PLANNING FOR EXCEEDANCE IN AN UNCERTAIN CLIMATE

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ABSTRACT

With assets in poor condition and the uncertain effects of climate change, New Zealand is facing an impending need for investing further and wider to deliver effective flood infrastructure. Yet today's method of adopting a fixed line flood map, coupled with a precautionary approach to stormwater infrastructure, can lead to significant over investment up front and across the life of the assets. This paper discusses planning for exceedance as an approach to flood risk management, against the backdrop of a fiscally-constrained economy and pressure on land use in flood risk areas.

Land is effectively classified in one of two ways - 'no flooding' or 'flooding' - and it usually adopts a precautionary approach representing the worst case situation. But in reality the flooding that actually occurs rarely matches what is shown on maps, nor provides planners with an understanding of how the flood map can vary.

As pressure on land availability increases, it is becoming increasingly important for planners to understand the 'grey zone' between the best and worst case flooding scenario when making land use and infrastructure decisions. In this paper we review methods for identifying exceedance areas and introduce the concept of probabilistic mapping - an alternative approach to floodplain mapping that can help planners understand uncertainty and probability.

The predicted high cost of future infrastructure investment as a result of climate change means protecting overland flowpaths is becoming an increasingly important feature of delivering effective flood management practices. Councils can apply policy to restrict new development in floodplains or on overland flowpaths, however managing exceedance of the stormwater system in existing urban areas represents a more significant challenge both in practicality and funding. This paper discusses approaches to designing for the exceedance of existing stormwater infrastructure. With the objective of mitigating potentially high costs, key success factors and design approaches are identified that recognise the uncertainty in magnitude, the necessary resilience and adaptability in design, and importance of community awareness.

KEYWORDS

Flood Resilience, Extreme Events, Climate Change, Risk Management, Infrastructure.

PRESENTER PROFILE

James is an experienced engineer and project manager having worked for over 15 years on a variety of flood risk management projects in both New Zealand and the United Kingdom. He has provided advice on strategic planning and policy making through to hydraulic modelling and catchment management and on stormwater detailed design and construction supervision.

INTRODUCTION

Stormwater infrastructure is constructed to control the risk of flooding, however for nearly as long as it has been constructed its capacity has been exceeded. Exceedance is generally a result of:

- Failure of stormwater infrastructure (e.g. blockage, collapse or breach); or
- Overtopping/surcharging due to a storm event that exceeds the capacity of the system.

The National Infrastructure Plan (New Zealand Government, 2015) identifies:

- *Infrastructure is aging and needs to be renewed;*
- *Infrastructure needs to support higher levels of productivity;*
- *Our growing economy will create infrastructure pinch points;*
- *Our climate is changing, and our natural resources are under pressure.*

In the UK, climate change is predicted to result in at least a six fold increase in damage from urban flooding by 2080 and the view of the Ofwat (the regulator) is increasing the traditional stormwater system capacity is unaffordable (Digman, 2012).

Infrastructure is usually constructed to provide an optimised level of service based on the frequency of use, cost to construct (or replace), and consequences of exceedance. Nonetheless, understanding and planning for exceedance is a relatively new phenomenon internationally, driven by a combination of factors, such as:

- Increased consequences when exceedance occurs, i.e. more people or property in areas at risk of flooding;
- Increased awareness of the potential effects of climate change (increased probability of flooding);
- Limited funding to keep investing in infrastructure as a result of climate change;
- Minimising economic losses (including insurance);
- Availability of more sophisticated tools for analyzing the consequences of exceedance (e.g. complex 1D-2D hydraulic modelling); and
- Community expectation regarding the level of service provided by a system.

While the potential effects of climate change on our existing stormwater infrastructure may be agreed authorities face two significant challenges in planning for exceedance, which are the focus of this paper:

