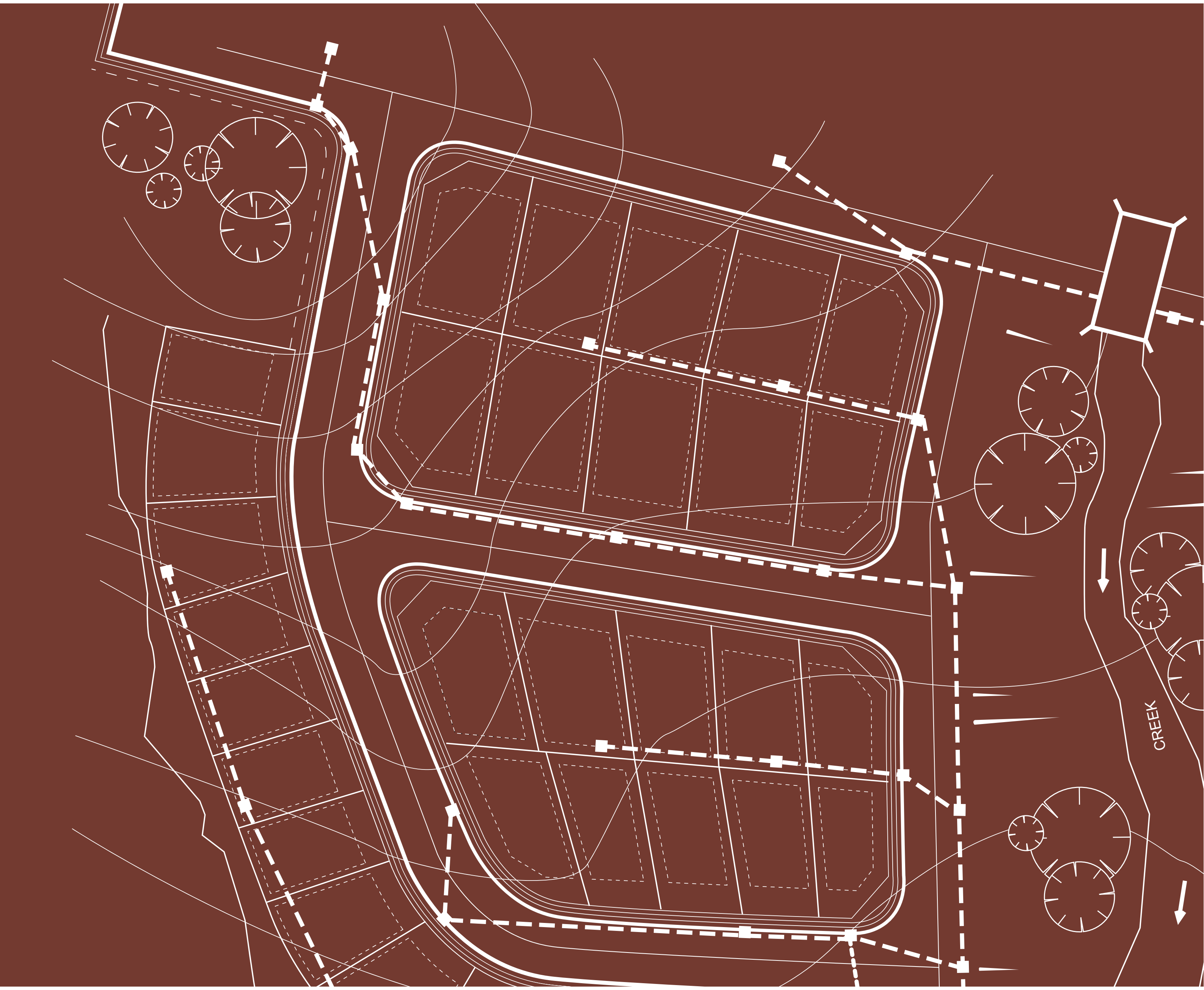
DESIGNING SAFER SUBDIVISIONS

Guidance On Subdivision Design In Flood Prone Areas



Prepared for the Hawkesbury-Nepean Floodplain Management Steering Committee

In April 2007, sections within the former Department of Natural Resources NSW where incorporated within the new Department of Environment and Climate Change NSW.

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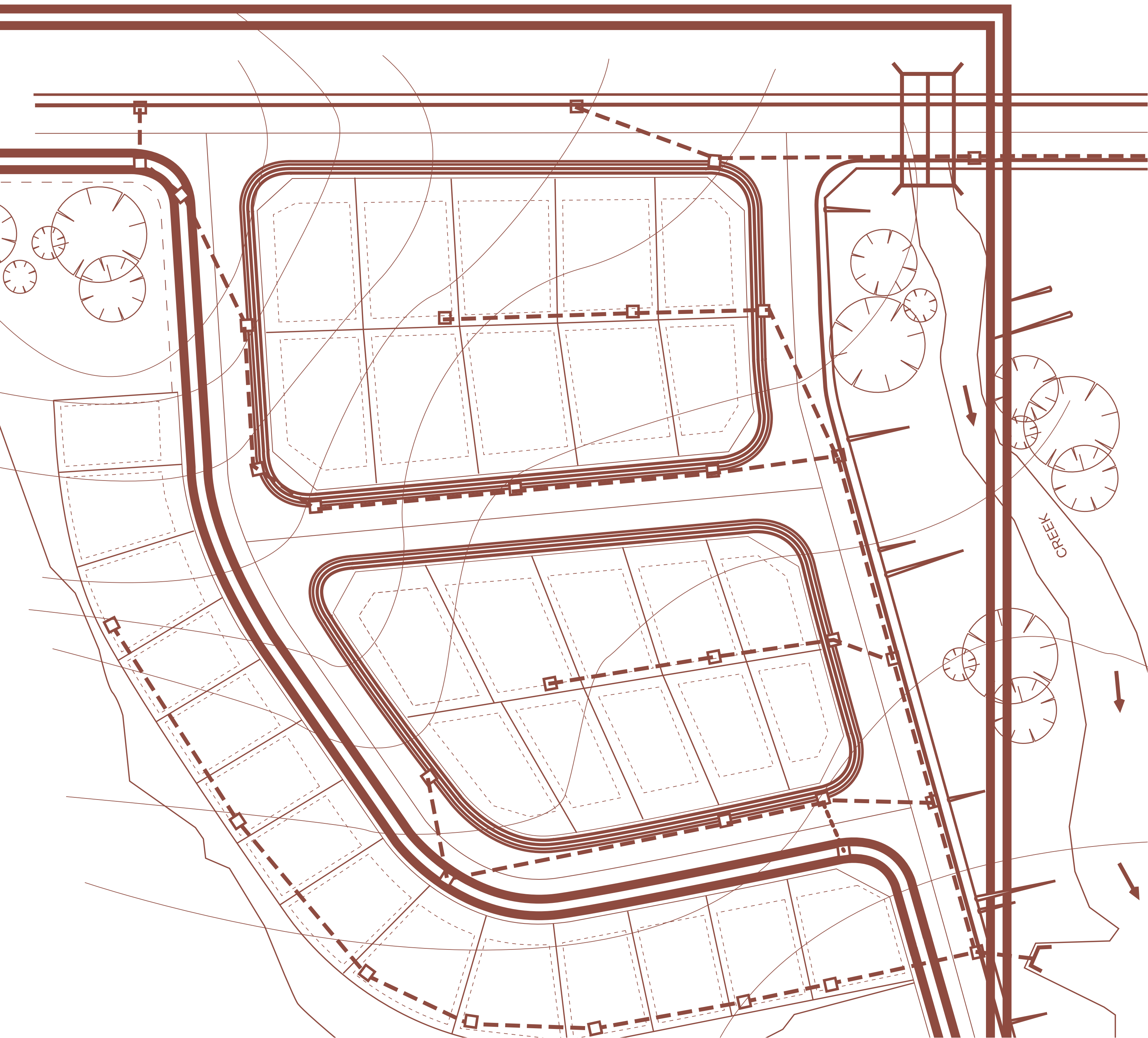

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In 2006 the three guidelines covering Landuse Planning, Building Construction and Subdivision Design for development on flood prone land received two awards from Emergency Management Australia - the NSW Safer Communities Award and a "highly commended" Australian Safer Communities Award for pre-disaster activities.

In 2007 the three guidelines covering Landuse Planning, Building Construction and Subdivision Design for development on flood prone land won the "Projects and Reports" section of the Engineering Excellence Awards conducted by the Sydney Division of Engineers Australia.

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FOREWORD

Floodplains provide land for both urban and rural development, however, there remains an ever-present risk in occupying land which is subject to flooding, even if that flooding occurs only rarely. Land-use planning for new areas provides opportunities to locate development to limit vulnerability to flooding and enable flood-aware design and materials to be incorporated into the construction of new subdivisions and homes. In this way, we can better manage future flood risk so that potential losses and damages are reduced.

In the floodplain downstream of Warragamba Dam, the potential for serious flood damages and losses following severe flooding of the Hawkesbury-Nepean River first became apparent during studies in the early 1990s. A strategy was required to ensure that should a flood event occur, that all loss, both personal and economic be minimised. The NSW Government has addressed this flood risk by allocating over $71 million to the Hawkesbury-Nepean Floodplain Management Strategy. A Steering Committee which included key government agencies, local councils and community representatives, oversaw the implementation of the Strategy. Under the Committee's guidance, improved flood warning and emergency response measures, upgraded evacuation routes, recovery planning and a regional floodplain management study have been put in place.

A key component of the regional floodplain management study is a suite of three guidelines on land use planning, subdivision and building on flood prone land. These guidelines accord with the Government's Flood Prone Land Policy and the NSW Floodplain Development Manual (2005). They have been produced by staff of the Department of Natural Resources, working under the oversight of the Steering Committee, with technical assistance from the CSIRO, Macquarie, New South Wales and Newcastle Universities, and a number of specialist consultants.

The three documents provide guidance to councils and others involved in land-use planning on flood hazards and risks and suggest practical and cost-effective means to reduce the risk both to occupants and to new buildings on flood prone land. Although specifically designed to address the unique flooding of the Hawkesbury-Nepean valley, they include information which can be readily applied to other floodplains where new development is proposed.

The guidelines will prove to be a valuable source of reference and information for councils and others involved in planning and building new development on flood prone land. Application of the guidelines can only result in safer communities and a more rapid recovery following flood events.

Brian Dooley

Chairman

Hawkesbury-Nepean Floodplain Management Steering Committee

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CONTEXT

Natural hazards including floods have the potential to threaten life and property. They impose social and economic costs on governments and the community. Indeed, flooding is recognised as the costliest natural disaster in Australia.

Historically, floodplains have always attracted settlement and today they are no less in demand to meet the needs of urban expansion. Posing risks to the relatively heavily populated east coast of New South Wales, riverine flooding tends not to follow a predictable pattern, occurring at any time of year and at irregular intervals. Floodplain risk management is a compromise which trades off the benefits of human occupation of the floodplain against the risk of flooding. The risk includes the flood hazard, social, economic and environmental costs and adverse consequences of flooding.

The scale and magnitude of the Hawkesbury-Nepean flood problem in the highly developed valley became apparent during studies in the early 1990's into the safety of the Warragamba Dam wall. The landforms of the Hawkesbury-Nepean valley have created a unique flood setting that has the potential for isolating and then totally inundating long-established towns and villages. Entire towns and extensive suburbs lie well below the level of the probable maximum flood (PMF) and would experience floodwater depths of up to 2 metres in a repeat of the 1867 flood of record and up to 9 metres depth in the extremely rare PMF above the current flood planning level (based on a 1 in 100 AEP flood event). Such depths create very hazardous situations for both people and property.

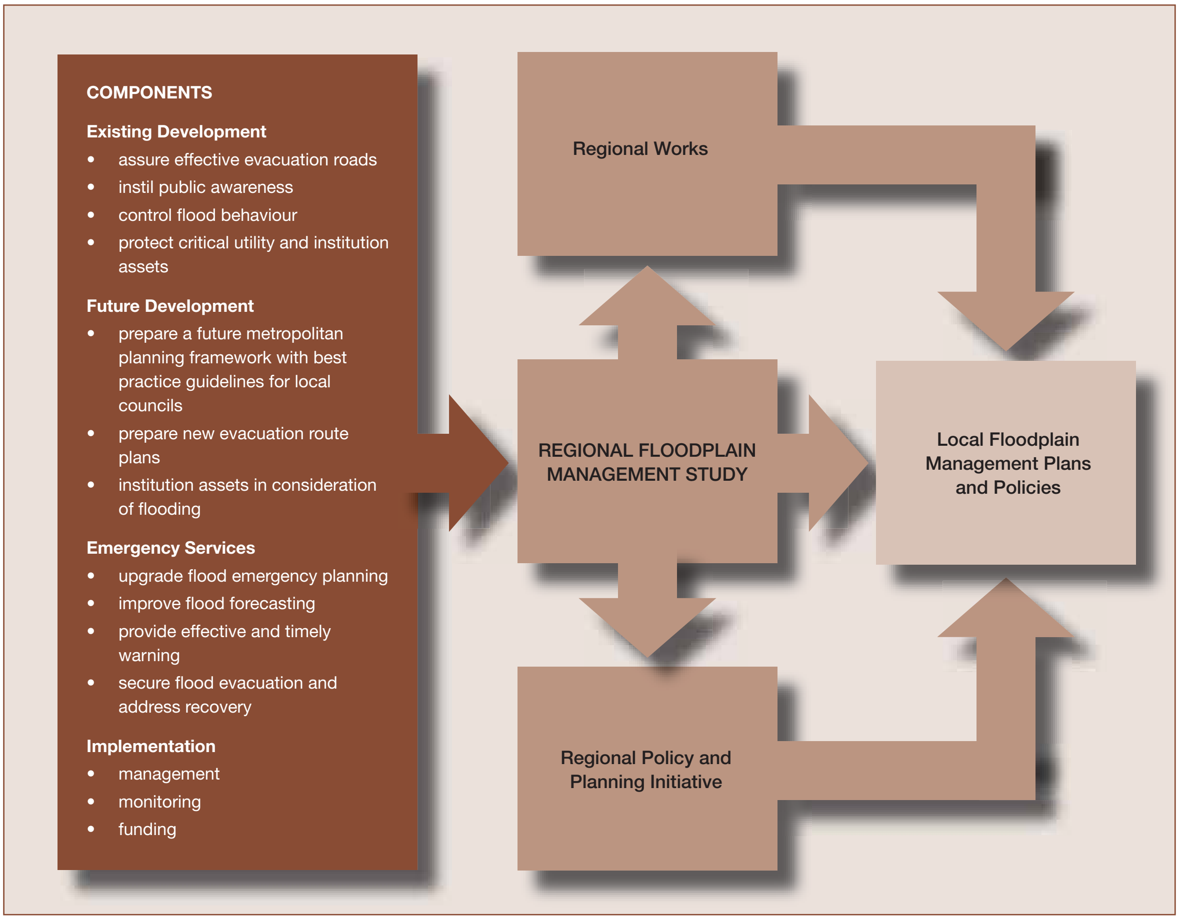
In order to address this problem and to protect existing and future communities and prevent an increase in damages and losses arising from new floodplain development, the NSW Government committed $71 million over six years from 1998 to the implementation of the Hawkesbury-Nepean Floodplain Management Strategy (the Strategy). This was done in conjunction with the decision to build an auxiliary spillway to protect the dam itself. The Strategy was directed by a multi-agency Steering Committee, chaired by the Department of Natural Resources (DNR).

Partner Agencies in the Hawkesbury-Nepean Floodplain Management Strategy

- Department of Natural Resources (DNR)
- Department of Planning
- State Emergency Service (SES)
- Roads and Traffic Authority (RTA)
- Department of Community Services (DoCS)
- Sydney Catchment Authority (SCA)
- Baulkham Hills Shire Council
- Blacktown City Council
- Gosford City Council
- Hawkesbury City Council
- Hornsby Shire Council
- Penrith City Council

The structure for the implementation of the Strategy, including overall components and proposed outcomes which was adopted by the NSW Government in 1998, is shown in Fig i.

Figure i *Integrated implementation process adopted for the Hawkesbury-Nepean Floodplain Management Strategy*

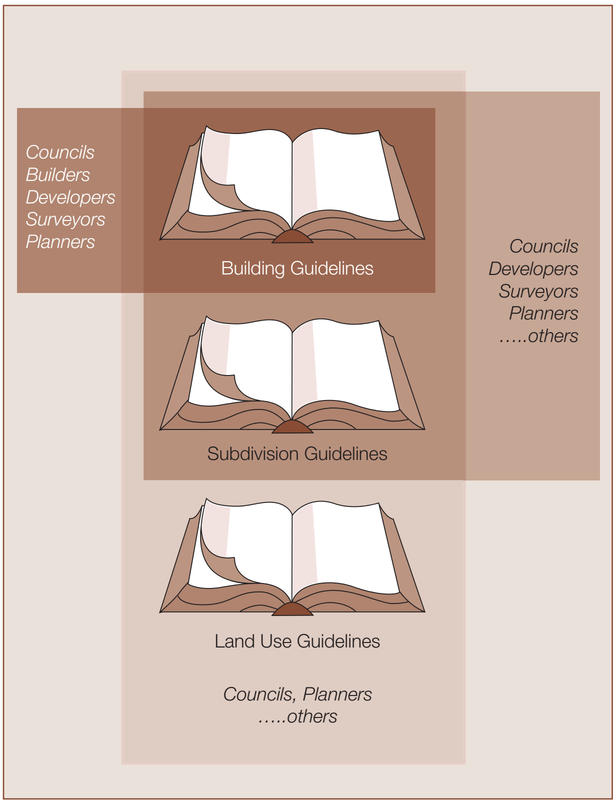


In NSW, councils have responsibility for floodplain risk management in their areas, assisted by technical and financial support from the State Government. One of the key Strategy outputs to assist Hawkesbury-Nepean floodplain councils in this process is the Regional Floodplain Management Study (RFMS). The RFMS includes a suite of emergency management and floodplain risk management measures including guidance on land use planning, subdivision and building on flood prone land. The information provided through the RFMS facilitates informed decision-making about development on flood prone land to assist in reducing the increase in the adverse consequences resulting from flooding.

What is the Hawkesbury-Nepean Regional Floodplain Management Study?

- Detailed evacuation routes upgrade program
- Guidance on land use planning in flood prone areas including a methodology to identify flood risk
- Guidance on subdivision design in flood prone areas
- Guidance on building in flood prone areas
- A flood hazard definition tool compatible with GIS
- Concepts for a regional public awareness program
- Briefing plans to assist utility providers prepare recovery plans
- Improving flood forecasting and flood warning

Figure ii *Who can the RFMS Guidance reports help?*



The guidance provided through the RFMS is available to *guide* development; in itself it does not *regulate* development. It offers a regionally consistent approach to floodplain risk management designed to facilitate informed decision making for strategic land use planning, infrastructure planning, subdivision design and house building on flood prone land. The guidelines provide councils, government agencies, developers, builders and the community with in-depth background information, methodologies, strategies and practical means to reduce the flood risk to new development and hence provide a more sustainable future for residents, the business community and workers.

MANAGING FLOOD RISK THROUGH PLANNING OPPORTUNITIES – GUIDANCE ON LAND USE PLANNING IN FLOOD PRONE AREAS

The guidance contained in *"Managing Flood Risk Through Planning Opportunities – Guidance on Land Use Planning in Flood Prone Areas"* (referred to here as the Land Use Guidelines) aims to provide local councils, government agencies and professional planners with a regionally consistent approach to developing local policies, plans and development controls which address the hazards associated with the full range of flood events up to the probable maximum flood (PMF). In accordance with good risk management practice these guidelines give weight to finding solutions for the more frequent flooding problems.

Guidance is provided on the development of flood prone land for a range of common land uses. A methodology to rate risk and define risk bands is included to assist councils in their flood risk analysis. For residential development, it proposes a series of risk bands as a tool to better manage the flood risk for the full range of floods. It is specifically aimed at all professionals involved in strategic, regional and local planning including development control.

Users are strongly advised to not limit their information sources only to the Land Use Guidelines, but to familiarise themselves with the concepts put forward in *"Designing Safer Subdivisions – Guidance on Subdivision Design in Flood Prone Areas"* and *"Reducing Vulnerability of Buildings to Flood Damage – Guidance on Building in Flood Prone Areas",* Fig ii. Together the three documents provide comprehensive information on how finished landforms, road layouts, building design, construction methods and materials can influence the consequences from flooding and hence flood risk.

DESIGNING SAFER SUBDIVISIONS – GUIDANCE ON SUBDIVISION DESIGN IN FLOOD PRONE AREAS

This document,*"Designing Safer Subdivision – Guidance on Subdivision Design in Flood Prone Areas"* provides practical guidance to assist in the planning and designing of safer residential subdivisions on flood prone land. Referred to here as the Subdivision Guidelines, the document aims to provide practical means to reduce the risk to life and property for new subdivisions. Although specifically written for development in the Hawkesbury-Nepean valley, it is generally applicable to all flood prone land. The Subdivision Guidelines offer increased safety for residents through the promotion of efficient design solutions, which are responsive to the varying range of flood risk. The guidelines include cost-effective and environmentally sustainable solutions to minimise future flood impacts on buildings and associated infrastructure.

The Subdivision Guidelines contain detailed information regarding site preparation, road layout and drainage information relevant to professionals engaged in the planning, surveying, development and assessment of residential subdivisions on flood prone land.

Users of the Subdivision Guidelines would find it beneficial to also familiarise themselves with the concepts of flood aware housing design provided in the Building Guidelines when designing or assessing flood-responsive residential subdivisions.

REDUCING VULNERABILITY OF BUILDINGS TO FLOOD DAMAGE – GUIDANCE ON BUILDING IN FLOOD PRONE AREAS

Modern housing construction results in houses that are ill equipped to withstand inundation or fast flowing water. Given the lack of availability of comprehensive domestic flood insurance, most homeowners of flood prone property are potentially very vulnerable to major losses. *"Reducing Vulnerability of Buildings to Flood Damage – Guidance on Building in Flood Prone Areas"*, referred to here as the Building Guidelines, provides specific and detailed information on house construction methods, materials, building style and design. This approach can reduce structural damage due to inundation or higher velocities and facilitate the clean up after a flood, thus reducing the costs and shortening the recovery period.

The Building Guidelines include information on how flooding affects the structural components of a house. The document:

- highlights potential problems for houses subjected to flood water;
- discusses the benefits and disbenefits of choosing various materials and construction methods and discuss methods to solve those problems;
- provides indicative costs of adopting those solutions; and
- advises of the appropriate post-flood actions to repair or reinstate the damaged components.

The guidance is provided for the building industry, council health and building surveyors, builders and owner builders. Assuming the appropriate zoning applies when a residential project is proposed, it is not anticipated that builders or owner-builders involved in single house projects would need to seek further information from either the Subdivision or the Land Use Guidelines. However, for larger scale housing developments or multi-unit housing, reference should be made to the relevant information contained within the companion Subdivision and Land Use Guidelines.

1 THE SUBDIVISION PROCESS

1.1 Rezoning of Land

The guidance offered in this document is based on the assumption that residential subdivision is a permissible use of the land in an environmental planning instrument. If rezoning of a floodprone site to permit residential subdivision is proposed however, supporting information should demonstrate how the land could be subdivided without compromising the objectives of the local environmental plan and should demonstrate how the flood risk can be managed. Whilst a conceptual layout plan showing lot boundaries, roads etc may be produced to support the rezoning, it does not form part of the amending LEP, and may not be the eventual layout which is developed on the site.

1.2 Traditional Subdivision Practice

The process of land subdivision includes several distinct phases, which are discussed below.

1.2.1 Pre-purchase Feasibility Studies

Feasibility studies aim to identify the major constraints and opportunities for development so that anticipated development costs and sales income can be compared to determine whether the projected returns are sufficiently attractive and cash flow viable.

These studies are often largely based on a site inspection, the judgement of experienced professionals, knowledge of local planning policies and assumptions as to likely final development outcomes. There is typically very little site specific descriptive data available for the analysis, but this is paradoxically the point at which the decision whether or not to commit to the development and bear the associated costs is made.

The guidance on flood related issues given in this document should be considered during the feasibility analysis to assess the implications for development potential and associated costs.

1.2.2 Development Application

A development application (DA) is made to the consent authority. This is usually the local council but for significant development, may be the Minister for Planning. The consent authority will usually require the DA to be supported by detailed studies into the range of issues that relate to the site to demonstrate how the land is to be developed for the proposed use.

Depending on the scale of the development proposed, broad scale neighbourhood planning and/or some preliminary design (eg road and drainage long sections) may be necessary. From these plans a layout plan is produced showing lot boundaries, roads, parks, drainage corridors and any other uses as required.

Councils generally welcome early pre-application discussion about proposed developments to avoid later delays, costs or disputes involved in any necessary re-drafting.

1.2.3 Approval

A development consent is subject to a range of conditions which ensures the development proceeds according to the approved plans and directs the applicants to carry out further matters e.g. site investigations, detailed plans, works or landscaping which may be required.

If staging is necessary, (usually only in larger subdivisions), this should be determined at the DA stage. It is common that a single DA will be approved for several sequential stages. Where the provision of a reliable flood evacuation route is essential for the first occupants, the correct sequencing of each stage of the development is essential. This can be controlled through appropriate development conditions.

1.2.4 Engineering design

Most detailed engineering design is generally done to meet the requirements of the development conditions. Whilst some preliminary design may have been done during preparation of the DA, (eg road long sections), detailed construction plans for roads, paths, power & telecommunications plant, sewer, water and gas mains and the like are not usually undertaken until the development is approved and the conditions of consent are known.

The connection points to existing infrastructure such as roads and sewers are identified and the site is then generally designed from those points uphill into the site. This approach usually minimises the initial infrastructure provision costs in the first stages of the development.

1.2.5 Construction

Construction of the physical infrastructure of the subdivision involves significant costs to the developer. The developer will therefore typically try to manage construction activities to bring lots onto the market at a rate which matches the demand.

1.2.6 Marketing and Selling

Developers provide a product, i.e. new dwellings, for which there is a demand. Marketing and selling the lots is the first step in the process that provides a return to the developer. In staged developments early lot releases can help finance later stages.

1.2.7 Why can this approach lead to problems on floodplains?

There is an assumption in the community that authorities would not permit residential subdivision in an area subject to natural hazards, (Cox & GHD 2001), and prospective purchasers are unlikely to ask about flood compatibility. Given this low level of community flood awareness, flood risks and hazards to residents are largely overlooked in the design of residential subdivisions. This is particularly true of the flood risks arising from events more severe than the adopted flood planning level.

There are numerous examples of relatively recent residential subdivisions on flood prone land, where evacuation is made more difficult than it need have been because the roadway which is also required for emergency access and evacuation is located at a lower level than the dwellings. Thus suburbs can become totally isolated in a flood with the potential to trap residents who, in the absence of any visible threat from floodwaters, (as is the case in Hawkesbury-Nepean flooding), fail to recognise the risk and do not evacuate in time. Opportunities are also lost at the subdivision stage by not recognising the potential to reduce property damage and disruption to urban infrastructure by appropriate design solutions.

1.3 Roles and Responsibilities Associated with Land Use Change

1.3.1 Land Owners

- May develop their own land or more likely, enter into a joint venture with, or sell to a property developer.
- Should undertake early consultation with the council.
- Can be a source of important information regarding site characteristics and historic flood or drainage behaviour.

1.3.2 Property Developers

- Bring together the land, finance, design, construction and marketing required for development.
- Determine a concept for the development and control the planning and design approach taken.
- Favour well-tried approaches successful elsewhere to avoid delays which tend to be costly.
- May choose not to go beyond the minimum development standards required by council.
- Tend to adopt innovative approaches only if there is a commercial advantage or financial risks are reduced e.g. fewer delays.
- Have duty of care obligations to the future residents to ensure all stages of the development are flood compatible and based on the best available information.

1.3.3 The Design Team

- Subdivision design often undertaken by engineers and/or land surveyors.
- Single discipline approach can limit vision or innovation.
- Use of multi-disciplinary team including landscape architects, town planners, urban designers, engineers (traffic, water, civil) and land surveyors is more likely to produce synergistic innovation in planning and design.

- At the detailed design stage, a multi-disciplinary design team should consult a range of experts which may include soil scientists, archaeologists, environmental scientists and others including any long term residents or owners.
- From the concept design stage onwards, the planning and design of the site should include the
  - evacuation capability of all occupied land within the development, and
  - minimisation of flood damage potential to public and private assets.
- The design team should be aware of the developer's duty of care obligations to future residents to ensure all stages of planning and design are flood compatible and based on the best available information.

1.3.4 Real Estate Agents

- Act as intermediaries and advisors to vendors and purchasers in most land sales.
- Have the opportunity to promote flood compatible subdivision to developers and residents.
- Can influence developers to adopt a flood compatible design and development approach by emphasising the marketing benefits of a product with reduced risk from natural hazards.
- Have duty of care obligations to both the developer and future residents to pass on their knowledge of the site and the advantages of flood compatible development.

1.3.5 Councils

- Council's local floodplain risk management study and plan can lead to amendments to the local environmental plan and development control plan, to respond appropriately to the flood risk through flood compatible development controls.
- Council consults and involves the community in both the floodplain risk management and the planning processes.
- Liaise with prospective developers regarding compliance with planning instruments and policies relating to flood compatibility.
- Determine development applications and apply and enforce development conditions.
- Have duty of care obligations to inform purchasers of land and occupants of land of council's flood prone land policies in relation to safety from known natural hazards including flooding.
- Communicate flood risks so that existing and future occupants of the floodplain can make informed decisions.

1.4 Duty of Care

This section is not intended to be a substitute for obtaining independent legal advice on floodplain risk management decisions. It is simply intended to alert public authorities and others to their duty of care when carrying out floodplain risk management functions.

The Local Government Act 1993 (s. 733) offers indemnity to a public authority for flood liable land decisions which it makes, or advice which it gives in good faith, provided that the decisions are substantially in accordance with the principles contained in the NSW Floodplain Development Manual 2005. *The Civil Liabilities Act 2002* may also assist in determining liability.

All parties involved in development decisions have a general duty of care to take reasonable care to avoid foreseeable risks of injury or harm to the residents and workers who will ultimately live or work on that land. The onus rests with the authority making the decision to ensure that due process in relation to floodplain risk management is complete and accurate and that reasonable recommendations are complied with. If it is known that flooding is inevitable and that steps can be taken to reduce damage and loss of life then a failure to act appropriately may be considered to be negligent. Authorities can take risk mitigation measures to assist in discharging their duty of care. These guidelines and the accompanying Land Use and Building Guidelines put forward a range of measures which can be adopted to mitigate the flood risk to future occupants of floodprone land.

Of importance, is how obvious is the flood risk. Research has found that public awareness of flooding is low especially in extensive floodplains such as in the Hawkesbury-Nepean where the flood risk is not obvious. The flood risk within the floodplain varies but this varying risk is not apparent to the average person. It is reasonable to conclude that most people would not regard Hawkesbury-Nepean flooding as posing an obvious risk. Those individuals who have been exposed to Hawkesbury-Nepean flooding in the past have only experienced relatively minor floods, even though they may have been extensive in area. These minor floods have affected predominantly rural land and have had benign behaviour compared to the severe Hawkesbury-Nepean floods which will occur at some stage in the future.

The Civil Liabilities Act 2002 states that a person (in this case, a floodplain management authority and consent authority) is not negligent in failing to take precautions against a risk of harm unless:

- ***The risk was foreseeable***
  If the flood risk is known, it is foreseeable.
- ***The risk was not insignificant***
  In many parts of the Hawkesbury-Nepean floodplain, major flood risk is very significant with serious consequences.
- ***A reasonable person in the same circumstances would have taken those precautions (against a risk of harm)***
  These guidelines promote better flood risk mitigation approaches to residential subdivision.

An important issue is the 'proximity' of those authorities who are making the decision on risk mitigation measures, and those taking the risk (residents, workers, tenants). Clearly the authority which makes a decision is not the same as individuals thus affected by that decision. That authorities know;

- major or severe flooding poses significant risks to residents, and
- those residents are made more vulnerable because they are not able to be protected by flood insurance,

puts a higher onus on the authorities to act reasonably to prevent losses and/or danger when determining residential subdivision. The low probability of major or severe floods occurring does not diminish that responsibility.

If this duty of care is not exercised appropriately, people whose property and possessions are flooded or whose lives and well being are endangered by flooding may be able to sue for damages under the law of negligence. In suing for negligence, a plaintiff must demonstrate that:

- a duty of care existed
- the duty of care was breached, and
- consequential injury and/or damage arose.

The existence or otherwise of a duty of care between a plaintiff (e.g flood affected resident) and defendant (e.g. council) depends upon what is known as the 'relationship of proximity' between the two parties. In other words is it reasonable for the plaintiff (resident) to rely on the defendant (council) for having ensured that appropriate protection against the risk of injury or damage arising from flooding is in place.

It would appear necessary for the decision maker to take all the reasonable measures that a 'reasonable person' would have undertaken. In the case of floodplain decisions, a 'reasonable person' is not expected to be an expert in floodplain management. Indeed simply employing an expert, even though he or she may be apparently competent in floodplain management, is not sufficient to discharge the duty of care.

If the flood risk is foreseeable, even although mathematically unlikely, and the seriousness of the potential damage is high, then the standard of care will be increased. This is particularly important because the consequences of rarer floods can be far more severe and possibly catastrophic if not managed adequately.

In determining the standard of care, the Courts balance the seriousness of the injury which is likely if the relevant risk eventuates, the likelihood of the risk eventuating, and the expense, difficulty and inconvenience involved in taking preventative measures. However, even if appropriate risk reduction measures incur a cost, additional cost will not be sufficient reason for not adopting those measures.

When conditions are imposed on a development in order to reduce the flood risk, the authority imposing those conditions has a responsibility to enforce those conditions.

If the flood risk is foreseeable, even although mathematically unlikely, and the seriousness of the potential damage is high, then the standard of care will be increased.

This is particularly important because the consequences of rarer floods can be far more severe and possibly catastrophic if not managed adequately.

1.5 Benefits from the Guidelines

These guidelines promote ecologically sustainable development (ESD) approaches to subdivision planning and design which is consistent with government policies and objectives. Their implementation could assist in producing safer subdivisions with a range of advantages that can benefit all parties involved in the subdivision process and the future occupants.

Conventional subdivision practice has not planned for the consequences of floods greater than the design flood, usually the 1 in 100 AEP event, which is generally adopted as the design flood for the residential flood planning level. As the largest flood on record in the Hawkesbury-Nepean is over 2 metres deeper than the 1 in 100 AEP flood, and the probable maximum flood over 9 metres deeper, it is clear that consequences of rarer floods can be severe[1].

By anticipating and addressing flood risk management concerns early in the subdivision process, as advocated in these guidelines then the approval process is likely to proceed more quickly and smoothly, thus avoiding costly delays.

By avoiding high hazard areas and by designing in response to the flood hazard, safer subdivisions with reduced flood risks can be achieved with a comparable yield to traditional subdivisions.

Subdivisions planned in accordance with these guidelines can offer more open space in the high hazard floodway areas with more compact residential precincts. This offers opportunities to reduce the amount of infrastructure required with shorter street and utility runs (water, sewer, power and communication). Street pavement area may also be reduced and thus stormwater costs reduced.

By mimicking or replicating the natural flood and stormwater drainage run-off rates and behaviour across the site there can be catchment-wide benefits through improved control of water quantity and water quality impacts.

The retention of riparian buffers in areas of high flood hazard provides social and environmental benefits including corridors of native vegetation for local fauna, wetlands and open space features such as playing fields for active recreation. Being highly visible and attractive features, buffers can enhance a development and its marketability is increased.

The retention of open space along identified drainage paths enables opportunities for multiple use and provides significant scope for the cost-effective provision of informal and formal recreational facilities, including pedestrian paths and cycle ways. It eliminates the costly provision of separate circulation, stormwater drainage and recreational facilities.

The guidelines provide information to enable subdivision to be designed to minimise flood impacts on future residents and their property as well as preventing flood impacts off the site. There are significant social benefits in making a development safer for the residents and in reducing the exposure to flood damages to their property.

[1] These figures relate to flood levels in Windsor and vary for other parts of the Hawkesbury-Nepean floodplain.

2

UNDERSTANDING CATCHMENTS AND FLOODING

2.1 Developing on Floodplains

Floodplains have been occupied since historic times with the lowest lying areas nearest to the rivers used mainly for agriculture and recreational purposes. Some commercial and industrial uses are also sited at lower levels. Although residential development has generally tended to locate on higher land out of reach of the more frequent floods, some older dwellings remain lower than the current flood planning levels applied to new development.

In highly developed floodplains such as the Hawkesbury-Nepean valley, the best available land tends to have already been developed, so the land that remains is often more marginal. It may have a higher flood risk or other constraints that present challenges. As flooding can materially affect the development of a site and influence its design, flooding should be addressed at the rezoning stage. Floodprone sites require careful planning and design if the flood risk is to be minimised. The more hazardous the location the more care needs to be taken in planning and design of new developments. Further information on this can be found in the Land Use Guidelines.

Many factors are considered when planning a subdivision on floodprone land, and flooding is only one of those considerations. However, flooding is a natural hazard which can have serious consequences if not given due regard and care at the subdivision stage.

However, the complexity of flooding has lead to a poor understanding of flood hazard and flood risk and this has been reflected in subdivision practice. That flooding varies along and across the river valley and includes both overland flow floods and floods caused by mainstream overflows, has not always been recognised in planning for new development. Flood risk has traditionally been addressed by very simplistic development controls that concentrate on one flood planning level for habitable floors – usually the 1 in 100 AEP flood level, plus a freeboard, typically 0.5 metre together with restrictions on land uses below that level. There are rarely any development controls relating to flooding on land higher than the 1 in 100 AEP flood, yet there remains a continuing risk from rarer floods that can be particularly hazardous because of extreme depth or velocity. Where flooding leads to isolation and eventual inundation if floodwaters continue to rise, as in the Hawkesbury-Nepean valley, early evacuation of residents is essential. There are many examples of new subdivisions where roads have not been designed with evacuation in mind, thus increasing the risk for the residents.

Whilst the Floodplain Development Manual (2005) provides guidance on areas within the floodplain that are suitable for different types of development, it does not discuss the relationship of development to local and main river flows. This guideline aims to bridge this gap to assist developers, planners and engineers in recognising how to minimise potential problems and make use of opportunities to reduce the risk. To achieve safer floodplain occupation, a better understanding and appreciation of flood behaviour and associated risks is essential if flooding is to be a fundamental upfront matter for consideration in planning new developments.

The primary objective of these guidelines is to promote better subdivision practice for floodprone land:

- to reduce the risk to the occupants of the floodplain.

Additional but nonetheless critical objectives are to promote better subdivision practice to ensure that:

- the hydrologic and hydraulic functions of the floodplain are maintained i.e. the safe conveyance of flood flows, provision of flood storage to attenuate and slow the speed of the discharging floodwater;
- the natural geomorphic processes of watercourses and floodplains can occur thus allowing for natural erosion and deposition;
- riparian corridors are retained in a natural state and are of sufficient size to promote flora and fauna conservation;
- space is provided to allow water to spread or be stored temporarily in wetlands or detention basins; and

- space is provided on the floodplain for community recreational needs together with maintaining landscape and open space values.

Provision of wetlands and riparian corridors within a subdivision can also ensure that water quality is maintained.

To achieve these objectives, consent authorities, usually councils, and others involved in the development design and approval process need to work within a multi-objective framework that takes into account the community's economic, social and environmental goals to develop urban land which is both safe and sustainable.

Different management measures are described in the guidelines to assist in minimising the flood hazard and reducing flood risks to development, recognising that each particular site has unique characteristics. Subsequent Sections give more detailed guidance on some of these measures including trunk drainage systems, retarding basins, floodways and riparian buffers.

This part of the guidelines explains:

- some of the important aspects of flood behaviour which warrant consideration in planning new subdivisions,
- how to enhance general understanding of flood behaviour,
- how flood behaviour varies longitudinally and laterally within a river valley, and
- how to better understand the constraints that the full range of flooding represents.

2

2.2 Variation in Flood Behaviour

As flood behaviour varies depending on location within a catchment, the potential flood risks for existing and future development also varies.

A typical catchment may be divided into three broad zones: the upper reaches, middle reaches and the lowlands, (Figure 1). However, the size of the catchment is an important contributing factor which can lead to significant variations in 'typical' values. For example small coastal catchments such

Figure 1 *Catchment Zones*

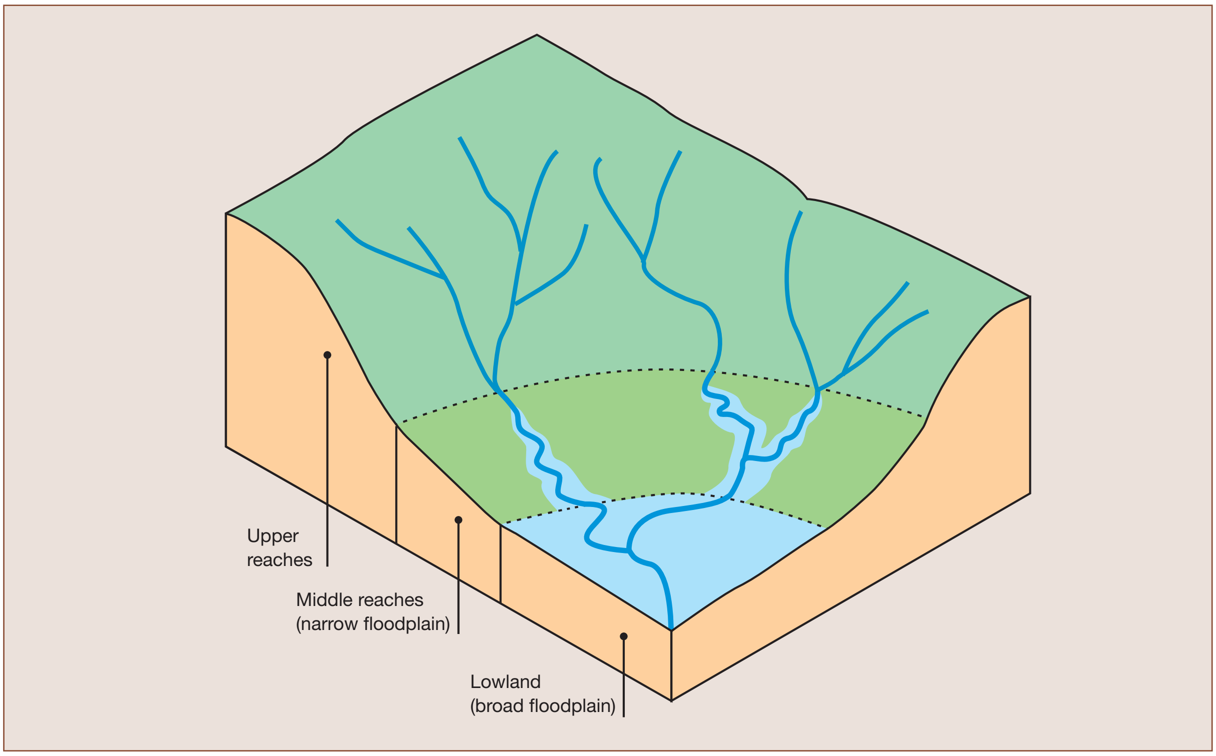


Table 1 *Catchment Zone Characteristics*

Typical Characteristics	Upper Reaches (and tributary streams)	Middle Reaches (Transitional zone)	Lowland areas (Floodplain proper)
Terrain	Steep and rugged	Gentle and undulating	Flat and extensive
Stream slopes	Steep	Moderate	Mild
Channel and floodplain definition	Incised channel, narrow floodplain	Variable	Wide channels with large overbank floodplain
Typical stream definition	Rills, depressions, overland flow paths, natural watercourses	Sinuous creeks and streams	Large creeks and tidal rivers
Speed of flood arrival	Flash flooding (less than 4 hours)	Moderate (in the range 4 to 18 hours)	Slow (up to several days for large rivers)
Typical warning time	None	Up to several hours	Generally up to several days (but as little as 10 hours in the Hawkesbury-Nepean)
Typical maximum velocities*	High (3 to 5 m/s)	Medium (1.5 to 3 m/s)	Generally low (<1 to 2 m/s)
Typical hydraulic hazard (depth x velocity)	Medium to high	Medium to high	Low to high
Effect of downstream and ocean levels	Usually nil to small	Can be significant.	River entrance can be closed intermittently.
Backwater effects from hydraulic restrictions	Can be significant on a localised basis but typically insignificant for areas upstream.	Greatest potential for impacts and can be just as great as for lowlands	Can have widespread implications and extend significant distances upstream

* Velocities at a given location increased until bankfull or overflow begins. With higher flows the impact of cross section geometry and roughness of the channel and floodplain combine to cause the average velocity to possibly decrease slightly or remain constant.

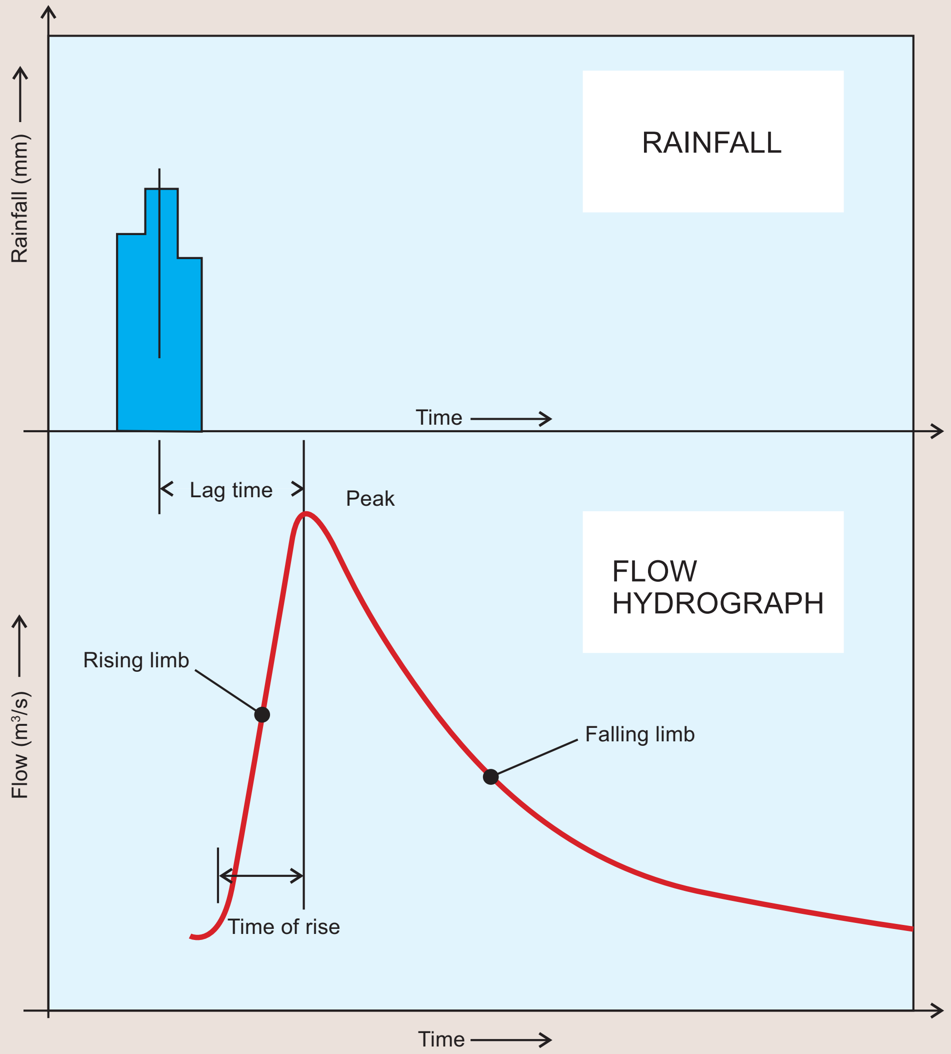
as those in Sydney, Wollongong and Coffs Harbour, are influenced by intense, short duration storm events which have no warning and can be over in a matter of hours. The typical characteristics of these zones are summarised in Table 1.

2.2.1 Timing Factors

Water which constitutes stream flow reaches the channel by any of several paths from the point where rainfall reaches the ground. As a result, there is a lag between the centroid[2] of rainfall and when the stream flow reaches its peak (Figure 2).

[2] *Centroid: This relates to the point in the duration of a rain event when as much rain has already fallen as has yet to fall. The centroid may not coincide with the peak rainfall. Clearly, the centroid of a rainfall event can only be ascertained after the event.*

Figure 2 *Typical Flow Hydrograph*

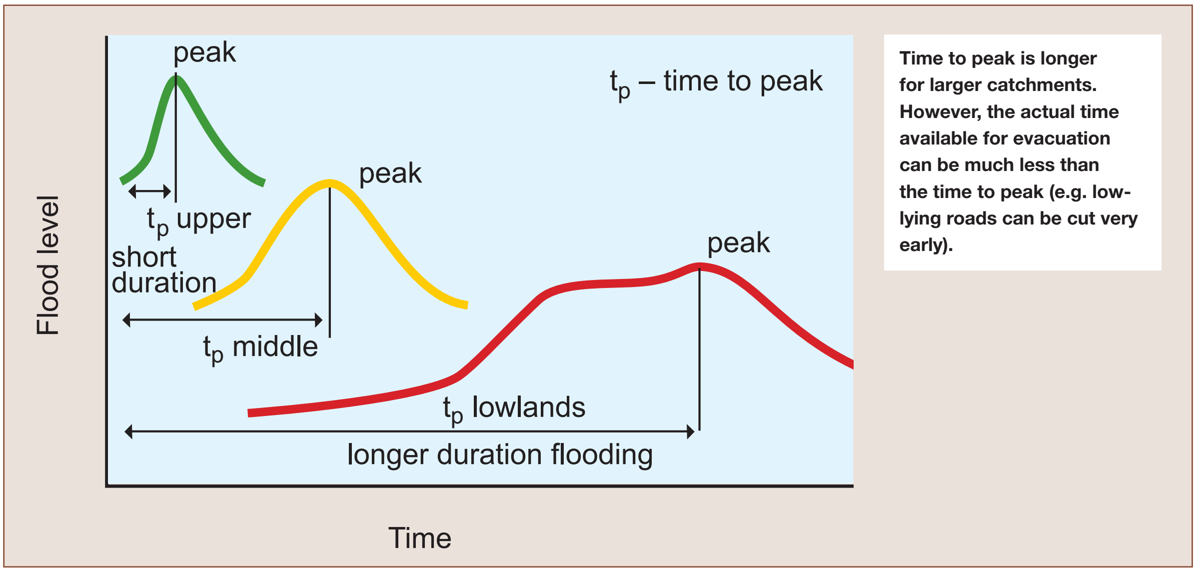


In addition to catchment shape and relief, the shape of the rising limb of the flow hydrograph is influenced by the storm intensity and spatial distribution. The shape of the falling limb is dependent on storage characteristics within the catchment (e.g. stream channel, surface soil and ground water storages).

Table 2 *Relative Timing Factors for 1% Events*

Upper Reaches			Middle Reaches			Lowland Areas		
Critical Storm Duration	Travel Time	Effective Warning Time	Critical Storm Duration	Travel Time	Effective Warning Time	Critical Storm Duration	Travel Time	Effective Warning Time
Typical Range of Values								
5min-2hr	nil-1hr	nil	15min-12hr	15min-6hr	nil-3hr	12hr-72hr	6hr-48hr	3hr-24hr
Example Values from Actual Catchments								
15min	<5min	nil	9hr	3hr-6hr	nil-3hr	72hr	24hr	12hr-24hr

Figure 3 *Time to peak and periods of inundation*



Because of their terrain characteristics, stream slopes and relative catchment sizes, the three zones also have different timing factors. As shown in Table 2, flooding in the upper reaches is usually caused by short duration storms, typically thunderstorms, or the more intense parts of larger storm systems. In such cases there is no opportunity for either flood warning or evacuation once the storm commences.

Flooding in the middle reaches is typically caused by longer duration storms in the order of up to twelve hours duration, giving limited opportunity for flood warning.

In the lower reaches flooding is a result of the accumulation of runoff from the upper and middle reaches of the various tributary systems.
Due to the extended travel time involved, it is the longer duration storms (with significant volumes of rainfall) which cause major flooding. Often the rain may have ended when the peak flood levels occur. Real opportunities exist to provide reliable flood warnings for the lowland areas giving the chance for residents to move belongings and thus minimise flood damages.

The relationship between hydrographs and timing are shown in Figure 3.

2.2.2 Hydraulic Properties

The variations in some expected value ranges for peak flows, velocities and potential hydraulic impacts (affluxes) in the upper, middle and lower reaches are shown in Table 3. The potential for greater affluxes due to obstructions in the upper reaches is directly influenced by the higher velocity values expected in these areas. While the peak flows are much larger in the lower reaches, the broadening of the overbank floodplain areas reduces the velocities, hence reducing the potential for large hydraulic impacts, (Figure 4).

The relative increases in depth of inundation for the different zones as they vary with location and flood magnitude, are shown in Table 4.

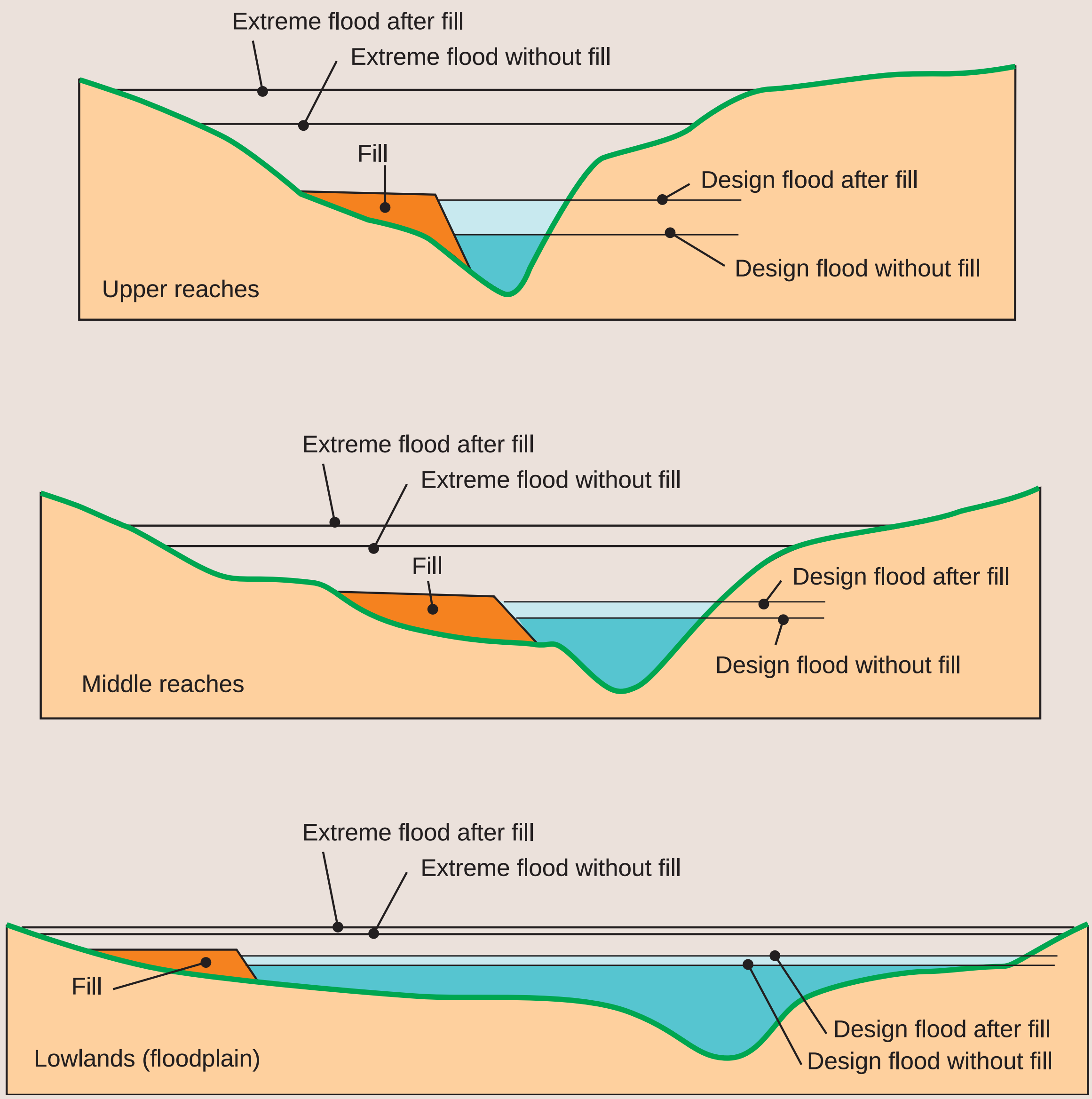
The contribution and volume of flow in a channel increases as it moves down the catchment and as the storm probability decreases with larger events. In the Hawkesbury-Nepean valley, the significant

***Table 3** Typical Hydraulic Properties*

	Upper Reaches			Middle Reaches			Lowland Areas		
Event	Peak Flows (m^3/s)	Velocity (m/s)	Impact * (m)	Peak Flows (m^3/s)	Velocity (m/s)	Impact* (m)	Peak Flows (m^3/s)	Velocity (m/s)	Impact* (m)
Typical Range of Values									
5%	1-40	1.5-4.0	0.1-0.8	15-350	1.0-2.5	0.05-0.3	200-15000	0.1-1.5	0.0-0.2
1%	1-50	3.0-5.0	0.2-4.4	20-500	1.5-3.0	0.05-0.4	250-20000	0.2-2.0	0.0-0.2
Example Values from Actual Catchments									
5%	20	1.7	0.29	270	0.9	0.08	8700	0.5	0.03
1%	30	1.9	0.37	370	0.9	0.08	11600	1.0	0.10

** Increase in flood level due to obstruction (afflux)*

***Figure 4** Hydraulic Impacts*



A similar amount of filling causes greater proportional increase in flood levels in upstream areas because of the greater impact of a reduction in flow cross section area. Stream velocity decreases downstream through the upper and middle reaches to the lowlands because of the widening cross section and more gradual stream bed gradient.

Table 4 *Relative Increase in Depth of Inundation (in metres)*

Event Frequency	Upper Reaches	Middle Reaches	Lowland Areas
Typical Range of Values			
5% - 2%	0-0.15	0-0.7	0.5-2.0
2% - 1%	0-0.2	0-0.7	0.5-2.0
1% - PMF	0.4-3.0	0.9-4.0	2.0-10.0
Example Values from Actual Catchments			
5% - 2%	0.15	0.2	2.0
2% - 1%	0.1	0.2	1.6
1% - PMF	0.7	10.0	8.2

increase in the values in the 1% to PMF range for the middle reaches and lowlands demonstrates the transitional hydraulic nature of these zones. Here, the increases in inundation for the smaller events are primarily influenced by local catchment behaviour, whilst the increases for the larger events can be due to backwater effects from downstream in the lower reaches.

2.3 Influence of Catchment Characteristics

Catchment are also known as drainage basins or a watersheds. An indication of the nature of flood hazard at a site and what can be done to ensure its suitability for development can often be gained from examining some of the catchment's physical characteristics. These include size and shape, stream network and drainage basin relief as in slope and elevations of the ground surface. These characteristics influence watershed processes both individually and collectively.

2.3.1 Catchment Size

In larger catchments, the significance of each of the characteristics tends to be harder to distinguish. This is because they become less uniform over a larger area and the non-uniformity of other properties such as soil cover, vegetation and land use, as well as rainfall intensity and distribution also become more evident. In general though, storm discharge per unit area is inversely proportional to the size of a catchment i.e. catchments of smaller area have higher floods per unit area. This is partly due to the increased storage potential of larger drainage basins such as in channels, floodplains and lakes etc. In addition, in catchments of larger size it is not possible to maintain high rainfall intensities over their entire area.

2.3.2 Catchment Shape and Stream Network

The shape of the catchment has an influence on the shape of the hydrograph, because it has an effect on lag time, time of rise and other hydrograph parameters, (Figure 5).

The shape of the catchment and its network of drainage streams are closely related.

2.3.3 Catchment Relief

The higher the relief, the steeper the slopes and the greater the energy available to move flows through the catchment. Catchments with the highest relief ratio (i.e. difference in elevation between top and bottom of catchment over its length) have shorter lag time and time of rise, (see Figure 6), as well as higher peaks and flow velocities. These catchments present a greater challenge, because even though the volume of floodwater may be the same for a similar size catchment, flooding can become far more dangerous because the waters are more concentrated and the magnitudes of the peaks higher.

Figure 5 *Catchment Shape Impacts*

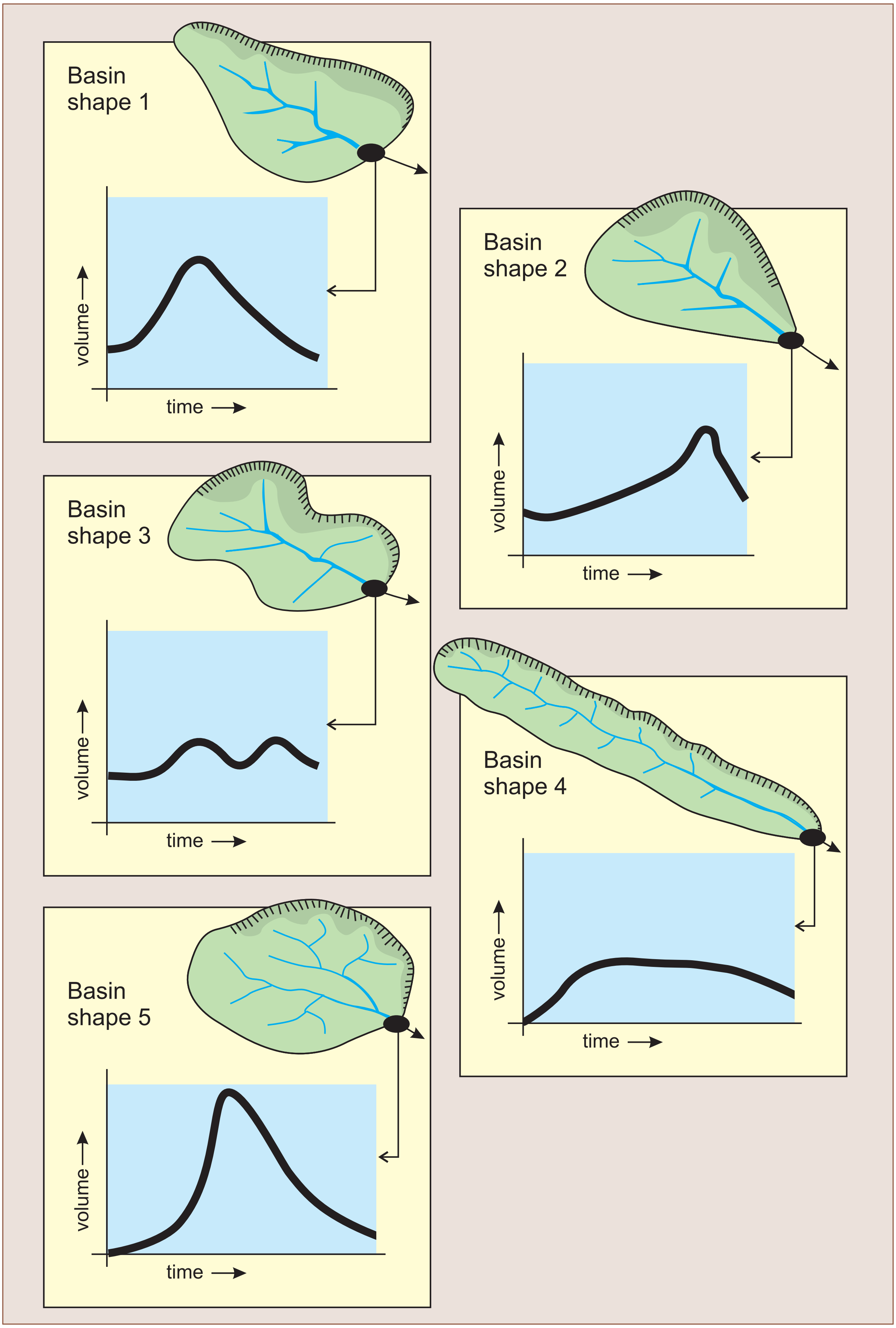
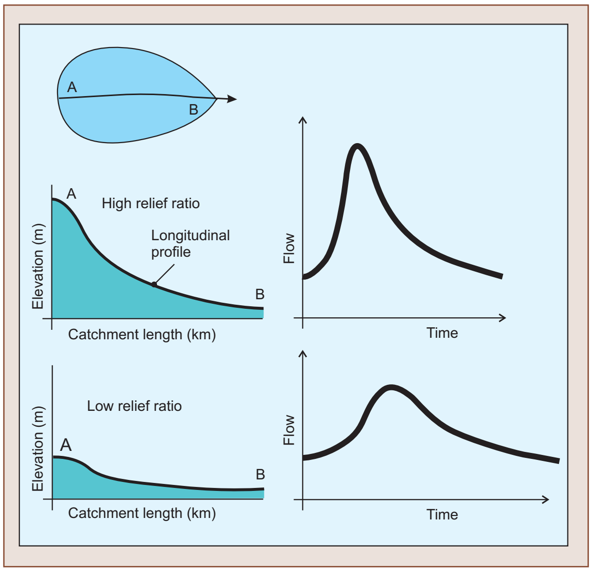


Figure 6 *Catchment Relief Ratio Impacts*



2.4 Modifying Flood Behaviour

In consideration of these characteristics and hydraulic properties, the suitability of various flood modification measures is described briefly in Table 5. Further details on how these measures can be implemented in practice are described throughout these guidelines.

