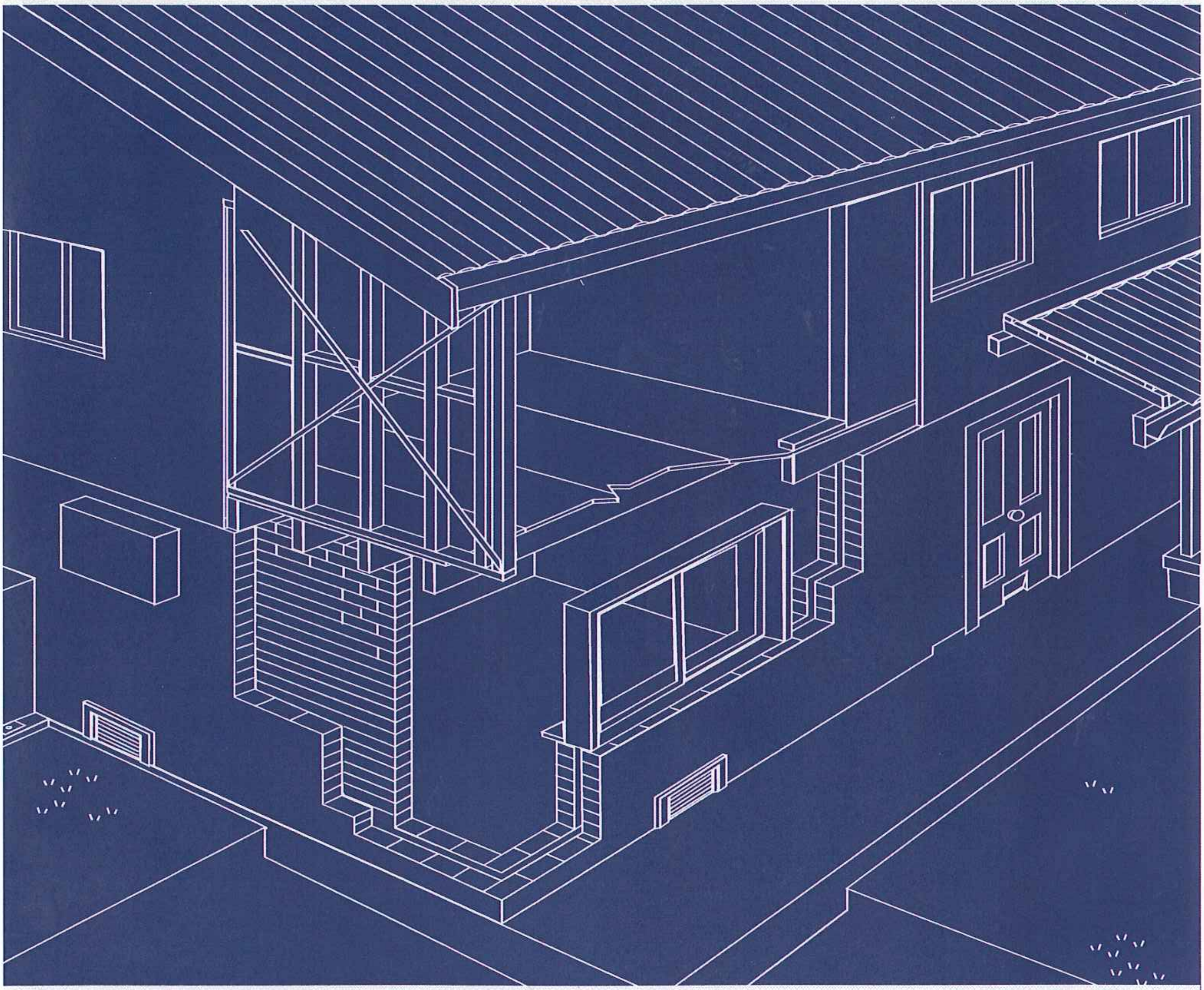
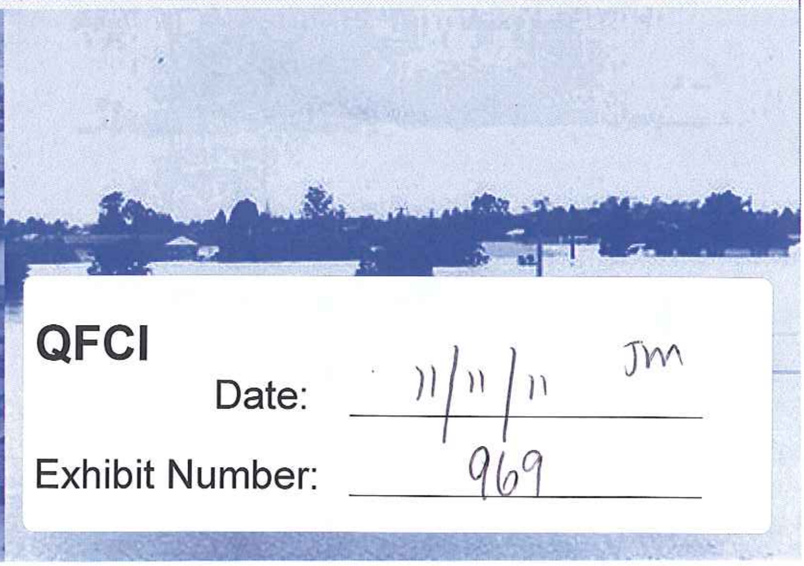
# REDUCING VULNERABILITY OF BUILDINGS TO FLOOD DAMAGE

## Guidance On Building In Flood Prone Areas





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Date: 11/11/11 JM

Exhibit Number: 969

**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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*Any representation, statement, opinion or advice expressed or implied in this publication is made in good faith on the basis that the State of New South Wales, its agents or employees are not liable (whether by negligence, lack of care or otherwise) to any person for any damage or loss whatsoever which has occurred or may occur in relation to that person taking or not taking (as the case may be) action in respect of any representations, statement or advice referred to above.*

*The Building Guidelines suggest ways to achieve a reasonable level of protection against serious damage to a house subjected to a combination of water velocity and depth. They aim to provide a higher degree of protection against structural flood damage than exists with a traditional house.*

*Nevertheless:*

- *individual designs and quality of buildings and specific flood conditions may lead to some damage still occurring. In rare cases, serious damage may still occur;*
- *damage may occur as a result of water contact and floating debris mobilised by floodwaters.*

# REDUCING VULNERABILITY OF BUILDINGS TO FLOOD DAMAGE

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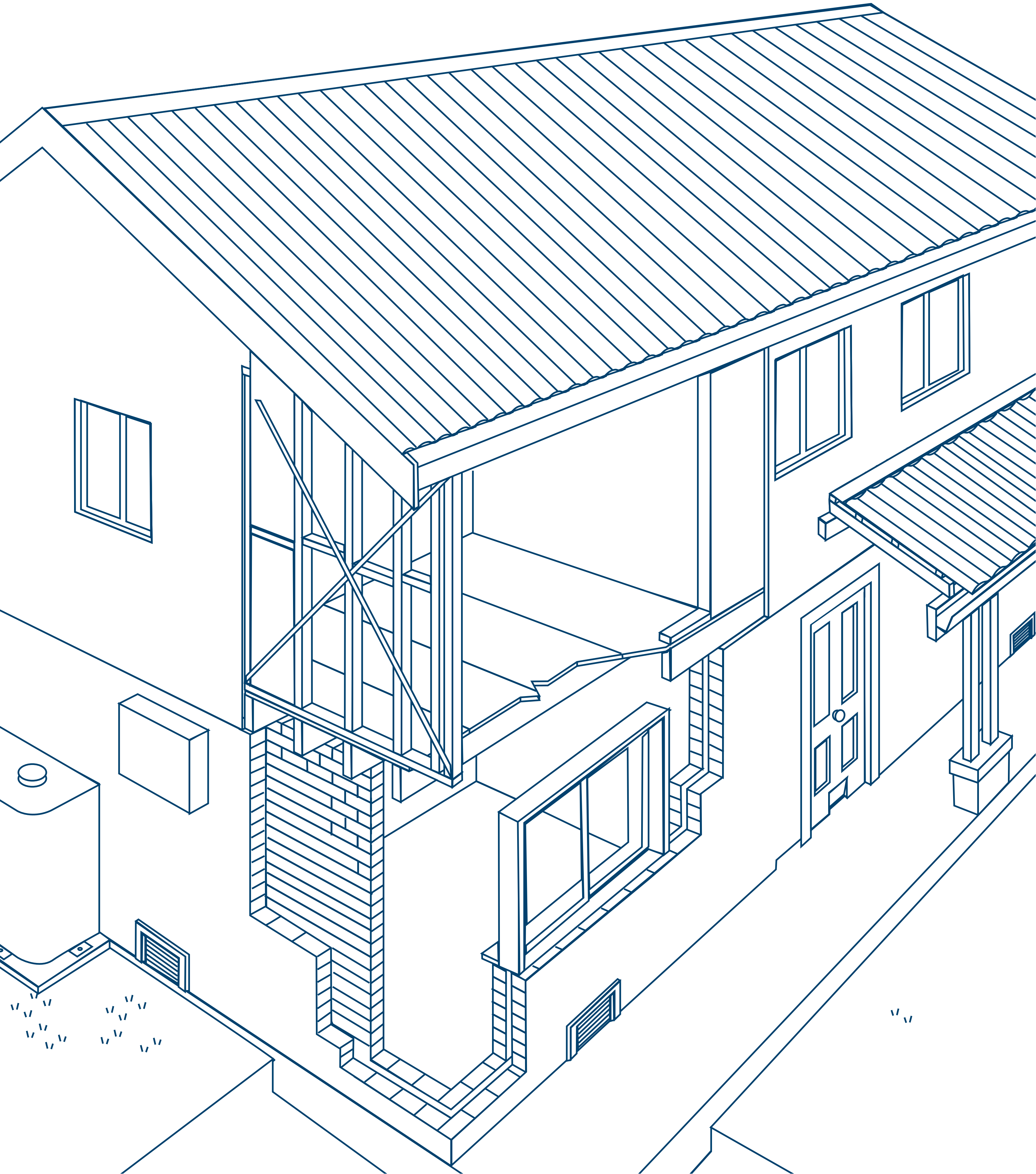

# ACKNOWLEDGMENTS

These guidelines have been produced through the Hawkesbury-Nepean Floodplain Management Steering Committee. The contribution from the many sources involved in their production is gratefully acknowledged.

Special acknowledgment is given to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for their valued contribution to the guidelines under a partnership arrangement with the Department of Infrastructure, Planning and Natural Resources (DIPNR). CSIRO provided substantial advice on the behaviour of materials under immersion and flood conditions which forms the basis of these guidelines. In addition, CSIRO undertook specific materials testing, computer flow modelling, and derived the equivalent N classification design procedure.

## Significant contributors to these guidelines were:

Department of Natural Resources
The University of New South Wales (via the Australian Centre for Construction Innovation)
The University of Newcastle
Granger Consulting
Coffey Geosciences
Napier and Blakeley
Macquarie University

## In addition, the contributions of the following Department of Natural Resources Project Team Staff are acknowledged:

Arthur Low, David Avery and Catherine Gillespie
Alan Jeffery and Sandra Wilson

## Appreciation is also given to:

material and product manufacturers and suppliers for their information and advice
builders and contractors for access to sites, and suppliers of photographs.

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.



*ISBN 0 7347 5614 3*

*Illustrations by Greg Gaul and Metro Graphics Group*

# 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.

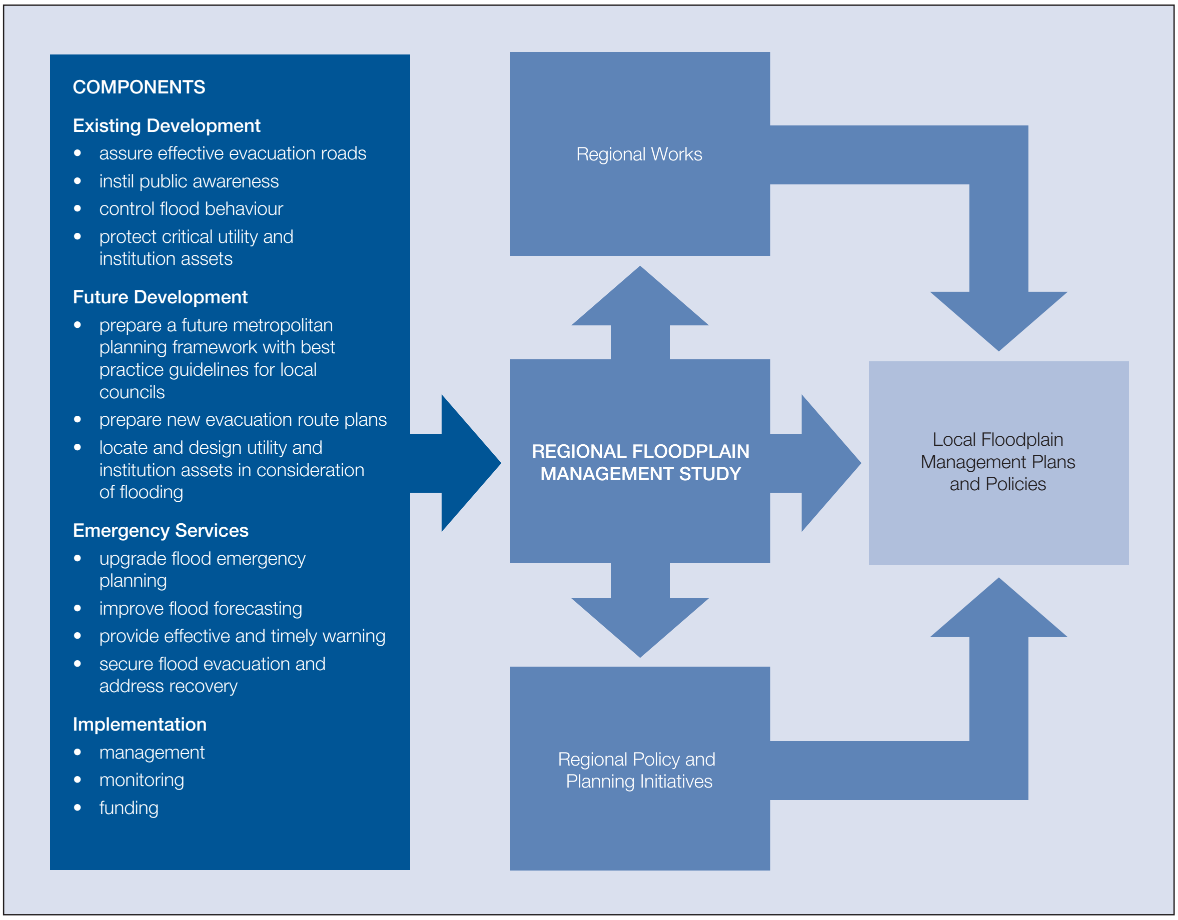
In order to address this problem and to protect existing and future communities and prevent an increase in damages and losses arising from new floodplain development, the NSW Government committed $71 million over six years from 1998 to the implementation of the Hawkesbury-Nepean Floodplain Management 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 Figure 1.1.

*Figure 1.1 Integrated implementation process adopted for the Hawkesbury-Nepean Floodplain Management Strategy*

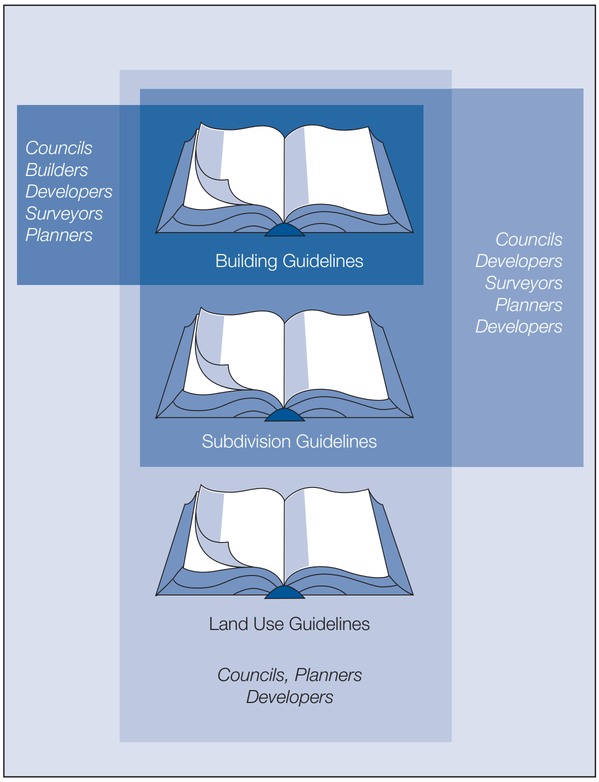



In NSW, councils have responsibility for floodplain risk management in their areas, assisted by technical and financial support from the State Government. One of the key Strategy outputs to assist Hawkesbury-Nepean floodplain councils in this process is the Regional Floodplain Management Study (RFMS). 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 1.2*** *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).

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"*, Figure 1.2. 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

*"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 INTRODUCTION

## 1.1 THE FLOOD PROBLEM

In Australia, floods cause more damage on an average annual basis than any other natural disaster. Historically our towns developed on riverbanks to facilitate the shipping of goods to and from the settlements but this also left them vulnerable to inundation.

It has been estimated that on average floods in New South Wales cause over $100 million of damages a year in financial terms alone. They also result in other intangible consequences such as trauma, stress and loss of memorabilia.

Although different types of flooding – e.g. mainstream, flash, and overland – behave differently, the damage from flooding fundamentally results from the depth and duration of inundation and the velocity of the water.

In severe conditions of depth and velocity an individual house can be totally destroyed. However, even in still water the house structure can easily suffer damage in excess of $20,000. This figure does not include costs for replacing any contents, (Figure 2).

While there are building codes for other natural hazards including bushfires, earthquakes and cyclones, there is currently no Australian standard for building in flood prone areas.

The result is that flooding is often neglected as a design consideration for houses and the majority of contemporary houses are highly vulnerable to component damage and severe structural failure when exposed to floodwaters. Typically there are also very few measures incorporated in building requirements to protect the structure from flooding above the flood planning level. Damage from water contact alone can be quite extensive and difficult to repair.

The nature and extent of flood damage on a building's load bearing components and its structural adequacy is also poorly understood. While basic information on the material suitability has been available, detailed technical information has been lacking to allow the structural system (e.g. timber frame) to be adequately evaluated and designed. This has hindered the building industry in selecting and developing alternatives, which perform better in floods, or can overcome some of the problems associated with traditional construction.

***Figure 2** Severe structural damage to buildings of traditional design and construction*

Houses can be severely damaged by flooding even if they are located above the flood planning level.

## 1.2 CONTROLLING THE FLOOD PROBLEM

Although flooding in Australia causes more damage annually than any other natural hazard, its nature and extent can be readily determined and therefore its impacts can be largely prevented. In recent decades, primarily because of economic and environmental constraints, the focus in New South Wales has been towards managing the consequences to limit flood damage rather than the tradition of modifying flood behaviour to decrease flooding.

