90% of the design storm predevelopment volume, which passes the attenuation chamber and directly exits the development. Once the plate orifice is overtopped, the excess flow enters the attenuation chamber, slowly exiting the site over a period of time. Bypass pipes are typically oversized to allow for the inlet plate orifice.

The combined flows of the bypass and detention chamber discharge never exceed the site's predevelopment peak discharge rate.

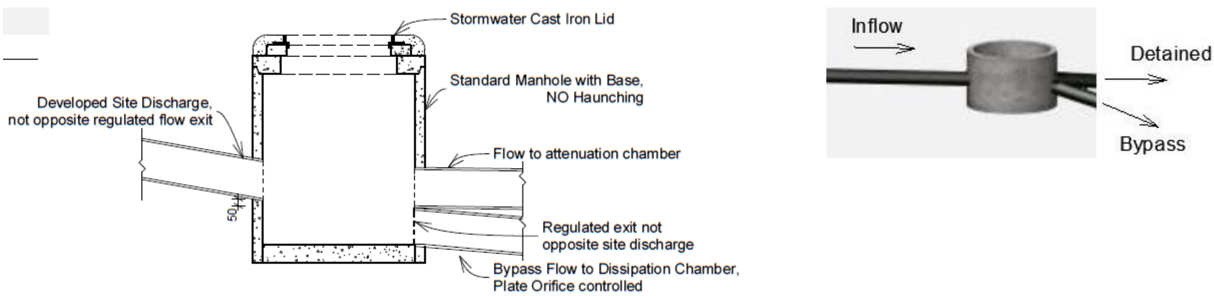


Figure 2: Attenuation Chamber Bypass.

The attenuation chamber is of typical piped chamber design having manhole access to enable ongoing maintenance. The water to be detained enters the chamber and accumulates while also slowly discharging via a small diameter pipe, usually of 100mm diameter. The discharge volume of the full chamber and the initial bypassed flow, combine to discharge the total design storm predevelopment flow.

Often the regulatory consent process requires a design to cater for multiple storm events. Figure 3 shows a typical two-year and ten-year storm event Peak Flow Attenuation System with an energy dissipater. The two year designed chamber works independently. Once full, a greater than two year event is occurring. The overflow from the two-year chamber is separated using an orifice plate in the same manner as the initial bypass method. The split flow partially bypasses the 10-year chamber while the volume not bypassing enters the second attenuation chamber. As the water accumulates, it is also slowly discharging via a small diameter pipe, usually of 100mm diameter. The combined outflow from the system discharges at a rate no greater than the site's pre-developed peak discharge rate for the ten-year design storm.

The attenuation system outflow may be designed to discharge at a predetermined rate directly to the municipal stormwater drainage system without exceeding the pipes capacity. When discharging to an open watercourse, the piped outflow enters a specifically designed energy dissipater (figure 3) reducing the discharge velocity of the flow immediately prior to entering the receiving watercourse.

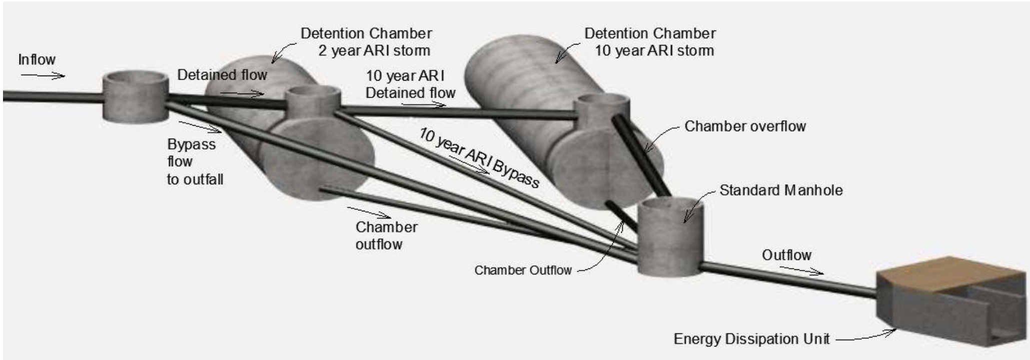


Figure 3: Attenuation Chamber with energy dissipater installed at outlet.

N.Z. Pat. No. 600579, U.S. Patent Pending, Canada Patent Pending, Australia Patent Pending.