2.5 Upper Reaches of Tributary Streams

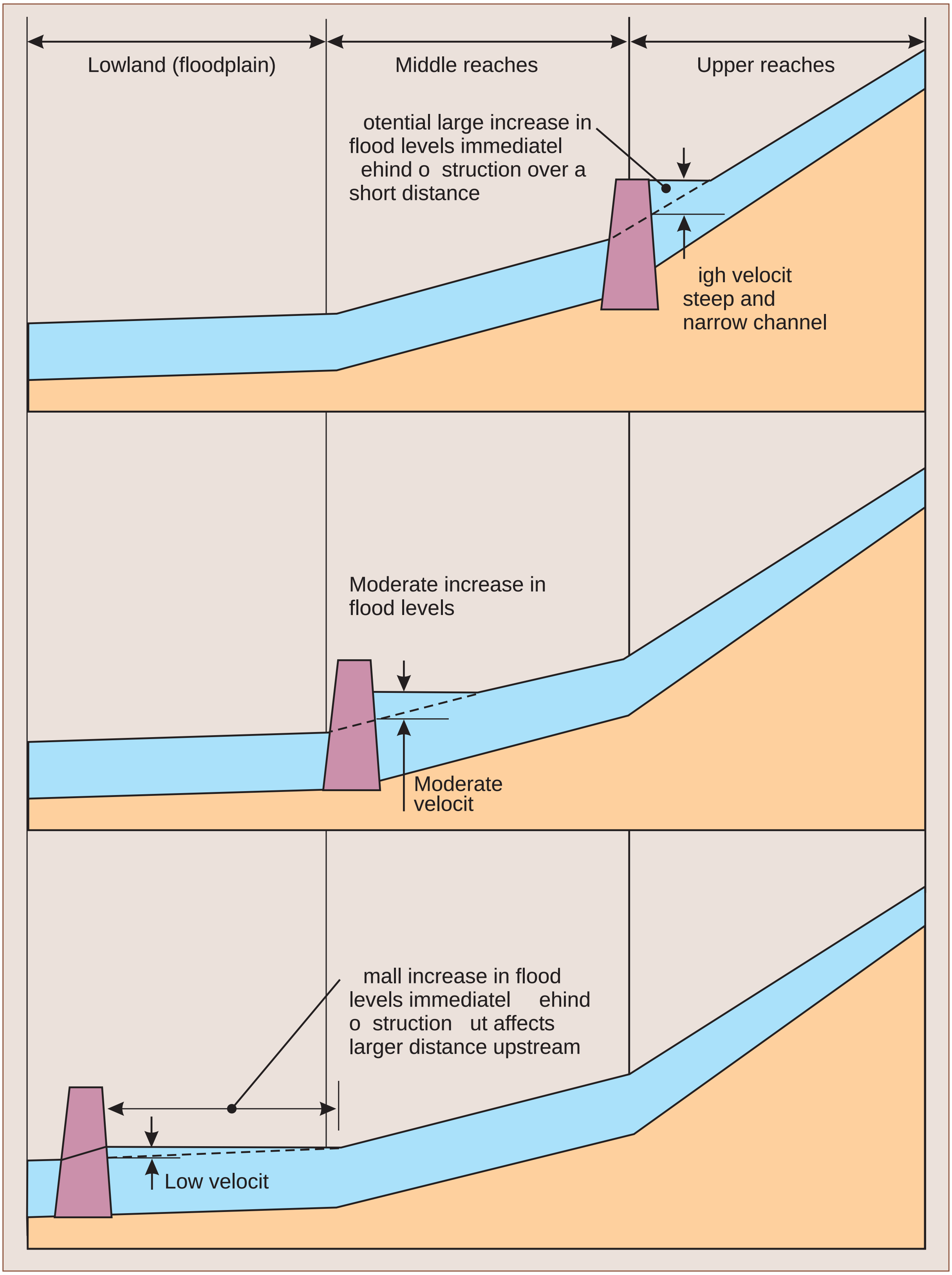
In the upper reaches of a catchment area, rain falling on the ground surface quickly builds up and becomes sheet flow or overland flow and runs perpendicular to the ground contours along the line of steepest slope towards the nearest depression or low point. The incipient watercourses merge further down slope and gradually increase in size in proportion to the accumulated runoff volume and the contributing catchment area.

Table 5 *Effectiveness of flood modification measures in different zones*

Measure	Upper Reaches (Tributary streams)	Middle Reaches (Transitional zone)	Lowland Areas (Floodplain proper)
Retarding basins	Need several small basins to achieve benefits	Can be effective but subject to availability of suitable sites	Not recommended (no suitable locations, too far downstream to provide benefits). Volumes relatively too small in a large catchment
Filling	Generally not appropriate. Reduces floodplain capacity and increases flood levels	Depends on scale and hydraulic impacts on surrounding areas	Suitable for fringe floodplain areas subject to ecological and other constraints
Levees	Not recommended - high velocities scour embankments, location of overtopping difficult to control and very rapid with negligible warning time, hydraulic impacts more acute	Depends on circumstances. Generally not recommended for new developments	May be suitable for protection of existing development. Not recommended for new development. Extensive areas flooded rapidly when overtopped. High continuing flood risk.
Dedicated floodway zones	Generally not appropriate	Sometimes suitable depending on local circumstances	Often necessary from planning perspective for larger events to prevent encroachment of development which is vulnerable.
Channel improvements	Can provide some benefits, but higher channel velocities increase hazard and can cause erosion problems	Can provide some benefits but typically moves problem downstream. Concentrates flows and loses advantages of natural detention	Extensive works typically required to achieve limited benefits (often ecological constraints and high maintenance)

With generally steeper slopes prevailing in the upper reaches, the speed at which the runoff accumulates in the depressions is rapid and the critical travel time for peak runoff to occur is relatively short. Consequently, floodwater depths tend to increase rapidly and giving no useful warning time, but then subside just as quickly when the rain stops. Such rapid development of flooding

Figure 7 *Characteristic Hydraulic Profiles*



is referred to as flash flooding. While the duration of flash flooding tends to be short - often less than a few hours, the potential hazards and consequences can be very significant.

Typically, the upper reaches of tributary streams comprise steeper bed slopes (see Figure 7) with incised or confined channels and narrow or even negligible overbank floodplain areas. Due to the constantly changing nature of the terrain, incised or readily definable streams are not always evident to an inexperienced observer, and potential flow paths can be more difficult to identify with certainty. This has led to the construction of developments within or immediately adjacent to natural depressions with serious and unexpected consequences when heavy rains inevitably occur.

Hydraulic behaviour in these upper areas is typically dominated by:

- the prevailing streambed slope and the waterway area,
- the conveyance as determined by the natural roughness and obstructions within the waterway, and
- their combined influence on flow velocities.

Figure 8 *Damage to House in Wollongong 1998 Flood*

Heavy rainfall in Wollongong in 1998 caused deep and fast overland flooding along natural depressions which resulted in significant flood damage to property, including failure of the brick wall to this house.

Figure 9 *Standing Waves in the Warragamba River near Wallacia*

High velocities can result in standing waves and other hydraulic phenomena as seen on this photo of 1990 floodwaters in the Warragamba River near Wallacia.

Within the upper reaches these geometric parameters ensure that hydraulic gradients exhibit the same trends for a range of flow magnitudes and there is generally less variation in water levels and depths of flooding at any given location. Conversely, obstructions along the flow path can cause significant hydraulic impacts and even result in uncontrolled flow diversions to unlikely or unwanted places, potentially causing significant damage (see Figure 8). Any increase in flood levels (backwater effect) is generally limited to a short distance upstream as the steep streambed slopes and hydraulic gradients prevent backwater effects from propagating over a long distance.

In the upper reaches, drainage or flooding problems can normally be sourced back to the local catchment rather than to other catchments or a main stream located further away. Whilst this makes identification of the flooding source(s) easier than in the downstream areas, existing development upstream can obscure the potential sources of floodwaters.

Debris mobilised by the high velocity flows and momentum effects (velocity) can easily exacerbate problems in the upper reaches. In areas of high velocity where the flow is shallow and there are bed irregularities, standing waves may occur, (Figure 9).

Flow diversions (see Figure 10) are common. They can be caused by natural or artificial features, or even by temporary features such as debris dams that restrict the flow of water.

An inexperienced observer may have difficulties in identifying all these characteristics on site especially as existing development upstream cannot necessarily be used as an indicator of flood risk for a new development site.

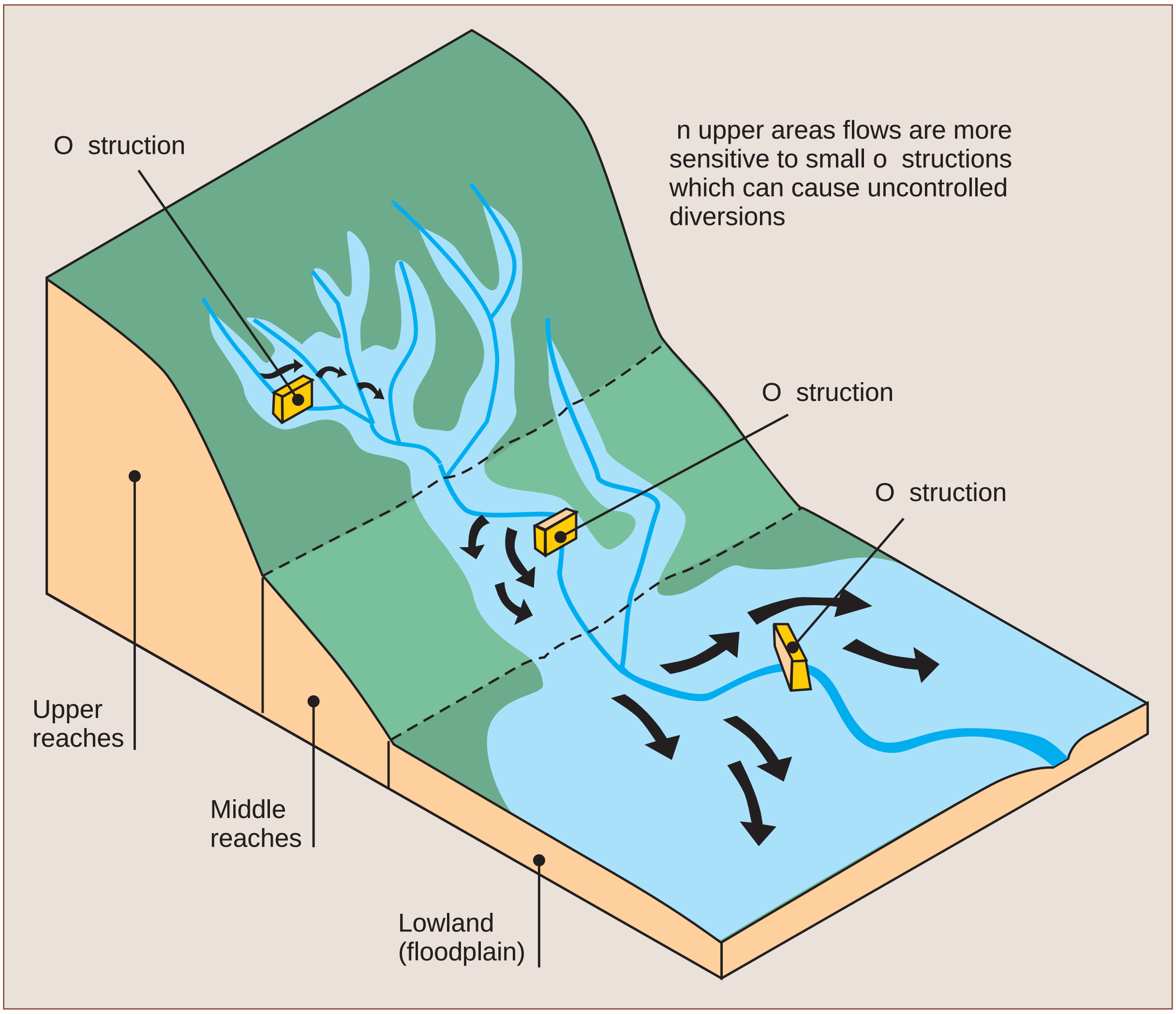
A reconnaissance trip which includes walking upstream to the watershed boundary and observing the nature of the depressions, channels or pipes that convey flood flows can provide an understanding of the characteristics of the site. Noting the features of any adjacent catchments is important. Observation should include the nature of the soils, both within the channels and in the riparian areas, and the potential for vegetation or detritus to be dislodged and become debris in flood events.

Soil type and erosion factors are often significant in the upper reaches. Treatment of bare soil areas by appropriate robust landscaping and re-vegetation should form an important part of any development plan to take full account of the hydraulic stresses likely to be imposed.

2.6 Middle Reaches or Transitional Zone

The middle reaches of a catchment are typically defined by undulating to hilly terrain where ground surface and stream slopes are quite varied. It is in this transitional zone where many of the feeder watercourses join to form the main stream(s) of the catchment and accumulated runoff peaks and volumes become substantial. The floodplain proper is more readily definable, with overbank

Figure 10 *Potential Flow Diversion Patterns in Different Catchment Zones*



areas beginning to appear and expand. With multiple changing geomorphological features, flood behaviour is more difficult to define, with velocities and hydraulic gradients varying in response to the stream slopes and accumulated flows. The timing and interaction of the tributary flows further adds to the complexity of flood behaviour by directly influencing flood levels.

It is the very nature of the terrain in the middle reaches or transitional zone which makes it attractive for development. The slopes are not as steep as in the upper reaches making building construction easier, while the elevation and topographic relief provide interest and landscape variety. However, the less predictable nature of flooding in the middle reaches also presents the greatest risks to development and hazards to occupants. Given that flow velocities are relatively high, any hydraulic obstruction within the floodplain has the potential to cause significant impacts, with a propensity for redirection of flood flows to unwanted places (see Figure 10). Debris, in the form of vegetation litter, tree branches, rocks and coarser sediments generated from the steeper slopes in the upper reaches, is deposited in the middle reaches, leading to blockages and failure of the trunk drainage system, (see Figure 11).

One positive aspect of the middle reaches from a development viewpoint is the variation in topography, which means that development can readily be kept out of the more hazardous areas of the floodplain, providing that thorough assessments are made and proper planning controls e.g. floodplain management plans and trunk drainage strategies, are implemented. Velocities are generally more manageable, even though high in places and flood levels although higher, are more easily definable than in the upper reaches.

A further major positive hydraulic factor in the middle reaches from a development perspective is that flood warning becomes a viable proposition

Figure 11 *Flood Debris Wollongong 1998*

In the Wollongong floods in 1998, debris caused blockages to the main drainage system.

Figure 12 *Typical middle zone on a tributary of the Lower Hawkesbury River*

Rate of rise at this location would allow enough time for a real time flood warning system to be beneficial.

because of the greater travel time for peak water levels (see Figure 12). The ability to warn is dependent on a network of quick response gauges such as a real time flood warning system.

2.7 Lowland Areas

In the lowland areas flood behaviour and its consequences for development are quite different than in the upper and middle reaches. The nature and extent of the floodplain proper is dependent on the size of the contributing catchment area upstream. The terrain is much flatter and floodwaters extend across the broadening floodplain (see Figure 13), with the lateral extent generally in relative proportion to the size of the event. Typically floods in the range up to 1 in 2 to 1 in 5 AEP stay in-bank in the main stream. They spread extensively across the floodplain for larger events.

This is the zone in which deposition of sediments typically occurs. These can consist of re-worked bedload materials as well as fine sediments carried in the floodwaters until lower velocities permit their settlement. Over time, this leads to the formation of natural levees along riverbanks and it is here that towns have often been developed. Unprotected, these towns typically have a frequency of flooding in the range of 1 in 10 to 1 in 20 AEP. In areas of

Figure 13 *Wide lowlands floodplain of the Hawkesbury River near Windsor during the minor flood in 1990*

NSW where flooding occurred soon after European settlement, development tends to be on the higher land. The absence of such salutary floods in other areas has lead to a continuance of settlement at low elevations resulting in the typical urban flood problems of today. Some towns were so dependent on river traffic for their very existence (good examples being Windsor on the Hawkesbury and Kempsey on the Macleay River) that the towns stayed largely unprotected on the floodplain in order to service their primary commercial function.

The depths of inundation and flow velocities in this lowland area vary significantly with changes in the topography. Downstream, the floodplain generally expands and becomes larger. Areas are more readily categorised in terms of their hydraulic function and are defined as:

- floodway,
- flood storage,
- flood fringe.

An example of a floodway area can be found on the George's River at Milperra, (Figure 14). The floodways are typically high velocity, high hazard areas adjacent to the main channel and any remnant anabranches. They are best kept free of obstructions and utilised for agriculture or recreation where they can be maintained as open space.

Flood storages are typically areas of low to moderate flow velocities which slowly fill up, then drain once the flood peak has passed, (Figure 15).

***Figure 14** The Milperra Floodway during the 1988 flood*

This floodway (see arrow) has been subject to an extensive voluntary purchase scheme in order to eliminate the high risk to people and property.

***Figure 15** Extensive flooding of the Hawkesbury River floodplain near Windsor – May 1988*

This area acts an important flood storage area during flood events.

They are often upstream of a topographic feature, which restricts flood flows.

They play a significant role in determining general flood behaviour and it is therefore vital that such areas are maintained. A small percentage loss of flood storage will usually not have any measurable impact if considered in isolation, but cumulative impacts of widespread development including filling of land, can reduce available storage. One management approach is to ensure that there is a balance of cut and fill to minimise the net change in storage volume. While this can be useful, there are alternatives and each situation should be considered on its merits.

Flood fringe is essentially the floodplain area which is left after floodways and flood storage have been identified. Flood fringe areas are generally situated around the edge of the floodplain (see Figure 16) and the hydraulic impacts associated with their development are low. Evacuation to higher ground is usually readily available. Flood fringe areas of the floodplain can therefore be suitable for development depending on the frequency and nature of flooding (i.e. whether velocities and depths are substantial).

By being situated at the lowest part of the catchment, the lowland areas are afforded the greatest relative warning time from flooding. The larger the catchment the longer the warning time but also, the greatest potential runoff volume and period of inundation. The extended lag time required for runoff from the upper reaches to build up and coincide, results in a much slower rate of rise (and fall) for flood levels. A key issue is evacuation. Evacuation is dependent on not only the warning time, but also the road and rail infrastructure available for evacuation, and the number of people that have to evacuate out of hazardous areas.

Subdivision in the lowland areas produces its own challenges based on these hydraulic features. Another and less obvious factor is that development can be subjected to flooding from local runoff as well as from mainstream overbank flooding. Provision therefore needs to be made to

Figure 16 *A typical flood fringe area along the edge of the South Creek floodplain under shallow backwater flooding*

cope with local runoff and overland flow, as well as mainstream flooding. Each type of flooding may occur independently of the other. A 1 in 500 AEP flood level was adopted as the design flood for the upgrades of the Hawkesbury-Nepean regional evacuation routes to give them a higher level of protection against unpredictable local flooding. Local flows have to be estimated for the relevant local catchment using design rainfall data. This compares to mainstream flood studies which have the advantage of historical rainfall data and more reliable flood height data, to assist in evaluating flood impacts for a new development.

The Hawkesbury-Nepean valley has a number of unusual physical features, which impact on flood behaviour. Unlike most coastal rivers in NSW, which progressively widen as they progress downstream toward the coast, the Hawkesbury-Nepean valley comprises a series of floodplain basins linked by gorges. The flat areas upstream of these gorges have many of the characteristics of lowland areas. The gorges limit the rate of floodwater discharge from the upstream floodplains, leading to potential flood depths of tens of metres across the floodplains. As the floodplains include riverside towns and villages, the potential impacts of this uncharacteristically deep flooding is extremely significant both socially and economically.

2.8 Types of Flooding

In designing subdivisions, it necessary to understand and to address five types of flooding, which may occur in a catchment. These different types of flooding are as follows:

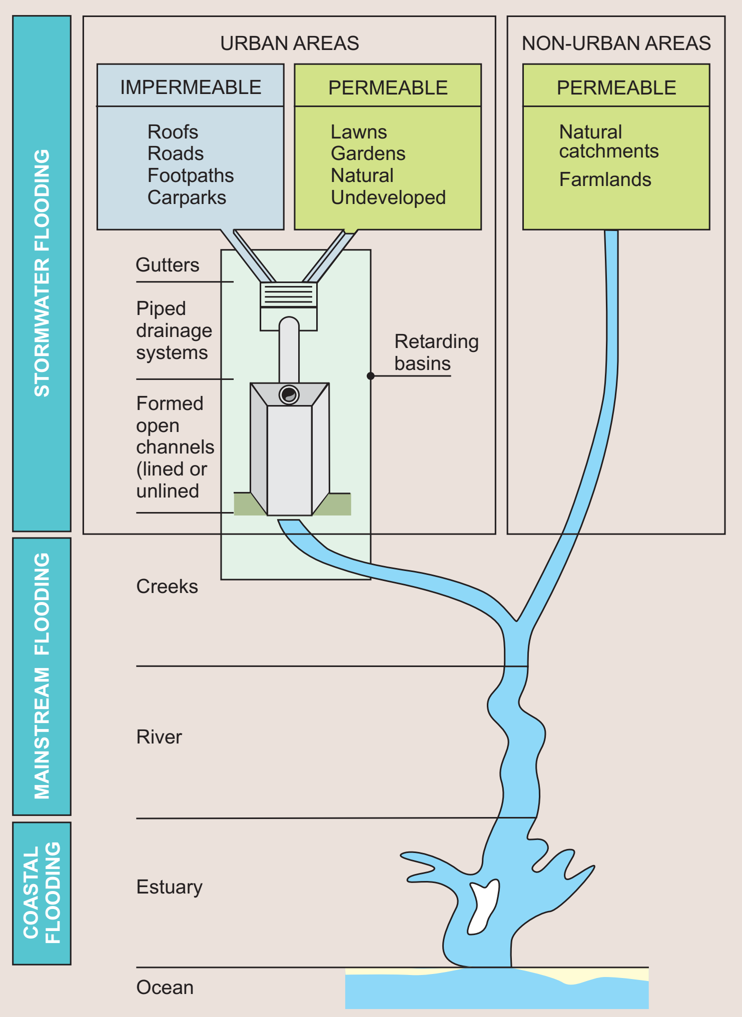
- Mainstream Flooding (including Coastal Flooding);
- Local Flooding;
- Flash Flooding;
- Overland Flooding; and
- Stormwater Flooding.

Details on the various types of coastal flooding can be found in the Coastline Management Manual (1990). A diagrammatic representation of the main types of flooding are shown in Figure 17.

2.8.1 Modes of Flooding

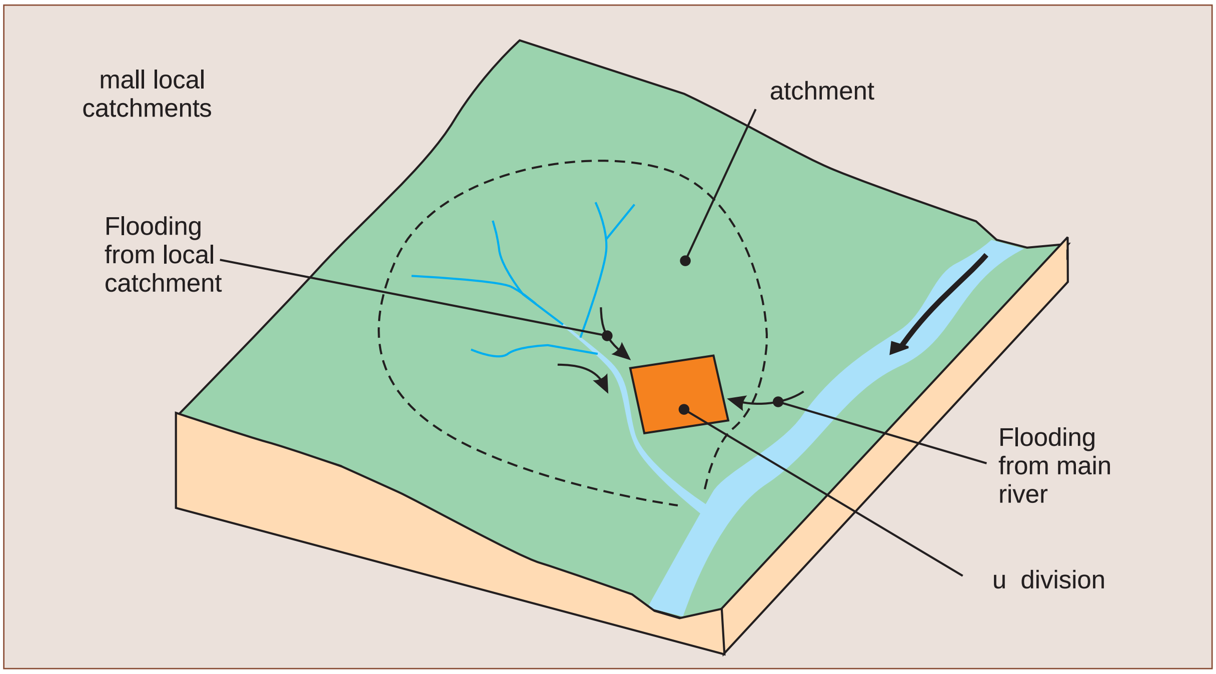
In subdivision designs, engineers and surveyors develop drainage designs for carrying storm water runoff through the site, with the aim avoiding nuisance and damage to a reasonable extent.
To achieve this:

Figure 17 *Types of Flooding*



The various types of flooding shown in this diagram are indicative only. Specific definitions (particularly in regard to Stormwater and Mainstream Flooding) will be found in local council policies and insurance policies. Specific relevant advice should be sought in this regard from councils and insurance providers.

Figure 18 *Small Local Catchment Flooding*



- channels or drainage depressions which run through a site, and/or if covered, a pipe system are large enough to convey flows of a certain design frequency; and
- overflows that occur in events that exceed the pipe's capacity (including the effects of any blockages), should be accommodated so as not cause serious damage or danger.

These objectives are normally achieved by locating the drainage channels and overland flow paths along natural drainage lines and to provide easements to carry overflows. Safety fencing may also be provided. In older established areas councils must cope with situations where houses have been built over drainage lines.

Many householders are at risk from flooding from local streams and flow paths, particularly in low-lying areas or close to drainage paths restricted by developments. However, on the Hawkesbury-Nepean floodplain and other areas subject to widespread riverine flooding, flooding can occur by a second mechanism i.e. large-scale flooding and the backing up of water along tributary creeks. As shown on Figure 18, some people are liable to be flooded either from the:

- top of their local catchment, or
- the river at the bottom of their local stream system.

Whilst a large storm may endanger properties and people due to both these flooding mechanisms, in most cases flooding will be due to one cause or the other. Statistically the size of floods is influenced by the duration of the rainfall and by the catchment area. On a large catchment, a short storm will not cause widespread flooding, whilst rainfalls likely to cause flooding of main rivers will usually not be so intense as to cause flooding on smaller catchments.

The longer the duration of the storm, the smaller the expected rainfalls will be. For each catchment there is a storm duration that will be most critical. For large catchments, this time is long; for small catchments it is short.

Whilst short intense storms can occur within larger storm events, those with the highest flows will mostly occur at the start of the long storm, before large flows have built up in the main river.

2.8.2 Local and Mainstream Flooding

The likely types of flooding faced by occupiers of the floodplain are broadly local and mainstream flooding.

Local flooding refers to floodwaters along a tributary that originate from the catchment of the tributary itself. Local flooding is caused by a relatively short storm, probably a thunderstorm with little warning; it happens quickly and is over in a matter of time. This type of flooding is therefore rapid in rise and decay and is often associated with fast flowing floodwaters.

Mainstream flooding refers to floodwaters along a river or creek system that originate from the catchment of a large waterway. Flooding is widespread from a main river and has a longer build-up in large catchments; warnings may be possible to enable evacuation of people at risk. Floodwaters from this form of flooding may "backup" along a tributary. This is often referred to as "backwater flooding". Whilst it can be the dominant form of flooding in the lower reaches of the tributary, it usually results in the inundation with "still water" (i.e. little velocity).

In areas that are liable to widespread mainstream flooding (up to the PMF level) both possibilities are an issue. Generally for smaller upstream areas only the first flood mechanism dominates.

Local flooding typically would follow this scenario:

- A thunderstorm occurs, with intense heavy rain,
- People scuttle for cover or if driving, stop their cars,
- Runoff flows across all surfaces and accumulates in drainage pipes and channels; a pulse of flow goes through the drainage system,
- Some inlet pipes block from debris swept into them, water runs across and down roads, accumulating in low points,
- Water runs through low-lying properties and along driveways,
- In some areas it backs up against fences, walls of houses and windows; if it is deep enough it knocks fences over and bursts into houses,
- Channels or creeks may overflow and affect cars and houses,
- Rainfall reduces but high flows continue in the lower part of the catchment because of the time lag involved in runoff flowing from its point of origin to the catchment outlet,
- People come out of buildings, take stock and assist each other,
- Emergency services arrive and clean-up begins.

Main river flooding would operate more slowly possibly with warnings from the emergency services and via the media. Assuming a worst situation in which no warnings are given however, this following scenario is typical:

- Heavy rain occurs for a day or so,
- People notice that the river is up and that adjoining low areas are flooded with levels steadily rising,
- Warnings are given over the media that some people should evacuate,
- Local people start to evacuate,
- Rising waters make evacuation imperative, people use well defined escape routes to higher ground; evacuation roads become busy,
- Some people are isolated in neighbourhoods where routes are already cut off by local flooding and await rescue,
- Waters are now high, flows rapid, houses are damaged,
- Emergency services are operating fully to protect people,
- Evacuated persons are directed towards evacuation centres,
- The flood peaks and recedes over two days, clean up and assessment of the damage and recovery begins.

Depending on the gradient of the tributary there may be a considerable reach where flooding results from the combination of mainstream and local flooding. For example, if the 1 in 100 AEP flood level is of interest along a tributary, then it could be determined by the 1 in 100 AEP tributary flow in conjunction with a small mainstream flood event (e.g. 1 in 10 AEP event) or it could result from a 1 in 100 AEP event along the mainstream in conjunction with a relatively small tributary flow event (e.g. 1 in 10 AEP event).

2.8.3 Flash Flooding

The term “flash flooding” refers to the speed of onset of flooding. The Bureau of Meteorology defines “flash floods” as those floods that occur as a result of rainfall of less than 6 hours. Flash floods are typically associated with the intense and often short duration rainfalls of thunderstorms. This type of storm event often causes stormwater or local flooding. The difficulty with flash flooding is that it occurs so quickly that it is not possible to issue warnings in time for the community to appropriately respond to the threat of flooding.

2.8.4 Overland Flooding

Overland flooding is the flow across land areas resulting from catchment runoff which has yet to reach the mainstream or tributary system.
It often follows slight depressions and if not catered for by way of open space etc it can flood above the floor level in houses. Generally overland flooding is only seen as a threat if it reaches a depth of 0.3 metre or more in a design event (i.e. 1 in 100 AEP or rarer flood event). However, consideration should be given to a full range of overland flooding events up to the PMF using a risk assessment approach.

2.8.5 Stormwater Flooding

Stormwater flooding is caused by overflowing stormwater systems. Such flooding often occurs in older urban areas where the existing stormwater system is not able to accommodate the increased runoff from further new development. Many of these older stormwater systems do not include a designed overland flow system.

3 IDENTIFYING THE FLOOD RISK

3.1 Flood Behaviour Assessment

3.1.1 Introduction

All too often purchasers of a residential lot in a new subdivision assume that residential development would not be placed in an area subject to flood hazards and therefore they are unlikely to enquire about the flood hazard on the land. This is particularly true of the flood risks arising from events more severe than the adopted flood planning level which is often the 1 in 100 AEP flood level. Until recently there were many areas in the Hawkesbury-Nepean where the extent of flooding due to the probable maximum flood (PMF) was not known with any certainty. However, the Hawkesbury-Nepean Flood Hazard Definition Tool[3] can provide information on the nature and extent of the PMF for most Hawkesbury-Nepean floodplain events. More detail of the Flood Hazard Definition Tool can be found later in this Section.

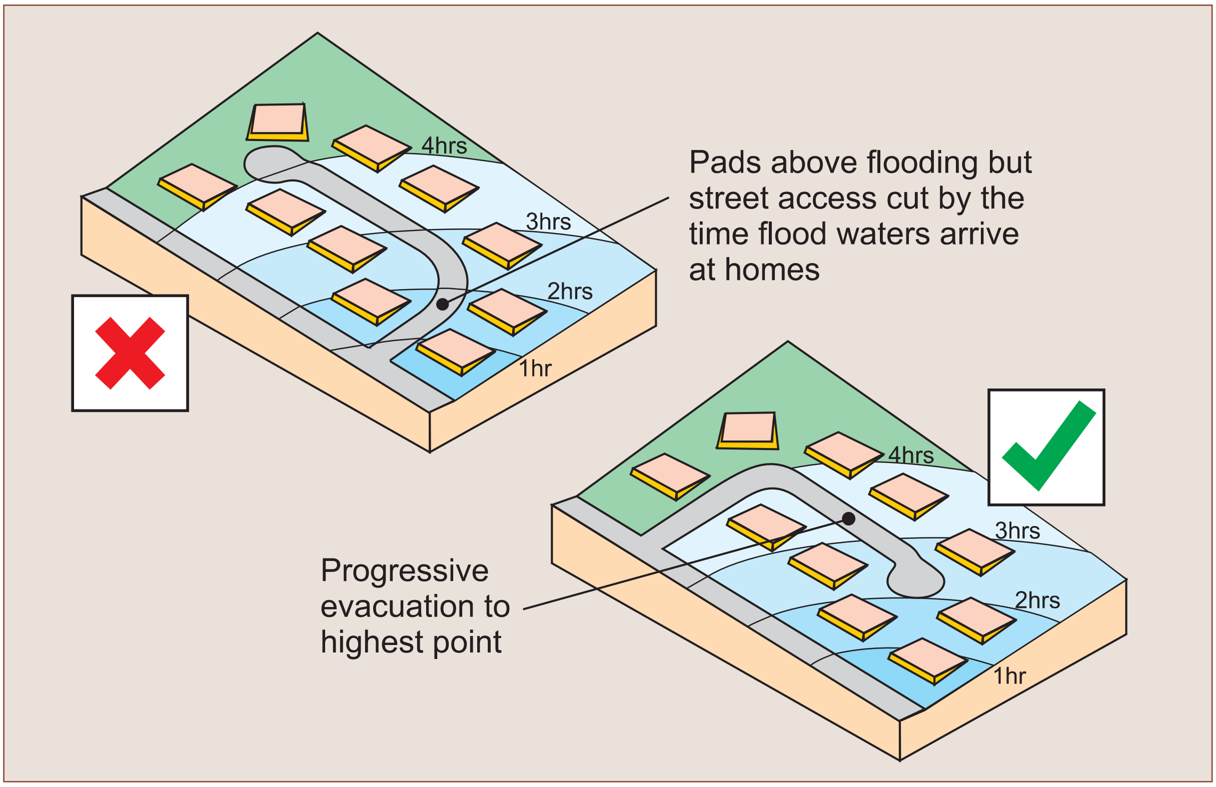
There are numerous relatively recent urban developments on floodplains, where evacuation is made difficult because roadways required for emergency access, are located below house levels and feed to main roads at even lower levels (Figure 19).

Access at the lowest point to this subdivision (upper arrangement) is cut very early resulting in little time for evacuation as the road is impassable. Through the simple adoption of this configuration, the designers have increased the danger to residents and hence risks to life. By rearranging the development (lower arrangement) with access at the high point rather than the lowest point, orderly and staged evacuation can be achieved.

The example in Figure 19 helps illustrate the way in which whole suburbs have the potential to become isolated in a flood and unable to be evacuated before the residents realise the flood threat. Potential for property damage and disruption to urban infrastructure has also been unnecessarily increased in existing urban areas because opportunities to reduce these losses are not always recognised in subdivision planning.

A section 149 certificate indicates whether a property is subject to a council's flood prone land policy. Councils may provide additional information

Figure 19 *Road Access to Subdivision*



[3] *The Flood Hazard Definition Tool (FHDT) is a computer software application for use with a geographical information system (GIS) to provide information on mainstream Hawkesbury-Nepean flooding.*

if a property is flood prone but lies above the flood planning level (often the 1:100 AEP flood level) and below the PMF flood level. However, information given on a section 149 certificate itself will not include information regarding other land in the locality which may flood early in a flood event and result in the subject property becoming isolated.

This section highlights some issues particularly relevant to floodplain residential subdivision, which should be carefully considered during the feasibility analysis to avoid unforeseen delays and costs arising as a result of constraints being discovered later in the process.

During their feasibility analysis developers and their advisors would be wise to consult with the local Council and/or other agencies with consent and/or compliance roles. This approach should assist in avoiding later disputes by ensuring relevant issues are considered and the most current available information is used.

3.1.2 Flood Susceptibility

The nature and extent of flood affectation on the site should be assessed as carefully as possible as it will influence the nature and layout of development suitable for the site.

The best available estimates of the nature and extent of flooding should be obtained. Such estimates should be for the full range of floods up to the PMF of all types of floods (local catchment runoff, overland flows from upstream areas and/or mainstream backwater floods) which could impact the site.

The local Council, previous owners or neighbours may be able to provide some flood information for existing conditions from personal observations or previous studies in or around the site. It is important to note that personal observations are generally anecdotal and limited to the more frequent events and may therefore not reflect the true nature of hazardous flooding. Professional engineers specialising in flood estimation may also be able to provide preliminary estimates of flood affectation and the potential associated hazards.

The developer should also consider how the proposed development would modify flood behaviour on and around the site (although this impact should be minimised) as well as what impacts flooding would have on the development.

The more rigorous and reliable the flood impact assessment, the less financial risk will be associated with the decision of whether or not to proceed with residential subdivision.

3.2 Flood Hazard

Flood hazard is mainly dependent on flood behaviour (i.e. depth, velocity, rate of rise and duration) and site characteristics. Consequently, the flood hazard, or threat to life and limb, and damage caused by a flood varies both in time and place across the floodplain. Floodwater flows fast and deep at some locations and in other places it is shallow and slow moving. The variation of the hazard across the floodplain needs to be taken into account in developing floodplain land. This assessment must take into account the full range of floods up to the PMF event.

To achieve responsible design of subdivisions in flood prone areas, it is necessary to divide the floodplain into areas that reflect first, the impact of development on flood behaviour (i.e. hydraulic effects), and second, the impact of flooding on development (i.e. hazard effects). Division of flood prone land according to these effects is referred to as “hydraulic categories” and “hazard categories”, respectively.

These guidelines follow the principles set out in the Floodplain Development Manual (2005) and the use of hydraulic and hazard categories to determine appropriate subdivision design.

One of three hydraulic categories applies to each hazard area:

- Floodway
- Flood Storage
- Flood Fringe

For the Hawkesbury Nepean area the hazard categories have been expanded to cover the greater range of flooding compared to other floodplains. These hazard categories are:

- Low
- Medium
- High
- Very High
- Extreme.

At the outset, it must be recognized that hydraulic and hazard categories are tools to assist in appropriate planning and design. It must be remembered that gradual on-going development over time can have cumulative impacts which may change both the hydraulic and hazard categories.

3.3 Flood Risk

The fact that a site can flood occasionally and be subject to a variety of flood hazards does not itself represent a problem. It is only when we choose to occupy and utilise a floodplain that we invite flood risks. What becomes a risk (i.e. lives and/or assets) and how great or small the risks (i.e. its severity) is a reflection of what development is allowed on the floodplain, how carefully it is planned and designed and how well or how poorly the flood hazards were understood before and after the site is developed.

The severity of the risks is directly proportional to how significant the impacts are from flooding i.e. consequences as a result of the flooding, limiting the flood hazards and reducing the degree of vulnerability to the flood impacts (such as proneness to water and velocity damage) can significantly lessen the consequences from flooding.

If the site hazards are not properly recognised and the development not carefully designed to respond to these hazard conditions, then flood risks to both people and property can be inadvertently and unnecessarily heightened. Sites that have the same flood hazard can have marked differences in both the nature and degree of flood risks simply due to how they were planned and laid out.

Table 6 lists a variety of factors that affect the flood risk.

Flood Behaviour Factors

Flood behaviour affects flood hazard. In general, the severity of a flood determines the area of land and number of people affected, as well as the other flood behaviour factors. The greater the depth and velocity of floodwaters, the greater the hazard. The faster the rate of rise of floodwaters, the less time people have available for evacuation. Floods occurring in an urbanised catchment can be extremely hazardous because there are usually no early signs of any major flooding.

Table 6 *Major Factors Affecting Flood Risk*

Flood Behaviour affecting Flood Hazard	Topography	Population at Risk	Emergency Management
Severity	Evacuation Access	Number of People	Flood Prediction
Depth	Isolated Islands	Flood Awareness	Flood Warning
Velocity	Size of Floodplain	Flood Preparedness	Flood Evacuation Plans
Rate of Rise		Type of Landuse	Flood Recovery Plans
Warning Time			
Duration			

3

Topographic Factors

Topography can influence the provision, safety and operation of evacuation routes. If evacuation routes become flooded and inoperable in the early phases of flooding, alternative routes or means of evacuation will be needed to avoid isolation and the potential for eventual inundation. Similarly, topography also determines whether or not people become marooned on 'islands' with consequent difficulties of rescue.

Population at Risk

The degree of risk obviously varies with the size and composition of the population exposed to floods. The larger the population, the greater the flood damage and the greater number of people that need to be evacuated.

The type of land use also influences risk. There are considerably greater difficulties in evacuating a hospital or an aged care facility than there are evacuating an industrial area. Conversely, the flooding of industrial areas might result in the escape of toxic industrial products with adverse environmental outcomes.

Flood awareness and flood preparedness refers to the ability of the population at risk to know what to do and how to do it effectively in the onset of a flood. A flood aware population can be more effective in evacuating itself and its possessions in the onset of a flood than one which is not, thereby reducing risk. Increased levels of flood awareness can be largely related to past experience with flooding.

Emergency Management Factors

Emergency management is to do with the management of the 'continuing risk'. In New South Wales, the State Emergency Service (SES) has responsibility for the preparation of local, regional and divisional flood emergency plans. Such plans encompass flood forecasting, flood warning, flood defence, evacuation plans and arrangements, and recovery plans.

Other government agencies, councils and non-governmental organisations are actively involved in emergency plans and have nominated roles in a flood event under the leadership of the SES.

A priority of emergency management is to reduce the risk to life and limb with only limited focus on reducing direct flood damage to fixed property.

3.4 Flood Hazard Assessment

The types of hazard associated with flooding are often considered as a single group. However, when designing a subdivision on a floodplain it is useful to recognize different categories that should be treated separately. They are:

- People attempting to wade to safety;
- Vehicles moving in floodwater;
- Vulnerability of buildings and structures; and
- Potential for isolation and/or eventual inundation.

Wading

Conditions for wading become unsafe as depth or velocity increases. As children are most at risk of being washed away, most research studies have focused on the instability of children in moving floodwaters. Both the Floodplain Development Manual (FDM) (2005) and Keller & Mitch (1992) provide the best available information on identifying hazardous floodplain conditions for people trapped in floodwater. In the interests of public safety, consideration should be given to using the most conservative combination of values.

Table 7 *Limiting Stability Conditions for Children*

Depth (mm)	Maximum Permissible Velocity (m/s)	
	FDM (2005)	Keller & Mitch (1992)
100	2.0	2.2
200	2.0	1.5
300	1.6	1.1
400	1.3	0.5[1]
600	0.7	0[1]
800	0	0[1]

[1] *interpolated from original publication*

Vehicles in Floods

Delaying evacuation until flood waters are lapping at the door results in extremely hazardous situations for drivers and passengers who attempt to drive to safety through floodwaters. Vehicles are easily washed off roads because they are unable to withstand the lateral force imposed by the flow. A significant contribution to this is the loss of stability when vehicles commence to float in relatively shallow water.

Table 8 shows maximum conditions for passenger vehicles derived the Floodplain Development Manual (2005).

Table 8 *Limiting Stability Conditions for Passenger Vehicles*

Depth (mm)	Maximum Permissible Velocity (m/s)
	FDM (2005)
100	2.0
200	1.3
300	0

Table 8 shows flooding depths in excess of 0.2 metre are likely to cause vehicle instability, even in relatively slow moving floodwaters. In the interests of vehicle safety, consideration should be given to using the most conservative combination of values.

Damage to Buildings

Buildings are damaged in floods by two general mechanisms:

- Structural damages from the force of floodwaters. This may be due to out of balance hydrostatic forces in still water or additional hydrodynamic loads from flowing floodwater, which may include impact from floating debris; and
- Unsuitable building materials that are damaged by contact with water (eg. plasterboard, hardboard, pine board, engineered beams etc).

The accompanying "Guidance for Building in Flood Prone Areas" provides comprehensive information on the selection of suitable building materials and measures to minimize structural damage to buildings. A limitation of commonly used brick veneer walls is that they can only withstand a flow velocity of about 1 m/s.

Location of Hazard

When considering the hazard related to a proposed subdivision, it is necessary to evaluate two broad location related hazards:

- Site Hazard; and
- Regional / Local Hazard.

"Site hazard" refers to the hazard at the proposed development site itself. "Regional / Local Hazard" refers to hazard in the area surrounding the site both regionally and locally and includes the potential for isolation as surrounding land floods before the development site, cutting evacuation routes and essential services. If the site can eventually be inundated after a period of isolation as flood waters rise, early evacuation of the new development is the only option if lives are to be protected. This hazard can be addressed through regional / local evacuation strategies, which should be reflected in the Local Flood Emergency Plan prepared by the SES. Ascertaining the flood liability of the surrounding area is critical when planning a subdivision as this can affect the ability for occupants to evacuate. Any site-specific evacuation plan for a subdivision should be an integral part of the regional / local evacuation plan prepared by the SES. A subdivision which cannot be evacuated and where no provision for evacuation routes is possible, or which adversely impacts on the ability of the emergency services to evacuate other floodplain occupants who are already at risk, cannot be considered sustainable development and alternative sites should be sought for development.

Provisional Flood Hazard

As outlined in the Floodplain Development Manual (2005) an area may be given a provisional hazard based on peak depth and velocity alone. To manage flood damage to property (as opposed to people) the flood hazards in the Hawkesbury-Nepean floodplain area can be divided into five provisional hazard categories ranging from low to an extreme hazard (Figure 20). These hazards are primarily linked to the potential for failure of different types of buildings and should be applied for managing risks to property. A more comprehensive assessment of hazard is required, which encompasses all factors, including rate of rise, evacuation difficulties and threat of isolation.

3.5 Flood Hazard Definition Tool

Through the Hawkesbury-Nepean Floodplain Management Strategy, Hawkesbury-Nepean councils have been provided with information on mainstream Hawkesbury-Nepean River flood hazard through a computer software application known as the Hawkesbury Nepean Flood Hazard Definition Tool (FHDT). It is designed to be used with a geographical information system (GIS) which generally includes cadastral and topographic data and aerial photographs. It can assist in visualisation of flooding behaviour by providing information on floodwater levels, depths, velocities and hazards over the full duration of a range of design floods (Figure 21). Data for five design floods from the

Figure 20 *Provisional Flood Hazards*

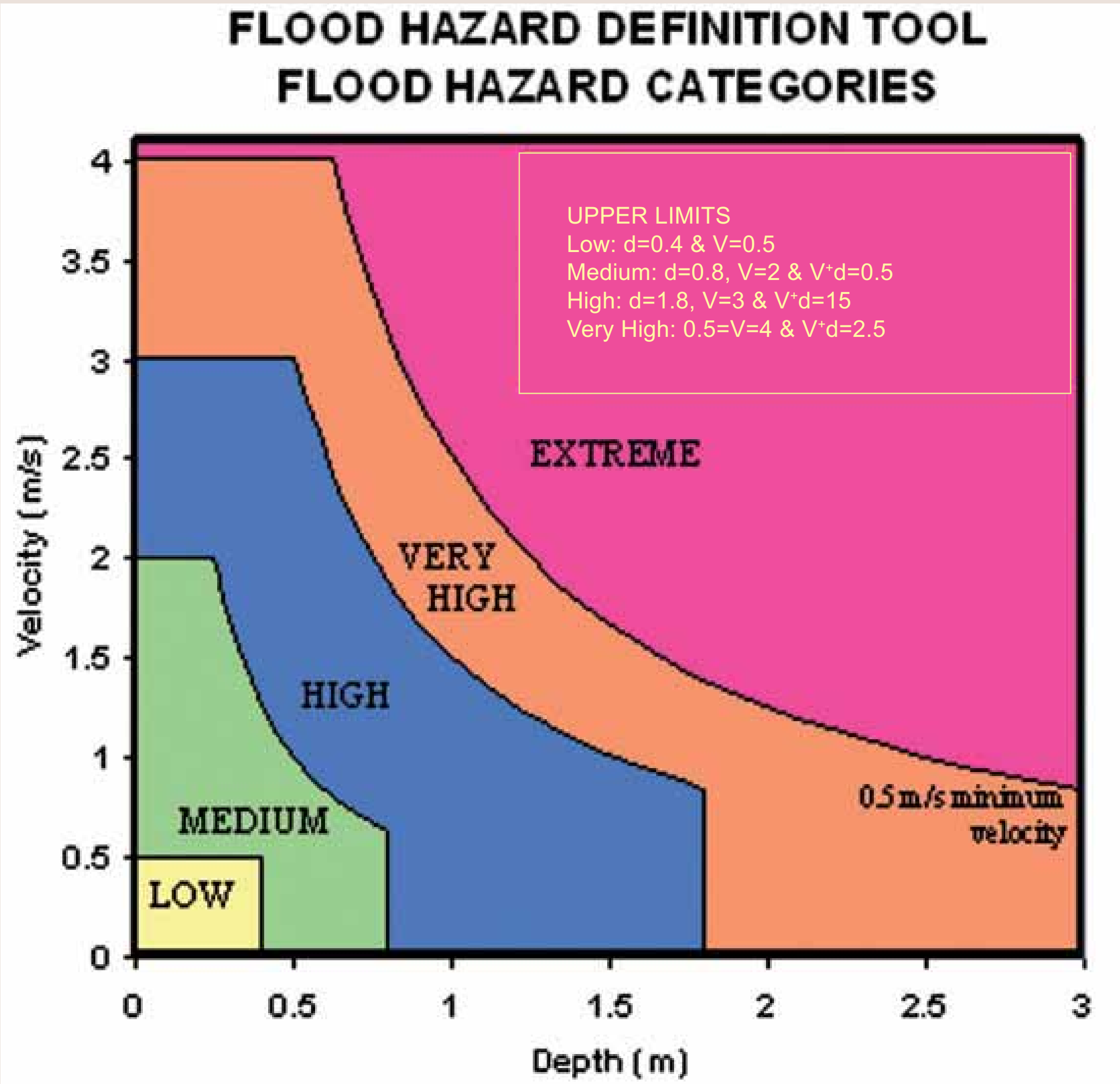


Figure 21 *A display from the Flood Hazard Definition Tool*

The Hawkesbury-Nepean Flood Hazard Definition Tool is capable of identifying bands of hazard from Low to Extreme on the floodplain. Other displays allow isolation and floodway conditions to be identified for the full range of design floods.

1 in 100 AEP flood to the PMF are included. Its primary purpose is to assist in councils' strategic management of flood risks. The tool can overcome the dangers and limitations from principally considering information, which is only specific to individual lots. The FHDT enables flooding over a larger area to be examined in a wider context to give a 'big picture' perspective such as identification of floodway conditions, and the potential for isolation. It is not intended to provide the precise extent of flooding. Depending on the quality of the Digital Terrain Model (DTM) linked to the FHDT, the tool may assist in defining the flood hazard at a subdivision design scale. FHDT software has been provided to the six Hawkesbury Nepean councils in the Strategy area as well as the State Emergency Service (SES), the Department of Planning and the flood section of the Department of Natural Resources.

3.6 Responding to the Hazard

Developers must consider how responding to the flood hazards may influence the built form of their development. For example, a site in the upper reaches of a catchment may be within a narrow floodplain, which may develop floodway conditions in a flood. Housing placed in such areas could have a major impact on flooding and be subject to high hydraulic hazards due to high velocity flows. In such areas clustering the houses away from the floodway areas could be beneficial and still maintain yield. In comparison at a site in a lowland flood fringe area within a much wider floodplain, flooding may be caused by slow backwater build up. Hydraulic hazards may be due mainly to deep flooding at the peak of the flood and the greater distances to reach safe areas out of the flooded area. In such a case the size and positioning of housing on the site has no affect on the hydraulic hazards.

4 HYDRAULIC IMPACTS

4.1 Hydraulic Impacts of Flooding on a Subdivision

Housing density is an important aspect of residential development in flood-susceptible areas. The greater the density, the greater the number of people who will need to be evacuated, and the greater the potential property damage and social disruption caused by a flood. It is essential that both local and regional evacuation routes can adequately handle the proposed increase in population at risk. These issues need to be discussed with the SES in light of the local flood emergency plan. If the evacuation of the present at-risk populations will overload the regional evacuation routes, additional residential development in the area requiring evacuation may not be appropriate or the proposed housing density may need to be curtailed unless new evacuation routes or additional capacity on existing routes can be provided as part of the new development.

It is important that housing clusters, terraces and buildings in general do not obstruct flood flows and thereby increase to an unacceptable degree, flood levels, flood velocities or the risk to life and limb.

In areas where there remains a risk of significant damage, e.g. due to deep inundation, dwellings should be designed to incorporate non-habitable rooms or car parking downstairs, and so reduce the probability of habitable rooms being flooded.

4.2 Hydraulic Impacts of Subdivisions on Flood Behaviour

It is essential that planners and designers of development on flood prone land (i.e. land below the level of the probable maximum flood event), recognise that flood hazard and evacuation are key elements of site planning – and need to be addressed in addition to enhancing the inherent qualities of the site and other principles of good urban design and environmental sustainability. Access from the site in a major flood needs to be evaluated and appropriately addressed at the planning stage of a subdivision development project.

The importance of adequate attention to detail in site planning cannot be over emphasised.
Many councils encourage liaison with developers prior to submission of a development application to determine issues that need to be addressed as part of the site planning process and the type of data and analysis required to satisfactorily address these issues. On flood prone land, it is prudent for the SES to also be consulted as that agency will be responsible for flood evacuation.

Important factors that need to be taken into account at the site planning stage include:

- provision of one or more suitable evacuation routes, depending on the size and configuration of the subdivision;
- limiting of flood damage to acceptable levels;
- impact of the development on flood behaviour; and
- the topography of the site.

It should be appreciated that the site layout of the new development can have a local influence on flood behaviour; e.g. filling to increase building areas on the site can raise flood levels, both at the site and upstream of it. Buildings located in areas of fast flowing floodwaters can significantly obstruct the movement of floodwaters through the site and increase local flood levels and velocities, resulting in an increase in the flood hazard to occupants (Figure 22).

It is essential that the impact of the proposed development on flood behaviour be assessed by a suitably qualified and experienced flood engineer. Close liaison with the local council is essential to ensure that any increases in flood levels meet council's requirements.

Flood hazard may also vary significantly across the site due to the site topography. For example, more elevated areas further away from the river will have a lower hazard as they are flooded to shallower depths and may experience lesser velocities than lower areas closer to the river. By locating buildings in the higher, more benign areas of the site, potential flood damage and the impact on individuals will be lessened.

***Figure 22** Movement of Floodwaters through a development*

Understanding the movement of floodwaters through a development is important to minimising flood damage to buildings.

Accordingly, site planning actions should include:

- confirmation that the intended land use(s) is appropriate to the various flood hazards within the site;
- assessment of the impact of the proposed development on flood behaviour, i.e. flood levels and flood velocities, both at the site itself and in adjacent areas;
- evaluation of the hazard and potential evacuation difficulties, both across the site and away from the site;
- provision of an evacuation route appropriate to the intended land uses for each part of the site;
- liaison with SES to ensure that proposed site evacuation infrastructure and plans are appropriate and consistent with local flood emergency measures;
- location of buildings in areas of the site where flooding is more benign, where possible;
- orientation of buildings in the direction of flow to minimise adverse impacts on flood levels; and
- assessment of the orientation and type of fences that are appropriate for the site.

4.3 Increased Velocities

4.3.1 Undeveloped Greenfield Velocities versus Local Developed Velocities

Flood water velocities can vary widely across an undeveloped or greenfield site. These velocities can range from being negligible in backwater areas to many metres per second in floodways. High velocity flows occur in areas where there is a significant gradient and movement of large volumes of water. These areas, known as floodways, can occur where floodwaters take a more direct route e.g. when flows cut across river bends in a larger flood. Flood models can simulate these flow paths. However, the modelling usually only represents average velocities across greenfield sites, many of which have been cleared for agricultural purposes.

When a house, or other structure, is built on the cleared site, the local velocity to which the house is subjected can be substantially higher than the average greenfield velocity. For a given average velocity, a house located in an open rural site is subjected to different local velocities and forces than is a house located close to many others within a residential subdivision. In a residential subdivision, the area available for conveyance of the flood waters is substantially reduced. Water trying to force its way between closely spaced houses accelerates between the houses, (Figure 23). This phenomenon is often referred to as the venturi effect. The resultant increase in velocities, perhaps threefold or greater, means that the walls of houses and other structures could be liable to severe damage or total destruction even though the average greenfield velocity may seem relatively low. This magnifies the dangerous conditions for residents who attempt to evacuate from these houses.

Depending on the subdivision size and layout, very low greenfield velocities may not increase sufficiently to cause damage. High local velocities may require a change in the subdivision size and/or layout for the site. The increase in velocity is dependent on many factors. In some cases, the shielding effects of the other houses can block flows and lead to a decrease in the local velocity and forces. Some computer flood models can provide reasonable estimates of both the greenfield and the local velocities occurring between the buildings. However, such modelling can be expensive and may not be warranted in cases of very low velocities or at some locations where velocities may be so high that development of the site may not be appropriate.

***Figure 23**: Higher Velocities between Houses*

Undeveloped greenfield velocity can increase significantly when flow must move along openings between houses.

Determination of the local velocity likely to occur around a house is very complex and site specific. As a rule detailed computer modelling is not normally done for an individual house but may under certain circumstances be worthwhile for a subdivision as a whole when likely velocities can cause damage to houses.

A preliminary method for assessing the impact of subdivision on flood velocities is outlined in Appendix A.

4

5 DESIGNING SUBDIVISIONS ON FLOOD PRONE LAND

5.1 Modifying Flood Behaviour

When preserving drainage corridors or altering the floodplain, care should be taken to ensure that floodwaters pass smoothly through the developed area and the impact on flooding caused by constrictions is minimised for all levels of potential flooding.

5.1.1 Land Filling

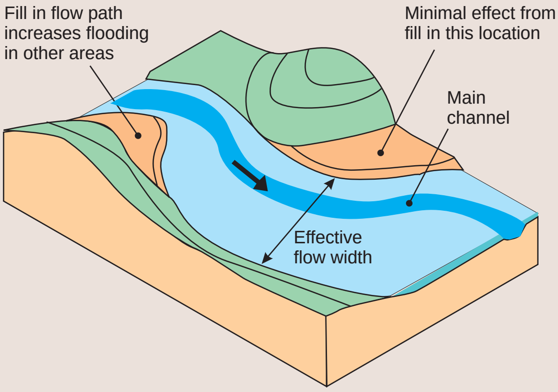
The filling of low lying land in floodplain areas is generally undertaken to increase developable land by raising the level of a building platform to ensure that the development area (habitable floor level in particular) is situated above the nominated flood planning level for the area. Filling can be used for a variety of reasons (Figure 24). No matter what the purpose, any filling of the floodplain can have adverse impacts which need to be assessed.

Placing fill in a floodplain changes the landform, which changes flood behaviour whether it is within or outside the effective flow area. Residents and their property can be harmed in areas where flood behaviour is changed.

Figure 24 *Filling floodplain areas for non-flood related benefits*

Filling of floodplain areas is often used not only to elevate development above the flood planning level but also to provide a landscaped barrier or noise screen from adjacent areas. Such filling has potential impacts on flooding which need to be carefully considered.

Figure 25 *Effective Flow Path*



The "effective flow" is the area where water is actively moving and not ponded in storage areas.

Depending on the scale of the filling relative to the size and slope of the floodplain, the changes in flood behaviour may extend well beyond the filled site, (Figures 25 and 26). Importing fill into the existing floodplain removes floodplain conveyance capacity and storage. Therefore, floodwater that may have been within the effective flow area will be confined to a narrower waterway area causing increased water levels locally and upstream. Floodwater that may have otherwise ponded outside the effective flow area of a watercourse will be forced downstream instead, thereby increasing downstream flow and water surface elevations.

The impact of fill is highly dependent on the part of the floodplain where it is placed. It is critical that flood behaviour across the floodplain needs to be thoroughly investigated and well understood before making any decision as to the appropriateness and scale of fill[4].

Hydraulic Category Impacts

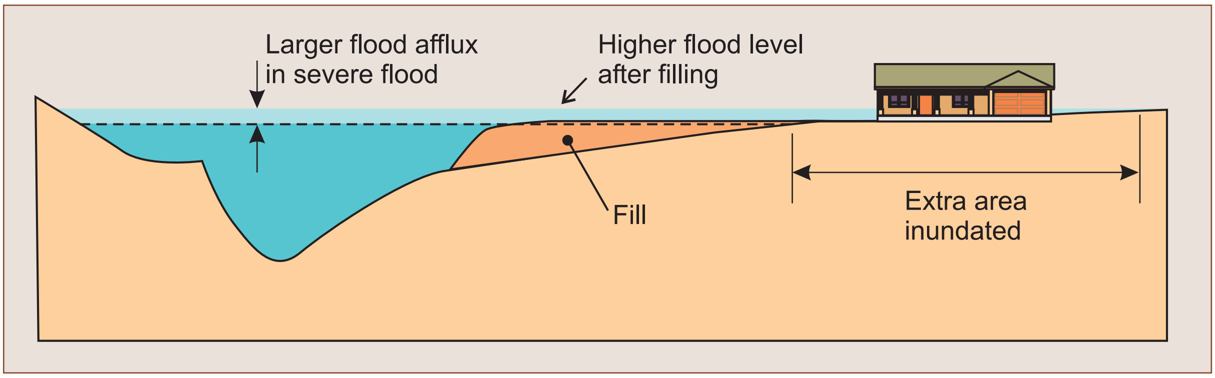
Placing fill in **floodways** should be avoided because it has the potential to create the greatest adverse effects including:

- Magnifies the impact of floods larger than the design event thereby increasing overall flood risks;
- Locally increases the flood depth, level, velocity, and hence hydraulic hazard in the reduced flow area remaining after filling;

[4] *Floodplain Development Manual 2005, Appendix L provides more information in this regard.*

5

Figure 26 *Impact of Filling on Flood Levels*



- Remotely raises upstream levels and/or diverts flows to new paths;
- Increased levels and/or diverted flows may flood into previously unaffected areas creating new hydraulic hazards and flood risks;
- Likely to increase bed and/or bank scour and decrease bank stability with increased velocity.

Land fill is often placed in **flood storage** areas to reduce flood depth. However this can produce adverse impacts similar to placing fill in floodways, as well as:

- Raising flood levels in adjacent areas not filled;
- Causing flooding in previously unaffected areas creating a more widespread flood risk; and
- Increasing peak discharge downstream.

Placing fill in **flood fringe** areas is generally a more acceptable practice since the impacts are much more limited and localised.

Appropriate Filling Criteria

Determining the appropriate volume and elevation of filling is the key issue, with the objectives[5] being to:

- provide a building platform which does not significantly increase the flood hazard at the development site, including those in rarer flood events;
- minimise flood impact for the surrounding floodplain users;
- provide direct evacuation access to existing flood free (higher) ground; and
- facilitate normal drainage provisions for the fill area during times of flood.

Strategies to Mitigate Impact of Fill

A range of strategies can be adopted to offset the impacts of fill on flood behaviour. The suitability of any given strategy or measure tends to be site dependent, but often includes:

- avoiding or prohibiting filling in floodway areas;
- requiring balanced cut and fill in flood storage areas and flood fringe areas[6] ; and
- providing compensatory remote flood storage eg an upstream retarding basin.

In floodplains where the hydraulic gradient and velocities are low (typical of lowland areas), the hydraulic impacts associated with filling tend to be small enough to allow filling for development. The implementation of cut-to-fill earthworks instead of importing fill is one means of minimising the overall loss of floodplain storage and potential hydraulic impacts up to the level of the fill. Consideration of the impacts on flood behaviour for the full range of flood events is still required to ensure there are no adverse effects in the small events as well as the

[5] There are a range of other relevant social, economic and environmental criteria which would have to be addressed in any proposal involving the filling of land, and which may be subject to controls or regulation, but as they do not relate directly to flooding, they are not discussed further here.

[6] Balanced cut and fill has sometimes been achieved by winning the fill for the house pads from the streets and roads. This practice has implications for evacuation. This is discussed further later in this section.

larger events which would exceed the fill level and inundate the development site.

The practice of cut-to-fill has been accepted from a floodplain management point of view as it assists in maintaining floodplain storage. Some councils have a “no imported fill” policy which also assists in this regard.