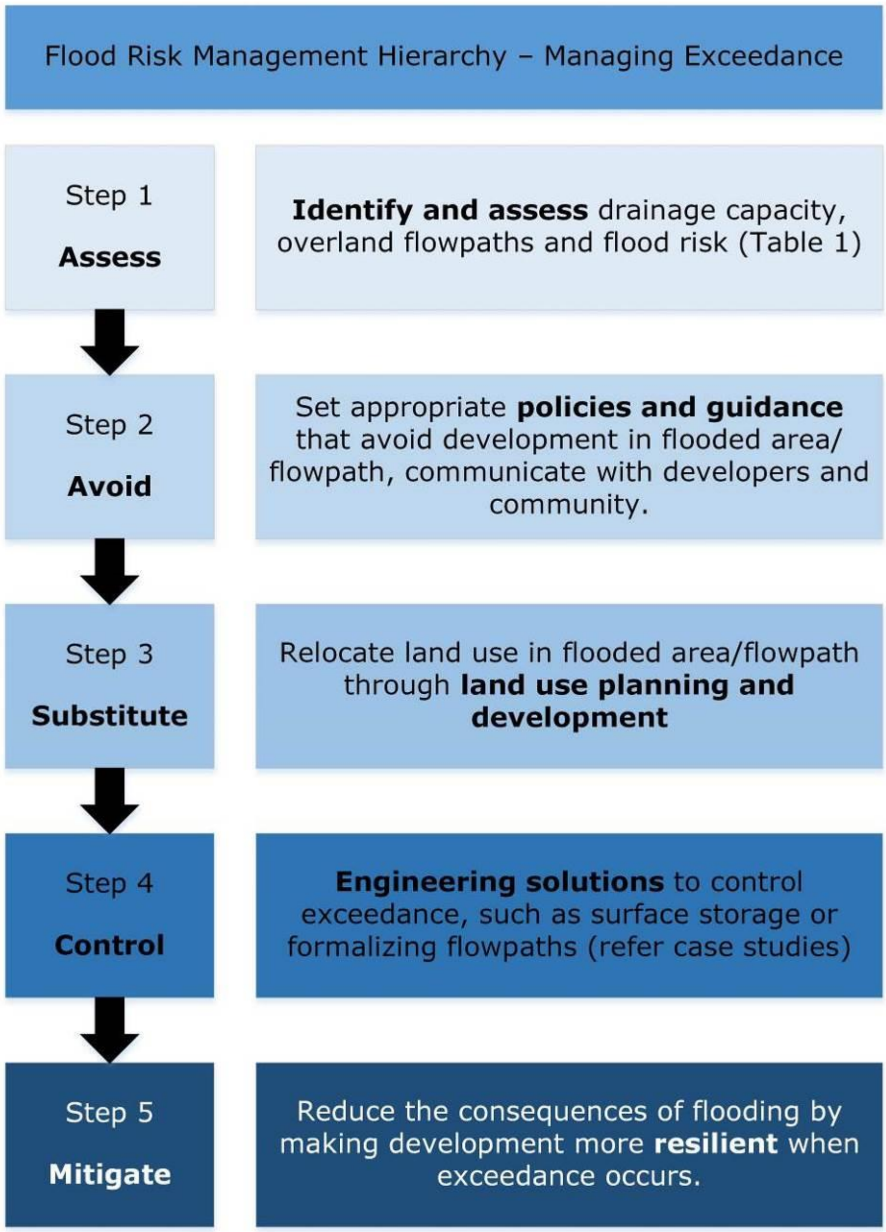
- Reliably identifying where and when exceedance will occur when faced with the significant uncertainties within a stormwater system – and then applying that information; and
- Delivering cost effective solutions in constrained urban environments.

PLANNING FOR EXCEEDANCE - PRINCIPLES

Planning for exceedance in new development is now enshrined in some planning policy internationally (e.g. UK National Policy Framework) and locally (e.g. Proposed Auckland Unitary Plan). However planning for exceedance in new development is a relatively new phenomenon, and despite it being a requirement of the Building Code, local policies are far more variable and are not applied or enforced thoroughly. This is partly down to a lack of suitable and reliable information for both planners and developers to make decisions – emphasising the importance of developing a suitable approach for identifying exceedance areas, as discussed later in this paper.

An approach to systematically plan for exceedance can be achieved through applying the Flood Risk Management Hierarchy (DCLG, 2009), as described in Figure 1. Regardless of whether it is applied at a regional scale by land use planners, or for a single-site new development, all steps are critical and must be applied in turn. Priority is obviously given to avoiding exceedance areas (Step 2 in the Flood Risk Management Hierarchy), over the subsequent steps. In almost all cases avoidance can be considered the most effective solution (DCLG, 2009).

Figure 1 – Using the Flood Risk Management Hierarchy to Manage Exceedance



Failure to adequately undertake Steps 1 and 2 will lead to significantly greater costs later to control or mitigate flooding when exceedance occurs. This paper identifies case studies where exceedance in existing urban areas is controlled. Although these projects are successful in their own right, the financial cost as well as the social cost on the community could have been avoided if appropriate, informed development control had been applied at the time.

Digman et al (2014) note some of the key factors in managing exceedance include:

1. Reducing runoff 'at source';
2. Using appropriate tools to design for exceedance (e.g. topographic survey, modelling at the appropriate scale);
3. Engaging and working with the public to explain exceedance will happen, e.g. through mapping;
4. Creating multi-functional infrastructure or shared spaces – such as parkland or road corridors;
5. Appropriate planning and policy guidance for new development/regeneration;
6. Collaboration within and between organisations;
7. Involving more disciplines than just drainage engineers;
8. Maximising funding opportunities;
9. Advertise successes and share knowledge to build momentum and understanding of what can be achieved; and
10. Maintaining and renewing existing assets is still critical.