Attenuation chamber installation is in accordance with standard drain laying techniques for a pipe diameter of 1350mm. When soil-bearing capacity is not adequate, a 100mm thick, 665 mesh reinforced, foundation slab is poured prior to pipe installation. Locations with a high water table create a potential for an empty chamber to float, especially during seismic activity. In this environment, stainless steel straps secure the pipe to the concrete foundation slab. Site-specific calculation is required to confirm foundation weight and strapping sufficient to counter buoyancy. It is likely a foundation depth of 0.4m is necessary in extreme locations, having 12KN strapping at 0.5m centres. Other methods, such as pore pressure reduction plugs may be installed which activate during seismic activity. This discussion is, however, beyond the scope of this paper.

Occasionally smaller sites have natural gradients that are not conducive to a gravity charged stormwater system. In these cases a pump is installed, either submersible or standalone, draining the chamber at a predetermined rate. The rate is set to provide the difference between the predevelopment and bypass peak flow rate.

Chamber combinations enable a simple structure to function for multiple storm event ARI periods offering flexibility in stormwater management.

3.3 ENERGY DISSIPATION

Piped attenuation system discharge often releases to a natural watercourse. Piped flows have a greater velocity than a natural flow. As these flows combine, the developed flows higher velocity accelerates the slower travelling watercourse flow causing greater erosion. The installation of the energy dissipater at the site outfall reduces the flow velocity, eliminating excessive outfall erosion.

Figure 6 shows the piped flow discharging into the primary chamber, reflecting 180° before returning on its own flow path prior to exiting the dissipater. The outlet flow path changes direction several times, colliding with blocks protruding along the outlet path further reducing the velocity.

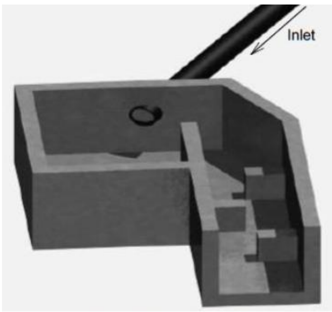


Figure 6: Energy Dissipation Unit - Top removed for clarity.

The dissipater is fixed in position with a concrete block, designed by the site engineer to resist any movement. This block counters the force of the water colliding with the internal wall of the unit during flood events. Depending on the flow path directly beyond the dissipater outfall, a small concrete apron or riprap may be necessary to protect the flow path as it joins the watercourse. This construction avoids the likelihood of damage to the outfall, a New Zealand Building Code Clause E1 Surface Water requirement.

3.4 COST ANALYSIS

Material quotes were updated 1st October 2013. An excel spreadsheet enables pricing of various chamber lengths. Each design includes; excavation, tidy slab, components, backfilling and labour, each calculated separately and attributed to the final cost. These calculations should be used for estimation only and do not allow for any site-specific conditions, consultant fees, Territorial Authority (TA) fees or supervision. All costs are estimated for sites having reasonable access.

The energy dissipation unit is not included in this costing process as it is not always required. The nature of their installation, possible remote location and anchoring method, requires individual costing on a job-by-job basis.

4 ATTENUATION CHAMBER HYDROLOGY

4.1 FLOOD ROUTING

Flood routing has at its core, the law of continuity. The volume of water discharge for a given interval must equal the volume of inflow during that interval, plus or minus any change in volume stored. This can be written as:

$$O = I - \frac{\Delta S}{\Delta t} \quad (1)$$

Where O is the mean outflow during time interval Δt, I is the mean inflow during time interval Δt and ΔS is the net volume change in storage during time interval Δt.

This formula can be modified by identifying each term at the start and finish of the time period Δt:

$$\frac{\Delta t(O_1 + O_2)}{2} = \frac{\Delta t(I_1 + I_2)}{2} - (S_1 - S_2) \quad (2)$$

Where O is the mean outflow during time interval Δt, I is the mean inflow during time interval Δt, ΔS is the net volume change in storage during time interval Δt and subscripts identify the start and finish of the time interval Δt.

For the attenuation storage chamber, the storage depth directly determines the outflow discharge. Therefore plotting Outflow vs. 2S/Δt + O produces a storage indication curve. This must be completed for each chamber as each different length of chamber has a unique storage indication curve.

Figure 7 shows a storage indication curve for a chamber 4.4m long and having a volume of $6.3m^3$. The formula within the graph is the line of best fit to the curve. This formula is used in the attenuation system spreadsheet to directly calculate chamber outflow.

