HOW EFFECTIVE IS STORMWATER ATTENUATION ON FLOOD RISK?

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ABSTRACT

Stormwater attenuation is commonly used to mitigate the adverse effects of urban development on flood risk. Peak flows are commonly reduced for specific design events through on-site attenuation. But does it work? Could it be that flow attenuation actually increases downstream flood risk? The answer is yes, and it occurs probably more often than what you would think.

New urban developments are often called upon to achieve “stormwater neutrality”, where post development run-off peak flows are not to exceed pre development flows for specific events. This requirement is driven through a number of legislative frameworks, and generally assessed through comparing stormwater runoff hydrographs of the development area under pre- and post-development conditions.

Stormwater attenuation can have adverse impact on flood risk, depending on the wider catchment characteristics, the location of the development in a catchment, and the design flow adopted. A catchment wide assessment may therefore be necessary to ensure that downstream flood risks are not increased. The objective of this paper is to summarise legislative drivers that are often applied to flood risk, demonstrate the potential effect of flow attenuation on the wider catchment, and to emphasise key factors for assessment when looking at effective stormwater management of the flood risk.

KEYWORDS

Stormwater neutrality, hydraulic neutrality, hydrological neutrality, flow attenuation, flood risk, attenuation pond design

1 INTRODUCTION

Urban development affects the hydrological and hydraulic processes within the catchment and consequently the natural and built environment. The effects may include:

- flooding
- loss of habitat quality and quantity
- accelerated erosion and land instability
- altering the natural water balance
- changes to existing stormwater infrastructure
- community use and cultural impacts

The government (national, regional and local) have policies and regulations in place to control these effects. The objective of this paper is to assess one of these controls, being the quantitative effect of stormwater run-off caused by urban development. Generally local and/or regional authorities have specific requirements to control increased runoff flows and volume. This is generally called “Stormwater Neutrality”. But how effective is this requirement and does it have the intended effect?

This paper first provides an overview of some of the key requirements and guidelines related to urban development and the associated management of stormwater. A definition is given for “Stormwater Neutrality” and some examples of how various councils deal with urban development and what they have as requirements.

A theoretical urban development case has been developed to analyse the effect of post development runoff in a quantitative sense. Generally post development runoff is being managed by either increasing infiltration and/or flow attenuation. The assessment analyses the impact of these methods on a localised level and within a wider catchment analysis. The results show that stormwater attenuation may not be beneficial under certain conditions.

It is noted that this paper deals with the quantitative stormwater effects of urban development only. It is acknowledged that stormwater attenuation can have significant environmental benefits such as improvements in water quality, minimising erosion, and maintaining baseflow. These are not addressed in this paper and the conclusions and recommendations are purely based on the quantitative analysis and its impact on flood risk.

2 REQUIREMENTS AND GUIDELINES FOR FLOOD MANAGEMENT

2.1 INTRODUCTION

There are numerous documents related to the effective management of stormwater runoff and associated flood risk and environmental effects. The key driver in relation to the impact of urban developments on the wider environment is driven by the RMA.

Legislation around flood management take a number of forms, and range from legislation at a national level, outlining responsibilities of councils and intent for resource management, through to national and regional codes. A brief summary of these are outlined below.

2.2 NATIONAL LEGISLATION

Within a national context there are common law decisions and many pieces of legislation that influence stormwater management. Perhaps the most significant are the Local Government Act (LGA) and Resource Management Act (RMA). The RMA is New Zealand’s main environmental statute. Its overall purpose is to promote the sustainable management of natural and physical resources. The purpose of the LGA, which sits alongside the RMA, is to provide for democratic and effective local government. To this end the LGA establishes the framework for local authorities to play a broad role in the sustainable development of their communities.

2.2.1 LOCAL GOVERNMENT ACT 2002 AND 1974 (SECTIONS NOT REPEALED)

The legal authority for a council to be involved in the provision of stormwater drainage services and ownership of assets is contained in the LGA under sections 124 to 129. In particular, a Territorial Authority may provide all drainage works necessary for efficient drainage of the district.

Among the obligations outlined in the Act, councils are directed to produce and maintain a drainage map, construct drains and cover and use watercourses for the discharge of stormwater subject to the provisions of the Resource Management Act.

2.2.2 RESOURCE MANAGEMENT ACT 1991

The purpose of the RMA is promotion of the sustainable management of natural and physical resources. This means:

> *‘managing the use, development and protection of natural and physical resources [...] while [...] safeguarding the life-supporting capacity of air, water, soil and ecosystems; and avoiding, remedying or mitigating any adverse effects of activities on the environment’.*

Under Section 6 of the RMA matters of national importance which need to be recognised and provided include the protection of wetlands, lakes, rivers and their margins from inappropriate subdivision, use and development.

The RMA goes on to set out key functions for Regional Councils (section 30) and Territorial Authroities (section 31) aiming “to achieve the integrated management of the natural and physical resources of the region”.

Crucially with respect to flood management, the RMA assigns councils a key role in the approval of sub-divisional consents. Specifically, Part 6 Section 106 has particular relevance:

> ***106 Consent authority may refuse subdivision consent in certain circumstances***
>
> *(1) A consent authority may refuse to grant a subdivision consent, or may grant a subdivision consent subject to conditions, it is considers that:*
>
> > ***a. the land in respect of which a consent is sought, or any structure on the land, is or is likely to be subject to material damage by erosion, falling debris, subsidence, slippage, or inundation from any source; or***
> >
> > ***b. any subsequent use that is likely to be made of the land is likely to accelerate, worsen, or result in material damage to the land, other land, or structure by erosion, falling debris, subsidence, slippage, or inundation from any source; or***
> >
> > *c. sufficient provision has not been made for legal and physical access to each allotment to be created by the subdivision.*
>
> *(2) Conditions under subsection (1) must be:*
>
> > *a. for the purposes of avoiding, remedying, or mitigating the effects referred to in subsection (1); and*
> >
> > *b. of a type that could be imposed under Section 108.*

Clauses 1a and 1b are generally interpreted to cover the risk of inundation of the subject land and also the risk of inundation to other land that may result from the proposed subdivision. It is noted that no design probability storm is referred to in Section 106 and this has caused inconsistencies nationally. Some councils have taken the requirement of the Building Code as their standard for inundation, others have specific level of service requirements as outlined in their code of practice or equivalent documents (eg. NZS 4404).