Planning and building controls have the potential to be far more cost-effective than engineering solutions which can eliminate more frequent flooding but have very limited scope to reduce impacts from larger floods. They also have a distinct advantage over flood modification works in that they can target specific problem areas and comprise of measures tailored to their solution.

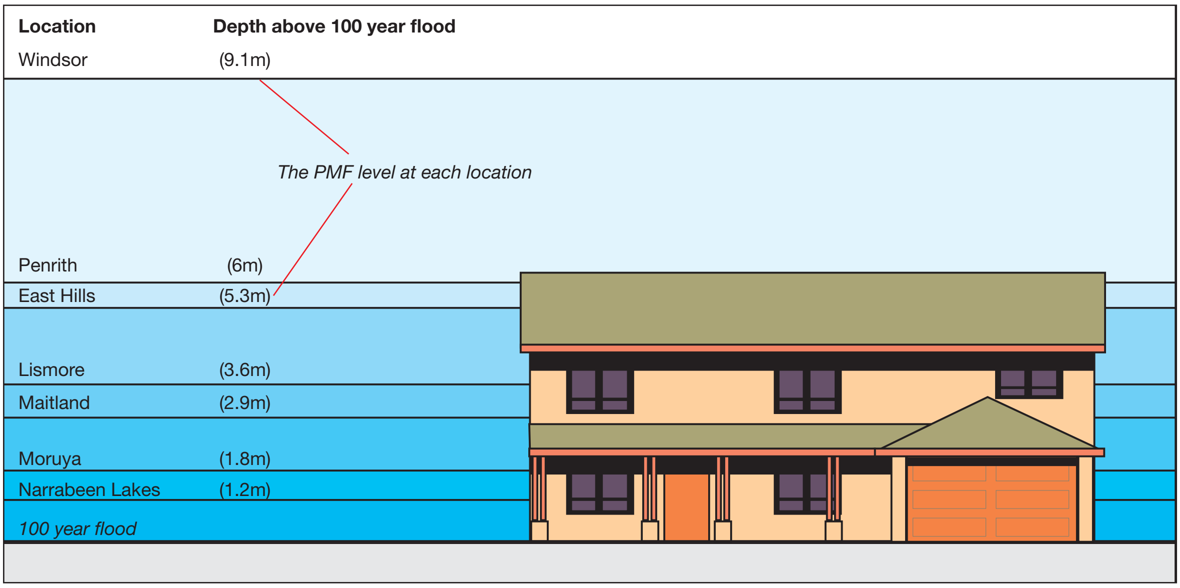
In NSW, councils have the statutory responsibility for managing floodplains and each selects a flood level as the basis for planning purposes. Commonly the 1% (or 1 in 100 AEP) flood is adopted as the basis for setting the flood planning level (FPL). As a result, new houses in many areas have their floor level at 0.5 metres (freeboard) above the 1% AEP flood level.

However, this does not mean that the house is “flood-free”. Depending on the location in the floodplain, the probable maximum flood (PMF) level can range from less than a metre to over 10 metres above the flood planning level. Accordingly, some houses with floors constructed above the planning level can still be fully submerged by floodwaters in larger floods. Even the Hawkesbury-Nepean flood of record in 1867, which is less than a 0.5% probability event (or 1 in 200 AEP), would result in two metre deep flooding over the floor of houses with floor levels at the current 1 in 100 AEP flood level. Although the chance of floods higher than the planning level may be small, the impacts on a house and its contents may be quite severe and therefore the damage risks remain relatively high. (Figure 3).

Restricting development to above the planning level can reduce the frequency of flooding, but has absolutely no effect on reducing its consequences when flooding occurs. This can only be controlled by reducing the vulnerability of assets at risk. For the majority, the home is a family’s largest asset and investment and unfortunately the most vulnerable.

*NOTE: For the purposes of these guidelines, unless otherwise indicated, the term “flood planning level” refers to the elevation below which residential floor levels are not permitted (commonly the 1 in 100 AEP flood level plus a “freeboard” allowance). In reality, councils may have a number of flood planning levels which may dictate other flood related controls on development. More information on flood planning levels and freeboard can be found in the Land Use Guidelines “Managing Flood Risk through Planning Opportunities.”*

***Figure 3*** *Comparison of flooding potential in New South Wales*



## 1.3 WHY THESE GUIDELINES?

The primary purpose of these guidelines is to provide councils, designers, developers and the public with:

- information on the disadvantages of traditional timber framed house construction and practice in flood prone areas, and
- guidance on measures that could be taken to improve the performance of buildings both during and after a flood.

Information is provided on:

- the performance of various types of building materials when subject to flood conditions (i.e water immersion),
- the performance of different types of residential building construction,
- special consideration for design of site foundations,
- likely physical damage and the typical costs associated with such damage for a range of different types of housing,
- use of more appropriate materials and designs for house construction to reduce damage and the costs involved in their use, and
- post-flood reinstatement of dwellings.

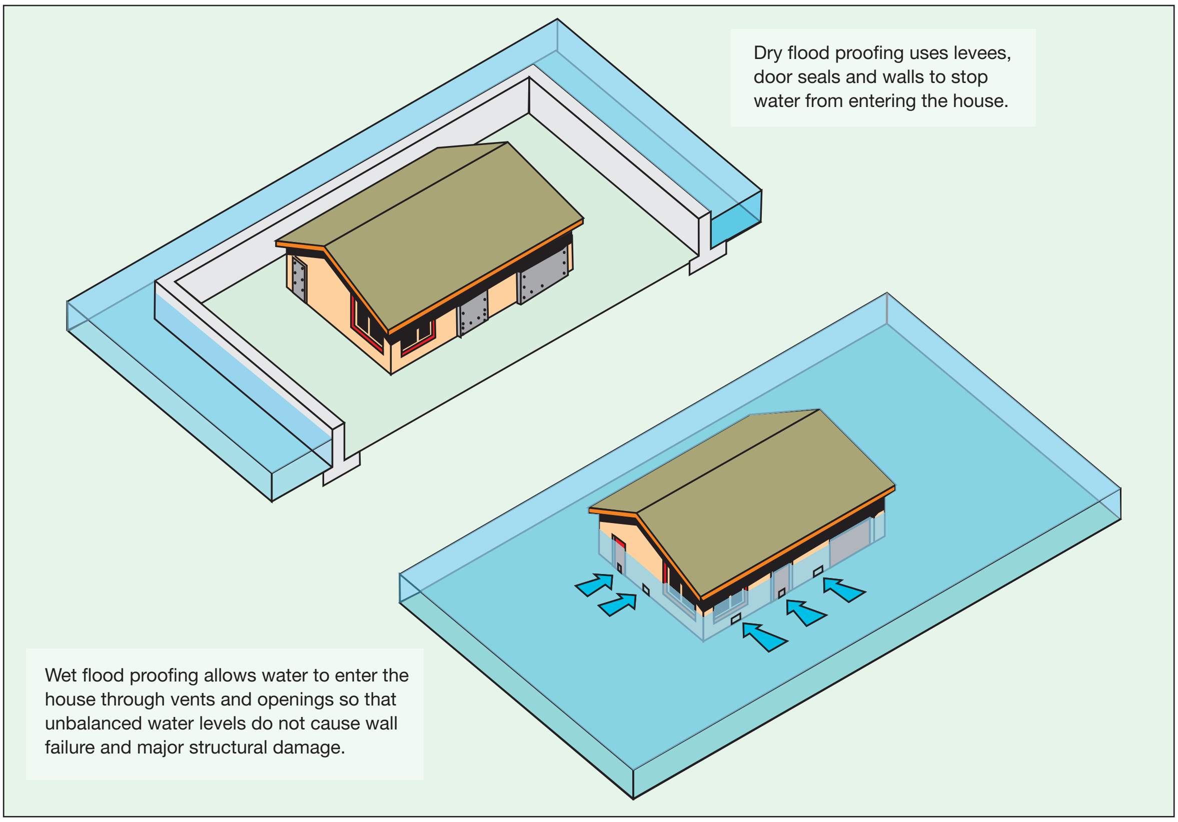
The intent has been to concentrate on identifying and addressing areas which contribute significantly to flood damage to the house structure or may be crucial for structural reasons. The aim is to provide a reduction in potential damages to traditional buildings, through better designs and more careful selection of materials.

The extent of damage, cost of repairs, inconvenience and cleaning required will depend on many factors including:

- depth and velocity of the water,
- period of inundation,
- debris loads and silt in the water,
- house location and its orientation to any flow,
- spacing of houses (which influence the velocity of the flow between buildings),
- materials used,
- construction detailing, and
- how quickly the house can be cleaned and completely dried out after a flood.

The approach in these guidelines is to "wet flood proof" a house because depths of inundation are potentially high. On floodplains like the Hawkesbury-Nepean River, it is better to allow water to enter the house to avoid water loads,

***Figure 4*** *Wet and dry flood proofing*



New houses are the focus of these guidelines rather than retrospective flood proofing of existing houses.

which can cause structural damage or collapse the walls. Flooded buildings that need only cleaning and superficial repairs can be reused quickly. In contrast, houses with major wall damage are difficult to assess structurally, and are likely to require lengthy and expensive reconstruction.

An alternative approach is to "dry flood proof" a house. This works on the principle that actions are taken to prevent water from entering a house such as constructing permanent or temporary barriers such as levees, sandbags or door seals. While there are arguments for and against each approach, dry flood proofing measures are normally expensive, cumbersome, require maintenance and, in many cases, need the occupant to be present to seal openings prior to flooding. (Figure 4).

A dry flood proofing approach is not appropriate on the Hawkesbury-Nepean floodplain where flood depths can be very large.

## 1.4 THE SCOPE OF THESE GUIDELINES

New houses are the focus of these guidelines rather than retrospective flood proofing of existing houses by elevation or relocation. Measures to reduce flood damage are more cost-effective at the design stage. The key aim is to minimise flood damage to the structural load bearing components of a building to prevent the structure from failing and leading to costly rebuilding or even demolition. Preferably, reinstatement of a flooded home should involve little if any content replacement, cleaning and minor repairs.

These guidelines are intended principally for use with traditional house construction such as double brick and framed houses clad with brick (brick veneer), fibre cement or plywood sheets, weatherboard or similar materials. Modern house construction materials are discussed and reference is made to unit and villa type construction. Although not specifically referenced, the principles and many of the recommendations provided in the guidelines are also applicable to commercial and industrial buildings.

These guidelines are divided into six sections and a technical appendix.

**Section 1 – Introduction**

Reviews the flood problem and how it is being addressed and why these guidelines have been produced.

**Section 2 – Controlling Risk Exposure through Flood Aware Design**

Looks at areas vulnerable to floods in typical house construction, what a flood-aware house is, the cost effectiveness of these buildings and prioritises flood-aware components/design to assist with decisions about which component/ design to select.

**Section 3 – Vulnerability of Housing to Floods and Potential Solutions**

Examines the types of flood damage that may be sustained.

**Section 4 – General Design and Construction Considerations**

Provides advice on such issues as choosing a site, the best form of house, material selection and how to maximise the rate of drying after a flood.

**Section 5 – Structural Component Design**

Looks at each of the major structural components of a house and potential problems and how to reduce the problems by better material selection and design. It also provides an indication of the cost of adopting various recommendations.

**Section 6 – Non-Structural Component Design**

Considers the non-structural components of a house and better solutions to minimise expensive replacement costs after a flood.

**Appendices**

*Technical considerations of flood forces*

Looks in depth at flood forces and how to manage them.

*Limitations*

Includes some of the assumptions used and advises of the safeguards that should be used when implementing the guidelines.

*Glossary*

Definitions of technical terms used in the guidelines.

*References*

Some useful references to books and publications.

## 1.5 FLOOD TERMINOLOGY

The magnitude of a flood is usually indicated by how high floodwaters reach above the normal river level or above a certain reference level. This can be related to how often such a flood is likely to occur or be exceeded on average over a long period. For example, a flood resulting in a level likely to occur or be exceeded once every 50 years on average is referred to as a 1 in 50 Annual Exceedence Probability (AEP) flood. The size of a flood can also be referred to in percentage terms i.e. the chance a certain level flood has of occurring or being exceeded in any one year. Dividing the expected average frequency of the flood in years by 100, gives the percentage value e.g. a 1 in 50 AEP flood has a (100 ÷ 50) percent (or 2%) chance of occurring, or being exceeded, in any one year.

The largest flood that could conceivably occur at a particular location is referred to as the probable maximum flood (PMF). Land which is inundated by the PMF is referred to as flood liable or flood prone land. It also defines the floodplain of the river.

At **Windsor** on the Hawkesbury River, the estimated flood levels are approximately:

| Flood | Flood Level (AHD) |
|---|---|
| 1 in 10 AEP | 12.3 |
| 1 in 50 AEP | 15.7 |
| 1 in 100 AEP | 17.3 |
| 1 in 1000 AEP | 21.7 |
| PMF[1] | 26.4 |

*The above flood levels are to Australian Height Datum (AHD) which is an elevation roughly equal to the mean (or average) sea level.*

## 1.6 THE BUILDING CODE OF AUSTRALIA

The Building Code of Australia (BCA ) contains the technical building requirements that must be complied with by any development in NSW, under the Environmental Planning and Assessment Act (1979).

The BCA is a national document referenced by all the States and Territories of Australia, who all cooperate and contribute to the objective (and associated processes) of creating and maintaining nationally consistent provisions for building design and construction, through the Australian Building Codes Board (ABCB)[2], via an Inter-Government Agreement.

Although the BCA is mandatory for all building work, at present it does not provide building requirements that specifically apply to flood prone land. This role currently rests with local councils who have knowledge of the particular flooding regimes that apply to their LGA and have building policies and/or controls specifically for their flood prone areas.

Any future revisions to the BCA to assist in preserving the integrity of buildings in flood prone areas are likely to fall into two categories:

- compulsory provisions that must be applied; and
- suggested methodologies and complementary guidelines.

Until the BCA is revised with appropriate provisions etc, the recommendations in this guideline are additional to the BCA for the purposes of construction in flood prone areas. However, in the event of any ‘conflict’ between the two documents the BCA should take precedence over this guideline.

*[1]Estimated as a 1 in 90,000 AEP event in the Hawkesbury-Nepean catchment.*

*[2]The ABCB Working Group is considering ways of enhancing the BCA to address all hazards, including those from flooding. This guideline contains information that would assist with the development of provisions for inclusion into the BCA to improve the integrity of houses built on flood prone land.*

# 2 CONTROLLING RISK EXPOSURE THROUGH FLOOD AWARE DESIGN

## 2.1 FLOOD IMPACTS ON DOMESTIC HOUSING

The illustrations in Figures 5, 6 and 7 indicate some of the more significant and common problems with various forms of house construction affected by floods. Full information is provided in the relevant sections of these guidelines.

***Figure 5*** *Problem areas in most common form of external wall construction – brick veneer*

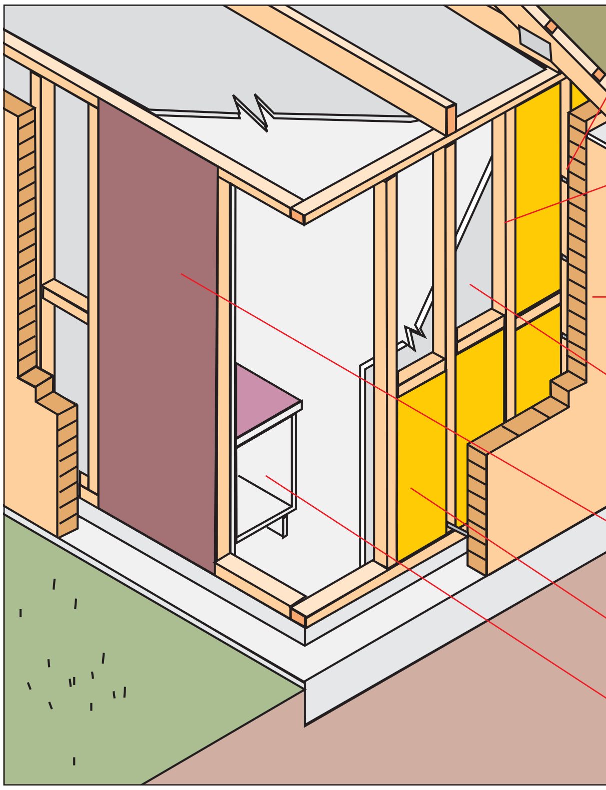
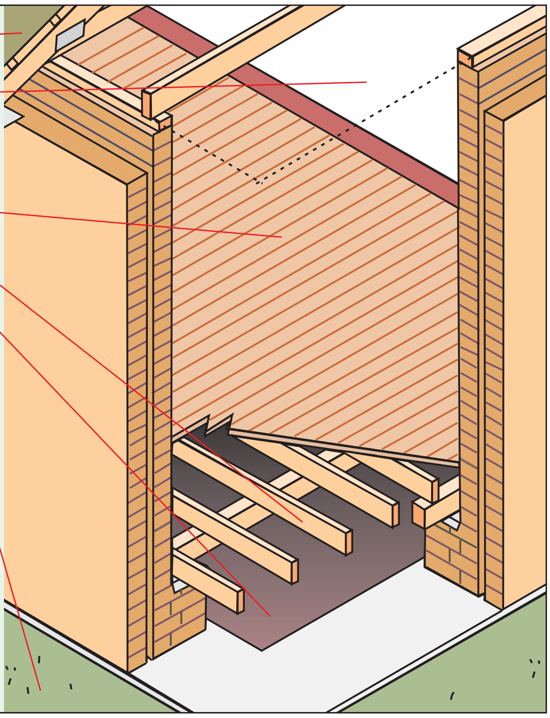



***Figure 6*** *Problem areas in domestic construction*



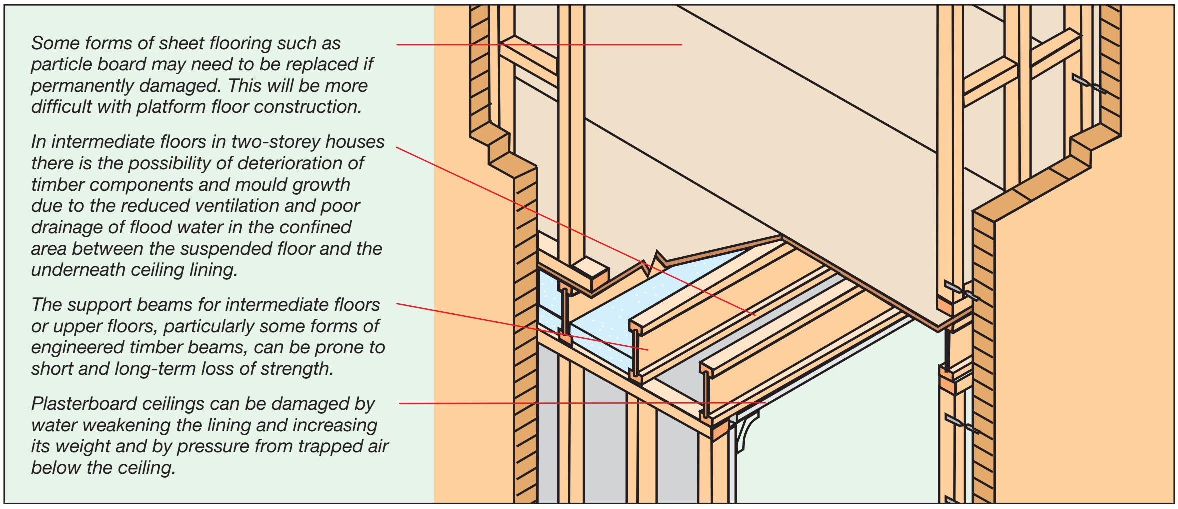

**Other problem areas in the house:**

- Some forms of sheet flooring such as particle board can lose strength and even collapse if heavily loaded when wet.
- Electrical supply components (conduits, powerpoint, light fittings and switchboards) can trap moisture and silt and become unsafe after immersion,
- Absorbant floor coverings such as carpet, linoleum and cork need to be removed to allow the floor to dry out.