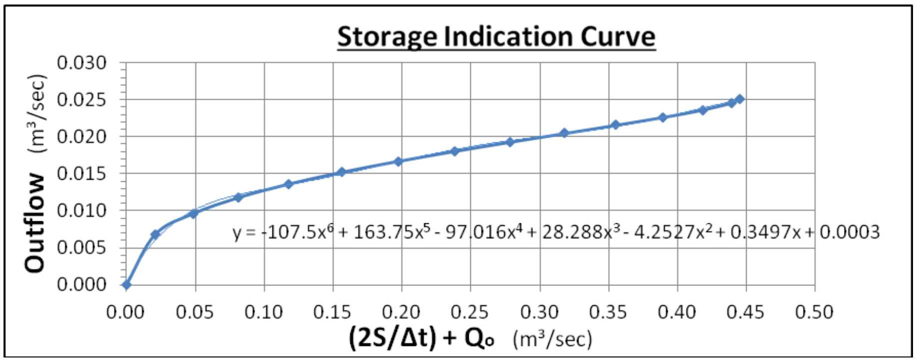


Figure 7: Storage Indication Curve – chamber volume $6.3m^3$

4.2 INPUT DATA REQUIRED FOR ATTENUATION SYSTEM DESIGN

Site characteristics must be determined to calculate the sites pre and post-development runoff. For catchment areas less than 50 hectares, the rational method is often used to calculate the stormwater discharge, measured in cubic metres per second (m^3/s). The Rational Method is described in the NZBC Compliance document E1 (MBIE, 2013).

Other methods which can be used to obtain a runoff hydrograph, are: TP108 (ARC, 1999), Unit hydrograph storm modeling or Manual input.
Manual input was used for comparison to Auckland subdivisions where the site runoff rate of those subdivisions had been previously calculated using TP108 (ARC, 1999) and provided in TP124 (ARC, 2000). The site's peak discharge rate is a combination of the bypass flow and the attenuation chamber discharge. This volume can be set at any volume although generally, this will be the original peak rate of discharge exiting the site. Occasionally, a reduced discharge may be selected to reduce the site discharge to volumes less than the predevelopment discharge. This may be necessary if existing downstream watercourses or piped conditions require relief or are susceptible to erosion.

5 SOFTWARE DESIGN

Software design was undertaken using the standard civil engineering flood routing method, Modified Puls, using an Excel spreadsheet. A Design Flowchart, figure 8, represents the protocols and input process of the software.

Chamber volumes were able to be determined for various scenarios, reducing post development peak flow rates to those occurring predevelopment.