In addition to the key statutes referenced above, legislation of potential relevance includes:

- Building Act – Including ensuring habitable floors free from inundation (50 year event), and provision for management of stormwater on-site.
- Health Act – Protection of public health with respect to stormwater quality.
- Climate Change Response Act – Legal framework and strategies pursed under the act for dealing with climate change.
- Civil Defence Emergency Act – Seeks to improve and promote sustainable management of hazards to contribute to well-being, the safety of the public and the protection of property (with reference to acceptable levels of risk).

In support of these Acts a number policies and standards have and are being developed at national and local level, key aspects of which are summarised below.

2.3 NATIONAL POLICY

The RMA under Part 5, Section 45 and Sections 43 and 43a respectively, allows for the development of National Policy Statements (NPS) and National Environmental Standards (NES) to provide stronger national direction on particular matters of concern or interest.

The purpose of National Policy Statements (NPS) is to state objectives and policies for matters of national significance that are relevant to achieving the purposes of the RMA. Such statements guide subsequent decision making under the RMA at the national, regional and district levels.

A recent Ministry for the Environment (MfE) Flood Risk Management Review identified the need for a NPS on flood risk management and in response the Minister for the Environment and Cabinet decided in March 2007 that a national policy statement on managing flood risk was desirable. However, initial work by MfE lead to the conclusion that a NPS may not be the best tool to assist local authorities to achieve reductions in flood risk. Further MfE analysis on this issue is expected to take place in late 2010.

National Environmental Standards (NES) are being progressed in a number of areas by central government. However, we understand that currently no work solely relating to stormwater catchment management (or specifically flood management) is being progressed. Initial work has been completed in a NES for Ecological flows and Water Levels (2008), but no recent progress appears to have been made. With the management of water resources rapidly evolving, and a trend (if not will) of government recently lending to a centralised approach, regard needs to be given to the possibility of standards of this nature evolving in the future.

2.4 NATIONAL CODES AND STANDARDS

Key Codes and Standards of relevance to the management of stormwater include:

- New Zealand Building Code (NZBC)
- New Zealand Standard Land Development and Subdivision Infrastructure (NZS4404:2010)

The NZBC sets minimum requirements related to flood protection, in terms of drainage capacity requirements and building levels. It does not include the impact of the proposed development on the environment.

The NZS4404 set more specific development design requirements, including management of the impact of the proposed development on the wider catchment. Specifically relevant clauses are presented below:

Clause 4.2.3 Local authorities' requirements

> *The requirements of relevant regional and district plans on stormwater shall be met. Regional plan requirements will generally be limited to effects of stormwater on the natural environment. The local territorial authority exercises control over infrastructure associated with land development and subdivision.*
>
> *Authorisation will be required from the regional council for the discharge of stormwater unless the discharge is to an existing and consented stormwater system and meets any conditions which apply to the existing system.*
>
> *The discharge of clean stormwater and other activities where effects are considered minor may be authorised as a permitted activity subject to certain conditions in the regional plan. Authorisation may also be by way of a comprehensive consent held by the TA for a large area or entire catchment.*
>
> *In other circumstances site specific discharge permits and water permits shall be obtained. Advice should be sought from the LAs at the earliest stage of planning for stormwater infrastructure and receiving waters.*

Clause 4.2.4 Catchment management planning

> *Stormwater management planning should be carried out on a subcatchment or catchment-wide basis. Where the proposed development is in an area covered by a local authority comprehensive catchment management plan, designers will be required to comply with the design philosophy in the plan.*
>
> *If there is no catchment management plan for the area of the proposed development, the stormwater planning requirements should be discussed with the LAs at an early stage.*

The implications of future development on adjoining land should be on the basis of replicating the pre-development hydrological regime whereby the maximum rate of discharge and peak flood levels post-development are not greater than pre-development.

Clause 4.2.5 Effects of land use on receiving waters

Impervious surfaces and piped stormwater systems associated with development have an effect on catchment hydrology. Faster run-off of storm flows, reduction in base flows, and accelerated channel erosion and depositions alter the hydrology and adversely affect the quality of receiving waters. Development should aim to minimise the increase in the frequency at which pre-development discharges are exceeded across a range of design rainfall events as this has implications for the biodiversity of the aquatic biological community.

Clause 4.2.7 Catchments and off-site effects

For all land development infrastructure the design of the stormwater system shall include the evaluation of stormwater run-off changes on upstream and downstream properties. This evaluation will be required at the resource consent stage and may be linked to a requirement to replicate the pre-development hydrological regime.

Upstream flood levels shall not be increased by any downstream development unless any increase can be shown to have not more than a minor impact on the upstream properties.

Downstream impacts could include(but are not limited to) changes in flow peaks and patterns, flood water levels, contamination levels and erosion or silting effects, and effects on the existing stormwater system. Where such impacts are more than minor, mitigation measures such as peak flow attenuation, velocity control, and treatment devices will be required.

2.5 REGIONAL AND LOCAL PLANS

As outlined above, Regional Councils have an overview function charged with establishment, implementation and review of objectives, policies and methods to achieve integrated management of the natural and physical resources of the region; pursuant to Section 30 of the RMA. District Councils have responsibility for the control and integrated management of the effects of the use, development or protection of land and associated natural and physical resources within a city or district. They are also responsible for controlling any actual or potential effects of activities, and for control of land subdivision.