All of these factors can lead to successes if managed appropriately, or can be roadblocks if not addressed. These success factors overlap with implementing a water sensitive design approach as well as when retrofitting measures in the existing urban environment (as demonstrated by the case studies later in this paper).

Items 1-5 in the list should be incorporated into planning policy and associated guidance so that exceedance is avoided – both on greenfield sites and as part of regeneration/redevelopment. In regeneration authorities have the most significant opportunity to plan for exceedance. This requires applying the flood risk management hierarchy to reduce existing issues both on and off site, however requires potential exceedance issues to have been identified.

IDENTIFYING WHERE AND WHEN EXCEEDANCE WILL OCCUR

The probability and consequences of exceedance are rarely as well understood as we think due to the inherent uncertainties associated with climate change predictions, as well as uncertainties associated with the operation of the system (e.g. blockage, silting), asset data, rainfall records and hydrological behaviour, gauging information for calibration, amongst others. Even where we have detailed hydraulic models available we can be lulled into a false sense of security that tells us there is sufficient capacity; or we may be over-investing in upgrades to the stormwater network due to an overly precautionary model. Given how difficult it is to calibrate extreme storm events within stormwater systems (due to a lack of gauging), often insufficient weight is given to understanding uncertainty.

Recognising that exceedance will occur, authorities responsible for managing stormwater infrastructure have the following options:

1. React to exceedance as and when it occurs and identify solutions on an as-needed basis;

2. Identify areas where exceedance will occur and proactively avoid or deliver solutions prior to flooding occurring.

Based on community expectations, where funding allows most authorities would likely seek to proactively manage exceedance prior to flooding occurring.

Potential options for identifying where and when exceedance will occur include:

1. A pragmatic, experience-based approach using historic flooding information, knowledge of a stormwater system and engineering judgement;

2. GIS-based analysis – using LiDAR data (or similar) to identify the location of overland flowpaths and ponding areas, such as that completed by Auckland Council (Irvine and Brown, 2013);

3. Deterministic hydraulic modelling – this is the usual hydraulic modelling approach adopted in New Zealand, running a defined large storm event (e.g. 1 in 100 year ARI) to identify areas of 'no flooding' and 'flooding', usually incorporating 'average', or sometimes precautionary parameters. Significant variations in levels of detail are available within this approach; and

4. Probabilistic hydraulic modelling –varying key input values within a feasible range to run a large series of model runs and produce a map of spatially varying flood probability.

Probabilistic hydraulic modelling is rarely undertaken in New Zealand and is therefore briefly introduced here, however it is increasingly being adopted internationally. Probabilistic modelling offers authorities an additional tool to improve their understanding of flood behaviour, particularly the uncertainty associated with flooding and overland flow. This can be critical when making land use planning decisions and also investing in infrastructure.

Probabilistic modelling includes identifying the probability density function (PDF) or a Monte Carlo framework for variables within a hydraulic or hydrologic model for a particular return period event (e.g. key parameters such as rainfall, losses, duration, roughness values, etc). A number of simulations are then run by sampling a range of parameters, until the PDF or Monte Carlo framework is appropriately represented. A floodplain probability can then be determined by counting the number of times a particular location is flooded. The more simulations run, the greater the certainty.

Historically this approach has not been applied as manually adjusting these input parameters and running model simulations was extremely time consuming (Smemoe, C et al, 2007). Similarly, this approach can involve a very large amount of processing time and power if applied directly to a complex deterministic model. However an understanding of flood variability can be assessed from running only a few scenarios (similar to sensitivity testing of deterministic hydraulic modelling), or alternatively creating a simpler probabilistic model of the stormwater system and running a large number of variables.

The following examples demonstrate how uncertainty can affect land use planning and infrastructure decisions, and how probabilistic modelling may assist in informing decisions:

1. An authority may be planning to construct a new hospital. A location is identified outside of the 100 year ARI floodplain (as identified in a deterministic model). However a probabilistic model is run with key parameters varied and shows that there is still a 30% chance of the hospital site being located within the 100 year ARI floodplain. Given the critical nature of this infrastructure, the authority may choose another site with a lower chance of being located within the floodplain.

2. A deterministic model may demonstrate a critical road culvert overtops in a 100 year ARI event, however a probabilistic model that is run with variations of rainfall, losses, runoff coefficients demonstrates there is a 50% chance it will overtop in a 10 year event and 90% chance it will overtop in a 100 year ARI event. The culvert therefore may become a priority for action.