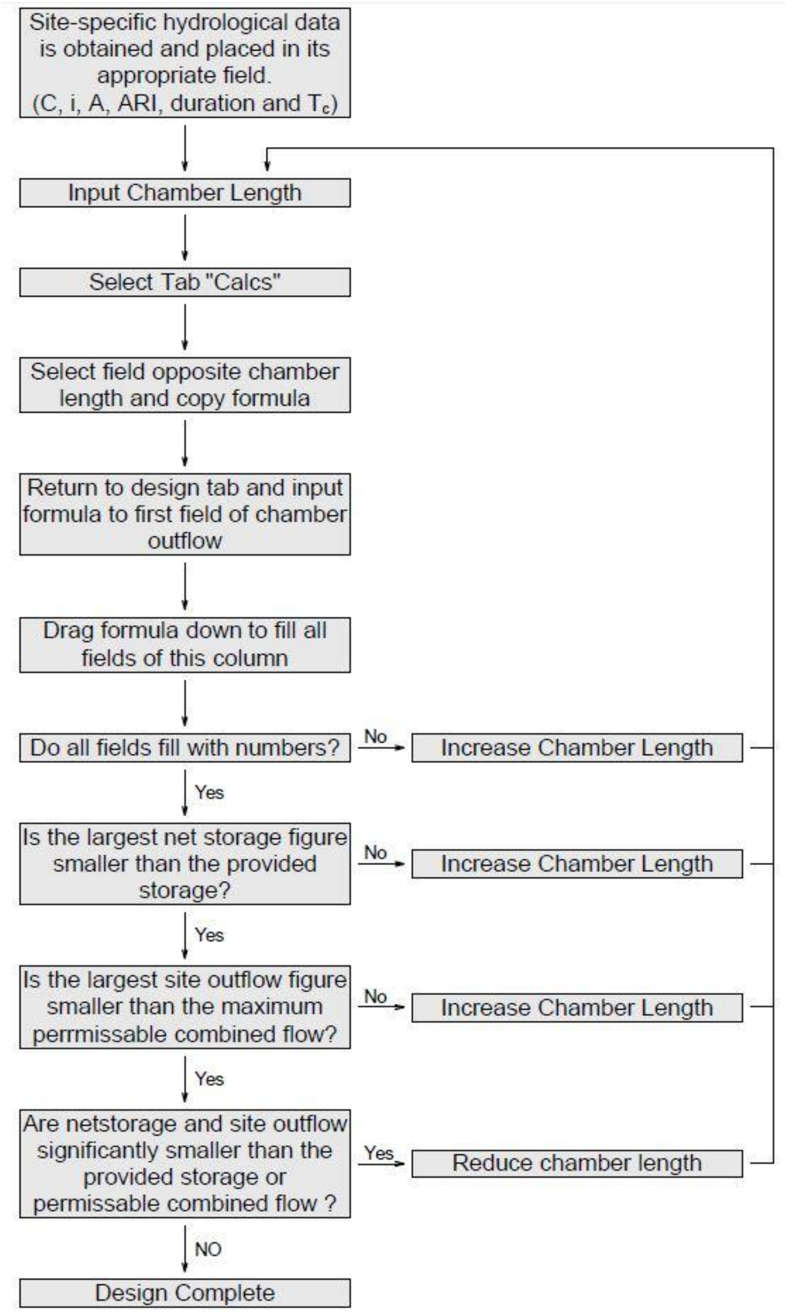


Figure 8: Design Procedure

Design storm Annual Return Interval is selected. An initial investigation of the site pre and post-development returns the Time of Concentration and the Rational Methods input data, which is then entered into the Runoff Calculation section of the spreadsheet. If the undeveloped and developed peak runoff rate or discharge hydrograph is provided, it is possible to input the data directly.

Observation is made of the chamber outflow column to confirm all column fields have generated with figures. If the chamber is smaller than required, the fields do not generate. Therefore, re-selection of chamber size may be necessary. Once the chamber outflow fields have generated figures, the largest figure in the Net Storage column is observed which must be smaller than the storage of the chamber. The largest figure in the Site Outflow column is observed which must be smaller than the maximum permitted site discharge. If any of these figures is larger than permitted, the chamber size is increased, a new formula is inserted, and the design process is repeated. If the chamber is larger than necessary, observations will determine calculated maximum storage is larger and flow rate is less than those required. Therefore, the chamber size is reduced and the design process is repeated. These manual observations are designed to engage the designer rather than permitting a less observant, automated design process.

Once complete, a hydrograph for the outlet is generated showing the flow rate vs. time for the pre-developed site, a conventional subdivision and an attenuation system, example figure 9. Manual calculations were conducted to assess the validity of the software model. These included chamber volume, part-full volume, discharge rate for specific chamber fill depths. No errors were found.

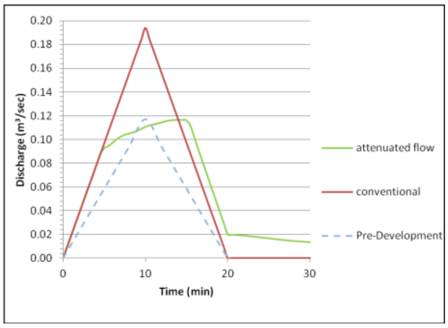


Figure 9: Generated site discharge hydrograph.

6 MODELLING RESULTS

6.1 COMPARISON OF CHAMBER DIAMETER – 1.8M VS 1.35M

Modeling of 1.35m and 1.8m diameter chamber sizes for a 100% reduction of the increased peak rate of flow post development enabled cost comparison of the two options. A lesser discharge from a full 1.35m diameter chamber enables a greater bypass while still achieving 100% efficiency. The smaller pipe diameter maintains adequate access for future maintenance. Cost reductions of between 16% and 21% were obtained when comparing 1.35m and 1.8m diameter chamber designs for various sites. Ease of handling the smaller diameter pipe further contributed to cost efficiency, confirming the 1.35m diameter chamber size as the default chamber size for all subsequent modeling.

6.2 COMMERCIAL AND INDUSTRIAL ZONED PROPERTY

Commercial and industrial properties have significant areas of impervious surfaces. When compared to a grassed predevelopment site, the stormwater peak runoff is greatly increased. An attenuation system was modeled for the Wellington City Council drainage design requirement of a ten-year ARI storm event having ten-minute duration. Eighty and one hundred percent site coverage has been modeled to simulate extreme and maximum site development.

Figure 10 and 11 shows site runoff for the pre and post development site. The one-hectare site modeled shows 220% and 250% increase in the stormwater peak runoff rate for 80% and 100% site coverage respectively from the pre-developed flow to that of the post-developed discharge. The attenuated flow, graphed green, does not exceed the pre-developed site's runoff rate. This was achieved in both cases with a single chamber attenuation system having a length of 21.2m costing $41,700 for 80% site coverage and 28.4m and $50,800 for 100% site coverage.