In addition to the legislation and associated codes of practice, regard needs to be given to relevant regional and local level plans and policies, which exist and cover the issue of stormwater management. This will include:

- Regional Policy Statements
- District Plans
- Desired community outcomes expressed through LTCCP
- Local Engineering Standards
- Specific stormwater related bylaws

There has been a shift towards the promotion of sustainable land management within a broad resource management setting. The management of stormwater is encompassed within this and it is seen as increasingly important to integrate land-use, stormwater and infrastructure planning and management either in the form of a Catchment Management Plan or Integrated Catchment Management. While there is no direct legal requirement to prepare a Stormwater Catchment Management Plan (SCMP), all discharge activities relating to stormwater drainage are subject to the provisions of the RMA and the relevant regional policy and planning instruments.

3 DEFINITION OF STORMWATER NEUTRALITY

The above described legislation and guidance documents commonly require that post development peak flows do not exceed pre-development flows for specific design rainfall events. This is generally called, either:

- Stormwater neutrality
- Hydraulic neutrality
- Hydrological neutrality

The differences between the above terminologies are subtle and typically the interpretation is similar. The quantitative effects of urban development on run-off are a combination of hydrological and hydraulic processes, such as:

- Increase in impervious area and earthworks affects the infiltration capacity, and speed of excess runoff (hydrological process)
- Incorporating flow attenuation features and the creation of additional storage volumes is common practice to mitigate adverse effects (hydraulic process)

The term Stormwater Neutrality is adopted for this paper as it covers both of these processes.

3.1 DEFINITION

As outlined in Section 2, various councils have various requirements, but generally it includes:

- Stormwater runoff from the site during one or more specific rainfall events must be managed so that the post-development peak flows are not to exceed the pre-development flows for specific design events.

Furthermore, it’s not uncommon that additional requirements are in place, such as:

- Minimal increase in average annual runoff volumes (say less than 5%)
- No decrease in the time of concentration
- Base flows in streams are to be maintained at pre-development levels

4 CONCEPT MODEL OF DEVELOPMENT SITE

4.1 INTRODUCTION

A conceptual model has been developed as a case study to represent sensitivities and analyse the impact of the following design conditions on the stormwater neutrality requirement:

- Location within the catchment:

  The effect of stormwater attenuation on the overall catchment run-off depends on the location of the development within the catchment. Speeding up the runoff in a downstream catchment may be beneficial as it results in an early discharge of the local peak flow prior to the wider catchment peak.

- Design rainfall event:

  Various councils have different requirements to which design rainfall event the stormwater neutrality requirement should comply. This can either be a variety of rainfall events (ie 2yr, 10yr & 100yr), a reasonably regular event 5yr only or an extreme event such as 100yr. For this conceptual model the attenuation pond has been designed to attenuate the 10yr rainfall event.

For the analysis in the following sections, Stormwater Neutrality is defined as:

- Post development peak flows during a 10year ARI (10% AEP) rainfall event are not to exceed the pre-development flows.

As stated in Section 1, the assessment analyses the quantitative affects of urban development on stormwater runoff only. Environmental benefits have not been addressed.

4.2 MODEL SET UP

The conceptual model consists of a catchment with 4 sub-catchment areas, being (refer Figure 1):

- Area 1 Upper Catchment: a 50 ha large undeveloped area at the upper catchment;
- Area 2 Middle Catchment: a equally sized catchment with 30% impervious area at the centre of the catchment representing a low to medium density urban developed catchment
- Area 3 Lower Catchment: a 10 ha high density catchment (80% impervious area)
- Development Site: a currently undeveloped 10 ha large catchment, to be developed with low density residential properties (25% impervious area). The location of this catchment varies depending on the scenario analysed.