In most cases, it is important to balance the loss of storage caused by filling at the elevations where peak flooding will reach (Figure 27). Off stream storage that is available at the time of peak flooding is considered the most effective in attenuating peak flow. The Department of Water Resources of the County of Sacramento (California USA) has a Local Floodplain Management Plan that recommends that in-kind replacement storage must be provided whenever fill is allowed to be placed within the 1 in 100 AEP floodplain for most watercourses. In-kind replacement is defined as excavating at the same relative (i.e. hydraulically equivalent) elevation as the fill is to occur. The impact of lost floodplain storage to flood elevations will vary from watercourse to watercourse depending on several factors such as width of the floodway, total instream and off stream storage, etc, (County of Sacramento, 2001).

The management of Potentially Acid Sulfate Soils (PASS) - often found in floodplains - requires special attention when cut-to-fill is proposed.

Another issue that can arise in cut-to-fill situations is management and maintenance of the water table. Very often “water features” are in fact created at the water table in order to obtain fill. If this is properly managed it can be appropriate, but it is necessary to ensure that the filling process and the re-shaping of the landscape associated with it, does not lead to high water table situations, which can cause waterlogging and possible adverse effects on adjoining properties. Salinity problems can also arise in such situations.

Facilitating Flood Evacuation

A continuously rising grade is required along all evacuation routes from occupied areas to higher land beyond the extent of the flood. Having a continuously rising grade facilitates a safe and orderly self-evacuation by road using private cars and other vehicles or as a last resort by walking out. Falling or level grade roads can result in being isolated or trapped and thus will require occupants receiving very early warning, which may not be possible in the limited time available. Experience has shown that there is a tendency for people to delay evacuation as long as possible. On a level site this may result in the highly undesirable and potentially highly dangerous situation where residents have no option but to evacuate through floodwaters, (Figure 28).

Figure 27 *Compensation for filling floodplain*

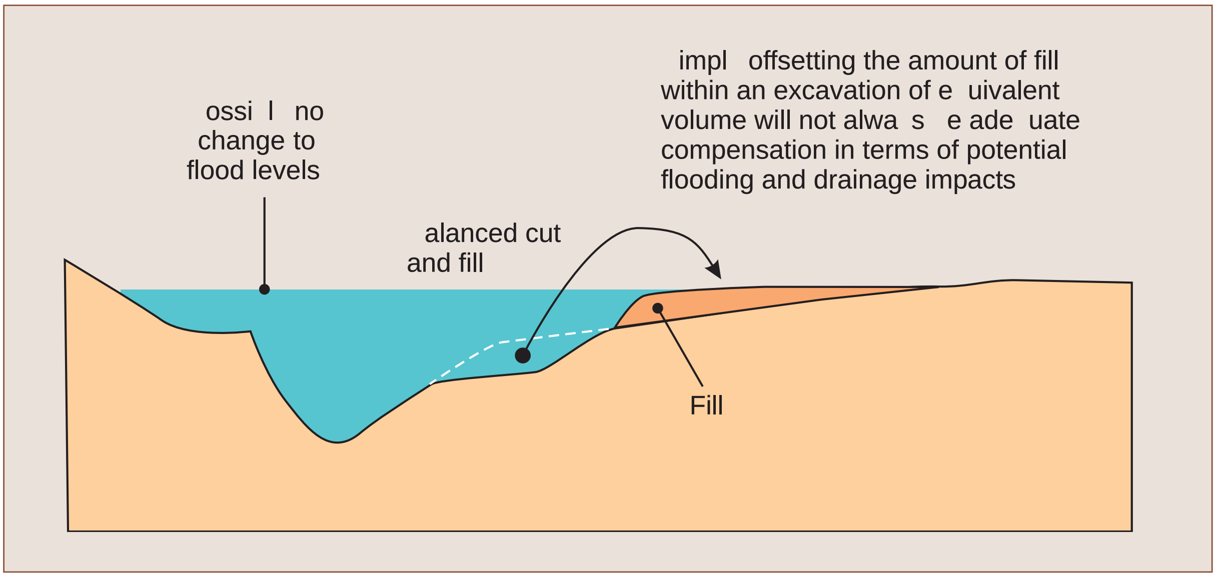


Figure 28 *Safer Escape from Rising Floodwaters*

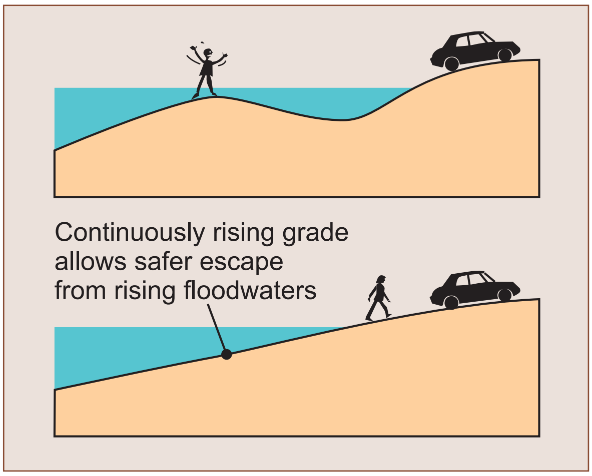


Table 9 provides information on how the gradient of fill and related evacuation routes affect the ability of people to walk out, bearing in mind that a lowest reasonable speed for walking out might be as low as 1km per hour. The example figures provided in Table 9 relate to an assumed evacuation route length of 1km and two possible, but extreme, rates of rise of floodwaters: 1 metre/hour and 2 metres/hour[7].

A level grade site has the potential to be highly dangerous. On a flat site, with no gradient to the roads, there is extremely limited opportunity for walk out when floodwaters are rising at either 1 metre/hour or 2 metres/hour. The entire site would have 200mm water levels after only 12 minutes or 6 minutes respectively and this level would be continually rising. After 12 minutes, at a slow walking speed of 2 km/hour only 200 metres of the total 1 km evacuation route would have been travelled. After 6 minutes only 100 metres would have been travelled. Whilst average adult walking speeds are normally higher than 2 km/hour, it must be remembered that people may be weighed down with possessions, young children etc which would inevitably slow their progress. Whilst wading through 200 mm deep water might be possible for able bodied adults, it is not a scenario that may be tolerated and is certainly not advocated as an evacuation strategy.

However, relatively flat but nonetheless rising gradients (0.1% to 0.5%) along a short evacuation route of say 1 km may provide enough opportunity to walk out to safety (Table 9).

Nevertheless, basing an evacuation strategy for a new subdivision on a ‘walking out scenario’ is not advocated. Many members of the community by reason of age, illness, disability or other impairment are quite unable to walk any distance at all, especially under adverse conditions. It is a measure of ‘last resort’ and in the interests of human safety and equity, should not be relied upon as an acceptable sole means of flood evacuation in a new subdivision.

Table 9 *Time available for walk out evacuation*

Rate of Rise of floodwater (metre/hour)	Route Gradient	Time for 1km route to be inundated	Slowest walking speed necessary to escape rising waters
1	0.1%	I hour	1 km/hour
2	0.1%	½ hour	2 km/hour
1	0.2%	2 hours	0.5 km/hour
2	0.2%	1 hour	1 km/hour
1	0.5%	5 hour	0.2 km/hour
2	0.5%	2 ½ hours	0.4 km/hour

[7] A typical rate of rise for the Hawkesbury-Nepean River at Windsor during major flooding would be 0.5 m/hour. However, 2 m/hour is more likely to be the upper limit and therefore may be considered appropriate for assessing a walk out scenario.

Balanced cut and fill has sometimes been achieved by winning the fill for the house pads from the streets and roads. This practice can result in an extremely dangerous situation as residents can no longer remain in their houses as flood waters enter, yet have lost all chance of evacuation because the roads have flooded first and have become impassable. In such a case, if the waters continue to rise, the trapped residents would require rescue, and rescue is itself fraught with difficulties and danger for both rescuers and those being rescued. There is a real risk of drowning in such situations.

Fill for Infill Development

The use of fill for infill development is more difficult to manage satisfactorily due to the potential impacts and implications for surrounding properties.

This is better addressed through the Floodplain Risk Management Study and Plan process, which can look at the potential impact of filling in a wider context rather than from an individual development site context.

> In many cases, it is possible to demonstrate that the impacts associated with small or localised fill proposals will be negligible, but it is essential that consideration be given to the cumulative effects of a number of likely proposals within the same floodplain as cumulative impacts can be substantial.

Large Scale Filling

Problems with large scale fill to create a uniform ground level over a large site include

- instantaneous flooding over entire area, which
  - > provides no warning;
  - > whole population required to flee to higher ground;
  - > requires high capacity evacuation routes and greater number of exit points to prevent traffic congestion and evacuation conflicts;
  - > does not allow orderly self directed evacuation;
  - > increases risk of outflanking and isolation of properties close to source of flooding;
  - > total area subject to similar hazard and virtually uniform risks at a high degree;
  - > all roads, power and services lost at early stage of flooding compromising safe evacuation; and
- localised flood impacts which increase risks for developments on fringes of the filled area by
  - > raising flood levels;
  - > increasing velocity; and/or
  - > diverting flows.

The advantages of using fill to add ground relief such as a gradual slope in the final levels include the following:

- It can minimise the potential negative impacts on flood behaviour:
  - > gradual rate of rise of floodwaters over the site;
  - > area of land flooded increases progressively and predictably rather than simultaneously and instantly; and
  - > any flow diversions are likely to be more localised and small in scale.
- It can ensure a more gradual onset of flooding over the site and adjacent areas:
  - > by providing scope for timely flood warning delivery; and
  - > giving more scope for orderly flood response and withdrawal to higher ground.
- It can enhance safe evacuation and recovery:
  - > by minimising the number of people needing to respond at any given time and hence potential for evacuation conflict and panic;
  - > by maximising opportunities to provide continuously rising evacuation routes;
  - > by providing refuges as not all the site may be flooded; and
  - > by reducing the potential for infrastructure damage thus assisting recovery.

Choice of Fill or Levee

Fill is sometimes considered to be an alternative to a levee, particularly in relation to infill developments or redevelopment. Leveed areas have particular problems that can arise in terms of floods larger than the design flood. They are also difficult to manage with regard to local runoff from rainfall falling over the leveed area catchment during major floods. Section 5.1.2 has further details in this regard.

Filling of Drainage Channels

It is common practice to increase developable areas on narrow floodplains through filling thus reducing the space taken by drainage channels. Such works are generally sized for the design flood event, with limited consideration given to the requirements for larger events. Without such consideration, there can be a dramatic increase in flood risk when the design event is exceeded. Developments on filled land can be overwhelmed when engineered channels are overtopped by flood waters.

Examples of this include:

- the sudden loss of the use of all roadways adjacent to the channels. This can be critical if they are the only means of evacuation or escape;
- widespread flooding when houses and roads are placed at a generally uniform level at the minimum flood planning level; and
- increased flood depths and velocities which can cause severe damage to the development. This is due to both loss of flood storage areas due to the fill as well as obstructions such as buildings and fences.

Strategies which might be effective in offsetting these problems include:

- grading fill so that floodwaters progressively inundate land;
- designing elevated homes for the lower areas which allow overland flow through properties (Figure 29); and
- identifying roads which would not be required for evacuation and designing them to be capable of accommodating and efficiently conveying floodwaters.

Using fill as a building platform can increase the risk of damage in larger floods, if the filling causes the flood levels to rise. There is also the potential for the site, including the building, to be exposed to higher velocities and increased risk from debris impact.

The use of elevated buildings is more feasible where the floodplain is narrow and slopes towards the channel. As these areas tend to be in the middle to upper reaches where the stream slopes and velocities are higher, they are typically more sensitive to obstructions.

Local Overland Flow and Drainage

In order to reduce or eliminate future flood damages in floodplain areas where fill is proposed it is important that existing overland flow and/or drainage paths and patterns are maintained. Such a strategy is needed to avoid consequential uncontrolled diversion of runoff. An area where this is an important consideration is "fringe filling".

An effective strategy to offset the impacts of fill on stormwater runoff and local drainage is to create requisite flow paths such as channels for local runoff in filled areas.

Figure 29 *Elevating the building above the flood planning level*

This elevated design maintains pre-development flood behaviour without an increase to flood levels. There is also less chance of damage with lower velocities and forces against the building.

Isolated Filling

If the sole aim is to reduce the risk of property damage and evacuation is not the primary consideration (but the risk to life should never be overlooked), then filling for the building pads for the house and garage may be all that is necessary. Damage to outside property would still occur in such a scenario. Careful shaping of the landscape could minimise fill while thus allowing for more flood storage to be maintained. Filling in isolated areas of the floodplain to provide a building pad for a house and garage should be considered on its merits.

In such circumstances however, it is vitally important that the risk to human life is not overlooked. Appropriate consideration must be given to the availability of timely flood warning and the ability to self-evacuate before rising waters cut off all access to higher ground. The risks from larger floods should not be ignored.

5.1.2 Levees

Appropriate Use of Levees

The primary function of a levee is to keep rising floodwaters out of low-lying areas, which require protection. Typically levees are best suited to expansive flat floodplains e.g. in inland New South Wales where the hydraulic gradients are relatively low (the Lowland Area). In such circumstances, the relative increase in flood depth across the range of flood events tends to be small, and the construction of ring levees have been used to great effect to protect towns and individual properties for even the large to extreme events[8].

Where the flood range is low as in most coastal floodplains in New South Wales, levees may be a practical option to consider.

In steeper areas (within the Upper and Middle Reaches) where the topography and flood gradients are constantly changing, levees are not a recommended floodplain management option due to the increased risk of overtopping associated with the uncertainties about flood behaviour arising from limitations in flood model estimates in these parts of the catchment.

In the Hawkesbury-Nepean floodplain, the depth of flooding in floods larger than the design flood event is relatively large and levees are therefore less of an option to help reduce the flood risk to urban development.

Depending on the circumstances, levees are worthy of consideration in some circumstances for existing flood problems, but alternative measures are generally more appropriate for new developments.

Levees should only be considered for new subdivisions after all other flood mitigation options have been investigated and found to not provide appropriate protection. It is unlikely that a new subdivision would conform with planning requirements if levees are required. However, there are circumstances when a levee may be necessary and this section is provided to assist in that consideration.

> Levees are generally not acceptable for new development.

Disadvantages of Levees

Levees are generally considered to be unacceptable for new development. They have several serious disadvantages:

- Levees create hazardous islands of land within rising floodwaters after floodwaters overtop the levees.
- Local runoff is retained behind them. When the area within a levee is large enough, local runoff volume may create local flood impacts within the levee, requiring pump out facilities.
- Levees are eventually overtopped. Unless a levee is designed and constructed to the probable maximum flood (PMF) level, it will be overtopped at some point in time. Under such circumstances, the potential hazards and risks for the protected areas can be significantly

[8] Where it is feasible to construct levees to exclude the probable maximum flood (PMF), e.g. around some towns on the Western Plains, not all the issues discussed in this section will be applicable. However, in such cases proper levee maintenance and provision of an adequate levee freeboard against wave action, climate change and subsidence remain essential.

5

increased. Overtopping floodwaters can flow at relatively high velocities within the protected area. Scouring of a levee due to overtopping may cause the levee to fail completely and suddenly collapse or breach, creating extreme hazards to the community protected by the levee. This creates a much greater risk with the potential for more damage.

- A levee when it overtops creates additional hazards if it breaks at a location which cuts the evacuation route.
- A levee can provide a false sense of security in the community. The mere presence of a levee can afford the general community with some reassurance of protection against floodwaters. However, the community may believe that they are protected from all floods, whereas in fact they are only protected up to the design flood level used for the levee design. People can be unprepared by sudden overtopping and delay evacuation until it is too late. The construction of a levee should be accompanied by effective warning system and on-going public awareness strategies to avoid these misconceptions.
- Levees have the potential to increase flood levels elsewhere on the floodplain and this issue should be addressed.

It is apparent that levees have their place in flood protection, but very often their adverse impacts and high cost make them impractical and unaffordable. In any benefit/cost assessment process a levee height is determined when the costs of construction outweigh the benefits of having a higher levee. The potential disbenefits of levees, in conjunction with the development of a wider range of floodplain management solutions have reduced the viability and/or acceptance of levees as a preferred option.

Advantages of levees

A levee can however, have positive attributes, namely:

- The protection afforded by a levee up until its overtopping or failure occurs, provides additional warning time (depending on the rate of rising floodwaters) for the occupants being protected;
- The additional warning time often enables the crest level of the levee to be nominally raised (through sand bagging or other means), and valuables and other items to be moved to safer locations and evacuation in the more hazardous areas to commence. In the March 2001 flood in Kempsey, for example, even though the CBD area was eventually flooded, the additional time afforded by the levee allowed large quantities of commercial goods and portable property to be removed to safety, significantly reducing the eventual total flood damages and aiding recovery; and
- Levees have long been considered to be one of the simplest and most appropriate of engineering measures used in floodplain management to control or prevent the inundation of existing flood liable development.

What to Consider When Designing a Levee

If a levee is identified as a possible flood protection option through a floodplain risk management study (FRMS) and plan, there are a number of issues which require careful consideration.

The level of flood protection required

Local circumstances including the nature of development requiring protection, the physical limitations of the site, the height to which floods can rise relative to the ground levels in the area and economics tend to dictate the maximum level of protection that can be achieved to meet community expectations. Through the floodplain risk management process, council together with the community determines the choice of design flood level for a levee design. Consideration should be given to designing the levee to the same height standard used for the flood planning level (usually 1 in 100 AEP event).

Determining Freeboard

A freeboard is an allowance used to raise the crest level of the levee to allow for uncertainties in hydrologic/hydraulic knowledge and flood

Figure 30 Lismore Concrete Levee System

modelling, climate change, afflux and wave action. These criteria are also used in determining freeboard used in setting flood planning levels for habitable floors. In levee design however, freeboard should also include an allowance for maintenance (or lack of). Earth levees tend to deteriorate over time by settlement, piping failure and inadvertent and unexpected lowering over time. The amount of freeboard on a levee is typically of the order of 0.5 metre, but local circumstances may warrant a higher freeboard of up to perhaps 1 metre. This figure is added to the level of the design flood to give the crest level of the levee.

Good understanding or definition of hydraulic gradients

Unexpected differences in flood gradients between design and actual floods can cause levees to overtop notwithstanding their design limits. Overtopping can be particularly critical if it occurs at the upstream end of the levee as it can cause potentially dangerous floodway conditions in the protected area.

Physical features and/or topographical constraints

The local topography can influence the design of a levee; there may be opportunities to incorporate higher ground into the levee structure.

Construction materials and geometry for the levee structure

Levees are normally made from soil, placed and compacted at a “safe” slope. These levees require careful selection of soil materials and good control of compaction of essential. Earthen levees have a large footprint (typically 30 metres wide or more) and this can be a problem in many areas. Therefore levees are sometimes made of reinforced concrete or concrete blocks

Provision for stormwater drainage within the protected area

Drainage of the area behind a levee may be disrupted by the construction of the levee leading to local overland flooding problems. Pump out facilities or storage within the leveed area may be

Figure 31 *Lismore Concrete Levee Spillway*

necessary. Floodgates, to allow one way flow out of the protected area, located at the outlet of the local drainage system behind the levee ensure that the main river floodwaters are prevented from entering the protected area via the local drainage system.

Flood-related planning controls for development within the protected area

Levees are generally used to reduce the flood risk to existing development, however there remains a need for flood related development controls (e.g. appropriate flood planning levels) for new development on land protected by the levee to address the continuing risk. Controls to reduce property damage can include requirements for flood-proofing of buildings and 'flood-aware' housing design (the Building Guidelines provide more information in this regard).

Consequences of overtopping or failure

In most designs a spillway is built into a levee; A spillway should be incorporated at the lower end of a levee. It has two primary functions. Firstly it allows water to flow into the area behind the levee before the main levee is overtopped or fails. The water then builds up gradually behind the levee to help reduce the chances of catastrophic failure of the main levee when it overtops. An analysis of flow conditions which may develop when overtopping occurs is necessary to ensure that high hazard floodway conditions do not develop in areas which would pose a risk to people and property.

Secondly, a spillway can give some practical warning to people inside the levee that the levee protection level is about to be exceeded, giving a sense of urgency to take appropriate flood damage minimisation actions and commence evacuation activities if they have not done so already. The location of an ingress and egress point and location of initial overtopping must be carefully positioned to ensure that evacuation routes to safe ground are not compromised by early operation of the spillway. Flood warning systems are essential to provide early warning of the levee overtopping.

Hydraulic Impacts

Construction of a levee displaces floodwaters that would otherwise flow through or be stored in that part of the floodplain. Depending on the overall size of the floodplain or flow path in the area, hydraulic impacts including increased flood levels outside of the leveed area, can range from minimal to significant. A careful hydraulic analysis is therefore required prior to designing and constructing a levee.

Social, environmental and economic aspects.

It is necessary to carefully canvass local community attitudes before proposing a levee solution. For example, people living near a river, generally value access to, and views across, the river. If a levee is likely to have a significant impact on views or access, public opposition can be anticipated even when the expected economic benefits are significant. A concrete levee wall can also be visually intrusive and careful design and landscaping is required. Earth levees are much easier to disguise with appropriate landscaping than walls. Levees also have the potential to disrupt natural environmental (e.g. aquatic and terrestrial fauna and flora) corridors.

Commitment to levee maintenance

If a levee is chosen as a preferred option, there needs to be a commensurate commitment to levee maintenance to avoid deterioration over time (including settlement leading to a lower crest level) and premature breaching even in floods lower than the design flood. Proper maintenance of the levee crest level, including maintenance of protective grass cover and the spillways, and the avoidance of damage from traffic or animals is essential.

Emergency flood management

There also needs to be emergency flood management plans in place to protect the community in the event of the levee overtopping. As part of the emergency flood plans, effective and timely flood warning systems need to be in place. Evacuation routes which will not be cut by early overtopping need to be identified and signposted. To avoid community complacency and to create a flood – resilient population, there is a need for an on-going commitment to raising public awareness and preparedness for floods which exceed the design level of the levee so that the community knows how to respond to the flood warnings appropriately and understand how and when to evacuate, when the need arises.

Case Study

A case study examining a subdivision where a levee has overtopped at the worst possible location can be found in Section 9. This case study demonstrates how lack of care in the design of a subdivision protected by a levee bank can increase flood hazard rather than reduce it. What went wrong and design issues are discussed and methods to design the site to reduce the risk are put forward.

Velocity Reduction Levees

Velocity reduction levees are a specialised type of levee (or barrier) constructed across active flow paths to effectively reduce floodplain velocities to an acceptable level, (Figure 32). Depending on factors such as flooding patterns and land form opportunities, these barriers can be built on the edge of development or within development incorporated into boundary fencing, (Figure 33).

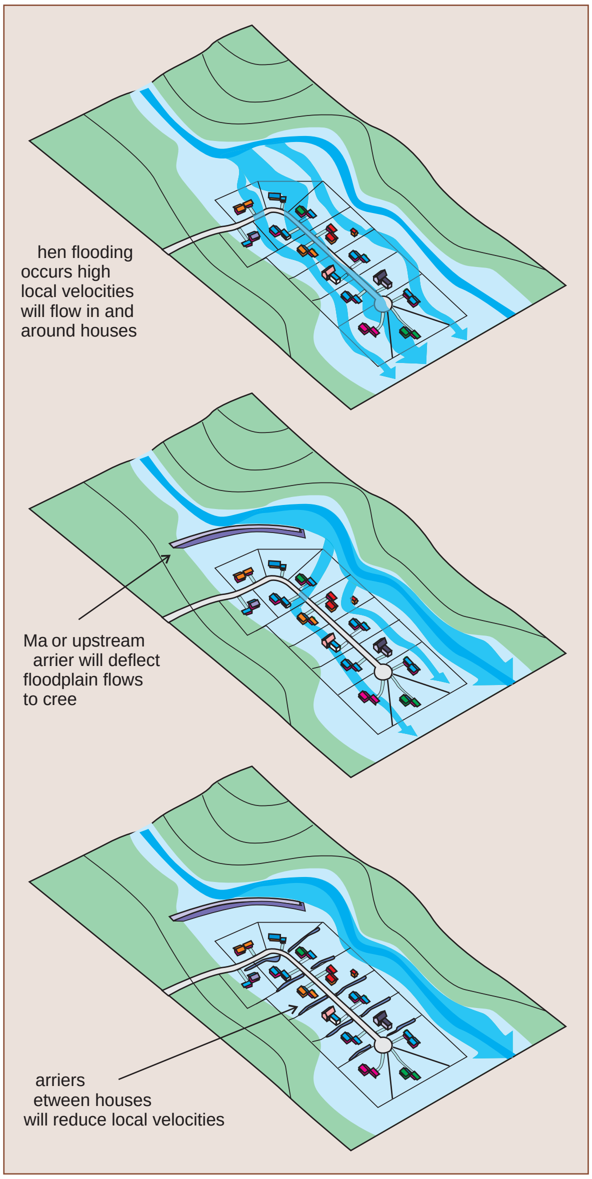
The velocity of moving floodwaters can be a significant constraint to building houses in floodplains. Work done for the companion Building Guidelines suggests that local velocities (not average velocities) in excess of about 0.8 metre per second will cause cracking and possibly structural failure to standard brick walls such as commonly used in the outer external brick wall for brick veneer housing. There are advantages in having measures such as a velocity reduction levee, which will reduce or eliminate velocity in order to reduce damage and encourage cost effective "flood aware" designed housing.

Key advantages of velocity reduction levees are, they:

- can be made to blend with the existing / future landscape;
- do not reduce floodplain storage; and
- do not pose a significant hazard when floodwaters overtop their crest level.

Notwithstanding these advantages, they can divert flow into adjacent existing developed areas and for future development resulting in higher flood levels and velocities in these areas.

Figure 32 *Velocity Reduction Levees*



Critical considerations for velocity reduction levees are:

- physical opportunities offered by the site;
- the extent to which local velocities are reduced; and
- impact of the levees on floods behaviour (level and velocity) and adjacent development.

Either two dimensional numerical modelling or physical modelling is required to determine how well velocities are controlled and the magnitudes of their impacts on overall flood behaviour. Given the local and regional impacts of such levees, they are best assessed as part of a full floodplain risk management study (FRMS) along with other competing or complementary options. By strategically assessing velocity management through a FRMS, it is possible to design a velocity management scheme which has the least impact on the future landscape and individual properties.

Figure 33 *Boundary Fence and Velocity Reduction Barrier*

Velocity reduction levee schemes along the Georges River floodplain in Western Sydney have received general community support as an acceptable method of controlling velocity. Effective barriers have been implemented by building appropriately located strong boundary fencing which will withstand the force of flowing floodwaters.

5.1.3 Detention Basins

Introduction

Detention basins are one of the most complex elements of a trunk drainage system. They have many issues which are unique in their design and function.

It should be recognised that the provision of detention basins on site has spatial requirements which preferably need to be determined early in the subdivision process as the solutions are likely to affect the final site layout, lot yield and open space provision. Early identification of land for detention basins (i.e. regional and on-site basins) can avoid delays in the approval process. Some councils may not be willing to allow dual purpose open space and drainage reserves.

Properly designed basins, with particular volume and outflow characteristics, will temporarily store flood waters for slow release, thus reducing downstream flows, levels and velocities.

Basins can have one or more hydrologic purposes, namely:

- to counter the effect of increased upstream runoff due to urbanisation;
- to reduce peak flows downstream to deal with flooding problems to existing development by reducing the frequency and level of flooding;
- to reduce downstream river bank erosion[9]; and
- combination of the above.

Detention basins are also commonly multi-functional in that they serve their primary function of attenuating the peak of the flood wave, but at the same time they may well have a wetland within or adjoining to improve water quality or are used as sporting ovals or parklands. Such functions should not compromise the intended hydraulic performance of the basin and the use of the basin should not pose an unacceptable risk to personal safety.

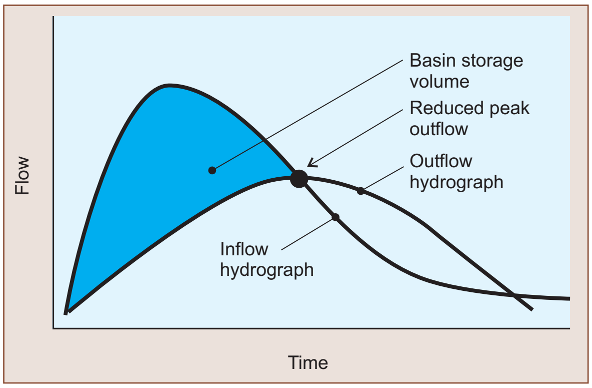
For many years, detention basins have been used to protect downstream floodplains. The statistical reliability of rainfall patterns and computer analysis techniques for designing basins have developed to the extent that the use of basins in subdivisions is now common place.

They may offer a cost effective alternative to increasing the size of drainage channels or pipes through existing areas downstream of the basin. In the case of new downstream development, basins reduce the flows so that smaller pipes and channels can be used leading to a more cost effective trunk drainage system. Despite this benefit, basins can also become extremely hazardous if the capacity of the basin is exceeded and the basin overtops dramatically without warning.

Types of Basin Systems

Basins have a significant effect on both the hydrology (the flows) and the hydraulics (the depth, velocities and flow paths) of a trunk drainage system. Of particular concern to the design process

Figure 34 *Attenuated Outflow Hydrograph from Detention Basin*



is the practical differences between theoretical analyses when compared to real life events. It is therefore very important to consider the flows, and the timing of the flows in the whole catchment when locating and designing basins, (Figure 34).

Flow detention can be achieved by one or a number of approaches. Typically these are:

- regional basin strategy based on a total catchment modelling; and
- on-site detention (OSD) for each site or development generally based on volumetric per hectare requirements; or
- combination of both of above.

There are a number of examples within the Sydney basin of where councils have had modelling studies undertaken to determine regional basin locations and sizing. These studies have involved modelling to determine flow regimes for existing or pre-development conditions and to assess a range of basin options to determine the preferred basin strategy. Figure 35 illustrates an example of a hypothetical regional basin system.

Subdivision design requirements within a catchment that has an adopted regional detention basin strategy vary according to location. These fall into four location categories, shown in Table 10.

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[9] Whilst this can be a successful outcome because of reduced flow rates, there may be individual cases where basins aggravate erosion as they cause downstream bank full flows to last longer. Furthermore detention basins do not reduce the run off volume from new upstream development. Complementary catchment flow management strategies (involving water sensitive urban design) are needed to ensure that the natural geomorphology of the subject waterway is preserved (see section 5.2.3).

Figure 35 *Regional basin system for urbanised catchment*

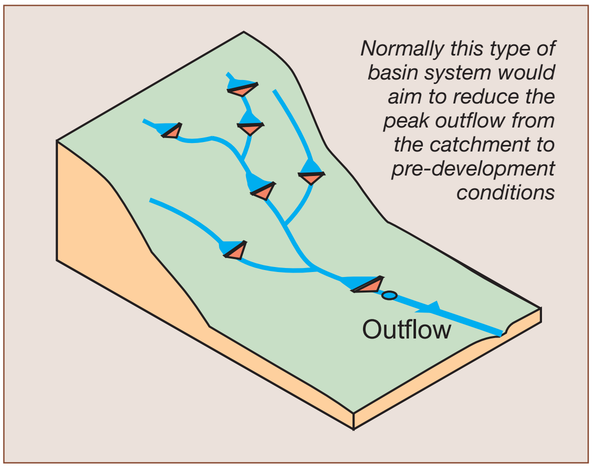
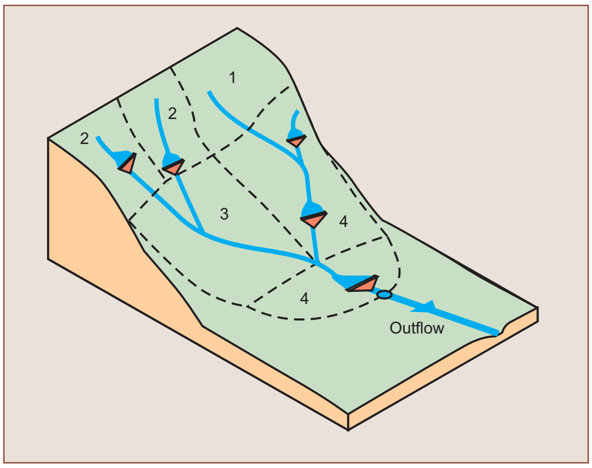


Table 10 *Basin Strategies*

Location of Subdivision	Basin Strategies
1. Upper catchment without Regional Basin(s)	Financial contribution to a council regional basin system based on $/ha.
2. Upper catchment with Regional Basin(s)	Main stream basin plus possibly sub-catchment basins as part of the development for subdivision
3. Middle or lower catchment without Regional Basin(s)	Financial contribution to a council regional basin system based on $/ha.
4. Middle or lower catchment with Regional Basin(s)	Main stream basin plus possibly sub-catchment basins as part of the development for subdivision

These potential regional basin strategies are shown in Figure 36.

Figure 36 *Regional Basin Strategy Areas*



Off-Line versus On-Line

An on-line basin is one that is located within the stream itself, and an off-line basin is where the basin is located on the floodplain some distance away from the stream. In an off-line basin, flows are diverted into the basin by way of a weir in combination with possibly a downstream choke or some equivalent diversion structure. Additionally, it should be noted that an off-line basin system might be achieved by having an on-line basin(s) located on tributary creek(s) to the mainstream. With this arrangement, it is possible to preserve the mainstream riparian corridor. Each of the basin systems is illustrated in Figure 37.

Dry off-line basins are preferred from a natural resource management perspective as they effectively preserve both terrestrial and aquatic environments. In doing so, they maintain vital habitat and ensure continuity of bushland corridors.

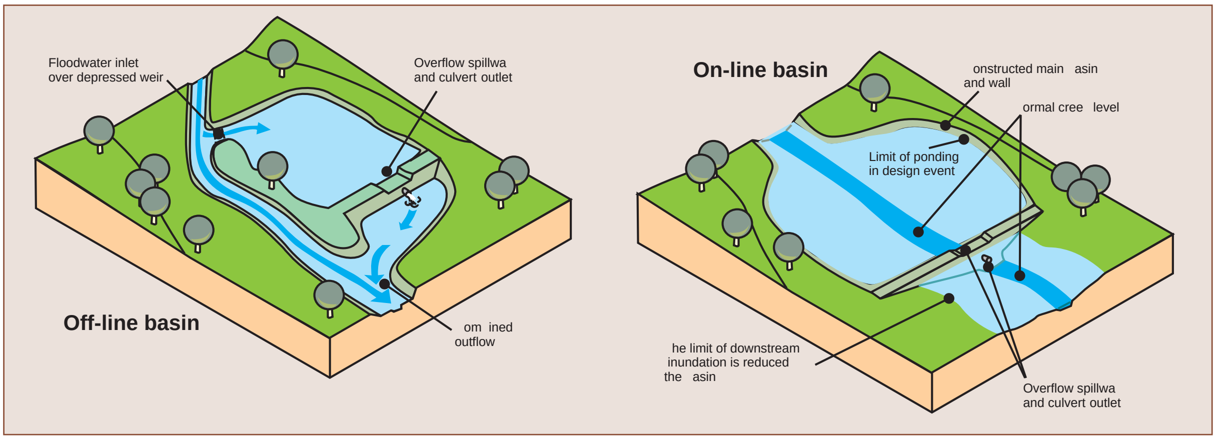
When it is not possible because of space constraints to have a full off-line basin system, it may be possible to have an on-line basin, which has some worthwhile environmental attributes. Whilst the on-line basin could have a low environmental impact retaining wall (with stepped opening arrangement to help reduce the impact on stream continuity), environmental gains may be achieved by:

- retaining or reinstating the creek system and its natural function through the basin area; and
- adoption of an appropriate vegetation management plan, which might involve blending adjacent bushland into the basin area.

An example of a creek system being reinstated in a basin area (prior to tree planting) is shown in Figure 38.

The use of a mainstream off-line basin system with on-line tributary basins can be preferred in new developments as the tributary basins are easier to accommodate and they can be designed to capture and hold/treat “first flush” flows from a storm and by-pass further flows once its capacity is reached.

Figure 37 *Off-line and On-line Basin Systems*



It is desirable to have mainstream off-line type basins "dry" as such a system helps to preserve the continuity of low environmental flows in the main creek or river system. Because of this, alternative water quality polishing ponds beyond the basin area may be required. Preferably these should be located as close as possible to the sources of any pollution, such as buildings and roads.

Theoretically, off-line basins used to control major mainstream flows can actually require less land and fewer earthworks. This means lower construction costs and may result in more developable land. The storage efficiency of off-line basins may be enhanced by locating the basin:

- adjacent to the inside of a bend(s) in the river/creek to aid placement of inlet and outlet structures;
- upstream of natural hydraulic controls;
- in lowlands adjacent to natural levee systems; or
- in steeper terrain to facilitate more effective inlet/outlet and storage design.

However, in practice it may not be possible to provide an off-line basin within a smaller footprint than the on-line basin approach. The merits of each approach need to be fully assessed, based on the constraints of the site before making a final decision.

A case study which illustrates the relative performance of on-line and off-line basin systems in basin size requirements can be found in Section 9.

Detention Basin Design

Detention basins are probably the most complex element of the trunk drainage system and their design warrants careful attention to detail from a design team with a wide range of expertise. Careful consideration needs to be given up front as to whether a detention basin is really the best means of addressing the problems that it is meant to solve. If it is the best solution, two equally important issues require careful attention. They are the:

- suitability, (from a hydrologic and hydraulic viewpoint), of the site that has been chosen, and
- the effects which the associated works and changes in flow regime will have on the environment.

As professionals become increasingly aware of the effects of their proposals on both the social and

Figure 38 *Reinstated creek bed through a basin*

environmental attributes of the landscape, finding satisfactory solutions to these problems presents challenges.

The key issue in basin design is to factor in that the real situation could actually be worse than might be identified by the adopted theoretical design scenario.

The following design considerations should be addressed.

Primary purpose or objectives

- to mitigate peak flows in medium or large events;
- to protect existing development; and
- to maximise proposed development while minimising downstream drainage requirements.

Hydrologic performance

- the required reduction in peak flows; and
- the storage volume available relative to the runoff hydrograph, detention/draining times.

Operational characteristics

- inlet and outlet structure details;
- stage – storage volume and detention; and
- provision for excess overflows.

Usage

- is the basin to be used purely for flood mitigation purposes; or
- does it also provide recreational or water quality benefit?

Safety

- implications of the basin overtopping; and
- hazards for passers by and/or nearby residents.

Maintenance

- potential for debris blockage; and
- ease of access for maintenance crews and machinery.

The design considerations are each discussed in more detail subsequently.

Hydrologic Performance

There are the practical differences between theoretical analyses when compared to real life events. In carrying out a theoretical analysis, consideration needs to be given to:

- Design storm rainfall patterns (which have been derived using Australian Rainfall and Runoff (Pilgrim (1987) primarily to estimate of peak flows) versus historical storm rainfall patterns;
- The status of the basin water level before the peak flow arrives has to be assumed. How much storage volume is actually available (i.e. is the basin empty or full?); and
- Relative timings of tributaries.

More information on large storms and catchment wide studies can be found later in this section.

Operational Characteristics

The operational characteristics of a detention basin will directly influence hydrologic performance, maintenance and safety aspects. The outlet structure typically has the greatest influence, but equally important is the actual shape of the basin storage area and the stage-storage-discharge relationship that applies. In conjunction with the hydraulic characteristics of the outlet, the shape of the basin will establish the rate at which the water ponds in the storage area and is discharged to the downstream areas, hence the time of detention.

The location, level and width of the overflow spillway are critical elements in controlling the rate and direction of discharge for the larger events. It is vital that overtopping occurs where it is intended and is accompanied by adequate warning of its impending occurrence. Such warning is best achieved by visual cues from good design by having the initial overflow contained in safe areas before wider inundation occurs.

The inlet details and the drainage characteristics through the basin for “normal” or smaller flows can also have a significant influence on the way the basin operates, utilising the storage lag or rate of filling to minimise peak outflows. Providing a direct drainage line under the basin will have little or no storage-lag effect on small inflows compared with the provision of a more tortuous drainage path. A surcharge pit arrangement for the inlet structure is often utilised to ensure the basin storage area is activated for smaller events where this would be beneficial in protecting downstream areas, or in providing water quality benefits, if these form part of the multi-objective design of the basin.

Usage

A detention basin typically occupies a large area of land that can have multiple uses. Depending on the size of the area available, uses in addition to flood mitigation include:

- incorporating a wetland area for landscape or water quality purposes;
- incorporating other water quality control measures;
- passive recreational areas in the form of open parklands and walkways, etc; and
- active recreational areas such as sports playing fields.

Where a basin is to be used for other purposes it is important that the primary flood control function with regard to hazard management is not compromised, nor is the safety of users of the dual use facility in flood events overlooked.

Safety

Careful consideration must be given to safe overtopping of a detention basin. Overtopping results from flows which exceed the design capacity of the basin and its outflow structure. Flow paths downstream of basins must be carefully considered as flows will inevitably exceed the basin capacity. This is particularly important where the basin is not designed for the PMF.

The issue of safety involves consideration of:

- designing the basin so that warning signs of overtopping are obvious and visible (i.e. not just reliant on emergency services for issuing warnings and ensuring personal safety);
- the integrity of the structure itself (embankment stability);
- the risk to downstream areas due to flood events larger than the basin capacity or damage to the embankment or blockage of the outlet;
- the risk to upstream areas should the ponded water level cause backwater problems; and
- the risk to passers by or users who may be inadvertently caught or swept into the basin (this raises issues such as depth of basin, means for escape, inlet/outlet structure details and is especially important if multiple uses are is envisaged).

Maintenance

Maintenance of detention basins is critical to ensure operational integrity over time. As with the implementation of any engineering infrastructure works, the need for ongoing maintenance can incur significant costs as well as exposing the responsible owner to potential legal liability. It is important that maintenance is addressed in the design process. Aspects which need to be carefully considered include:

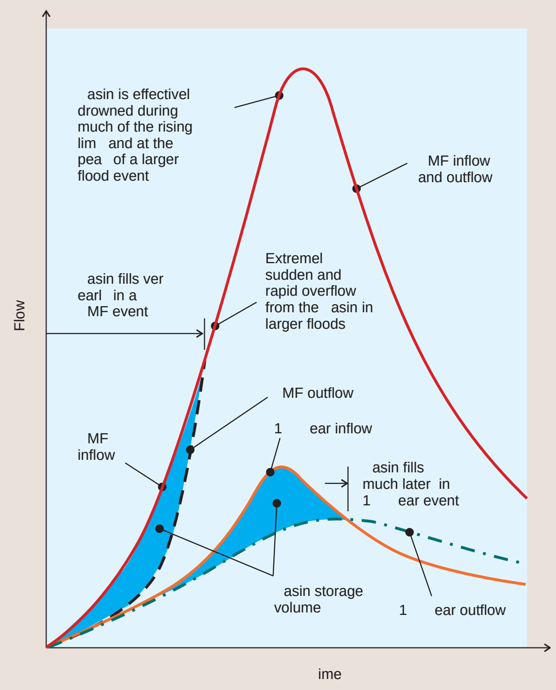
- provision of appropriate measures to minimise the potential for blockage of the basin outlet structure;
- the potential debris or sediment load generated by the contributing catchment or within the basin itself;
- appropriate safe access for maintenance crews in order to facilitate easy and/or regular inspections and cleaning to occur before the build-up of collected / trapped material causes a problem;
- potential wear or settlement of the embankment and/or overflow spillway;
- choice of surface material to be used for the basin floor and batters and any potential vegetation within the basin;
- surface (and sub-surface) drainage characteristics of the basin floor and batters to allow proper drainage of the basin following rainfall events; and
- potential for scour at the inlet and outlet structures.

Catchment Wide Studies

The hydrologic purpose or function of a basin is to temporarily store the runoff volume for delayed and extended release at a lesser flow rate. In some situations (either with individual or a combined basin systems) this can make the peak flow obtained downstream worse than would normally have occurred. This phenomenon is due to the relative timing of flows combining from different tributaries. The extended flow rate associated with the tail of the hydrograph discharging from an individual basin can coincide with the flow from another tributary to produce a greater total flow.

As a result of the combined effect of all basins in a catchment, catchment wide studies are clearly desirable in order to address the complex cumulative hydrological performance of basin systems. However, these types of studies are often outside the ability of many subdivision designers. Catchment-wide studies and works warrant being commissioned by councils, perhaps using funds from Section 94 or other developer-generated contributions.

Figure 39 *Basin Overflow in Larger Flood Events*



Downstream flooding during basin overflow in larger flood events can be significantly more hazardous than in the design flood event.

Design flood events

In general, the storage and outflow characteristics of basins should be aimed at reducing the impact to people and property from significant flooding. Such flooding may include the 1 in 100 AEP event. Nevertheless, this approach may differ from the traditional approach of requiring detention storage for floods from the 1 in 100 AEP event down to and including the 1 in 2 AEP or 1 in 5 AEP events. Targeting the more frequent events may be counterproductive by not making best use of often limited funding resources. Furthermore, low flow from the more frequent events are generally controlled within the catchment through the use of water sensitive urban design strategies (refer to section 5.2.3).

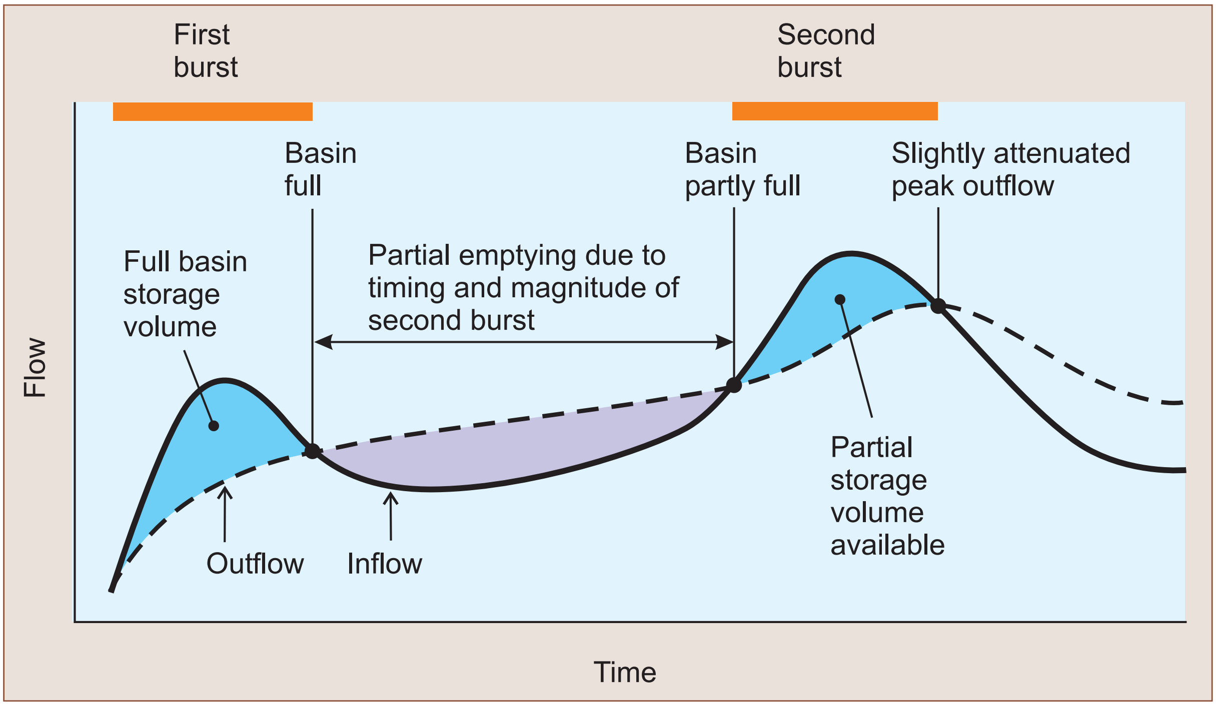
Overflow from basins can result in fast and deep downstream flows, which develop rapidly without much warning (Figure 39). In order to avoid these potentially hazardous (and in some cases catastrophic) conditions it is vital that the overflow up to the PMF event is controlled through the use of an appropriately designed spillway system. To adequately address this issue, particular attention also needs to be given to the location and level of downstream properties.

Storm types

Another important hydrologic feature of basins that must be considered is their behaviour in complex storms. Design storms from Australian Rainfall and Runoff (Pilgrim 1987) are typically single-peaked storms, and there is no specific guidance on the likely status of the detention basin at the commencement of the designing storm. In other words should it be assumed that the basin will be partly full from an antecedent storm or from the first peak of the same storm (see Figure 40) or can it be assumed to be fully available for storing a substantial part of the storm run-off?

Short duration intense storms will often produce the higher peak flow rate which requires attenuation to protect the downstream areas. However, less

Figure 40 *Impact of Multiple Peaked Storms on Basins*



intense long duration storms will produce greater volumes of runoff which may readily fill the basin storage area and potentially result in flows passing straight through the basin without being attenuated.

The location of the basin(s) within the catchment and the movement of a storm event is important. For example, in situations involving cascading or multiple basins where the storm moves up the catchment, the lower basins may already be full when the peak flows from the upper catchment and basins arrive. As such, the expected benefits from the performance of the combined basins are not realised.

The best guide for determining this issue is to look at historical storms in the area as well as the normal design storms. For example in Coffs Harbour the two largest storms in the 1970's were generated by remnants of tropical cyclones, and the first peak of the flood hydrograph in each case would have filled any normal sized basin. If this storm feature is typical of an area, then as a minimum it needs to be considered in the design, and more likely, it could be seen as negating the value of using a basin as a design element of a trunk drainage system in this area.

Hydraulic impacts of basins

In evaluating the function of detention basins as part of an overall trunk drainage strategy, it is necessary to consider their effect on hydraulic behaviour.

Upstream Impacts

Ponded water behind the basin wall creates a backwater profile (see Figure 41) which is normally higher than the level it would have been prior to the basin being installed.

It is important therefore to ensure that this is taken into account when designing the upstream channel or locating the limits of development upstream.

Figure 41 *Upstream flood profile with Basin*

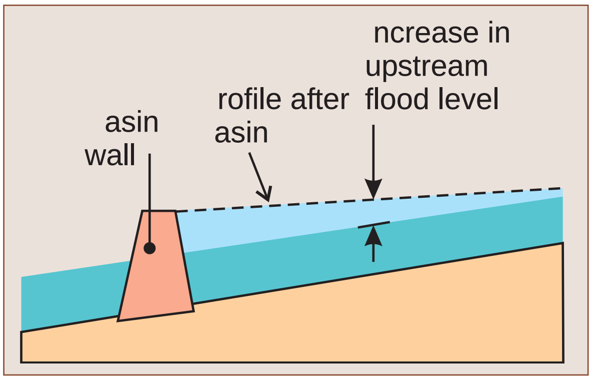


Figure 42 *Velocity Dissipator in outlet channel*

Downstream Impacts

With reduced peak flows from a basin outlet structure downstream flood levels are generally lowered, except in situations where the timing of combined flows from tributaries causes an increase in the downstream peak flow and flood levels. Although the outflows from individual basins are reduced, they can exit at high velocities. The resultant energy needs to be effectively dissipated using appropriate hydraulic structures, which can occupy a substantial downstream area. An example is shown in Figure 42.

Velocity dissipation structures alone will not adequately mitigate the downstream flood hazards up to the PMF event. It is also necessary to ensure that the downstream channel configuration is compatible with these hazards.

Cascading Basins

In some catchments the required flow detention is achieved by the use of multiple cascading basins. However, it is critical that this cascade effect does not exacerbate downstream flooding as a result of flow from the upper basins spilling into the lower basins when overflow or collapse occurs to the upper basins.

Stream Erosion Potential

A further downstream hydraulic effect that needs to be considered is that the falling limb (of the hydrograph) flows will be sustained for longer periods at higher flow levels. This can lead to undesirable downstream scour and stream bank instability problems.

Community Perception and Basin Outflow Behaviour

Another problem with detention basins is the false sense of security, which the residents living below the basin might acquire. Should a basin overtop, it would be likely to fail and generate both great depth and velocity of downstream flow without any warning.

Basins should be modelled to determine their performance over the full spectrum of possible flooding up to and including the PMF. This modelling must check for sensitivities to parameter selection and consequences. Basins should be designed with the spillway located away from development. Consideration should be given to the possible use of wide spillways to help reduce the downstream flood hazard by dispersing flow to achieve lower depths and velocities. High hazard flow from spillways should initially traverse non-residential areas.

Overtopping of small retarding basins may not lead to property damage, but other larger basins may pose a threat to the safety of both life and property. Hence there should be categories of design to cover varying degrees of risk to people and property downstream. This is generally more of an issue with large basins, which may have a high wall similar to a dam-type wall to temporarily retain the floodwaters for slow release. Overtopping of the basin wall is less of an issue if existing or proposed downstream development is sufficiently clear of the basin wall. Advice should be sought from the Dam Safety Committee regarding appropriate requirements for significant “dam-like” water retaining structures.

Usage of land downstream of a detention basin

The basin may reduce the width and depth of flows for smaller events up to its designed event. The actual impact on downstream development will depend on the function of the basin:

- If it was designed to just attenuate increased urbanised flow from upstream, it will have no impact on the amount of developable land downstream, and the only development impact will be the risk of structural dam failure and the attendant impacts;

Figure 43 *Recreation area downstream of Basin*

Wall and outlet works on a large detention basin with appropriate land use i.e. recreation areas, immediately downstream. This avoids the dangers to downstream development when the basin capacity is exceeded.

The situation should be reviewed in light of all the changes that have occurred to flood behaviour as a result of the basin's construction, including the attendant increased risks from dam failure. Consideration should be given to the events greater than the 1 in 100 AEP flood to see whether flood behaviour or warning times have changed from the natural situation.

- If it was designed to reduce the impacts on existing flood liable development, then it would have the effect of improving the value and development potential of the existing developed land, and may open up new land for development. The risk due to dam failure or overtopping above the designed flood level will need to be considered in new environmental planning instruments for the area; and
- If it was designed to significantly reduce flows downstream from their existing levels then the potential for further development downstream would require consideration.

The development issues that are raised for land downstream of a new detention basin are not dissimilar to some of the issues that arise when a levee is built around an area. They include appropriate flood planning levels for habitable floors, land use, development and building controls. Through the floodplain risk management process a council may decide appropriate land uses include bushland, open space or recreational uses or even residential or parking areas, although dwellings may require an elevated configuration, (Figure 43).

5.2 Flood and Stormwater Management to Control Risk

5.2.1 Introduction

This section of the guidelines focuses on flood and stormwater management issues relevant to master planning of neighbourhoods or large scale subdivisions for housing estates. By integrating flood and stormwater management works into neighbourhood planning, opportunities evolve to safely and economically accommodate flood and stormwater flows in streets and multi-purpose reserves to protect lives as well as preserve and enhance the built and natural environment.

Before the distribution of land uses, streets, lots and houses is determined, flood and stormwater flow paths, behaviour and impacts on the site should be determined to enable the development to appropriately respond to the flood and other overland flow behaviours and impacts by allowing the water to flow through safely. Flood and stormwater management strategies, which mimic the pre-development state, will pose the least threat to residents.

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> This guideline is consistent with the Floodplain Development Manual 2005, which "treats local overland flooding as a significant problem that needs to be considered along with mainstream flooding". It is also consistent with Chapter 14 of Australian Rainfall and Runoff (Pilgrim1987), which states:
>
> "The pipe and trunk drainage systems are likely to be parts of some large urban or partly-urban catchment, for which an overall plan of management is required".

5.2.2 Common Issues

Flood Flows and Impacts

The traditional approach to managing flood impacts has largely been limited to flood constraint mapping and precluding development in areas below an adopted flood planning level.

While this approach limits the frequency of exposure to flood hazards and damage, it does little to manage the flood hazards and damage caused by the rarer floods.

Constraint mapping is often limited to only considering flooding on land below the adopted flood planning level. It therefore often overlooks the full range of possible floods above that level and overlooks how houses, buildings and other changes to the landscape modify flood behaviour.

Stormwater Flows and Impacts

Traditional stormwater management has tended to concentrate on minimising the nuisance caused by stormwater runoff. Designers accepted that urbanisation increased the speed and volume of runoff, due to the decreased areas available for infiltration and to efficiently dispose of the runoff, particularly that from roofs, roads and other impervious surfaces.

The major/minor drainage system approach using piped minor systems was widely adopted to keep the frequent flows out of sight. This approach became less affordable as higher density developments increased stormwater infrastructure costs.

Designers and councils then sought to limit the growth in stormwater costs by limiting the peak flow rates for which the systems were designed. Strategies such as detention basins and on-site detention (OSD) use temporary flood storage to limit peak flow rates to pre-development rates. The temporary storage however prolongs the duration of peak flows which can then cause other flood problems.

5.2.3 Better Practice

Flood Flows and Impacts

A council can prepare and adopt a Floodplain Risk Management Plan (FRMP) in accordance with the process in the Floodplain Development Manual (NSW Govt. 2005). Having in place flood policies and flood-related land use and development controls in the planning instrument, enables council to control development on the floodplain.

Consideration of flood hazards in rarer floods i.e. above the flood planning level (FPL) is crucial in flood risk management. In planning a new subdivision in the absence of a FRMP or existing flood studies, a developer should identify areas of the site affected by the full range of floods. This should consider the nature and severity of all flood impacts. It is important to remember that the floods above the FPL will inundate land around the dwelling houses causing damage and result in the need for evacuation.

The important consideration in the design of flood mitigation works is that they all have a design capacity, which will be exceeded. Flood behaviour and hazards in events larger than their design capacity must be carefully assessed to avoid creating unexpected and unnecessary risks.

Dwelling houses blocking floodway areas have a high exposure to serious structural damage. They are also likely to divert flows through adjacent houses, which may otherwise have been flood-free and therefore damage-free. Floodway areas in events above the FPL are best left as flow paths. This could be achieved by avoiding placing houses there, using set backs or elevating structures where possible. Houses in flood storage and flood fringe areas are not only less likely to suffer significant structural damage than houses in floodways, they are also less likely to cause major flow diversions.

Flow diversions can also be caused by earthworks for roads or streets cut into the natural ground level creating artificial channels. The flood impact assessment should therefore ensure that road works, fill or other land shaping measures are managed to avoid unnecessary flow diversions creating new hazardous flow paths.

Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is a balanced approach to achieve stormwater management of a site. It aims to apply the right applications in the right locations having regard to site conditions and constraints, to achieve sustainability (conservation, protection and recharge) for water cycle management. In terms of stormwater management, WSUD offers an alternative to the traditional conveyance approach. It seeks to minimise the extent of impervious surfaces and mitigates changes to the natural water balance through on-site treatment and reuse of the water, as well as through temporary storage and infiltration within the source catchment.

To meet the needs of the environment and community it is essential that urban drainage systems are designed as a total solution. The key is integrating the practices of flood management, WSUD, stormwater quality control, community needs and preservation of the natural environment. The objectives include:

- preventing flood damage in developed areas;
- reducing stormwater runoff volumes and peaks, and the velocity of discharges;
- preventing excessive erosion of waterways, slopes and banks;
- minimising water borne sediment loadings;
- minimising contaminant transport from stormwater to surface or ground waters;
- designing development and associated roads and infrastructure to recognise and respond to salinity conditions;
- improving efficiency in the use of water, and reduce demand for imported mains water;
- reducing sewer overflows in wet weather;
- protecting riparian ecosystems, including restoration of degraded ecosystems; and
- promoting scenic, landscape and recreational values of stream corridors.

A range of applications are available for the integration of WSUD concepts and technologies into urban developments. They include:

- grassed or vegetated swales - primary treatment and conveyance function to provide secondary treatment benefits;
- filtration trenches - primary treatment and conveyance and detention options to provide secondary treatment benefits;
- bio-retention systems - secondary treatment, conveyance, detention and retention functions (through infiltration) to provide tertiary treatment benefits;
- wetlands - tertiary treatment systems, storage, detention, possible reuse options;
- rainwater tanks - using stormwater as a resource not a nuisance - detention, retention, a substitute for potable supply in garden irrigation, car washing, toilet flushing, etc;
- greywater reuse - collect from households, primary treatment on site, reuse for external irrigation or internal toilet flushing options;
- rain gardens, rooftop greening, urban forests - provide natural vegetated features of aesthetic value and provide treatment function by filtering stormwater, (Figure 44).

Linking WSUD to Stormwater and Flood Management

From a stormwater and flood management perspective WSUD may impact by conveying flow or controlling flow or a combination of both. Conveying flow may be achieved by natural watercourses, swales, low and high level channels, roadways and underground pipe systems. Flood control might be through the use of measures such as infiltration and various basins systems as well as rainwater tanks. Effective WSUD often requires the integration of a number of multi-purpose elements.

Figure 44 Integration of filtration system into a drainage corridor

A WSUD approach maximises harvesting and re-use of stormwater runoff. This reduces the amount of runoff in frequent rainfall events and reduces daily demand on mains water supply. The reduction in peak stormwater flows in rare to extreme rainfall will be less than for frequent storms, but some reduction may still be achievable[10].

Whether a WSUD approach is adopted or not, management of flood risks from stormwater runoff should follow the same principles as for any other flood risks.

Conveyance and Management of Overflows

In WSUD combinations of many elements are used to convey flood flow. Small frequent flows may be conveyed by a low flow stream or pipe system. Major but less frequent flows may be substantially accommodated in high level floodway areas. Figure 44 illusrates an example of appropriate design for accommodating minor (frequent) and major flows.

Flow conveyance may be achieved through a combination of the following:

- naturally functioning streams;
- stream buffer zones;
- swales;
- enhancing natural watercourse at grade;
- higher-level diversion channels;
- roadways; and
- underground pipes.

Any ancillary features such as culverts, bridges, levees, barriers, walls, basins and landscaping can affect flow conveyance along a drainage corridor. Generally bridges have less impact on flow and are preferred for this reason. They are also less likely to become blocked and might be designed to better accommodate the movement of aquatic and terrestrial fauna. Holistic consideration of all elements that affect the performance of the drainage system over a full range of floods needs to be made in WSUD.

In some communities an increase in flood levels as small as 10 mm has needed to be addressed. The acceptability of any adverse change to the flood hazard (i.e. depths, velocities, rate of rise or duration of inundation) should be based on a risk assessment which would identify:

- who or what will be affected by these changes;
- what these changes mean to those directly affected and to the general community; and
- what mitigation measure(s) might be required to address the changes.

A number of conveyance combinations were analysed as part of the Balmoral Road Release Area evaluations (GHD 2001). Results in terms of space, hydrologic, water quality, maintenance issues are reproduced in Table 11.

Flow diversions to other catchments can result in floods larger than the design capacity of the stormwater drainage system.

Planning of the stormwater system and any flow management measures such as channels and detention basin systems must incorporate assessment and management of inter-catchment flow and overflow behaviour to avoid creating hazards. It is the behaviour and interaction of overflows caused by flow diversion, blockages or rare storms exceeding the design capacity of the individual measures which is crucial in this assessment.

When planning the make-up and layout of the overall drainage system, ensuring it can safely flow and also overflow in a gradual non-hazardous way is very important. This may require flow areas to be sufficiently graded or stepped in a continuously rising fashion to help with warning and to provide a safe exit path.

Councils have adopted blockage prevention (i.e. debris traps such as log barriers, gross pollutant traps) and/or allowance considerations for trunk drainage design (i.e. design based on 100% blockage up to a certain waterway opening). However, as debris sources and stream maintenance practices differ, the outcomes may vary.

Identification and retention of existing floodway areas for extreme event overflows is likely to be the most successful and cost effective strategy for stormwater flood risk management. As with mainstream floods, floodway areas with high hazards for people or property are of major concern. Encroachment into these areas should be avoided by set backs where necessary or elevating structures where flows can pass safely underneath.

An aim of WSUD is to avoid the concentration of flows. For example, where roadways act as flood evacuation routes, using them as flood flow paths should be avoided as they can be potentially hazardous as flow is concentrated and trapped within the roadway corridor. In other areas, concentration of flow can be avoided by adopting appropriate spacing between houses and fencing and using flood compatible landscaping formations.

In some overland flow areas it may be desirable to open or elevate fencing in order to accommodate concentrated overland flow. Examples of these approaches are shown in Figure 45.

5

***Table 11** Impacts of Flow Conveyance Options*

Option	Space Issues	Hydrologic Issues	Water Quality Issues	Maintenance Issues	Cost
Conventional pipe system with overland swales	Minimal	No flow control	No treatment	Low	Low
Natural channel and swale	Large	No flow control	Some treatment	Moderate	Very high
Infiltration system with underground pipe	Large	Some flow control	Greater treatment	Very high	Very high
Swale with low green channel	Large	No flow control	Some treatment	High	Moderate

[10] *A technical guide on WSUD for use by Western Sydney councils can be found at http://www.wsud.org/tech.htm*

Figure 45 *Open and elevated fences*

Under past subdivision practice, natural watercourses have been modified to create sharp or right angle bends, which follow allotment boundaries. Such alignments are used as a way of maximising the utilisation of available land. The practice of using sharp or right angle bends should be avoided because of the potential for hazardous concentrated overflow at the outside bend, resulting in unexpected high level flow paths and damaging stream bank erosion. WSUD is based on a more natural stream alignment, which is in keeping with geomorphic and erosion processes.

A swale is a grass lined natural depression or wide shallow ditch used to temporarily store, route, or filter runoff. In low-density residential areas, swales are a very common alternative to kerbs and gutters. Landscaped swales located along natural drainage paths and on the lower portions and edges of a development site can collect or redirect flow from yards or streets.

The sides of swales should be shallow to allow for the slow, even flow of runoff, stabilise soil, and reduce weed growth.

Buffers are vegetated areas adjacent to water bodies designed to stabilise banks, limit erosion, reduce runoff volume, preserve wildlife habitats, and create open space and recreational areas. Buffers are also useful in their ability to store the larger events, reduce velocity of flows with vegetation, reduce erosion and in their infiltration ability hence reducing the amount of flow which requires attention.

