LID PRINCIPLES IN INTEGRATED STORMWATER DESIGN

J. Jefferys, D. Fortune,

XP Solutions, 8 – 10 Purdue St, Belconnen, ACT 2617, Australia.

ABSTRACT (200 WORDS MAXIMUM)

We know how to design traditional pipe drainage as the core of stormwater management, to protect our urban areas from flooding. Now the LID (Low Impact Design) movement gives us instruction on how to manage stormwater in a sustainable way to protect water quality. In recent years, these two approaches have been brought together through legislation and industry practice. Yet they remain strangely incompatible in practice. It could even be said that together they result in poor stormwater management, or at the very least, that opportunities for good stormwater management are lost. However, this does not have to be the case.

This presentation highlights the apparent areas of incompatibility between traditional drainage design and LID. It goes on to show that, drawing on experience from around the world and with some innovation in the way we design drainage and with the support of emerging technology, we can get the best of both worlds, maintaining the focus on good stormwater management while putting into practice the sustainable approach of LID. As a result, we should be able to mitigate urban flooding and reduce degradation of water quality in a way that is affordable now and in the future.

KEYWORDS

LID, stormwater, stormwater management, drainage design, sustainable, water quality.

PRESENTER PROFILE

Jessica Jefferys is Product Manager at XP Solutions. Jessica provides technical expertise supporting the development of best practice in flood modelling and drainage design. She ensures the company’s software is compliant with the latest legislation and regulations. Jessica also has experience representing XP Solutions on educational and industry research committees.

David Fortune is Director of Product Innovation at XP Solutions. He has over 30 years’ experience of producing software systems for engineers and scientists. He has worked in drainage design and modelling and flood defence around the world, including Australia, USA, UK, China, Japan and India.

1 INTRODUCTION

This paper takes a brief look at the principles of LID and highlights differences with traditional pipe and tank drainage. LID changes the way urban planning works. It also should change the way we design drainage for a subdivision. But these changes have led to some significant problems. We take a look at some of the issues that arise with LID when no account is taken of the different approach that should be taken in design.

We highlight the limitations of existing design tools.

Can these issues be resolved? The paper reviews LID experience in Australia, UK and USA to see if the answers lie there. There are some lessons that can be found – but not all the answers we want.

Looking to the future, we conclude that we do need to be practicing integrated drainage design, bringing together the best practice of traditional drainage design with the benefits that LID can give. And we believe that a new generation of design tools is needed to allow analysis of integrated drainage designs for short-term flow, long-term flow, surface flows and pollutant removal.

2 DISCUSSION

2.1 LID PRINCIPLES FOR STORMWATER MANAGEMENT

While Low Impact Development (LID) can affect both wastewater management and water supply, we are only considering its impact on stormwater management here. Let's just review the workflow that results in a completed drainage design. We will take a subdivision that is to be newly built: let's say it is mainly housing in the suburbs. A developer has bought the land and employed a consulting engineer to design the site, before building the roads and the utilities, after which the developer will sell-on plots for houses to be built.

Around the world, there are variations on this pattern – sometimes the city will build the roads and utilities, sometimes the developer will build only the roads and utilities before selling on the plots, sometimes the developer will build it all. But whichever pattern is followed, drainage needs to be designed and built and, increasingly, some aspects of LID will need to be applied to the site, even if it is not called LID in other countries.

We should have some idea of the ideal workflow for drainage design. This is how we would like it to happen, to incorporate both LID and good principles of traditional drainage design. But before the design can even be started, the site will have been subject to some sort of local planning application, and the resulting planning approval will specify flow, flow rate and pollutant management that the drainage system must provide.

In the past (before 1980), the general aim for management of stormwater on a newly developed subdivision was to use channels or pipes to shift the water off the site and into the nearest watercourse as quickly as possible. Combined with the increased impervious areas of new developments, this tended to increase the rate of downstream flooding. During the 1980s, retention structures started to be built in the watercourses to slow up the rate of stormflow and reduce the chance of downstream flooding. In the 1990s, detention basins were generally located at the outfall from the subdivision. Up to this time there was very little concern for what happened to the pollutants picked up by stormwater washing off a subdivision.