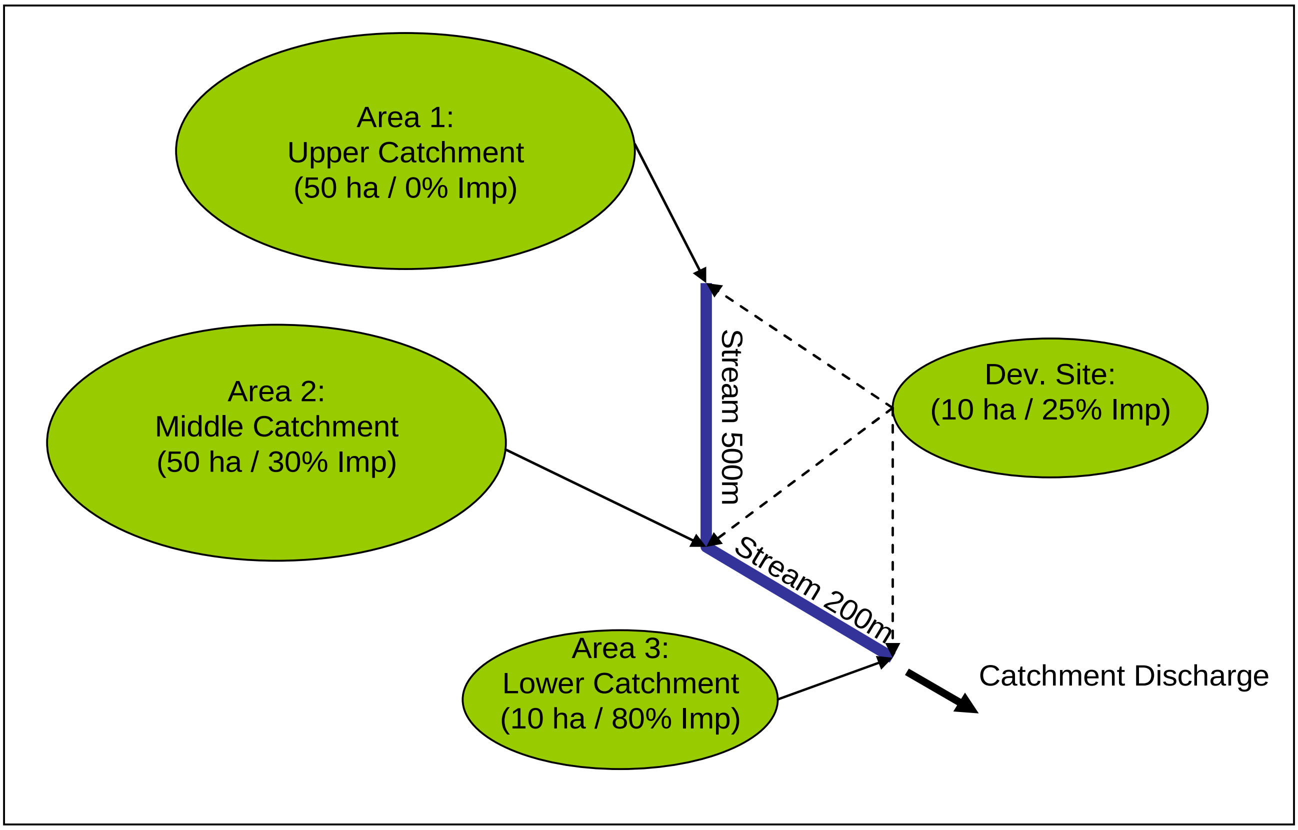

Figure 1: Set Up Conceptual Model

The catchment characteristics are presented in Table 1 below. The numerical model is based on the Unit Hydrograph Method and a 24 hour nested rainfall event in accordance with ARC TP-108.

Table 1: Modelled Catchment

Catchment Area	Area (ha)	Imp Area	Time of Concentration (min)	Q_{10} (m^3/s)	Discharge Location
Area 1 Upper Catchment	50	0%	45	1.6	Ch 700m
Area 2 Middle Catchment	50	30%	30	3.3	Ch 200m
Area 3 Lower Catchment	10	80%	10	1.7	Ch 0m
Development Site Pre-Dev Post-Dev	10	 0% 25%	 30 15	 0.4 0.9	Varies

Note: A channelled slope of 0.5% has been assumed between Ch 700m & Ch 500m and a slope of 0.2% between Ch 200m and Ch 0m.

Table 1 shows that the post-development peak flow of the site more than doubles from Q_{10} = 0.4 m^3/s to Q_{10} = 0.9 m^3/s. The impact of this on the total catchment peak flow depends on the location of the development site within the catchment as demonstrated by three modelled scenarios in the next section.

4.3 MODELLED SCENARIOS

4.3.1 LOCATION WITHIN THE CATCHMENT

The following three scenarios have been modelled:

- Scenario 1: Runoff of development site at the upper catchment (site discharge at Ch 700m)
- Scenario 2: Runoff of development site at the centre of the catchment (Ch 200m)
- Scenario 3: Runoff of development site at the lower end of the catchment (Ch 0m)

The modelling results have been summarised in Table 2 below and as example the hydrographs for Scenario 1 are shown in Figure 2.

Table 2: Modelling Results – ARI 10 yr Rainfall Event

Scenario	**Development Site Peak Runoff (in m³/s)**			**Total Catchment Peak Runoff (in m³/s)**		
	Pre Dev	**Post Dev**	**Post Dev with Pond**	**Pre Dev**	**Post Dev**	**Post Dev with Pond**
1				5.31	5.67	5.30
2	0.40	0.85	0.40	5.29	5.36	5.29
3				5.27	5.28	5.29

Note: The flows are presented in 2 decimal places to show the relatively small differences between the results. It does not reflect the accuracy of flows.