Sharp or right angle bends should be avoided in creek alignments because of the potential for hazardous concentrated overflow at the outside bend, resulting in unexpected high level flow paths and damaging stream bank erosion.

Linear open space corridors can be established along a natural corridor, such as a riverfront, stream valley, and used for recreational purposes. Within a corridor, a riparian buffer is the area immediately adjacent to the watercourse. The appropriate width of a buffer depends on the site conditions (e.g. slope and vegetation), the nature of stormwater flow from adjacent properties (e.g. the quantity and velocity of water, and the existence of channels), and the cost and benefits of the buffer to the developer and the community. To assemble a riparian buffer, a council may purchase the land or it may require a developer to set aside lands immediately adjacent to waterfronts.

A building setback line further protects the waterways from erosion and water quality degradation due to runoff caused by development.

Delineating the appropriate boundary of a buffer zone or setback is part of the planning process to protect the watercourse. In riverine areas, the setback distance can be adjusted according to the particular site conditions, such as the presence of slopes and the location of natural drainage paths. Variable water levels, the nature of the vegetation, and the flora and fauna values of adjacent land also need to be taken into account when determining the setback.

Good subdivision design manages the location, distribution, density and configuration of the dwellings on a site in a manner that prevents the structures from impeding or disrupting the movement of flood waters. Where a building sits in relation to flood waters has direct bearing on its susceptibility to flood damage. Clustering houses is an effective way of keeping floodplains largely free from development while achieving the same lot yield. This is discussed further in section 5.3.2.

Urban salinity causes damage to urban infrastructure including roads, buildings, gardens and the environment with attendant social, economic and environmental costs. When making locational and site layout decisions, care needs to be taken not to impede groundwater movement. On-site effluent disposal methods, stormwater infiltration, potable water supply pipes and the amount of native vegetation which is to be retained, all impact on salt and water movement and decisions made can have impacts both on and off the site.

Flow Control

As with conveyance systems, there are a number of techniques used to control flood flows. Often these also serve a multi function role such as storing water for re-use or to improve water quality through sedimentation or filtration processes. Broadly these flow control techniques are as follows:

- Infiltration Storage;
- On-Site Storage;
- Regional and sub-regional Storage;
- Corridor Storage; and
- Rainwater Tanks.

On-site storage, regional and sub-regional storage have some worthwhile flow reduction benefits (GHD 2001). Of these, regional basins and corridor storage are the most practical and effective systems. To achieve ESD objectives, it is preferable for all flood detention systems to be off-line. Topography, stream gradient and land take considerations can be critical to the successful design of off-line regional detention basin systems. More information on this can be found in the case study in Section 9.

To protect an individual site from flooding without increasing flood levels elsewhere, the developer must ensure that the stormwater runoff rate after development does not exceed the rate that existed prior to the site being developed. To meet the runoff-rate goal, common solutions include impervious surfaces limits, retention and detention ponds, infiltration devices and swales.

Detention basins of sufficient size and depth are used to hold and gradually release runoff. It is up to the regulating body to dictate the size, location, storage capacity, and release rate of detention basins. Release rates are based on water polishing requirements. A typical requirement is enough capacity to capture the 1 in 2 AEP, 24 hour event and hold it for at least 24 hours before it is released into a wetland or other watercourse.

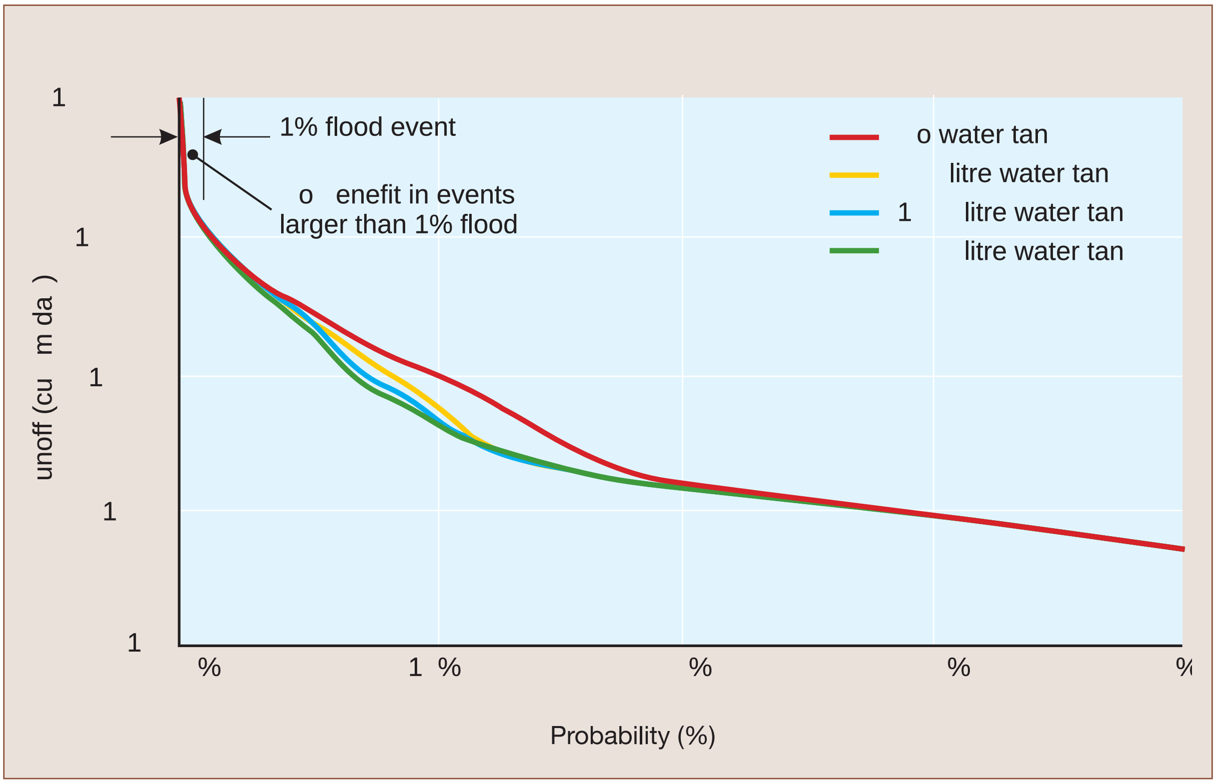
On-site detention is a method of providing stormwater and flood detention on individual properties. It can be a fair and equitable means of reducing peak downstream flow to a predetermined figure. This might be obtained only by OSD or it may be integrated into a regional basin strategy. Although OSD can be effective, it has a number of limitations for flow control that need to be considered:

- whether it meets global peak flow reduction objectives given that staged implementation of OSD can limit the total catchment flood mitigation effectiveness of this approach;
- possible under or over estimation of OSD based volumetric requirements; and
- practical aspects of maintaining OSD capacity on individual sites given that responsibility for maintenance rests with individual landholders. Surveys have shown that this maintenance is often not undertaken.

Rainwater tanks are generally only effective at controlling frequent floods as shown in Figure 46 (GHD 2001).

Considerable debate has taken place over the issue of rainwater tanks as flood mitigation devices and what role they have in contributing towards meeting OSD objectives with research in recent years by the University of Newcastle. In modelling their

Figure 46 *Effect of Rainwater Tanks on flood flows*



capability to reduce peak flood events a sensitivity analysis must be considered. Their effectiveness in major flood events is very limited because of the likely small "air space" available in the tanks as a result of domestic tank size restrictions, practical rainwater capture and usage uncertainties. The other consideration is that not all homes in a subdivision may have rainwater tanks installed unless they are a mandatory requirement. In the cases where they are installed, there may be no monitoring to ensure their appropriate use.

As a result, there is no case to reduce the existing requirements for traditional major/minor stormwater infrastructure based on the inclusion of rainwater tanks. From a major flood mitigation perspective it would be prudent to view any detention that rainwater tanks provide as a potential bonus rather than a given.

Retention basins, or water ponds, are subject to similar requirements to detention basins although they are not usually designed to release stormwater at a particular rate other than through naturally occurring evaporation and seepage. They also act as wildlife habitat and as recreational facilities.

Infiltration devices are designed to promote percolation of stormwater runoff from roofs, downpipes, driveways and large lawns into the ground before that runoff can reach a water body (e.g. a creek). These devices can reduce the flow of water downstream, help preserve natural vegetation, and potentially lower costs by limiting the size of the trunk drainage system needed.

Natural depressions are also created by roadway embankments. Some depressional storage areas release rainfall excess only via evaporation or by slow infiltration into groundwater, thus preventing runoff from contributing to the flood. Grading and site preparation can result in the loss of these depressions and can have serious effects on the rate and volume of site runoff, particularly for more frequent storm events. The initial site analysis and subsequent drainage plan should identify depressional storage so that they can be retained.

5.3 Lot Layout and Design

5.3.1 Introduction

Master planning for subdivisions which contain floodprone land (i.e. land below the level of the PMF), must include provision for safe evacuation in the design and not allow the finished development to reduce the area of flow or flood storage. This process requires care to provide a road layout that allows and does not prevent safe evacuation. There are many conflicting criteria in designing a new subdivision, but in a floodprone site, flood evacuation must be considered as one of paramount importance as it relates to human safety.

5.3.2 Lot Layouts

Cluster Development

Examples from contemporary practice in the USA have proved cluster development subdivisions can combine a reduction in flood risk, WSUD and the preservation of bushland and rural character, (Arendt 1991). A similar approach has been promoted for rural subdivision on the North Coast of NSW, (DUAP 1995).

Cluster development reduces the investment needed for land clearance, site preparation and infrastructure by concentrating activity to a limited and usually more accessible part of the site.

The type of development shown in Figure 47 allows the same gross density or overall amount of development, but construction is typically limited to one-half of the parcel. Through a community title subdivision, the remaining open space can be reserved for common use. The open space can be permanently protected under a conservation easement and would require maintenance by the community title homeowners association. Councils are generally reluctant to take on the maintenance of small and perhaps isolated additional parcels of open space due to costs and there may be difficulties of integrating such areas into a wider public open space network.

Having minimum lot sizes in planning instruments discourages cluster development. Traditional zoning emphasises separating incompatible uses and establishing development standards such as maximum densities and minimum setbacks.

Certain development controls for subdivisions, such as limits on impervious surfaces, requirements that identify a building footprint for each lot, riparian buffers, setbacks, as well as drainage control regulations that prohibit an increase of runoff from a site after it is developed, can encourage a flexible approach which favours a cluster configuration. In a floodplain, the cluster concept can be applied so that the homes are grouped on the natural high ground area of the site or on a small, contiguous,

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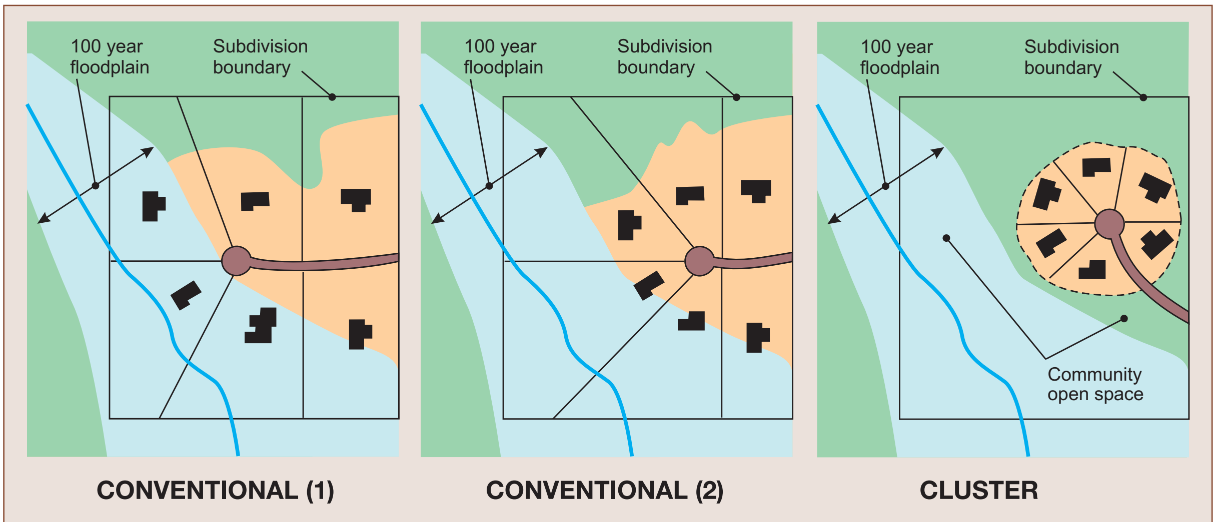
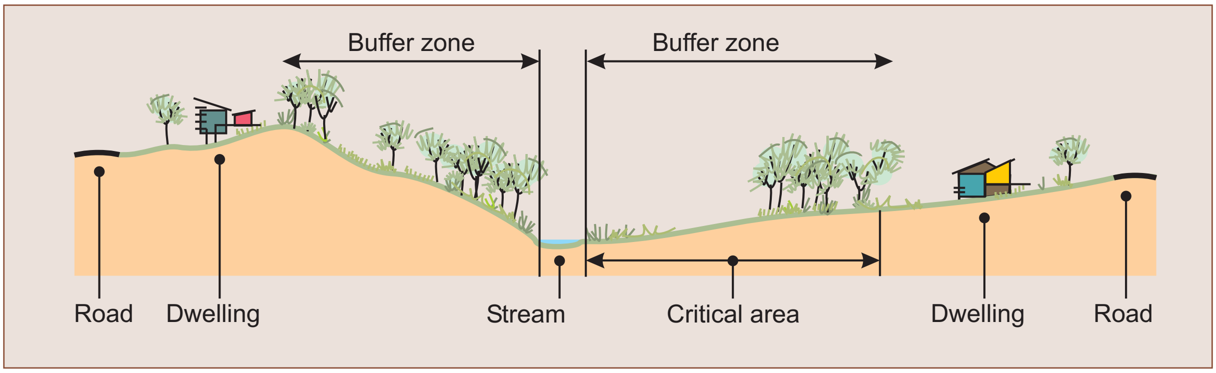
Figure 47 *Conventional and Cluster Development Layouts*



Cluster Development can help to avoid hazardous floodway areas within a limited subdivision footprint

Figure 48 *Setback and buffer zone for development*



filled area with the remainder left as open space or recreational land. The open space may be publicly or privately owned as a park, golf course, private grounds or similar use, (Figure 48). The area shown as 'critical area' in Figure 48 is critical to protect the high hazard flood area and the natural aquatic and terrestrial flora and fauna environment.

This buffer zone can be incorporated into the area of highest hazard along the watercourse. By preventing development within the area of highest hazard, protection is afforded to people and property.

Cluster development can also be used successfully to prevent urban salinity problems arising. There can be benefits of clustering higher density development leaving the salt affected areas for low density or as natural buffer areas where disturbance can be minimised and vegetation retained.

Prevent buildings from becoming flood obstructions

Good subdivision practice manages the location, distribution, density and configuration of the homes on a site in a manner that prevents the structures from impeding or disrupting the movement of flood waters, (Figures 49 and 50).

Where a building sits in relation to flood waters has direct bearing on its susceptibility to flood damage. The simplest and most obvious method if minimising flood damage to structures is to locate or elevate them above the flood level or to reduce their risk of damage by elevation to a rarer flood level. If development is to occur within the floodplain there are a number of provisions that can be made to reduce damages, such as:

- orientate buildings in a way that foundations minimise disruption to natural flood flows, with the narrower portion of the structure upstream, (Figure 51);
- use water resistant materials, floor covering, adhesives and coatings (more information can be found in the Building Guidelines);
- design the structural walls to withstand the lateral forces of floodwaters, the uplift forces from floodwaters and rising groundwater levels, and the impact of debris collecting on the walls;
- footing and foundations should be at sufficient depth and on bearing soil to provide lateral resistance to water pressure and to reduce vertical pressure; and
- adequate connections need to be made between a building's foundation, floors, walls and roof so that loads are transferred to the foundation.

5.3.3 Public Recreation Areas

Subdivision layout designs which included multiple use public recreation areas need to take into account the following:

- consideration of the provision of adequate signage of flood affectation at all access points. Having a local policy on signage would assist council in meeting its duty of care and provide consistency throughout the area. This may alternatively form part of a public flood awareness strategy;

Figure 49 *Location of development in floodway areas*

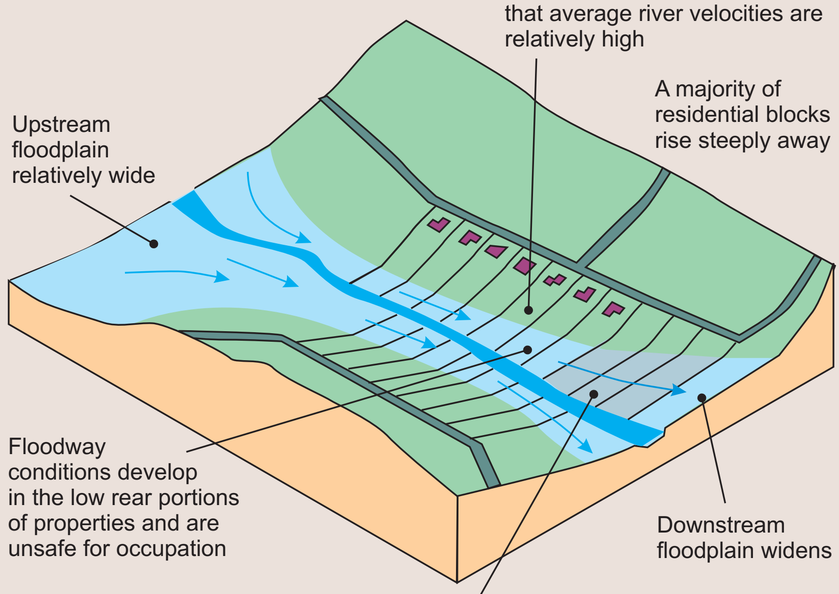


Figure 50 *Flood impacts on development downstream of river bends*

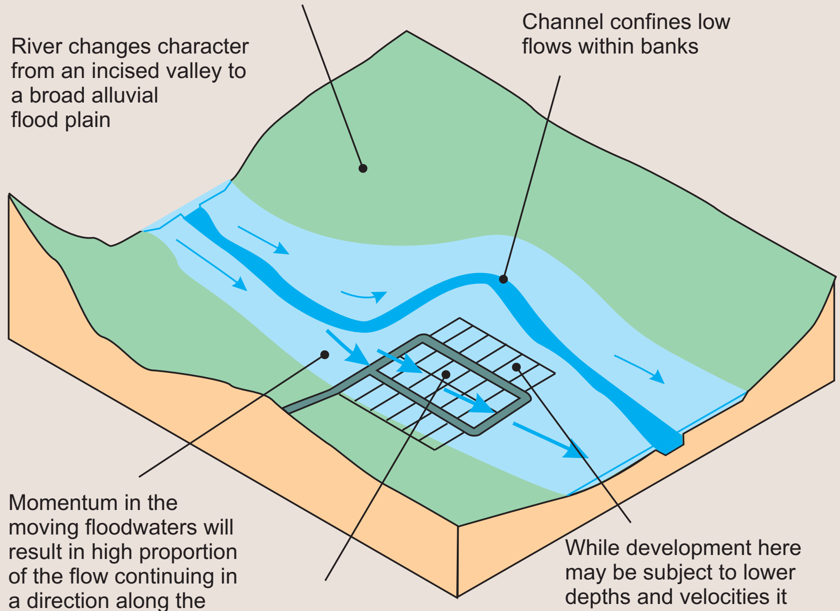


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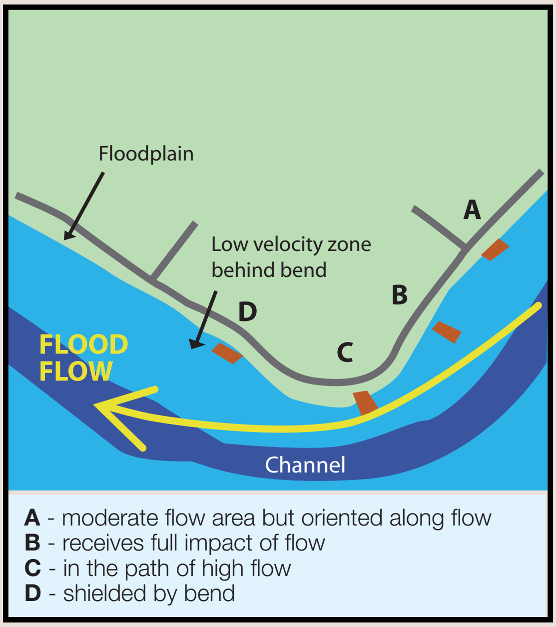
Figure 51 *Impact of location and orientation of buildings*



Buildings need to be sighted with consideration of damage potential from moving floodwaters.

- recreational uses consistent with the potential flood hazards;
- cycleways may be placed adjacent to trunk drains with advisory signage and frequent escape routes;
- children's playgrounds should only be placed in low hazard flood fringe locations;
- detention basins which are also used as sporting fields should be off-line to avoid potential for high hazard when the basin is filling from storm flow run-off;
- children's playgrounds should not be downstream of detention basin embankments;
- opportunities for evacuation and the capacity of the evacuation routes for the intended users, taking into account the rate of rise of floodwaters; and
- ensuring adequate points of egress at appropriate locations for the number and mobility of intended users, e.g. sporting facilities are likely to attract large numbers of users and spectators who need sufficient vehicular and pedestrian egress to safely evacuate in the time it takes the basin to fill up (note spectators should not be assumed to necessarily be fit or even ambulatory).

5.3.4 Utility Services

Essential utility services such as water, sewerage, power, gas and telecommunications are likely to be widely disrupted during flooding. New subdivisions offer the opportunity to minimise the disruption by factoring in the impacts of flooding into the design of plant, equipment and such like. If flood risk is not factored in a regional context, it may lead to situations where it becomes necessary to evacuate dry areas which are only subject to indirect flood impact and which might otherwise have been used as refuges. This could adversely impact on the evacuation of areas which do become inundated.

The loss of essential utility services, even if only temporarily, makes an area less habitable and in extreme cases uninhabitable due to health and safety risks. The rapid restoration of services after the flood can facilitate rapid clean-up and aid a speedy and thus less costly recovery.

It is necessary to maintain telecommunication and power services for as long as possible during a flood to allow warnings and evacuation advice to be supplied to residents at risk. Street lighting and traffic lights need power but outages would hamper a safe evacuation. Designs which delay service disruption for as long as possible will thereby promote public safety during a flood.

The time taken to repair, flood damage to supply infrastructure and re-establish supply once the flood has receded will be a major factor in the disruption of the community. Residents may be able to return as soon as the flood recedes and access is available, but their ability to clean up will be limited if services remain unavailable.
They may be able to shovel out the silt and dispose of damaged carpets and contents, but washing out the house and starting repairs will be delayed until services are re-established. Some emergency work on dangerous structures may be carried out immediately to prevent collapse, but generally the community will have to wait until services have been reinstated before they can make their homes habitable again.

Utility service supply networks should be designed to be as robust and reliable as practicable under the range of flood conditions foreseeable at the site.

Underground pipe and cable delivery networks will generally be less prone to physical damage during storms therefore presenting less of a public risk during floods and requiring fewer repairs afterwards.

Pump stations for water supply or sewer networks should use submersible pumps, which can remain in place during a flood. The pump switchgear should be elevated as high as practicable, possibly pole mounted, to minimise both the risk of flood damage and the time required for reinstatement.

Underground cabling, including joints and other connections will need to be as waterproof as practicable to promote speedy service resumption following network reinstatement after the flood.

Vulnerable and important power infrastructure such as transformers and substations should be located at the highest practical elevation to minimise both the risk of flood damage and the time required for reinstatement. As a general principle transformers and substations should be at a higher elevation than the fuse/meter boxes in the houses they service.

5.3.5 Signage

Hazard warning signage and depth indicators should be considered for all points of known flood hazard whether local or mainstream, for example:

- where streets or paths cross creeks, rivers, trunk drains or other know drainage paths;
- at the entrance to reserves which incorporate trunk drains and/or retarding basins;
- within accessible multi-use detention basins, such as playing fields; and
- at the overflow spillway of detention basins.

Where the street network has been planned so that the local evacuation routes are the same as the daily traffic routes, evacuees will be able to drive out as normal. If the evacuation routes do not follow the daily traffic routes to the main site entrances, then additional directional and way-finding signage will be required to direct evacuees to and along the nominated evacuation route to areas beyond the extent of the flood.

Any signs used should be on both public and private property (road verges, reserves, sports grounds etc). Preferably, they should display relevant information in a clear, consistent and unambiguous manner and are best approached as an integral part of any public flood awareness strategy for the locality. To achieve a consistent approach, liaison will be necessary between the SES, council and the developer. It should be recognised that there are cost and maintenance implications in providing evacuation and flood hazard signage to ensure they remain legible and display current information.

5.3.6 Fencing

Fences can obstruct flood flows, increase flood levels and damage and perhaps hamper evacuation. This is particularly an issue in floodways. Solid or open mesh fences tend to collect debris, but may be suitable if they are orientated in the direction of flow. Fences which are across the direction of flow may require special treatment (Figure 45). The type of fences that would be appropriate for land ideally need to be identified in the floodplain risk management plan and could be controlled for a development site through a development control plan. Fence treatments for ‘problem’ areas might include:

- low open fencing;
- open style post and rail or wire fences;
- open hedges or shrubs for privacy with spaces to allow water flow. These could be combined with post and wire for property boundary definition;
- semi-solid fencing with widely spaced planking, augmented with shrubs; and
- special fencing with hinged/vacant panels that allows water to flow underneath.

6 DESIGNING FOR EMERGENCY RESPONSE AND EVACUATION

6.1 Planning Subdivisions to Facilitate Evacuation

To achieve sustainable subdivisions on flood prone land which can provide a safe environment for the residents, flood hazard and evacuation requirements need to be evaluated and appropriately addressed at the planning stage of the project. Early liaison with council and the SES is advisable to identify the issues that need to be addressed as part of the site planning and design process and to determine the type of data and analysis that is required. Appropriate and creative site planning can reduce hazard and can prevent potential difficulties in evacuating the site and so reduce the risk to life and limb.

Evacuation and emergency response are key aspects of planning any new development that need to be adequately addressed in order to demonstrate that an appropriate 'duty of care' has been exercised. As emphasised in earlier sections of these guidelines, the functioning of the evacuation routes needs to take account of a range of floods up to the probable maximum flood (PMF) with varying rates of rise, not just the adopted design flood. Flood-related development controls for residential development have traditionally relied solely on ensuring habitable floor levels are built above a minimum design flood level (typically the 1 in 100 AEP flood) to reduce the possibility of over-floor flooding. However, in many instances no consideration has been given to the risks to residents' safety and the need for evacuation when more severe floods occur. It remains a concern that there continue to be examples of new subdivisions where road access towards safe high ground has been overlooked yet it is critical to enable residents to escape from deep or rising floodwaters.

If, after studying the flood behaviour and type of flooding for a range of floods both on a site and in the catchment, it becomes foreseeable that a severe flood will necessitate the evacuation of the residents, then designing for evacuation is essential. Evacuation may be necessary either for personal safety reasons or because essential services such as power, water and sewerage are no longer available. It may involve residents leaving the site entirely or remaining on an upper floor or on a higher part of the site. This varies from site to site and is dependent on the type of flooding, flood behaviour and duration of flooding, hence the need for flood studies to provide a sound basis for decision making. A flawed site design has the potential to put residents' lives at risk if a timely evacuation is prevented through design failings. A sustainable neighbourhood is also one which is designed so that speedy reoccupation of homes after a flood is possible. If evacuation can be achieved in a timely manner, post-flood recovery may be assisted as occupants have more time to protect contents from damage.

> A measure of sustainability of a development on flood prone land is the ability to safely evacuate and the capacity for speedy post-flood recovery.

6.2 Subdivision Evacuation Scenarios

A key requirement for a new development on flood prone land is that it must be inherently safe and allow the occupants to evacuate themselves in a safe and orderly fashion when a large flood occurs. The hydrologic and hydraulic assessments used for flood and stormwater management planning should provide sufficient information to assess whether evacuation is necessary and if so how should the subdivision be designed to ensure community safety. The planning process should identify the areas that may need to be evacuated at different flood levels. It may be necessary to liaise with the SES regarding how the development of the site can be integrated into that agency's evacuation planning for the wider area. Figure 52 provides a flow chart which can assist in determining what type of evacuation strategy is necessary for a site.

Typically, one of the following scenarios will apply:

- Shelter on-site;
- Local evacuation to an area within a flooded site;
- Local evacuation to an adjacent site;
- Evacuation to a regional evacuation centre along regional evacuation routes.

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Figure 52 *Evacuation strategy process for a new subdivision*

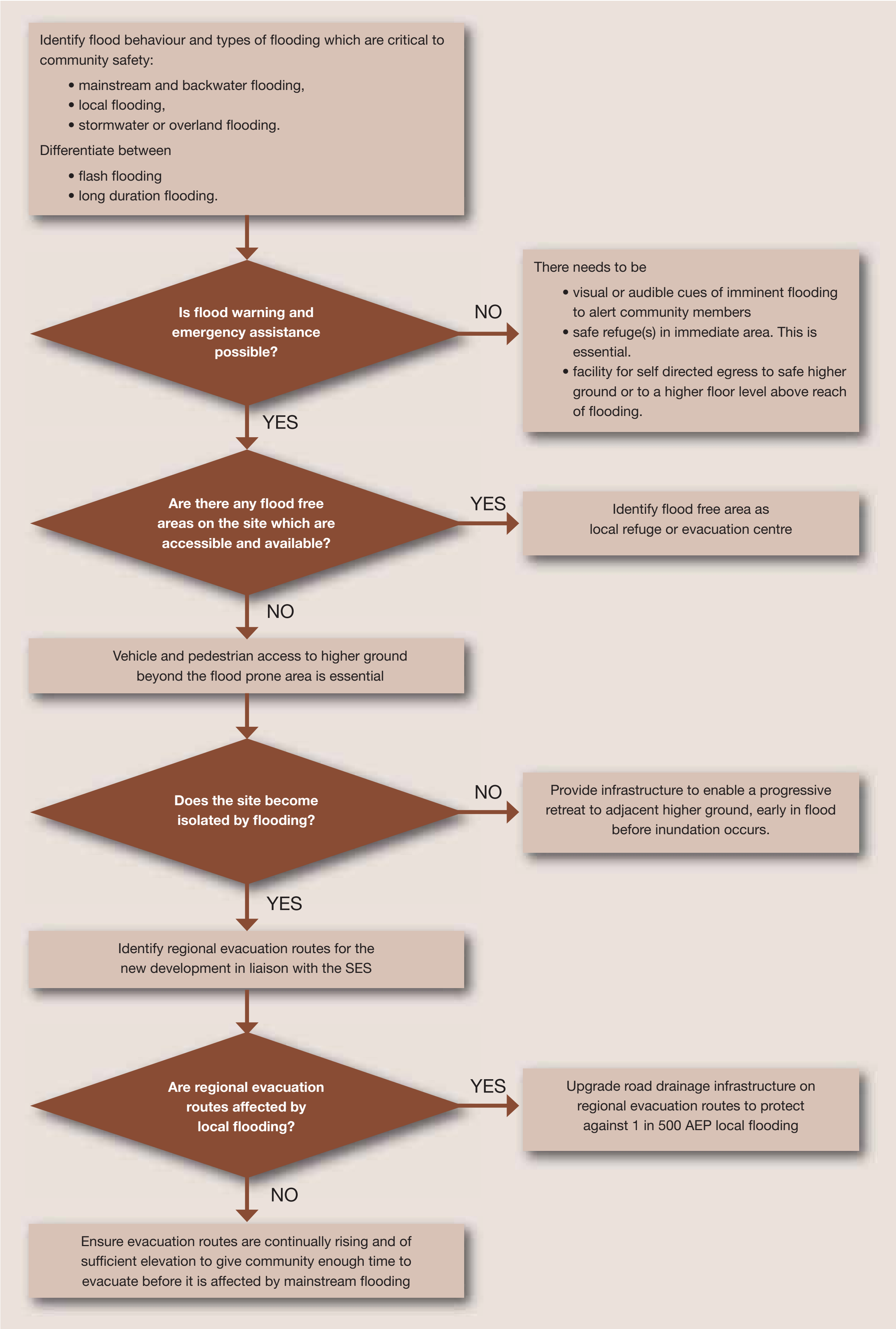
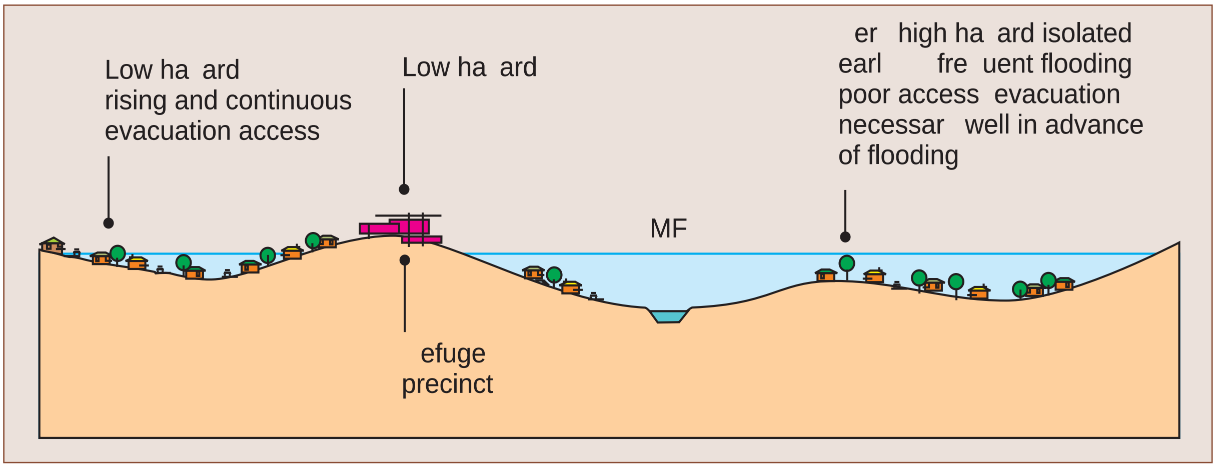


Figure 53 *Location of hazards and evacuation scenarios*



These are discussed briefly below. The relevance of the scenarios other than sheltering on the site depends on what proportion of the site can flood and the proximity to a safe refuge or an evacuation centre (Figure 53).

6.2.1 Shelter on-site

Shelter on-site in houses or buildings (Figure 54) would only be viable where:

- flooding will not enter the houses or premises in which people are sheltering;
- flooding will be of limited duration i.e. only a few hours;
- hydraulic hazards to both the people who are sheltering in buildings and buildings themselves are not life threatening e.g. depths will be only very shallow;
- the buildings have some habitable rooms with floor levels above the level of the PMF so that people will have somewhere dry to shelter; and
- utility services can be safely reinstated within hours of recession of the flood.

6.2.2 Local evacuation to an area within a floodprone site

Local evacuation to a building or centre which is suitable as a refuge within the site may be considered when:

- some part of the site is higher than the level of the PMF;
- the building or centre will be available to the first occupants of the new development i.e. it is part of the first stage of the development; and
- continuity of essential services can be assured for the duration of the period when people remain in the refuge.

6.2.3 Local evacuation to an area within a flooded site

Local evacuation to an adjacent area of higher land may be required where:

- safe areas above the PMF level are closely connected to the site; or
- where residents have no advance warning of flooding and are exposed to life threatening hydraulic hazards.

6.2.4 Evacuation to a regional evacuation centre along regional evacuation routes

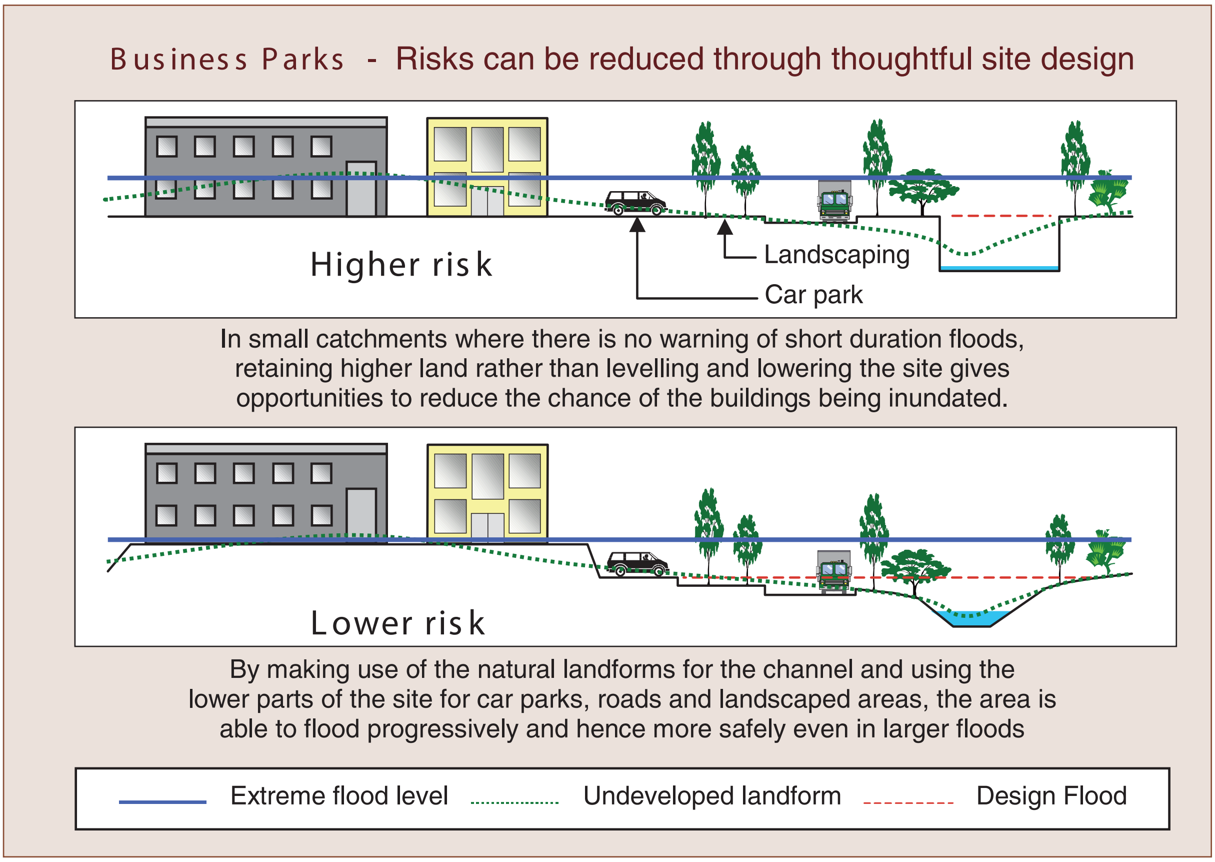
Evacuation to a remote evacuation centre may be required where:

- all development is below the level of the PMF; or
- the locality may become isolated and lose essential services for several days during flooding; or
- there is no local evacuation option available.

6.2.5 Methods of evacuation

In these guidelines, evacuation planning focuses on the use of motor vehicles as the preferred means of evacuation and the provision and trafficability of road networks.

Figure 54 *Example of sheltering on the site from short duration flooding*



Alternative methods of evacuation include:

- privately owned vehicle - driving one's own vehicle to evacuate family and friends is the preferred means of evacuation;
- walking, as a measure of last resort;
- buses - may be called upon by the emergency services to transport those without cars, dependent upon the availability of buses at short notice;
- rail – not a favoured means due to logistical problems associated with mass evacuation by rail. In addition it is not a practical option in the Hawkesbury-Nepean valley due to the low-lying Richmond-Blacktown railway line being cut by floodwaters early in a flood event;
- planes – not a practical option for moving the general population. Roads in the vicinity of the Richmond RAAF airbase are low-lying and would be cut early in a major Hawkesbury-Nepean flood event;
- helicopters – not a practical option for moving the general population, they may be used by the emergency services for monitoring operations and search and rescue operations;
- boats – not used for evacuating the general population but by the emergency services for rescue purposes.

Note that the use of boats, planes and helicopters would only occur as part of a rescue operation rather than a planned evacuation strategy.

Walking over long distances is not considered to be an acceptable means of evacuation in the face of a flood. Walking as a means of evacuation is only acceptable if walking through flood water can be avoided and it involves only short distances (say less than 200m). For some, walking is likely to be physically difficult or even impossible, and the cause of significant mental and physical stress to the elderly, families and the young. However, walking may possibly be an appropriate means of evacuation for some people in very close proximity to safe and accessible high ground (i.e. to a refuge that does not become an island which is ultimately submerged as the floodwaters continue to rise).

6.3 Regional Evacuation

There are two interdependent aspects to evacuation planning, the first involves providing a site layout, road design, drainage etc that will enable an evacuation to take place in a staged and orderly manner in the time available, and it is this element on which these guidelines focus. It requires local evacuation route planning within the site and identifying external linkages and possibly funding upgrades to regional evacuation routes that provide access to land above the PMF.

The second aspect is the emergency flood planning for which the State Emergency Service (SES) is the lead agency. Major flooding is highly unlikely to only affect one subdivision, (although this can sometimes be the case for flash floods, it is not the case for mainstream flooding such as in the Hawkesbury-Nepean). Severe demands are placed on the emergency services during widespread major flooding. Careful site design can assist rather than hinder the emergency services and thus result in safer occupation of floodprone sites.

In the Hawkesbury-Nepean River floodplain, flood waters may rise by tens of metres above normal river levels and rise quickly at a rate in excess of 0.5 metre/hour. This would flood a large proportion of existing residential areas in less than a day and rise from floor to ceiling in less than 5 hours.

The result is that entire suburbs which are below the PMF level may be inundated. In surrounding areas which are not directly flooded, access roads may still be cut by floodwaters, leaving isolated “islands”. While these “islands” may remain above the peak flood level, they are still likely to be uninhabitable due to public health concerns arising from the loss of power, potable water supplies and sewerage services. The duration of major flooding would mean that residents of these “islands” would also need to evacuate to areas not affected by flooding.

The objective of evacuation planning is to protect the lives of occupants when a flood overwhelms a development by providing for safe evacuation. The provision of sufficient adequate local connections to regional or main evacuation routes is a primary requirement to prevent occupants becoming trapped by flood waters. Poor layout and inadequate design can jeopardise this objective.

When new subdivisions, including redevelopment or infill within the existing urban footprint, are proposed, the provision of reliable connections from the proposed subdivision to the appropriate regional evacuation route is crucial to ensure a safe living environment. Any flood prone site affected by riverine flooding up to the PMF where residents cannot get to safe ground must be considered hazardous and may not be suitable for residential development if evacuation routes cannot be provided to land above the PMF.

Guiding Principles

- A simple fundamental principle for evacuation is that it is better to travel continuously away from the hazard rather than go through the hazardous area to reach safety.
- Within a floodplain it is generally best to evacuate continuously upwards. This enables evacuees to retreat away from rising floodwaters which are progressively flooding lower ground so that forward movement is not hindered.

A road network consisting of an easily comprehended network of local streets will best allow drivers to find their way by vehicle to a designated evacuation route. This is discussed further in section 6.4. If travel to a designated evacuation route is not possible, an escape route leading to a safe location is essential. This location may be a local hilltop or a more distant flood-free neighbourhood.

The SES has developed a State Plan for Hawkesbury-Nepean flooding. The Plan recognises that a large scale evacuation of the flood-affected population will place high resource demands on all of the emergency services. The SES has developed and continues to refine an Evacuation Time Line Analysis model that enables detailed and comprehensive assessment of evacuation dynamics for Hawkesbury-Nepean flooding. A simplified illustration of the sequence is shown

***Figure 55** Evacuation Sequence Diagram*

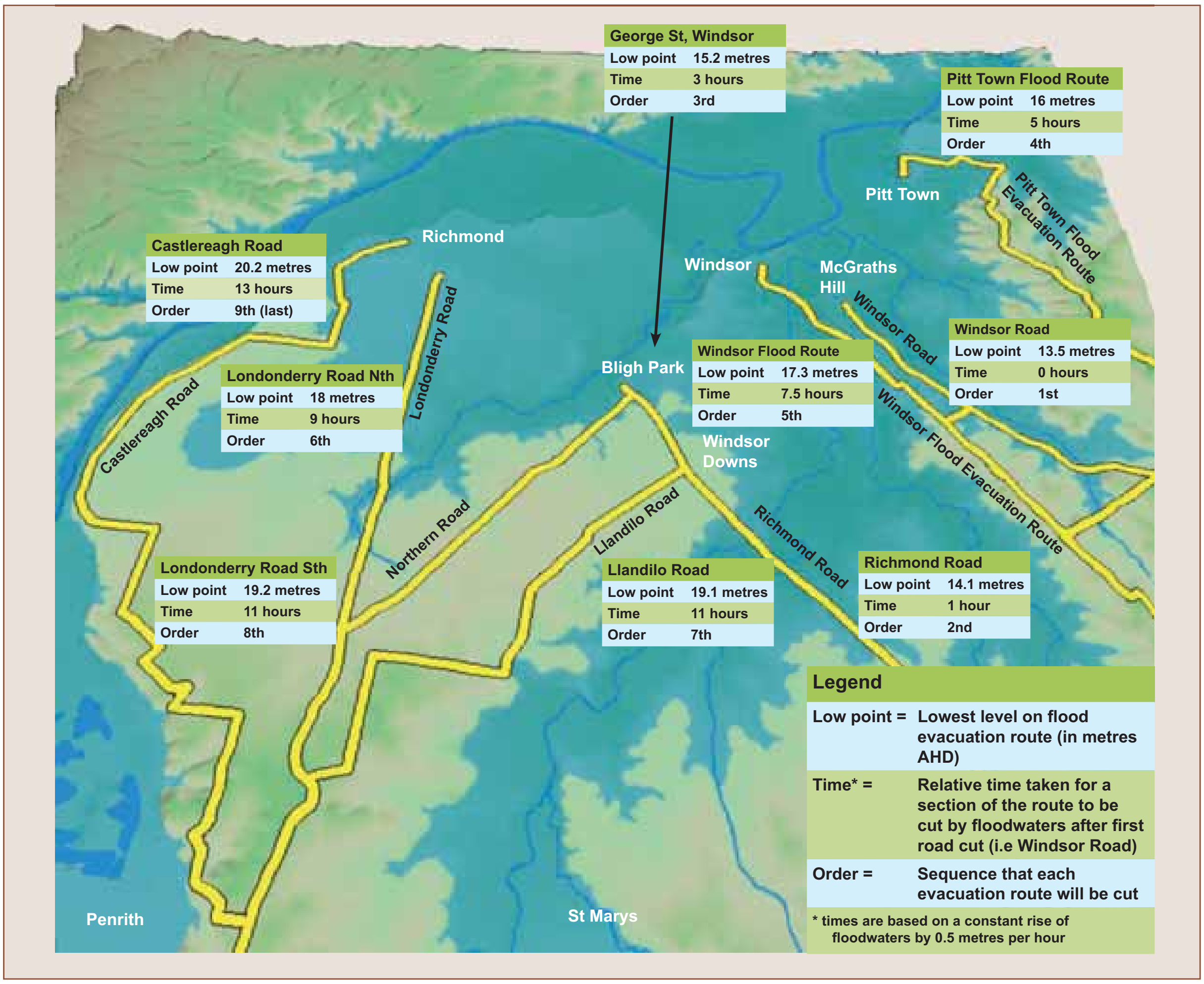
in Figure 55. The model helps the agency in its operational planning by graphically displaying the chronology of the evacuation process: commencing with the time of initial flood forecast, followed by the time of making the decision to evacuate and the time required to mobilise emergency personal and deliver warnings. Time is allowed for people to accept and act upon the warnings and begin to leave. The vehicle capacity of the evacuation routes (estimated at 600 vehicles per hour per lane) and the number of vehicles estimated to be using the routes (based on 1.8 vehicles per dwelling, a figure derived for Western Sydney from ABS data) determines the minimum time needed to evacuate each town. The time line includes realistic assumptions on the rate of rise of flood waters (0.5m/per hour) and the height of the low points on each regional evacuation route. These two elements dictate when the route is no longer available to be used as an evacuation route.

The Hawkesbury-Nepean regional evacuation routes have been upgraded through the Hawkesbury-Nepean Floodplain Management Strategy funding to a 1 in 500 AEP local design flood standard to protect them from closure by concurrent local flooding during the evacuation period.

If the number of households requiring evacuation continues to increase, in order to have enough time to evacuate everyone on the existing routes, the decision to evacuate may have to be made using predicted rainfall, ahead of any visual cues to reinforce the warning message. Using predicted rainfall to call an evacuation increases the degree of uncertainty and has a higher potential for ‘false alarms’.

The time available to evacuate before evacuation routes are cut by rising floodwaters is limited and a successful evacuation depends upon a prompt response by all concerned, including the residents, before the evacuation routes are cut by rising floodwaters (Figure 56). However, experience has shown that people are generally reluctant to leave early in a flood event, and tend to delay departure until the last possible moment, encouraged less by official warnings and more by visual cues of approaching floodwaters. In the Hawkesbury-Nepean such a delay could result in large numbers of people isolated on ever-shrinking “islands” with essential services cut off. The staged emergency evacuation then shifts its emphasis to emergency rescue operations, with associated resourcing problems and extreme hazards for both those requiring rescue and emergency personal.

Figure 56 *Key Hawkesbury-Nepean Regional Flood Evacuation Routes*



The planned evacuation for mainstream Hawkesbury-Nepean flooding contrasts to flash flooding which occurs in many small urbanised catchments. In such situation, flooding can occur far too quickly for any early warning by the emergency services and staged evacuation to higher ground or out of the area is often impractical and more hazardous than staying in situ. As flash flooding tends to be of short duration, upper floors in houses and buildings can often provide a temporary refuge in flash floods provided of course that the upper floor level remains above the level of the flood waters.

Safe subdivision design practice requires provision for evacuation, which extends beyond the boundaries of the proposed development site. The example in Figure 57 shows how all of the access roads crossing drainage paths will be impassable during floods and how alternative roads along the ridges could prevent this situation arising.

6.3.1 Performance Criteria for regional evacuation route planning

All residential developments where there are risks from flooding require safe road links to an external road which can take residents to a safer area.

The roads which are necessary for residents to use to reach safety should not be rendered unusable by local catchment flooding, (Figure 58).

Such roads should have the traffic capacity to evacuate all occupants (residents, workers, transient population) to areas above the PMF in the time available after receiving the warning of a flood.

Safe road links to a designated evacuation route should:

- Be part of a simple/logical road network that gives cues that lead to safe evacuation;

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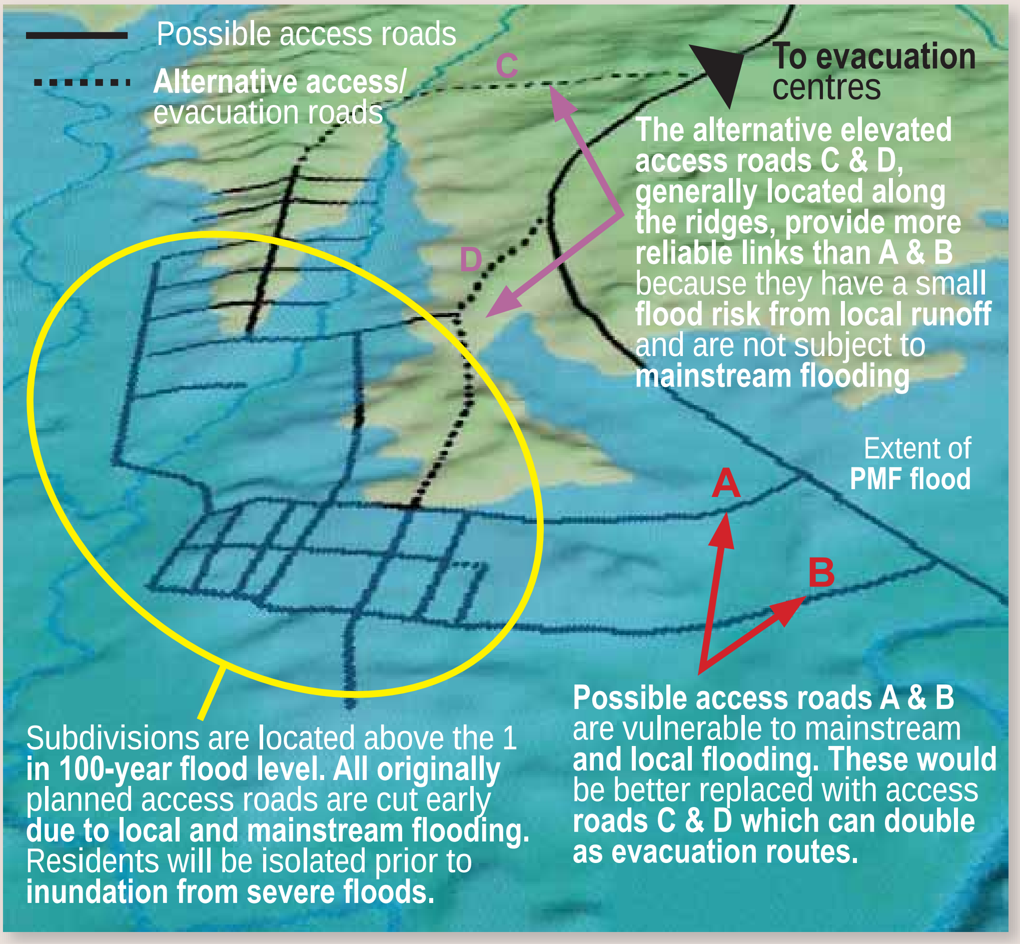
Figure 57 Example of road layout for safe evacuation from a subdivision



Safe subdivision design requires provision of evacuation routes which extend beyond the boundaries of the proposed development site.

- Provide an easily accessible road link to a designated evacuation route and/or a safe, flood-free area;
- Minimise potential isolation by rising floodwaters through appropriately located entry points to the development;

Figure 58 Frequent flooding along Londonderry Road evacuation route due to local storms prior to upgrades

- Rise continuously from the lowest point on a site to the highest point on a site allowing the road to be progressively flooded while allowing residents to evacuate as floodwaters approach their dwellings;
- Connect with an existing road at a point, which is higher than the majority of the subdivision;
- Avoid low points and drainage lines so that in the event of riverine or local flooding the road will not be cut by floodwaters before it is needed, (Figure 59);
- Provide alternative evacuation routes via multiple links to surrounding areas or via multiple estate entry points to the development. This allows for redundancy in case of traffic accidents;

Figure 59 Low lying main road cut by mainstream flooding

- Connect either directly with a designated evacuation route or via the existing road network that rises continuously.

Road links between a flood prone urban development and surrounding major roads are shown in Figures 60 and 61. It can be seen from these illustrations how carefully located and designed road links can provide a more effective route for flood evacuation than others simply by avoiding river or creek crossings or other low spots which are prone to early inundation and by providing direct access to higher land.

6.4 Local Evacuation Routes and Street Network

The evacuees' journey does not begin at the regional evacuation route but at the home or workplace and includes travel along existing local roads. It is not unreasonable to assume that adverse weather conditions would occur concurrently with an evacuation in a mainstream Hawkesbury-Nepean flood. This may result in hazardous driving conditions or existing local roads being impassable due to overland flow flooding. If upgrades to existing local roads or construction of new roads are not feasible or not able to be funded as part of the development, (because of the local topography, drainage or the constraints posed by existing development), then the only alternative to avoid people being trapped, is to seek an alternative site for the development.

Figure 60 Road Network – major road links

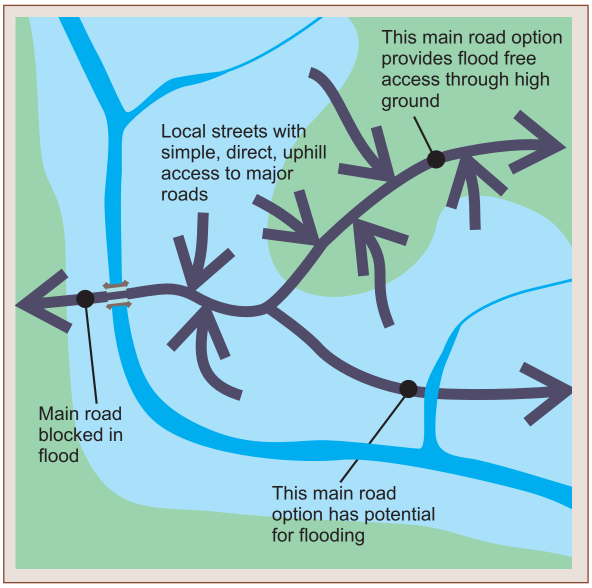
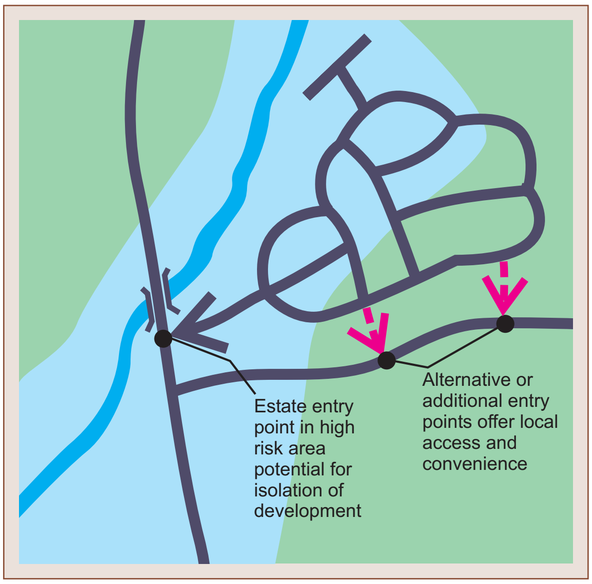


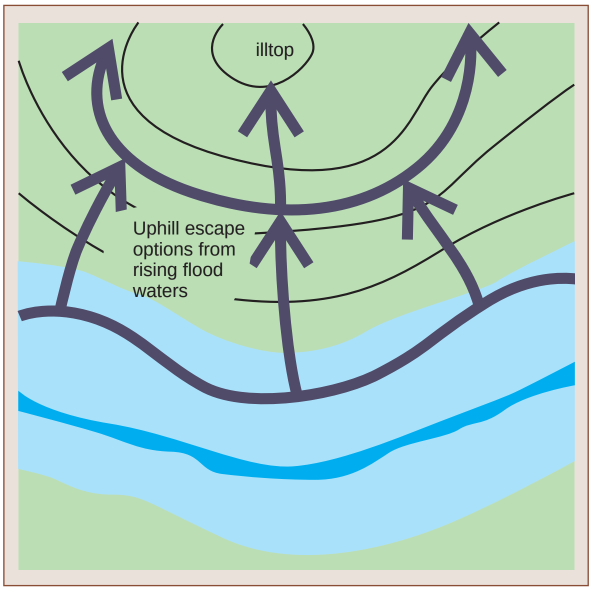
Figure 61 Road Network – estate entry points



A well connected street layout is critical to ensuring self-directed vehicular evacuation. Ideally it can be designed to allow an evacuee, at any point in a neighbourhood, to follow streets which rise obviously and continuously as flood levels rise to a safe point without external assistance, (Figure 62).

Physical separation of evacuation and drainage paths allows evacuees to flee hazards rather than attempting to cross them.

Figure 62 *Streets leading uphill away from the floodplain connecting into a legible local street hierarchy*



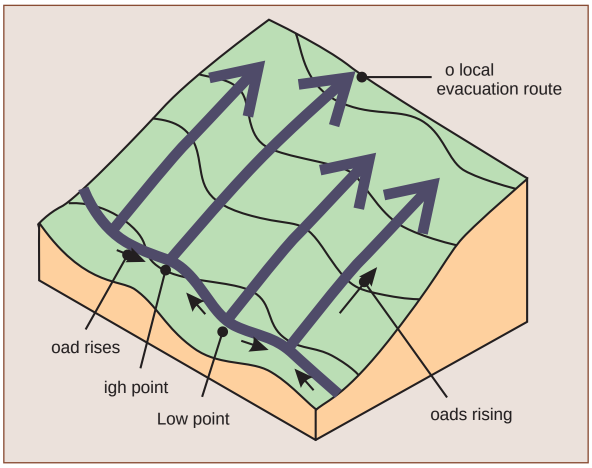
By avoiding low points and drainage lines the evacuation route is less likely to be cut by flood waters in local storm events.

Where a critical evacuation route crosses a drainage path, a very high design standard in terms of the probability of flooding should be applied to minimise the possibility of the route being cut by local storms and to maximise its availability for evacuation. The scale and cost of works to meet this high standard can be minimised if the drainage crossings are restricted to higher locations in the local catchment where drainage is usually more efficient and where the volume of runoff is relatively smaller due to the smaller catchment area.

> A conservative approach should be taken in choosing the recurrence interval for the design of the cross drainage paths given the high degree of uncertainty of the joint occurrence of local and mainstream flooding which has the potential to frustrate an evacuation. As an example, all of the regional evacuation routes upgraded as part of the Government's Hawkesbury Nepean Floodplain Management Strategy were designed to be protected from a 1 in 500 AEP local storm event.

It may be acceptable for a residential street to cross a trunk drain, a watercourse or some minor drainage path provided both of the resulting legs of the street rise continuously away from the drainage path and intersect other continuously rising streets or local evacuation routes on either side, (Figure 63).

Figure 63 *Rising linkages to local evacuation routes*



Minor culs-de-sac and local access roads may run parallel to trunk drains or other major or minor watercourses only if the residents of homes facing the street can still safely evacuate. This could be achieved by ensuring the set back of the street from the watercourse is such that overflows to the street during severe to extreme local catchment storms do not block the carriageway. Alternatively, it could be achieved by providing an alternate route via either an access lane or a dedicated right of way which connects to a suitable cross street and runs over the uphill side of the adjoining properties also facing the street adjacent to the watercourse.

Where mainstream or local flooding effectively divides the site each evacuation precinct may need to be identified and separate evacuation routes provided. Staging of development should not result in the first occupants being left without evacuation routes until later stages of development are completed.

The capacity of the road to carry the required number of vehicles in a given worst case time-frame will need to be calculated. Unfortunately, people have a tendency to delay evacuating and so the time period for mass evacuation can be too short. Vehicles may also be overloaded or low on fuel and the drivers not necessarily in the best position to drive due to the stress of the situation. Road designers need to allow for vehicle breakdown and poor weather conditions which can reduce road capacity.

The street network should be ‘legible’ and not exacerbate problems by making navigation needlessly difficult. It is preferable that the local evacuation routes follow the normal road hierarchy. If evacuees know travelling uphill takes them to safety, and roads go uphill, they can more easily find their way to a local evacuation route. They can also more easily circumnavigate any blockages if there are adequate interconnections to give them alternate uphill options. Evacuees can then easily follow a known route rather than an unfamiliar route out of the neighbourhood, given that the emergency may occur at night or in poor visibility, (Figures 64 and 65).

Figure 64 *Poorly Connected Road Network*

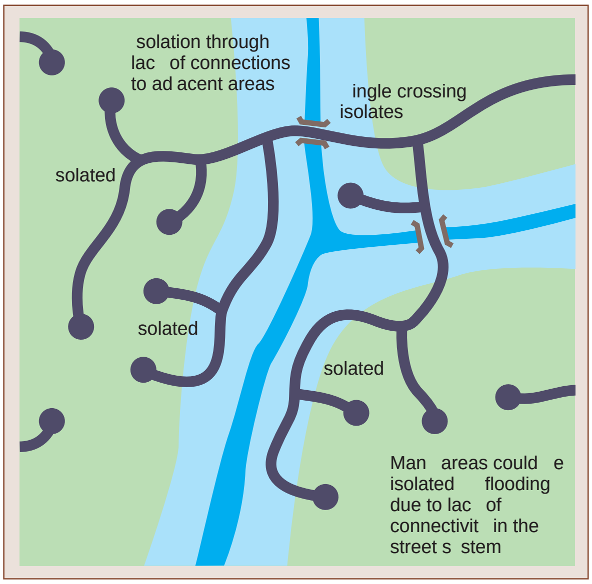
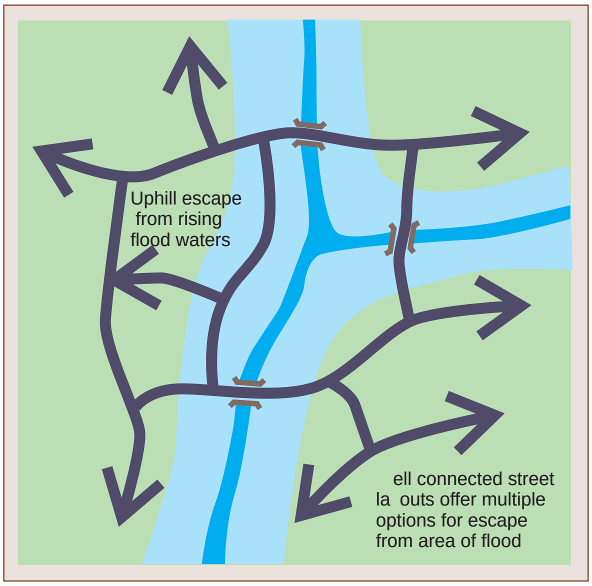
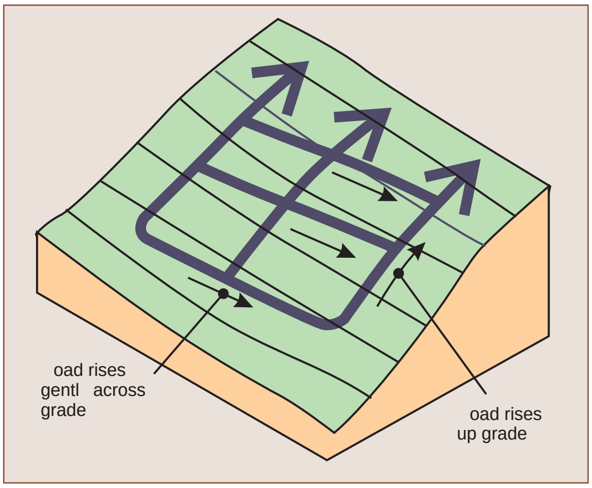


Figure 65 *Well Connected Road Network*



The streets which generally follow the contours should travel obliquely across them connecting the lots via a rising grade to the collector roads that form the local evacuation routes linking to the regional road network, (Figure 66). A curvilinear street grid incorporating residential streets running uphill to connect to local evacuation routes can both respond to the site topography and provide sufficiently obvious evacuation options to promote safety. Regular intersections mean that no single local evacuation route need be relied on during evacuation.