From around 10 years ago, LID principles have led to attempts to more closely mimic the natural hydrology of each subdivision and, of course, reduce the impact of development on the natural environment. One of the important changes for drainage design is that detention should be distributed across the subdivision using rainwater tanks, swales and local ponds – control at source. But perhaps the larger challenge that LID brings is that subdivisions or larger areas should no longer export stormwater-bourne pollutants. So control at source now also means pollution removal at source.

If the guiding principle of LID is that a newly developed site should have as little impact on the natural state of a site, perhaps we had better know how well each natural site behaves. We want to know how much water evaporates from the site, how much infiltrates into the ground, under a variety of rainfall conditions and groundwater conditions. This is easier said than done. For larger areas, the various hydrological models available give a reasonable approximation to the profile of runoff for various rainfall profiles, taking some account of infiltration and evaporation. For smaller sites, the approximations become less informative but can still be useful. That leaves the question of the natural surface water flows for the subdivision.

Perhaps we can reduce the problem to some simple questions: under a variety of rainfall conditions, where would the natural stormwater flows go and, more importantly perhaps, where would they pond? Under true LID principles for stormwater design, we would analyse the natural flows on a new site, not just before designing the drainage, but also before locating the buildings and roads. We would analyse the flows again with the new-build design in place, and compare the flows before and after.

We should consider a similar pre and post development comparison for pollutants. To a large extent, LID for drainage has become synonymous with pollution control. We really need to estimate how much pollution any new urban development is likely to introduce to stormwater runoff. Then when we design treatment measures, we need to estimate how much pollution is likely to be removed. And of course, pollutants can be floating, attached to sediment or dissolved. This sort of analysis is possible for planning for large areas over long time periods. It is not so easy for drainage design for a subdivision, particularly when considering pollutant removal performance during single storms.

LID sets some pretty tough targets for stormwater system planners and designers. Besides the desire to control flows and pollution according to natural patterns, there are other desirable characteristics. One is that stormwater management should increase quality of life: stormwater should have amenity value. It ought to be attractive – and fun! So we are starting to see stormwater as a valuable asset, and beginning to put this message across to the public. Ideally, we would have an idea of the increase to quality of life brought by a good drainage design – and the extent to which this increases the monetary value of a subdivision.

Of course, stormwater has always had a value as a water resource, but we are only now making use of it locally, with rainwater tanks and local community use for watering. Increasingly we are also identifying the problem of urban overheating. Stormwater can also come to the rescue through the urban cooling effect of green-roofs, green walls and other green places. The value of LID here is to the city as a whole, it is difficult to attribute the value to a single site or building. So again, this sort of analysis is easier as part of urban planning than individual subdivision design.

2.2 LID PLANNING

When it comes to larger urban areas, some planners are better equipped to understand the impact of LID on stormwater management than others. There has been a succession of planning tools, largely used in Australia, in particular XPRAFTS, AQUALM and, more recently, MUSIC. These tools have allowed the planners to understand what changes in policy might mean for water management. xpRAFTS and AQUALM are focussed on water flow management, whereas MUSIC is focussed on pollution removal. Water quality analysis for planning has evolved to consider long time periods of tens of years, or even one hundred years or more.

The impact of progressive use of stormwater harvesting for support of water resources can be assessed. But planners have very little support if they want to look at the impact of policy decisions on public amenity or other measures of quality of life. And, as yet, it is difficult to assess reduction in urban heat island effect given by different types of green infrastructure.

2.3 LID DESIGN ISSUES

While planning is reasonably well catered for, there is more of a problem with designing drainage for a subdivision using LID principles. One of the issues is that there is more choice with LID: there are a large number of potential sustainable drainage systems that could be used, each with different benefits and drawbacks. And under the principles of LID, we want to use a variety of these drainage systems, distributed across the subdivision at the most suitable locations. Clearly, landscape architects and designers need the support of software tools.