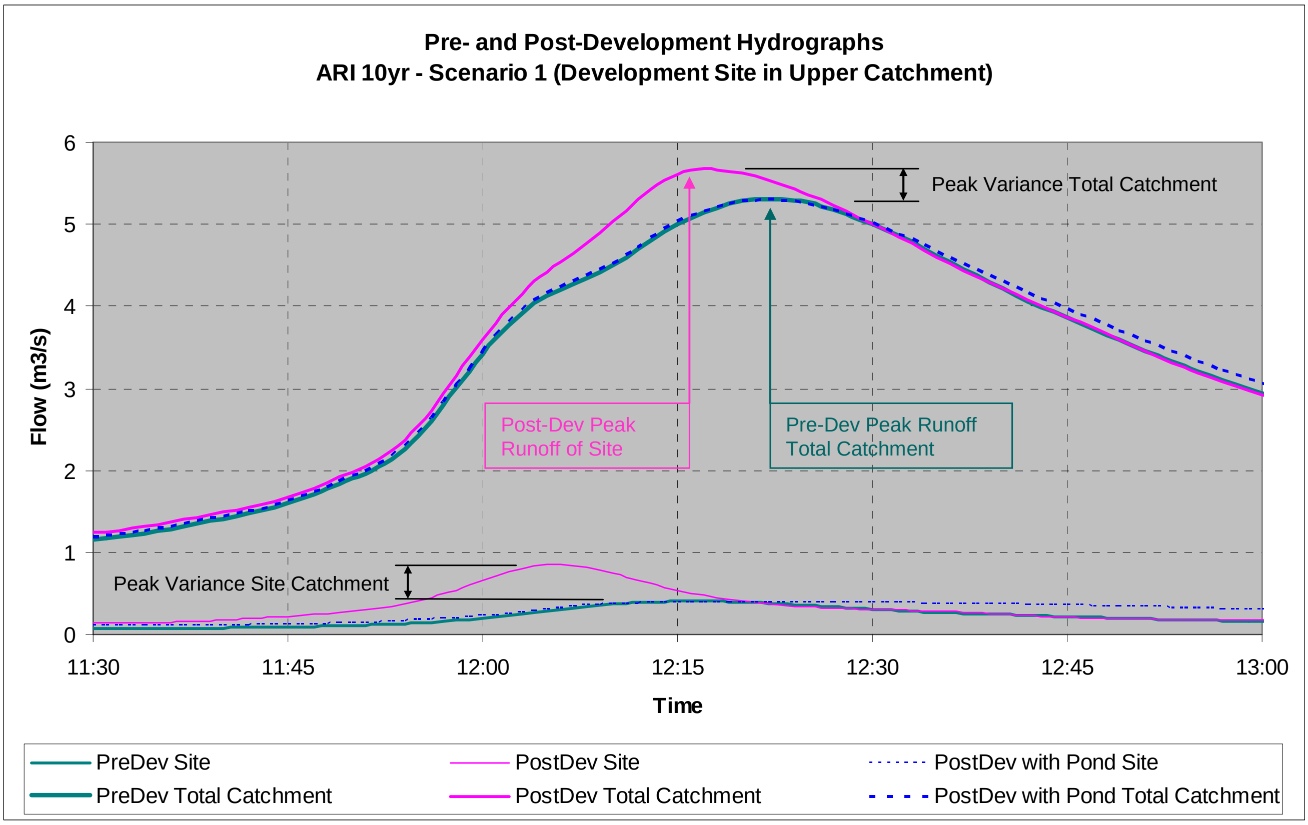

Figure 2: Hydrographs ARI 10yr – Scenario 1

The development of the site increases the runoff peak as shown in Figure 2 above (Peak Variance Site Catchment). The impact of this increased runoff for Scenario 1 is clearly noticeable in the Total Catchment hydrograph. As the timing of the post development peak runoff of the site is relatively close to the pre-development peak runoff of the Total Catchment, the impact of the development is relatively significant (Peak Variance Total Catchment).

Figure 2 shows as well that the post development flows for the attenuated case is similar to the pre-development conditions with a insignificantly small difference in peak flow and slightly increased post development peak runoff.

Figure 3 shows the results for Scenario 3, where the development site is located at the downstream end of the catchment. In this scenario, the additional runoff of the development site is entirely discharged prior to the peak runoff of the Total Catchment. As a result the variance between the pre- and post-development peak flow is reduced to nill. The reduced catchment response time in the lower catchment has benefits for the overall catchment peak run-off.

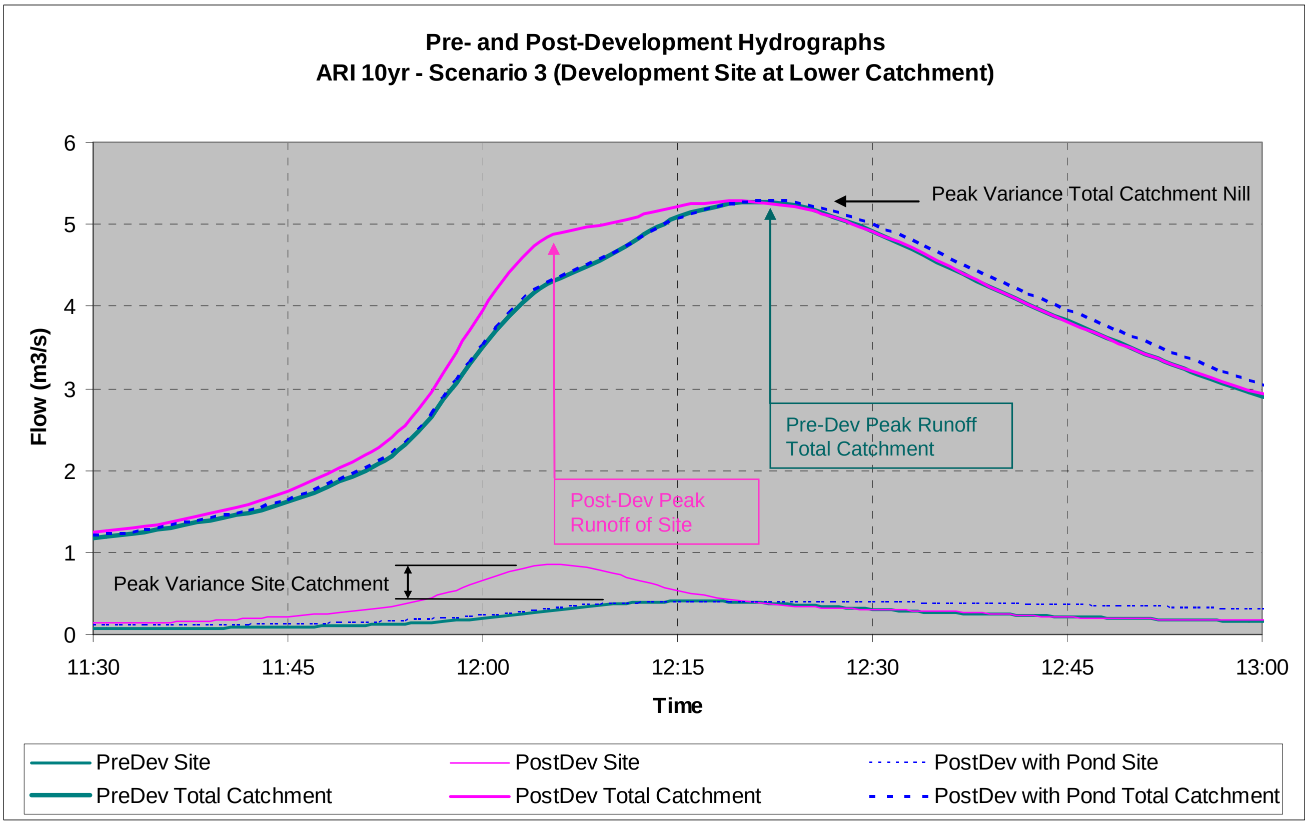

Figure 3: Hydrographs ARI 10yr – Scenario 3

Key observation:

The results of this analysis demonstrates that the impact of urban development on the total catchment peak run-off depends highly on the location of the development within the catchment. The final impact of the urban development on the total catchment is dictated by the timing of the catchment responses. Reducing the post development catchment response time can be beneficial for the wider catchment especially when the development is located in the lower reaches of the catchment.

4.3.2 DESIGN RAINFALL EVENT

The attenuation pond for the conceptual model has been designed for an ARI 10 year design event. What happens for such development during an over design event (ie ARI 100 year event)? The results are presented in Table 3 and Figure 4 & 5.