3. Another deterministic model may demonstrate a stormwater pipeline surcharges in a 10 year ARI storm event, however a probabilistic model may demonstrate there is only a 30% chance of surcharging in a 10 year ARI event. The authority may therefore put off upgrading the network or managing exceedance as a lower priority for investment.

Table 1 below summaries the benefits and limitations of the four identified approaches for identifying where and when exceedance may occur. All four approaches have benefits and limitations. Probabilistic modelling is another approach available, not without limitations, however when appropriately applied can be used to increase confidence in critical infrastructure and land use planning decisions.

Table 1: Review of methods to assess stormwater exceedance

Method	**Scale**	**Benefits**	**Limitations**	**Application**
Experience-based approach	Site specific	Low cost. The location has flooded before, so is likely to flood again – validates the business case for investment.	Does not provide defendable information that can be used by land use planners to control development in exceedance areas. May not identify the full extent of the problem. No knowledge of frequency or magnitude. Flood mitigation methods may not solve the problem.	Not suitable for informing land use planning. Could be suitable for developing options for simple systems with easily identified issues and low cost solutions.
GIS-based approach	Regional	Low cost (subject to availability of suitable LiDAR data). Easily derived, consistent dataset for a large area. Provides an initial 'screening' that can be used regionally by land	Ignores the operation of stormwater infrastructure (i.e. can be overly precautionary). Provides limited information on the magnitude of the	Suitable for land use planning. Suitable for identifying locations where exceedance may be an issue and further investigation is required. Not suitable for making

Method	Scale	Benefits	Limitations	Application
		user planners to control development based on the precautionary approach. Provides a 'flag' for areas that require more detailed investigation.	issue.	capital works decisions.
Deterministic modelling	Catchment or subcatchment	Provides detail on the probability, magnitude and consequences of exceedance. Can be used to quantify the benefit of a mitigation measure.	Moderate to high cost depending on complexity. Provides a 'line on a map' flood extent. Natural variability in model parameters lead to uncertainty in floodplain.	Suitable for informing land use planning (assuming precautionary parameter assumptions). Suitable for identifying and flagging potential system performance issues. Sensitivity testing of key parameters should be done to inform decisions. Can be used to inform capital works decisions, if appropriate contingency is provided in design and sufficient funding is available.
Probabilistic modelling	Catchment or subcatchment	Potential to save on cost of infrastructure or mitigation measure as more certainty on probability of flooding, avoiding precautionary approaching. Doesn't rely on user defined parameters or estimations on critical storm profile.	Moderate to high cost depending on complexity. Many more simulations required. Potentially confusing to those accustomed to 'line on a map' (e.g. public, insurers, etc).	Suitable for informing land use planning, with appropriate guidance. Suitable for validating complex deterministic modelling results or critical designs with significant implications. The need to run multiple simulations means in practice the model area would need to be relatively small for complex systems (e.g. to inform design), or simplistic at a catchment scale.

DESIGNING FOR EXCEEDANCE

New stormwater infrastructure in development generally adopts a precautionary approach, often including water sensitive design and providing an allowance for the predicted future effects of climate change. Regardless of whether it follows a traditional below ground infrastructure approach, or a water sensitive design approach, the primary stormwater system capacity will still be exceeded at some point. As discussed previously, where authorities have suitable rules that restrict development in exceedance areas, many developers and engineers are aware of the techniques and benefits of designing for exceedance and incorporate these as a fundamental of the development layout.

More challenging is addressing exceedance within existing urban areas - where stormwater infrastructure may have been constructed to a lower standard, has not been increased to cope with intensified development, and planning for exceedance has historically not been undertaken. The potential effects of climate change coupled with intensification of land use exacerbate exceedance – unless our stormwater infrastructure is upgraded to keep pace with these changes we can expect the magnitude and frequency (i.e. the probability) of exceedance to increase.

Our urban centres need to be resilient and adaptable to cope with uncertainties in our predictions of system performance and flooding - designing for exceedance must become the primary focus, rather than an afterthought. Retrofitting exceedance into the existing urban environment can be challenging, however even if small opportunities are taken they can cumulatively add to a more resilient community as well as potentially being more cost effective than traditional drainage upgrades (Digman, 2012).

With reference to the Flood Risk Management Hierarchy in Figure 1, it is not usually possible to apply Steps 2 and 3 when addressing existing exceedance issues in the existing urban landscape, therefore it may be appropriate to jump to Steps 4 then 5 after Step 1. The following case studies demonstrate a number of examples of control stormwater exceedance within the existing urban landscape (Step 4). Mitigating flooding from exceedance (Step 5) is based on reducing the consequences of flooding, rather than the probability and is generally focussed on property level flood protection, including flood resilience measures such as demountable defences, sand bags, flood gates on doors and pumping. These measures are undertaken reactively in New Zealand when flooding occurs, however to date are not common in the proactive management of exceedance. In high density urban environments property level flood protection may be the only remaining solution.