And some tools do exist: DRAINS has a good record for 1D pipe and pit drainage design. In Australia, Aqualm and MUSIC have been widely used to size and verify sustainable drainage systems such as wetlands and bioretention (over long time periods for water quality). There is plenty of choice when it comes to full hydraulic models, such as XPSWMM, MIKE by DHI combining 1D and 2D flow analysis.

However, none of the existing tools allows a single model to be analysed in all the ways we would wish under traditional drainage design good practice and under LID. The main issue is that traditional drainage and LID are nearly always two different designs. OK, designers try to pull these two aspects together. But very often it will be a different person or team doing the LID aspects. This is far from ideal and leads to unfortunate compromises – either in the traditional drainage or, more likely, in the LID aspects. And if a designer were to want to consider the surface water flows (either before or after construction), then a third model, and a third tool (a 2D hydraulic model) will be used. Instead, all too often, this aspect of design is ignored.

These tools don't exchange data readily – a model created in one system cannot be used in another (at least, not without considerable extra effort) – they don't talk to each other. Perhaps that would matter less if design was a simple process requiring a single pass through. But it is rarely this simple. A design can take a matter of days to be finished and done with, but more likely it takes weeks or sometimes even years. This is because outside influences keep changing – roads layouts are moved, buildings are resized and redesigned, councils demand changes. Each time, the drainage system design has to be changed also. And if flow, surface flow and water quality are all affected, then that is three different models to be updated by three different teams.

We are left with a disjointed approach to drainage design. Maybe we have been somewhat complacent in our understanding that we are fairly well equipped to introduce LID into drainage design. Yet clearly we have made progress with LID, so how can this be? Perhaps because, in the majority of cases, we have dumbed-down our LID drainage designs to a point where we can make use ofthe procedures and tools we have available. Design is competitive, commercial work. The quicker an acceptable design can be completed, the better. There is rarely time to use a fancy modelling package. If the readily available tools and procedures don't allow creative LID designs, then the ambitions of LID will not be realized.

Traditional drainage is typically used throughout a site to carry stormwater runoff to a suitable storage location or discharge point. Unimaginative LID can lead to much larger land-grab than traditional drainage and therefore can be opposed by developers who don't adopt a multi-benefits approach to drainage design. One result of this is where LID devices end up in the wrong place on site and can lead to dull, end-of-treatment designs.

Bioretention areas and raingardens are popular for addressing issues of water quality. However, they can be prone to washout during flood because of their location – at the lowest point downhill. Whilst many local authorities are recognising the benefits of rainwater and stormwater harvesting systems they are not yet fully integrated with design. Agreeing on the quantity savings and dealing with the water quality can still be a challenge. Particularly in the driest areas, competition can occur between green roofs, raingardens and harvesting schemes for stormwater. Identifying the greatest need is important.

Historically, pipes and tanks have been designed in a separate model to LID elements. Integrating the more complicated flows through LID devices cannot necessarily be done in a simple 1D channel/pipe flow model. Standard practice drainage design includes little or no analysis of surface water flows before or after development. By bringing water to the surface in LID designs, this limitation becomes critical.

So we don't carry out any analysis of surface water flows either pre or post development under heavy rainfall. We design 1D pipes, tanks and road channels with little or no thought to the natural drainage of the site. And, perhaps worst of all, LID has come to mean an unattractive bioretention pond stuck out of sight downhill of the subdivision. And pond is often the right word – too often a traditional pond design is filled in with soil and a few unsuitable plants and expected to work. Come the first heavy rain the bioretention is washed out – but it is not much missed as it added little of attraction or quality of life to the subdivision. There is evidence that some bioretention systems have been wiped out in flooding, and that some designed without sufficient inlet protection have been scoured out during the first heavy storm.