*Note: Ceiling types with a confined roof space, e.g. cathedral, can exacerbate roof problems due to difficult access and poor ventilation.*

Simple changes to design detail or building materials have been identified which will improve a home's flood performance.

***Figure 7*** *Problem areas in intermediate floors and ceilings in two-storey houses*




## 2.2 WHAT IS FLOOD-AWARE HOUSING?

A house is usually an individual's or family's most expensive investment and possession. Severe flooding can potentially cause major or total damage to the house structure. However, there are a number of relatively simple and cost-effective measures to reduce the vulnerability of the house structure to flood inundation.

The illustrations in Figures 8 and 9 depict the key suggestions from these Building Guidelines to achieve flood-aware housing which:

- reduces flood damage to critical components of a house which, if damaged, can impair a building's structural performance,
- reduces post-flood repair costs,
- allows a resident to return to their home more quickly after a flood.

Only the highest priority and most cost-effective measures have been selected for the illustrations out of the many possible measures discussed throughout these guidelines. They focus on components which have both a high vulnerability to water damage and are structurally important.

In many cases, modification to design detail or simply choosing a more flood-resistant building material, will improve a home's flood performance, as well as avoid high repair costs and prolonged recovery periods.

Other more fundamental design considerations include whether to build a single or two-storey dwelling. Both these options are addressed here, with a two-storey flood aware option preferred for high flood depth locations (e.g. in the Hawkesbury-Nepean valley: Pitt Town, Riverstone, Windsor and Richmond).

### The two-storey advantage

The large flood range on the Hawkesbury-Nepean floodplain, means that a severe flood such as the event in 1867 would result in two metres of floodwater in any house placed at the 1 in 100-year flood level. This could result in a contents damage bill exceeding $50,000, plus building repairs ranging from minor to major reconstruction.

Using a flood-aware two-storey house will reduce major structural damage and allow residents to store valuable contents upstairs at the time of a flood. This preferred design includes a full brick ground floor as a structural enhancement which will also improve recovery after floodwaters have receded (see Section 4.2.1.2 for more information).

Choosing to build a two-storey house instead of a single-storey with a similar floor area, adds less than 10% to building costs. But already many home owners are making this decision in response to smaller lot sizes available on the market and the high land values.

| | |
|---|---|
| To adapt a standard two-storey brick veneer house to flood-aware design principles to withstand a flood of record in the Hawkesbury-Nepean valley, would cost an additional $10,000 (as illustrated here), representing a 5% increase in the total cost of the standard house. | The long-term benefits of designing and building a flood-aware two-storey house, which can provide a family greater assurance against loss of the building and dramatically reduce their personal liabilities from flood damage, far outweigh the initial cost of building. |



***Figure 8*** *Single-storey flood aware design for low hazard areas*

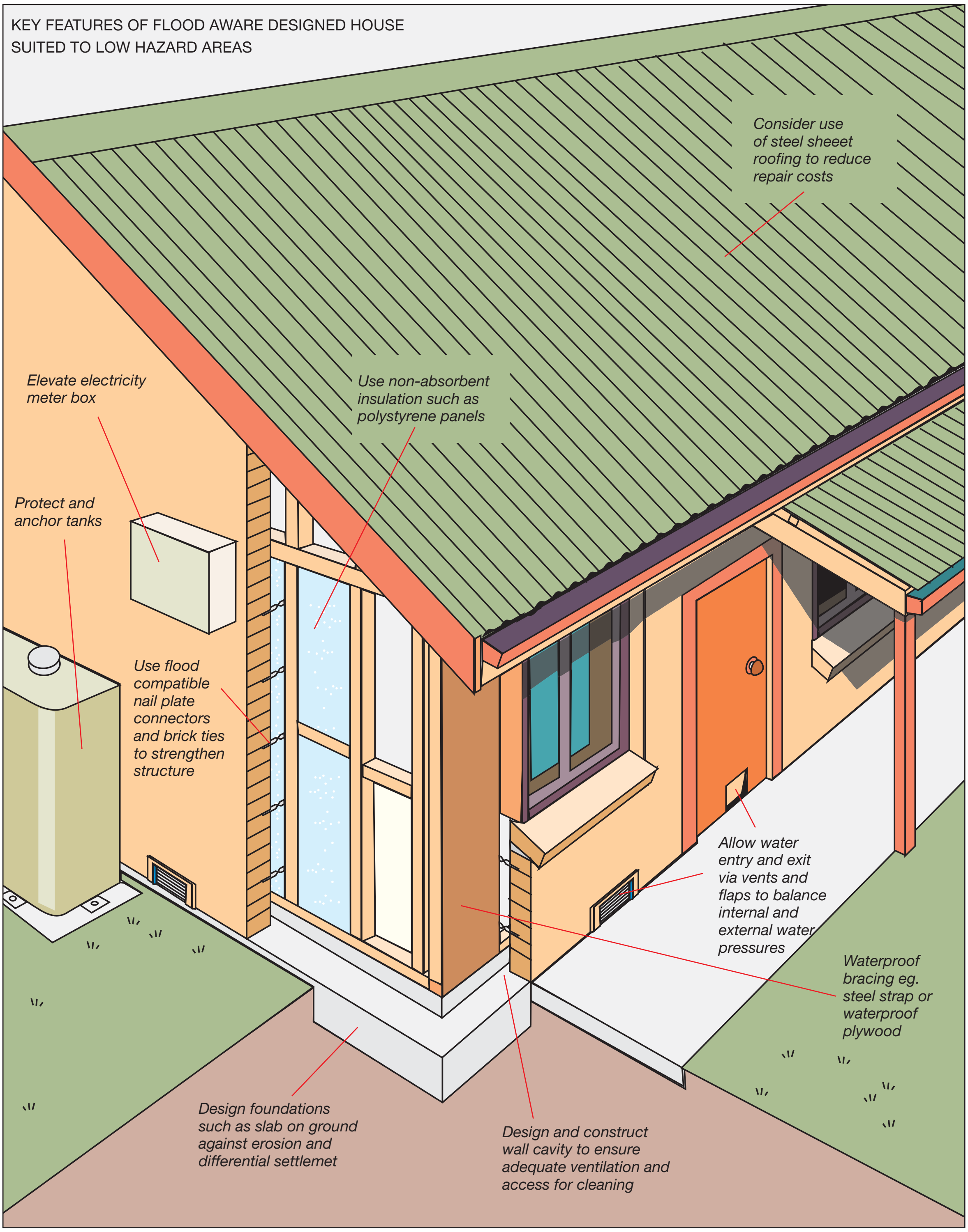
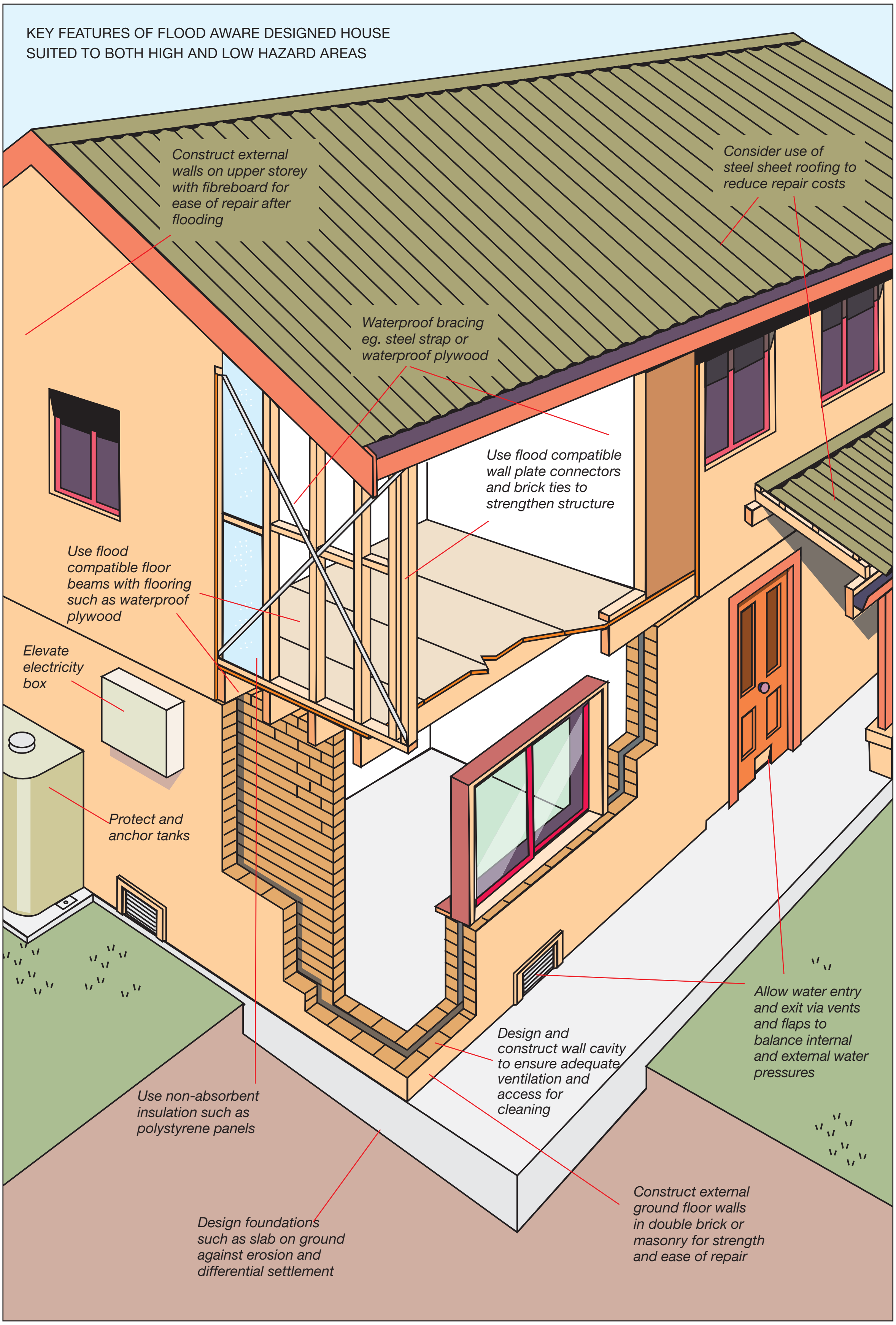


***Figure 9*** *Two-storey flood aware design for high hazard areas*



## 2.3 COST COMPARISON OF FLOOD-AWARE HOUSING DESIGN WITH STANDARD CONSTRUCTION

Figures 10, 11 and 12 provide a cost comparison of one and two storey flood aware housing with standard house construction. The indicative costs provided are based on a two-storey house with a 100m$^2$ ground floor area and 80m$^2$ upper floor area and a single-storey house with a floor area of 180m$^2$.

***Figure 10*** *One-storey versus two-storey*

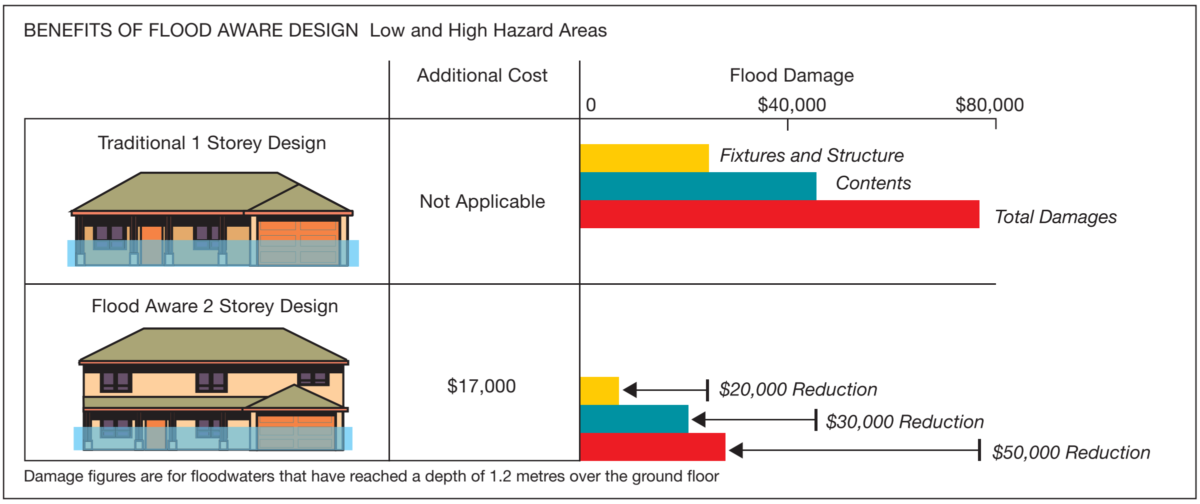



***Figure 11*** *Traditional two-storey versus flood-aware two-storey*

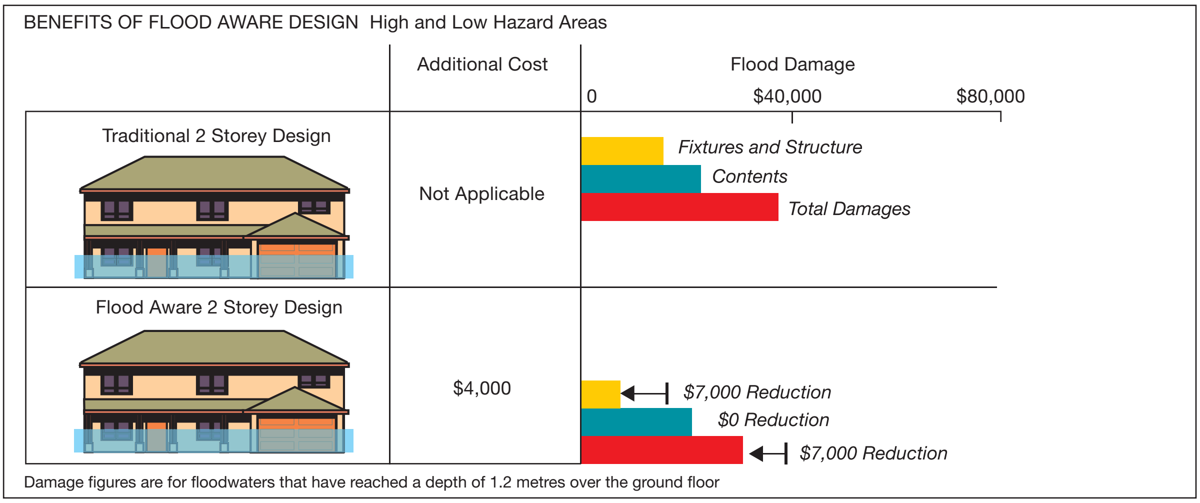
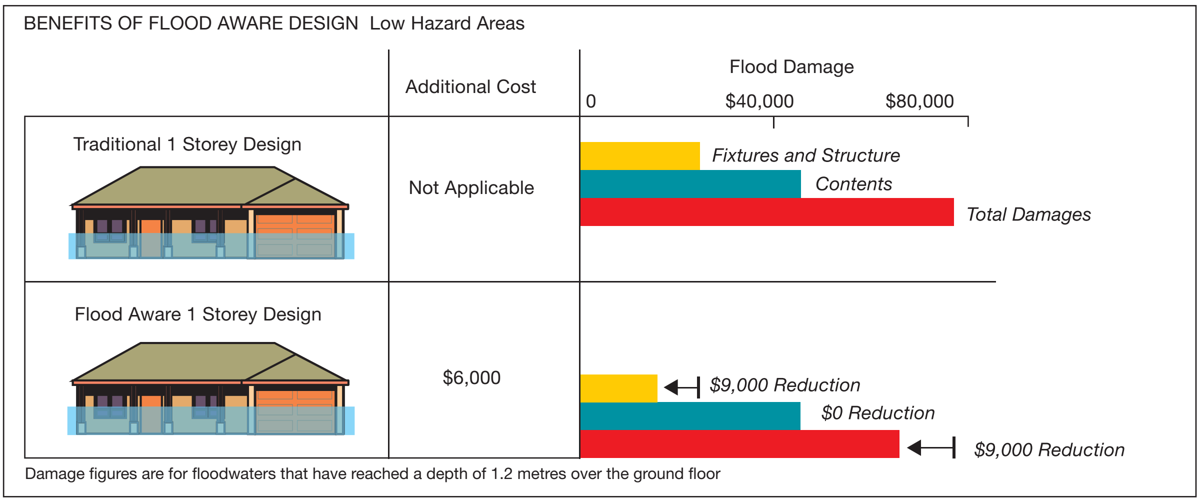



***Figure 12*** *Traditional one-storey versus flood aware one-storey*



## 2.4 BUILDING COMPONENTS AND FLOOD-AWARE DESIGN

To help councils and the building industry to make decisions on which flood aware solutions to use for their local situation, the following set of basic structural systems have been addressed:

- Foundations
- Ground floor
- Walls
- Intermediate floors
- Roof frame

These structural systems are not only fundamental to any building, but their condition is critical to it remaining a sound structure that is safe to occupy.

As detailed in Table 2.4.1, building components have been graded according to their vulnerability to water damage and repair difficulty. The most flood-aware options head each category followed by options which progressively increase the building's vulnerability to the impact of flooding.

These gradings have been developed following considerable research, testing and analysis involving the CSIRO, University of New South Wales, University of Newcastle, leading architects and engineers, and the Department of Infrastructure, Planning and Natural Resources.

To assist with decisions on which flood-aware designs and components to use, the four performance criteria listed here should be applied in the following order of priority:

- Does the component preserve structural performance during and after a flood?
- Will it prevent further post-flood deterioration?
- Will it help reduce high repair costs following a flood?
- Is the use of the component cost-effective?

Table 2.4.1 discusses the advantages, disadvantages and design considerations of key components and designs for a range of common house construction types in order of their vulnerability to flooding.

The foundation system for the majority of dwellings is based on a concrete slab which is inherently resistant to water damage. No comparison has been made with other systems as the suitability of various options is largely dependent on site conditions. In addition, the existing building codes cover a full range of site conditions and soil types. Foundation designers need to recognise the potential for flooding and therefore make due allowances for it in their design assumptions. The comparison presented in the following tables is not of the foundations but that between concrete and timber floor support systems.