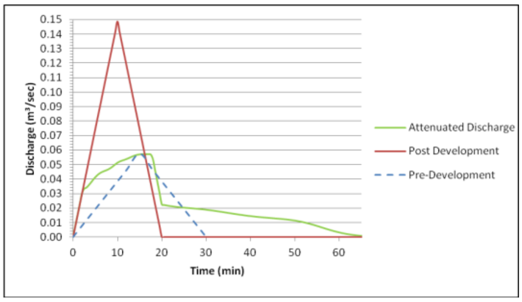


Figure 10: Site Runoff Hydrograph – 100% site coverage

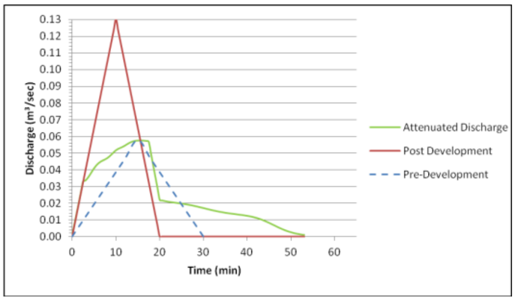


Figure 11: Site Runoff Hydrograph – 80% site coverage

6.3 RESIDENTIAL ZONED PROPERTY

6.3.1 THREE AUCKLAND CASE STUDIES – TP124 (ARC, 2000)

TP124 chapter 6 contains a case study of three Auckland subdivisions, each having a conventionally designed subdivision's peak flow post-development compared with a Low Impact Design option. Auckland Council provided this data for comparison with an attenuation system designed for each site. Hydrological data obtained from TP124 is input directly into attenuation system design. The predevelopment land-use was predominantly pasture and reserve with some areas of regenerating bush. Conventional subdivision design utilised current design practices within the Auckland Region. Low Impact Design implements techniques to reduce runoff volumes and peak discharges to reduce erosion and sedimentation occurring due to subdivision development (ARC, 2000).

The L.I.D. approach taken invariably reduces the size of the sections, often by 50%, developing smaller areas to maintain section numbers. This does not provide an accurate comparison between the techniques of L.I.D. practice, but rather reduces site runoff by developing less area. TP124 states the section sizes were often smaller than those generally developed and their sale-ability may be compromised.

Significantly, the TP124 subdivision designs alter the discharge outlets of the pre-developed site, in some cases removing the flow completely. This is not low impact or good design practice. All developments should maintain the predevelopment outfall location and not exceed their peak discharge flow.

6.3.2 ATTENUATION SYSTEM SUBDIVISION DESIGN

Currently, the purchase price of developed land has never been greater. This is the first ingredient in any homebuyers purchase. The RMA requires developers to have no effect on the environment while optimising the use of the land. L.I.D. should not be limiting the area of land used; it should promote a balanced living environment that maximises site numbers of usable area while providing recreational and green areas for an enhanced amenity. Time of concentration and hydrological data was input directly into the attenuation system software from TP124 (ARC, 2000).

The Peak Flow Attenuation System design combines stormwater management with functional section size of between 500m^2 and 600m^2. Five percent of the sites have a smaller size of 400m^2 to simulate some areas of high intensity residential development. Compared to a more traditional design of the same total footprint, this enables additional sites and improves financial feasibility. This improved profit funds construction of the Attenuation System generally rendering the process cost neutral and often returning a financial benefit. Cost of attenuation system construction is calculated from quotes provided 20/10/2013. No allowance has been made for inflationary cost to the comparative conventional or L.I.D. subdivisions figures from 2004. In today's terms, financial benefit described in this document would therefore be greater.

6.3.3 CASE STUDY ONE

The site area is 7.4 hectares having four outfalls discharging to a harbour environment. Conventional development proposes 100 Lots averaging 760m^2, while L.I.D. design proposes 104 Lots averaging 400m^2 - 500m^2. Attenuation system design proposes maintaining the site coverage of a conventional subdivision with an average area per site of 600m^2 enabling 125 Lots.

Figure 12: Case Study One - Conventional Design. (ARC, 2000)

Figure 13: Case Study One - L.I.D. Design. (ARC, 2000)

Figures 12 and 13 represent the conventional and L.I.D. subdivision designs. Attenuation Design is similar in layout to a conventional design but having sites averaging 600m^2. The site has four outlets, each having an attenuation system installed for each of 2,10 and 100 year ARI events. A net return on each additional section of $50,000 returns a financial benefit of $633,300 and a design storm peak runoff rate at pre-development levels.