Figure 66 *Roads running obliquely across contours*



6.4.1 Performance criteria for local evacuation route planning

The principles for local evacuation routes reflect the same objectives as regional routes in that they must remain trafficable throughout the evacuation; this means being graded and drained to ensure they are not flooded by local or mainstream flooding early in a flood event. In a local context, there is more scope to provide redundancy by having multiple alternative local evacuation routes.

To facilitate evacuation, the local street network should have a clear hierarchy where:

- Each lot has access to a continuously rising local street so that people can walk to their garage and then drive out.
- Each evacuation precinct is made up of clearly visible and sign posted routes to the local or regional evacuation route.
- Each neighbourhood has access to a regional or local evacuation route that has the capacity to safely evacuate all of the area requiring evacuation to a designated evacuation centre within a reasonable time;

- Streets should rise continuously to intersect with the local evacuation route so that each lot within the subdivision can access the regional road network leading to local or remote evacuation centres;
- Streets should be angled to the contours in order to achieve a suitable grade;
- Street intersections maximise the availability of uphill evacuation options to enable obstructions to be circumnavigated.
- All streets, which serve an evacuation function, particularly the collectors, are designed not only for daily traffic flow but also for the traffic volume they will carry during a flood evacuation.
- Streets nominated as primary evacuation routes should not be positioned along side drainage corridors/channels. Street alignment particularly near stormwater flow paths should not promote the diversion of stormwater from its existing flow path to flow along the street.
- Use of culs-de-sac should be minimised as they limit interconnection and hence available route options in an evacuation. If they are used, culs-de-sac should:
  - > include a turning circle at the low end with the cul-de-sac grading continually upward to its intersection in the same way as for streets crossing drainage lines (Figure 67);
  - > only be considered where other continuous streets cannot be used and used only sparingly in a clear and otherwise well-connected street layout, (Figure 68);
  - > be short and serve no more than 10 dwellings;
  - > include a dedicated drainage reserve, easement or other suitable provision for an overland flow path with adequate capacity at the low end of the cul-de-sac i.e. the turning circle to accommodate stormwater flows in severe to extreme local catchment storms to limit damages to the adjacent dwellings.

6.5 Case Study

To illustrate the points raised in this Section on designing for emergency response and evacuation, a neighbourhood evacuation case study has been prepared and can be found in Section 9. The case study relates to the planning of a large residential subdivision within an area subject to mainstream flooding. Typically such a development would also include non-residential land uses such as local shopping centres, parks, primary school etc.

***Figure 67** Examples of culs-de-sac showing both inappropriate and appropriate designs for evacuation*

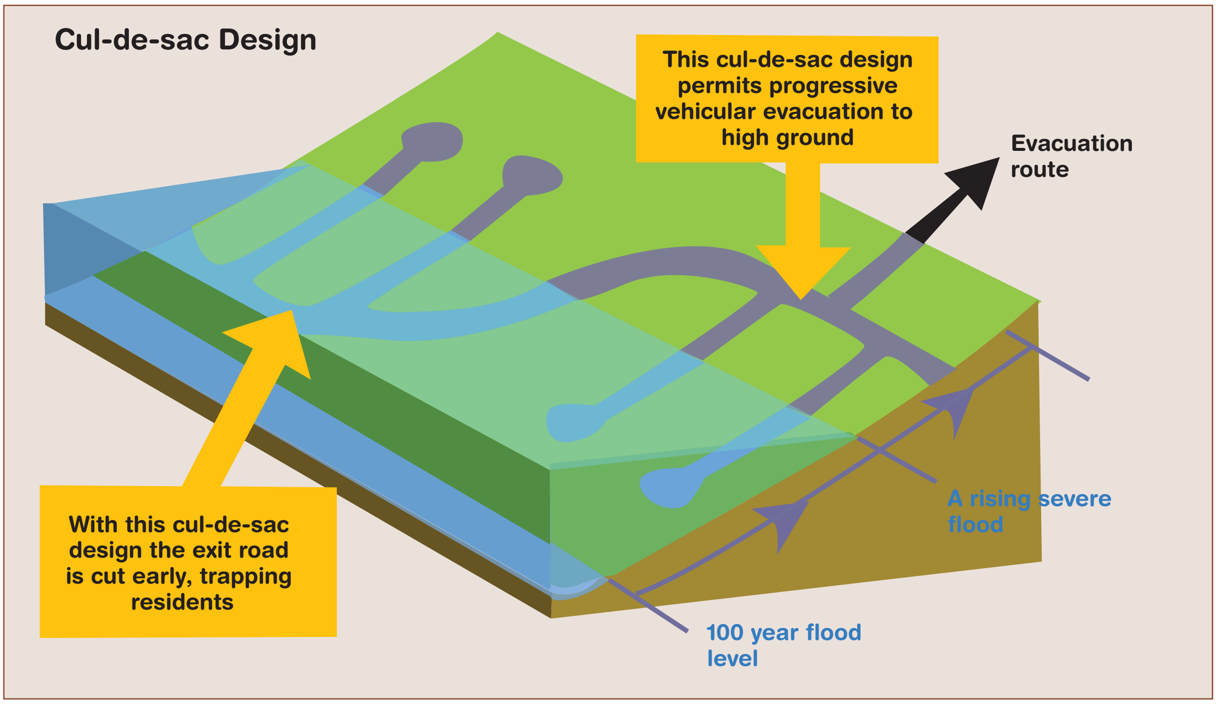
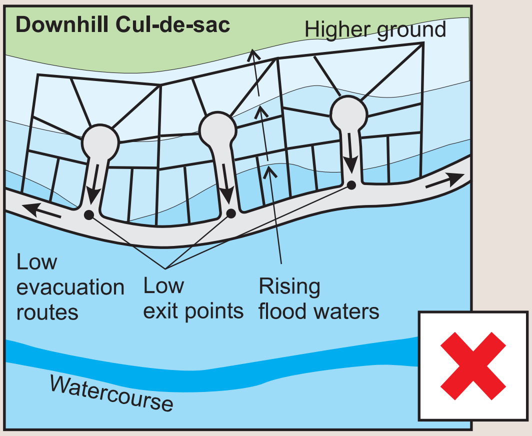
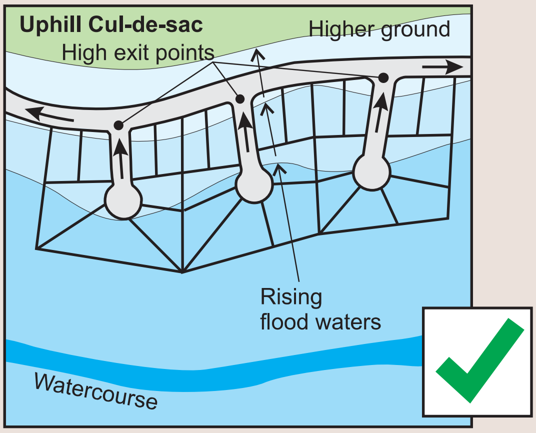


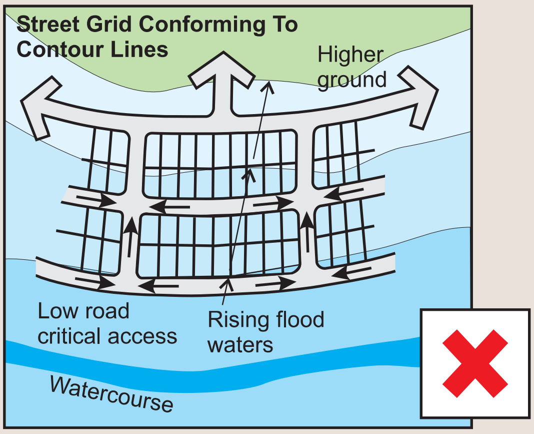
__Figure 68__ Advantages and disadvantages with alternative local road layouts



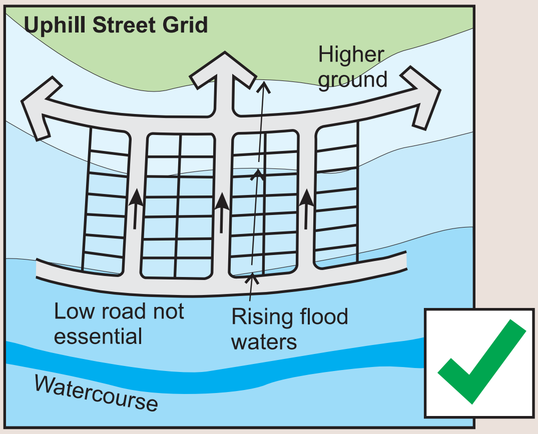
- Difficult uphill escape from flood risk area
- Residents must leave their homes earlier before their lowest road exit point is cut by flooding
- Need for evacuation based on an early prediction of flooding
- Evacuation necessary as a precaution even when flooding not visible or evident
- Impossible to evacuate in a vehicle after local road flooded – evacuation over long distances not practical without road transport
- Loss of road access in the very early stages of a flood compresses the time available to conduct an evacuation and increases the risk of failure
- Greater evacuation route capacity required to allow all residents to get to safety in a much shorter timeframe
- Occupants must rely on the availability of emergency management resources to warn them and co-ordinate an evacuation



- Easy uphill egress from rising floodwaters
- Residents prompted to evacuate by imminent flooding of their homes
- Progressive flooding of the site allows evacuation to be gradual
- No additional risk factors (eg late and inadequate dissemination of flood warnings, reluctance to evacuate and insufficient roadway capacity) introduced into the evacuation process
- No "weak links" designed into the vital road evacuation network
- Not crucial to have an ongoing flood education program to achieve necessary preparedness and co-operation from residents



- More difficult escape from homes in flood risk area
- Long sections of roadway at similar elevations are flooded simultaneously
- Residents in houses facing downhill compelled to evacuate before their local access road is flooded
- Evacuations must take place while an opportunity to use the roadways remains available
- Emergency response planning is critical to provide adequate warning, ensure timely evacuation and prevent residents attempting to shelter in homes which could be flooded



- Easy uphill egress from rising floodwaters
- Each house has direct uphill road access to safer ground
- Simple retreat as floodwaters rise
- Time available for neighbourhood evacuation maximised
- Street layout improves road drainage increasing reliability against risk of local stormwater flooding

7 DESIGN OF ASSOCIATED STORMWATER SYSTEMS

7.1 Stormwater Drainage

"Stormwater drainage systems have evolved differently throughout Australia due to climatic, economic and social factors. Some design rules can be applied universally while others must be established on a local basis." (Pilgrim 1987 p 291).

Design probabilities vary within and between local government areas and for various land uses.

Residential subdivision on floodplains can be viewed as a special case requiring specific rules, which respond to the particular circumstances. Since it is a given that floodplains will flood, many residential areas on floodplains will require evacuation at some time. In such areas, design rules, which facilitate evacuation, such as the physical separation of drainage paths and evacuation routes, are therefore justifiable to promote public safety.

Adoption of the major/minor approach to stormwater management is common practice in New South Wales. Chapter 14 of Australian Rainfall and Runoff Volume 1 1987, provides the following description:

"The minor system is the gutter and pipe network capable of carrying runoff from minor storms. The major system comprises the many planned and unplanned drainage routes which convey runoff from major storms to trunk drains, sometimes causing damage along the way.

While the routes of the minor systems may differ from the natural drainage path, to conform with street layouts and other obstructions, the major drainage system generally follows the natural pattern." (Pilgrim 1987 pp 297, 298).

This quote reflects the fact that water typically flows down hill by the easiest available path and will continue to follow existing flow paths where possible. The apparently widely held perception that carriageways are always the most appropriate major drainage paths suggests that the quote has been widely ignored or overlooked.

"The overall aim of the major/minor approach is to ensure that hazardous situations do not arise on streets and footpaths, and that all buildings in urban areas are protected against floodwaters to a similar standard to that applying in zones adjacent to rivers." (Pilgrim 1987 p 298).

This statement has widely been interpreted to justify adoption of a 1 in 100 AEP design standard for major drainage design.

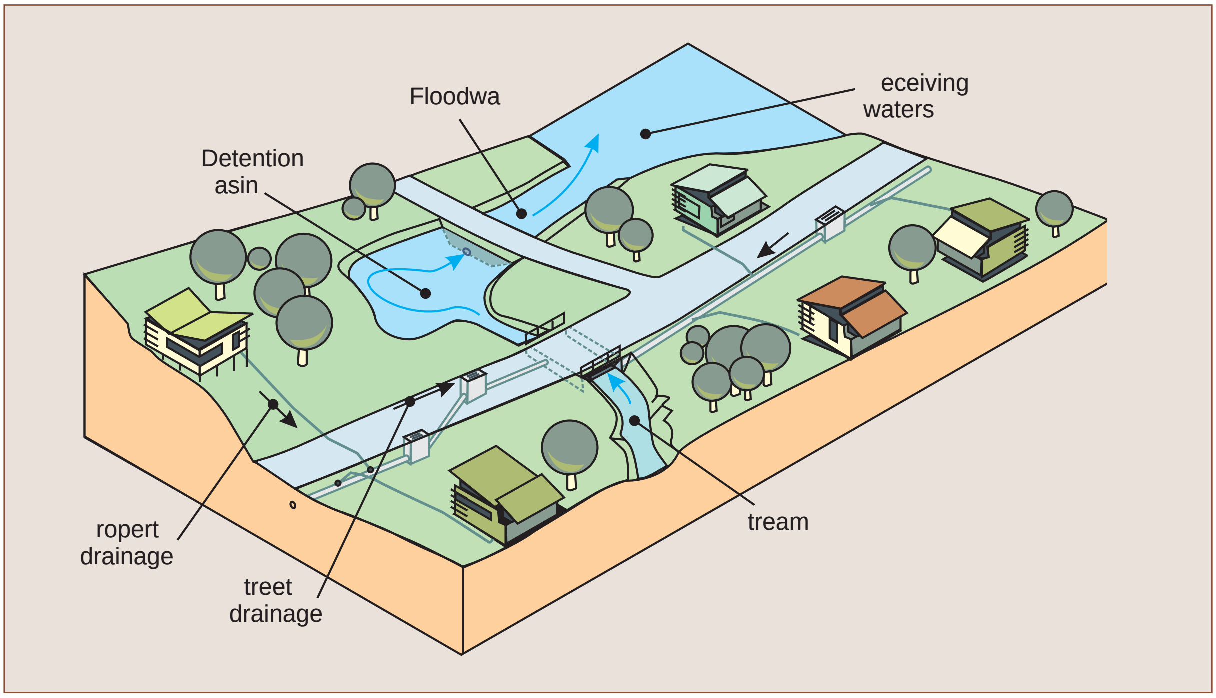
The NSW Government's Floodplain Development Manual 2005 includes local overland flooding within the Flood Prone Land Policy. No specific flood standard is applied to drainage systems in this Manual with councils having the discretion to deal with the problem. However, all flood risks (whether due to local runoff or mainstream overflow) should be assessed so that merit based planning decisions consistent with the flood risks (arising from both local or mainstream flooding) can be made.

Stormwater drainage systems have been designed using the major/minor approach to minimise nuisance by allowing the minor system to efficiently and invisibly dispose of the runoff from frequent rain events. The reduced nuisance in residential areas has been obtained at the expense of suppressed community awareness about flooding and adverse water quality and flood hazards and consequences further downstream.

Water Sensitive Urban Design (WSUD) is gaining popularity as an approach to site design which seeks to temporarily store stormwater for use as a valuable resource using tanks, ponds, swales, infiltration to aquifers and/or existing flow paths. More information on this can be found in Section 5.

Stormwater or trunk drainage can have a significant impact on the level of risk to people and property during flooding. Regional or local evacuation routes will only function effectively if they are not cut by local catchment floodwaters (and in some cases mainstream overland flooding) which are conveyed by trunk stormwater drainage systems.

Figure 69 *Traditional Stormwater Drainage System*



Chapter 14 of Australian Rainfall and Runoff Volume 1 (Pilgrim 1987), provides the following description of drainage systems: *"Stormwater drainage systems can be divided into the parts shown below, viz:*

- *roof and property drainage;*
- *street drainage (including both piped and surface flows);*
- *trunk drainage (consisting of larger conduits, usually open channels located on lands reserved for drainage purposes); and*
- *receiving waters (a river, lake, groundwater storage or the sea)".*

This Section highlights issues specific to design of trunk or stormwater drainage systems[11].

Major system drainage should not be confused with trunk drainage.

7.2 Trunk Drainage Systems

7.2.1 Definition

A trunk drainage system is a collection of pipes and channels (both natural and artificial) that is used to convey stormwater runoff from developed areas to downstream receiving waters such as rivers, streams and the ocean (Figure 69). Normally the description "trunk drainage" is limited to the major drainage elements above a certain pipe size (450mm minimum diameter is quite commonly used). Smaller pipelines at the head of catchments, inter-allotment drains, roof drainage lines, and drainage lines within development sites are not normally included in the term "trunk drainage" although similar philosophies and principles apply. The main reason for this distinction lies in the "ownership" or responsible authority for the asset. Trunk drainage works are normally in public ownership, typically councils, although some are owned and managed by Water Boards or similar authorities.

[11] For more general guidance on design procedures, readers are referred to Pilgrim D. H. (Ed.) (1987) Australian Rainfall and Runoff, A guide to Flood Estimation, Vol. 1, The Institution of Engineers, Australia, or Argue J. (1986) Storm Drainage Design in Small Urban Catchments: A Handbook for Australian Practice Special Report SR34, Australian Road Research Board.

Trunk drainage not only conveys minor flows but also floods larger that the "design flood". This is commonly referred to as the major/minor system of drainage design, where the minor system consists of the pipes and channels and the major system consists of the overflow paths, which are commonly along gutters and road reserves and in depressions or dedicated overflow paths lying above or adjoining the pipe/channel system. Even though the major/minor concept has been around for a long time, and was included in the current version of Australian Rainfall & Runoff (Pilgrim, 1987) and in the earlier edition of the same publication (1977) it has not been adequately recognised in practice. As an extension of this concept, this Section addresses management of not only the locally sourced stormwater runoff, but also the flows sourced from main stream flooding, which in very large floods, may need to pass through the subdivision. Again this is an issue which is very often not considered in subdivision design.

The limitations of such a design philosophy have been highlighted by the actual floods experienced in Coffs Harbour in 1996 and Wollongong in 1998.

7.2.2 Design Philosophy

The provision of drainage infrastructure for any new or infill development has very often been a secondary consideration when developing an overall concept. Unfortunately, inadequate allocation of drainage corridors in the early planning stage can result in problems for their appropriate location at the detailed design stages. Significant benefits can be gained through careful and practical assessment of both local and mainstream flood behaviour and flood risk at the concept and design stages.

Attempts to maximise the developable area can result in encroachment into the riverine or drainage corridors. In assessing such proposals, care should be taken to consider the full range of potential risks across the various flooding scenarios up to the PMF to ensure they are not overlooked but managed appropriately.

Risks to the future occupants, other floodplain users and the community as whole that may be impacted by the development need to be considered. Increases in likely demands on emergency services such as the State Emergency Service and Department of Community Services should form part of these considerations.

Innovative or creative subdivision concepts which pro-actively address the flooding issues and risks to provide a net benefit for the overall community are more in keeping with the State Government's policy of promoting sustainable development.

Until recently, trunk drainage systems were designed to cater for a particular design frequency storm with little or no attention paid to larger floods. Even where the major/minor design concept has been used, commonly the minor system has included floods up to the 1 in 10 or 1 in 20 AEP event, and the major system has only included floods up to the 1 in 100 AEP. This involves meeting a specific performance standard whilst balancing and trading costs against safety and system adequacy. However, this approach ignores the significantly increased risks associated with larger flood events even though the probability of occurrence is less.

The Coffs Harbour and Wollongong floods are not the only recorded instances of design failures, but rather they are notable for the severity of the events, the widespread damage suffered (and the controversy over insurance cover) and the lessons that, hopefully, will be learnt from the experience.

Some of these lessons include:

- the importance of maintaining natural flow paths;
- the consequences of blockage;
- the need to consider the effects or implications of floods larger than the design event;
- provision for controlled overland flow paths in the event of system failure;
- the effects of velocity and scour.

It is imperative in trunk drainage design that developments are not considered in isolation

7

but within the overall context of the surrounding floodplain environment. The design should not be limited to a particular design flood frequency or by the site boundaries to ensure that not only are the impacts of the development on flooding considered, but also the impacts of the full range of floods on the development, leading to fewer unfortunate surprises when floods inevitably occur. This approach will help ensure that "foreseeable risks" are reasonably and adequately dealt with. To do less could result in very serious harm to the public and may not be seen as exercising a duty of care.

7.2.3 Standards of performance for a range of situations

The provision of trunk drainage infrastructure requires consideration of critical factors including the following:

- the level of hydraulic performance required to suit the needs of the surrounding areas and floodplain occupiers;
- economics - up front capital and ongoing maintenance costs;
- safety – minimising hazards and risks to people;
- liability – potential impacts and risks for floodplain users;
- maintenance requirements and sustainability of infrastructure works;
- environmental issues – flora and fauna habitat, erosion and sedimentation;
- social benefits – reduction in flood nuisance and damages, provision of recreational open space.

Defining the appropriate level of serviceability or performance is difficult and will vary depending on circumstances (hazards and risks) and the expectations of the different users. For example, recreational areas warrant a low level of serviceability whilst commercial and industrial areas require a somewhat higher level but lower than that required for residential areas or essential services and key infrastructure e.g. hospitals, emergency operations and response facilities.

Some reduction in performance may be acceptable in the upper reaches of the floodplain, where the flood affectation is relatively short lived, provided the hazards and risks are low. However, in the lowlands where the inundation extent and duration can be significant and evacuation essential, a higher level of trunk drainage serviceability may be required to ensure that evacuation routes remain trafficable for the required time. The performance standards adopted should depend on the particular circumstances.

Traditional design objectives have focussed on optimising or maximising system performance whilst minimising capital and maintenance costs. Failure of such a system (i.e. when its design capacity is exceeded) is recognised as being inevitable. While provisions for the safe or controlled management of such an event may be incorporated in some subdivision designs, the likely implications and broader consequences have rarely, if ever, been considered. In some circumstances failure of the trunk drainage system has resulted in:

- frequent and/or excessive damages;
- significant hazards and damages in unexpected and unwanted places;
- a lack of community confidence in drainage professionals and increasing expectations with regards to serviceability of future drainage infrastructure (together with expectations of rectification of some past "mistakes").

> The community's expectations with regard to the level of drainage serviceability are rapidly increasing, particularly in response to the recent major floods experienced in Coffs Harbour (1996) and Wollongong (1998).

While the flood events in Wollongong and Coffs Harbour were typically in excess of historically accepted design standards, the nuisance and damages experienced were not acceptable to the general community who were outraged and called for immediate remedial action. The social, economic and safety concerns experienced there highlighted the need for more detailed consideration by designers and planners particularly in the provision of infrastructure appropriate for the larger events that fall outside the normal design standards.

7.2.4 Design Issues

Trunk drainage systems can comprise any or all of the following elements:

- natural streams and watercourses;
- artificial channels;
- pipes and/or culverts;
- hydraulic structures (energy dissipators, drop structures, transitions, etc);
- retarding basins; and
- high level diversion paths/floodways.

How these individual elements combine and interact with each other determines the overall performance of a trunk drainage system. The design process therefore needs to:

- consider the level of serviceability required;
- determine the most appropriate combination of drainage components;
- analyse and review the functioning of the system as a whole to ensure the performance criteria are satisfied and there will be no unexpected or adverse problems encountered; and
- consider storm events much larger than the design standard.

In the process of designing the individual elements, it is important to also consider:

- alternative options and configurations;
- degrees of uncertainty in the data, calculations and assumptions;
- interaction with and hydraulic influence of surrounding elements and the floodplain;
- the need for freeboard and/or controlled overflows in the event of system failure;
- real or actual event scenarios, not only theoretical design cases provided in Australian Rainfall and Runoff (Pilgrim 1987), (particularly important for retarding basins);
- "what if?" scenarios (including joint probability, multiple or coincident peaks);
- the effects of debris and blockages;
- potential scour and maintenance issues;
- safety – potential hazards and risks to identifiable or inadvertent users; and
- aesthetics and environmental aspects.

Further discussion of these issues as they relate to the design of key drainage system elements is provided here.

Achieving Stability through Natural Streams

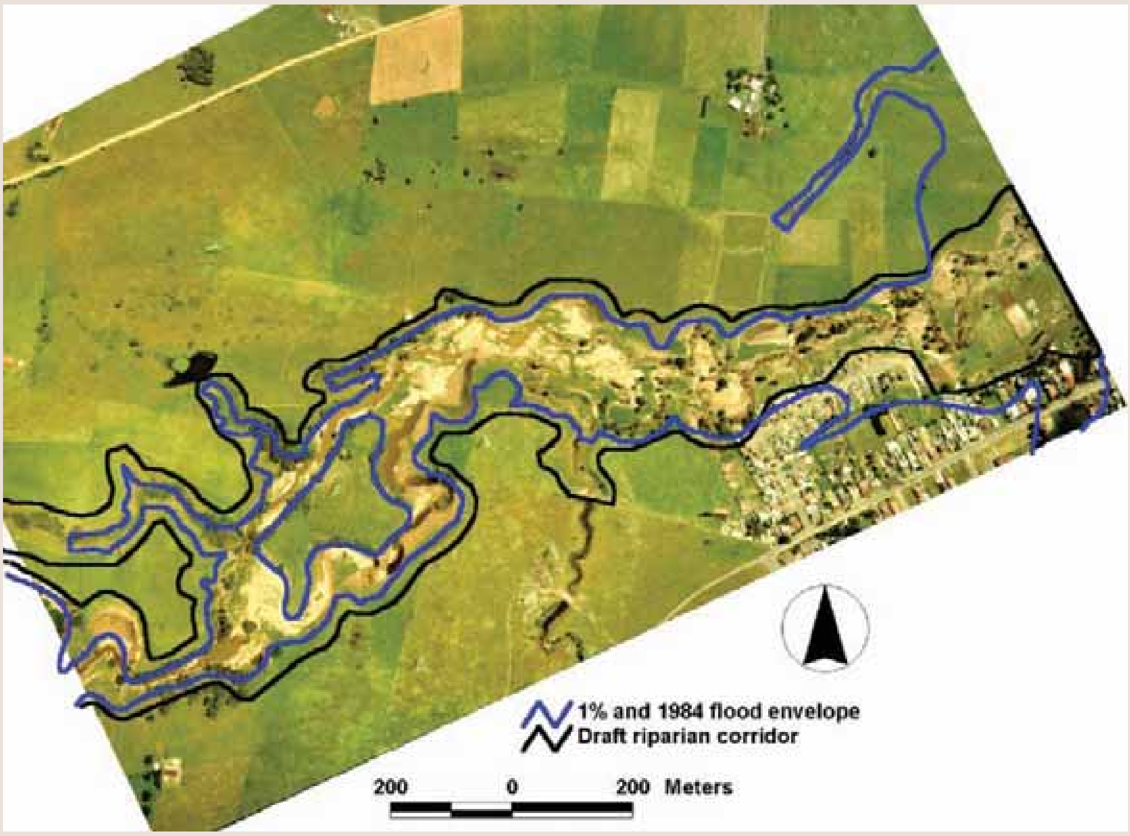
Development on floodplains, (particularly floodplains subject to active flow such as along or near a watercourse or those that store floodwaters), can significantly impact on both flood behaviour and/or environmental values. The importance of maintaining or restoring natural floodplain functions is increasingly being recognised in flood prone land policies and planning instruments. Floodplains, particularly the land near rivers and creek systems are generally the most fertile and productive parts of the catchment and provide a vital ecological role with finely balanced ecosystems that often support a high diversity of native flora and fauna species.

Having stable and healthy riparian areas can be effective in reducing the risk of adverse flood impacts associated with bank instability or channel widening. The events critical to the health of riparian areas are the low flow, more frequent events.

Responsibility for the management of riparian corridors is an issue which should be addressed early in the planning process. Initial stream and riparian corridor mapping can assist with early identification of critical areas and facilitate a strategic approach to their protection (Figure 70).

Many streams in the Hawkesbury-Nepean basin are known to be dynamic, subject to frequent floods, generally have moderate channel and over bank velocities and transport significant debris and sediment loads. Any development in the over bank areas may concentrate or redirect flow, thereby increasing velocities.

Figure 70 *Flood Envelope and Riparian Corridor – Mullet Creek Illawarra*



Flood limits and riparian corridors need to be fully assessed to account for the potential impacts from flooding and to accommodate natural geomorphic processes etc. In this example a wider area is generally needed to meet riparian requirements on the western por tion of the creek, whereas flood limits exceed riparian corridor requirements in the eastern section.

Bank erosion is a natural geomorphic process, contributing to meandering movement of streams and the creation of floodplains over geological time. Between major floods, streams and floodplains experience vegetation growth of both native and exotic species that can affect the behaviour of flood events. Some floodplain areas have been modified by vegetation clearing, filling, channel realignment and piping of water. These changes, which are often associated with increased stream velocity and energy, can cause erosion, bank slumping, floodplain stripping or bed lowering (e.g. via head cuts etc). Over time equilibrium is achieved in the stream erosion process. Potentially this may occur in a wider area than originally modified by realignment etc.

Stream bank and floodplain vegetation has a vital role in maintaining bank stability by root reinforcement of soils, energy dissipation of stream current and waves, increased water infiltration, and depletion of soil moisture by uptake and evaporation. In addition, vegetation acts as a buffer against the abrasive effect of flow transported sediment and debris. It also contributes to be bed strength through the root system and fallen timber, which can provide a natural bed level control. Vegetation also helps to slow flow, which enhances the temporary storage of floodwaters in floodplain areas. As a result, stream bank and floodplain vegetation can in some circumstances provide effective natural flood mitigation.

Floodplain areas adjacent to streams should be of sufficient size and as natural as possible in order to achieve an appropriate range of uses consistent with preservation and/or improvement of natural floodplain functions and values, including maintenance of stream stability. Riparian corridors and vegetated buffer strips can help protect the natural stream environment (DIPNR 2004).

Sufficient width needs to be given to this core floodplain area. The actual width required is dependent on a range of factors, which include:

- geological and geomorphic features;
- bank and floodplain vegetation type, extent and density (hydraulic roughness);
- soil type, slope, land use;
- magnitude and duration of catchment run-off / flood flows, including outflow areas and overland flow; and
- social and economical factors.

Other factors to be considered in determining the width of vegetation include the requirements for flow attenuation or retardation, maintenance of diversity of fauna habitats, continuity and connectivity for flora and fauna, provision for settlement of debris loads and water quality controls.

As a general rule subdivisions should incorporate a generous allowance for natural streams and their associated floodplain vegetation. Such design involves the retention or creation of a channel with meandering low flow, pool and riffle sequence zones and the use of natural materials and floodplain vegetation native to the area to ensure stream bank and bed stability and water quality as well as providing for biodiversity, habitat and connectivity.

It should be remembered that within any river system, there are variations in the upper, middle and lower reaches of the catchment. In the upper reaches where the floodplain tends to be more confined, the land required to provide an adequate riparian corridor will represent a greater proportion of the floodplain than in the lower reaches where the floodplain tends to be more extensive.

Successful integration of stream and over bank vegetation considerations into the floodplain risk management evaluation process requires that the adopted vegetation and development strategy does not increase the flood risks to existing or future occupants of the floodplain. This applies to both personal safety and property damage.

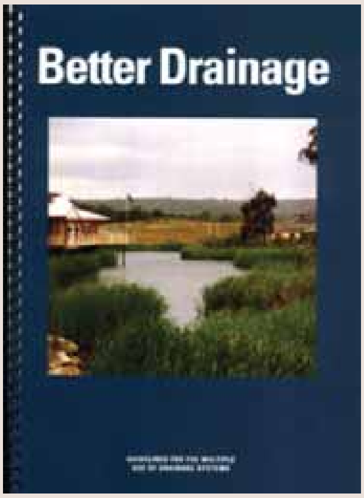
A natural stream environment with a fully or partially vegetated floodplain not only slows floodwaters, but tends to flood progressively. This ensures safer evacuation conditions, even in larger floods as there is more visual warning of approaching floodwaters. Notwithstanding this, the flooding and environmental considerations also need to be balanced against economical and social needs.

The science of stream and floodplain areas is complex and proper management of these areas requires access to reliable data on both flood behaviour and environmental attributes. Mapping of important vegetation boundaries along streams can facilitate environmental protection and enhance natural functions and processes, as has occurred within the Hawkesbury Nepean catchment.

> There are many examples of subdivision designs from the 1960's in fringe metropolitan areas such as Hornsby, Bankstown and Parramatta which have attempted to vary the natural drainage paths or characteristics in order to suit particular development needs. Experience has since shown that such attempts often fail, resulting in excess overland flows which revert to the natural flow paths. This experience reinforces the approach of working with the natural system rather than adopting a highly modified or artificial system.

Natural streams and watercourses also have the potential to enhance the appearance of a development and provide positive social and recreational benefits. The benefits of having multiple appropriate uses in drainage reserves has been recognised and promoted by the NSW Government in guidelines entitled "Better Drainage" (1993) (Figure 71). There are potential hydraulic benefits in not allowing development to restrict the natural capacity of the floodplain to cater for the

Figure 71 *Better Drainage Guidelines for Multiple Use of Drainage Systems*



larger events. These events must not be ignored as they bring about more dangerous conditions as well as greater and more destructive hydraulic forces.

Typically there is little design required where a natural stream is to be utilised as part of the trunk drainage system. The main criteria are to ensure that a sufficiently wide drainage corridor is set aside to maintain adequate waterway capacity. Issues such as erosion and sedimentation, effects of debris (both supply of debris, and build up debris generated outside of the area) and general maintenance should be considered in detail to protect and/or enhance the existing situation. The use of rock riffles is a currently favoured treatment to form localised pools to artificially create flora and fauna habitats and to provide a means for energy dissipation to reduce velocity scour problems.

Careful consideration needs to be given to how flows might change for the more frequent events due to the effects of urbanisation. Typically the flood peaks are greater for the more frequent events than for rarer events. The frequent flows determine the geomorphological response of the channel system. This means that there are two choices – modify the natural channels so that they can accommodate more flow or modify the urbanised flows entering the channels so that they do not disturb the balance. Failure to consider this factor will lead to erosion and sedimentation problems which will destroy the aesthetic and ecological benefits of maintaining a largely natural trunk drainage system.

The adoption of natural waterways and minimal encroachment to convey flood flows is particularly recommended in the upper reaches of a catchment where the velocities are high and geomorphological processes are most active and dynamic (Figure 72). There is also still plenty of scope within the middle reaches or transitional zone for creating an effective natural stream-like environment, but it is more likely that artificial modification or enhancement will be required in order to convey design flood flows. In the lowland areas the main creek or rivers are the major flow carriers and are typically best left alone. It is the expanding overbank floodplain areas where there may be some scope for enhancing the trunk drainage capabilities.

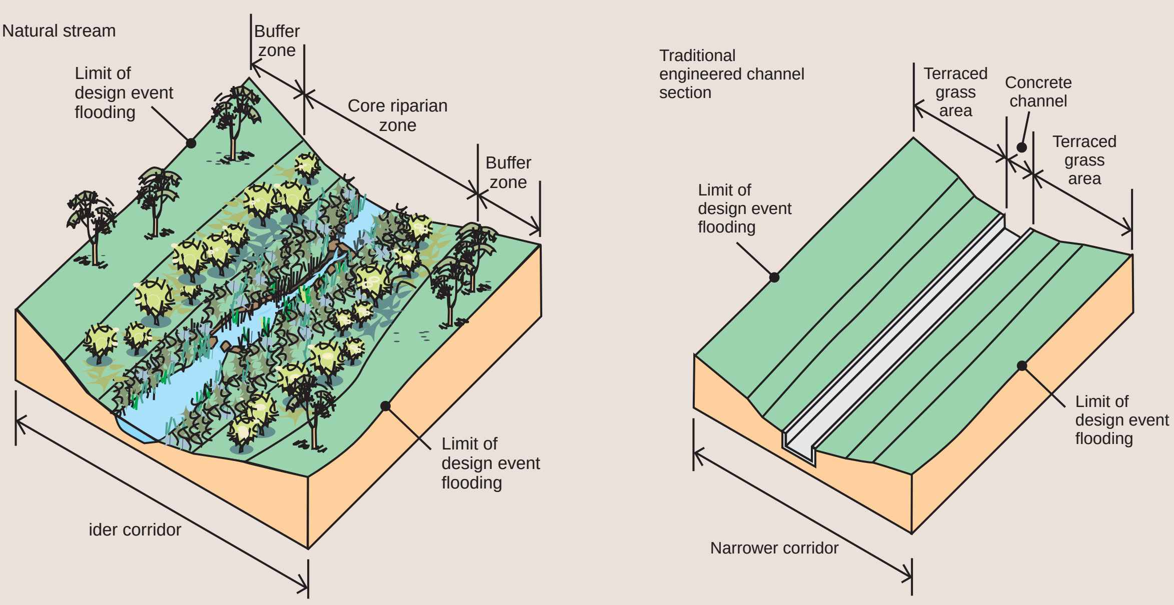
Figure 72 *Open area below house*

Dwellings elevated above potential flooding can provide open areas for conveyance or storage of floodwaters and minimise flood damage, but raise safety issues for the occupants who may become isolated over prolonged periods of time.

The riparian corridors for these streams can be landscaped and planted to create public or private recreation areas providing for floodways and flood storage areas for overflows and support for local flora and fauna by providing habitat.

It is not uncommon for natural stream to require a greater corridor width than an engineered channel design with grass slopes above the channel (see Figure 73). However, the natural stream cross section can to some extent be shaped to

Figure 73 *Natural Stream and Engineered Channel Corridor Widths*



Wider corridors are often required to accommodate natural features (i.e. pools and riffles, reeds, rocks, native vegetation) and to compensate for the greater roughness of the natural stream system, which results in an increased waterway area needed for a given flow. Whilst a concrete channel / grass bank channel system may require less overall width, greater velocities and increased flood problems downstream are more likely with such a system.

increase the waterway area to offset the increased roughness of the natural stream. The lower reaches of a natural stream located in significant backwater area, where there is a high tailwater condition and therefore potentially low stream velocities, may not need a wider corridor to convey flood flow.

While a riparian corridor may take up more space than a traditional engineered channel, the land take can be at least partly offset against recreation reserve requirements. Where flood hazards remain high in the riparian corridor, there is justification to discourage structures because apart from being subject to flood damages, they may exacerbate problems arising from larger floods. In this regard, set backs which control but not necessarily prevent development can be justified.

Open Channels

Open artificial channels, as opposed to natural watercourses, are usually utilised in the middle to lower reaches of a trunk drainage system where the flows can be substantial and channels provide a more economical solution than pipes (Figure 74). The design and construction of open channels allows consistent channel shape and hydraulic characteristics (waterway area and surface roughness), when compared to natural channels. The availability of a drainage corridor of sufficient width is normally a critical factor in determining the overall dimensions for the open channel and its alignment. If the width is insufficient, pipes may have to be installed as they can be located

Figure 74 *Channel with terraced banks*

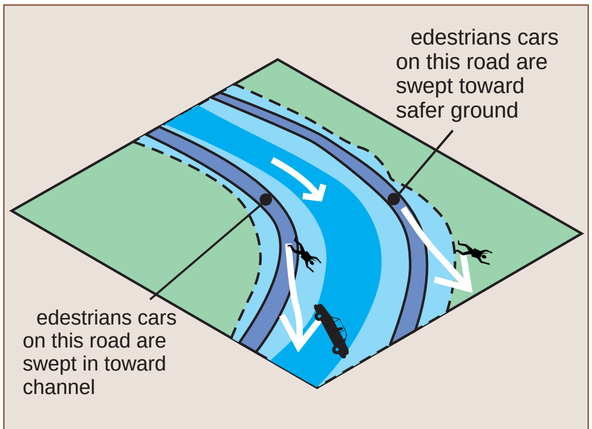
Having terraced sides to channels can help to warn of rising floodwaters making it easier to escape the hazard.

under open space areas or under roads with less disruption to the subdivision layout.

Channel shapes and surface treatment are mostly designed as a single cohesive unit, but compound arrangements can also be appropriate depending on the needs of a particular site. Compound channels can comprise a natural low flow “pool and riffle” sequence instead of a low flow concrete lined channel, and a larger trapezoidal shape or even a benched overbank floodway berm. Designers should be careful when detailing surface treatments for these compound arrangements as it is the velocity differential (which can vary significantly across the section) which can cause scour problems at the boundaries between the different surfaces. This is most common where hard concrete low flow channels adjoin grass-lined berm inverts. It is recommended that suitable transitioning of surface materials, using rock or gabion protection (or similar), be installed to enable the flow velocity conditions to vary more gradually across the section.

Consideration of the channel slope is also important, as this requires balancing of possible additional flow capacity against increased velocities with consequent hazard and scour problems. It is possible to address the potential scour problems through proper assessment and detailing of surface treatment measures. Drop structures can be used to limit velocities where required. The overall shape and alignment of the channel also influences how hazardous it is in regard to safety. For example, gradual changes within the channel make it easier for a person caught in the channel to escape from rising floodwaters (Figure 75). The need for this provision is greater if playing fields are near the channel.

Figure 75 *Positioning a curved road near a stream*



Adopting a curved alignment for an open channel can make it easier for a person caught in floodwaters to reach safety. For example roads and footpaths located on the outside of a bend in a major overflow pathway provide an escape route for cars and/or people from hazardous flood flows.

The prevailing hydraulic conditions are also influenced by channel slope. In the steep upper reaches, flows are often supercritical with very high velocities. Under such circumstances the theoretical depths of flow calculated by normal hydraulics formulae are very low because of the high velocity head. This can lead to a false sense of security, as the actual depths can quickly be elevated by obstructions within the flow path such as debris resulting in unexpected depths and possible flow diversions. In the middle reaches or transitional zones where slopes are in the process of flattening from steeper to flatter grades, flow conditions can vary rapidly depending on local features, and considerable care is required when analysing channel performance and designing appropriate channel sizes and shapes. In the flatter lowlands areas depths and velocities are more predictable and “robust”.

Because the primary function of open channels is to convey significant volumes of stormwater in an efficient manner, public safety and potential liability issues represent major concerns for designers. It is therefore essential to carefully consider the potential hazards and risks for adjoining landholders and users of the drainage corridor, especially as they may be unfamiliar with its hydraulic function. Designers and planners need to be fully aware of public safety issues when locating land uses which will result in people being in close proximity to open channels and overflows. Some investigation of “what if” scenarios outside the normal scope of expected flood behaviour such as consideration of floods larger than the normal design standard or explicitly analysing flash flooding implications, can identify unexpected hazards that might develop during extraordinary flood circumstances.

Figure 76 *Residential Development located away from natural stream*

Housing within this subdivision is located some distance from and elevated above the channel and the lower floodplain area.

This design provides for conveyance of the more hazardous flows away from the housing.

Channels are designed to carry a specific flow. This is often the peak flow in the 1 in 100 AEP storm, but other probability events may sometimes be more appropriate. System analysis, following preliminary design, should use a PMF assessment to identify the full extent of the overflow floodplain associated with the channel. The potential hazards and risks on the overflow floodplain can then be assessed for lesser floods. The merits based decision on an appropriate AEP event for channel design should include damages and losses likely to result from overflows.

In contrast to pipes systems, both open channels and natural watercourses can more readily accommodate floods larger than the design standard. A small increase in water level can normally accommodate a large increase in flow. Nevertheless, designers of open channel systems need to consider the implications of larger flows than the design standard. These implications are likely at the edges of the channel. Keeping development and large trees or other landscaping features away from the immediate channel area can assist in accommodating excess flow situations. In accordance with the principles of the major/minor system, all elements of a trunk drainage system should be analysed for very large floods, including the PMF (Figure 76).

Thus whilst open channels may be designed for certain design standard between top of banks, with careful channel and adjacent floodplain design the impacts from rarer floods can be effectively contained and limited.

Pipes and Culverts

Pipes and culvert drainage elements have a specific hydraulic capacity with a fixed upper limit of available waterway area because of their “closed conduit” nature. This capacity will inevitably be exceeded at some point in time even when pipe diameters larger than the design standard are adopted. Being closed elements, pipes and culverts are prone to blockages and the potential for this should be analysed. It is therefore essential to incorporate surcharge and overland flow paths when a trunk drainage system includes pipes. As noted above in the open channels section, all elements of a trunk drainage system should be analysed for a range of floods, including the PMF in some circumstances.

Pipes are primarily utilised as part of the stormwater collection system in the upper reaches of drainage systems and in more densely developed areas. They are also used further downstream on the main trunk drainage line to convey flows under developed areas or across transport corridors, which span the natural flow paths. Their purpose is to convey the runoff quickly and efficiently to discharge points downstream. Their hydraulic efficiency and closed solid construction leads to them being preferred to open channels for the middle to upper reaches, as they require a reduced easement width for the same flow capacity with lower maintenance requirements.

Velocities in pipes are typically high requiring appropriate protection and energy dissipation at the outlets. In very steep areas, velocities in the pipes can become excessive, and with the transport of sediments, can lead to scouring of the pipe invert. Hydraulic losses at pits and junctions are typically high in these situations also resulting in flows surcharging at the pits to then flow overland. Pit inlets are also often prone to blockage by debris or direct bypass. Design of pipe and pit system requires careful consideration to ensure velocities

7

Figure 77 *Pools and Riffles in a stream*

Rock weirs as used in pool and riffle sequences act to help control erosive velocities and enhance the natural qualities of the stream.

are not excessive (e.g. use of drop structures may be necessary) and any surcharge caused by blockages can be safely accommodated by suitable overland flow path.

Although open channels and natural watercourses have recognised public safety issues, with people falling in and drowning during major flood events, piped systems can also pose safety issues. This can be at least partially overcome by providing suitable treatments, such as safety fencing near their inlets, whilst taking care to ensure that they do not add to debris blockage problems. In designing a trunk drainage systems it is sensible to include appropriate trash racks, or similar, when transitioning from open channels or natural watercourses to a piped system.

Maintenance of piped systems is normally accommodated by providing access holes at recommended intervals. Access for inspection and maintenance raises significant occupational and health safety issues due to the build up of toxic gasses from decaying vegetation or sewerage system leaks. Particularly with long or deep piped systems adequate provision needs to be made for access to clear debris after major storm events.

Hydraulic Structures

The range of elements discussed above can be appropriately combined to develop the major part of a trunk drainage system, with other elements used as required, to complete the system. These include weirs, transitions, energy dissipators, drops structures, flow diversion structures, bridges, water quality ponds, trash racks, etc. All of these have some effects on the function of the overall system and its hydraulic behaviour.

Weirs

Weirs are commonly used to provide small ornamental lakes for aesthetic and recreational reasons or to separate saline areas from freshwater systems. As weirs can interrupt environmental flows they are not favoured in many locations.

Depending on its size and location, a weir can have a significant effect on velocities and peak heights. Consideration of velocity is important in designing scour protection around and downstream of the weir itself. Peak heights are increased upstream due to the backwater effect of the reduction in waterway area at the weir cross-section. The weir needs to be included in the hydraulic model to account for these effects on the overall hydraulics of the system. A key element of any such analysis is using an appropriate “weir coefficient” to reflect the shape of the longitudinal overflow path across the weir (Figure 77).

Transitions

Transitions can appear in many shapes and forms, ranging from complex concrete structures to natural or semi-natural rubble or gabion structures in natural or artificial channels (Figure 78).

Transitions provide a link between different channel elements, typically when changing from an artificial channel to a piped system. Mostly such systems can be analysed using normal hydraulic tools, but sometimes it may be necessary to construct a physical hydraulic model in a laboratory to enable more accurate evaluation of design variations in critical locations. Transitions need careful consideration as they can have a significant impact on flood levels, and if improperly designed, can cause unexpected hydraulic losses.

Figure 78 *Channel – Pipes Transition*

Short transition of two piped systems converging into a hard surface channel. Adverse increases to flood levels or velocities can occur if the transition is not designed appropriately.

Figure 79 *Drop Structure*

Engineered drop structures such as this provide certainty in terms of design outcomes. However, less intrusive structures can be designed using rocks for less hazardous situations.

Energy Dissipators and Drop Structures

Energy dissipators and drop structures are used to dissipate excessive hydraulic energy.

Drop structures are commonly inserted in piped systems where there are excessive slopes and it is necessary to keep the velocity of flow in the pipe below a threshold scour level to ensure that it does not threaten the integrity of the pipe structure (Figure 79). Drop structures can also be necessary in channel systems for the same reasons, i.e. where it is necessary to reduce channel slopes and dissipate energy. Drop structures also function as energy dissipators though they do not necessarily have to serve this function. Energy dissipators, as their name suggests, dissipate energy and are more commonly found as concrete or rubble structures that receive high velocity flows such as outflows from retarding basins. Typically this involves concrete bollards or steps or a rough rubble apron, (Figure 80). Such structures have high-energy losses which need to be considered in the hydraulic design of the trunk drainage system. They also can trap debris in unexpected ways and this should be anticipated as far as possible in their design.

Flow Diversion Structures

Flow diversion structures appear in many forms. One common example is a weir or similar structure used to divert high flows around a wetland. Another example might be a concrete training wall used to direct flows towards a pipe or culvert inlet whilst allowing higher flows to bypass. Again the important issues with such structures involve consideration of the likely hydraulic effects, debris collection problems, and their behaviour in flows higher than they are nominally designed for. If these issues are neglected in design there is the potential for serious impacts in larger floods.

Bridges

Bridges are commonly found across trunk drainage lines and over natural streams as an alternative to culvert crossings (Figure 81). Bridges are well catered for in design manuals such as the RTA's Road Design Guide and in various AUSROADS publications. From the viewpoint of a trunk drainage system it needs to be recognised that bridges are flow obstructions and they have adverse hydraulic impacts upstream (a term referred to as afflux). Careful analysis is therefore required using HEC-RAS or other appropriate design tools. The potential for bridges to trap debris needs to be considered in trunk drainage design.

Bridges also impact on the connectivity of aquatic fauna movement but through careful design this issue can be integrated into bridge design without compromising flood conveyance capacity.

Figure 80 A typical outlet arrangement with natural rock velocity dissipators

Water Quality Ponds and Gross Pollutant Traps

Water quality ponds or wetlands are commonly included in trunk drainage systems to improve water quality. They are also commonly associated with Gross Pollutant Traps (GPT's), trash racks, and other sediment and debris collection devices (Figures 82 and 83).

Although wetlands and their associated features are not normally intended to have any impact on the hydrology or hydraulics of trunk drainage systems, they can have adverse impacts if not designed carefully (Figure 84).

Off-line wetlands are placed away from the main flow path with water diverted into them, whilst on-line wetlands have higher flows diverted around them. From a trunk drainage viewpoint it is important to consider any adverse hydraulic impacts which wetlands might have. Debris can collect in wetlands with attendant maintenance issues, causing unexpected adverse hydraulic effects unless factored into the design of a trunk drainage system.

Other hydraulic structures not specifically detailed above, may possibly interact with other elements in a trunk drainage system; however, their characteristics probably fall into one or more of the above examples.

Figure 82 Large Debris Trap

This is an example of an effective system for trapping large debris upstream of a culvert. It can help prevent blockages, which reduce waterway capacity.

Figure 81 Bridge over Stream

To minimise the impacts on flood behaviour bridges are often preferred to culverts as they are an effective means of obtaining effective waterway openings. This also helps to minimise interruption to fauna movements along the stream corridor.

Figure 83 A typical Gross Pollutant Trap (GPT)

GPTs can catch fine debris, which would otherwise choke the drainage system

Figure 84 *Wetland Area*

Wetlands polish stormwater discharges and provide habitat for native fauna. They can also provide worthwhile flood water retention to reduce downstream flood levels.

7.3 Street Design

7.3.1 Introduction

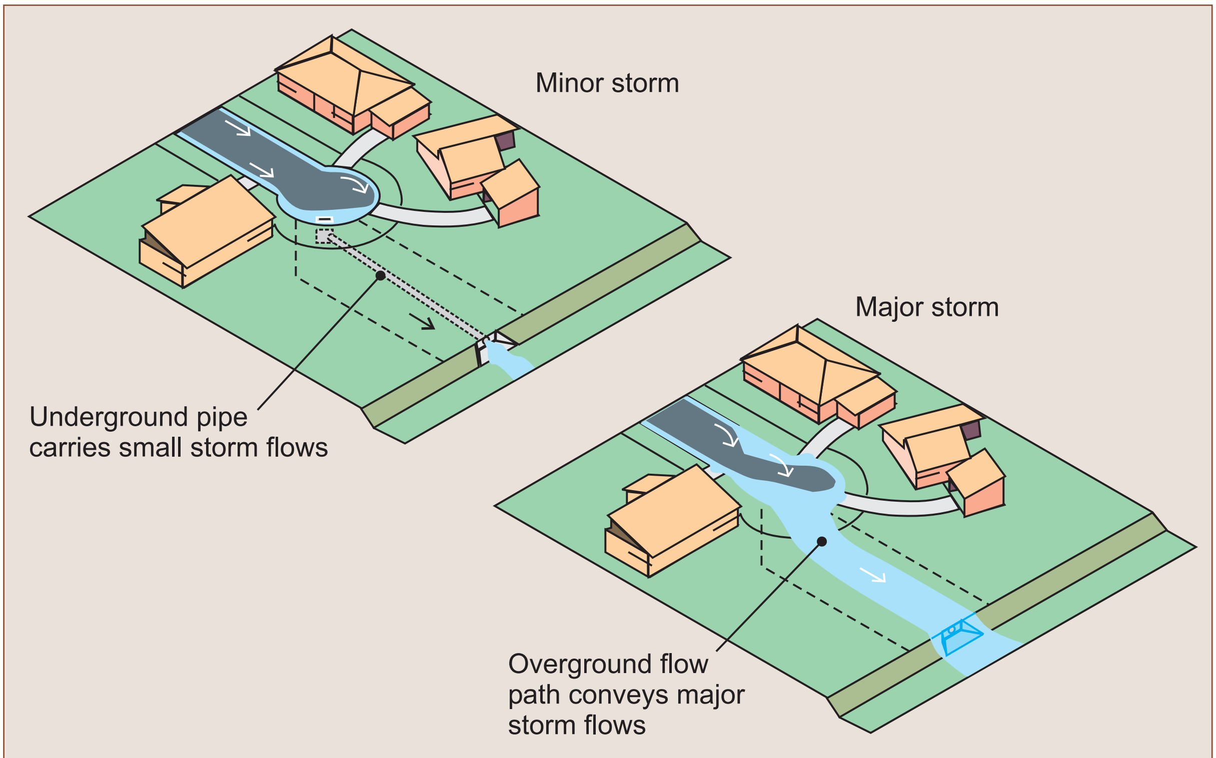
The major - minor drainage system is characterised by a minor system of underground pipes to carry small storm flows and a major system of overland flow paths designed to convey major storm flows when the minor system capacity is exceeded (Figure 85).

Roads are generally designed with a dual function to carry both pedestrian and vehicular traffic and as part of the stormwater system to carry major storm flows on the road surface.

In minor storm events the roads are designed to be trafficable. In the event of storms say greater than the 1 in 20 AEP event the road is designed to flood. The assumption is that people will stay indoors or stop driving and pull over to the side of the road and wait for the storm to pass. In this case, the main criteria are to ensure that the depth and velocity of flow is not sufficient to wash people or cars away.

However, in floodplains subject to riverine flooding, where roads also serve as evacuation routes there is conflict with road being an integral part of the major drainage system. When evacuation is likely to be essential, the design of the drainage system will need to be modified in such a way as to ensure that the local drainage system does not prevent the safe evacuation of residents via the road system during mainstream flooding events. In the case of Hawkesbury-Nepean flooding the 1 in 500 AEP design flood has been selected as the standard for local drainage on evacuation routes.

Figure 85 *Major and Minor Drainage Systems*



Public safety should always be the primary function of a street within a floodplain, and secondary uses such as overland flow paths for the drainage system should only be adopted when they can be compatible with public safety. It should be recognised that it is preferable for major flow paths to ultimately follow existing drainage paths rather than seeking to contain them within street alignment.

7.3.2 Design Considerations

Access and Evacuation

Whilst vehicle movement and vehicle, cycle and pedestrian safety are primary considerations for road design, the need for self evacuation by car, albeit infrequent, must be adequately accommodated on nominated routes. In this regard, the following should be considered:

- Carriageways and crossovers should be designed primarily for vehicles (other uses e.g. drainage are secondary);
- Verges or the nature strip can accommodate street or lot drainage without disrupting traffic;
- Verges or the nature strip and any drains within the verge should be sized to convey flows to drainage paths without isolating occupants of adjacent property who may need to evacuate;
- Use of street gutters or verges for drainage should maintain trafficability of the carriageway and crossovers;
- Where a street dips to cross a drainage path, care needs to be taken to ensure that residents who might need to evacuate can continue to travel upslope, if necessary in either direction to a reliable connection to local evacuation routes.

Drainage

To ensure effective drainage, existing flow paths and patterns should be retained wherever possible. Nevertheless, effective road drainage can be achieved by adhering to the following principles:

- Significant flows on the carriageway are better avoided to prevent compromising trafficability;
- Flows along any carriageway should not cause flotation of cars etc, or be capable of washing people away;
- A major-minor stormwater drainage design which results in streets being closed is only advisable for areas where there is no need for evacuation and where residents can shelter safely in their homes during short duration, flash flooding events;
- A major-minor stormwater drainage design where residents require evacuation can be acceptable provided adequate trafficability can be maintained throughout the evacuation period;
- Minor drainage paths may include conventional gutter and pipes, diffuse sheet flows to adjoining lots, swales and infiltration trenches.

Rural road drainage design approach

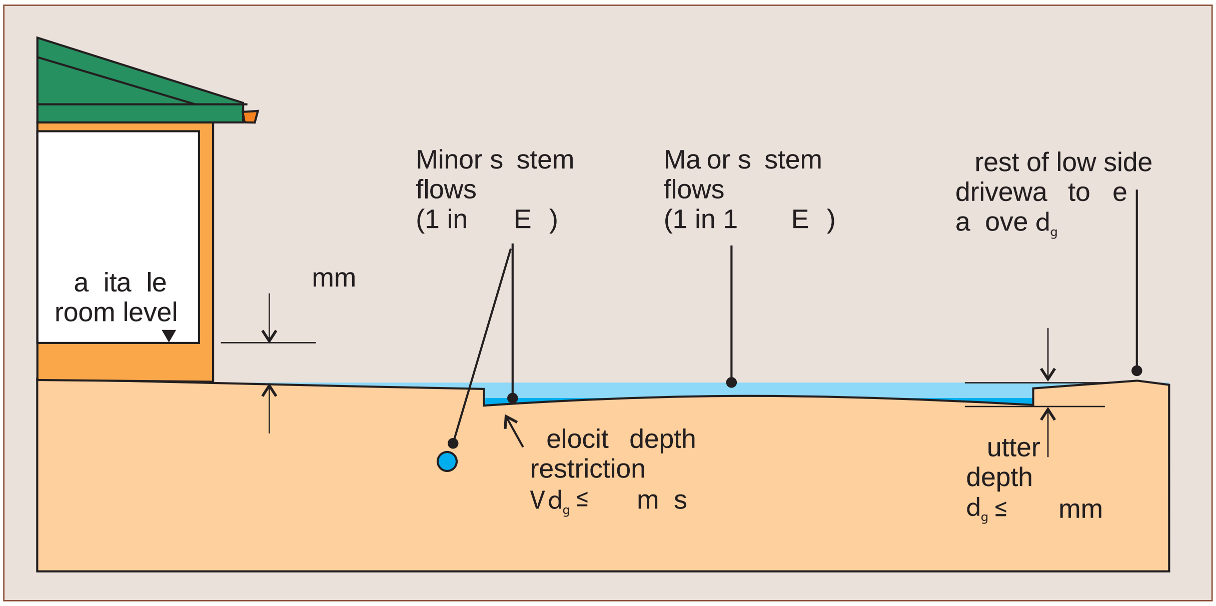
The approach used for designing drainage on rural roads may sometimes be a viable alternative to accepted contemporary urban road drainage practice for use in urban areas. Matters for consideration are:

- By using no kerbs, water is able to be shed from the carriageway as quickly and diffusely as possible;
- A raised formation can encourage diffuse shallow sheet flow of runoff to adjoining lots;
- Where topography necessitates longitudinal flows, they can be conveyed the minimum distance in swales or table drains to the first available point of relief to an existing drainage path.

Relative level of streets and houses

When street carriageways are used as a major flow path it is paramount that adequate drainage is provided. The following need to be addressed:

Figure 86 *Cross section showing relationships between house and street (Australian Rainfall and Runoff, Pilgrim 1987, Fig 14.3)*



- When the road conveys significant flow the carriageway level needs to be below the habitable floor level of the adjacent houses so as to protect the houses from water damage;
- Typically the carriageway level is lower than the habitable floor level of adjacent houses by an amount equal to the expected 1 in 100 AEP flood level plus 0.3 metre allowance for overland flow (Figure 86);
- Habitable floor levels built lower than the streets fronting them should be located such that overland flows from the carriageway do not enter the houses or necessitate unsafe evacuation;
- Residents who evacuate should not be faced with unnecessary hazards by finding themselves totally isolated and vulnerable because the streets are impassable due to floodwater deeper than at the houses they have just fled;
- Designing carriageways to be level with or higher than the habitable floor level of the adjacent houses will minimise the risk of residents being isolated by rising floodwaters.

Flood permeability

The continuity of the street pattern and the streetscape, including tree planting and street furniture, can influence the hydraulic roughness and flood flow along streets. Within the individual lots, the distribution and density of buildings, fences and vegetation will influence hydraulic roughness and flood flow (Figure 87).

In designing the road and lot arrangements the following need to be considered in regard to flood permeability:

- The relative hydraulic roughness of the drainage reserves, the streets or between the houses on the lots will determine where the flood flows concentrate;
- Streets are typically more open than the adjoining lots which include houses, sheds, fences, gardens and other flow obstructions;
- Flood flows will tend to concentrate in the less cluttered areas where flow is not impeded, e.g. along streets rather than through the lots (unless unobstructed floodways are provided and maintained on the lots);
- Keeping street frontages and lots more continuously open rather than fenced will help to minimise flood flows around houses and related flood damages.

Figure 87 *Differing Flood Permeabilities in a subdivision*

This aerial photo contrasts differing flood permeabilities. Housing on the lower right would impede creek bend overflow. House orientation and street alignment on the left side provides less restrictive conveyance for overflow.

The following roads need to be designed to be safe in case of flooding:

- Roads in drainage depressions
  - > are normally designed to flow as channels.
  - > are normally lower than surrounding ground levels and are therefore liable to flooding by both stormwater flooding and riverine flooding.
- Roads that are on a grade
  - > as they are perpendicular to the contours they can develop high velocity flows.
  - > such flows need to be checked to see that they will not wash cars and people away and will not cause flotation.
- Roads running across the contours
  - > can be cut at points where they cross a creek or drainage line.
  - > need to be designed to ensure people and cars will not be at risk of being caught by floodwaters.
- Roads that follow ridges
  - > run-off will need to be shed off at regular intervals and directed through or between lots via drainage swales or engineered overflow paths.

As a final check - 1 in 100 AEP and more extreme flood flows should have a safe escape route when the minor system fails. The escape route should follow a pathway or road system, developed as part of the subdivision, providing this is not needed for evacuation.