***Table 2.4.1*** *Advantages and disadvantages of key components and designs*

### GROUND FLOOR

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| ADVANTAGES | DISADVANTAGES | PROVISIONS FOR PROTECTING STRUCTURAL PERFORMANCE |
|---|---|---|
| **Raised Concrete Slab (Section 5.1.2.2)** | | |
| • All the advantages of slab on ground construction<br>• Raised floor (on fill, waffle pod, suspended slabs) minimises risk of water entering house when surrounding ground is flooded | • Steps may be required | • In areas of high silt deposition, use a deeper slab rebate to hold more silt without it bridging the wall cavity |

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| | | |
|---|---|---|
| • Suitable for uneven ground / sloping site – avoids need for cut and fill and reduces costs of retaining walls and drainage<br>• Can also utilise a range of proprietary precast flooring systems where fill is not employed | | |
| **Slab on ground (Section 5.1.2.2)** | | |
| • Generally undamaged by immersion for any period<br>• The additional weight and strength helps to resist buoyancy forces<br>• Slab on ground floors tend to be the least expensive option | • For a given ground level, slab on ground floors will normally be only slightly higher and more vulnerable to inundation including local overland flooding<br>• Potentially suffers from scouring/ underminding effects | • In areas of high silt deposition, use a deeper slab rebate to hold more silt without it bridging the wall cavity |
| **Suspended Timber floor (Section 5.2)** | | |
| • Likely extra elevation reduces the flood risk<br>• The house can be designed so that minor flooding and overland flow can pass under the floor | • Timber components more prone to damage and may need replacing or repairing<br>• Timber strip flooring should not suffer any significant loss in strength but may swell or cup (moisture resistant flooring, bearers and joists could be used as substitute for natural timbers)<br>• House could be more prone to uplift (especially sheet clad houses)<br>• Suspended floors are more expensive | • Ventilation needed to ensure drying and to prevent decay of timber components<br>• Allow for some loss of load bearing capacity with manufactured / engineered timber beams<br>• Select plywood flooring with waterproof glue bond<br>• Avoid particleboard flooring (which weakens after immersion) and underfloor thermal and noise insulation or remove it post-flood to assist drying |

2

## LOAD BEARING WALL SYSTEM (lower and upper storeys)

Supports vertical loads from upper structure and roof, and resists horizontal forces from wind, flood water, earthquake, etc.

*Increasing vulnerability*

*Increasing vulnerability*

| ADVANTAGES | DISADVANTAGES | PROVISIONS FOR PROTECTING STRUCTURAL PERFORMANCE |
|---|---|---|
| **Concrete Walls (including concrete panels, blockwork and poured in-situ concrete) (Section 4.3.2)** | | |
| • No cavity to hold moisture and/or silt<br>• Very strong<br>• Immune to water damage<br>• Minimal clean-up and repair<br>• Extra weight helps to cancel uplift forces<br>• Skirtings and architraves commonly not used | • Specialised construction needed for in-situ and concrete panel<br>• Unfinished concrete blockwork may not be acceptable for appearance reasons | • Concrete walls can be designed to resist additional wall loads by use of suitable reinforcement<br>• Unfinished concrete blockwork may need to be painted if any waterproofing is required in a wall |
| **Cavity Brick (Double Brick) (Section 5.3)** | | |
| • Brickwork unaffected by immersion<br>• Minimal clean-up and repair<br>• No chance of decay, distortion or rusting of supporting frame<br>• Normally no wall insulation required<br>• Extra weight helps to cancel uplift forces<br>• Skirtings and architraves not required<br>• Cement render finish is durable | • Full brick lower floor with brick veneer upper floor will cost around $4,000 more than brick veneer for both lower and upper floors<br>• Full brick lower and upper storey walls will cost around $7,000 more than brick veneer for both lower and upper floors<br>• Double brickwalls will take considerable time to dry after a flood which must be factored in to repairing any coatings on the brick | • Provide for ingress of water to balance hydrostatic forces inside and outside of the walls<br>• Include openings into cavity to facilitate removal of silt from cavity |

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| Steel wall frame (Section 5.3) | | |
|---|---|---|
| • Steel strength unaffected by immersion<br>• Frame unlikely to warp or corrode over short period<br>• Cavity can be cleaned by removing the internal lining | • Exterior cladding or brick veneer can be damaged with movement of the wall frame<br>• Some internal linings may need extensive replacement<br>• Some types of bulk insulation retain moisture and may need to be removed to aid drying – replacement would only follow adequate drying of structure.<br>• Difficult to remove silt from upturned framing channels<br>• Unsuitable types of wall bracing may need replacing<br>• Steel frame is slightly more expensive than a timber frame<br>• Retained silt or salt may lead to corrosion | • Provide for ingress of water to balance hydrostatic forces inside and outside of the walls<br>• Include openings into cavity to facilitate removal of silt from cavity<br>• Provide adequate drainage and ventilation to prevent deterioration from moisture over time<br>• Bracing is critical to resist horizontal forces from wind gusts and flowing water – use materials not impaired by immersion to avoid failure under loading and to minimise need for costly replacement due to lack of accessibility after construction eg. fibre cement or waterproof plywood sheets (extra cost less than $100 for the house) |

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| Timber wall frame (Section 5.3) | | |
|---|---|---|
| • Timber frame construction is traditional and economic<br>• Cavity can be cleaned by removing the internal lining<br>• Least expensive construction | • Frame can warp or swell<br>• Frame may suffer decay or mould can grow if not dried<br>• Exterior cladding or brick veneer can be damaged with movement of the wall frame<br>• Some internal linings may need extensive replacement<br>• Some types of bulk insulation retain moisture and may need to be removed to aid drying – replacement would only follow adequate drying of structure.<br>• Some bracing types may need replacing | • Provide for ingress of water to balance hydrostatic forces inside and outside of the walls<br>• Include openings into cavity to facilitate removal of silt from cavity<br>• With load bearing members such as stud wall frame; lintels; spanning beams:<br>– avoid materials /glue bonds which can weaken significantly with immersion, &<br>– prevent deterioration from moisture over time by providing adequate drainage and ventilation.<br>• Bracing is critical to resist forces from wind gusts and flowing water |

## NON LOAD CARRYING COMPONENTS EXTERIOR WALL CLADDING

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*Increasing vulnerability*

| ADVANTAGES | DISADVANTAGES | SPECIAL FLOOD PROVISIONS |
|---|---|---|
| **Brick Veneer cladding with stud frame (Section 5.3)** | | |
| • Brickwork unaffected by immersion<br>• Extra weight to resist buoyancy<br>• Painting not required | • Brickwork can be damaged by impact loads, excessive deflection of wall studs, brick ties breaking, buckling or pulling out or movement of wall frame<br>• Prone to cracking which can weaken the brickwork and cause it to be unsafe, if inadequate openings | • Improve brick wall stability through use of side fixed ties<br>• Use articulation joints to limit cracking from uneven foundation movement<br>• Provide generous venting through brickwork to balance hydrostatic forces and maximise cavity drying rate to minimise timber decay<br>• Protect frame from failure and bottom sliding. For locations where there may be a high frequency of flooding or there is a chance of salt water flooding use stainless steel or other high durability ties with angled surfaces to promote runoff |
| **Sheet or plank weatherboard cladding on stud frame (Section 5.3) eg fibre cement, plywood** | | |
| • Lower construction costs than brickwork<br>• Cheaper to repair than brickwork when damage localised as sections are easily removed and quickly replaced<br>• Timber cladding can have high impact resistance<br>• Cladding adds to the the strength of the frame<br>• Sheet cladding can be finished to resemble rendered brickwork<br>• Lighter structure can result in cost savings for 2 storey construction | • Some cladding may be damaged by immersion<br>• Painting / coating required to protect cladding | • Use materials not impaired by immersion e.g. fibre cement or waterproof plywood sheets |

## NON LOAD CARRYING COMPONENTS INTERIOR LINING OF WALLS

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| ADVANTAGES | DISADVANTAGES | SPECIAL FLOOD PROVISIONS |
|---|---|---|
| **Bare Face Bricks or Cement Render (Section 5.6)** | | |
| • Unaffected by water immersion<br>• Not prone to impact damage<br>• Easy to clean or repaint | • Slightly higher cost compared to alternative linings | • Staining of light coloured face bricks may be a consideration |
| **Fibre Cement with Stud Frame (Section 5.6)** | | |
| • Minimal water damage<br>• Screw fitting can allow removal to clean and dry out cavity and possible reuse | • More difficult to replace than other wall boards<br>• Higher cost than plasterboard | • Horizontal jointing reduces replacement costs<br>• With a timber frame, the cavity should be well ventilated to reduce the chance of timber decay<br>• Leave lower edge lining 30mm above bottom wall plate or cut notches to allow entry of water, ventilation and silt removal. Use deeper skirting boards to cover openings on lining. Screw fixings enables easy removal |
| **Plywood with Stud Frame (Section 5.6)** | | |
| • Waterproof plywood would suffer minimal water damage<br>• Higher impact resistance<br>• Screw fitting can allow removal to clean and dry out cavity and possible reuse | • Potentially higher cost than plasterboard | • Grades with waterproof bond recover strength after drying out<br>• Horizontal sheet fixing can reduce replacement costs<br>• With a timber frame, the cavity should be well ventilated to reduce the chance of timber decay<br>• Leave lower edge lining 30mm above bottom wall plate or cut notches to allow entry of water, ventilation and silt removal. Use deeper skirting boards to cover openings on lining. Screw fixings enables easy removal |

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| | | |
|---|---|---|
| **Plasterboard with Stud Frame (Section 5.6)** | | |
| • Most common wall lining<br>• Relatively cheaper than other linings | • More easily damaged when wet<br>• Likely to need replacing after prolonged immersion (longer than flash flooding)<br>• Whilst this is the least expensive form of wall construction, repair of internal linings could cost over $8,000 for a single storey house and over $5,000 for the lower walls of a 2 storey house | • As sheets are weakened and can incur permanent damage and loss of strength, ignore wall bracing contribution from lining<br>• Horizontal sheet fixing can reduce replacement costs<br>• With a timber frame, the cavity should be well ventilated to reduce chance of timber decay<br>• Leave at least 30mm above bottom wall plate or cut notches to allow entry of water, ventilation and silt removal. Use deeper skirting boards to cover openings on lining. Screw fixings enables easy removal |

## INTERMEDIATE FLOORS

Support floor loads as well as any wall and roof loads placed over the floor

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| ADVANTAGES | DISADVANTAGES | PROVISIONS FOR PROTECTING STRUCTURAL PERFORMANCE |
|---|---|---|
| **Suspended Concrete Slab (Section 5.2)** | | |
| • Minimal water damage<br>• High strength | • Concrete has very high weight loading which is unsuitable for stud wall construction<br>• High cost - around $10,000 more than a typical timber floor (assuming the lower walls are suitable) | • Minimal flood damage if no under slab false ceiling.<br>• False ceilings are prone to damage and should be removed to permit cleaning of under slab area |

| Suspended Timber Floor (Section 5.2) | | |
|---|---|---|
| • Quick and economic construction<br>• Material costs savings with introduction of alternatives to solid timber floor beams and platform construction<br>• Can be used when the lower floor walls are stud frame construction | • Unsuitable timber components may warp, swell or deteriorate perhaps requiring replacement<br>• Ceiling lining likely to need replacing if floodwaters reach this high<br>• The under floor area can be a moisture trap causing subsequent decay or other problems if floodwaters rise above the second storey and the ceiling is not removed | • Ventilation needed to ensure drying and to prevent decay of timber components<br>• Floor Joists (2nd storey) – solid sawn timber – ensure drying to prevent decay. Manufactured engineered beams – allow for some loss of load bearing capacity when saturated and blocking to provide extra restraint and resist distortion<br>• Avoid using components that may degrade (particle board) under structural components (wall frames)<br>• Flooring - structural platform carrying weight of furniture and other contents<br>– Platform (walls constructed over flooring) use floor sheets which do not deteriorate significantly under wet conditions and have a fully waterproof bond e.g. extra cost for waterproof plywood flooring is around $100 - $300.<br>– Cut in (flooring laid after walls completed)<br>> timber strip flooring (tongue and groove) – no loss in strength.<br>> possible cupping after drying out.<br>A polished hardwood floor costs around $10,000<br>• Thermal and noise insulation – avoid or remove to assist drying. |

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2

## NON LOAD CARRYING COMPONENT CEILING LININGS

Any measures adopted to improve the flood resistance of ceilings need to recognise the much lower probability of the floodwaters reaching the ceiling due to the extra elevation over the floor.

*Increasing vulnerability*

| ADVANTAGES | DISADVANTAGES | SPECIAL FLOOD PROVISIONS |
|---|---|---|
| **Fibre Cement (Section 5.6)** | | |
| • Minimal water damage<br>• Unlikely to collapse if flooded<br>• Water resistant fibre cement ceilings are unlikely to need removal for repair | • Not commonly used for ceilings<br>• More difficult to remove and replace than plasterboard | • Where the area above the ceiling is confined (eg intermediate floors, cathedral ceilings), use non-absorbent insulation (eg polystyrene, foil) to reduce the risk of decay to timber joists and underside of floors<br>• Insert small air vents in the ceiling to relieve pressure from trapped air in the room and ventilate enclosed areas to reduce risk of timber decay |
| **Plasterboard (Section 5.6)** | | |
| • Less expensive than alternatives<br>• Easy to remove and reinstall or undertake patch repairs | • Likely to sag due to increased weight from absorbed water and loss of strength<br>• Can collapse if there is a loss of strength and water trapped above<br>• May be damaged by trapped air pressure in floods that almost reach the ceiling | • Insert small air vents in the ceiling to relieve pressure from trapped air in the room and ventilate enclosed areas to reduce risk of timber decay |

## ROOFS

Any measures adopted to improve the flood resistance of roofs need to consider the reduced probability of the roof flooding due to the extra height above the floor.

*Increasing vulnerability*

| ADVANTAGES | DISADVANTAGES | PROVISIONS FOR PROTECTING STRUCTURAL PERFORMANCE |
|---|---|---|
| **Traditional Pitched Roof** | | |
| • Good access for cleaning and repairs<br>• Generally good ventilation<br>• Able to support a range of light and heavy roofing materials | • Non-tiled roofs or roofs with sarking may need additional ventilation | • Roof Truss – careful detailing required to help avoid potential weakening of timber truss connections upon immersion<br>• Terracotta or cement roof tiles absorb moisture – increased weight on roof frame should be taken into account<br>• Sheet metal roofing can add strength because of its structural properties and its ability to span |
| **Low Pitch (Near Flat) Roof** | | |
| • Low height and lighter supporting structure<br>• lower costs generally | • Greater need for thermal insulation<br>• Roofing or lining may need to be removed for cleaning and repair<br>• Difficult to ventilate effectively | • Consider using insulation that does not absorb or retain moisture |

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2

## 2.5 KEY RECOMMENDATIONS

To effectively limit flood damages, key recommendations have been prioritised into three categories to assist consent and certifying authorities set appropriate housing control policy (Table 2.4.2). These priorities are based on information in Table 2.4.1 and the risk implications of the various recommendations. For example, systems / components close to the ground such as ground flooring and the lower storey wall structure have been assigned a high priority.

Components located at a higher level, such as ceilings and roofing have been assigned a lower priority due to the lower probability of being flooded and thus the resultant lower damage risk.

The final decision on the application of these prioritised recommendations by the consent and certifying authorities needs to be based on merit, which can be determined through the floodplain risk management study and plan preparation process. Through this process the full acceptability of flood aware residential housing recommendations can be finally assessed by balancing technical merit against socio – economic and household financial impacts.

***Table 2.4.2** Summary of key recommendations for flood aware residential housing in high risk (flood) areas*

Priority 1 = measures needed to achieve effective flood aware design in the possible to unlikely flood probability range (e.g. 1 in 100 to 1 in 500 AEP).

Priority 2 = measures which are worthwhile but may not be considered essential

Priority 3 = measures which only provide benefits in very low probability events

| Priority | Measure |
|---|---|
| | **Building Type** |
| 1 | • In areas of higher risk from deep flooding, adopt 2 storey housing with double brick or masonry walls for lower storey for strength and ease of repair and to reduce damage costs by availability of higher upper storey<br>• Consider use of multi level buildings, which usually comprise of flood resistant concrete/masonry structural elements. Such buildings have lower floors which are used for commercial or common purposes. This allows elevation of the residential premises above areas exposed to a more frequent threat from flooding<br>• In areas where the ground level is higher but the risk from inundation is still high, adopt flood aware housing for single storey buildings with measures detailed in this table |
| | **Foundations** |
| 1 | • Ensure that adequate regard is given to the properties of the soil types under potential flood inundation, drainage and the impact from flow velocities<br>• Support foundations on the same stratum<br>• Protect exposed areas, including embankments |
| | **Ground Floor** |
| 1 | • Raise floor to provide protection from local overland flooding and ponding<br>• With slab on ground in areas of high silt deposition, use deeper slab rebate to hold more silt without the build up of silt bridging the wall cavity |
| | **Wall Systems** |
| 1 | **A. Cavity brick (double brick) or masonry walls for the lower storey of 2 storey homes in areas of deep inundation**<br>• Provide for ingress of water to balance hydrostatic forces inside and outside the walls via vents and flaps (which are compatible with the energy conservation requirements)<br>• Also include openings into the cavity brick walls to facilitate removal of silt from the cavity |

| Priority | Measure |
|---|---|
| | **Wall Systems** |
| **1 for lower storey and 3 for upper storey** | **C. Interior Wall Linings**<br>• Horizontal jointing to reduce replacement costs<br>• With linings used on external perimeter walls, raise lower sheet to provide narrow gap behind skirting board to aid post-flood ventilation and cleaning |
| **1 for lower storey and 3 for upper storey** | **D. Insulation**<br>Use insulation such as polystyrene panels, which is :<br>• Waterproof and non absorbent<br>• Drains and dries quickly<br>• Resistant to retaining silt<br>• Maintains its shape after loading<br>• Anchored to withstand buoyancy forces |
| | **Ground Floor Doors** |
| **1** | • Doors fitted with a pet flap, which open both ways to facilitate the effective movement of water both into and out of the house |
| | **Intermediate Flooring** |
| **2** | • Waterproof / resistant timber for flooring and joists<br>• Allow for loss of strength, if engineered timber beams are used<br>• Ensure ventilation which is needed for efficient drying and reducing chance of timber decay |
| | **Ceiling Linings** |
| **2** | • Insert small air vents to relieve pressure of trapped air<br>• Ensure ventilation of enclosed areas to reduce the risk of timber decay |
| | **Stairways** |
| **2** | Straight and wide stairs with treads and risers of comfortable proportions to facilitate relocation of contents from ground to upper floors |
| | **Fasteners** |
| **3** | • Given that flooding is a relatively rare occurrence above the 1 in 100 AEP flood level, most bolts, nails and screws do not warrant corrosion free alternatives<br>• In more corrosive environments or critical areas (i.e. where any loss of strength cannot be tolerated e.g. balcony, which supports a live load), consideration should be given to using galvanised or stainless steel alternatives for fasteners |
| | **Roofing** |
| **3** | • Traditional pitched roof with painted sheet metal roofing (e.g. colourbond) to ensure the strength of the roof<br>• Roof truss based designed to avoid weakening of the timber truss connections due to immersion |

# 3 VULNERABILITY OF HOUSING TO FLOODS AND POTENTIAL SOLUTIONS

Modern houses benefit from improvements in technology and choice in a wide range of advanced building materials in their construction. Provided those products are used in the right conditions for which they were developed and within their intended limitations, the home owner can enjoy greater performance and durability as well as significant cost savings.