6.3.4 CASE STUDY TWO

The site area is 27 hectares having four outfalls, discharging to a stream, which discharges to a harbour environment. Conventional development proposes 297 Lots averaging 600m^2, while L.I.D. design proposes 275 Lots averaging 511m^2. Attenuation system design proposes maintaining the site coverage of a conventional subdivision with an average area per site of 500m^2 enabling 356 Lots. The conventional and attenuated designed subdivisions provide significantly flatter Lots than the L.I.D. option.

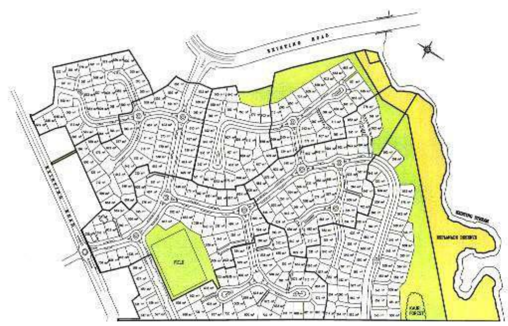


Figure 14: Case Study Two, Conventional Design. (ARC, 2000)

Figure 15: Case Study Two, L.I.D. Design. (ARC, 2000)

Figures 14 and 15 represent the conventional and L.I.D. subdivision designs. Attenuation Design is similar in layout to a conventional design but having sites averaging 500m^2. The site has four outlets, each having an attenuation system installed for each of 2,10 and 100 year ARI events. A net return on each additional section of \$50,000 returns a financial benefit of \$784,800 and a design storm peak runoff rate at pre-development levels.

6.3.5 CASE STUDY THREE

The site area is 14.2 hectares having five outfalls discharging to a harbour environment. Conventional development proposes 128 Lots averaging 766m^2, while L.I.D. design proposes 138 Lots averaging 651m^2. Attenuation system design proposes maintaining the site coverage of a conventional subdivision with an average area per site of 651m^2 enabling 150 Lots.

Figure 16: Case Study Three, Conventional Design. (ARC, 2000)

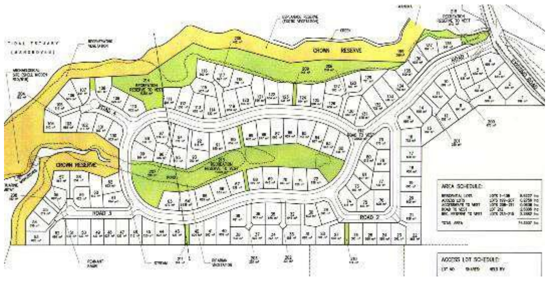


Figure 17: Case Study Three, L.I.D. Design. (ARC, 2000)

Figures 16 and 17 represent the conventional and L.I.D. subdivision designs. Design is similar in layout to a conventional design but having sites averaging 651m^2. The site has five outlets, each having an attenuation system installed for each of 2,10 and 100 year ARI events. A net return on each additional section of \$50,000 initially returned a financial deficit of \$384,600.

It was found TP124 case study three is not in keeping with L.I.D. or conventional design protocol. The predevelopment runoff discharged to five catchment outlets. This is the natural environment and should be maintained. Redirecting the flow, mostly into a single outlet, is unnatural and not RMA compliant. This large outlet therefore requires very large attenuation. A more natural approach is to maintain the five outlets requiring smaller attenuation chambers for each. This would generate a financial benefit of \$640,300 and a design storm peak runoff rate at pre-development levels.

6.4 SYSTEM PERFORMANCE FOR MORE FREQUENT STORM EVENTS.

A simulated site had 3.3-hectare area having a predevelopment runoff coefficient of 0.35. Post-development runoff coefficient is 0.45. The pre-development peak runoff rate was 0.116 m^3/sec. A two year ARI attenuation system, modeled for a 1.56-year ARI event produced a post-development peak flow rate of 0.118m^3/sec, demonstrating 98% efficiency. Modeling of a lesser event, likely to occur six times per year, demonstrated post development peak flow rate reduction to events likely to occur naturally several times per year.