Of course, there are some wonderful examples of LID in action too. There are prize-winning drainage designs that are, quite rightly, applauded by us all at conferences such as Water NZ Stormwater 2013. We go and see them, we take photographs, we tell people in other countries about them. But for ordinary stormwater management across the country, we generally accept designs that don't really meet the aspirations of LID. And we want that to change.

2.4 DO OTHER COUNTRIES HOLD THE ANSWERS?

Because of WSUD (Water Sensitive Urban Design), engineers around the world often look to Australia for guidance on sustainable approaches to drainage. However, other countries also have valuable experience in the introduction of green infrastructure. Germany, for example, probably leads the way in use of green roofs. There are limits to the extent to which experience in one country can be used in another, with perhaps the largest factor being climate or weather patterns. But when you consider that the Christchurch climate is closer to the climate in London than that in Wellington, there is clearly some benefit in exchange of experience.

The UK has produced some excellent guides to implementing sustainable drainage (or SuDS) as has Australia with the overlapping principles of WSUD. One outstanding example would be the city of Cambridge. Its guide recommends that you should always take a good look at the site and understand the natural flows and infiltration – then take account of those in the drainage design. In Australia, Healthy Waterways, Water by Design lead the way.

The UK in general has taken a rigorous approach to flow management in drainage system design. Indeed, the tool used by most design engineers, WinDes, includes a module to analyse ponding and surface water flows, or integrated 1D/2D flows. However, the UK is some way behind both New Zealand and Australia when it comes to planning and design with respect to pollutant management and rainwater harvesting

Where the UK does have a lead is in consideration of the value of infiltration to recharge groundwater, indeed, ground infiltration has almost become synonymous with SuDS. Opinion is polarized: some argue that most UK cities have very little prospect for allowing substantial infiltration of stormwater into the ground, with clay soils often cited as being the main problem. Others would argue that the opportunities are there, but we don't take advantage of them. In any case, developers practising the good principles of drainage design always dig a number of test pits across a new site to test for rate of infiltration, before deciding on the location of infiltration systems.

One thing for sure is that most UK cities and towns do have a lot of green spaces: public parks, private gardens and small municipal spaces such as the centres of roundabouts. Many of these green spaces are graded or sloped so they drain off into the roadway and so into public drainage. And in many cases the green spaces then need to be artificially watered. The UK has been very slow to reverse this trend.

Building development has been slow, and legislative drivers for SuDS have been even slower in recent years in the UK, so design engineers have had little practice at the new approaches to drainage. In fact, developers and local councils are still waiting for new government legislation that will either encourage sustainable drainage approaches, or will bring them to a halt for a number of years. In summary, progress with sustainable drainage in the UK is better in theory than in practice.

Legislation is not such an issue in the USA. Individual cities have had a reasonable degree of autonomy and have been free to take their own approaches to drainage. Traditional piped drainage has been designed along conservative, some would say over-sized, guidelines for many years. The key aspect has been curb inlet sizing and spacing – and the HEC22 inlet sizing guide has been welcomed around the world. But on, the whole, stormwater quality management and water resource management have had little impact, until recently.

Some cities, for example Portland, embraced LID some years ago. Their success has been hugely encouraging around the world. Other cities are following, but in different ways to take account of their climate and urban density. San Francisco, for example, is experimenting with a range of greenstreet initiatives, where permeable paving and plants are introduced in residential and commercial streets. The enthusiasm for these new forms of sustainable drainage is encouraging, but there are a number of long-established trees growing in the streets of San Francisco that are being ignored. They could have stormwater redirected to their roots as a contribution towards evapotranspiration at little cost.

In both the USA and the UK, developers have got very keen on using permeable paving with an underlying tank supported by "egg-crate" structures. Where these tanks are designed to infiltrate stormwater into the ground, it is easy to see that permeable paving can be a pragmatic approach to sustainable drainage. However, without infiltration, is permeable paving really any better than cheaper, impermeable paving feeding traditional tanks? This debate is just warming up.