Table 3: Modelling Results – ARI 100 yr Rainfall Event

	Development Site Peak Runoff (in m^3/s)			Total Catchment Peak Runoff (in m^3/s)		
Scenario	**Pre Dev**	**Post Dev**	**Post Dev with Pond**	**Pre Dev**	**Post Dev**	**Post Dev with Pond**
1	0.85	1.55	1.33	10.10	10.47	10.56
2				10.05	10.02	10.32
3				10.02	9.92	10.16

Note: The flows are presented in 2 decimal places to show the relatively small differences between the results. It does not reflect the accuracy of the flows.

The results in Table 3 show that for all three scenarios the attenuated peak flow is higher than the non-attenuated post-development peak flow, due to the attenuation of the flow. This is illustrated in Figure 4 & 5. The installation of an attenuation pond designed for the ARI 10 year rainfall event increases the risk of flooding during an ARI 100 year event.

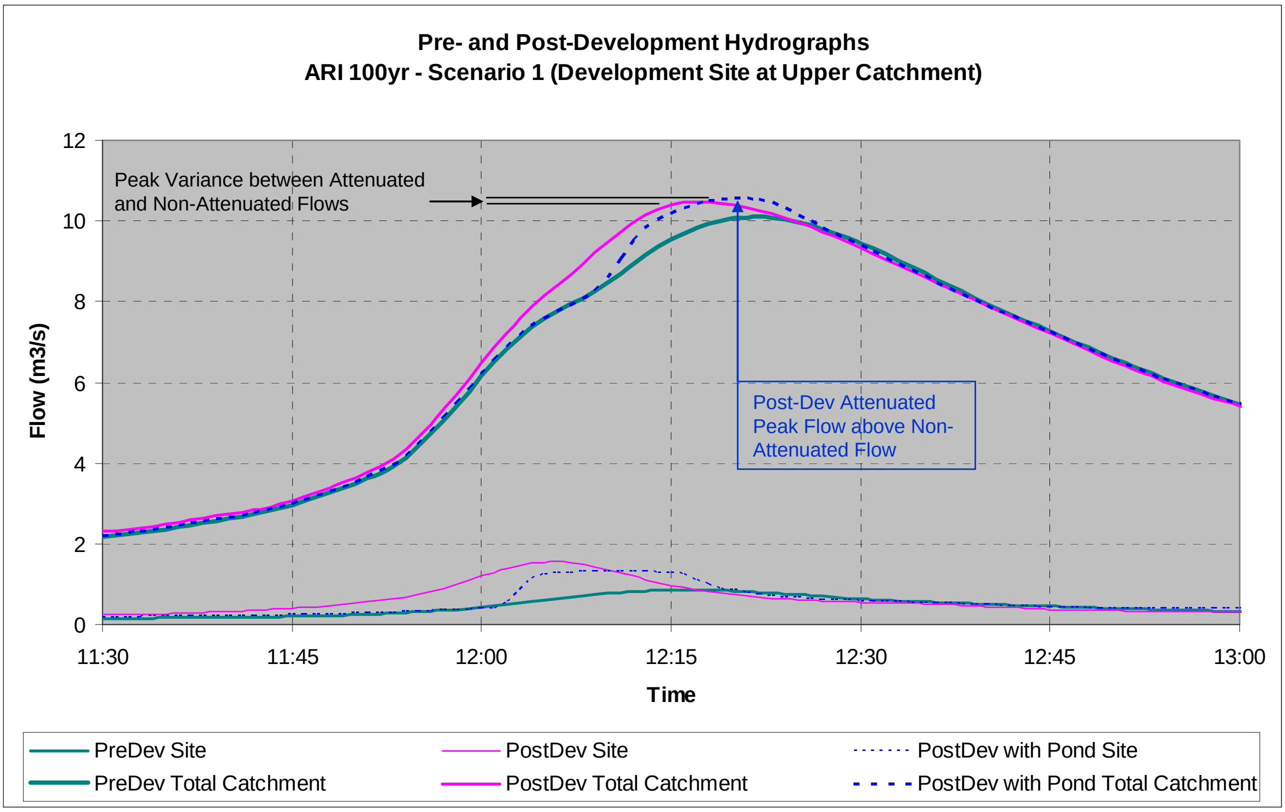

Figure 4: Hydrographs ARI 100yr – Scenario1

It is also noted that for Scenario 2 (Middle Catchment) and Scenario 3 (Lower Catchment) the post-development non-attenuated peak flow is less than the pre-development peak flow. In Section 4.3.1 it was demonstrated that the location within the catchment could affect the peak flow depending on the location of the development in the wider catchment. The above demonstrates that urban development can reduce peak run-off in the Total Catchment, due to the timing of the flow runoff.