What is often overlooked is that flooding is not a normal design condition for houses. This results in the vast majority of contemporary houses being more vulnerable to component damage and severe structural failure when exposed to floodwaters.

Furthermore, sufficient priority is not given to the risk of damage on a building's critical load bearing components and its structural adequacy caused by still and moving floodwaters, as it is very poorly understood, even by those involved in managing flood risks. Attention tends to be focused towards fixtures and fittings that are highly visible and the problems more apparent (e.g. floor coverings, cabinets, or building contents), rather than structural components hidden by surface finishes. None of these are long term assets and none are critical to a building's safety and serviceability.

These guidelines are concerned primarily with the structural components of the house and not its fixtures or contents.

Damage to the structure or fabric of a house in a flood is mainly due to:

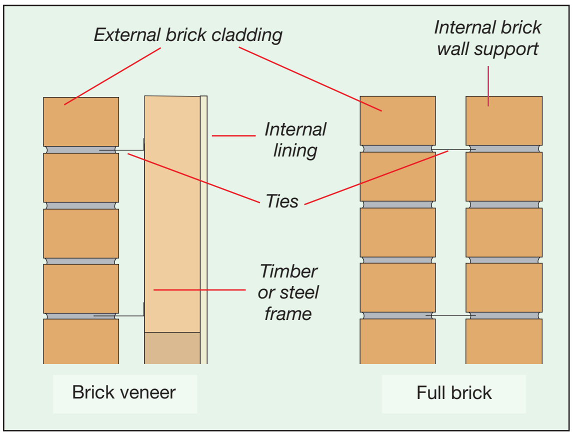
- the forces created by the water on the components of the house;
- the building materials in contact with water leading to immediate or subsequent longer term deterioration; and
- movement of foundations due to geotechnical (soil) failure.

This section explains what types of damage can be expected, how this damage occurs, as well as providing some design solutions.

## 3.1 DAMAGE FROM WATER FORCES

Contemporary houses are predominantly constructed from either brick veneer or full brick. Both rely on an internal load bearing wall constructed of either a timber or light gauge steel frame (brick veneer) or another brick wall (full brick) which supports the roof structure, (Figure 13). There are many ways in which these wall units can fail and more detail on failure mechanisms is provided in Appendix A.

***Figure 13*** *Structural components of brick wall*




In summary, some of the main ways that brick walls may fail are:

- cracking of the brickwork (to varying degrees);
- bowing of the wall;
- collapse of all or part of the external brick wall (or cladding) either inward or outward;
- in brick walls, the timber frame may snap or the steel frame bend although the brick veneer may suffer significant damage long before this would happen; and
- in double brick walls, the inner brick wall may collapse upon failure of the external wall.

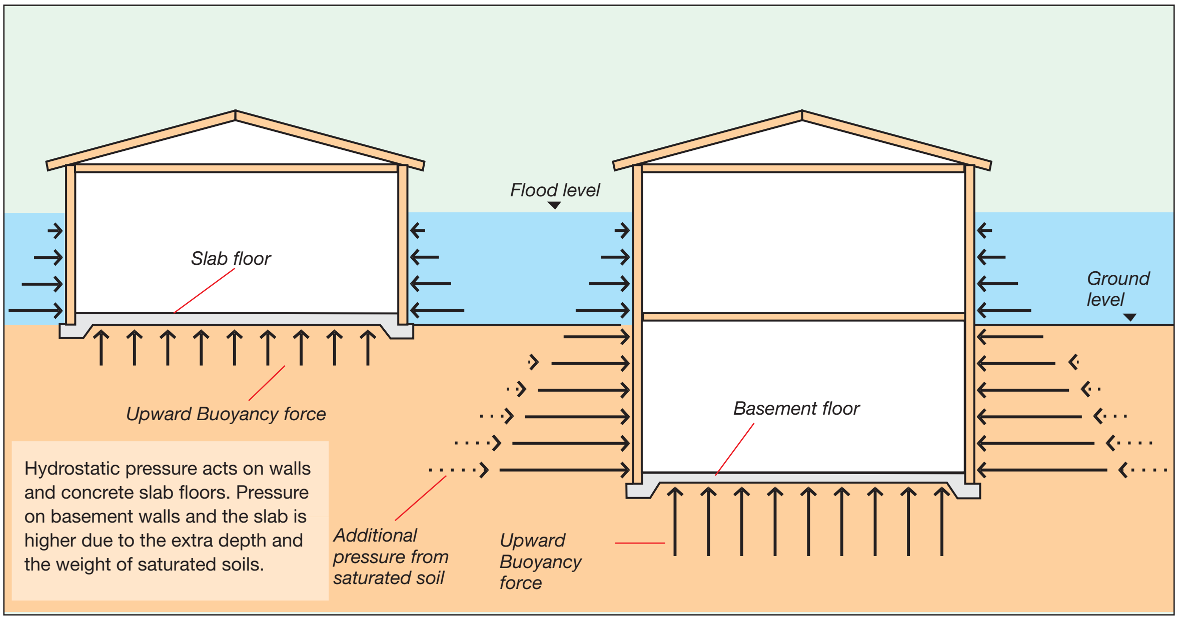
These failures are due to the three main types of forces which floodwaters exert forces on the house structure:

- hydrostatic forces associated with pressures of still water which increase with depth;
- hydrodynamic forces associated with pressures due to the energy of moving water; and
- impact forces associated with floating debris moved by water.

Additional loads may also occur from wave action produced by wind or boats. It has been estimated that waves can exceed 1 metre in height especially in open areas where the surface of floodwaters can be very large, such as around Windsor and Richmond.

A difference of just 1 metre in water levels inside and outside a brick house could result in bowing, cracking and even collapse.

**Figure 14** *Hydrostatic forces*




## 3.1.1 Hydrostatic Forces – From Still Water

The pressure exerted by still water is called "hydrostatic pressure", (Figure 14). A solid object can only exert a downward pressure as a result of its weight. In contrast, a fluid such as water exerts the same pressure in all directions (i.e. downwards, upwards and sideways) and these always act perpendicular to the surface on which they are applied. As hydrostatic pressure is also caused by the weight of water, it increases as the depth of water increases. The pressures exert a force or load which is a function of the product of the water pressure and the surface area upon which the pressure acts. Hydrostatic loads consist of three types: lateral loads, vertical loads and uplift loads.

### Lateral loads

Lateral hydrostatic loads are those which act in a horizontal direction, against vertical or inclined surfaces, both above and below the ground surface. These loads tend to cause sideways displacement and overturning of the building, structure, or components.

The walls of houses built according to typical construction practice are not designed to resist these loads. They comprise slender frames, windows and doors, which are structurally inefficient in resisting lateral loads. Once these pressure loads exceed the strength of the walls, it can push them in. Walls are the most vulnerable structural component in a house. Consequently there can be extensive structural damage, possibly resulting in the collapse of a house or the need for its demolition.

The force on a vertical wall in still water increases rapidly with depth (it is proportional to the square of the water depth). For example, when water is up to the eaves of a single-storey house, the force on the wall is similar to the weight of two cars for every metre of wall length, (Figure 15). If this force is applied to only one side of a standard brick wall (i.e if water is excluded from entering the house to balance the forces on the wall), this force will easily destroy the wall. Tests conducted by the US Army Corps of Engineers have shown that the maximum depth of water a cavity or brick veneer wall can support without collapsing is only 0.75 to 1.0 metre, (Figure 16).

Hydrostatic pressure is exerted not only by still surface water but also by soils saturated by floodwaters. Where there is soil against a wall, as in the case of a basement area, there can be much greater pressure on these walls than those in the upper floor areas.

### Vertical loads

These are loads acting vertically downward on horizontal or inclined surfaces of buildings or structural elements, such as roofs and floors, caused by the weight of floodwater (including water absorbed into building components/contents) above them.

***Figure 15*** *Unbalanced water forces on a wall can be very large*

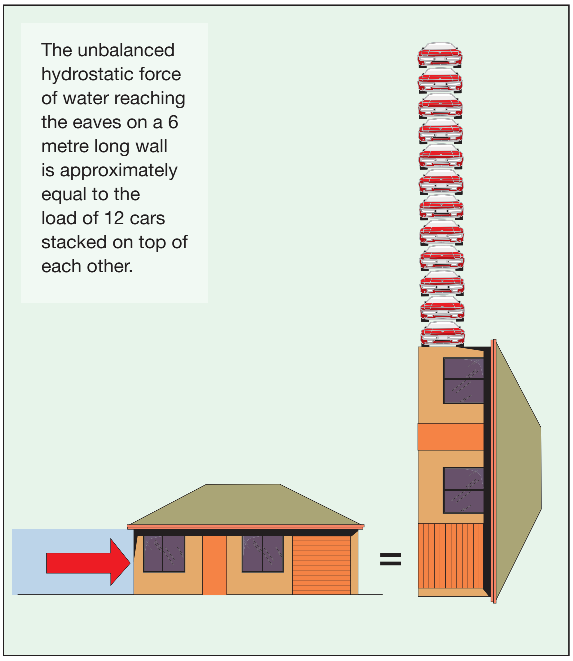


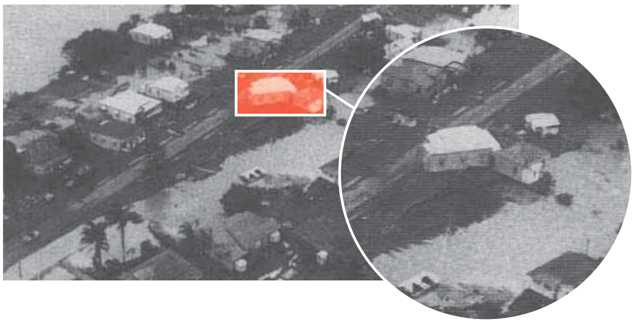

***Figure 16*** *Collapse of walls due to hydrostatic pressure*

## Uplift loads

Uplift loads act vertically upwards on the underside of horizontal or sloping surfaces, such as floor slabs, footings, suspended floors, and roofs. The upward force on floors is called "buoyancy" (due to the volume of water displaced by the structure).

This unbalanced force can also cause houses to float. This is a problem with lightweight structures such as weatherboard houses, which can lift off the piers and float downstream (Figure 17). In overseas examples where basements are common, the buoyant force on the basement floors has pushed entire houses out of the ground.

***Figure 17*** *Lightweight clad houses may float*



Full brick and brick veneer houses are unlikely to float – especially those with slab-on-ground construction – even if water is prevented from entering the house. In these houses, hydrostatic forces are likely to damage the walls or doors and allow water entry before sufficient buoyancy forces can develop to lift the slab (including the weight of the walls etc.). However, very fast-moving water has been observed shifting small reinforced block wall structures due to a combination of horizontal forces, buoyancy forces and reduced friction between the slab and ground, but these scenarios would be very rare.

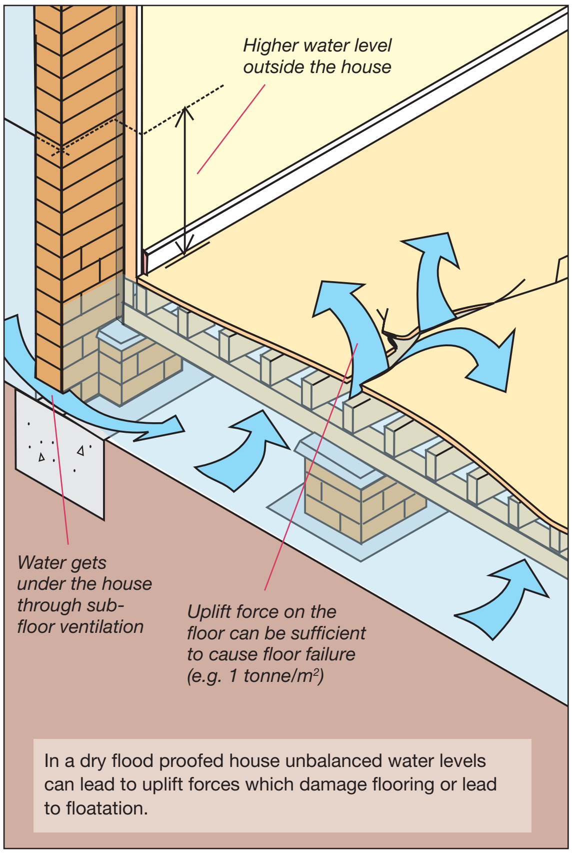
Houses with suspended floors could suffer structural damage due to the buoyancy forces on the timber floor, even at relatively small depths, especially if the house is tightly sealed so that water cannot enter the house, (Figure 18).

Even with small differences of water level, the upward forces can be much greater than normal downward loads (from furniture, people etc.) and this could damage flooring material or dislodge the framing structure.

Other than in structures which are constructed of heavy engineered components and/or reinforced concrete, it is generally not cost effective to design houses to withstand large unbalanced hydrostatic forces.

Building in areas of the floodplain where flowing water is likely will result in a house being subjected to increased pressures and forces.

***Figure 18*** *Uplift forces on suspended floors*

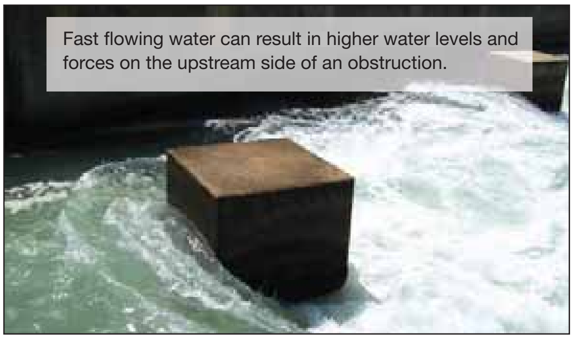



## 3.1.2 Hydrodynamic Forces – From Moving Water

Flowing water places pressures on the sides of any obstacle in its path. The magnitude of the force transmitted on the object from these pressures is primarily dependent on the flow velocity. The faster the flow, the greater the force. Houses built on a floodplain where there can be flowing water, will be subject to increased pressures and forces i.e, it pushes harder on the walls of a house than in still water.

Changes in pressures and forces are associated with the change in water level as water flows around the house. As shown in Figure 19, the water depth increases on the upstream walls (facing the flow) and decreases on the side and rear walls. Significant suction/outward loads are created on the side walls as the water flows along the sides of the house. On the side of the house that faces away from the flow (the downstream side) the water also creates a suction that pulls on walls.

***Figure 20*** *Example of water levels around an obstruction*




These changes in level are illustrated in Figure 20 where fast flowing water passes around a block in a channel that is used to "dissipate" energy in flowing water to reduce velocity downstream.

With outside flowing floodwaters, the water level inside a closed house (i.e. doors and windows closed) will be relatively flat and at a level somewhere between the external upstream and downstream levels. Accordingly, the increased water depths that normally occur on the upstream walls result in an inward force on the wall. Similarly, the decreased water depths that normally occur on the side and downstream walls result in an outward force on the wall which tends to strip the wall away from the house.

***Figure 19*** *Levels of moving water around a house*

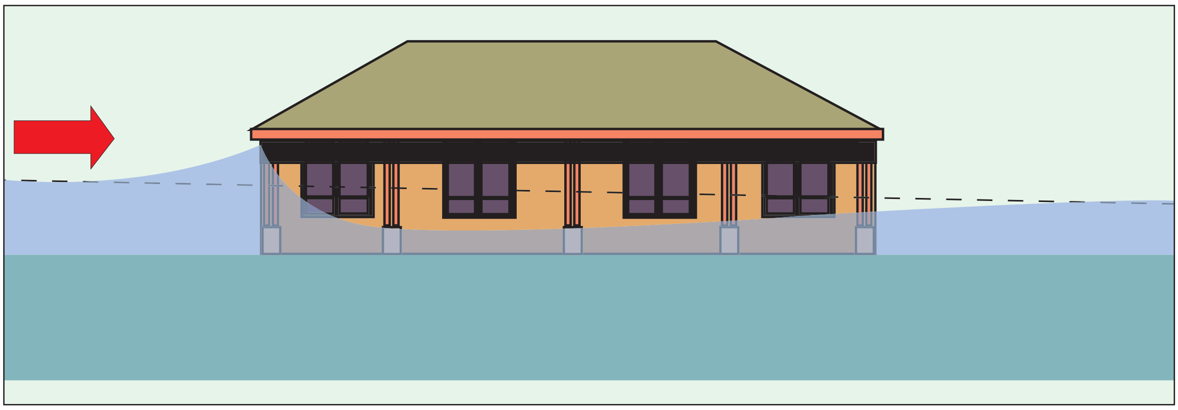
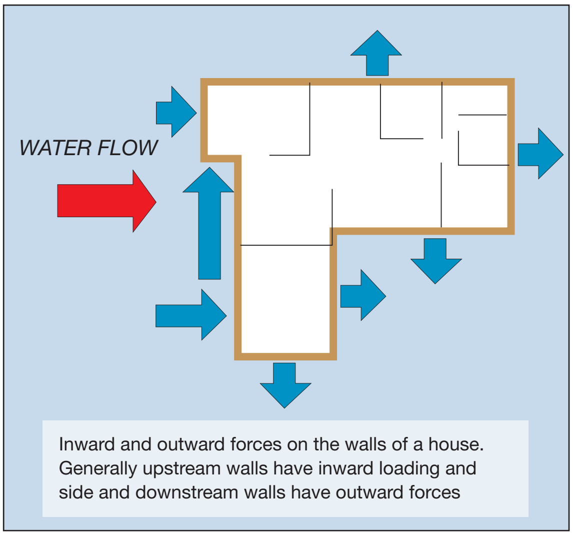


***Figure 21*** *Direction and relative magnitude of pressures around a typical house*




These forces vary for house shape, size, flow behaviour, etc. but as a rough guide water flowing at 4 m/s is likely to produce wall forces which are equivalent to the hydrostatic forces due to unbalanced water reaching the level of the eaves. The pressures estimated using computer modelling of a typical house are shown in Figure 21 where the arrow length is proportional to the pressure.

Calculating all the pressure and associated forces imposed on a house from flowing water is complex and depends on many factors. It is important to realise that water velocities may be increased if the flow is channelled between houses or between a house and other obstructions, (Figure 22). Thus significantly higher velocities can occur after an area has been developed. This is discussed in more detail in Appendix B.

If houses are not properly designed to resist the forces associated with flowing water, it is possible that sections of the house can fail in sequence and result in very severe damage. For example, the downstream and side walls of houses can fail due to "negative" pressures i.e. those acting in an outward direction on the outside of the walls. These walls may continue to resist these forces, but if an upstream wall, door or window should fail suddenly, it is possible for a pressure wave to travel through the house which could cause wall collapse. This can be made worse if there is little water in the house and a "wave" rushes through the house (see Figure 23).