One interesting trend is that LID drainage design is no longer restricted to engineers. We see landscape architects, in particular, taking a lead with defining sustainable drainage schemes.

In the USA, there has been a wealth of practical research into the effectiveness of individual types of LID. There are also pockets of long-term experience in implementing a variety of types of LID systems. And the take-up of LID is expanding rapidly, including West Coast, East Coast down to Carolina, and now even Kansas City.

Perhaps all that is missing is the development of design tools that allows LID and traditional drainage to be combined effectively. Individual LID can be sized using state and city specifications. But there is no accepted way of analysing the effectiveness of LID under different flow conditions across a subdivision. Standard hydraulic modelling systems only do part of the job and they are generally too complex for design engineers to use. So combinations of LID are put together as a matter of faith or trial and error. This is not ideal, but at least reasonably complex mixes of LID are being built.

2.5 THE FUTURE – INTEGRATED DESIGN

Drainage design can be a fragmented process, with pits and pipes sized using traditional methods, then bioretention or other LID elements added later, and surface water flows ignored completely, resulting in the issues listed above. But we should now take an integrated approach to design, assessing the impact of a mix of traditional drainage and LID elements on the flow and water quality coming off a site and on the surface water flows onsite. We should allow a wider mix of LID systems, and allow them to be distributed across the subdivision to take account of the natural lie of the land, and perhaps even "waste" less of the valuable development land.

The answer is surely to apply different analyses to the same drainage design. This does not necessarily mean a single set of tools that spans all desired aspects of drainage planning and design. That would be fine thing – except that no such set of tools exists yet in New Zealand, or elsewhere in the world. While the software developers are busy working on these tools, perhaps more progress can be made by better integration between existing tools.

So let's be clear what we want. We can use 2D flow analysis to indicate the natural flows on site, as guidance for best location of LID and traditional drainage. The resulting designs should show a variety of LID elements located throughout the site, hopefully in locations that make them attractive and robust yet minimizing land-grab. They should appeal to both the developers (increased value of the site) and the occupiers (increased quality of life). We should take advantage of infiltration opportunities across the site wherever possible, to recharge groundwater.

Options for green roofs, rain gardens and rainwater harvesting should be incorporated in the drainage designs, to assess the trade-offs. And we can simulate the flow of extreme rainfall through the resulting integrated design, checking in particular with 2D analysis where the out-of-roadway flows will go.

3 CONCLUSIONS

Practical expertise in building and maintaining LID is growing around the world. However, the limitations of the tools we use have to some extent reduced our ability to design LID across subdivisions with the same rigour with which we would design traditional drainage, and subsequently we have not yet met our ambitions for the implementation of LID.

We want to optimize combinations of pipes, tanks and LID devices to provide an integrated design that meets targets for both flow control and pollution control. We want to take a sustainable approach to drainage while maintaining focus on traditional standards and good stormwater management. And we need to do all this in a cost-effective way because drainage design is generally commercially competitive.

There are lessons that we can learn from other countries that, through WSUD and SuDS, have focused on aspects of LID that have been less well implemented in New Zealand.

Integrated design is an innovative approach, and does demand the support of advanced software technology to allow models to be built that combine LID with pipes and tanks, and allow those models to be analysed for impact on flow and pollutants over both short and long periods. Some, but not all, of that technology is in place. Some of the necessary software tools exist – but certainly not all of them. And those that do exist are not integrated. LID design is not as yet both effective and efficient.

As tools are improved and integrated, design teams should be able to develop a single design, but analyse it in the necessary different ways. This will improve the quality of drainage designs – they will become more exciting (to a LID enthusiast). Collaboration should be more effective with landscape architects able to share design tools with engineers (for example): less design mistakes will be made and the workflow should be more efficient.

We have some great examples of LID, but we have more work to do before the full LID principles are implemented as a matter of course in drainage design. We are still on the way!