CASE STUDIES – MANAGING EXCEEDANCE IN CONSTRAINED URBAN ENVIRONMENTS

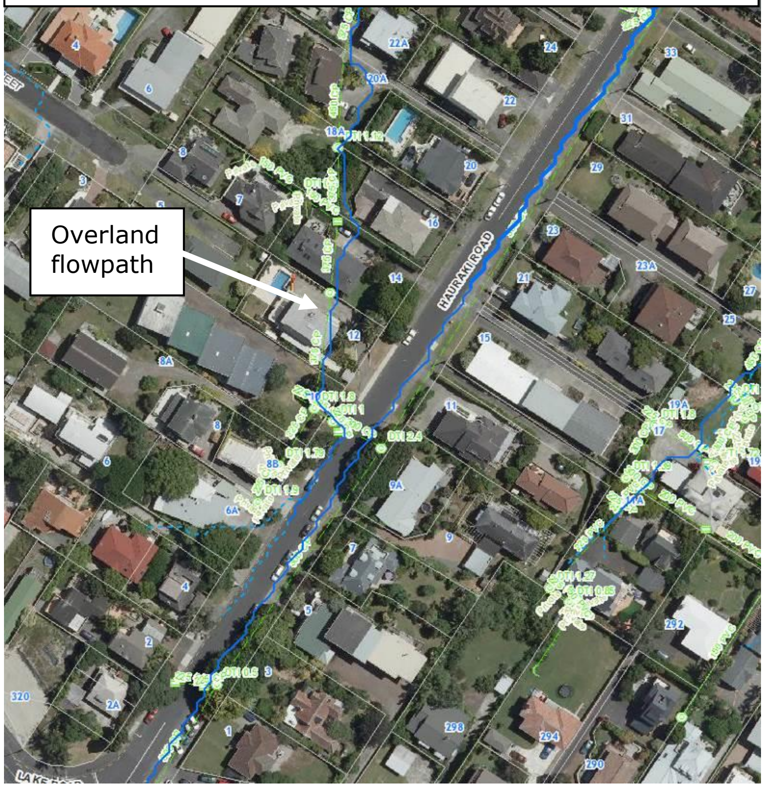
The following projects are cost effective examples to address exceedance within the existing urban landscape. These demonstrate some of the success factors identified above, as well as how uncertainty in the performance of the primary (or secondary) stormwater system is considered.

Case Study 1 – Managing exceedance through multi-functional infrastructure

The problem

When the stormwater network capacity is exceeded surface water runoff overtops the berm and results in overland flow through private property. It would be expensive and disruptive to construct a larger pipeline through private property, or create an overland flowpath, that follows the natural topography through private property.

Figure 2: Case Study 1 - overland flowpath through private property results in flooding

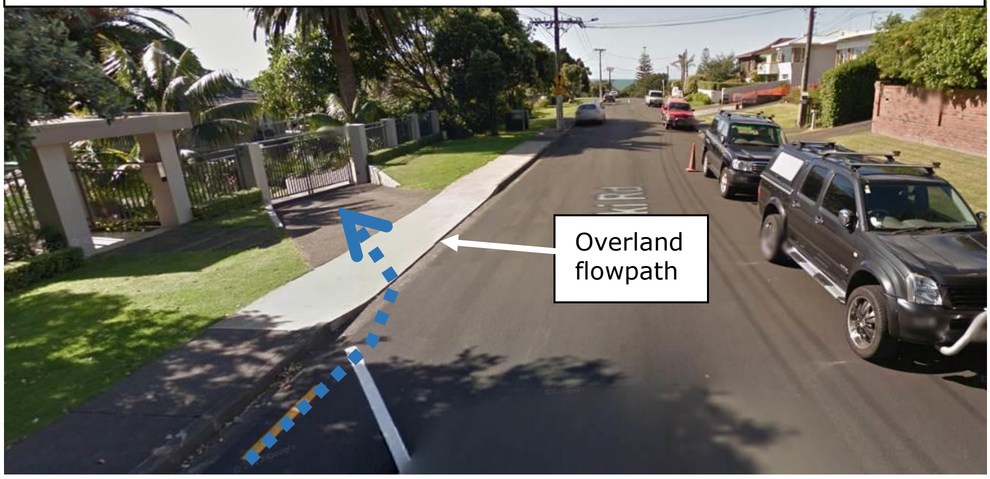


The solution

An existing deterministic hydraulic model of the catchment was refined to predict overland flowrates. A range of storm events were run to understand how sensitive overland flowpath flood levels are to change in flow, i.e. inform a likely range of uncertainty.