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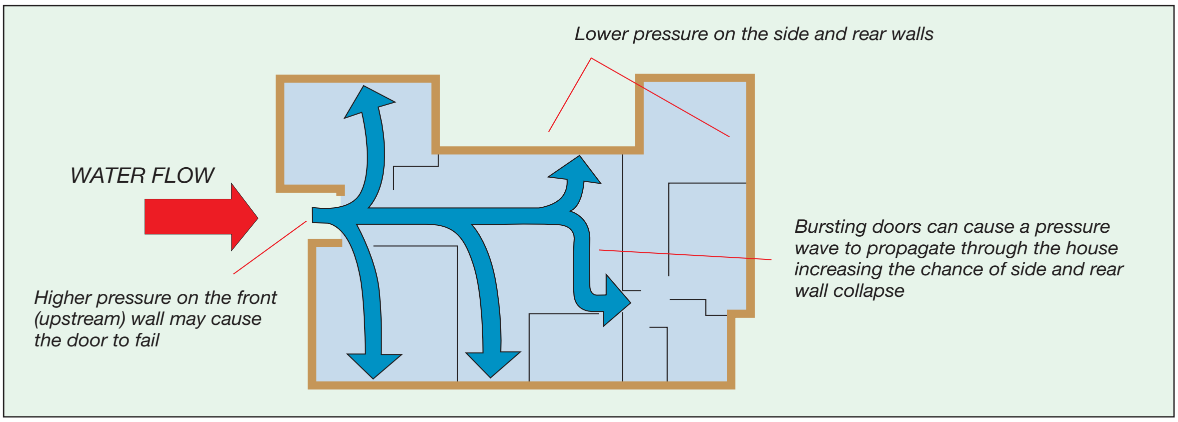
***Figure 22*** *Flow between houses*


***Figure 23*** *Collapse of walls due to pressure surges*



### 3.1.3 Debris Impact Forces

Floodwaters can move a wide range of floating objects which can vary in size and weight e.g. from small plastic bottles to large trees and sometimes even motor vehicles and caravans, (Figure 24).

Generally two types of debris loading can cause damage:

- impact from single floating objects such as logs and cars striking part of the building; and
- increased drag from an accumulation of debris mass e.g. vegetation pushing against a house.

The forces associated with floating debris depend on the shape, weight, quantity and orientation of debris (e.g. brushing against a wall, glancing it at an angle or hitting it perpendicularly), and the velocity of the flow. These are difficult to allow for not only because there is such variability in what can be carried by floodwaters and how fast it is moving, but also what part of the house is hit (e.g. doors, windows or walls). Impact from a small object moving very quickly can cause damage similar to that from a large object hitting a house at a slower speed. The affect of impact forces is also dependent on the size and shape of the house and its rooms.

The majority of houses are constructed by project home builders and are not designed individually. Therefore, if a house site is at risk from debris impact then the house design and orientation will need to be specially tailored to the site by a structural engineer, experienced in designing for such impacts. The risk of debris impact can also be reduced by raising the house structure on piers above the path of flowing floodwaters or by constructing barriers to prevent the debris from hitting the building and/or reducing the impact velocity.

Where the direction of flow is obvious, the house can be orientated with the more vulnerable sides of the building (usually the longer walls) aligned with the flow to minimise both the chances of being struck by debris and the magnitude of impact forces.

As with overseas practice, it is considered impractical to design houses to withstand extreme impact loads. It is best to avoid areas where this is a potential problem particularly if it is associated with high flow areas.

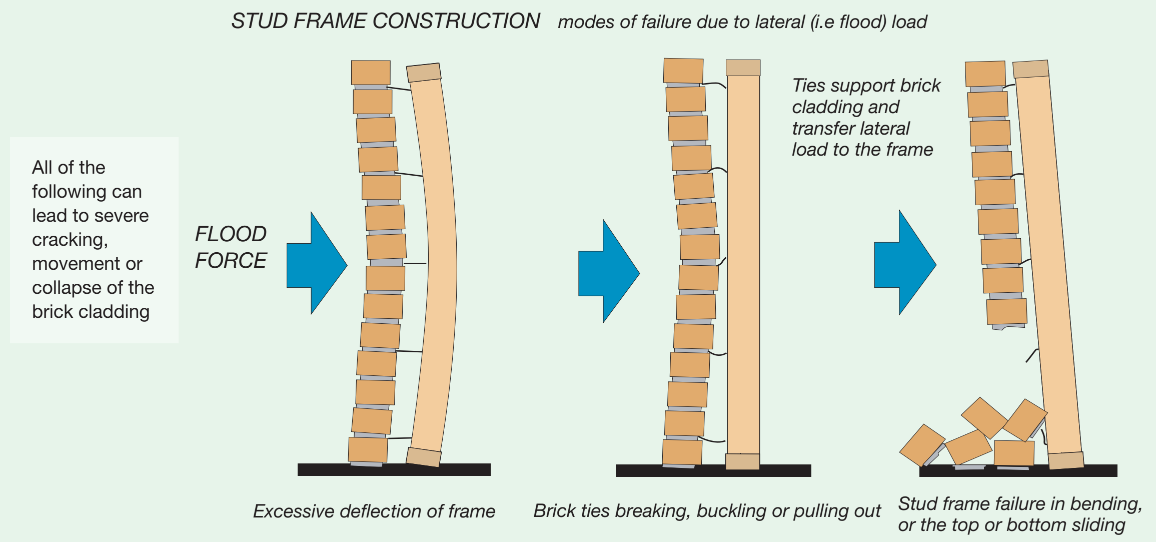
## 3.2 DESIGNING FOR WATER FORCES

Houses are designed to resist some degree of horizontal wall forces because all houses are exposed to wind loading. However, typical houses are unlikely to be able to resist even relatively low water velocities or shallow depths of still water against one side of the wall, (Figure 25).

This section looks at designing a house to resist still and moving water. Much of the technical content for this section is located in Appendices A and C which should be read in conjunction with this section.

***Figure 24*** *Accumulation of debris at Windsor 1978*

***Figure 25*** *Brick wall failure*




Research was also carried out to analyse loading and failure mechanisms in masonry brick wall construction to understand the forces that brick can withstand from moving waters.

## 3.2.1 Designing for Hydrostatic Forces

### 3.2.1.1 The Need to Balance Water Levels

Brick walls provide excellent protection from wind, rain and fluctuations in temperature and are capable of supporting very large vertical loads under compression (i.e. they resist crushing). However, brick walls alone are not efficient under sideways loading because the mortar bonding in the brickwork (and to some degree the bricks themselves) has relatively low strength in tension (i.e. when pulled apart). A sideways load will cause the slender wall to deflect against the frame. If this movement is excessive, the bending action will cause the mortar and bricks to crack and the overall wall is no longer capable of helping the frame to resist the load. The brick wall is the weakest link in the wall system.

A difference of less than 1 metre of water each side of a brick wall could cause extensive bowing, cracking and possibly even collapse of the wall.

Saturated and weakened plasterboard could fail with as little as 100mm of differential water pressure. However, collapse of the internal wall linings should not threaten the structural integrity of the house and is relatively easy to repair or replace, (Figure 26).

The brick wall is the weakest link in the wall system. A difference of less than 1 metre of water each side of the wall could cause extensive bowing, cracking and possibly even collapse.

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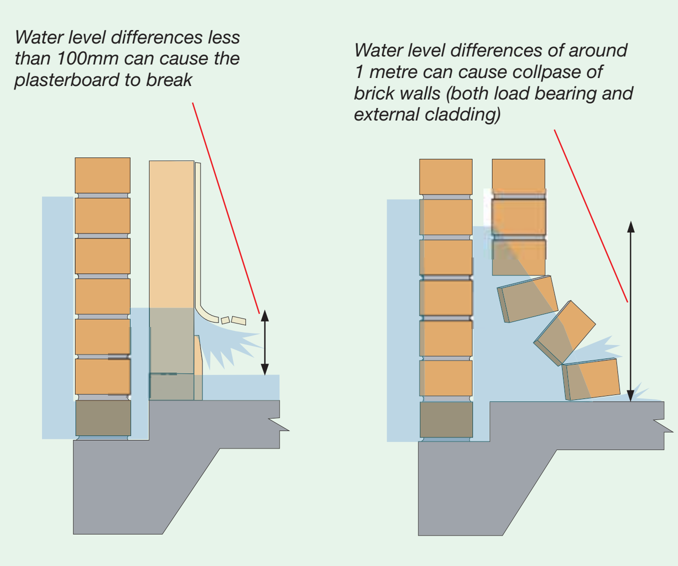
***Figure 26*** *Problems caused by differential water levels*




Plasterboard pushed into the wall cavity by higher pressure on one side of the lining.

Battened plasterboard lining on brickwork has failed due to unbalanced water pressures within the cavity.

Water levels inside and outside the house need to be balanced to prevent extensive structural damage from water forces.

It is difficult to cost-effectively design the walls, doors and windows to resist the increased loads from significant water level differentials particularly given the rarity of flooding.

Accordingly, water levels outside and inside the house need to be approximately balanced in order to prevent structural wall damage from still floodwaters through a "wet" flood proofing approach.

In this regard, it is considered more important that specific measures to let water in quickly be implemented for full brick houses than those of brick veneer or clad construction. This is because in a stud frame house, it is likely that if no special provisions for water entry are made, then sections of plasterboard will give way and allow water to flow through the wall. This will probably occur before doors and windows are pushed in and should prevent structural failure of the wall system.

However, in a full brick house, this degree of "in-built safety" is not present as water cannot easily pass from the wall cavity into the house and a faster flow rate is delayed until doors and windows burst to allow higher flood levels in. Another important factor is that the larger the floor area of the house, the greater the volume of water required inside the house to balance water levels.

### 3.2.1.2 How Does Water Enter Traditional Houses?

As more emphasis is being placed on energy efficiency, modern houses are becoming much more "air-tight" to meet thermal insulation requirements. This also means that it will be increasingly difficult to ensure that a sufficient amount of water enters the house without some special attention to achieve this.

In a typical brick veneer house with slab-on-ground foundations, water would enter:

- through the waste outlets and floor drains via the gully trap surface grates installed in the sewer lines
- under the external doors,
- into the wall cavity through the weepholes (unmortared vertical joints) at the base of the brick cladding, and
- from the wall cavity into the house via small gaps around the skirting boards and internal lining, (Figure 27).

Without the presence of low floor drains e.g. in a toilet, bathroom or shower base, water would have to enter through small gaps. These gaps cannot be relied upon to balance water levels. Tests have shown that while solid brick walls can leak significantly, this leakage is not enough to fill the average size house, particularly in rapidly rising floodwaters.

In a typical double brick house with slab-on-ground, very little water would enter from the wall cavity into the house. In this case, it is likely that the door or window would burst with the undesirable consequences mentioned above.

Leakage around the skirting board will be insufficient to balance the water levels and it is likely that, unless special provisions are made, sections of the plasterboard will collapse.

Doors also provide insufficient area under them for adequate water flow, especially if they are fitted with draught excluders that seal the opening.

### 3.2.1.3 Methods to Balance Water Levels

It is important that water is permitted to enter the house if it is likely to exceed depths of 300mm above the floor. Furthermore, the water must be able to enter and drain from the house

***Figure 27*** *How water enters a house*

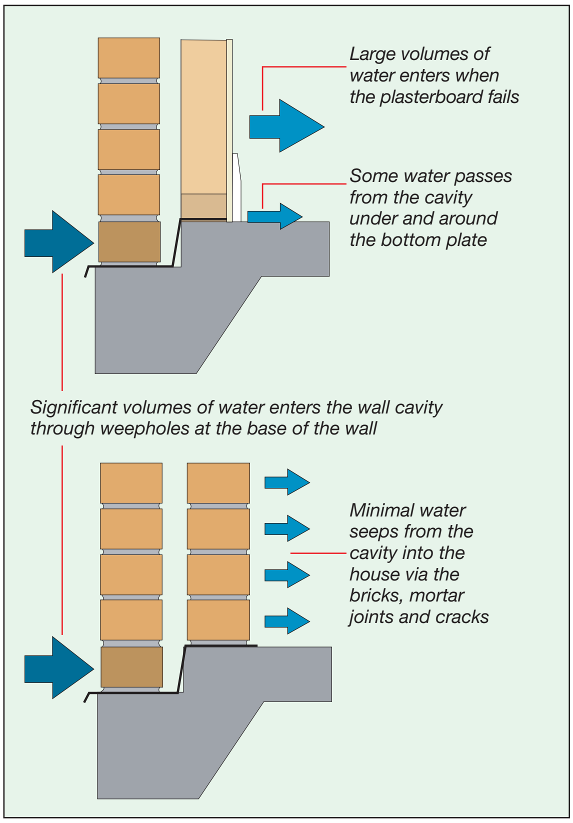
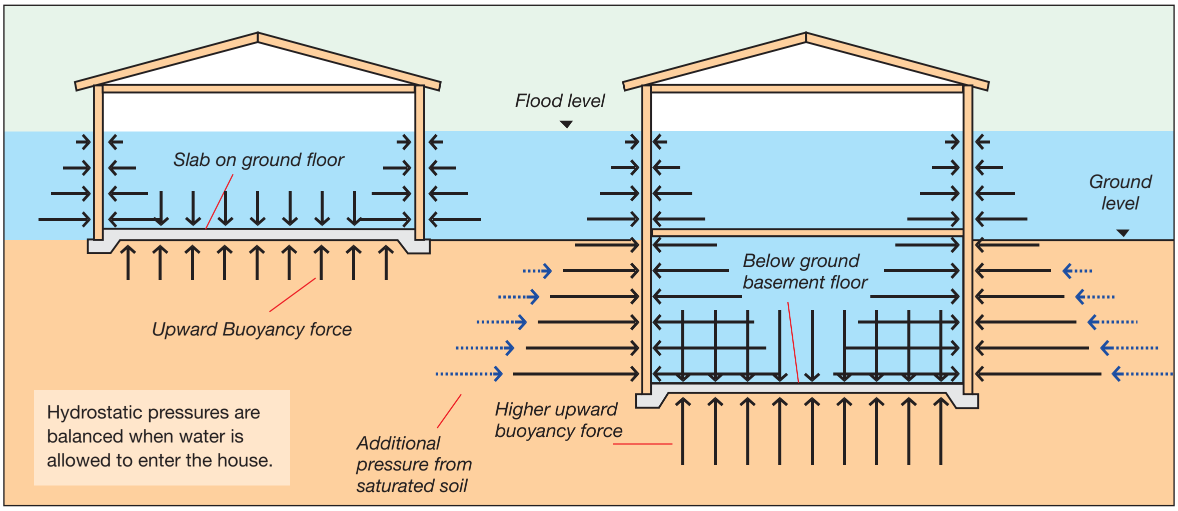


***Figure 28*** *Balanced hydrostatic forces*




Approximately 0.2m² of openings should be provided for a house with an enclosed floor area of 200m² for each predicted 1 metre/ hour rate of rise.

sufficiently quickly to maintain no more than a 300mm difference between the inside and outside water levels, (Figure 28).

How large the openings need to be to allow sufficient movement of water to occur depends primarily on the area inside the house and the rate of rise and fall of the floodwaters outside the house, (Figure 29).

The rate at which floodwaters rise and fall varies greatly depending on the characteristics of the catchment and the predominant type of flooding. On the Hawkesbury-Nepean floodplain, rates in excess of one metre an hour are possible and such rates require large openings. In most other areas, the local council should be able to provide an indication of the rate of rise of floodwaters from historical records or flood studies, bearing in mind that greater than observed rates of rise can occur.

### Calculating the size of openings needed

If the PMF is more than 500mm above the ground floor level, it is strongly recommended that the floor drains in "wet areas" be utilised as much as possible and sufficient additional built-in openings be provided in the house to ensure adequate entry and exit of water.

Research by the Federal Emergency Management Agency (FEMA) has resulted in a United States (US) standard of adopting 1 square inch (25.4mm) of opening for each 1 square foot (0.09m²) of enclosed floor area under the impact of a 5 feet/ hour (1.52m/hr) rate of rise. This opening size relationship incorporates a factor of safety of 5 to cover uncertainties such as potential blocked openings and the higher probability of basement area flooding.

A lower standard, of providing around 200,000mm² (i.e. 0.2m²) of openings for a 1 metre/hour rate of rise and an enclosed area of 200m² would be sufficient in situations to which these guidelines apply. The opening size can be scaled up or down in a linear fashion depending the rate of rise and/or the size of the enclosed area. However, the amount given by this

***Figure 29*** *Rates of floodwater rise*

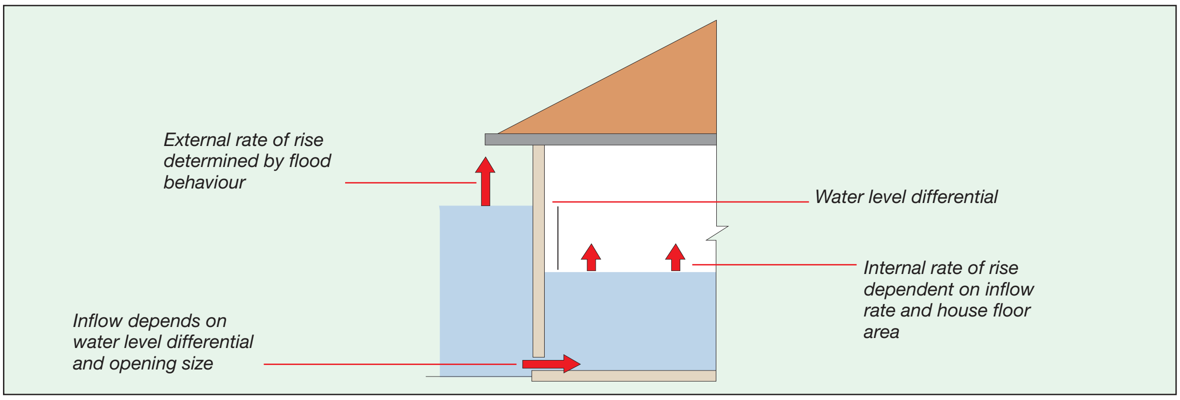


***Figure 30*** *Water inlets in external brick cladding*

***Large vents at frequent spacing can provide significant inlets for flood water as well as improve ventilation of the cavity.***

***Wide weepholes at every second or third perpend can help water entry and exit from the house.***

formula should be considered as a minimum and additional openings should be provided if greater protection is required.

To help disperse water throughout the house, it is best to provide openings in a number of locations rather than one. This might be achieved by a number of openings 100mm high and 600mm wide.

The openings should be located as close to the floor as possible but should this be difficult, the bottom should be no higher than the skirting board. Where the openings are provided in a cavity wall, each of the external and internal skins should have opening areas 1.5 times those given by the above formula, in order to ensure adequate through flow.

### Options for creating openings

Four of the preferred options for creating openings are given below and illustrated in Figure 30.

1. **Vents** placed in the external brickwork have the advantage of increasing ventilation in the wall cavity which will greatly assist in drying out the cavity after a flood.