7 ENERGY DISSIPATER CASE STUDY

A critical aspect of L.I.D. is an effective energy dissipater located at the pipe outlet. It consists of a prefabricated reinforced concrete unit and is fixed in position with concrete anchor blocks. The Wellington site discharges from a 315mm ID HDPE pipe on a twentyfour degree gradient. Rainfall data, supplied by Greater Wellington Regional Council, of three gauged sites confirm significant rainfall events post construction of the energy dissipater.

Creek condition immediately downstream from a one-year-old dissipater outlet demonstrates no change to its natural form. This environment is also in keeping with upper reaches of similar creeks in the area. Therefore, no effect on the environment was evident. A comparison of the area of flow at the pipe's outlet and the dissipater outlet indicates the reduction in flow velocity. The flow exiting the pipe is the same flow exiting the dissipater therefore:

$$Q = V \times A \rightarrow V1 \times A1 = V2 \times A2 \ (3)$$

Visual observation indicated a considerable reduction in velocity between the pipe and dissipater outlets confirmed by comparison of pipe and dissipater flow area. Refer table 4.

Pipe discharge (mm^2) A_1	Dissipater discharge (mm^2) A_2	% Reduction in velocity $1 - \left(\frac{A1}{A2}\right) \times 100$
518	900	42.4%
658	1500	56.1%

Table 4: Energy Dissipater Efficiency.

8 DISCUSSION

Watercourses are in a natural state of flux, altering their level as catchments contributing to their flow discharge water. As the stream level alters, the embodied energy fluctuates creating sediment and causing deposition. Erosion is more rapid at larger rates of flow. During the Manawatu floods of 2004, extreme river flows attributed to a one hundred and fifty year ARI causing massive erosion. (Fuller, 2005) The sediment load of a significant event greatly exceeds the contribution from hundreds of yearly events. Therefore, the greatest erosion causing flow is the watercourse peak flow, attributed to a given event.

The RMA requires development to have no detrimental effect of the environment. Urban development includes areas of impervious surface, which increase the peak runoff rate beyond those experienced in the natural predevelopment state. Without mitigation, this accelerated flow effectively alters the ARI of the watercourse causing larger flows to occur on a much more frequent basis. The erosion therefore matches this unnatural environment and becomes excessive. Therefore, it is necessary to limit a developments peak runoff rate to that of the predevelopment state. L.I.D. attempts to mitigate any effect that may occur from a developments stormwater runoff. Currently, L.I.D. has limited effect (ARC, 2000) and must be at least cost neutral (Eason et al., 2004).

A site's predevelopment runoff rate determines the naturally occurring urban development's runoff rate for any design storm event, usually occurring from a two, ten and one hundred year ARI. Recent research may indicate a necessity to limit the peak flow from lesser occurring ARI for watercourses sensitive to erosion activity. Attenuation system modeling of smaller than two year ARI events demonstrated the system continued to reduced the post-development peak flow to a lesser peak than those of a conventional subdivision and to predevelopment peak flows which are likely to occur naturally several times a year. It is therefore unlikely to cause erosion to a greater extent than is expected naturally. The attenuation system includes an energy dissipation unit, installed at outlets discharging to a watercourse. This unit reduces the velocity of the developed flow prior to watercourse entry. Observation and flow measurement of an existing one-year-old energy dissipater has demonstrated adequate velocity reduction resulting in minimal, if any, alteration to the watercourse's natural environment, effectively eliminating environmental impact. While this period of observation is short, several significant storm events occurred during this period.

The attenuation system enables any developed site's storm event peak flow rate to be no more than the pre-developed site, while significantly reducing the chamber size from traditional detention processes. Stormwater management infrastructure generally becomes a Local Government asset. An economical attenuation system and energy dissipater reduces the capital cost of the asset, thereby reducing long-term maintenance and replacement costs. Material selection for the system has a small footprint and provides long life with minimal ongoing maintenance when compared to other forms of L.I.D., such as swales, green roofs and ponds while chamber structure permits the attenuation system to be installed in virtually any location; under vehicle load or below the building when adequate access is provided. Sites having minimal falls for a gravity-operated system can have an attenuation chamber emptied by a pump gauged to a predetermined discharge rate.

8.1 COMMERCIAL AND INDUSTRIAL DEVELOPMENTS

A developed site's impervious cover has the greatest effect on the peak runoff. Therefore, commercial and industrial sites will have the greatest effect on the environment as the impervious cover often exceeds eighty percent, and is often one hundred percent. Modeling of a one-hectare site was conducted, having impervious cover of eighty percent and one hundred percent, each designed for a Wellington City Council development requirement of a ten year ARI, having ten minute duration.