The route of overland flow into private property is via existing driveways. Raising low vehicle crossings along the road keeps controls exceedance within the road corridor – creating a multi-functional use of an existing asset. The road corridor eventually leads to the beach.

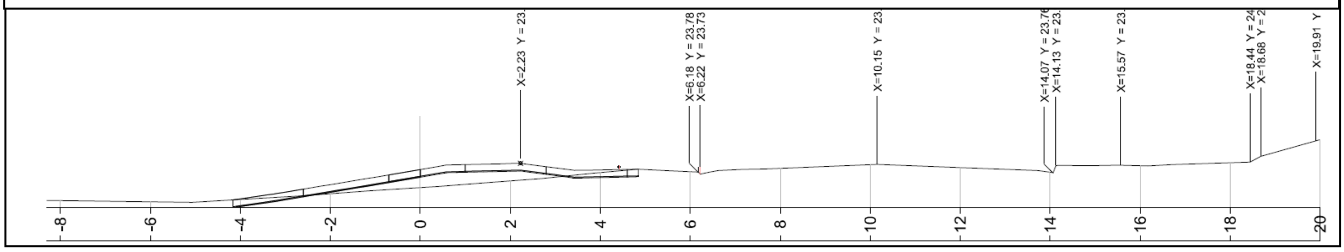
Figure 3: Case Study 1 - overland flow occurs from the road down driveways and into homes



The hydraulic model was used to determine the crest level of the vehicle crossings to retain flow and avoid overtopping. Civil 3D was utilized to design crossings that conform to vehicle passing standards while still achieving overland flow retention.

The proposed solution provides protection to around eight homes in a 1 in 100 year event at an estimated cost of $70,000.

Figure 4: Case Study 1 – raising driveway profiles to control overland flow in the road corridor

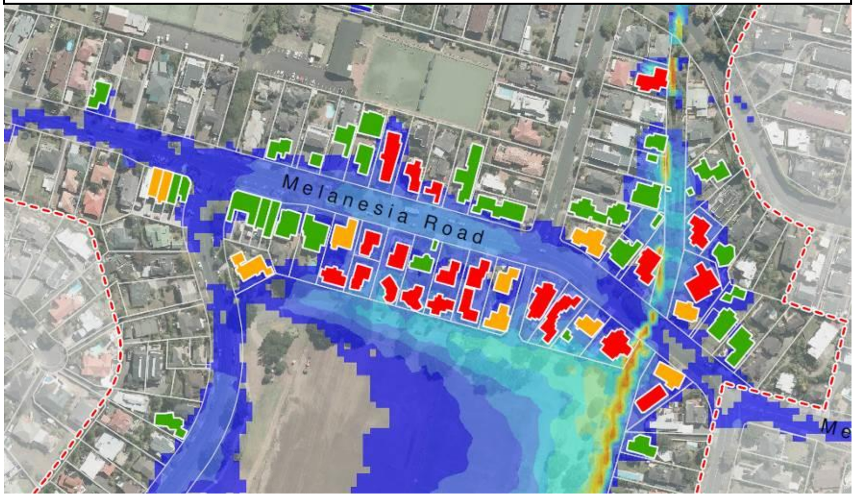


Applying the same approach strategically, opportunities could be sought to link road corridor renewal works with overland flowpath management.

<u>Case Study 2 – Working collaboratively for win-win exceedance infrastructure</u>

<u>The problem</u>

Figure 5: Case Study 2 – exceedance of stream results in flooding to properties



21 properties are at risk of flooding from an overtopping stream. A large culvert is proposed to convey additional flow downstream, reducing the risk of flooding, however site constraints mean the maximum size is 1.5m x 2.5m. During a 1 in 50 Year design event the system is still exceeded, and some properties remain at risk.

<u>The solution</u>

Working collaboratively with The Council Parks department to design a small flood defence wall that controls stream exceedance within a park, and protects properties from flooding. The wall is integrated with parks improvements, such as accessway, footpath and planting that adds value to the park.

A hydraulic model was used to inform the design of the wall. Recognising the inherent uncertainty in modelling results, the wall level was set to include freeboard, but also designed to be adaptable (the wall could be raised in the future), depending on the actual effects of climate change.

Figure 6: Case Study 2 – flood defence wall providing additional protection to property (currently under construction)

Case Study 3 – Engaging with the public to control and formalize overland flow through private property

The problem

Overland flow was generated due to blocking of inlets on a state highway. This led to stormwater passing onto local roads and flooding three properties.