   A brick wall vent (minimum 13000mm$^2$) can be provided every 1.8 metres. (see Section 5.4.2). To maintain the thermal integrity of the house and to stop vermin entry these vents will need to have protective mesh which does not impede water flow.

   Consideration should be given to making vents easy to remove so that a hose can be inserted fully into the cavity to assist cleaning and flushing. A weaker mortar could be used around the vent so that it could be removed after a flood, (Figure 31).

   Alternatively, a special nozzle can be easily made so that it can be fed in through the weepholes to help clean out silt after a flood, (Figure 32).

2. **Additional weepholes** can easily be provided at the base of the wall. In locations where the expected rate of rise is less than 0.5 metres/hour, it should be adequate to leave every second perpend (vertical joint) in the lowest brick course dry (unmortared).

   In areas of very high rates of rise (greater than 1.5m/hr) consideration should be given to using both increased weepholes and vents.

3. **Hinged "pet doors"** installed in external doors, need to be left unlocked at all times but could be used in conjunction with security screen doors that do not impede their opening. To permit water to escape as the flood recedes, it is important that hinged doors can operate effectively in both directions, (Figure 33).

4. **Internal wall vents.** Vents can be installed in the lower sections of the wall. There are a range of products in plaster, metal and plastic suitable for brick and plasterboard lined walls. These should operate effectively and are either clipped in or fastened with screws or glues.

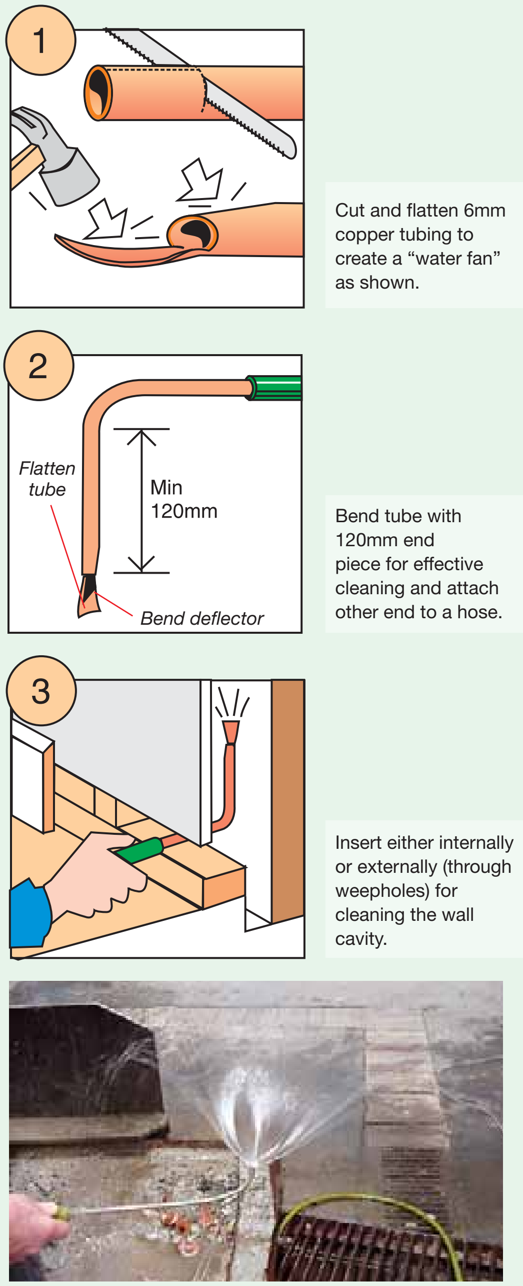
### 3.2.1.4 Counteracting Uplift Forces

Buoyancy forces can cause some types of houses to float and move off their foundations resulting in severe or total damage. Allowing water to enter a house helps to prevent flotation.

***Figure 31*** *Removable vents allow easy cleaning and flushing of the cavity*

Increased vents are the best option for increasing water entry and exit from a house, plus they improve ventilation to assist drying after a flood.

***Figure 32*** *Constructing a nozzle for cleaning cavities*

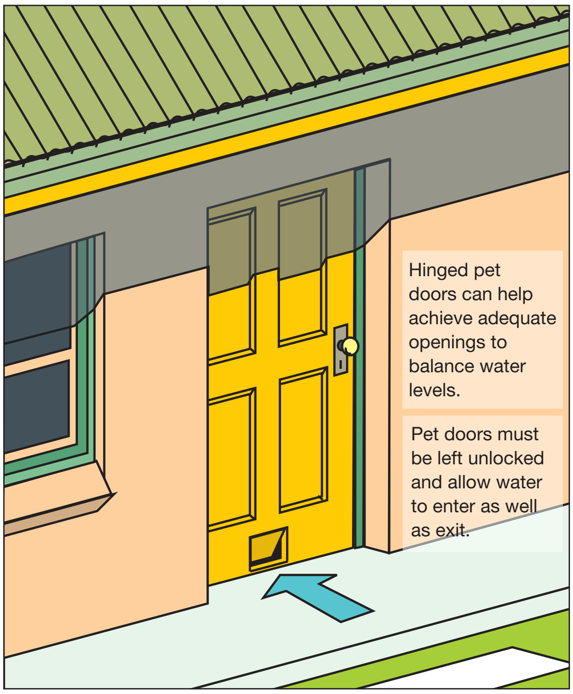



Some components still have a tendency to float due to their reduced weight. In cases where flotation may not be resisted by weight alone, then the difference needs to made up by providing dependable and permanent anchorage to other portions of the structure and to its foundations. For example, timber frames can float and therefore it is important that they are firmly secured to the slab. This is particularly the case where lightweight wall cladding and roofing is used. Steel frames are not vulnerable to flotation. Anchorage also serves the purpose of resisting overturning and sliding of the structure when buoyancy reduces its ability to resist lateral forces through the weight of the building.

Suspended timber floors are also more susceptible to flotation and need to be designed to ensure they are adequately secured to the foundations irrespective of whether they are used in a full brick, brick veneer or clad house. Platform floors in framed houses have the advantage of having more dead weight than a fitted or cut-in timber floor because the frame is placed over the floor sheeting and supporting joists. Also tiled roofs are heavier than metal clad roofs and therefore add weight to the frame and floor. However, allowance must be made for the reduced weight due to buoyancy if the components (e.g. wall frames, roof frames, tiles) will be submerged in a very large flood event.

Section 3.2.2.2 covers a design procedure whereby the additional forces from moving flood waters may be dealt with by adapting a system currently applied in strengthening buildings to resist various wind loads. Related to this is a general discussion on fixings and tie down requirements in timber frame construction.

***Figure 33*** *Use of pet doors for water entry*




## 3.2.2 Designing for Hydrodynamic Forces

Designing for the hydrodynamic forces associated with moving water involves two major steps:

- estimating the velocity of the water in the area the house is located, and
- designing the house structurally to resist the forces associated with the velocity.

Sometimes an intermediate step may be necessary to calculate the forces on the house due to the velocity and then these forces, rather than velocities, are used to design the house. However, as these guidelines explain a procedure to design directly from the water velocity, the intermediate step is not included here.

It is good practice to avoid building in any area where significant water velocity is possible. Moving water can produce dangerous conditions putting life at risk as well as damage, or even destroy, houses. Whilst the estimation of hydrostatic forces is based on flood depth and therefore straightforward, the estimation of hydrodynamic forces is dependent on many factors which are more difficult to estimate e.g. local conditions and debris loading.

When planning to build in such areas, it would be wise to adopt a conservative design approach because of the greater uncertainties.

### 3.2.2.1 Determining the Design Water Velocity

For the same flood, a single house located in an open field is often subject to lower velocities and forces than a house located as part of a close group of houses within a residential subdivision. In a development, moving water accelerates between closely spaced houses and the velocity and forces on the houses can increase significantly.

Determining water velocity within a flooded development is a highly specialised and expensive task. An indication may be gained by a "velocity multiplier" which is used to determine approximate local velocities from the known greenfield velocities. The velocity multiplier is the ratio of the "local" velocity at a location within the development and the "greenfield" (or pre-development) velocity. As the local and greenfield velocities (usually estimated by computer modelling) vary throughout the development, so to does the velocity multiplier.

The derivation of velocity multipliers is discussed in more detail in Appendix B.

### 3.2.2.2 Designing for Water Velocity Forces

Designing for the impact of water velocity introduces a high degree of uncertainty into the design, as damage is dependent on water depth and velocity.

A curve shown in Appendix C has been developed to indicate combinations of water depth and velocity which may initiate damage to brick walls. Unlike results from earlier studies, this curve is more applicable to modern house types and the modes of failure that occur with brick walls.

In conjunction with this curve, a design procedure has also been devised which enables houses to be strengthened by adopting the existing and familiar N classification system used to design for wind loads. This greatly simplifies the design process and it can be readily adopted by builders and designers as it is related to existing standards and design practice.

The loadings from flowing and rising floodwaters are similar to those from high winds. As water has a thousand-fold greater density than air, very high destructive forces can be developed at much lower velocities than that required by wind. Another major difference with wind is that while there is no suction force above the roof, there can be immense uplift forces on the structure due to buoyancy.

In designing for wind forces, the superstructure of a timber frame house is normally anchored to its supports or foundations. This is to prevent it from both lifting from its foundations due to high uplift or suction forces on the roof and leeward side of the house and to resist any lateral shear forces pushing the walls sideways. Furthermore, the entire structure must be strong enough to resist these forces and be able to effectively transfer them to the foundations. Consequently, the timber framing code has requirements for normal and specific fixings and tie down connections for all houses and wind speeds.

As the design wind gust speed increases, additional specific fixings and tie down connections are required to resist the increased uplift and sliding or lateral forces (shear forces between wall/floor frame and supports) generated by the higher winds. The design wind speeds are given an N classification.

The adapted procedure suggests a suitable design N rating for a house based on the water velocity of a flood event that reaches the eaves level. Thus, the N1 would apply to low velocities and N6 for higher velocities. As a guide, each step increase in meeting the N rating forces to

***Figure 34*** *Tie down of bottom plates to concrete slab*

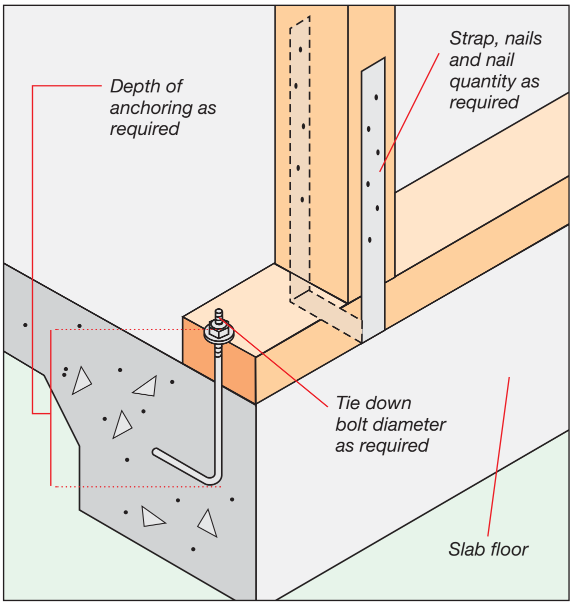
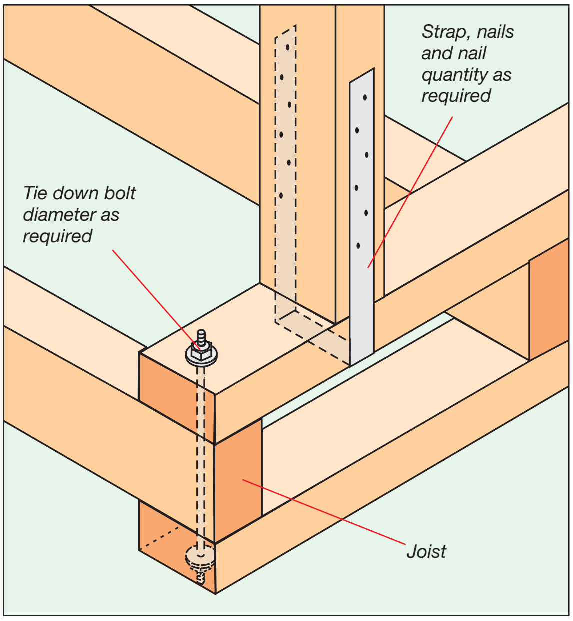



***Figure 35*** *Tie down of bottom plates to timber*



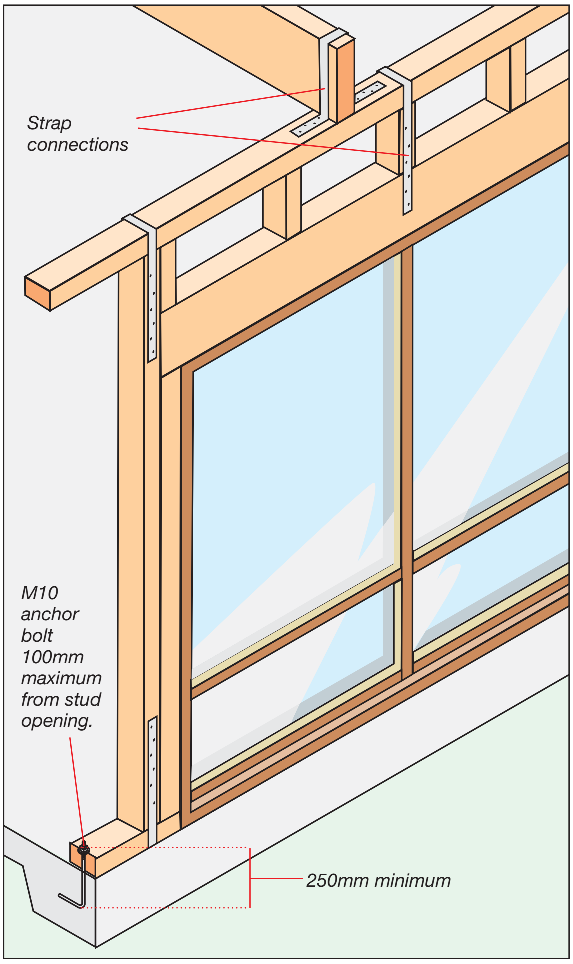

protect against total loss in a flood is likely to cost around $2,000 to $3,000.

The stronger connections needed to effectively anchor bottom plates used in timber frame construction to concrete floor slabs or flooring joists and in strengthening the walls to ceilings connections, would normally arise from potential increased horizontal forces (i.e. shear forces) caused by the impact of flowing flood waters against the wall structure. In houses with the timber frame resting on a concrete slab floor, uplift forces should be limited by the adoption of “wet flood proofing”. However, in the case of platform floor construction where the frame is positioned on top of sheet flooring, there is a greater possibility of uplift. This may occur when insufficient flood waters have entered over the floor and the weight of the superstructure is unable to counter higher hydrostatic pressures pushing up against the entire suspended floor. In this type of construction, the tie down connections will need to act to resist higher shear and uplift forces.

The stronger connection requirements to withstand the additional shear forces from flowing flood waters can be determined through the N classification system and reference to “AS 1684.2 – 1999 residential timber-framed construction”. Examples of some common tie down methods are shown in Figures 34, 35 and 36.

Appendix C has more details on this design procedure and explains how the rating should be

***Figure 36*** *Studs and lintels to plates connections*




modified to allow for the loss of material strength due to immersion (which is not a concern in wind design) along with other advice on its application.

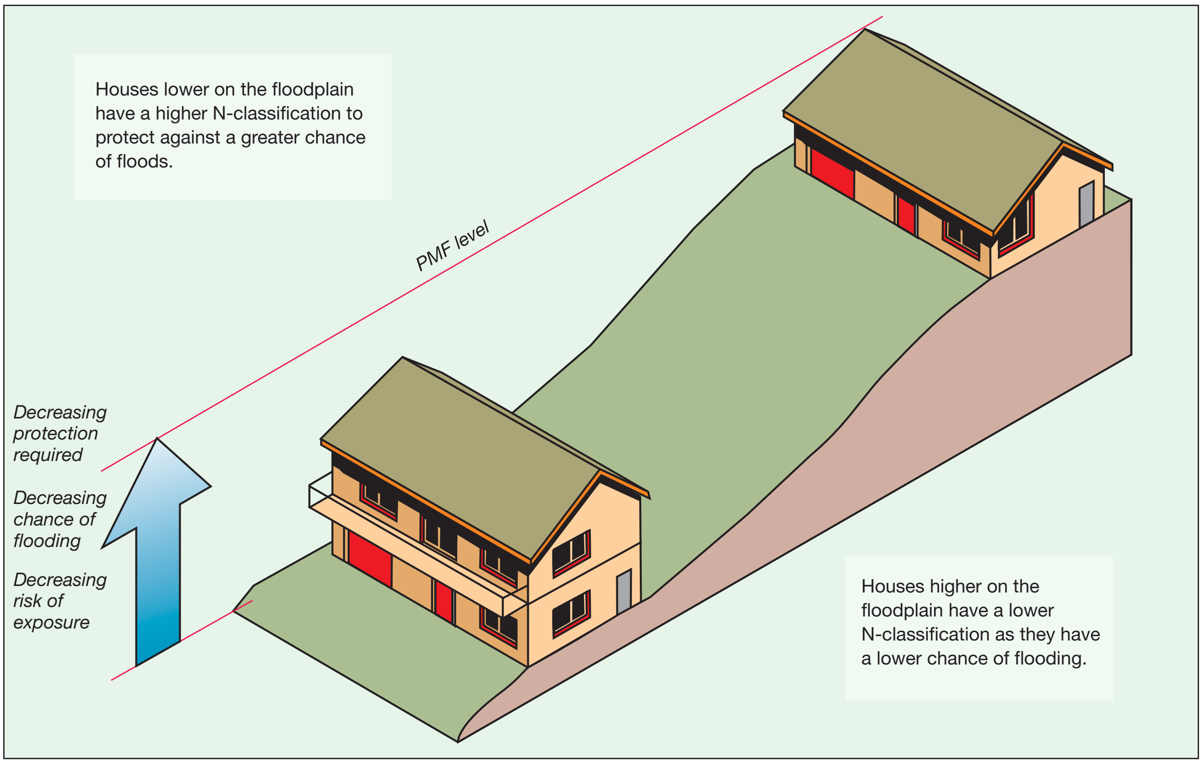
### 3.2.2.3 Designing for Debris Impact Forces

Given the many variables involved in estimating potential debris impact (discussed in Section 3.1.3), the approach in the USA is to apply regulations which stipulate certain allowances for impact loads in the design of buildings. These are summarised as follows:

- Normal impact loads – due to isolated occurrences of floating objects of "normally encountered size" striking a building. The design requirement is a concentrated 1000 lb (454kg) mass travelling at the velocity of the floodwater acting on 1 square foot (0.1m$^2$) surface area of the structure.
- Special impact loads – due to large conglomerates of floating debris either striking or resting against a building. Where this is likely, a load intensity of 100 lb per foot (148.9 kg per metre) acting horizontally over a 1 foot (300mm) wide horizontal strip is to be applied in the design.
- Extreme impact loads – due to large objects and masses such as collapsed buildings. Designing buildings with adequate strength to resist these loads is considered to be impractical.