Attenuation chamber lengths of 21.2m and 28.4m respectively, effectively managed the peak flow runoff to those expected from a grassed paddock with costs of \$41,700 and \$50,800 respectively. This cost is commercially viable when compared to the Firth permeable paver case study in Auckland. Specification of 300m^2 of Firth permeable pavers, costing \$30,000, enable an increase in building footprint of 30m^2; a cost of \$1,000/m^2 (Crossland, 2012).

8.2 RESIDENTIAL DEVELOPMENTS

It must be noted, the conventional and L.I.D. stormwater drainage design for the case studies does not follow good design practice. No design maintained its outlet's predevelopment sub-catchments. Therefore, none of these designs was able to maintain the predevelopment peak flow. Some outlets were eliminated, while others catchments were combined and discharged to a single outfall, totally altering the microenvironment at these locations. TP124 discussion and conclusions are based on the performance of the combined discharge of each subdivision. To enable a comparison between attenuation system design and traditional methods this report adopts the same hydrological data and outlet configuration as TP124.

Comparison of L.I.D. and conventional subdivision performance is made with the predevelopment peak runoff rate as the benchmark. Attenuation subdivision design has 0% increase in predevelopment peak flow rates. In contrast, the L.I.D. solution has an average increase of 48.5% while the conventional subdivision designs have an average increase of 59.8%. All attenuation system designs achieved a one-hundred percent reduction from conventionally developed peak runoff to predevelopment peak runoff. Maintaining the natural outlet configuration and their designated sub-catchments further enhances the environmental benefits of this system. Attenuation system design achieved significant financial benefits when compared to traditional design.

An attenuation system can be implemented in any location and be of significant ecological benefit, reducing peak flows to those of the pre-developed site. An attenuation system specifically tailored for multiple ARI events, maximising land use while accommodating both green space and recreation areas, and producing pre-developed peak flow rates occurred in all case studies.

8.3 ENERGY DISSIPATION

The attenuation system includes an energy dissipation unit, installed at outlets discharging to a watercourse. This effectively reduces the velocity of the flow exiting the piped network. Without its inclusion, this rapid flow joins the slower flow of the watercourse, combining and increasing the watercourse velocity having wide spread detrimental effects, increasing erosion and deposition throughout the channel.

Measurements of a one-year-old dissipater confirmed energy dissipation of between 42% and 56%. Visual observation confirmed significant velocity reduction between the outflow from the pipe and the dissipater. The watercourse beyond the dissipater appears in a natural state when compared to other natural upper reach watercourses. This confirms significant velocity and energy reduction for more significant flow rates occurring during the past twelve months. The observation period included several significant rainfall events having greater intensity than a five-year ARI occurring within the district.

9 CONCLUSION

The Resource Management Act requires development to have no detrimental effect of the environment, requiring preservation of a watercourses natural character and having no adverse effect on the environment as society discharges water to water. Historically, this is very difficult due to the nature of the task and the potential cost of compliance.

The greatest erosion causing flow for any event is the watercourse peak flow rate attributed to that event. The increased runoff from developed impervious surfaces rapidly increases a watercourses peak discharge, accelerating erosion and deposition.

For three case studies, an average 11.3% reduction in peak discharge rate was achieved when comparing L.I.D. subdivisions with conventional subdivisions. Extreme care must be taken when implementing L.I.D. infiltration systems. For the same sites, a patented attenuation system design achieved 100% reduction in excessive peak rate of runoff caused by impervious surfaces. The attenuation system proved smaller and more cost efficient than other forms of stormwater detention.

Most significantly, attenuation system design maximises the potential of any urban development and maintains the ethos of the RMA. Use of an attenuation system can optimise a subdivision design, enabling; green space, recreational areas and a greater number of sections with minimal, if any, environmental affect to existing watercourses and provides significant financial benefit.

The attenuation system can be designed for any specific ARI storm event. Applying smaller than two-year ARI events to a two-year ARI attenuation unit demonstrated the system continued to reduce the post-development peak flow rate. These low intensity post development peak flow rates were attenuated to levels that are likely to occur naturally several times a year. Therefore, it is unlikely to cause erosion to a greater extent than is expected naturally.

The energy dissipater is designed to reduce discharge velocities that would otherwise affect watercourse erosion activity and subsequently its ecology. Effective, efficient energy reduction has been achieved with the energy dissipation unit.

Most significantly, attenuation systems and energy dissipation units can be installed to existing piped networks to mitigate existing stormwater flow issues. The attenuation systems cost benefit, low maintenance, small footprint and environmental performance is likely to appeal to the wider engineering community

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