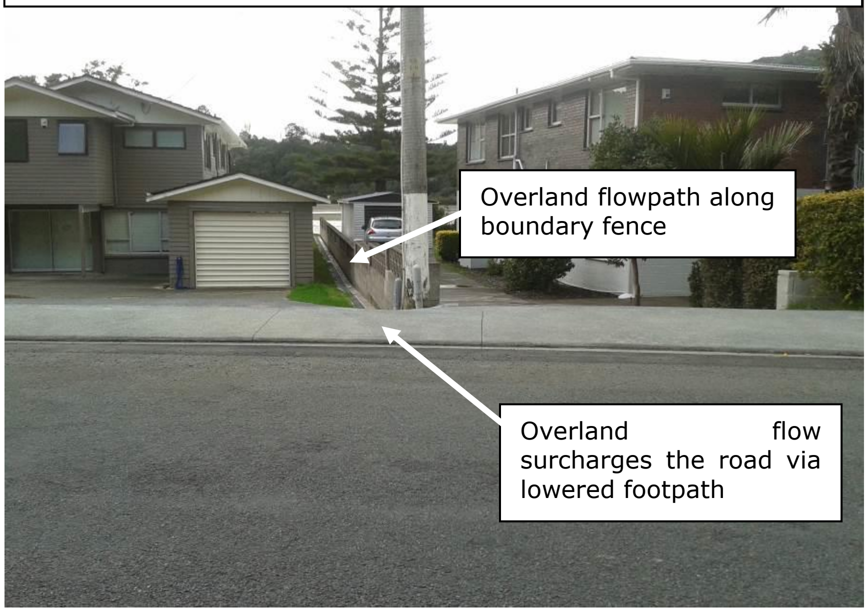
Figure 7: Case Study 3 – debris blocking inlets resulting in overland flow

The solution

A pragmatic experience-based approach to assessing the exceedance issue was considered appropriate, supported by basic modelling to determine existing pipe capacities. This was considered appropriate given the simplistic nature of the stormwater system.

The probability of blockage was reduced through appropriate screening, collection of debris and improved maintenance regime.

Figure 8: Case Study 3 – reprofiling vehicle crossings and formalizing an overland flowpath through private property



Engaging with the landowners and explaining the options available, a best practicable option was identified to manage overland flow through private property. This was done by recontouring vehicle crossing and driveways, and installing a grated channel to formalize a route for overland flow.

The cost of formalizing the overland flowpath was approximately $80,000.

Case Study 4 – Controlling the location of stormwater exceedance

The problem

Existing overland flow occurs along the road corridor, overtopping the berm and flooding private properties. A new pipeline and underground storage was constructed to reduce the frequency of overland flow, however the proposed works cannot achieve the desired level of service due to downstream network constraints.

Figure 9: Case Study 4 – overland flow down driveway and into house

The solution

Orifice plates have been added to the new stormwater infrastructure. These limit discharge to the downstream network, allow for on-line storage, and control where surcharging occurs so it has the least impact to people and property. The orifice plates provide an adaptable solution – they can be removed or replaced.

Vehicle crossing improvements increase the capacity of the road corridor to carry overland flow at a cost of approximately $20,000.

Figure 10: Case Study 4 – reprofiling vehicle crossings so road corridor acts as overland flowpath

Figure 11: Case Study 4 – using orifice plates to control surcharging locations

Case Study 5 – Relocating flooding areas to form multi-purpose land use

The problem

Poor performing private soakage systems quickly led to exceedance of the stormwater system, generating overland flow that hydraulic modelling predicted would lead to flooding of 5-6 private properties. There is significant uncertainty associated with the performance of private soakage systems.

A lack of stormwater infrastructure in the area meant it would be expensive and impractical to install a new system.

Figure 12: Case Study 5 – landscape architects sketch of proposed bund

The solution

Figure 13: Case Study 5 – final constructed bund

Stormwater engineers worked with Council Parks department and landscape architects to relocate flooding from private property to parkland. This was achieved by forming a bund across the overland flowpath and storing water for slow release into the network, creating a multi-purpose use for the park. The overall cost of parks improvements works was approximately $100,000.

A range of soakage assumptions and rainfall events were tested and the impact on the level of service established. This was then used to inform Council staff and local residents of the probability of overtopping.

Case Study 6 – Retrofitting exceedance measures through regeneration

The problem

An under capacity combined sewer network resulted in sewage flooding of private property. The lack of network capacity and historic lack of understanding of flowpaths also resulted in overland flow through a tennis club.

Figure 14: Case Study 6 – combined sewer flooding of private property

The solution

Two separate projects worked collaboratively for mutual benefit.