8

MEDIUM DENSITY AND HIGH RISE DEVELOPMENTS

8.1 Opportunities to reduce flood risk

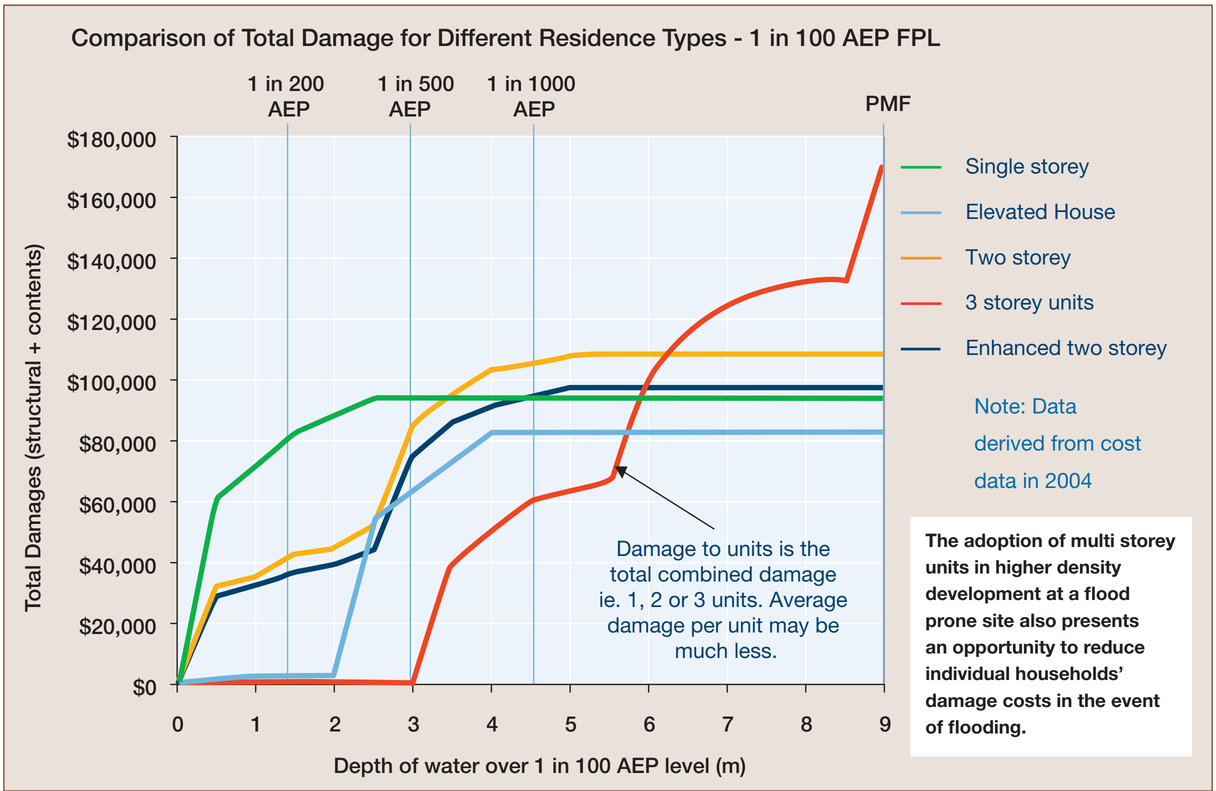
In general, higher density development could be of particular benefit lower down on the floodplain where a higher-set development could greatly reduce the probability of dwellings being flooded. In some cases it may be possible to raise the habitable areas above the PMF. In areas of higher velocity the danger to occupants and buildings increases significantly and although it is possible for residential structures to be designed to resist the flows, having dwellings in areas where they are exposed to hazardous velocities should not be a first option. However, the "Guidelines for Building on Floodplains" gives more detailed information on N classifications of dwellings required to withstand higher velocities.

The principles contained in these subdivision guidelines relating to evacuation requirements, landform modification and site layouts also apply to higher density development sites. However, as higher density development generally includes both the subdivision and dwelling design, it offers substantially more opportunity to adopt more effective flood risk management measures than does a traditional subdivision designed for individually designed and built detached dwelling houses (Figure 88). These measures include orientation of the buildings to reduce the impacts from velocities and raising floor levels above the PMF thus alleviating the requirement for evacuation in areas subject to short duration floods.

8.1.2 Medium Density - Villas, Town Houses and Three Storey Unit Blocks

Depending on the size and topography of the site, medium density development may provide an opportunity to locate or cluster the dwellings and their habitable areas in higher areas of the site or at higher elevations and retain open space on the lower parts of the site thereby reducing the probability of flooding on the occupied part of the site. It also provides the opportunity to orientate and position the development to reduce obstruction to flood flows. Better orientation and location of buildings can reduce the local velocities between the buildings and by presenting a building's stronger wall to the flow the chances of velocity and debris damage are reduced.

Figure 88 *Impact of development type on flood damages*



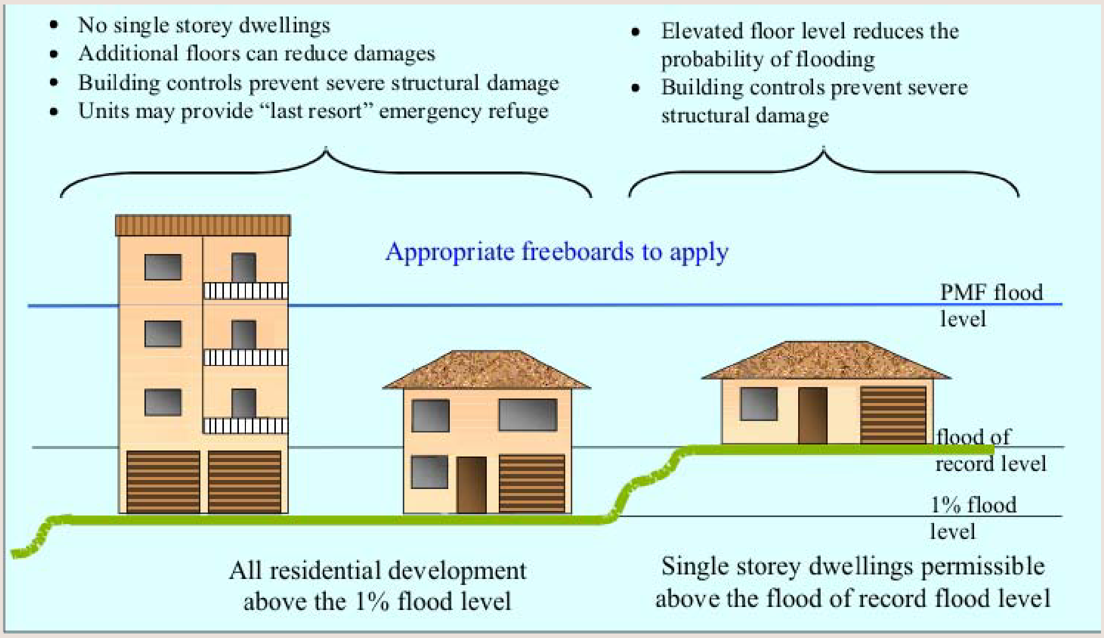
8.1.3 Multi-storey and High Rise Units

Whilst there are substantial damage reduction benefits in multi-storey unit construction, this should not be used as justification for increasing the overall numbers of households in high hazard areas where it would otherwise not be acceptable because of evacuation difficulties. Although the units may provide an opportunity for refuge within the building in flash flood events, it is much safer if residents are evacuated particularly in locations where inundation lasts for long periods. The numbers of people housed in any new floodplain development, regardless of design or type, should be consistent with the SES evacuation plan for the area.

However, if residential development is considered an acceptable land use in a vulnerable flood prone area, then flood damages can be reduced if high rise or multi-storey unit development is adopted rather than single or two-storey dwelling houses, villas and townhouses, (Figure 89). In many cases multi-storey units or high rise units could:

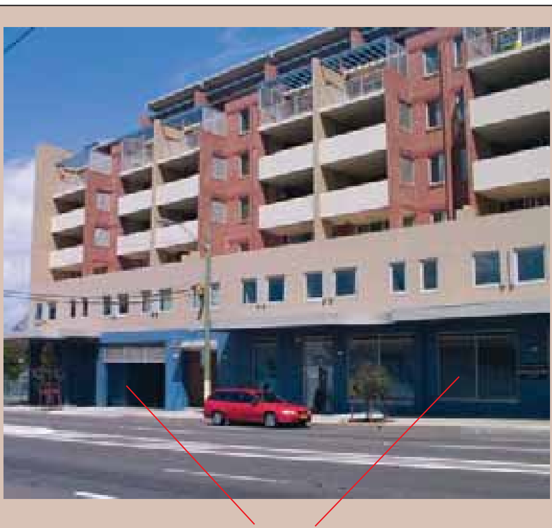
- Enable all units to be above the level of the PMF leaving only garages and common property at risk from flooding. Having to repair flood damage only to common property represents a massive reduction in the liability of individual unit owners compared to the liability of house owners on the same site who may be faced with severe and expensive damages to their homes in a flood of the same magnitude;
- Economically use flood resistant construction materials e.g. concrete and steel;
- By using stronger and conservatively designed reinforced concrete construction, be structurally designed to resist any additional forces imposed by the flowing water and debris;
- Utilise components such as a concrete lift core to provide additional strength; and

Figure 89 *Property Protection through Building Controls*



Benefits of high-rise development include a direct reduction in the flood risk to individual residents and in cases of short duration flooding can provide a flood free area to shelter.

8



Parking and shops at ground level

Flood compatible residential buildings (e.g. multi-level developments with lower floors used for commercial or common property purposes such as gyms, meeting rooms etc.) can totally remove the threat of household flood damage.

Multi-storey home units placed above parking levels can elevate apartments above the PMF level and eliminate flood risks to residents.

- Provide a refuge for occupiers in short duration flooding. Although occupiers would normally be asked to evacuate if the predicted flood level was above the critical level for that area, in an emergency any people remaining in the building would not necessarily be risking life and limb by remaining in the building until the flood recedes. In such short duration floods, emergency workers would not necessarily need to put themselves at increased risk to rescue trapped residents.

Additional benefits can be delivered through multi-storey high-rise units. By achieving the same yield in a vertical plane rather than by increasing the overall footprint of the buildings, the potential for flow obstruction is reduced. This gives more opportunities to maintain lower velocities between the buildings on the site thereby reducing the potential for damage due to flowing water. As the forces are proportional to the square of the velocity any reduction in velocity produces significant advantages.

There are also more opportunities for buildings to be orientated and positioned to minimise concentration of floodwaters and improve flow through the development when subdivision and building design are integrated.

9 CASE STUDIES

9.1 Introduction

The purpose of the following case studies is to show how the principles of the Guidelines can be put into practice in the design of the layout of a number of sites with differing requirements and characteristics. These should not be regarded as stereotype solutions to be copied, but as demonstrations of the application of the floodplain management approaches advocated in the Guidelines.

A number of hypothetical floodprone sites have been selected to demonstrate how traditional practice has not necessarily addressed the flood risk for the full range of floods and how through a range of appropriate subdivision design practices the flood risk can be managed and reduced. Each case study introduces a particular problem and puts forwards measures to reduce that particular risk. However, some of the problems caused by flooding are common to all the sites and thus several of the proposed management measures are applicable to several case study sites.

The case studies illustrate how lack of attention to flooding characteristics can result in poor outcomes.

Section 9.2 Case Study A	Neighbourhood evacuation
Section 9.3 Case Study B	The impact of fill on different parts of the catchment
Section 9.4 Case Study C	On-line and off-line basin system
Section 9.5 Case Study D	Endangering residents by not understanding the direction of flow in bigger floods
Section 9.6 Case Study E	Site modifications which disadvantage residents and handicap their ability to reach safety
Section 9.7 Case Study F	Redevelopment of land resulting in occupants at greater risk because of increased severity of flooding
Section 9.8 Case Study G	Siting residential development in unsafe areas downstream of detention basins
Section 9.9 Case Study H	Poorly designed flood protection works can increase flood hazard

9.2 CASE STUDY A

NEIGHBOURHOOD EVACUATION

9.2.1 Introduction

This case study illustrates the complex evacuation issues discussed in Section 6. The example relates to the planning of a large residential subdivision within an area subject to riverine flooding. Typically these larger residential subdivisions will include a hierarchy of roads, some non-residential uses including shops and open space.

The elements described are:

1. Linkages to Regional evacuation routes;
2. Community safe point;
3. Evacuation Precincts;
4. Local Streets.

Each element is described under the following headings:

- Rationale;
- Site assessment;
- Common issues;
- Better Practice;
- Objectives; and
- Performance Criteria.

9.2.2 Element 1 Linkages to Regional Evacuation Routes

Rationale

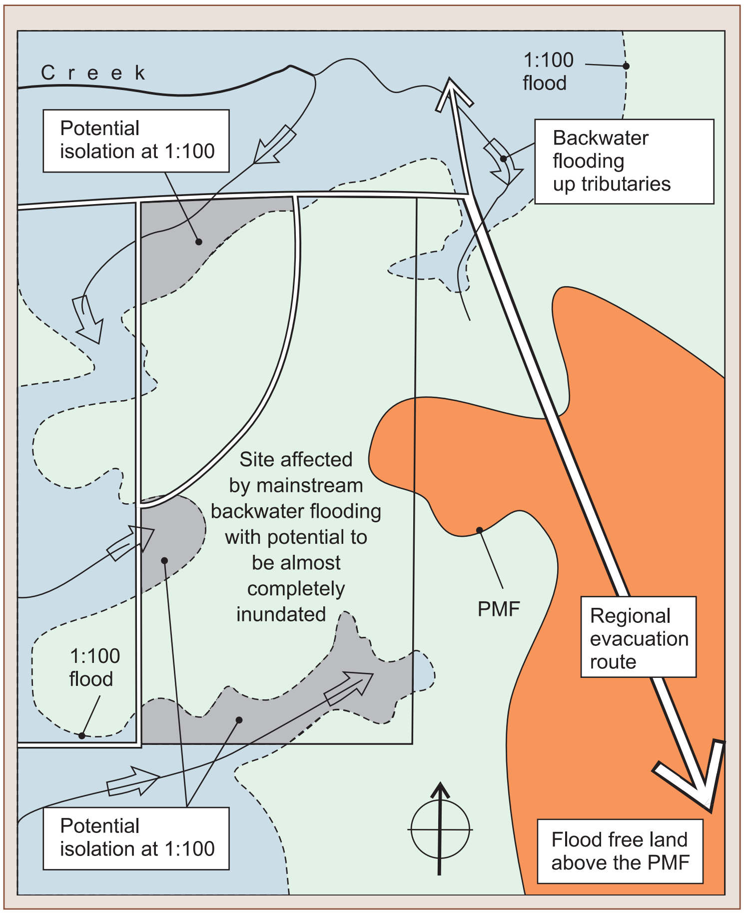
In some areas, floods can rise quickly, initially cutting off access roads, leaving isolated "islands" of housing and then eventually inundating the entire development. Although the likelihood of flooding may be low in new residential subdivisions, safe access to regional evacuation routes from residential subdivisions is critical for public safety. It is far safer and more efficient use of limited resources for large numbers of residents to evacuate beforehand than for the emergency services to have to mount seek and rescue operations using boats in unsafe conditions when roads and dwellings are flooded. Timing is critical to a successful evacuation to minimise loss of life especially when floods can rise rapidly by as much as 0.5 metre or more per hour.

Regional evacuation routes may be identified and designated by the SES or in small catchments they may simply be a road that can be used by residents to reach safer areas out of the floodplain and harms way. The critical issue for residential subdivision is that safe and reliable connections are provided from the site to a regional evacuation route. Where a site is affected by riverine flooding and a safe connection cannot be made to a regional evacuation route, then the site may not be suitable for development.

Site assessment

In order to determine if and how a site can be connected to the regional evacuation routes the following site characteristics should be identified:

Figure 90 Regional evacuation – site assessment



- Flood levels (land below the FPL and land above PMF) and potential isolation points;
- Site boundaries and natural barriers (e.g. cliffs and ridges);
- Existing surrounding road network (arterial, collector and local roads);
- Location of regional evacuation routes.

The site should be assessed for

- continuing flood risk,
- potential isolation points, and
- potential connections to the regional evacuation routes (Figure 90).

Continuing Flood Risk

The case study shows a site that can be almost completely flooded. Therefore it has a continuing flood risk and at some stage will need to be entirely evacuated.

Potential Isolation

The site will be isolated before it is completely flooded and there is no safe access to the regional evacuation routes via any existing roads in the event of severe flooding.

Connections to regional evacuation routes

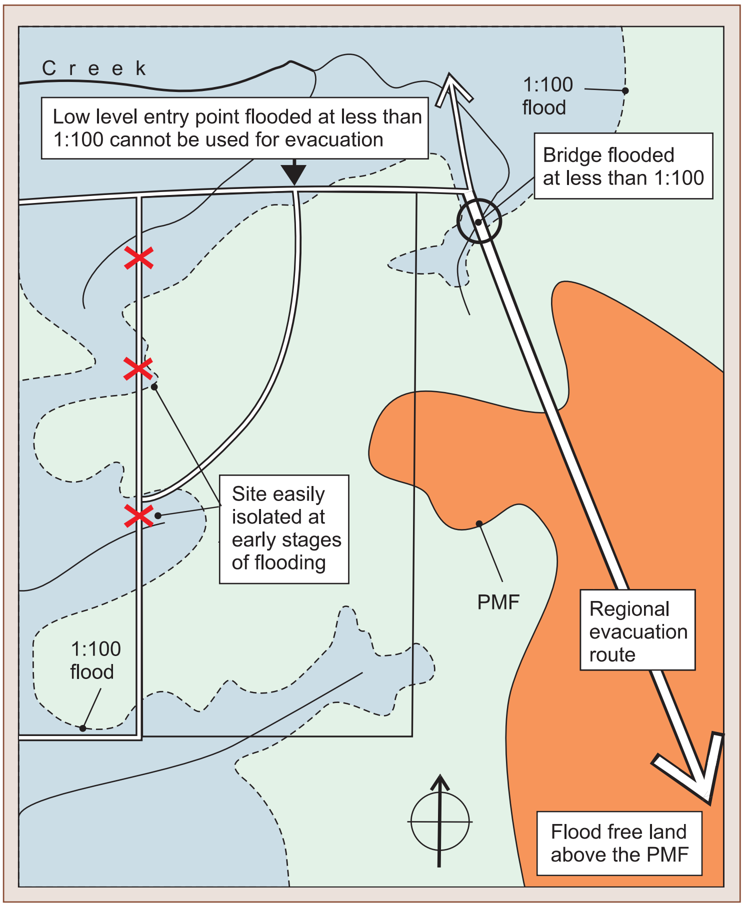
The regional evacuation route is located east of the site. The site is connected to this route via an existing arterial road on the northern boundary. However, the main road culverts are affected by 1 in 100 AEP mainstream backwater flooding and 1 in 20 AEP local storm flooding due to the limited capacity of the drainage culverts under the roadway.

Common Practice

Current subdivision practice generally limits the number of entrances to a residential estate to a single entry point commonly at the lowest point on the site (Figure 91). There are a number of reasons for this configuration including:

- for marketing reasons it is seen as preferable to locate the entry at the lowest point so that all residents drive up to their houses creating a sense of arrival;
- a marketable image and identity for the estate is established using a single well presented entry point;
- marketing criteria limit access points to the estate from adjoining roads and other residential areas to create the image of an exclusive, secure enclave; and
- practical considerations make the entry at the low point on site the most economic configuration as this relates to the location of gravity fed services such as sewer and stormwater drainage.

Figure 91 *Regional evacuation – common practice*



The implications for residential subdivision in areas affected by riverine PMF is threefold:

- where an estate has limited entry points greater pressure will be placed on these points in the event of a large scale evacuation;
- where the entry point is at a low point it will flood earlier thereby isolating the estate and preventing all vehicular access to and from the site.
- Many residents will only be convinced of the need to move to a safer location, when their home begins to be flooded. By this time it will be too late for them to get out via road access.

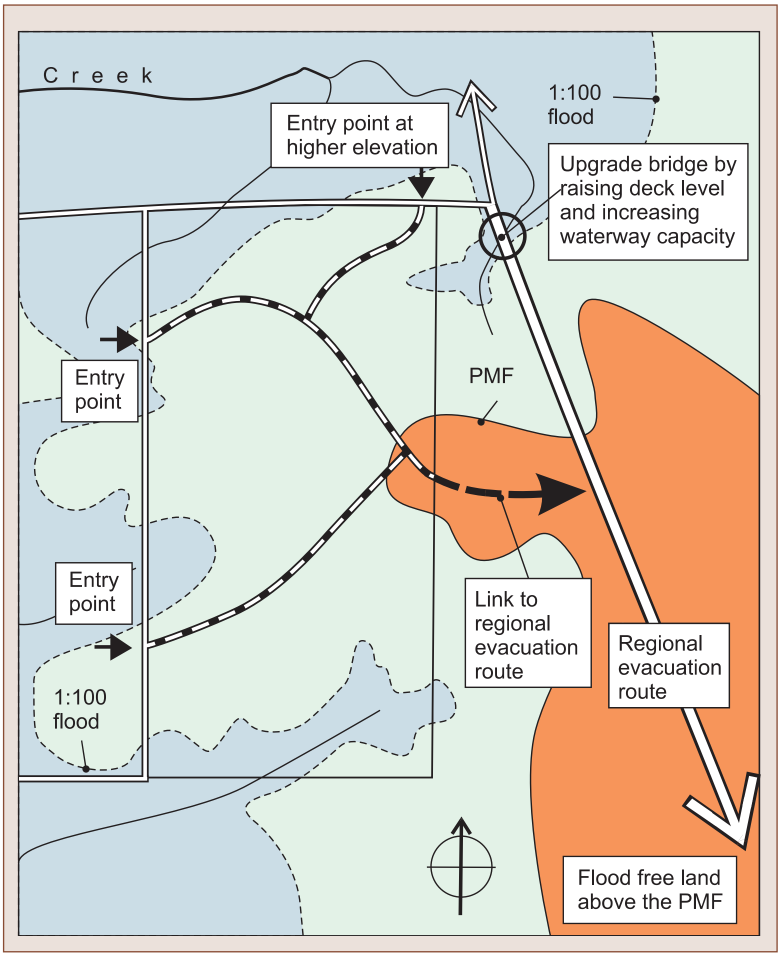
The case study shows a subdivision layout with one major entry point off an existing arterial on the northern edge of the site. Depending on how many people are on the site, and the time necessary for flood warning, evacuation will need to commence many hours before this low entry point is cut. If say the entrance is located on land 2 metres below the 1 in 100 FPL, then the entire neighbourhood will need to be evacuated 4 hours before the suburb starts to flood.

Better Practice

A connection to the regional evacuation route will vary according to the site:

- an estate entry point may provide a direct on-site link to an adjoining arterial road which is a regional evacuation route;
- an existing road network may be suitable but may require some modifications to be a safe link to an evacuation route; and
- a site may not be adjacent to an evacuation route and may need to provide a new off-site road to link to the regional evacuation route.

***Figure 92** Regional evacuation – better practice*



A better practice suburb will also provide multiple entry points to an estate both for day-to-day use and for evacuation options (Figure 92). Multiple entry points are also considered a desirable urban design outcome (DUAP, 2000). The case study shows a site with multiple entry/exit points where evacuation is possible up to a level slightly above the FPL (i.e. about 0.3 metre higher).

However, the arterial road link to the regional evacuation routes is at the bridge which is cut off by flooding at a level just below the FPL (i.e. 0.3 metre lower). Most probably it will not be trafficable because local storms frequently cause water to pond over this low spot. This constraint can only be rectified by raising this section of pavement and substantially increasing the road culvert capacity to reduce the possibility of local storms coincidently closing the road before or during an evacuation. A better solution is to construct a new “off-site” road link through an adjoining property to the east so that evacuation is possible in all flood events up to PMF thus eliminating any possibility of isolation. This new road also provides access for any future development on the adjoining land.

This approach does not exclude having a main entrance for identity or marketing reasons. It can be seen on Figure 92 that a main estate entry can be located further east along the adjoining arterial at the highest point available on the road.

Objectives

Neighbourhoods should be designed to provide orderly self directed vehicular evacuation of the community in the event of flooding.

Each suburb/development which is wholly or partially flooded in the event of a PMF should have safe road links to an identified regional escape route.

Performance Criteria

- Regional evacuation road network has capacity to accept traffic from the subdivision exit points without compromising the safe evacuation of existing communities.
- All roads should be safe during PMF riverine flooding combined with the 1 in 500 AEP event in the local catchment (refer stormwater design).
- All roads should have the traffic capacity to safely evacuate the whole area to a designated regional evacuation route within a reasonable time.
- The shorter the period available for evacuation of all residents, the higher the required traffic capacity. Multiple entry/exit points can minimise evacuation times and reduce concentration of traffic and therefore increase traffic capacity.
- Avoiding routes over drainage paths minimises uncertainties from local flooding and costly drainage works.
- Neighbourhoods should provide multiple links to surrounding areas catering for a range of early evacuation options and to allow day-to-day convenience.
- Neighbourhoods should provide a road connection to a regional evacuation route via the highest land on the site which is safe in all floods up to the PMF.

9.2.3. Element 2 Community Safe Point

Rationale

As a general principle, self-directed vehicular evacuation from the house to an evacuation centre remote from the site (nominated by the Department of Community Services) should be considered the normal situation for planning residential subdivision on flood prone land. However, it could be anticipated that some able-bodied evacuees may well have to walk from their house e.g. people who do not have vehicles or are not able drive. In such a situation a safe point is required as a focus for people to walk to and from which the SES may coordinate their evacuation. For this reason the safe point should be located with safe access to a regional evacuation route.

Subdivisions which would benefit from having a safe point include those which:

- are larger than say 1km long and where walking distances to the nearest arterial road would exceed say 800m or 10-12 minutes;
- include aged or retirement homes or other uses with a concentration of people who are more likely to require assistance in evacuation.

Site Assessment

In order to determine whether a safe point is required and where it should be located the following should be considered:

- location of high points;
- regional evacuation routes;
- walking distances.

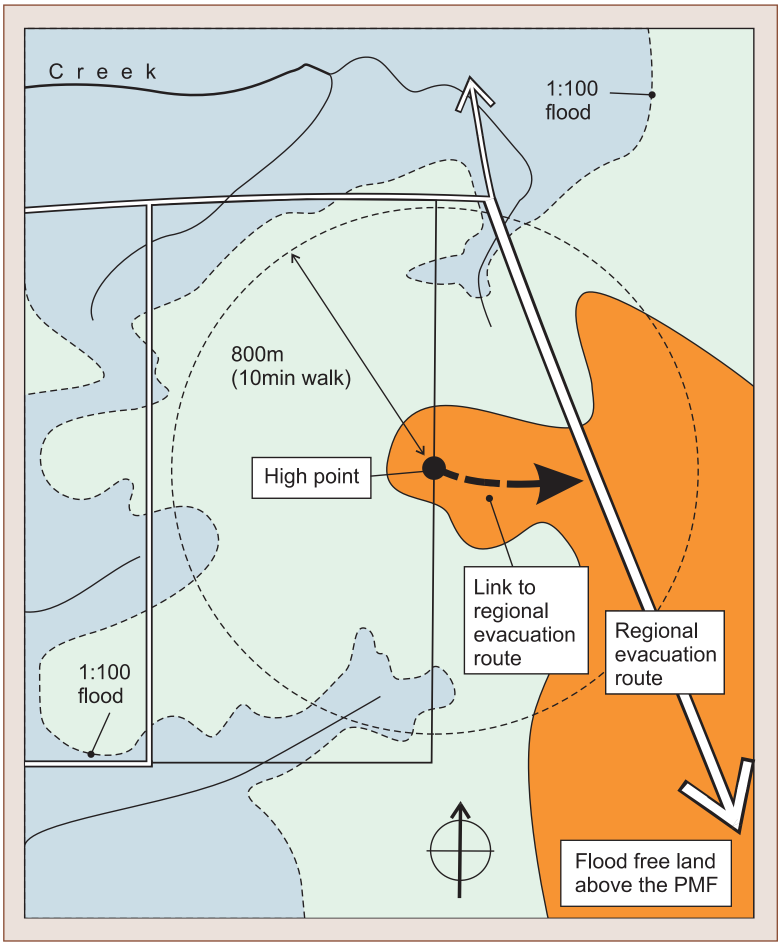
The site should be assessed for possible locations for the safe high point. While in principle this may be the highest point on the site this will need to be balanced with other criteria including the location of evacuation routes (Figure 93).

Where a site is large and walking distances generally exceed 800m from the edge to the centre a "Safe Point" will be required.

The site has a safe high point located centrally along the eastern boundary. This point is an optimal location for the safe high point as it is located adjoining the proposed link to the regional evacuation routes and is within a 10 minute walk of most of the subdivision.

If future development of the adjoining site to the east proceeds it may require an additional safe point. This could either be co-located with the one provided for the case study site or a separate safe point provided on the existing arterial road.

***Figure 93** Community safe point – site assessment*



Common Practice

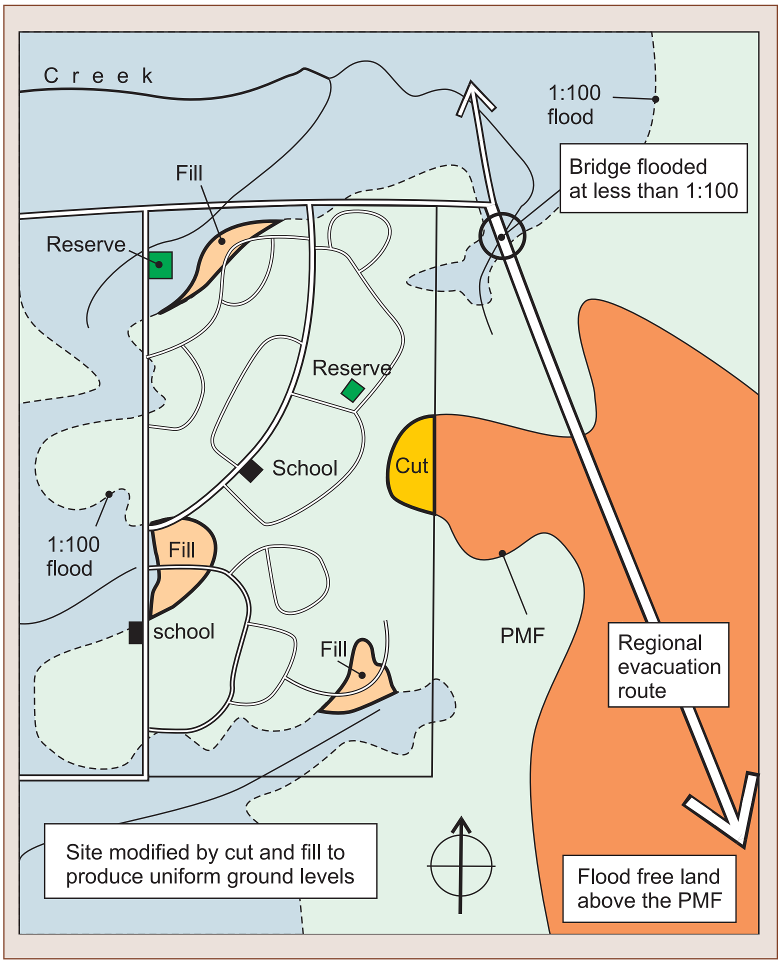
The high land is the most important place on a site in areas subject to riverine flooding, as this is where all residents should move towards in the event of a flood. In the past, urban development often emphasised high points and ridges through the location of landmarks such as churches and town halls etc. These points are often further emphasised by the grouping of retail and commercial uses to form neighbourhood or town centres.

Current floodplain residential subdivision design tends to require these high points to be removed to balance cut and fill at the site in order to maximise the number of lots at or above the FPL. Current practice also has tended towards mixed developments with the community and retail uses throughout the site (Figure 94).

This has a number of implications for residential areas in areas prone to riverine flooding:

- Homes will flood at the same moment of time and people are forced to evacuate to separate places rather than one central location as there is a lack of community focus.
- The opportunity for community facilities as a safe point is missed because they may not be on high land or otherwise well located.
- The uniform ground levels exacerbate problems due to inefficient drainage causing flooding of local roads.
- Residents have difficulty distinguishing higher ground and the pattern of site flooding.

***Figure 94** Community safe point – common practice*



The example in Figure 94 shows a typical subdivision layout where community facilities such as shops, schools, clubs and parks are spread throughout the site.

The urban structure does not reflect the flood risk of the site and as there is no clear emphasis on the importance of the high ground on the site people may not instinctively know where to move to in the event of a flood.

Better Practice

A safe point will need to be accessible in wet conditions and provide a range of facilities including areas for temporary car parking and buildings to provide shelter. The safe point also requires safe and reliable access to a regional evacuation centre.

The example in Figure 95 shows a better practice subdivision where some community facilities are clustered into a neighbourhood centre that is well known to residents and used on a daily basis. This centre is located on the highest point on the site and at the intersection of the link to the regional evacuation route. Co-locating activities in central locations creates the opportunity for the multiple use of facilities, such as school halls or clubs for evacuation shelters and sports fields for temporary car parks. This avoids having to provide single purpose facilities for a community safe point.

Objective

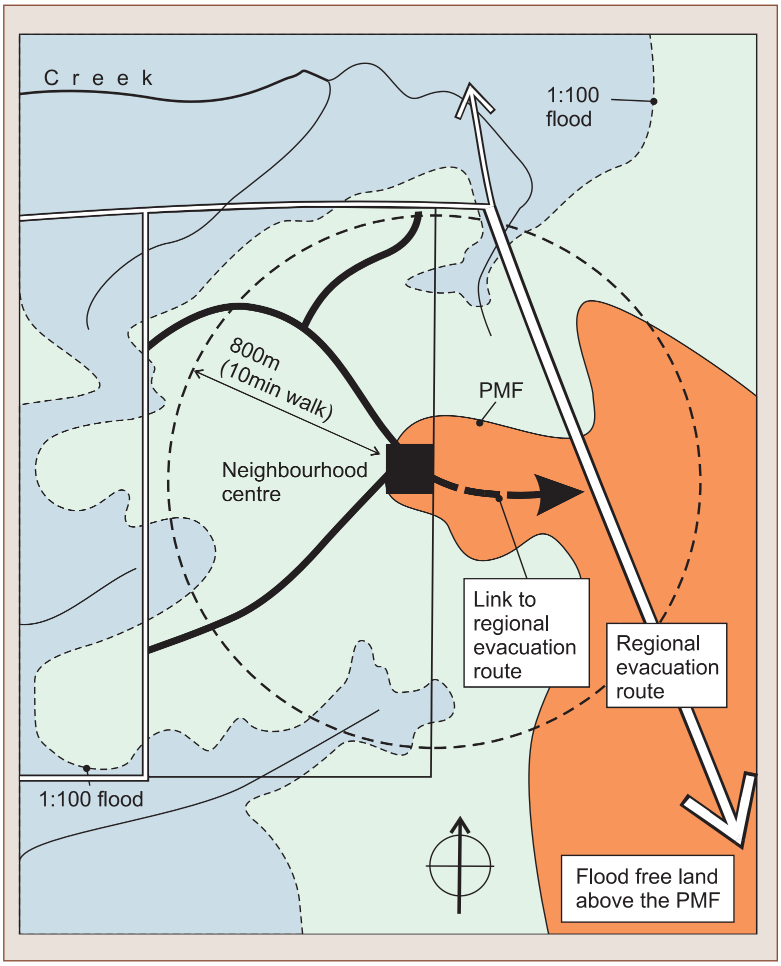
To establish a neighbourhood centre as the focus of day to day community usage which also functions as a community safe point for evacuation purposes or an evacuation centre in the event of a flood.

Performance Criteria

Neighbourhood centres intended for use as safe points in the event of a flood should:

- Be located so as to be in a central location that is well known to the community and so that in the event of flood evacuation is easily accessed by all residents;
- The safe point will need to provide adequate temporary car parking and be readily accessible in wet weather
- Be accessible from all areas of the site (or sub-site) under flood conditions;
- Be in the least flood susceptible area of the site (or sub-site) to maximise the duration of their availability;
- Be a suitable facility for people to muster at, shelter in and embark from, onto such transport as the SES identifies as servicing that locality;

***Figure 95** Community safe point - better practice*



- Have reliable egress routes to the nominated evacuation centre for that locality;
- Be located no more than 800m or 10-12 minutes walking distance from houses which that point serves;
- Nursing homes and retirement centres[12] should be located within close proximity to the safe point;
- If used as an evacuation centre a neighbourhood centre should be located above the level of potential flooding and be able to accommodate the expected number of cars from the area served without causing queuing of traffic which may be forced to extend back into the flood hazard area.

9.2.4 Element 3 Evacuation Precincts

Rationale

In order to ensure safe evacuation by vehicle all roads should be designed to rise continuously to the neighbourhood safe point. This allows the street system to be flooded while allowing progressive evacuation from each lot as the waters encroach.

The first step in this process is to develop evacuation precincts that respond directly to the site topography and drainage patterns that is, they are contained within defined topographical units i.e. sub-catchments. Within each precinct all local roads can be configured to rise continuously to the local evacuation route and thereby connect logically and clearly to the community safe point. Evacuation precincts also increase legibility and provide a basis for community to meet and plan evacuation in the event of flood.

Site Assessment

In order to determine the boundaries of the evacuation precincts (Figure 96) the following physical site characteristics should be considered:

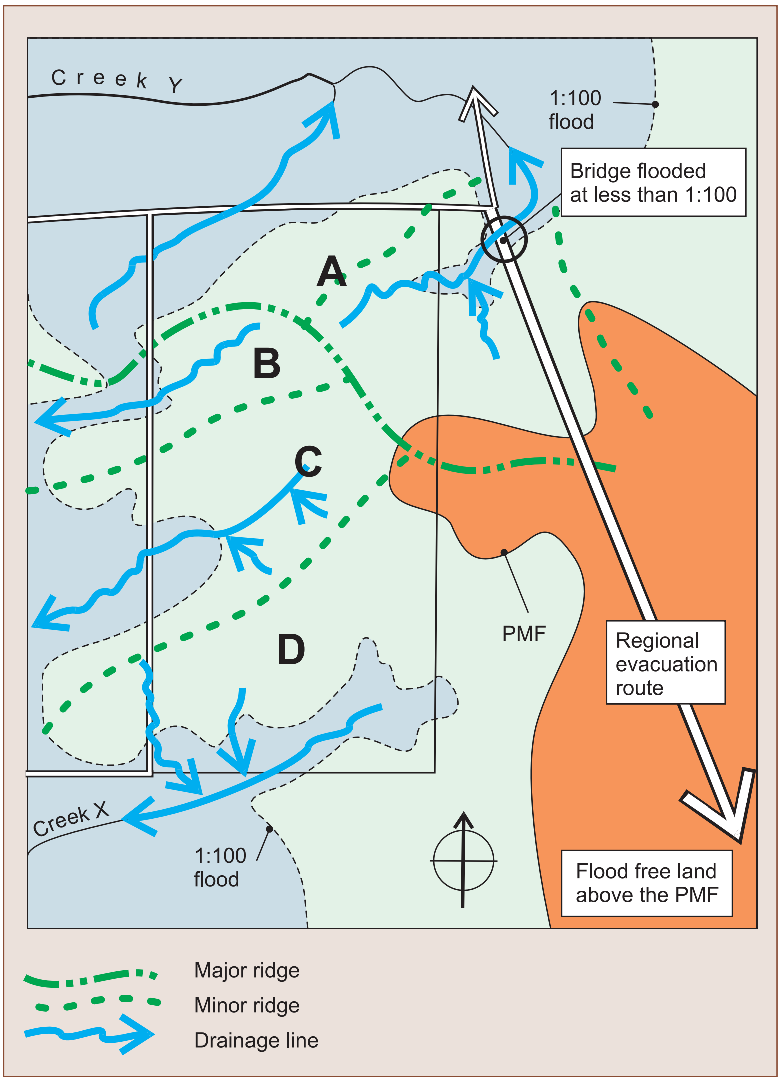
- major ridges and minor ridges;
- flood levels;
- creeks, tributaries and drainage lines.

The site should be assessed for

- potential isolation points within the site;
- evacuation precincts;
- local evacuation routes;

[12] New aged care facilities and other development for special needs occupants who are vulnerable in flood events are preferably not located on flood prone land.

Figure 96 *Evacuation precincts – site assessment*



The drainage lines and watercourses of the site form a number of sub-catchments (A,B,C and D). The sub-catchments generally form the boundaries of the evacuation precincts. These boundaries may be modified by cut and fill along the lower edges to some degree.

Local evacuation routes

The site has a major ridge running through the site from east to west. Most of the site is within creek X catchment with the watercourses flowing in a south westerly direction. The remainder of the northern part of the site is within creek Y catchment. Several minor ridges further subdivide the site. The highest point on the site as noted in Element 2 is on the main ridge on the eastern boundary of the site. It is preferable for roads which will be used as local evacuation routes to rise up from the low points or drainage lines to the ridges in order to minimise the crossing of low points.

Potential isolation points

The minor watercourses are constraints to development particularly in relation to roads. Roads that cross drainage lines are likely to be flooded causing isolation of residents and therefore their use should be minimised. Significant bridging or earthworks would be required to make major roads safe in the event of a PMF.

Evacuation precincts

Tributaries of creek Y and creek X flow through the northern and south western corners of the site respectively. A number of minor watercourses rise in the centre of the site and flow to creek X. Another minor watercourse rises within the site in the north–western corner and flows from the site to creek Y.

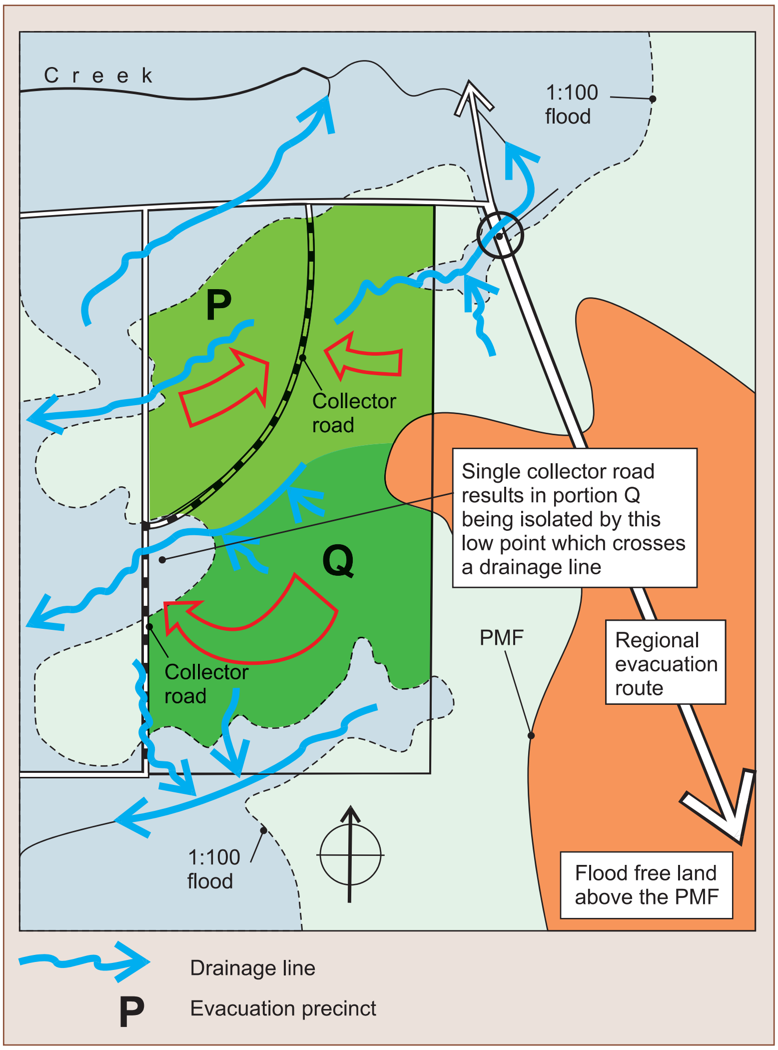
Common Practice

Where flooding (whether mainstream or local) effectively divides the site into separate sub-sites each sub-site should be treated as a separate evacuation precinct (Figure 97). In such cases, separate trafficable evacuation routes should be provided for each sub-site or sub-catchment.

By designing residential subdivisions in areas subject to riverine flooding to increase yield and minimise development costs, the configuration of collector roads and streets can result in limitations on the safe evacuation of residents.

Current subdivision practice typically has used a single major collector road to service the estate. This layout has minimised the number of properties along main roads and maximised the number of more marketable properties on local streets and culs-de-sac.

***Figure 97** Evacuation precincts – common practice*



Such a street layout is unsuitable in areas subject to riverine flooding because:

- The street network does not provide sufficient options so that evacuees can readily find an alternate route;
- The use of a single collector road to service the site will require the road design particularly the carriageway width to cater for the anticipated peak numbers during flood evacuation. In a large subdivision this may result in an unnecessarily wide road;
- The nature of these roads often requires them to traverse the topography from ridge to drainage line creating low points.

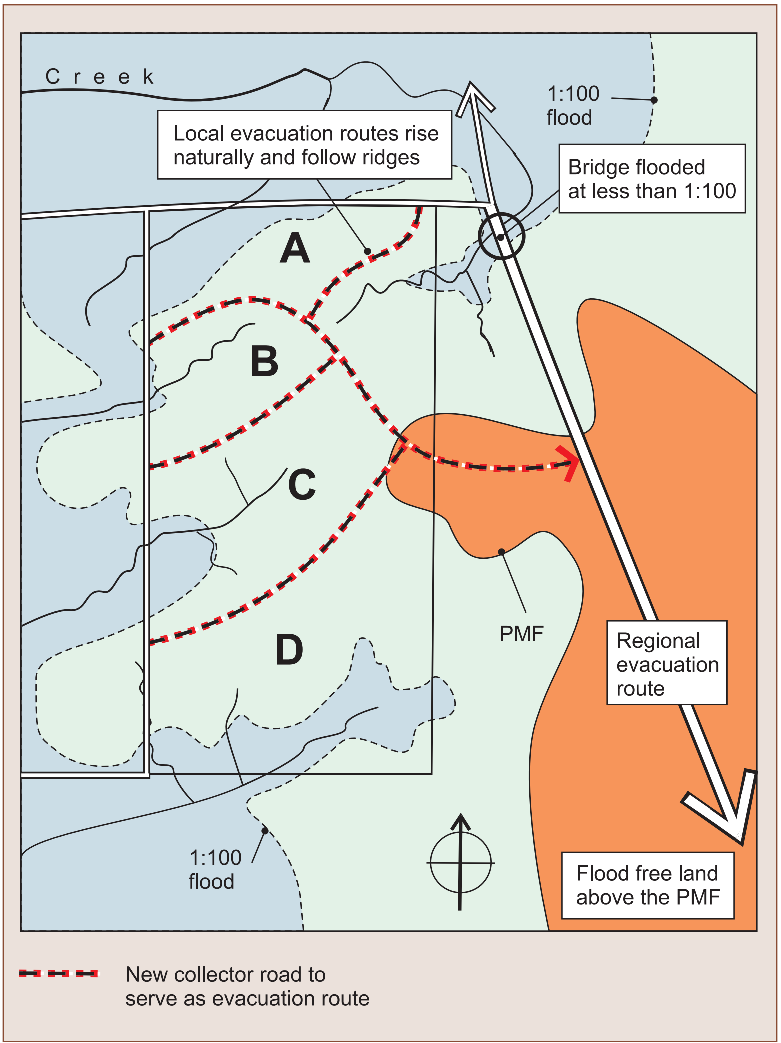
The case study shows a typical residential subdivision with single collector road running from the estate entry point through the middle of the site and creating two large precincts to the north east and south west (P and Q). The road starts in catchment Y goes over the main ridge down into catchment X and across a minor watercourse thence to the northern portion of the site. It can be seen that the two parts of the site will be isolated from each other which prevents any possible evacuation.

Better Practice

Local evacuation routes following the ridges which define the evacuation precincts (Figure 98). They are the main collector roads servicing a subdivision. Their function is to provide a primary level evacuation route for all residents fronting the route and for all residents on local streets connected to them.

The case study shows a site serviced by multiple local evacuation routes. These roads all run along the major and minor ridges within the site ensuring that each route rises continuously through the site to the community safe point, thence to the regional evacuation route. The evacuation precincts provide the optimal structure for evacuation of the neighbourhood because no part of the site is isolated. All evacuation movements are through the safe point and can be monitored and directed accordingly. Roads located higher up the minor tributaries will be used and relied upon by a larger portion of evacuees, but will have the added advantage that they are located in areas of decreasing flood risk. This is gained from a continual increase in elevation and a reduction in catchment area and hence volume of local stormwater runoff which might affect the roadway.

__Figure 98__ Evacuation precincts – better practice



Objective

All roads should be designed to continuously rise to the community safe point so that each house within the subdivision has access to the regional evacuation route via continuously rising road network.

Performance Criteria

- Local evacuation roads are to be located along the top of the major and minor ridges of the site (in a reverse fit to the stream system).
- All local evacuation routes rise naturally from the lowest to the highest point on the ridge avoiding and low points.
- A large subdivision with more than one sub-catchment will be serviced by multiple of local evacuation routes rather than just one.
- Road meet recognised safety limits on depth and velocity of flow (e.g. $V*d<0.4m^2/s$).

9.2.5 Element 4 Local Streets

Rationale

It is essential that areas subject to riverine flooding are planned with a legible street network to promote safe, orderly and self-directed evacuation. A legible street network comprises two key characteristics:

- interconnected street network; and
- a clear road hierarchy.

The street network should provide sufficient interconnections that evacuees can readily find an alternate route around unexpected street blockages that may occur during a flood evacuation. Blockages could include traffic accidents, fallen trees or power lines, major drainage system overflows caused by pipe or pit blockages, or other overland flow paths.

An appropriately configured street grid will provide sufficient interconnections because all streets intersect with one another at regular intervals so that no single road needs to be relied on during evacuation.

The street network should have a clear hierarchy where:

- Each lot has access to continuously rising local streets so that people can walk to their garage and drive out;
- Each evacuation precinct has a clearly visible and sign posted route to gain access to the local evacuation route (Element 3); and
- Each neighbourhood needs to have access to a regional evacuation route that has the capacity to safely evacuate the whole area to a designated centre within a reasonable time (Element 1).

Site Assessment

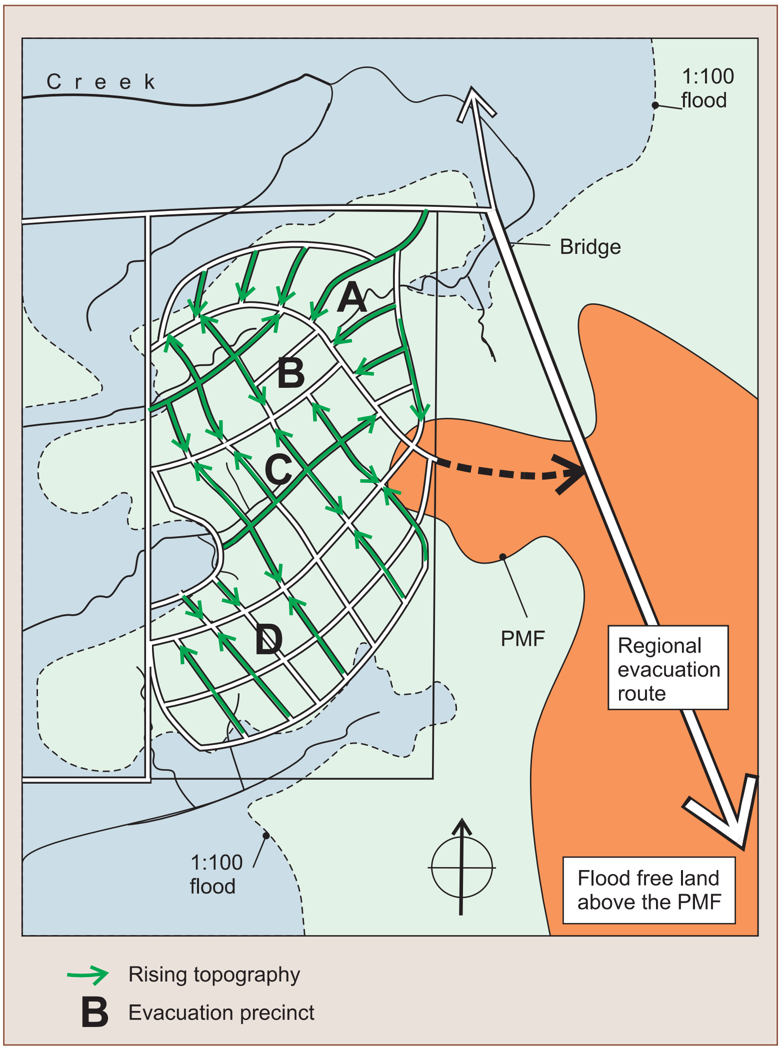
In order to determine the locations of the local streets the following physical site characteristics should be considered (Figure 99):

- major ridge and minor ridges;
- flood behaviour, including levels, depths, velocities and rates of rise;
- creeks, tributaries and drainage lines;
- detailed contours.

The site should be accessed for:

- location of roads perpendicular to or across contours;
- locations of roads parallel to contours;
- any site filling that facilitates effective staged and orderly evacuation by road.

***Figure 99** Local streets – site assessment*



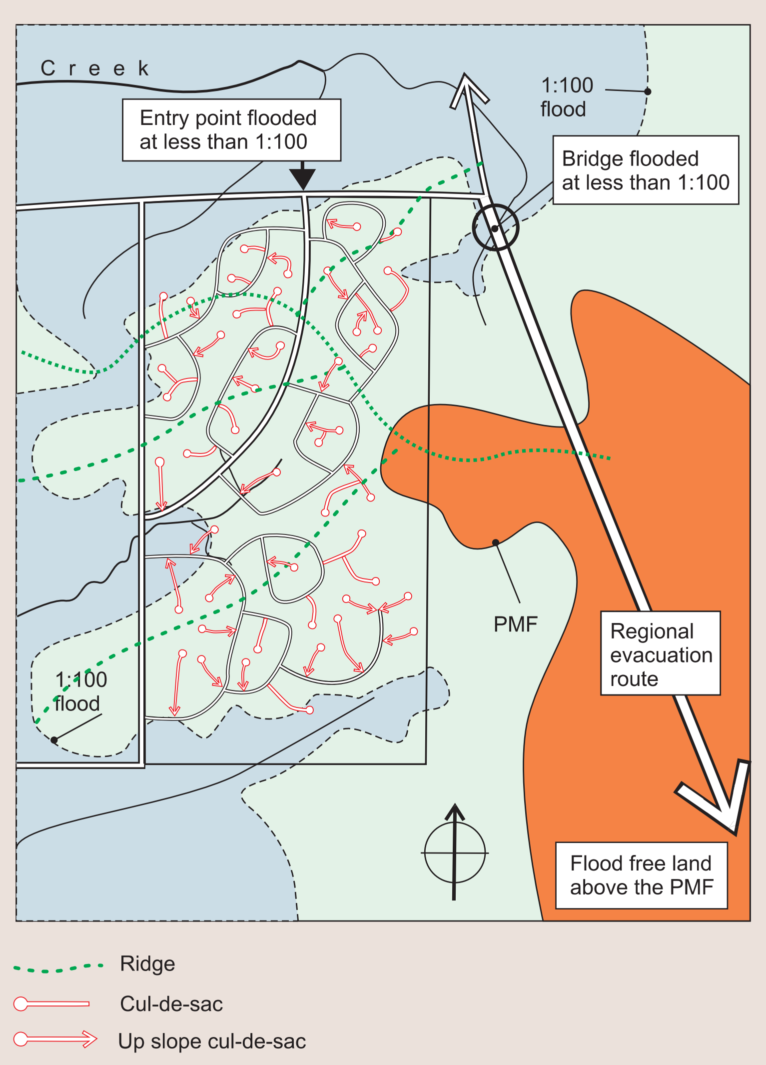
The critical issue for road design is that all roads should rise continuously from low points to high points or ridge lines. The site assessment shows the site divided into evacuation precincts. In the two central precincts (B and C) a low point runs through each precinct following the drainage line this forms a spine from which local streets may be configured to run up the slope to the ridge. In the northern and southern precincts (A and D) the 1 in 100 AEP FPL defines the edge of the subdivision. From this low point local streets may be configured to run up the slope to the ridge.

Common Practice

The local street pattern of many residential subdivisions is dominated by culs-de-sac. These roads have been seen by the market as favourable because through traffic is limited and thus making the street safer for children. However, culs-de-sac are generally unsuited to areas subject to riverine flooding because:

- Culs-de-sacs limit the general connectivity and legibility of the street network;
- Up-slope culs-de-sac (where the access point is lower than the turning circle) prevent up hill evacuation of residents by vehicle; and
- The momentum of the flows down the cul-de-sac may carry stormwater flows across the road with which it intersects, jump the gutter and footpath and cause flooding of the downstream properties. This also has implications for the safety and evacuation of these properties in the event of riverine flooding.

__Figure 100__ Local streets – common practice



The case study shows a layout with a predominance of culs-de-sac (Figure 100). Many culs-de-sac run up slope potentially trapping a significant number of residents. The street layout is confused further by long culs-de-sac where drivers may find it impossible to determine which road is a dead end and which road is a through road. The road hierarchy creates up to four intersections from cul-de-sac to collector creating increased potential for a blocked route or getting lost.

Better Practice

The preferred approach is to provide a network of local streets that run either parallel or perpendicular to/across the contours and interconnect with each other to form a grid (Figure 101). The function of local streets is to provide a secondary level of evacuation for all residents fronting these roads in each evacuation precinct and a range of evacuation options for all in the precinct.

There are two local street types that are appropriate:

- Street Type A – streets generally parallel with the contours.
- Street Type B – streets perpendicular to or oblique the contours.

Street Type A

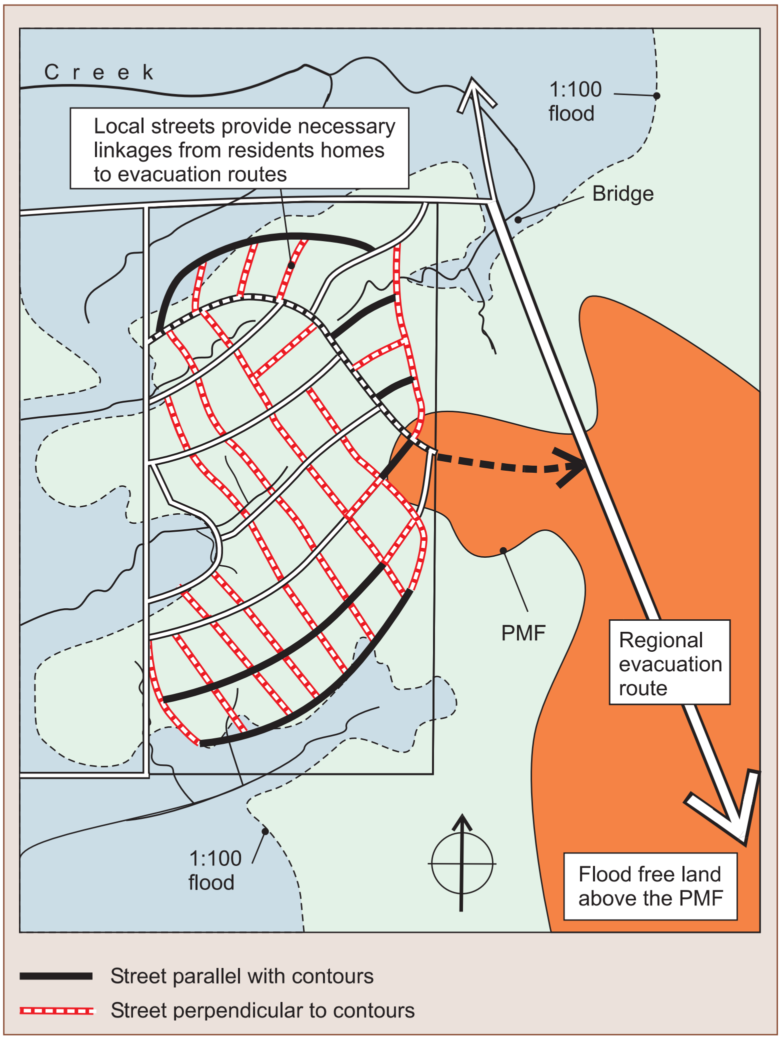
Street Type A may define the down-slope boundary and thereby the lowest area of the developable portion of the site. Typically they are located along the FPL line or across the lowest part of the sub-catchment within the site (and above the FPL). They may also be located up slope to provide cross linkages within a connected street network. This street type will have low points which may be cut off in floods. Therefore they should be designed to rise continuously from the low points to other rising local streets.

Street Type B

Street Type B will either run directly up slope from Street Type A to connect with the local evacuation routes (refer to Element 3) or it will follow the main drainage lines through an evacuation precinct. This street type runs perpendicular to the contours and will therefore have no low points. Where this type runs parallel to a drainage line it may include a drainage corridor overland flow path within its carriageway.

The case study shows a connected grid of local streets that run either parallel or perpendicular to the contours. Where the local street crosses a drainage line this point will be the low point from which the road rises continuously in both directions to intersect with local streets at high

Figure 101 *Local streets – better practice*



points to create a continuously rising road network. Local streets which follow drainage lines intersect with local streets that run up slope to the local evacuation routes.

Objective

The development layout should provide a clearly legible street layout to promote public safety during floods by facilitating safe, orderly and self directed evacuation. This can be achieved through a hierarchy of continuously rising roads to provide a connected network of local streets.

Performance Criteria

- Local streets should either be generally parallel or perpendicular to the contours.
- Local streets that run down slope from the local evacuation routes should interconnect with local streets that run across the grade to form a grid.
- Local streets parallel to the contours should have a minimum grade.
- Where a local street crosses a drainage line that point will be the low point from which the road should rise continuously in both directions.
- Culs-de-sac should be used only as a minor element in a clear and well connected street layout.
- Culs-de-sac should be used only where using continuous roads are not an alternative.
- Culs-de-sac should be short and serve no more than 10 dwellings.
- If culs-de-sac are used, down slope culs-de-sac are preferable (i.e. turning circle at the lowest point).
- Use of up-slope culs-de-sac should be avoided.
- The use of down-slope culs-de-sac should only be used if an overland flow path with adequate capacity is provided at the end of the turning circle to protect residents.
- Although ideally road networks should be self evident rather than rely on signage, appropriate, easily recognisable evacuation wayfinding and directional signposts should be normal practice in flood prone subdivisions. Signs should also indicate flood affected roads and include water depth indicators as necessary.

9.3 CASE STUDY B

THE IMPACT OF FILL ON DIFFERENT PARTS OF THE CATCHMENT

9.3.1 Introduction

This case study examines the impacts of fill on different parts of the catchment.

The acceptability of flood impacts is determined by the magnitude of the increases to flood levels (i.e. "afflux") over a range of floods and the extent to which these impacts occur either upstream and/or downstream. As the upstream impacts tend to be more substantial, this case study focuses on such impacts.

To illustrate the nature of the upstream impacts a 4.6 km length of a creek which drains a small steep 7 km^2 catchment was examined (Figure 102). The lower reach of the creek has a flat slope of 0.02% whereas the upper reach has a slope of 2.8%.

In determining the extent of encroachment of filling on the floodplain, the basic aim of the assessment was to not increase flood levels in a 1 in 100 AEP event by more than 0.1 metre. However, under the impact of a more severe flood event, the limited waterway and storage areas imposed by the same extent of filling results in greater relative increases in flood levels and velocities.

In this case study, a flood event two times a 1 in 100 AEP event (in this case, about half PMF size) was used as the basis for assessing severe flood conditions. The peak flows used to investigate the relative impacts were:

- for the 1 in 100 AEP flood - 190 m^3/s; and
- for the two times the 1 in 100 AEP (i.e. 2xQ100) flow - 380 m^3/s

where Q denotes discharge or flow.

The assessment was undertaken with a steady flow hydraulic model (i.e. HEC-RAS) based on fill encroachment on the floodplain for the 4.6 km length of channel. Channel, floodplain and fill surface roughness values chosen have a bearing on the magnitude of relative impacts. Typical roughness values were used for this assessment (i.e. Manning's "n" is 0.05 in the channel and 0.1 in the floodplain).

9.3.2 Results

The hydraulic modelling undertaken determined cross section encroachments in the lower and upper reaches based on filling which yields a 0.1 metre afflux under 1 in 100 AEP flow conditions.

Figure 102 *Upper and lower cross sections showing filling on floodplain*

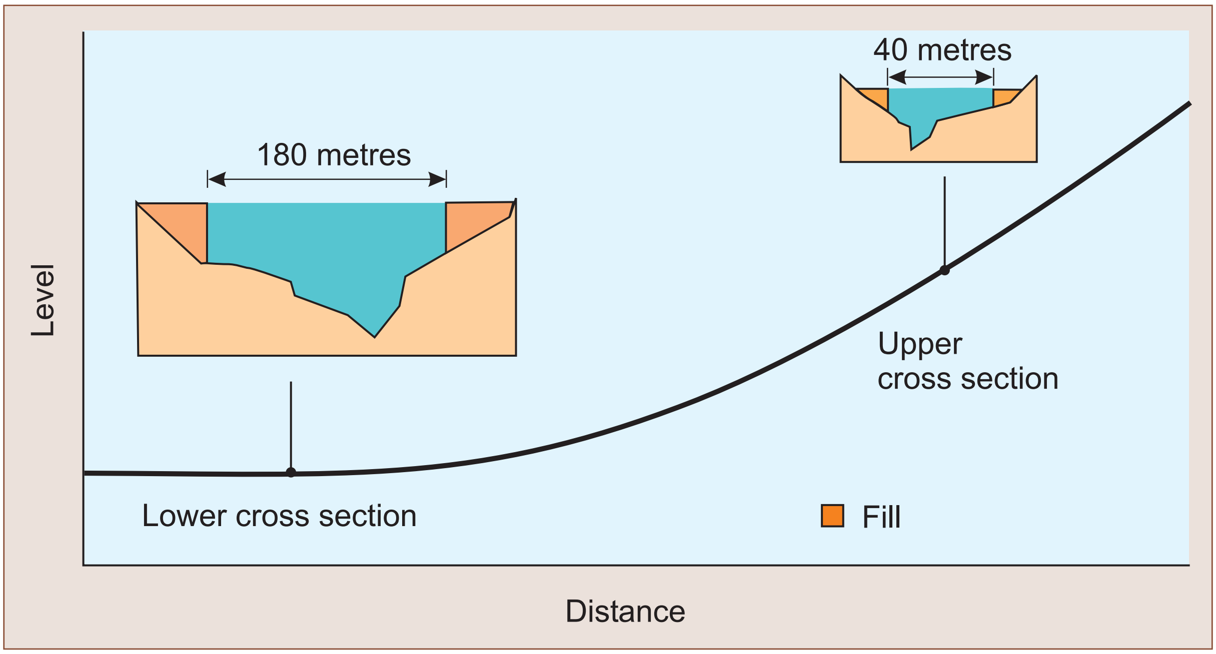


Table 12 *Impact of Filling on Flood Levels and Extent*

Cross Section	Bed Slope %	Natural Flow Width (m)		Q100 Flow Area after filling (m^2)	Q100 Afflux (m)	2xQ100 Afflux (m)
		Q100	2xQ100			
Upper Reach	2.8	48	59 (11m increase)	276 (18% less than existing)	0.10	0.16 (60% increase)
Lower Reach	0.02	215	244 (29m increase)	61 (17% less than existing)	0.10	0.12 (20% increase)

Impacts on flood levels

To test the impact under more severe flood conditions the filling was assumed to extend vertically to the level of extreme flooding. Under two times the 1 in 100 AEP (i.e. 2xQ100) flood conditions, the increases to flood levels and flood extent were determined.