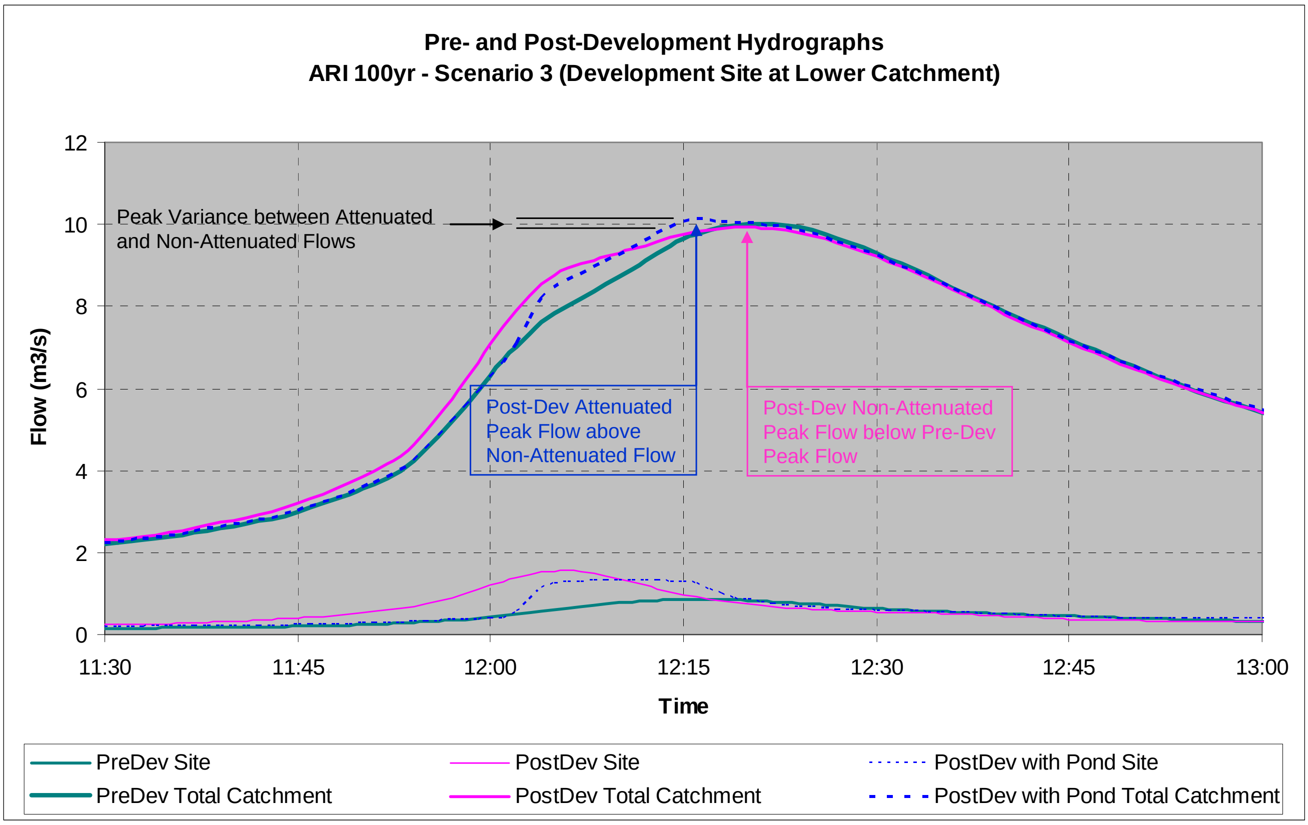

Figure 5: Hydrographs ARI 100yr – Scenario 3

Key observation:

The performance of attenuation ponds is specific to selected design events. The results of this analysis demonstrate that attenuation of run-off can worsen flood risk during an over design rainfall event.

It also demonstrates that reducing the post development catchment response time can lower the non-attenuated peak flow of the wider catchment to below pre-development levels. Speeding up the runoff rather than attenuation flows can reduce downstream flood risk.

4.4 CASE STUDY

The implementation of a stormwater attenuation pond has also been modelled for an existing development as a case study. The development and the catchment are shown in Figure 6 and the catchment parameters are presented in Table 4. Figure 6 shows the total catchment and the proposed development in the north (yellow hatched area in the drawing). The catchment discharges into a stream through a gully prior to draining through a culvert underneath the state highway.

Under the post-development stage sub-catchment boundaries have been changed and the majority of the development discharges at the upstream end of the stream. For this model an attenuation pond has been designed attenuating the ARI 10 year design event.

Table 4: Catchment Parameters Case Study

Catchment Area	Pre-Development			Post-Development		
	Area (ha)	**Imp Area**	**Time of Concentration (min)**	**Area (ha)**	**Imp Area**	**Time of Concentration (min)**
A	10.7	10%	25	4.2	20%	15
B	3.3	0%	20	3.3	0%	20
C	1.6	0%	15	8.1	55%	10
D	55.3	30%	35	55.3	30%	35

Note: Sub-catchment area boundaries have changed as part of the development.

Figure 6: Case Study Catchment

The results of the simulation are presented in Figure 7. The figure shows that for the ARI 10 year event the non-attenuated post development peak flow is approximately equal to the pre-development flow. The runoff of the development area occurs prior to the total catchment peak runoff. Consequently impact on the wider catchment is nill.

For the ARI 100 year development the total development non-attenuated peak flow is higher than the attenuated peak flow and increasing the flood risk in the wider catchment.