A partially separated stormwater network was installed to reduce the frequency of combined sewer surcharging. Adjustable orifice plates were added to control surcharging locations. The proposed redevelopment of the park incorporated a change to the overland flowpath location to convey overland flow away from the tennis club.

Joint funding between different Council departments led to a better overall outcome for the community.

Figure 15: Case Study 6 – redevelopment addressing existing exceedance issues

CONCLUSIONS

Stormwater infrastructure is constructed to control the risk of flooding, however for nearly as long as it has been constructed its capacity has been exceeded. Infrastructure is usually constructed to provide an optimised level of service based on the frequency of use, cost to construct (or replace), and consequences of exceedance. Nonetheless, understanding and planning for exceedance is a relatively new phenomenon.

An approach to systematically plan for exceedance can be achieved through applying the Flood Risk Management Hierarchy. Regardless of whether it is applied at a regional scale by land use planners, or for a single-site new development, all steps are critical and must be applied in turn. Priority should be given to avoiding exceedance areas as it is the most effective solution.

Failure to adequately assess and avoid areas of exceedance will lead to significantly greater costs later to control or mitigate flooding when exceedance occurs - the financial cost as well as the social cost on the community can be avoided if appropriate, informed development control is applied. In regeneration authorities have the most significant opportunity to manage exceedance. This requires applying the flood risk management hierarchy to reduce existing issues both on and off site, however requires potential exceedance issues to have been identified.

The probability and consequences of exceedance are rarely as well understood as we think due to the inherent uncertainties associated with climate change predictions, as well as uncertainties associated with the performance of the system (e.g. blockage, silting), asset data, rainfall records and hydrological behaviour, gauging information for calibration, amongst others. Even where we have detailed hydraulic models available we can be lulled into a false sense of security that tells us there is sufficient capacity; or we may be over-investing in upgrades to the stormwater network due to an overly precautionary model. Given how difficult it is to calibrate extreme storm events within stormwater systems, often insufficient weight is given to understanding uncertainty.

Probabilistic hydraulic modelling offers authorities a tool to understand the inherent uncertainty associated with the performance of their stormwater system, and therefore the probability associated with exceedance. Understanding uncertainty assists with making more informed decisions, where infrastructure upgrades and managing exceedance does not necessarily always want to be based on the precautionary approach. It will not always be necessary to undertake probabilistic modelling to inform exceedance design, however it can help planners and engineers improve their understanding of flood risk, prioritise funding and confirm the value of investing in infrastructure.

Designing for exceedance of the stormwater system in new development is now well established through principles such as water sensitive design and sustainable drainage systems. The most success examples of retrofitting to manage exceedance, both in this paper and internationally, are where solutions are integrated into the urban fabric, either as part of a regeneration project, or using existing assets or infrastructure for multiple uses. With significant uncertainties, particularly with respect to the actual effects of climate change, it is important to create adaptability in exceedance design. Retrofitting exceedance into the existing urban environment can be extremely challenging, however even if small opportunities are taken they can cumulatively add to a more resilient community.

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REFERENCES

Apel, H., Thieken, A.H., Merz, B., Bloschl, G. (2006). A probabilistic modelling system for assessing flood risks. Natural Hazards (2006) 38: 79-100 DOI 10.1007/s11069-005-8603-7

Balmforth, D., Digman, C., Kellagher, R., Butler, D. (2006) C635 Designing for exceedance in urban drainage – good practice. CIRIA, London.

Department for Communities and Local Government (2009). Planning Policy Statement 25: Development and Flood Risk Practice Guide (London, DCLG)

Digman, C.J., Ashley, R.M., Balmforth, D.J., Stovin, D.W., Glerum, J.W. (2012). C713 Retorfitting to manage surface water. CIRIA, London.

Digman, C., Ashley, R., Hargreaves, P., Gill, E. (2014). Managing urban flooding from heavy rainfall – encouraging the uptake of designing for exceedance. Lessons and success factors. CIRIA, London.

Irvine, J., Brown, N. (2013). Overland flow path and depression mapping for the Auckland Region. Proceedings from Water New Zealand's 8th South Pacific Stormwater Conference 2013.

National Infrastructure Unit (2015). The thirty year New Zealand infrastructure plan. [Online] Available from: http://www.infrastructure.govt.nz/plan/2015 [Accessed on 5th January 2016].

Smemoe, C.M., Nelson, E.J., Zundel, A.K., Miller, W. (2007). Demonstrating Floodplain Uncertainty Using Flood Probability Maps. Journal of the American Water Resources Association (JAWRA), 43(2):359-371. DOI: 10.1111/j.1752-1688.2007.00028.x