As evident from the results shown in Table 12, significantly greater impacts are experienced in the upper reach. This is because the confined terrain and steeper slope result in higher stream and floodplain velocities.

If the 0.1 metre afflux was to be retained at this lower section under 2xQ100 flow conditions, the top width of the waterway at the lower reach cross section would have to increase from 100 metres to 180 metres.

Whilst any filling of the floodplain will potentially increase flood levels over a full range of floods, the actual afflux under real development conditions would normally be less than shown in the table, as filling to create developable land, would largely be to a flood planning level which is generally well below the PMF level. This lower level of filling below the PMF level would provide some additional conveyance and storage in the floodplain above what would be available for full height filling.

Potential Impacts

While the percentage of filling is similar, a greater volume of fill is possible at the downstream site and will still satisfy the same simple afflux criteria. However, it is very important to consider what the full consequences are across the floodplain and along the channel (i.e. both upstream and downstream). To illustrate such real consequences, it is useful to consider changes in flow widths under natural conditions, bearing in mind that greater widths of flooding would occur for floods that rise above the level of fill. The narrower more confined channel at the upstream location ensures that the absolute increase in the width of flooding is only about 11 metres for a larger flood event. At the downstream site this results in increases in flooding over a 29 metres wider area. This has the potential to affect a greater number of surrounding properties.

Longitudinal Impact

In assessing the impact of filling on flood behaviour it is important to not only consider the maximum magnitude of the afflux but also how far upstream the afflux extends.

To illustrate the nature of this impact for different reaches, the upstream distances from the relevant cross section to where the afflux reduces to zero

Table 13 Relationship between slope and afflux length

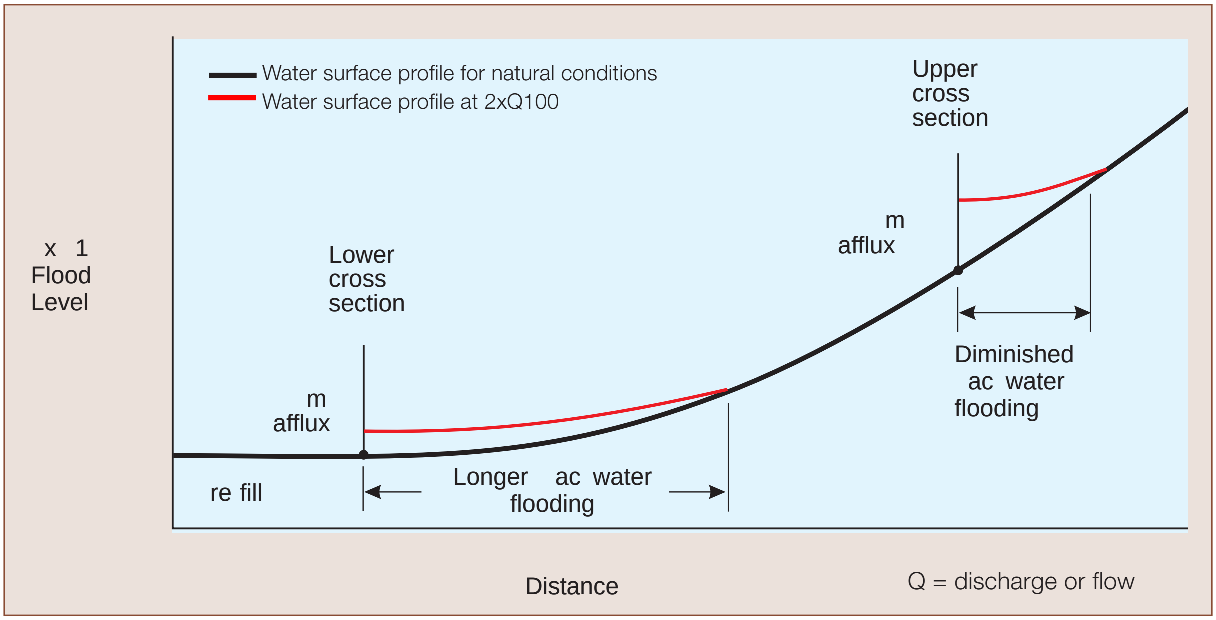
Cross Section	Bed Slope %	Q100 Afflux (m)	2xQ100 Afflux (m)	2xQ100 Afflux Length(m)
Upper Reach	2.8	0.1	0.34	324
Lower Reach	0.02	0.1	0.19	970

has been calculated for the 2xQ100 flow event. These calculations were based on comparing the water surface profile for natural conditions against those for local filling of the floodplain at the relevant cross section to limit the local afflux to 0.1 metres under Q100 flow conditions (Table 13).

As evident from Table 13, although the afflux at the lower section is about half that at the upstream section, the length of section affected in the lower reach is almost three times longer than that in the upper reach. This is largely due to the much flatter longitudinal slope of the channel / floodplain in the lower reach.

Potentially more properties are affected in the lower reach, due to the much longer length of creek-side development that would be affected. This can be seen in the long section in Figure 103.

Figure 103 Longitudinal extent of Hydraulic Impact



9.4 CASE STUDY C

ON-LINE AND OFF-LINE BASIN SYSTEM

9.4.1 Introduction

This case study involved evaluation of off-line and on-line detention basins storage requirements needed to achieve a hypothetical 40% reduction in peak 1 in 100 AEP urbanised flow from a 550 ha catchment. The case study is based on the following:

- 1 in 100 AEP peak urbanised inflow of 160 m^3/s.
- 1 in 100 AEP peak attenuated outflow of around 95 m^3/s.
- 1 in 1 AEP stream bank full capacity of $20m^3/s$.
- No local runoff into basin.
- Basin dry prior to storm event.
- Stream bed slope of 0.5%.
- 20 metres long side weir with crest at bank full level.
- 3.3 ha basin up to 3 metres deep.
- Basin inundation that does not drown the side weir (i.e. weir is discharging freely).
- Basin outlet relationship which may mimic free or tailwater control.

Indicative flood analysis was undertaken using desk top calculations for weir flow and uniform stream/floodplain conveyance. Basin flood routing was carried out using the level pool flood routing facility of RORB. The same stage - storage and stage – discharge relationships were assumed for both the on-line and off-line basins. The description of flow distribution for the two basin types is shown in Figure 104.

9.4.2 Results

The resultant inflow, bypass and outflow hydrographs are shown in Figure 105.

It should be noted that the outflow hydrographs in Figure 105 are for the total stream flow downstream of the basins. In the case of the off-line basin, the outflow is the sum of basin outflow plus non diverted stream flow (i.e. flow that bypasses the weir).

Similar peak system outflows were achieved with the storage values shown in Table 14.

Table 14 *Basin Storage volume and land take needs*

Basin Type	Volume (m^3)	m^3/ha
On-line	96,600	175
Off-line	69,500	126

Figure 104 *Flow distribution through on-line and off-line basins*

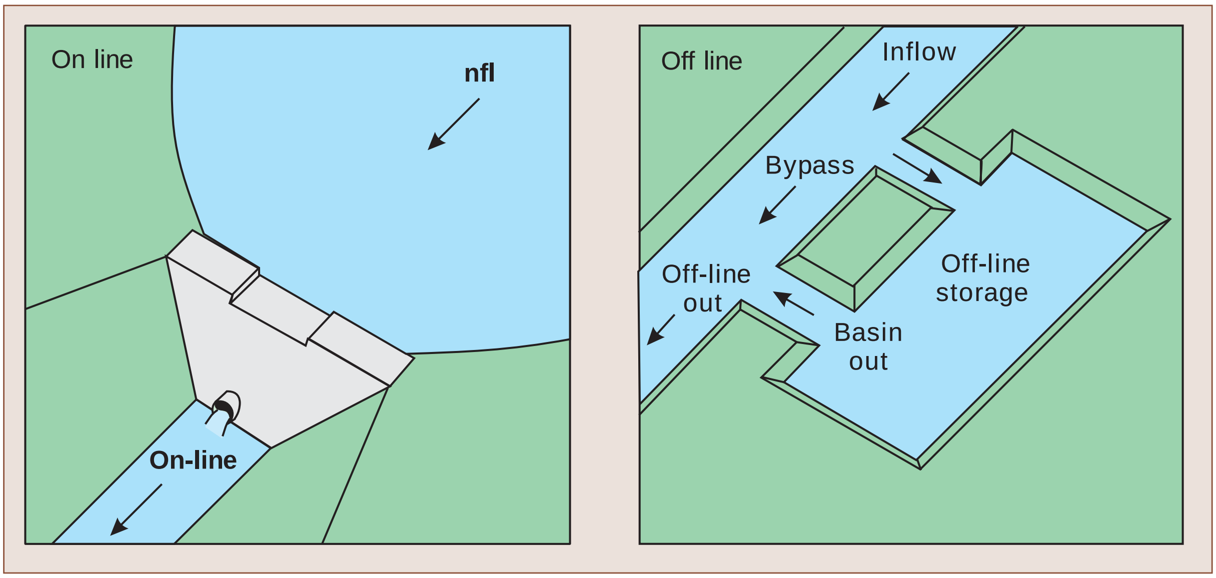
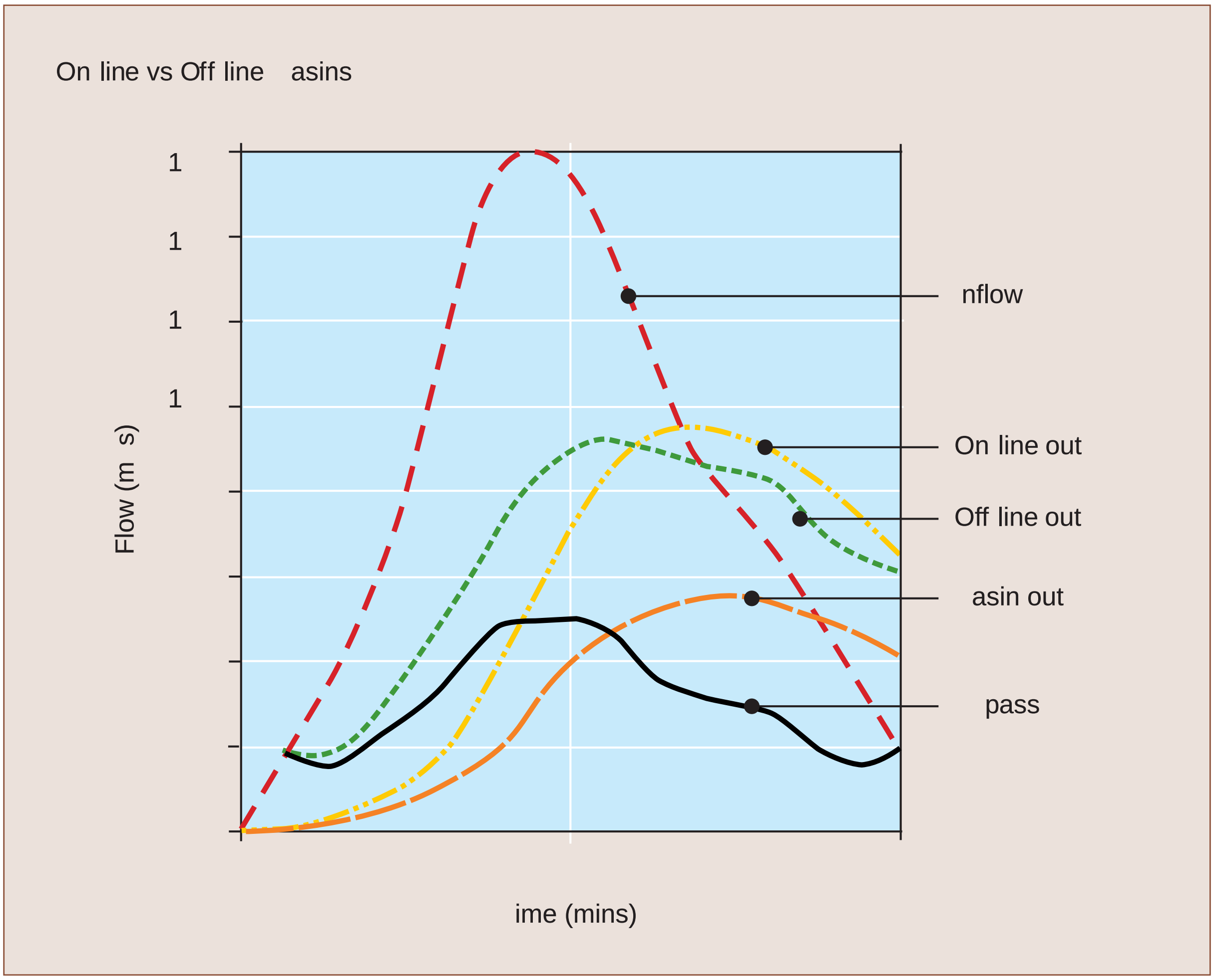


Figure 105 *On-line and Off-line Basin Hydrographs*



In this case study, the storage requirement for the off-line basin was 70% of that needed for the on-line basin. The hydrographs help to demonstrate that the lower storage needs of the off-line basin system are obtained from the different timings of the peak flow bypass and peak off-line basin outflow.

Nevertheless, in practice there may be significant difficulties in achieving the potential smaller land take for an off-line basin system. Factors, which may result in an off-line basin system requiring less land than an equivalent on-line basin system, include:

- Flatter stream slope or high tailwater levels resulting in a drowned outlet for the off-line basin; and
- Straight alignment of the main watercourse which may limit inflow and outflow control.

Potential basin sites need to be assessed on their merit to determine which basin type is appropriate from a land take perspective.

Advantages and Disadvantages of On-line versus Off-line Basins

The main advantages and disadvantages of on-line and off-line basins are set out in Table 15.

Table 15 Advantages and Disadvantages of On-line versus Off-line Basins

Type	Advantage	Disadvantage
On-line	• Required flow detention is more simply obtained. • Length/width ratio within desired range of 3 to 10 more easily obtained. • Short circuiting more readily avoided.	• Interrupts sediment transport and geomorphic processes. • Susceptible to damage from high flows. • Interrupts wildlife corridor and the movement of aquatic fauna along the watercourse. • Treats whole catchment, even when part of it may be pristine and not require treatment.
Off-line	• Can be used to treat flows from an adjacent urban sub-catchment before mixing with 'cleaner' flows in the main stream. • Better at treating first flush. • Does not disrupt the natural creek processes.	Required flow detention can be more hydraulically complex to achieve. • In some instances the required detention effect may not be obtainable because of the difficulty in creating an effective flow diversion to the basin. • More careful design is required to avoid stagnant zones and short circuiting.

9.5 CASE STUDY D

ENDANGERING RESIDENTS BY NOT UNDERSTANDING THE DIRECTION OF FLOW IN BIGGER FLOODS

9.5.1 Introduction

Flood behaviour can vary dramatically over a range of flood events. Channels and floodplains which are non-uniform in shape, slope and alignment demonstrate this variation. Failure to recognise this potential and allow for it in the road and lot layout and final surface contours of a subdivision design can increase hazards for residents when larger floods occur.

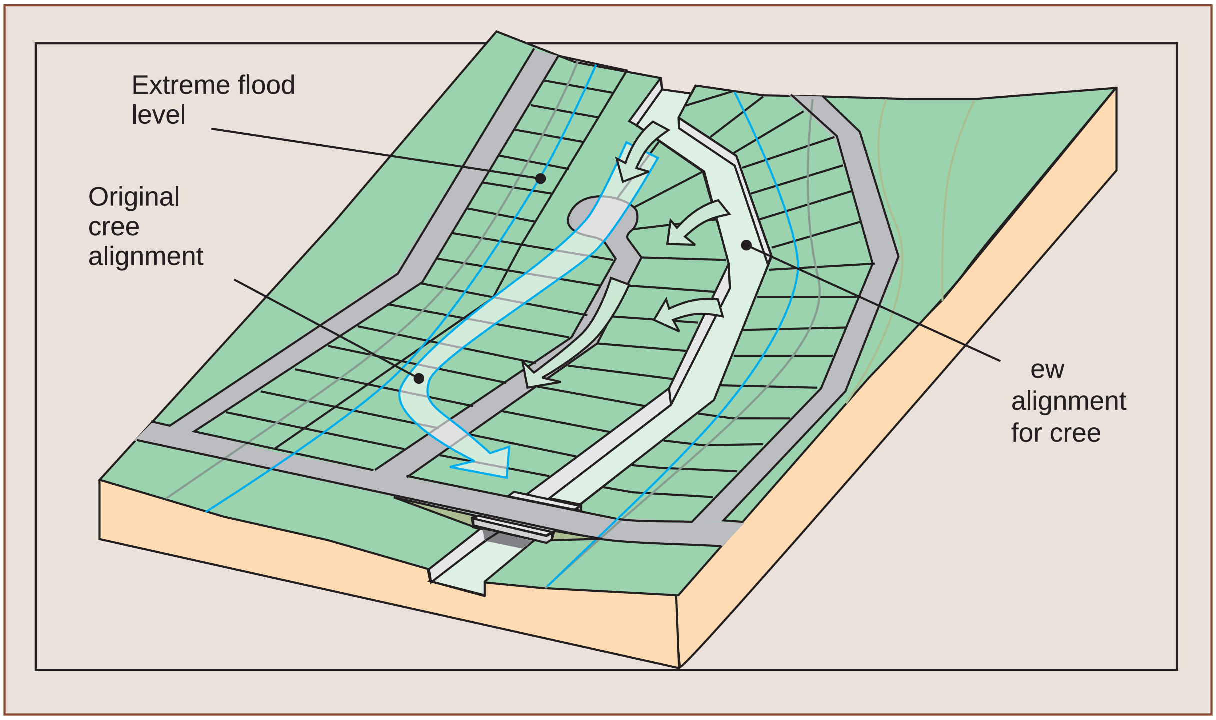
This case study looks at a subdivision on a site with a creek running through it. The original watercourse has been replaced by a larger sized channel on a new alignment with a bend located upstream of the subdivision. The area has generally been filled to form suitable building lots (Figure 106).

As the development is located in the middle of a small catchment where large floods can result from storms of short duration, there is insufficient time for residents to be given warning of the serious flooding which is about to occur.

9.5.2 What can go wrong

- The capacity of the channel will be exceeded very quickly in a larger flood event.
- A greater proportion of the flow occurs in the floodplain (which is now developed) than in the channel itself.
- Irrespective of the bend in the new channel, the bulk of floodwaters will take a more direct path along the access road and through the development.
- The road floods before residents become aware that there is a threat of more hazardous flooding.
- All residents are dependent on this road as the only means of evacuation.
- Occupants are not safe in floodway conditions. Floodwaters rise from floor to ceiling in less that 30 minutes. With deep flooding of buildings, occupants of single storey dwellings are forced to flee. However, the road acts as a relatively efficient secondary flow path conveying floodwaters at high velocities. Even if at shallow depths, it becomes a dangerous barrier to people trying to evacuate from their homes.

Figure 106a *Relocation of natural flow paths creating floodway conditions through the subdivision*



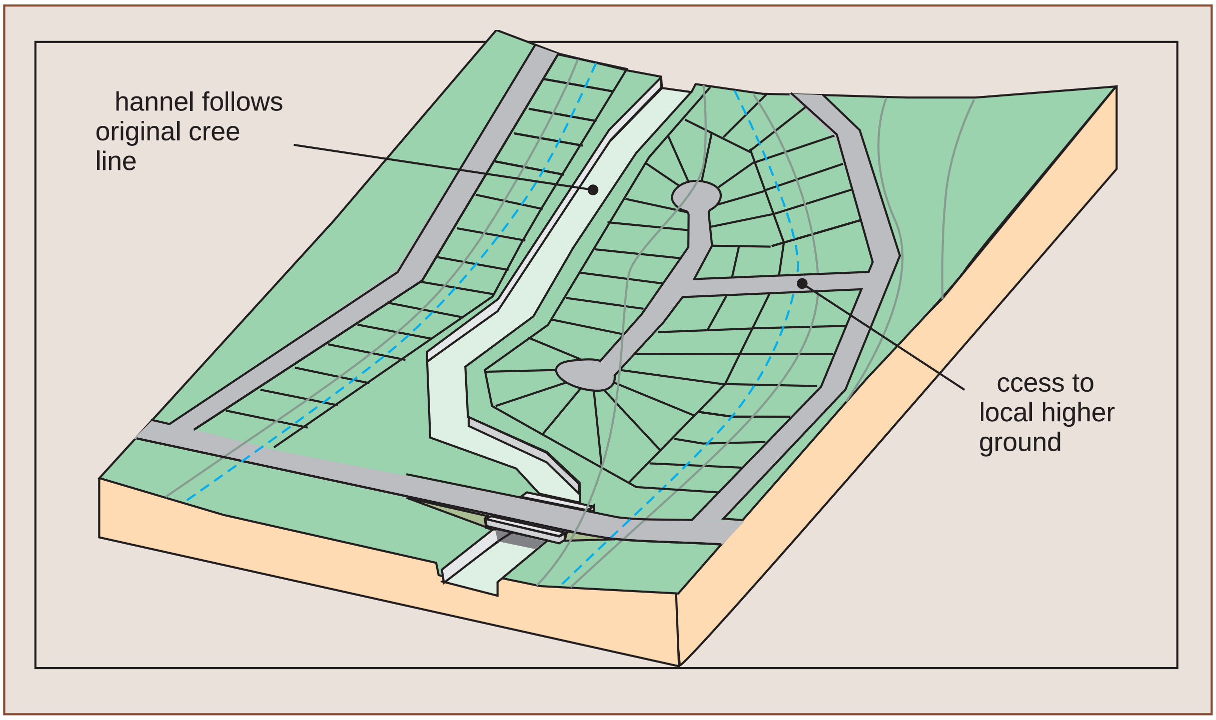
9.5.3 Design Issues

- The degree of flood hazard at the site is extremely high as is evident from the potential for deep and fast moving floodwaters, rapid rates of rise, no effective warning time, evacuation problems, low community awareness of flooding and no possibility of external assistance from the onset of the emergency. While this warrants a failsafe design to protect residents, the location of a sharp bend, re-alignment of the creek and layout of the access road has been instrumental in increasing the dangers from flooding. The design has:
  - > Increased the potential for a sudden change in flow direction at the bend as floodwaters swell out the channel;
  - > Presented greater difficulties for any hydraulic analysis to reflect realistic behaviour at a sharp bend because of complex flow conditions and modelling limitations;
  - > Relied on the channel to confine design flows to a narrow corridor with no room for safe overbank flows;
  - > Significantly altered the flow path for smaller flood events, but was unable to prevent floodwater reverting back to its natural path in a major flood;
  - > Allowed instant flooding of the whole development;
  - > Facilitated floodway conditions to occur;
  - > Did not enable roads to be used for safe evacuation.

9.5.4 What can be done to reduce the flood risk

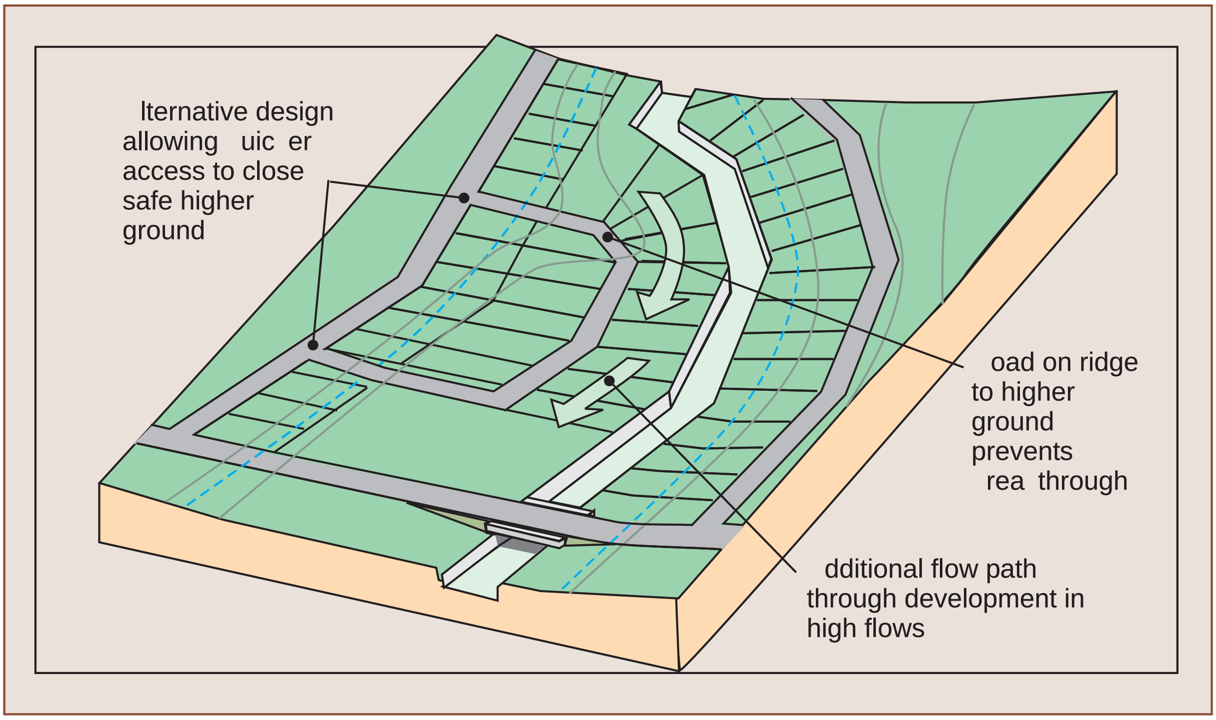
- Avoidance of creating an artificial channel which has a sharp bend upstream of a development which
  - > can direct flows towards houses placing occupants in harms way in larger floods, and
  - > induces a false sense of security and reduces levels of flood awareness.
- Leaving the channel in its natural path would have been safer.
- Provision of a safer path for the initial channel overflows.

***Figure 106b** Safer alternative layout maintaining original channel alignment*



- Avoidance of placing development in low areas which are likely to flood suddenly. Making use of higher elevations to deflect flows and give some warning and time to evacuate. (Note: sufficiently high deflector barriers may be useful in disrupting high energy flow by pushing flood waters away from vulnerable areas and reducing velocities behind barriers. However, if they are not part of a ring levee system, they cannot control the height flood waters will reach nor slow down their rate of rise).
- Ensuring that higher ground forms ridges which rise steadily to areas with no flood hazard.
- Avoidance of flat land forms. A graded site which allows more progressive flooding is much safer.
- If the site can be overwhelmed rapidly in an extreme event, then ensuring reliable evacuation routes are strategically placed in the road network would enable convenient and quick escape. Escape routes should:
  > not be aligned with flow paths;
  > rise continually; and
  > be at minimum length to permit a more direct path to higher safe ground.
- Consideration of the use of flood aware design two storey houses to overcome the need to possibly evacuate and to also reduce flood damages.
- Ensuring that the spacing and alignment of buildings does not result in excessive velocities between houses. Such velocities could increase the need for early evacuation and make structural damage more likely.

***Figure 106c** Modified layout to deflect flows and give warning of flooding*



9.6 CASE STUDY E

SITE MODIFICATIONS WHICH DISADVANTAGE RESIDENTS AND HANDICAP THEIR ABILITY TO REACH SAFETY

9.6.1 Introduction

Many subdivision designs increase danger because of the lack of appreciation of the importance of ensuring the site floods in a steady and predictable manner. A sudden, unexpected emergency and lack of time to respond effectively are severe disadvantages for the community and a major constraint to a successful emergency response. Priority should be given to maximising the time available for residents to recognise and react appropriately to the danger.

Development sites are commonly levelled to a generally flat grade to ease dwelling construction and maximise lot yields. However, this practice can significantly impede safe and orderly evacuation when all of the community is forced to leave the site within very short timeframes because widespread flooding is made to occur all at once.

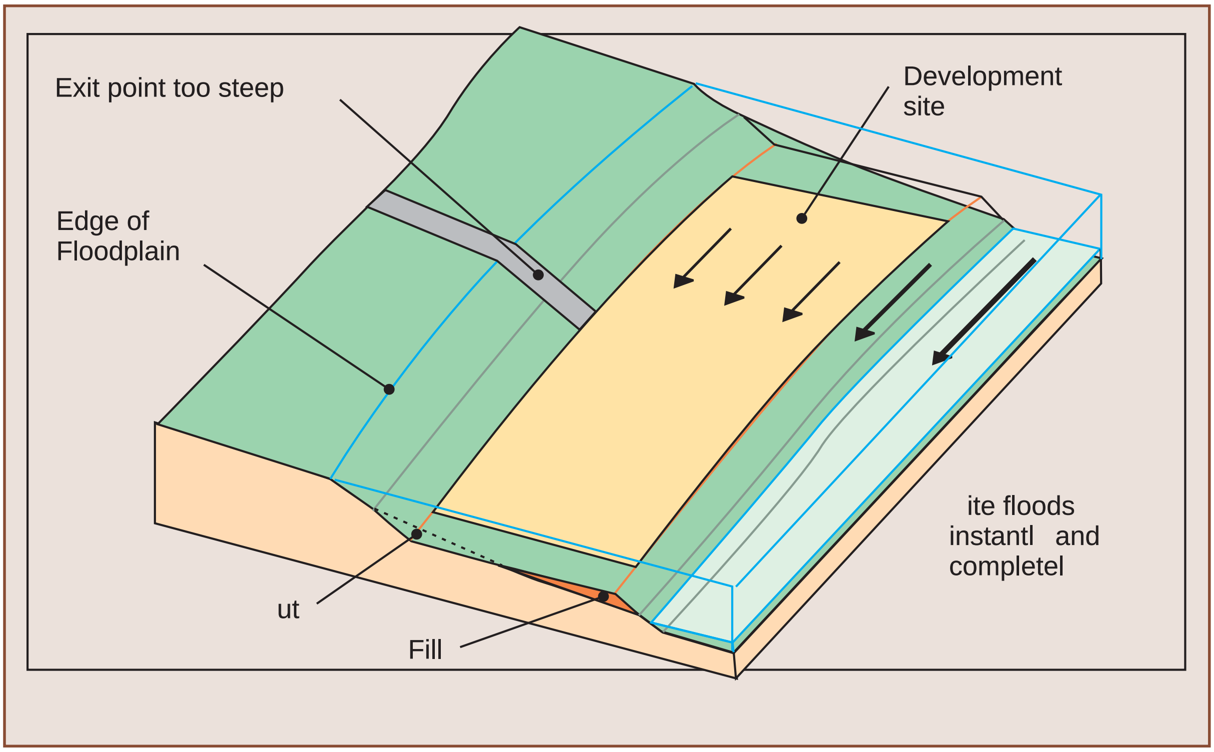
9.6.2 What can go wrong

- When the site floods it will spread quickly over the entire site creating hazardous conditions throughout.
- The instantaneous flooding provides little time for residents to act calmly and therefore increases the chance they will not evacuate safely. This problem can be more acute in catchments with short flood response times (i.e. when there is no advance warning because of short duration flooding and high rates of rise).
- Local roads are flooded before residents can use them for evacuation access.
- The lack of high ground nearby prevents a gradual retreat out of the floodplain.
- The prospect of an efficient evacuation becomes impossible when traffic at the few exit points become congested and chaotic as too many people try to move off the flooded site at the same time.

9.6.3 Design Issues

- The design is flawed because it compresses the onset of flooding of the whole site to a single moment in time.

Figure 107a *Site levelling resulting in sudden inundation and jeopardising safe and efficient evacuation*



- Maximising lot yield using bulk earth works to achieve the required minimum flood level has taken priority over managing the risks of occupying the floodprone site.
- It is not safe for occupants to remain in their houses (particularly single storey houses) but they have no reliable means of escape from rising flood water.
- There is increased dependence on “official” early warning messages and a reliance on regular community education programs to raise flood awareness and preparedness.
- A heavy reliance is placed on the emergency services being present beforehand to conduct and control evacuations.
- The more complicated and demanding the requirements of emergency management, the higher the risk of failure and loss of lives.

9.6.4 What can be done to reduce the flood risk

- Avoidance of flat landforms to increase the time it takes a site to flood.
- Ensuring any high ground cannot be isolated and forms a ridge steadily rising to areas with no flood hazard.
- The site should grade upwards from the watercourse to the edge of the floodplain.
- A graded site
  - > allows more progressive evacuation during flooding;
  - > has the advantage that the flood hazard (velocity x depth) varies incrementally – being higher at the channel and decreasing towards the perimeter of flooding;
  - > can control the extent of the site flooded – in that it depends on the magnitude of flooding (i.e. the larger the storm the greater the area flooded);
  - > maximise areas with low flood hazard characterised by shallow depths and low velocities.
- If the site has the potential to be completely flooded in an extreme event, then reliable evacuation routes should:
  - > have multiple exit points;
  - > not be aligned with flow paths;
  - > rise continuously;
  - > be of minimum length to permit a more direct path to higher ground and minimise travel time.

Figure 107b *A graded site allows progressive flooding and evacuation*

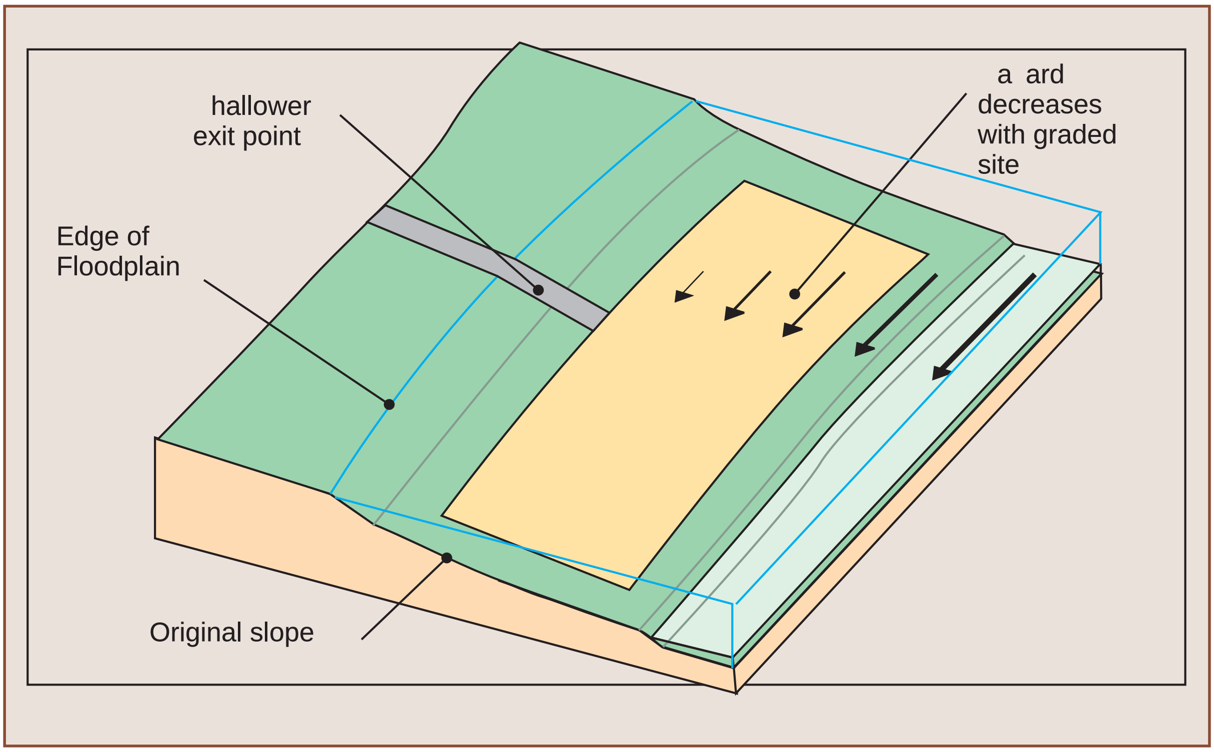
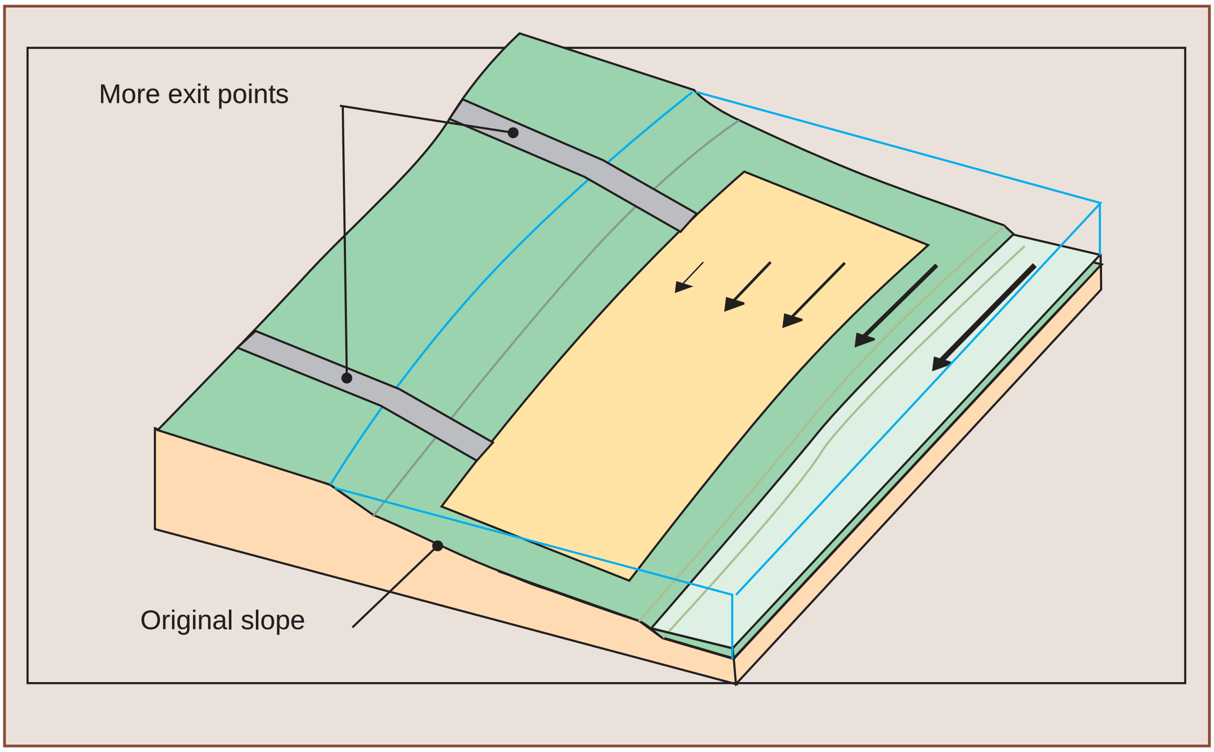


Figure 107c *Multiple exit points increase evacuation capacity and reliability*



- Vegetated buffer zones and building set backs should be considered as alternative and complementary land uses in the relatively high hazard zone (where the flows are deeper and faster) adjacent to the watercourse thus avoid exposing dwellings to the higher hazards.
- Elevated houses should be considered to provide upper floors above the level of potential flooding provided flow velocities are relatively low.

9.7 CASE STUDY F

REDEVELOPMENT OF LAND RESULTING IN OCCUPANTS AT GREATER RISK BECAUSE OF INCREASED SEVERITY OF FLOODING.

9.7.1 Introduction

The redevelopment of already developed large lots ('brownfield' sites) to medium or high density residential development, often involves greater site coverage to accommodate the additional dwellings. This is commonly achieved by increasing the efficiency of the watercourse through chanelisation and raising any remaining areas of low ground using landfill.

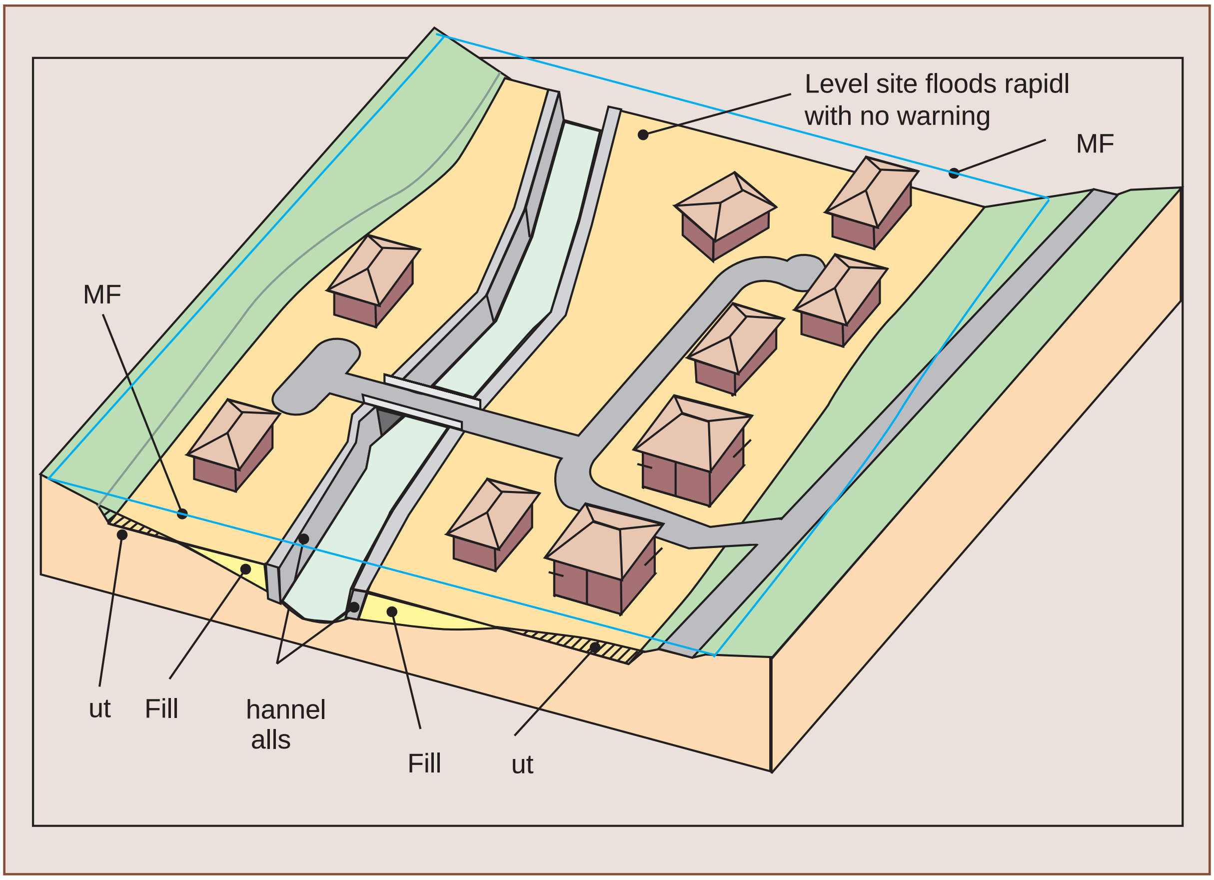
Done poorly, this practice can lead to a major reduction in floodplain capacity resulting in both an increase in flow depths and velocities. Thus more hazardous conditions can be present after the site is redeveloped. A very high level of care is required to prevent the design and layout of the development resulting in an increased level of danger to residents.

In this case study, a medium density development has been constructed on a large block where previously there was only a single house (Figure 108a). A small creek with gently sloping banks meandered through the site. As part of the redevelopment, the creek was replaced with a wider and straightened channel to improve capacity up to a nominated 1 in 100 AEP design event. Townhouses were erected throughout the entire site on both sides of the channel and linked by a small bridge. Landfill was used to enable all the dwellings to be built with habitable rooms at or above the minimum floor level requirements.

9.7.2 What can go wrong

- The narrow width of the original watercourse is indicative of a small catchment or an upper tributary area. Flash flooding is a characteristic

Figure 108a *Encroachment on the floodplain giving rise to more hazardous conditions*



of such catchments whereby runoff concentrates very quickly after rainfall from an intense storm. The hydrographs of such floods have a sharp and distinct peak.

- Whilst the channel modifications are very efficient up to the design event, they have no effect on larger floods and they do not reduce the size of, or the need for, the floodplain.
- What is commonly overlooked is that flows from less frequent storms can be many times greater than the design event. Coupled with the small catchment area and rapid commencement of runoff, there is little opportunity for longer travel times or floodplain storage effects to spread the floodwaters and flatten the peaks of the hydrographs.
- Steep slopes are likely to compound this problem further.
- Consequently, larger proportions of the floodplain become active in carrying swollen floodwaters and at this site flooding will occur in the following manner:
  - > Spill from the overflowing channel spreads quickly over the fully developed site.
  - > Residents have no way of knowing that the flood is rapidly escalating into a very serious and potentially life threatening event.
  - > The efficient passage of higher flows across the floodplain is now no longer possible. House and fences block floodwaters and divert and concentrate flows towards any gaps between these structures.
  - > Driven by the high build up of water behind these obstructions, flows through the narrow gaps are extremely fast and highly turbulent.
  - > Unpredictable and terrifying conditions discourage residents who want to move to higher parts of site.
  - > When their houses are flooded, residents at the end of the cul-de-sac and across the bridge are forced to traverse even more dangerous parts of the site in order to evacuate to a safe flood free area.
  - > The higher flow resistance caused by the development increases the severity of flooding by raising water levels and widening the lateral extent which floodwaters will reach. More adjoining properties are now subject to flood risk.
  - > The higher velocities result in greater structural damage to the walls and foundations of buildings as well as increased erosion throughout the site and along the channel.

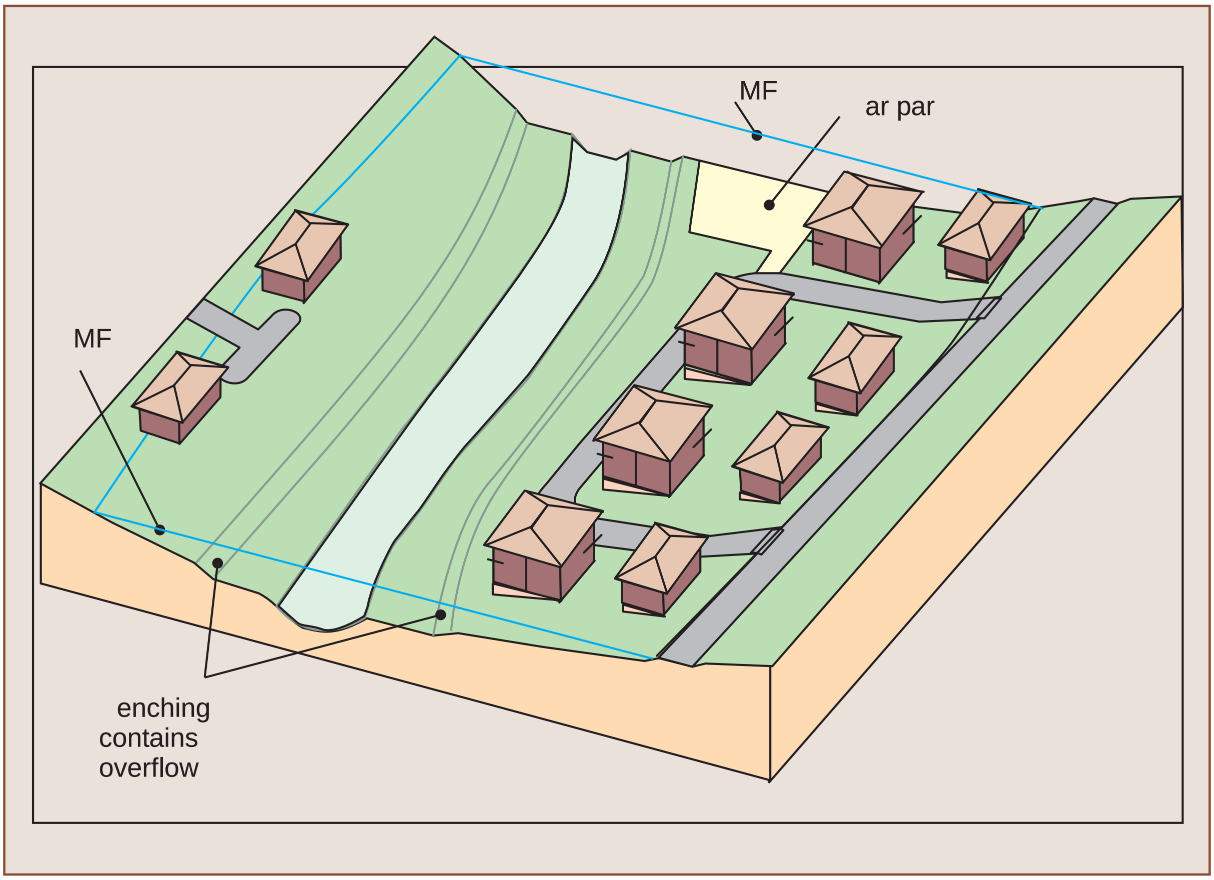
9.7.3 Design Issues

- There has been no appreciation of the scale of the difference between the design flood event and more extreme floods and the flood hazard implications of larger floods.
- The impact of the structures on local flood behaviour and the site's high sensitivity to blockage was not adequately recognised and therefore there was no provision in the positioning of the dwellings and roadways to accommodate proportionally higher flows.
- Designers overlooked the fact that this area is subject to flash flooding conditions. This results in the emergency services having no possibility of receiving early warnings, no capacity to alert residents or respond if they are in imminent danger. Residents would have to largely rely on in-built, physical measures at the site to assist them in a flood emergency.
- There is an absence of refuges or evacuation routes to protect residents in the event of a larger flood occurring.

9.7.4 What can be done to reduce the flood risk

- Investigation of the full nature of flooding at the site can identify those portions of the site which are not at risk from flooding which could be used by residents as a safe haven. This will also enable a more optimal adjustment of the floodplain to minimise constrictions.
- The layout of streets and dwellings on the site should aim to minimise encroachment on the floodplain and provide controlled or streamlined flow paths through the site.
- Placing dwellings as high as possible on the site and concentrating any land filling around the higher edges of the floodplain reduces risk.
- Enlarging the capacity of the channel reduces the possibility of overflows.
- Lowering and enhancing the capacity of the floodplain adjacent to the channel compensates for the loss of cross sectional flow area.
- Retention of a riparian buffer or ‘green belt’ along the creek can maintain some natural values and incorporate open areas such as car parking or landscaped areas where high velocity flows can be conveyed safely in larger floods.
- Realignment and regrading of the internal roads can provide an overland flood path in some sections while the remaining sections rise out of the site to facilitate better evacuation access.

Figure 108b *Safer alternative layout with better emergency egress and reduced risk of damage to dwellings*



9.8 CASE STUDY G

SITING RESIDENTIAL DEVELOPMENT IN UNSAFE AREAS DOWNSTREAM OF DETENTION BASINS

9.8.1 Introduction

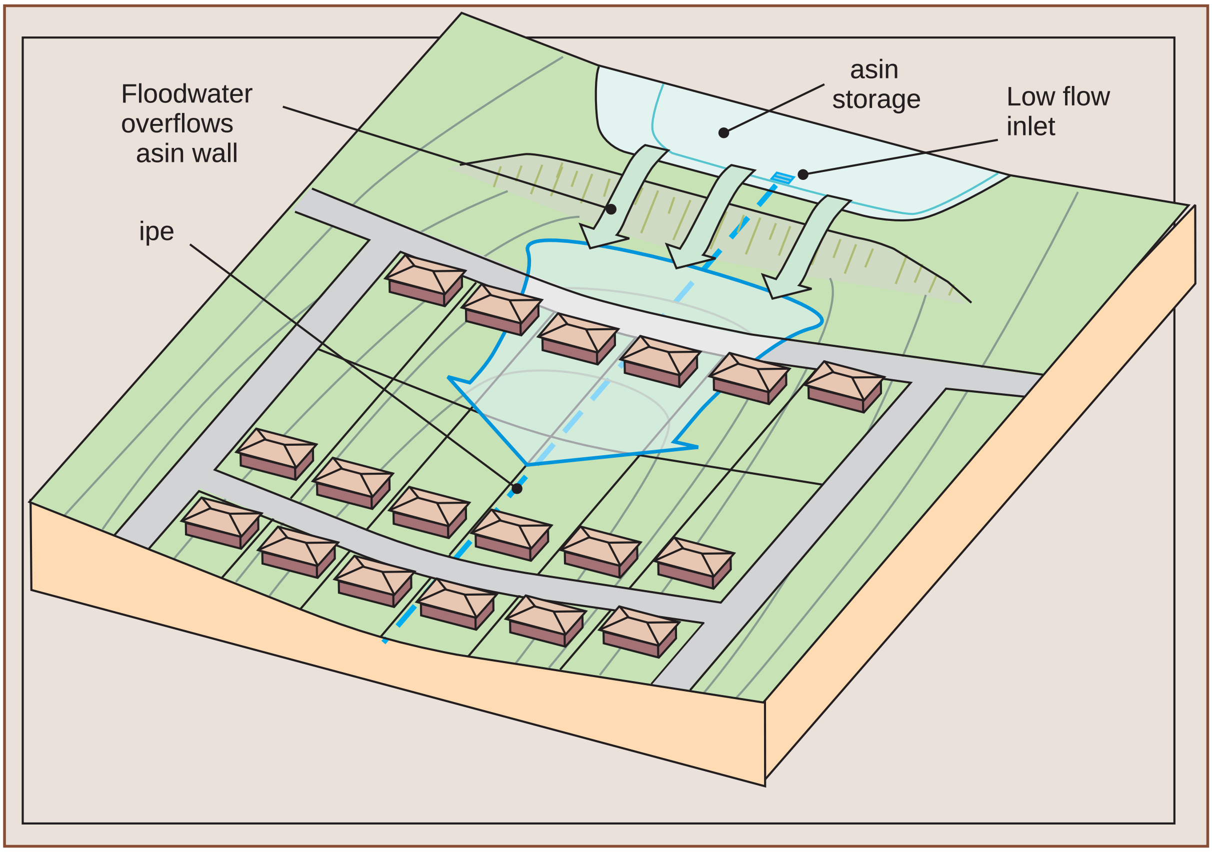
By restricting outflows, detention basins temporarily store floodwaters and thus can be highly effective in protecting downstream development, but only to the limit of their design capacity. When higher inflows overwhelm a basin's capacity to hold back floodwaters, flows downstream of the structure no longer follow a natural and gradual regime. Instead, in more rare and extreme flood events there is a sudden transition from low flows, which are well below what was previously normal for the watercourse, to very high flows (Figure 109a).

This creates a highly dangerous environment when basins are used inappropriately as a means to increase development potential immediately downstream, or are closely placed upstream of houses. As the capacity of these basins is typically only a fraction of that necessary to cope with larger flood events, the consequences and risks associated with floods which can no longer be safely contained by the structure resemble that from dam failure when large volumes of water are released suddenly.

Typically this basin is sited in the upper part of a small tributary sub-catchment to delay and reduce the peaks of concentrated flows from short duration storms. The basin has substantially reduced outflows which are conveyed principally via an underground pipe drainage system.

Residents downstream of this basin system do not witness any minor flooding from the occasional non-extreme storms. The lack of any obvious watercourse or apparent flooding has encouraged the construction of houses immediately downstream of the basin embankment. A combination of piping and land filling results in floor levels being above the FPL.

Figure 109a *Basin with no provision of safe overflows when capacity exceeded*



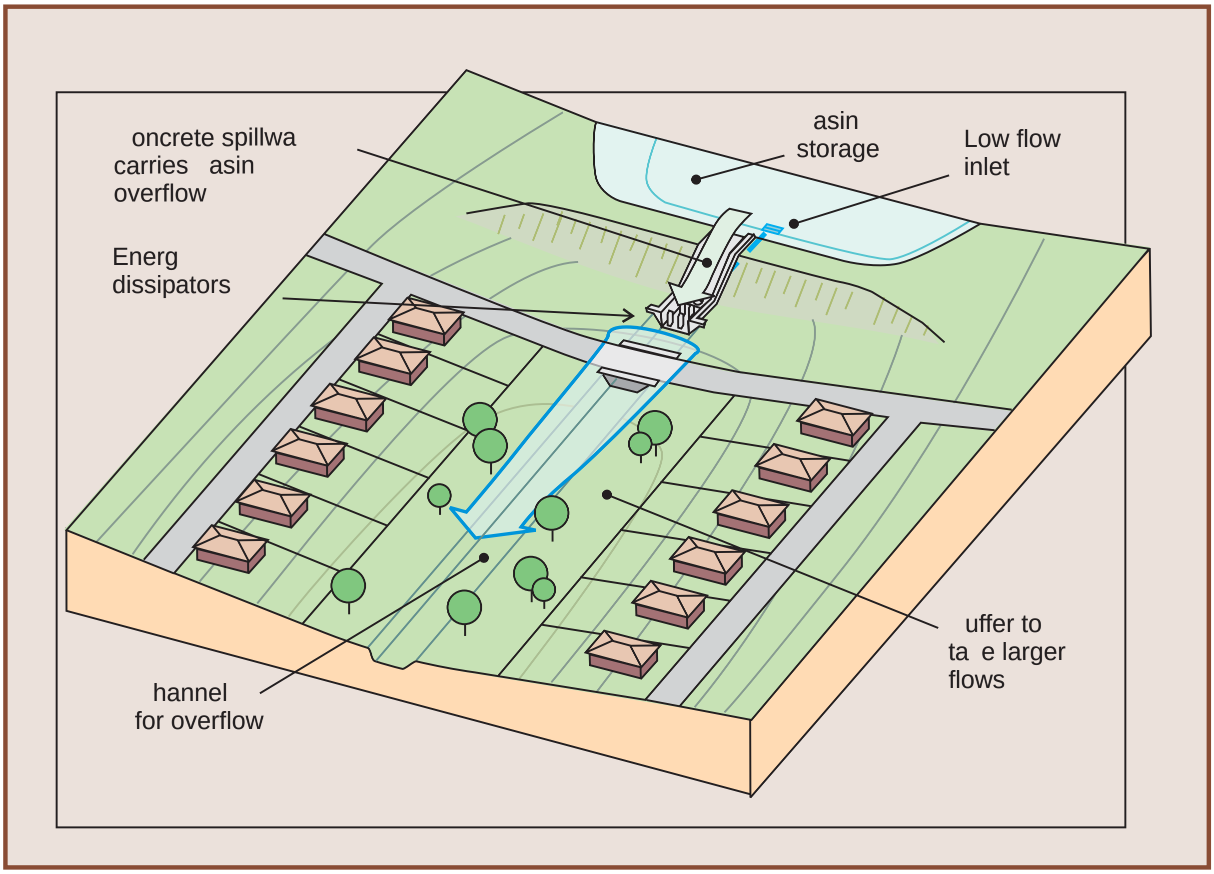
9.8.2 What can go wrong

- A late evening storm results in an intense burst of rainfall over the catchment areas above the basin. Peak outflows will occur within an hour after commencement of rainfall and the volume of runoff will be three times that of the 1 in 100 AEP flood used for the basin design.
- Within 45 minutes the basin storage fills very quickly and quietly; thereafter spilling occurs very efficiently and evenly over the entire embankment. The confined shape of the valley downstream of the basin concentrates the high rate overflows.
- The lack of any defined channel to carry the overflows means that the floor of the valley where there is development becomes a river of rapidly rising floodwaters.
- Within minutes floodwaters burst into homes.
- People and objects are unable to resist the substantial forces generated by the high velocity flows. Swift flow currents are strong enough to sweep residents downstream if they attempt to escape from their houses which are rapidly flooding.

9.8.3 Design issues

- The basin is not designed to perform safely for the full range of flooding.
- The basin design is limited to modifying initial flows up the design flood event with factors such as costs, available capacity and site constraints overriding operational safety.
- There is no spillway available to control overflows or provide visual signals that the basin has reached its capacity to hold back waters.

***Figure 109b** Alternative spillway design and subdivision layout which reduces risk downstream when the basin overflows*



- There is no provision for safe overflows in residential areas downstream. The absence of a channel of sufficient capacity and a drainage corridor to convey pre-basin flows safely through the development site only encourages a false sense of security amongst the residents who remain complacent and ignorant of the continuing flood risk. In fact, the potentially hazardous conditions require them to be more vigilant.
- There is no recognition of the fact that the residential area continues to be in a high hazard zone because it rapidly reverts to floodway conditions with larger floods.

9.8.4 What can be done to reduce flood risk

- Incorporation of a spillway in the basin embankment enable floodwaters to be released at a safe location and at a controlled rate before general overtopping occurs.
- The spillway should :
  > be sized to accommodate PMF;
  > be located so that it directs overflow into appropriate areas such as open space, parkland or watercourse to avoid exposing people and houses to high hazards; and
  > drain into a downstream drainage system which is designed to safely handle the full range of basin overflows.
- In locations where the consequences of overtopping are severe, provision of additional storage volume will cater for much larger events and thus minimising the frequency of overtopping.
- If pre-basin conditions indicate the area to be a high hazard flood area, development should not be placed there. Instead locating development further downstream where the sharp overflow peak can be dampened by a wider floodplain and greater channel storage, is preferable.
- Outflows should not be overly constricted or maximised for a single design event. Using a low capacity pipe to throttle flows is particularly inappropriate in densely urbanised areas.
- Upgrading underground pipe systems to a higher capacity in conjunction with above ground works will provide a clear and unobstructed overland flow path.
- Dwellings should not be located in zones of high potential velocities to minimise erosion impacts and damage to buildings. Including an appropriately vegetated drainage corridor can achieve this.
- Ideally, inbuilt mechanisms should be provided in the design as a signal to warn residents of impending danger when overflows occur. Such design mechanisms could include noise from water cascading or passing through baffles or energy dissipators as it flows through channels.
- Only if the roads are not critical for evacuation, should the roads be aligned to provide additional conveyance in extreme events so that people and property can be kept further away from high flow areas.

9.9 CASE STUDY H

POORLY DESIGNED FLOOD PROTECTION WORKS CAN INCREASE FLOOD HAZARD

9.9.1 Introduction

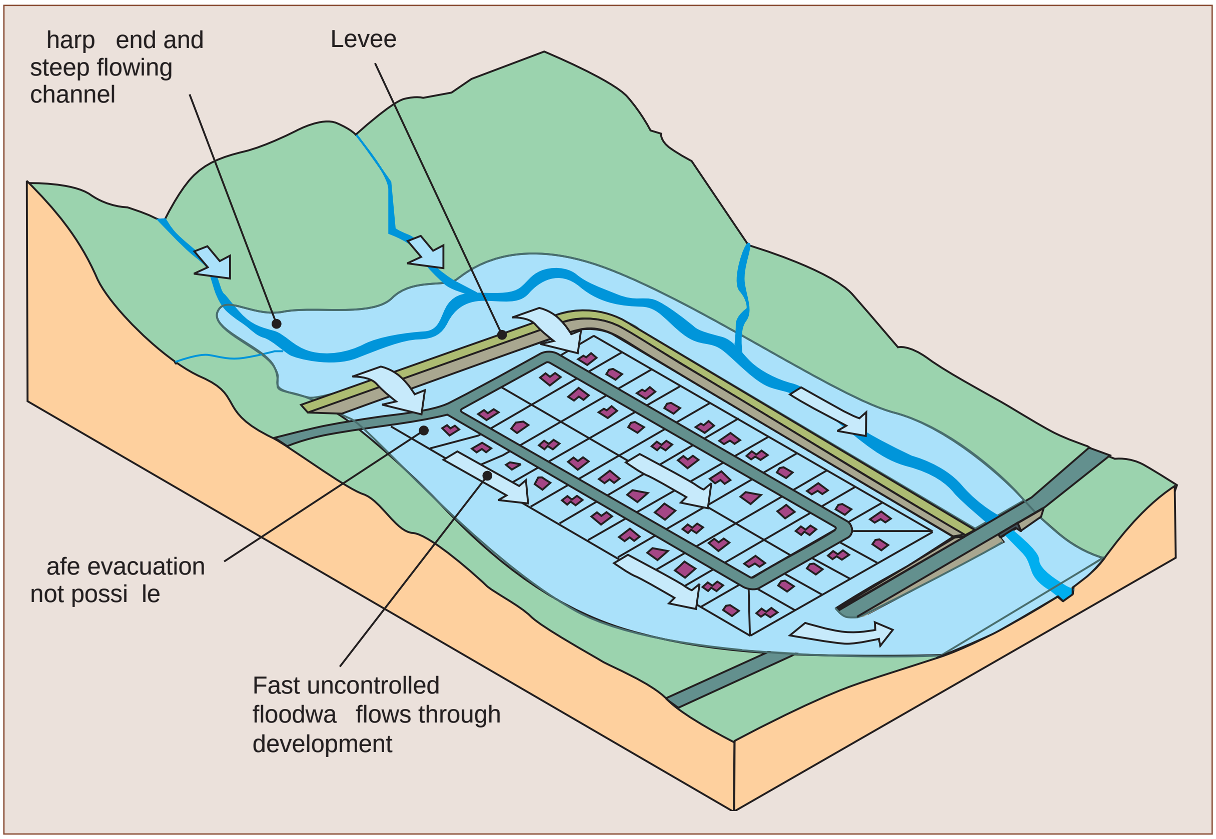
Lack of hydraulic modelling experience and care in designing a subdivision to be protected by a levee bank can result in an increase, not a reduction, in the flood hazard.