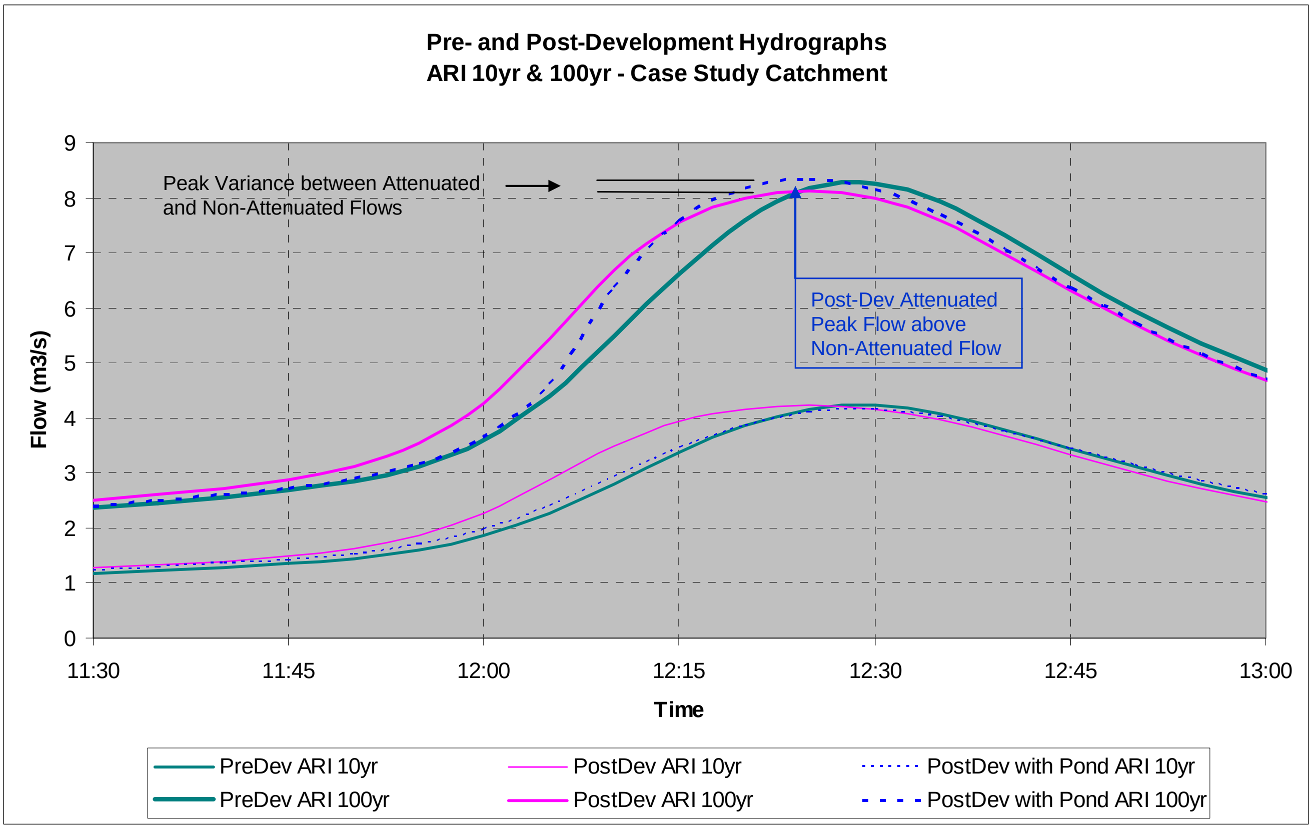

Figure 7: Case Study Catchment Results

4.5 IMPLICATIONS

4.5.1 WIDER CATCHMENT ANALYSIS

The impact of the timing of sub-catchment runoff on the overall flood risk of a catchment and the need for wider catchment analysis has been recognised as shown in the following quote from The Auckland Regional Council TP10 (ARC, 2003):

> *"Depending on the catchment, the number of tributaries and the location of the development in a catchment, timing of flow discharges may be an issue. If so, a catchment wide study may therefore be necessary to ensure that downstream flood risks are not increased. If there is no catchment-wide study, work done by Manukau City Council and overseas has indicated that limiting the peak discharge of the 100 year storm to not exceed 80% of the pre-development 100 year storm will reduce downstream flood increase concerns. The 80% peak discharge rate reduces potential for coincidence of elevated flow downstream. The ARC will accept this approach as an alternative to a catchment wide study"*

This requirement has been checked in the conceptual model and the results confirm the outcome. A holistic approach and understanding of the wider hydraulics of the catchment and associated timings is essential for effective flood management.

4.5.2 IMPACT ON SUSTAINABLE URBAN DESIGN PRINCIPLES

Current sustainable urban design promotes facilities that generally provide storage (eg green roofs, rain tanks, grassed swales, etc) and attenuate the peak run-off. It is acknowledged that such facilities have great environmental benefits in terms of water quality, water consumption, groundwater recharge, maintaining base flows, etc. But from purely a flood risk management point of view, such systems are effectively small attenuation ponds if infiltration is insignificant during extreme rainfall events. Typically these structures are designed for specific design events (ie AIR 10yr) and understanding of the wider catchment dynamics is encouraged so as fully understand implications on attenuation prior to approval need be considered at a policy level. Who fulfills this role, whether it be council or developers, is a wider issue to be considered depending on the size of the development and its surrounding environment.

5 SUMMARY AND CONCLUSIONS

Under the Resource Management Act (Section 106) it is required that developments do not adversely affect the risk of inundation to other land that may result from the proposed development. It is noted that no design probability storm is referred to in the RMA and this has caused inconsistencies nationally. Some councils have taken the requirement of the Building Code as their standard for inundation, others have specific level of service requirements as outlined in their code of practice or equivalent documents (eg. NZS 4404).

Typically councils would require stormwater neutrality for urban development, which is defined in this paper by:

- Stormwater runoff from the site during one or more specific rainfall events must be managed so that the post-development peak flows are not to exceed the pre-development flows for specific design events.

To achieve this, flow attenuation is commonly used by developing attenuation ponds and/or other facilities creating additional flood storage and increased infiltration capacity. The efficiency of attenuation ponds has been analysed using a conceptual model of an urban development.

Various scenarios have been developed and the following sensitivities have been analysed:

- The location of the development within the wider catchment.

- The impact of over design rainfall events on stormwater attenuation.

The analysis shows that:

- Urban development may reduce downstream flood risk, due to the increase in catchment response time.

- Flow attenuation may increase downstream peak flows during rainfall event larger than the design event.

It is noted in ARC TP10 (ARC, 2010) that the location of the development in a catchment and the timing of flow discharges may be an issue for assessing flood risk. The following principal design requirements for attenuation ponds are therefore recommended:

- Where there are downstream flooding issues, a catchment wide approach is required where the post development attenuated peak flow of the catchment is not to exceed the pre-development flow during the ARI 100 year design rainfall event. Alternatively, without a catchment wide analysis the post development peak flow of the site should not exceed 80% of the pre-development flow during the ARI 100 year design rainfall event.

- A sensitivity review using an over design rainfall event (ie ARI 200 or 500 year event) with the aim that the attenuated post-development peak run-off is not to exceed the non-attenuated post-development peak flow.

- Additional attenuation requirements for more regular events may be specified if required.

It is acknowledged that sustainable urban design facilities (such as rain gardens, rain tanks, grassed swales, etc) have great environmental benefits in terms of water quality, water consumption, groundwater recharge, maintaining base flows, etc. But considered in isolation from the environmental benefits and looking purely at flood risk management, such systems could have an adverse affect on the risk of flooding during over design rainfall events.

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