In this case study a levee was constructed to enable a new development to be located within a small floodplain beside where the creek channel commences to meander with sharper bends. The areas upstream of the development are more rugged in landform with the creek and the many small tributaries having relatively steep gradients. The development occupies a significant portion of the floodplain and is flanked by high ground.

9.9.2 What can go wrong

- The steeper gradients, fast flowing channel reaches and sharp bend immediately upstream of the development site should alert the designers to the fact that floodwaters will no longer follow the direction of the water course in larger floods. Therefore flood behaviour needs to be analysed with greater caution.
- In a larger flood, high energy flow from the steeper channels and the sharp bend causes floodwaters to overtop the levee upstream of the development and take a more direct path through housing lots and along roadways.
- Overtopping at this location results in the whole site flooding rapidly.
- Residents face greater dangers because rapid flooding prevents any warning of flooding.
- Roads which are essential for safe and orderly evacuation (via the upstream end of the development) are subject to deep and fast moving waters at the early stages of the flooding and homes are flooded prematurely causing panic and confusion to residents.

Figure 110 *Overtopping of levee at worst possible location*



- As the severity of flooding intensifies, residents should flee their flooded homes, but the dangerous flow conditions along the roadways will prevent this being done safely.

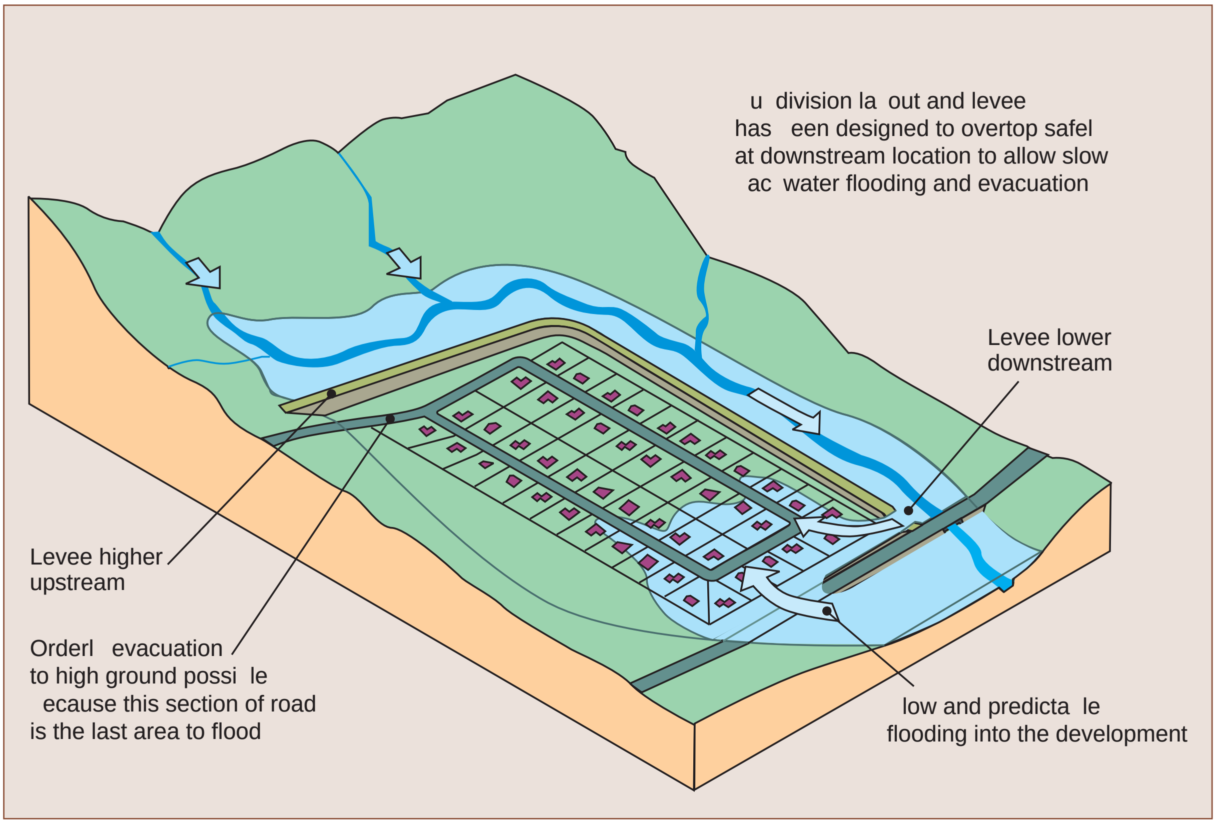
9.9.3 Design issues

- Inexperienced designers or flood modellers have designed a subdivision which is inherently unsafe in floods larger than the design flood.
- Narrow design objectives have focused on matching levee crest levels with a hydraulic model profile rather than anticipating real flood behaviour which would have lead to the design of a comprehensive system combining protection and a safe means of escape from larger floods.
- There has been no recognition that the direction of flow will be different in a larger flood.
- There has been limited appreciation of the increased danger to residents when the protection works cease to confine flooding.
- The adopted design approach is inadequate to overcome hydraulic modelling limitations.
- The flood protection works are completely compromised by failure to predict flood behaviour.

9.9.4 What can be done to reduce flood risk

- Prevention of premature and rapid overtopping of the levee is essential. Such overtopping results in uncontrolled flooding conditions throughout the development and gives insufficient warning to residents to evacuate safely.
- The upstream section of the levee should be designed so that it overtops last. This can be achieved by adopting a larger freeboard and thus a higher levee crest to allow for greater flood modelling uncertainties at this locality.
- The levee system should be designed so that overtopping commences from the downstream end. This can ensure that when the whole development site is flooded, the flooding occurs in a more controlled and predictable manner through more gradual, slower backwater flooding.

Figure 111 *Design of levee to overtop more safely*



- The levee spillway for overtopping should be located so that it directs initial overflows away from dwellings and into appropriate unoccupied areas such as parkland.
- Design of the local road network should ensure it floods progressively from the lower end where the levee commences to overtop, thereby allowing residents to retreat to safety by road to higher ground.
- Roads should be designed to rise steadily to flood-free land within the site if possible and/or provide links to an effective evacuation route.

APPENDIX

Preliminary Assessment of Local Velocities

To avoid excessive structural damage to buildings from high hydrodynamic forces subdivisions located in flow areas may require assessment of the potential local velocities. For many subdivisions a preliminary assessment of the local velocities may be sufficient to determine the appropriate nature and scale of proposed development so problems can be minimised. In other cases, detailed modelling would be required to better estimate the local velocities and explore mitigation options before final design decisions can be made.

The following procedure has been devised to permit a preliminary assessment to be made. The velocity increase is dependent on many factors which vary in complexity. Accordingly, this procedure should be treated as an estimate purely to determine how much detailed modelling may be required. If the procedure suggests local velocities are likely to be very low, then further modelling may not be required and the envisaged development may be appropriate. If, on the other hand, local velocities are estimated as being sufficient to damage houses or create a hazardous evacuation situation, velocity management strategies need to be considered for the subdivision which may involve the use of an appropriate physical or computer model (e.g. 2D computer model).

Preliminary Assessment Procedure

Floodplain developments, such as an individual dwelling or a subdivision comprising multiple dwellings, will obstruct local flow and modify the local flood behaviour. Local flow velocities at the site could become higher or lower than before the development. The flows should not be hazardous to residents, potential rescue workers nor the proposed structures. A number of examples are provided at the end of this Appendix to illustrate how subdivision design impacts on flow velocity and puts forward strategies that might be used to limit excessive velocities.

Detailed two and three-dimensional flow modelling which can provide reliable local flow and velocity estimates is often expensive and site-specific.

Broad scale floodplain numerical models of large areas such as obtained from a linked one-dimensional flow model provide general indications of flood behaviour. Typically these are used to provide estimates of peak water levels, flow rates and flow velocities and are often determined for an undeveloped or “greenfield” site.

In the absence of local (site specific) two-dimensional (2D) or three-dimensional (3D) modelling, a preliminary estimate of the likely flow velocities between dwellings can be obtained from graphical technique which is based on the results from a series of many 2D model runs for a range of development scenarios. Such a technique is able to relate greenfield velocity to the:

- proportion of the floodplain flow that would be blocked by development; and
- volume of floodwaters passing through the proposed development.

The preliminary estimated velocity can be refined considering the:

- length of the proposed subdivision;
- relative hydraulic roughness of the existing floodplain and the development;
- relative orientation of the floodplain flow direction and the subdivision; and
- availability of effective flood flow paths within the subdivision.

Based on detailed 2D modelling results for a number of development scenarios, this approach could be used to identify if there is a need for localised modelling, or otherwise assist in determining an appropriate development pattern for a site. Revising the subdivision layout and size might assist in reducing local flow velocities if they are too high.

Any areas where the local velocity is likely to exceed 1 metre per second should be subject to detailed local modelling as velocities of this magnitude or greater may result in structural damage to housing.

Preliminary Estimate of Flow Velocity

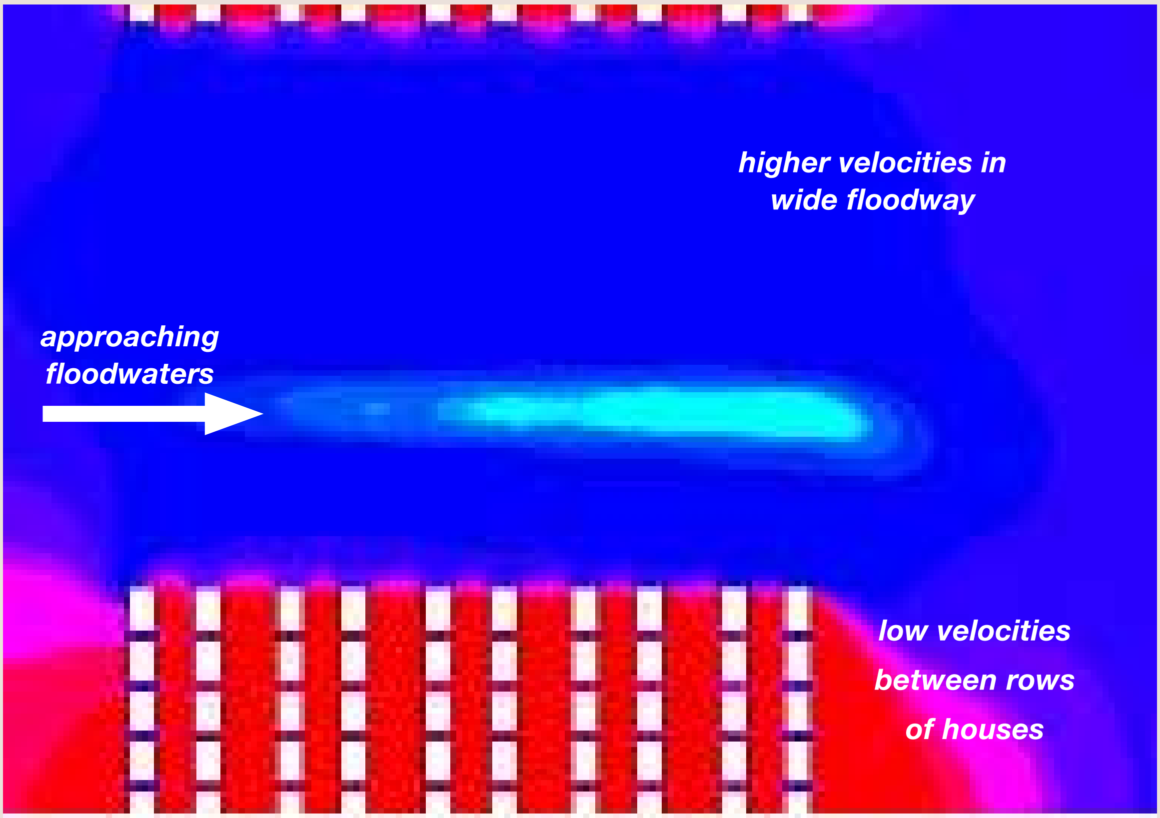
The difference between modelled greenfield average velocities and actual post development local flow velocities will be influenced by many factors, including the adequacy of alternative flow paths.

Flood flow patterns and velocities can change dramatically when a development is built on the floodplain. Flows must move between objects such as buildings and fences which also concentrate flows in adjacent areas. This may be unacceptable if existing development is located in these adjacent areas.

A range of factors influences changes in local velocities. Among the most significant factors is the extent that the development blocks the floodplain, and whether adequate flow paths remain around or through the development (Figure A1).

Consideration needs to be given to choosing the appropriate design event velocity. This design event should be based on sound floodplain risk management principles and would normally be greater than the event adopted by council for the Flood Planning Level (FPL). For example in the Hawkesbury Nepean valley an 1867 flood of record type event (i.e. approximately a 1 in 200 AEP event) might be considered to be a satisfactory standard by council. More severe conditions should also be considered if there is any possibility that people might take flood refuge in the structure.

Figure A1 *Velocities on open space land and between dwellings*



The display shows the computer modelled velocity distribution in a wide floodway and amongst an adjacent group of evenly spaced dwellings. With an approach velocity of 0.9m/s, the velocities vary from around 1.7m/s in the floodway (blue) to almost negligible between dwellings (red). This demonstrates how a wide floodway reduces velocities between houses. Even so dwellings on the perimeter of the development immediately adjoining the floodway could be exposed to higher velocities. Other modelled scenarios showed that without a sufficient floodway, the velocities between dwellings can be significantly increased.

Velocity Change due to Floodplain Blockage

Where floodwater must pass between closely spaced houses, it needs to accelerate. As a result, the velocity and hydraulic forces exerted on the dwellings will increase significantly. The increase in velocity, perhaps threefold or greater, means that dwellings and other structures could be liable to severe damage or total destruction even though the average greenfield velocity may seem moderate. More dangerous conditions will also exist for evacuation procedures.

Local Velocity Multiplier

Two of the most significant factors modifying greenfield floodplain velocities into local velocities are the

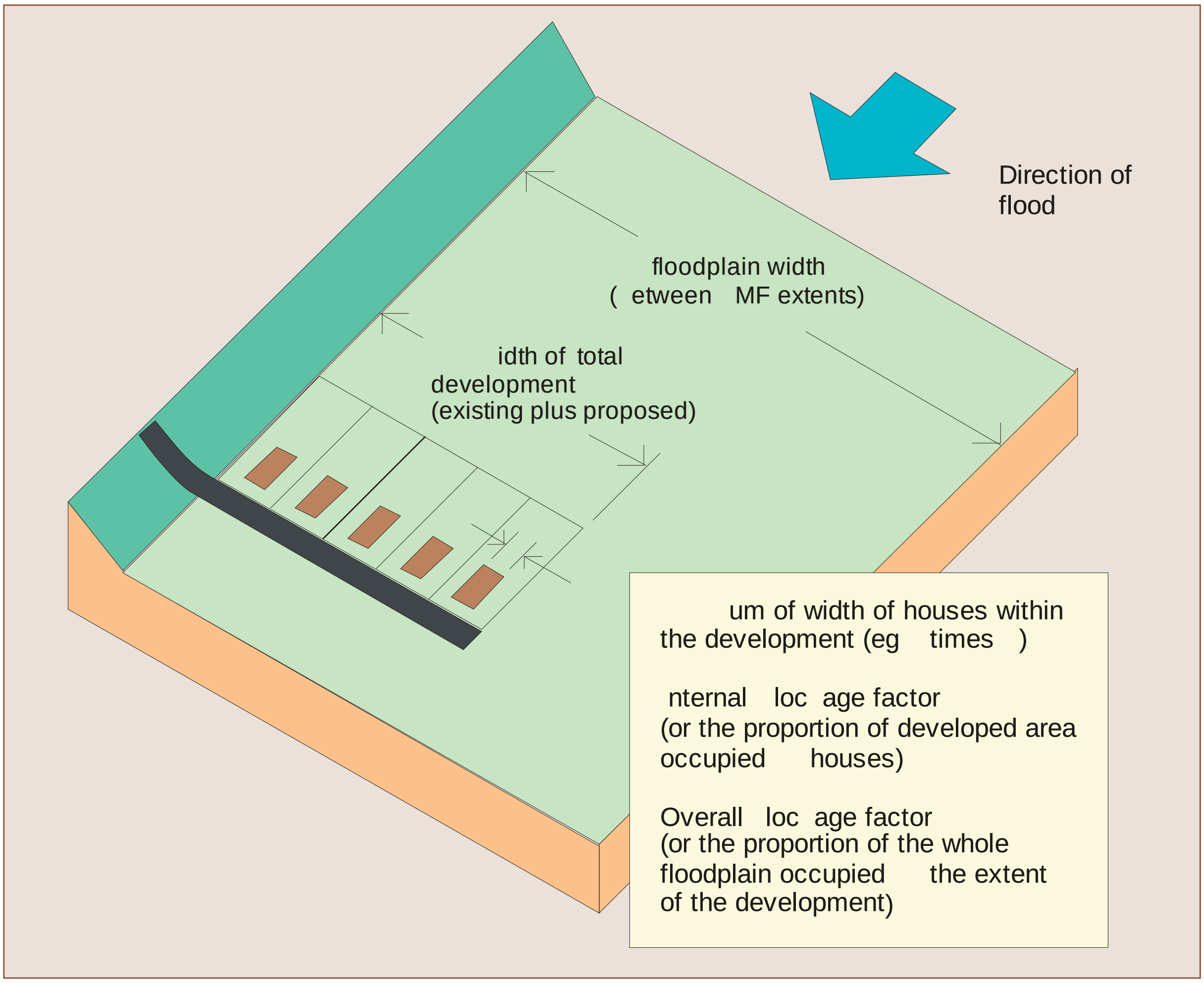
- Overall Blockage: proportion of the total floodplain width occupied by the development as a whole, and
- Internal Blockage: the density of the development itself.

How is the Local Velocity Multiplier calculated?

Overall Blockage

Estimate the average percentage of the floodplain width occupied by the development as a whole.

Figure A2 *Internal and Overall Blockage*



The floodplain width should be taken at right angles to the general flow in the area and extend from one PMF extent to the other (see Figure A2).

As other developments may also block the floodplain, all developments (existing and proposed) should be included when assessing the overall blockage.

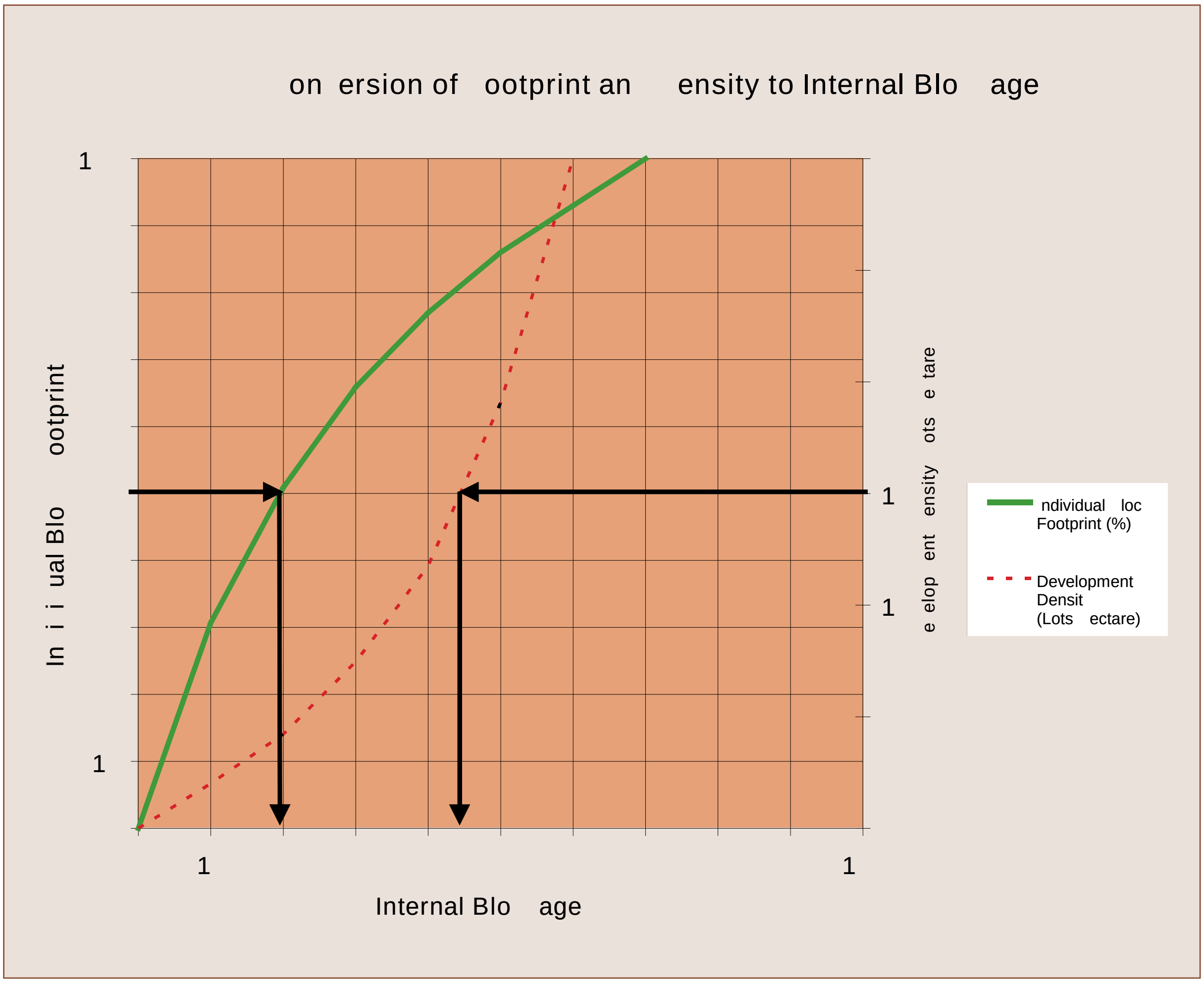
Internal Blockage

Estimate the average percentage of the internal blockage of that part of the proposed (and existing) development that intrudes onto the floodplain. This factor approximates the amount of blockage caused by all development to the flow through the floodplain (see Figure A2).

In some cases the maximum footprint of the individual buildings should be conditioned as part of the development approval e.g. only 70% of the block should be built on. In other cases the number of blocks or lots per hectare (density) for the development as a whole may need to be controlled. Preferably, this type of development control should be included in the environmental planning instrument (e.g. LEP) rather than imposed as a condition of consent. Although not directly related to each other, both the footprint and lots per hectare provide an indication of what percentage of the built form would block the flow path. Generally the footprint provides a better indication.

Figure A3 allows lots per hectare and footprints to be converted to an approximate internal blockage percentage. The internal blockage from lots per hectare is based on x% footprint per lot.

Figure A3 *Conversion of Footprint and Density to Internal Blockage*



Where a number of developments encroach onto the floodplain, some adjustment may need to be made if there is any variation in the internal blockage of each of the developments. It is suggested that this is best handled by adjusting the overall blockage percentage. For example, assume there is an existing development on the floodplain located approximately at the same cross section of the waterway as the proposed development:

- Where the internal blockage percentage of the existing development is approximately the same as the proposed development no adjustment is required and the internal blockage of the proposed development can be used in the graph;
- Where the internal blockage percentage is significantly lower or higher than that of the proposed development, the overall blockage should be decreased or increased respectively so that the total blockage or obstruction of the floodplain is retained.

The subdivision layout and results of the example are shown diagrammatically on Figure A4.

To estimate local flow velocities in the proposed development, both developments were assumed to have an internal blockage of 70% (the same as that of the proposed development). Without further refinement, this assumption would modify the total floodplain blockage. An adjusted overall blockage for the floodplain is required to restore the effective total floodplain blockage. The overall blockage is decreased to 41.4%.

The graph in Figure A5 may be used to determine the likely Velocity Multiplier which can be used to multiply the greenfield velocity to obtain an estimate of the local velocities.

Figure A4 *Example of Internal Blockages in a Floodplain Development*

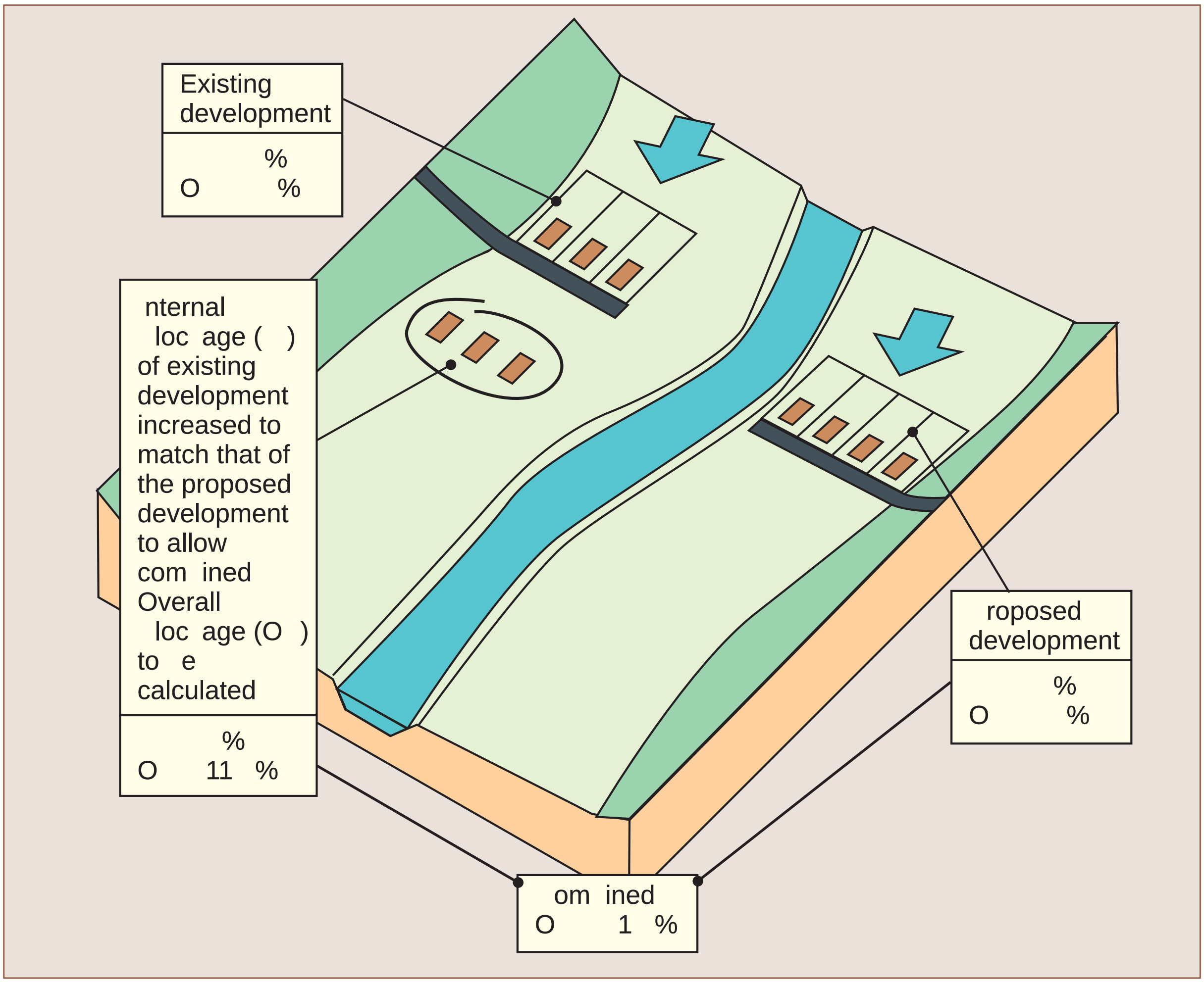


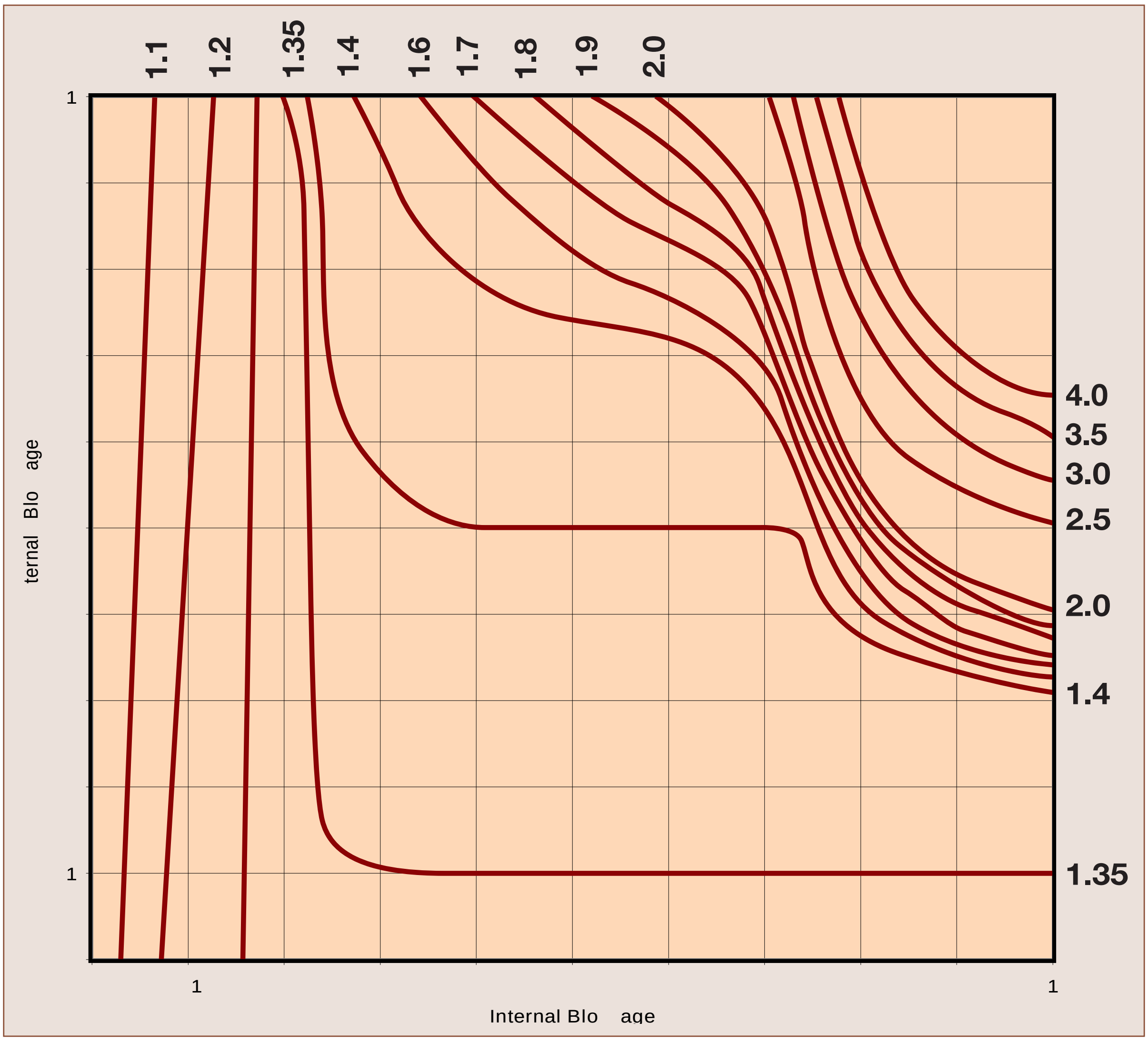
Table A1 *Assessment of Overall Blockage Percentage*

Type of Blockage	Existing Development	Proposed Development	Combined
Overall Blockage	20%	30%	N/A
Internal Blockage	40%	70%	N/A
Adjusted Internal Blockage	70%	70%	N/A
Adjusted Overall Blockage to compensate for the adjusted internal blockage	20 x 40/70 = **11.4%**	30%	11.4% + 30% = **41.4%**

Velocity Multiplier Modifiers

The provisional velocity multiplier must be modified to allow for several of the other important factors, which can affect the multiplier. To quantify these modifications in order to be consistent with the overall accuracy of the procedure, only broad-brush assessment of the parameters is needed.

Figure A5 *Velocity Multiplier Estimator*



Subdivision Length

The length of the subdivision along the river flow, affects the velocity multiplier. The provisional velocity multipliers are based on a development length of approximately 400 metres. They can be modified by multiplying by the appropriate modifier given in Figure A6 below.

For a development length of over 1000 metres, site specific flood modelling should be carried out.

Greenfield Roughness

Velocity multipliers have been calculated assuming the adopted greenfield roughness is equivalent to open pasture / lightly timbered land (Manning's n value of 0.06). Greater or lesser vegetation density will affect the velocity multiplier.

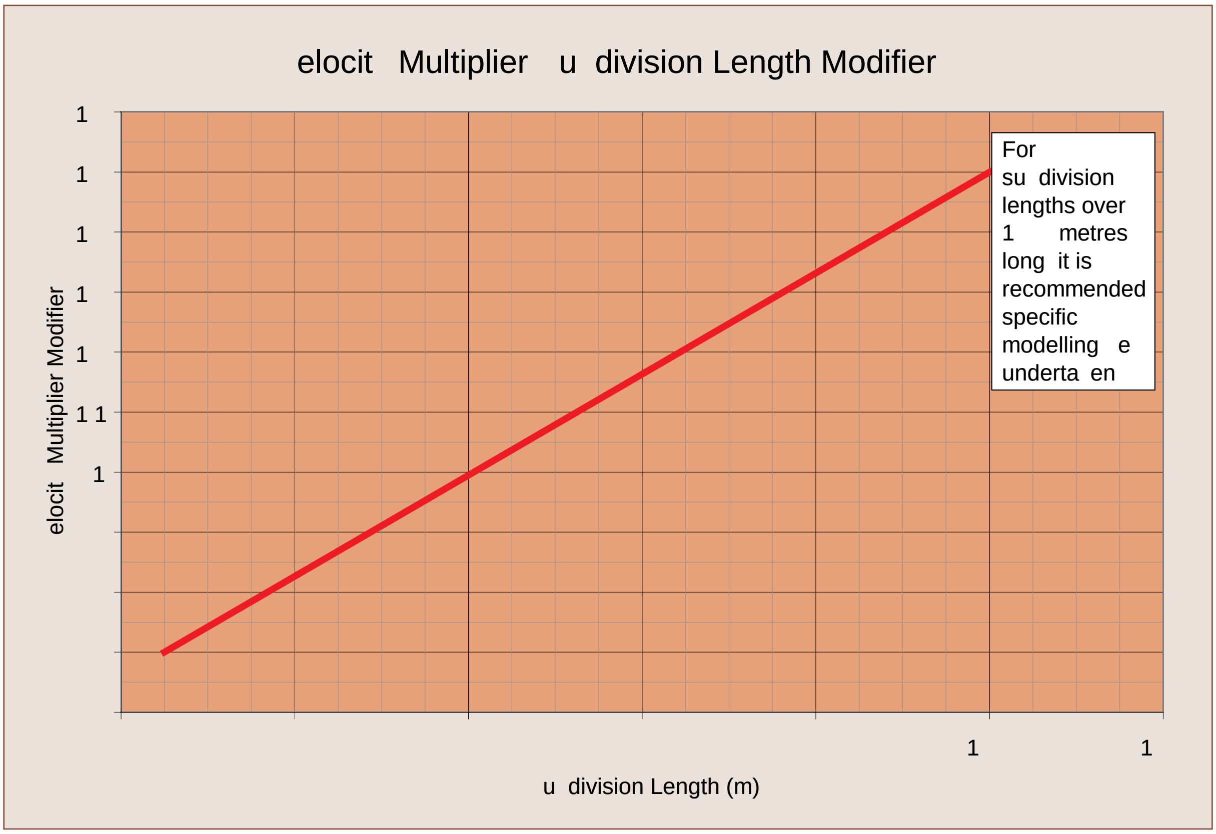
- For a higher greenfield roughness (Manning's n value of say 0.08 to 0.10, representing dense woodlands), the velocity multiplier should be adjusted by a factor of 0.8.
- For a lower greenfield roughness (Manning's n value of say 0.03 to 0.05, representing existing rural-residential land / turf farms or low height crops), the velocity multiplier should be adjusted by a factor of 1.2.
- Intermediate values can be linearly interpolated.

Subdivision Layout

A development, in which dwellings are clustered closely together with dedicated flood flow paths between, tends to have a lower overall flood flow resistance than a development where houses are equally spaced across the development area, despite having the same internal blockage factor. This is because some individual dwellings can be sheltered from higher flood velocities by other dwellings within the cluster.

An even distribution of houses within the development was adopted for the base case for the hypothetical modelling exercises.

Figure A6 *Subdivision Length Modifier*



It should be recognised that most subdivisions are unlikely to be oriented with roads aligned with main flow directions as adopted in the base case. As such, some allowance should be given to more typical development layouts than those considered in the hypothetical modelling exercises.

- For developments that incorporate dedicated (and substantial) flood flow paths, other than the main waterway, the velocity multiplier can be adjusted by a factor of 0.8.
- For developments that incorporate simple, but non-linear layout designs, the velocity multiplier should be adjusted by a factor of 1.2.
- For more complex layout designs, particularly for larger subdivisions, site specific modelling should be carried out.

Overall Use of Adjustments

Because of the numerous variations in the contributing factors, the prediction of post-development velocity changes using the general method covered in this document can only be taken as indicative rather than precise. It should not be a substitute for detailed modelling where it is required.

The multiplier modifiers provide an indication only of the likely impact of development length, greenfield roughness and subdivision layout on local velocities and should therefore be applied conservatively. Even so, this method is intended to identify those developments where, due to the combination of floodplain and development characteristics and low greenfield velocities, costly detailed modelling may be avoided.

After application of the velocity multiplier modifiers it is possible that the final velocity multiplier will be less than 1.0. It is recommended that a minimum value of 1.0 be used as any further reduction may be dependent upon the shielding effect offered by other dwellings. As this will only occur in a fully constructed development site, there may be a considerable time lag during which exposure to hazard will be greater. In practice, detailed 3D computer flow modelling indicates that even individual dwelling houses in open areas still experience significantly increased local velocities.

Estimate Local Velocities

Having determined the final velocity multiplier, the appropriate greenfield velocity is factored by this value to obtain an estimate of the local velocities that will apply around houses within the proposed development.

If the local velocities obtained by the above procedure are less than 0.4 m/s then it is less likely to generate severe forces on the house structure. The matter of safety to people needs to be considered separately by taking into account the expected velocities, depths, rates of rise, warning time, isolation, etc. Such consideration is beyond the scope of this general procedure and each case needs to be considered individually.

Where the local velocities obtained by the above procedure are greater than 0.4 m/s there is a chance that severe damage imposed by the movement of floodwaters may occur to houses. Accordingly, it is strongly recommended that detailed modelling be undertaken to more accurately local velocity impacts. Furthermore, when this preliminary procedure suggests that local velocities may be greater than 1.5 m/s, it may be worth reconsidering the development (layout, density, landform modification, velocity reduction barriers etc.), as detailed modelling is likely to confirm a problem with damaging velocities.

Further advice on the velocities, which may cause severe structural damage to a house, is included in the companion document to these guidelines: “Guidelines for Building on Floodplains”. The Building Guidelines also include advice on how to strengthen houses to resist lower range velocities, (e.g. 0.8m/s to 1.8 m/s) although building dwelling houses in the higher end of this range is strongly discouraged under normal circumstances. This is particularly the case where large numbers of houses are being constructed as this could significantly increase the costs to the community because:

- building flood compatible housing to withstand damage from high velocities has cost implications compared to dwellings on less hazardous sites; or
- if dwellings are built to normal (i.e. non flood compatible) building standards, the result would be greater structural damage or even loss of a large number of dwellings in the event of major flooding.

Where the greenfield velocity changes significantly across the site so too will the local velocities. This procedure may help identify general areas within the subdivision where redesign or other measures may be required to limit the local velocities to acceptable values.

Examples

Example1: Subdivision on a floodplain; velocity estimation

Q). Estimate the local velocities between houses in a subdivision proposed on a right bank floodplain as shown below. Use the following parameters: the right bank floodplain is 200m wide while the development is 80 metres perpendicular to the general direction of flow. The proposed development length would be 250 metres parallel to the flow direction and yield 30 lots/hectare. The street layout would be simple but non-linear. At the time of broad scale modelling, the site was used for turf farming with a greenfield average floodplain flow velocity of 0.2 m/s.

A). To determine the likely floodwater flow velocity between houses, consider:

i. the development would occupy 80m/200m = 40% of the floodplain conveyance, or a 40% overall blockage factor (Figure A2). It is intended to have 30 lots/hectare or a 60% internal blockage factor (Figure A3), yielding a velocity multiplier of 1.24 from Figure A5.

ii. In a direction generally parallel to the general direction of floodplain flow, the subdivision is 250m long. Figure A6 provides a modifier value of 0.87.

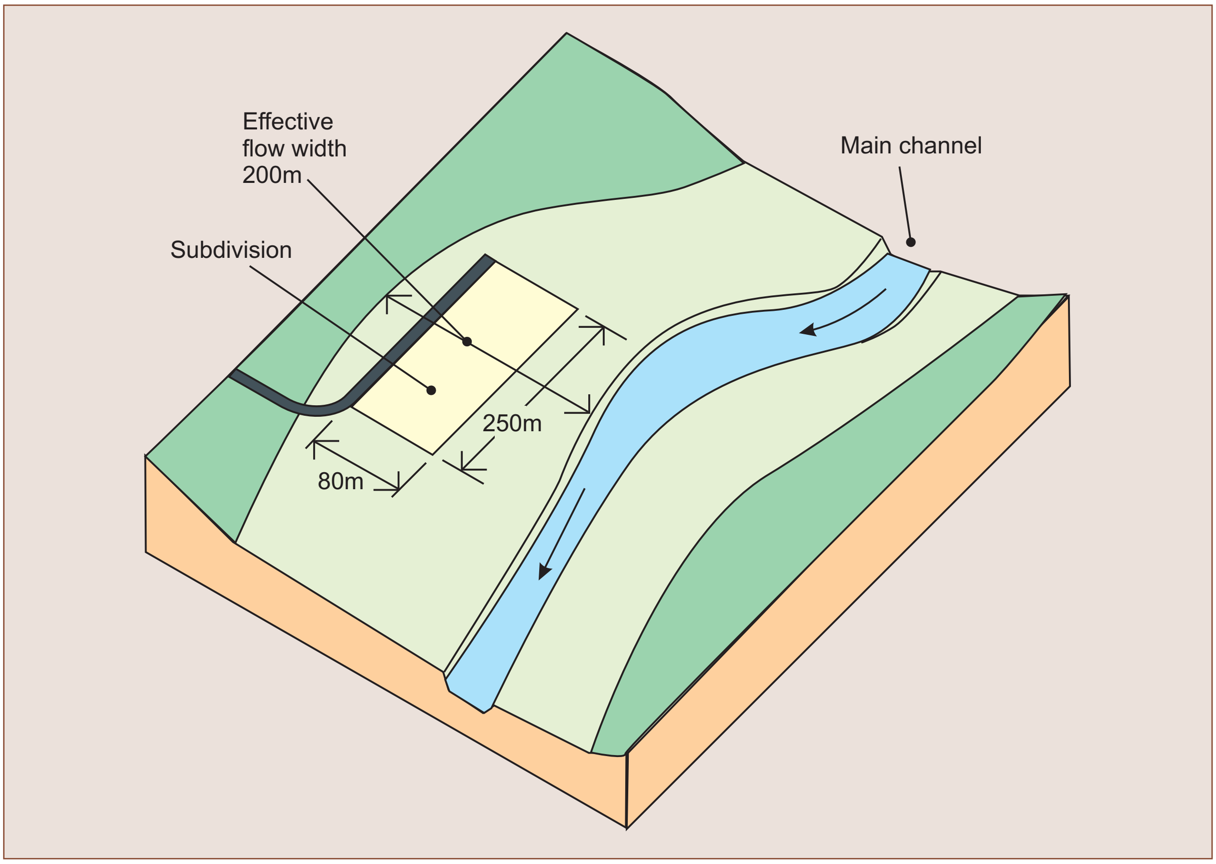
iii. The subdivision would be hydraulically rougher than the current turf farm. Use the recommended factor of 1.2.

iv. Dedicated hydraulic flow paths are not indicated, nor is there an indication of existing sheltering development. The alignment of streets is considered simple but non-linear, relative to current floodplain flow directions. Apply factors of 1.0 (dedicated hydraulic flow path), 1.0 (sheltering development) and 1.2 (alignment of streets) respectively.

So the likely local flow velocity of the floodwater is:

Local velocity = 0.2 m/s x 1.24 x 0.87 x 1.2 x 1.0 x 1.0 x 1.2 = 0.31m/s.

Figure A7 *Example 1 Subdivision*



Example 2a: Extension of a subdivision on a floodplain; equivalent combined development

Q). A floodplain is 550 m wide. Half of this width already includes dwelling houses with a footprint equal to 30% of the block area, over a river reach length of 1000m. It is proposed to extend the subdivision by 80 m onto a greenfield site and develop with a 65% dwelling footprint. Use Figure A5 to determine the Velocity Multiplier Estimator for the proposed development.

A). To evaluate flow conditions in the proposed development, disregard the internal blockage factor for the existing development. Adopt the internal blockage factor for combined development. Using a 65% dwelling footprint, Figure A3 provides an Internal Blockage factor of 30%.

Disregard the sum of the Overall Blockage factors for the combined development. Use the technique at Figure A4 to evaluate an adjusted Overall Blockage factor for the combined development with the adopted Internal Blockage factor.

Example 2b: Extension of a subdivision on a floodplain; velocity estimation

Q). Estimate the local velocities between houses given that the estimated flow velocity is 0.8 m/s from a broad scale hydraulic model. For simplicity, disregard relative greenfield roughness, orientation, sheltering of development or subdivision flow paths.

A). Figure A5 indicates a velocity multiplier estimator of 1.3. Figure A6 indicates a modifier value of 1.5 due to river reach length, consequently:

Local velocity = 0.8 m/s x 1.3 x 1.5 = 1.6 m/s.

***Figure A8** Example 2a - Extension of Subdivision*

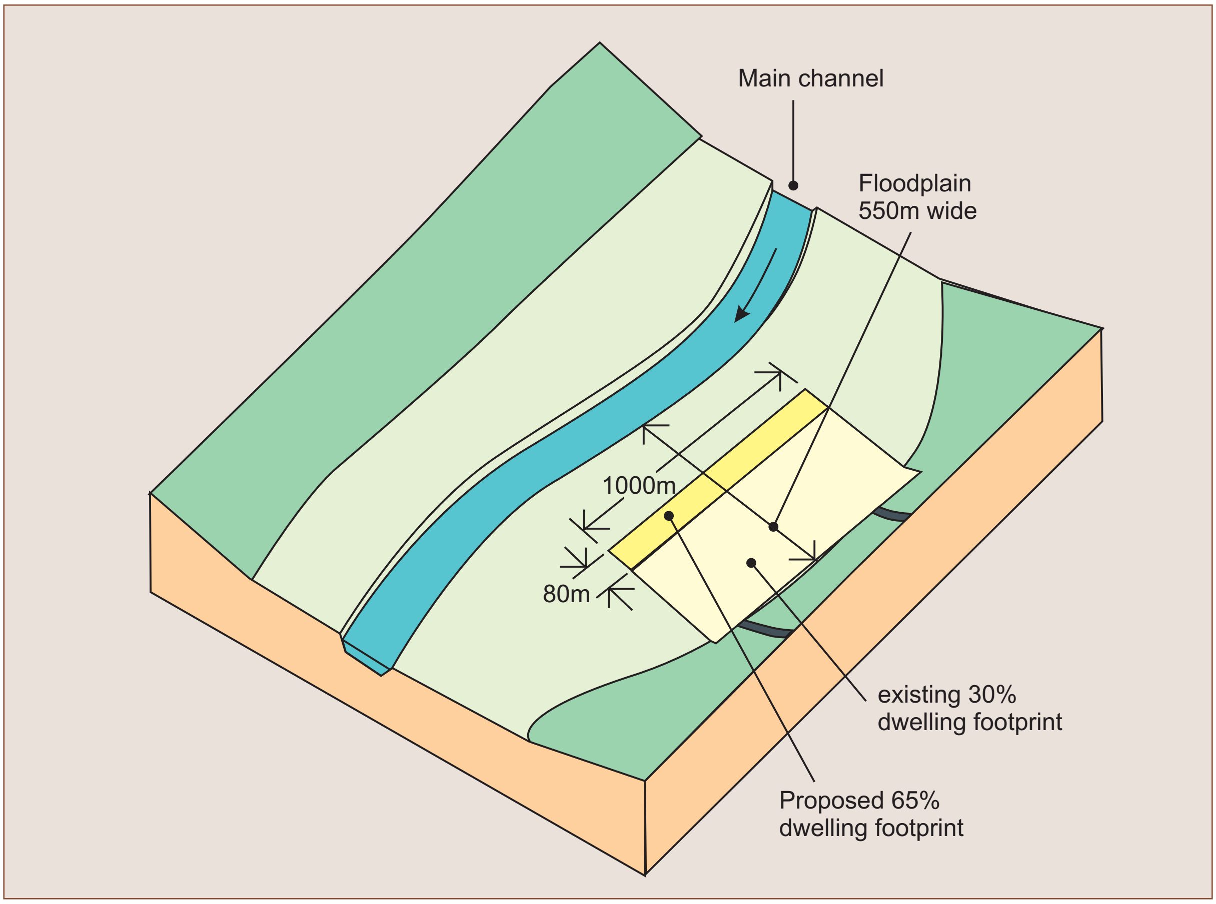


Table A2 *Assessment of Overall Blockage - Combined Development*

Blockage Type	Existing Development	Proposed Development	Combined
Overall Blockage	50%	80/550 = 14.5%	N/A
Internal Blockage	10%	30%	N/A
Adjusted Internal Blockage	30%	30%	N/A
Adjusted Overall Blockage to compensate the adjusted internal blockage	50x10/30 = **16.7%**	14.5%	16.7% + 14.5% = **31.2%**

Adopt an overall blockage factor of 31.2%. Figure A5 indicates a velocity multiplier estimator of 1.3.

Example 3a: Managing undesirably high velocities – Example A

Q). A floodplain is 200 m wide and has an estimated average greenfield flow velocity of 0.2m/s. The current predominant use is cattle grazing. Residential development is proposed with a 93% footprint (or about 190 lots or 28 lots/ ha) and 170m width across the floodplain. Development would run 400m roughly parallel with the riverbank. The proposed street layout would be simple but non-linear.

Determine if the anticipated local velocity is acceptable. If there is a problem, consider some means of rectifying it.

A). Using a calculation similar to Example 1, the likely local floodwater flow velocity between homes is:

Local velocity = 0.2 m/s x 1.775 x 1.0 x 1.2 x 1.0 x 1.0 x 1.2 = 0.51m/s; an excessive velocity.

The following strategies could be considered to reduce the anticipated local velocity by 28% to 0.4 m/s.

i) A reduced development width 132 m reduces the velocity multiplier estimator to 1.39, and local velocity to 0.4m/s (147 lots). Alternatively, the velocity multiplier estimator can be reduced to 1.39 by revising the internal blockage to 5 lots/ha or 57% footprint (block yield of 34 lots).

ii) Reduced length of Subdivision to 75m (formerly proposed length 400m) would reduce the length modifier by 28%, from 1.0 to 0.72. It would also reduce the block yield from 190 to about 35.

iii) A dedicated and substantial flood flow path could reduce local velocities to about 80%. Note that 80% of 0.51m/s is 0.41m/s, which might be marginally acceptable. However a suitably sized flow path would need to be about 38m wide as determined at Example 3(a)i above. Such a flow path would affect the size and arrangement of the allotments and likely isolate some properties in times of flooding.

iv) Consideration could also be given to structures that minimise the adverse impact of flood behaviour in adjacent subdivision areas. It will likely be necessary to model these.

Example 3b: Managing undesirably high velocities – Example B

Q). Similar to Example 1, a subdivision is proposed on a right bank floodplain. The floodplain is 200m wide while the development is 80 metres wide in a direction that is perpendicular to the general direction of flow. The proposed development length would be 250 metres parallel to the flow direction and yield 30 lots/ hectare. The street layout would be simple but non-linear. The site was previously used for turf farming. However in this case the average greenfield floodplain flow velocity was 0.3m/s at the time of broad scale modelling.

Determine if the anticipated local velocity is acceptable. If there is a problem, consider some means of rectifying it.

A). Using a calculation similar to Example 1, the likely local floodwater flow velocity between homes is:

Local velocity = 0.3 m/s x 1.24 x 0.87 x 1.2 x 1.0 x 1.0 x 1.2 = 0.47m/s; an excessive velocity.

The following strategies could be considered to reduce the anticipated local velocity by 15% to 0.4 m/s.

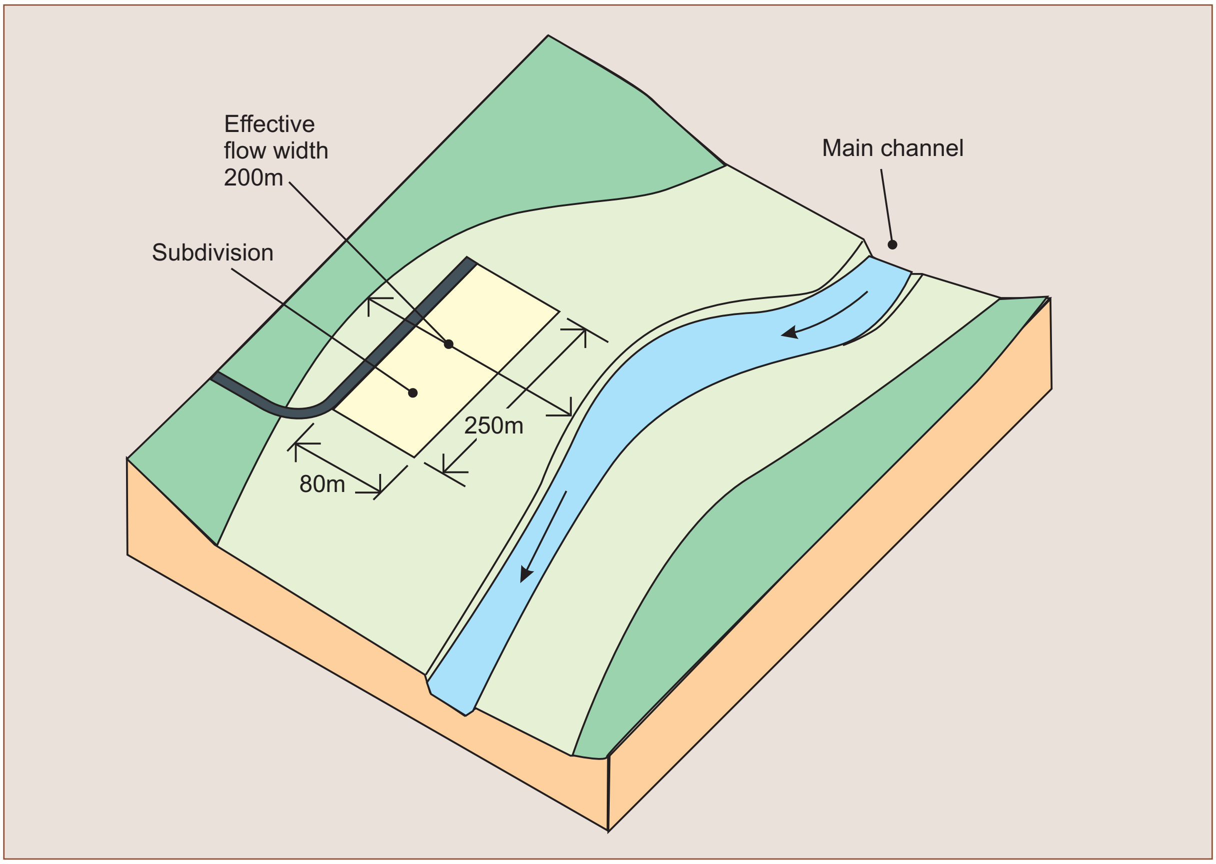
i) Reduced internal or external blockage alone cannot produce a sufficient reduction in local velocity. The bottom left hand corner of the "Velocity Multiplier Estimator" (Figure A5) is particularly insensitive to variations in blockage ratios. Adjusting these parameters singularly or in tandem could be used together with other strategies (eg subdivision length) to achieve the necessary reduction.

ii) Subdivision length reduced to 120m (formerly proposed length 250m) would reduce the length modifier by 15%, from 0.87 to 0.74. It would also reduce the block yield from 60 to 29.

iii) A dedicated and substantial flood flow path could reduce local velocities to about 80%. Note that 80% of 0.47m/s is 0.38m/s. An extraordinarily wide flow path would be necessary because the relevant part of Figure A5 is insensitive to blockage factor adjustments. Any adjustment to reduce velocity would significantly reduce the block yield.

iv) Consideration could also be given to structures that minimise the adverse impact of flood behaviour in adjacent subdivision areas. It will probably be necessary to model these.

***Figure A9** Example 3b – Managing high velocities*



GLOSSARY

Acid sulphate soils	Sediments, which contain sulfidic mineral pyrite. These sediments may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual prepared by the Acid Sulfate Soil Management Advisory Committee (ASSMAC).
Afflux	The term used for the change of water level when water is held back by an obstruction to the water flow in the conveyance areas. Immediately downstream of the obstacle, levels may be reduced as a result of an obstruction, whilst upstream levels may rise.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is 1 in 20 chance) of a peak flood discharge of 500 m^3/s or larger occurring in any one year.
Anabranch	A stream that leaves a river and re-enters lower downstream.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time. Refer Appendix M of the Floodplain Development Manual.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Building Envelope	Means a diagram drawn on a lot of a subdivision plan defining the limits for the siting and/or wall height of any dwelling and/or outbuildings, private open space, driveways and/or garages/carports.
Cadastre, cadastral base	Information in map or digital form showing property boundaries.
Caravan and moveable dwelling parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the Local Government Act, 1993.
Catchment	An area of land, which is drained to a specified point, such as the sea, by a main stream including tributary streams.
Consent authority	The council or government agency having the function to determine a development application under the Environmental Planning and Assessment Act (EP&A Act).
Conveyance	Is a measure of the carrying capacity of a channel section (or shape) for a given slope and roughness.
Crossover	Refers to the paved access way between the carriageway of a street and a development site.
Depositional zones	Areas where sediments such as gravel, sand and silt or logs, litter and other debris settle out of slowing flows to form either sedimentary deposits or debris dams.
Development	Is defined in the Environmental Planning and Assessment Act 1979 (EP&A Act) and includes the subdivision of land. Infill development: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. Greenfield development: refers to development of rural land for urban purposes. It is usually preceded by changes to the environmental planning instrument and may involve detailed subdivision design criteria through a Development Control Plan before development can occur. It may require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment may not require either rezoning or major extensions to urban services.

Development Control Plan (DCP)	A detailed guideline that illustrates the controls that apply to a particular type of development or in a particular area. A DCP makes more detailed provision with respect to development to achieve the purpose of an environmental planning instrument and is made according to the Environmental Planning and Assessment Act 1979, as amended.
Disaster Plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
Discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
Ecologically Sustainable Development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this publication are related to ESD.
Effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
Emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
Environmental Planning Instrument (EPI)	Means a State environmental planning policy, a regional environmental plan or a local environmental plan prepared in accordance with the Environmental Planning and Assessment Act 1979
Flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood damages	Direct tangible damages: loss of assets with an easily quantifiable value such as buildings, contents, vehicles, stock and crops. Direct intangible damages: loss of lives, pets, memorabilia, or other assets with value beyond the simple monetary value. Indirect tangible damages: costs of evacuation, accommodation, lost production, clean up, lost sales and the like. Indirect intangible damages: costs associated with health effects, business failures, loss of residential amenity, disruption to communities, pollution and the like.
Flood education, awareness and readiness	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness. Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures. Flood readiness is an ability to react within the effective warning time.
Flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood liable land	Is synonymous with flood prone land ie land susceptible to flooding by the probable maximum flood (PMF) event.
Flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
Floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.

Floodplain Development Manual	A manual published in 2005 by the NSW Government to support its Flood Prone Land Policy
Floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
Floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in the Floodplain Development Manual 2005. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
Flood plan (local)	A sub-plan of a Disaster Plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
Flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area is explained in the Floodplain Development Manual.
Flood planning level (FPL)	Is the combinations of flood level and freeboard selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
Flood prone land	Is land susceptible to flooding by the probable maximum flood (PMF) event. Flood prone land is synonymous with flood liable land.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in the Floodplain Development Manual is divided into three types, existing, future and continuing risks. They are described below. Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain. Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management options, the continuing flood risk is simply the existence of its flood exposure.
Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Fluvial	Of or found in rivers
Freeboard	A factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as model inaccuracies, data quality, wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as “greenhouse” and climate change. Freeboard is included in the flood planning level.
Geographical Information System (GIS)	A system of software and procedures designed to support the management, manipulation, analysis and display of spatially referenced data.
Geomorphology	The study of the shape and development of land forms

Habitable room	In a residential situation: a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom In an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
Hazard	A source of potential harm or a situation with a potential to cause loss. In relation to these guidelines the hazard is flooding which has the potential to cause damage to individuals and the community. Definitions of high and low hazard categories are provided in Appendix L of the Floodplain Development Manual.
Hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
Local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
Lot	A distinct portion or parcel of land shown on a plan of subdivision.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purposes of the Floodplain Development Manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff (Pilgrim 1987)). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flowpaths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
Management plan	A document including, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve defined objectives. It may also include description and discussion of various issues, problems, special features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. Mathematical models are run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
Merit approach	The merit approach to decision making weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into council plans, policy, and environmental planning instruments (EPIs). At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

Minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: Minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. Moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. Major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
Modification measures	Measures that modify either the flood, the property or the response to flooding. Appendix J of the Floodplain Development Manual 2005 provides further information.
Multiple-use drainage corridor	A corridor of land within which drainage system elements such as channels and retarding basins are integrated with public open space, taking into account water quality maintenance, water conservation and harvesting, habitat retention and enhancement, and choice of recreational opportunities.
Nature strip	See verge
Peak discharge	The maximum discharge occurring during a flood event.
Performance criteria	Criteria to be used in the preparation, submission and assessment of development proposals for measuring performance of the proposals against the intent or objective of the element.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the probable maximum flood.
Probability	A statistical measure of the expected chance of flooding (see annual exceedance probability).
Regional Environmental Plan (REP)	Is an environmental planning instrument prepared in accordance with the Environmental Planning and Assessment Act 1979, relating to a region, or part of a region. The extent of the region will vary depending upon the issue to be addressed, but it may relate to more than one local government area.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the Floodplain Development Manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
Run-off	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Section 149 Certificate	A certificate issued under section 149 of the Environmental Planning and Assessment Act 1979, by a local council for any land within the area of the council advising of environmental planning instruments, zoning and other relevant matters including whether policies on hazard risk restrictions (including flooding) affect the land.
Section 117 Direction	Ministerial directions pursuant to Section 117(2) of the Environmental Planning and Assessment Act 1979, specify matters which local councils must take into consideration in the preparation of LEPs. Section 117(2) Direction No 15 (in regard to flood prone land) is aimed to ensure that development of flood prone is consistent with the NSW Government's Flood Prone Land Policy and the principles contained within the Floodplain Development Manual
Section 94 Contribution Plans	Provide a basis for levying of development contributions to contribute to works (including drainage and flood mitigation works) required as a result of future development. Section 94 contributions can only be utilised to fund works associated with the new development and cannot be used for purposes of rectifying past inadequacies. The Environmental Planning and Assessment Act (Development Contributions) Act 2005) introduces voluntary planning agreements whereby a developer can contribute to a public purpose including the provision of infrastructure.

Setback	The minimum distance which a wall-face is required to be from a property boundary. It is measured as the horizontal distance between the proposed wall and the boundary plus any amount greater than 600 millimetres that any eaves extends beyond the wall face.
Site	The area of land to be developed or subdivided.
Stage	Equivalent to “water level”. Both are measured with reference to a specified datum.
Stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
State Environmental Planning Policy (SEPP)	Policy proposed by the Minister and approved by the Governor. A SEPP addresses matters of state significance.
Stormwater flooding	Inundation resulting from the incapacity of an urban stormwater drainage system to handle runoff.
Street alignment	The horizontal shape of the street reserve boundary.
Street reserve	The land set aside for a carriageway and verge.
Subdivision	The division of a parcel of land into two or more parts (or lots) for the purpose of enabling the lots to be sold separately.
Survey plan	A plan prepared by a registered surveyor.
Topography	A surface which defines the ground level of a chosen area.
Verge	That part of the street reserve between the carriageway and the boundary of adjacent lots (or other limit to the street reserve). It may accommodate public utilities, footpaths, stormwater flows, street lighting poles and planting.
Water sensitive urban development	Is a design approach that endeavours to highlight stormwater treatment and use as a primary urban design feature. By integrating stormwater elements into the design, many environmental values may be optimised, whilst also providing aesthetic and recreational benefits.
Water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
Wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

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