Appendix C.8 provides a method for calculating impact loading.

***Figure 37*** *Using N-classifications for designing flood-aware houses*



## 3.3 DAMAGE FROM CONTACT WITH WATER

A primary source of flood damage is from the effect of immersion and contact with water on the building materials and fasteners used in house construction. The extent of damage will depend on a number of factors including the:

- depth of water,
- construction details and type of materials used,
- period of immersion, and
- contaminants and substances in the water.

The properties of some building materials remain unaltered during long periods of immersion while others change rapidly after saturation. This can be critical to the structural integrity of a building's load carrying components such as floors and walls. In some cases the original properties return to normal after drying, while in others the material structure is permanently weakened. Glues and fastenings can be affected by immersion. Decay and corrosion can cause permanent damage, therefore rapid drying is imperative if damage is to be minimised. These issues are covered in more detail in other sections of these guidelines.

### 3.3.1 Depth of Water

The damage to a building will vary with depth of water above the floor level, (Figure 38). Provided the foundations are adequate, damage below floor level is limited.

Above floor level, low-level components are damaged including:

- the floor structure,
- floor coverings,
- skirting boards,
- low level electrical outlets, and
- wall structure, particularly in the case of timber frames.

With a further rise in floodwaters there is then damage to wall linings, insulation, and fixtures such as built-in storage areas and cabinets. Increasing amounts of silt can also be trapped within the wall cavities. Furniture and appliances can begin to float and cause impact damage to wall linings and windows.

Damage can increase markedly when flooding rises above the ceiling and the lining, insulation, and roof timbers become wet.

***Figure 38*** *Increasing damage resulting from deeper floods*

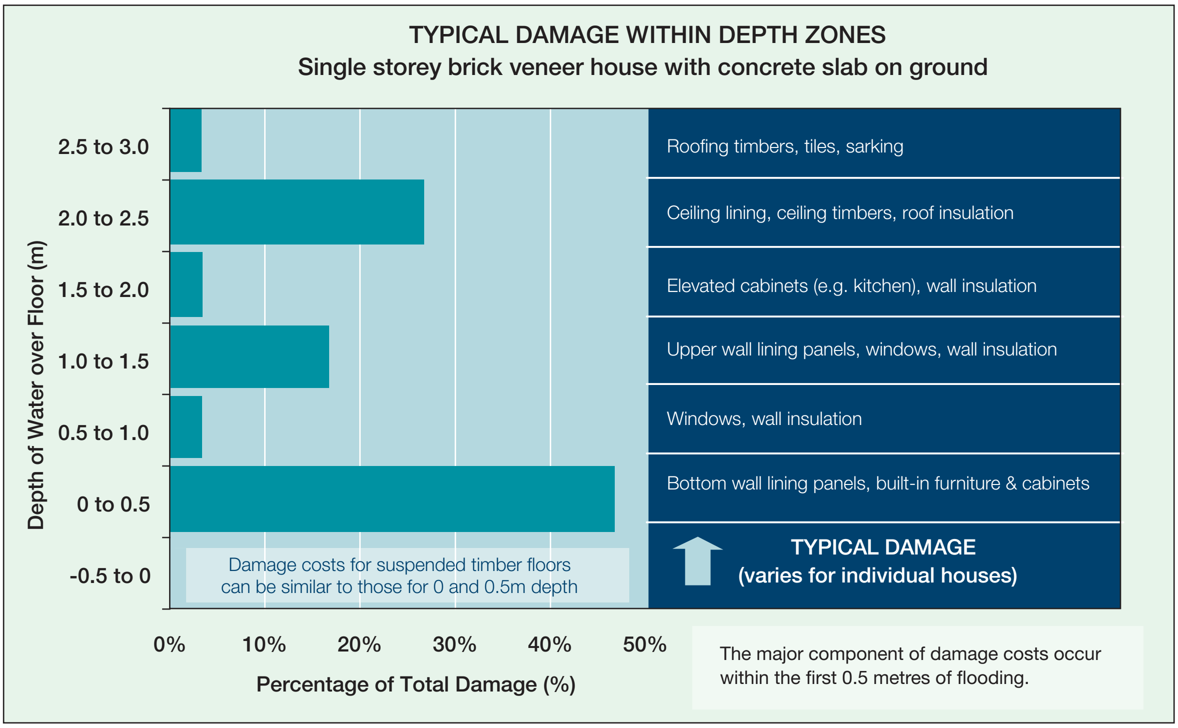
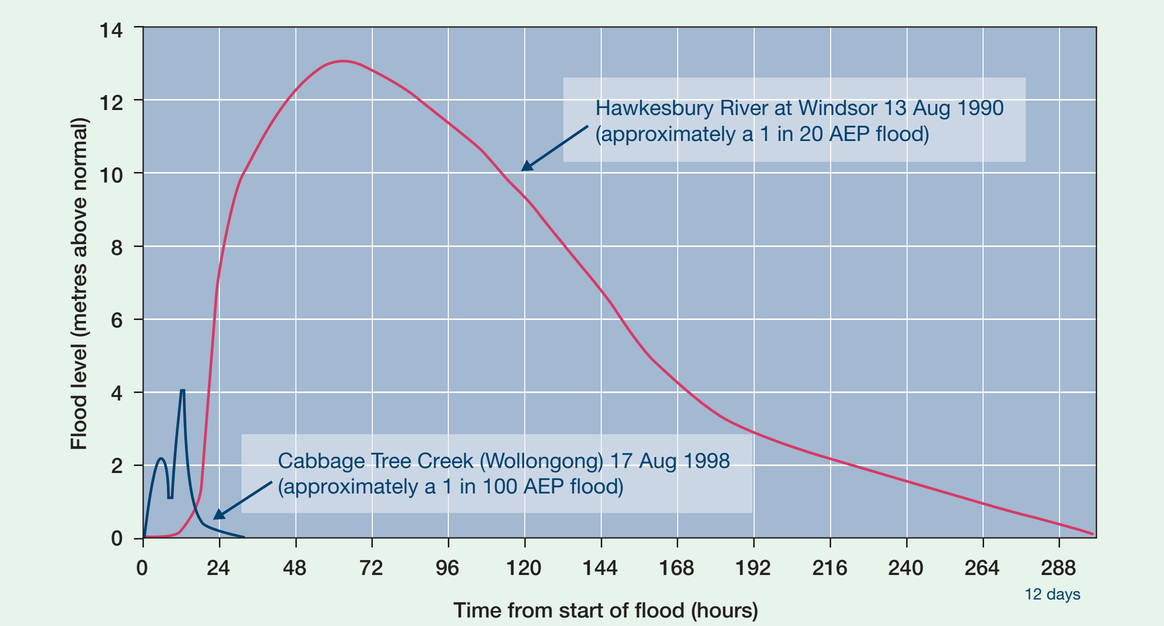


***Figure 39*** *Varying periods of inundation*




Flash floods may occur with only a few hours duration compared with long duration flooding that can last over a number of days.

## 3.3.2 Construction Details and Materials Used

Contact with water can cause a number of problems to building materials, some occurring immediately, others occurring only after prolonged immersion, whilst others do not occur until a long time after the immersion. Some of these problems are made worse by the way the house is constructed if, for example, cleaning and/or drying is made more difficult.

Design of a standard house is based on factors such as cost, ease of construction, functionality and appearance. The ability of building materials to withstand flooding is usually not a consideration. Similarly, common types of building will not minimise flood damage. For example, cavities which would never become wet in normal use can trap water and promote rotting, corrosion, and the growth of mould.

Careful selection of materials and construction methods can greatly reduce these problems as detailed in these guidelines.

## 3.3.3 Period of Immersion

Flood duration depends on catchment characteristics and can vary widely. In large catchments found in western NSW, severe flooding can be prolonged and take several weeks to subside, while floods on coastal rivers rise and subside within days or even hours. A 1 in 100 AEP flood of the Hawkesbury-Nepean River would occur over a 4 to 7 day period, (Figure 39).

In contrast, flash flooding can be over in hours or even minutes. The Wollongong flood of 1998 inundated some houses with depths halfway up the walls yet was gone in a matter of two or three hours.

For any given flood event, the period of inundation is also affected by the height of the floor above the river. For example, in a 1 in 500 AEP flood, a floor at the 1 in 200 AEP flood level will be inundated for a much shorter period than a floor at the 1 in 100 AEP level.

## 3.3.4 Contaminants and Substances in the Water

Whilst immersion damage is predominantly from water affecting the materials, the contaminants and substances in the water may contribute to a lesser extent.

High silt loads carried by floodwater can be a concern. Silt can be deposited in concealed areas of a building and may lead to prolonged and ongoing wetting and drying. This can cause a gradual deterioration in the building materials and encourage mould growth, smells and health-related problems.

Floodwaters can also be contaminated by sewage, fertilisers and chemicals which may be a problem upon contact with a building. However, the massive volume of floodwaters usually means that the contaminants are very dilute.

Sometimes the weather conditions that cause flooding can also result in elevated ocean levels and wave action. If a house is located close to the ocean, the floodwaters may have a high salt concentration and could lead to an increased chance of corrosion to metal components.

## 3.4 DAMAGE TO FOUNDATIONS FROM GEOTECHNICAL FAILURE

Soils exhibit a wide range of properties, which depend largely on the properties of the constituent soil particles (sizes and composition of the grains and the relative proportions of the various components) as well as the nature and quantity of water in the soil, the past consolidation history of the soil, and soil structure.

Soils are usually described as either coarse-grained soils or fine-grained soils. Sand and gravels where the particles are clearly visible to the naked eye are coarse-grained soils. For building foundations, coarse-grained soils tend to be less problematic as their properties are usually due to their grain size. The water contained in a coarse grained soil does not have a great influence on its properties. On the other hand, the properties of fine-grained soils (which range from silt to the finest fraction, clay) are more due to their mineralogical and chemical characteristics. The water content of a fine-grained soil has a great influence on its properties because of its interaction with the clay materials in the soil. As water is removed from fine-grained soil it shrinks and its strength increases. Conversely, some clay soils will take up water when it is available and will swell and decrease in strength.

The following geotechnical failure modes have been identified as the principal modes of failure that would accompany flooding:

- erosion of soil both during initial flooding and as floodwater receeds,
- collapse of soils following inundation and saturation
- soil piping
- batter slumping, and
- swelling/shrinking of soils following inundation, and subsequent drainage.

These are discussed in detail below and illustrated in Figure 40.

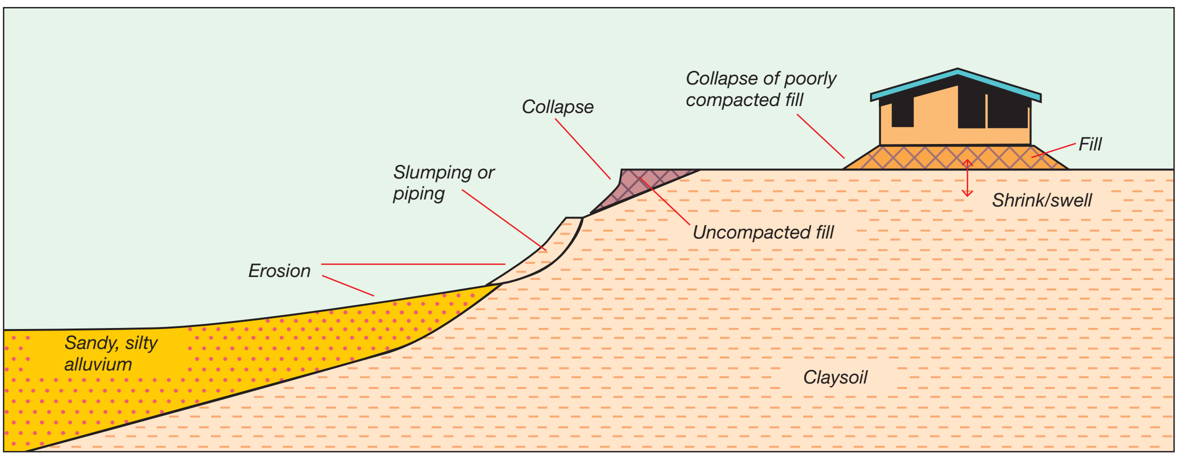
### 3.4.1 Erosion

Soil erodibility is defined as the susceptibility of a soil particles to be detached and transported by erosion agents, such as water flowing through and over the soil. Soils least resistant to erosion tend to be those with moderate silt or sand contents and limited clay contents, because their particles are easily detached and transported, and cohesion is not as strong as in soils of higher clay content. This is distinct from dipersive soils, i.e. soils which by nature of their mineralogy and the chemistry of the water in the soil, are susceptible to separation of the individual clay particles and subsequent erosion of these very small particles under seepage flows.

A 1 in 100 AEP flood of the Hawkesbury-Nepean River would occur over a 4-7 day period.

3

***Figure 40*** *Principal geotechnical failure modes*



A simple laboratory test to identify soil erodibility is the Sherard Pinhole Test.

Flowing floodwater performs the functions of erosion, transportation and deposition of sediments. Water, because of its relatively high viscosity and density is able to carry particles at much lower velocity than it requires to pick them up (erode). The following table gives an indication of the threshold at which various soil types may begin to erode. The absolute values of these velocities may vary, however it is the relativities between the various threshold water velocities that is of significance.

***Table 3.4.1.1** Velocities at which different soil types erode*

| Soil Type | Water Velocity (m/sec) |
|---|---|
| Clay (up to 0.002mm dia) non-dispersive | 1.5 |
| Silt (0.002 – 0.06mm dia) | 0.6 |
| Sand (0.06 – 2mm dia) | 0.2 |
| Gravel (2mm – 20mm dia) | 1.0 |
| Cobbles (20 – 100mm dia) | 3.0 |

The above table shows that sand is the most erodible followed by silt, gravel, clay and cobbles. Therefore the most erodible material in the Hawkesbury-Nepean valley are the Agnes Banks Sand and the Pitt Town Sand. As velocities up to 5m/sec are possible, it is apparent that at these velocities all of the materials exposed will be eroded unless protected by properly designed protection measures. These areas are unsuitable for housing as measures to protect the sites and foundation would involve lining with rock-filled gabions or mattresses.

As a rule, housing should be sited well clear of areas of significant velocity when erosion is likely, to avoid potential undermining of foundations.

For lesser velocities, measures such as the establishment of appropriate grasses, and protection of sandy soils by compacted clay may also be considered.

Erosion is also an issue where fast flowing water may remove or strip soil from around freestanding piers with shallow foundations and at the corners of walls, slabs or toes of embankments where flow velocity can increase.

### 3.4.2 Collapse of Soils on Saturation

Soils in which absorbed water and particle attraction work together to produce a body which holds together and deforms plastically at varying water contents are known as cohesive soils or clays. Those soils which do not exhibit this cohesion are termed cohesionless.

For cohesive soils, the undrained shear strength may be significantly reduced after saturation. Loss of strength by up to 50% or more due to saturation is often a cause of progressive failure by tilting of older, very shallow foundations.

In the more clayey materials, conventional consolidation settlement is not normally significant because of their stiffness. However, in areas where poorly or inadequately compacted clayey fill is subject to inundation, collapse of the soil may occur, leading to distress and possible failure of any structures supported by these materials. It is therefore important for all earthworks that may support engineered structures to be carried out in accordance with AS 3798-1996 *(Guidelines on Earthworks for Commercial and Residential Developments)*.

### 3.4.3 Piping Failures

Failure of a soil mass by piping generally occurs within clayey dispersive soils that are subject to seepage flows, but may also occur in some structured, more sandy soils. Dispersive soils are defined as soils which by nature of their mineralogy and the chemistry of the water in the soil, are susceptible to separation of the individual clay particles and subsequent erosion of these very small particles under seepage flows. In particular, soils with montmorillonite present tend to be dispersive, while kaolinite and related minerals are non-dispersive. Illite tends to be moderately dispersive. Dispersivity also depends on the pore water chemistry, e.g. particularly low salt concentrations may lead to greater dispersivity. When saline soil (such as found along South Creek) is percolated by fresh water during a flood, the risk of dispersion may therefore increase. Piping failures in structured sandy soils is via the movement of sand materials along pre-existing defects, such as fissures or shrinkage cracks.

A simple laboratory test to identify dispersive soils is the Emerson Crumb Test.

### 3.4.4 Batter Slumping

Of particular concern in areas underlain by cohesive soil, is that following a relatively rapid drainage of the inundated area, the presence of high pore water pressures in the clayey soils (therefore a significantly lower shear strength of the soil) may lead to slope instability in cuts, fills and steeper natural slopes. This would be expected to occur particularly within steeper river banks where the soils consist of relatively impermeable clayey materials, or in areas where clayey fill has not been adequately compacted.



### 3.4.5 Shrink/Swell Movements

With respect to shrink/swell movements, where the depth of influence is generally regarded as about 1.5m, inundation may extend the depth and extent of “normal” climatic effects. In typical years, “normal” site movements are usually under 15mm. However, movements as high as 60mm have been reported in adverse situations. It could be reasonably anticipated that following a period of inundation that subsequent shrink/swell movements throughout the more clayey areas, will result in significant distress to structures supported on shallow footings. This will particularly apply to older structures where footings have not been constructed in accordance with AS 2870-1996 *(Residential Slabs and Footings)* or where earthworks have not been carried out in accordance with AS 3798-1996 *(Guidelines on Earthworks for Commercial and Residential Developments)*.

The differential movement of clayey soils is a normal consideration when building on expansive soils. However, flooding creates effects that are significantly different to those that exist after normal rain. The rapid immersion of a site from flooding can accelerate soil expansion under some parts of a building relative to others, exaggerating the differential movement of the structure.

# 4 GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS

**Careful siting, design, detailing and quality construction can limit the damage to houses, even when a flood goes well above the internal floor level.**

Good practice can ensure that:

- the structure is soundly built with no additional weaknesses resulting from poor workmanship,
- the construction is clean so that building waste (e.g. mortar and scrap materials) is not left in building cavities to attract or trap moisture, and
- edges, surfaces and joints of components are well sealed in order to minimise water uptake.

This section looks at:

- site and siting issues;
- the impact of water on the building and the site;
- structural issues and detailing to minimise moisture accumulation and absorbency;
- methods to promote the drying out of a house; and
- material selection, fittings, and joinery issues.

## 4.1 SITE FACTORS

There are several important considerations relating to the location of the building block on a floodplain and placement of the building on that block, which influence exposure to flood damage.

### 4.1.1 Elevation of Land

Building on the highest practical site on the floodplain reduces the chance of flooding and the period of inundation. This may also increase warning time to allow some preparation before the flood.

Safe access from the site is essential. The driveway should provide easy exit from the house and should be as high as possible along its full length to provide the longest period for evacuation. Links to safe flood-free locations, which continually rise to safe high ground, offer greater security for safe evacuation in flood events.

### 4.1.2 Avoid Areas of Flowing Water

Appendix A – C provides a guide as to what combinations of water depth and velocity may cause severe damage to a house. Whilst houses can be strengthened to improve resistance to low velocities, it is better to avoid building in areas where significant flows may occur to avoid risks from hydrodynamic forces, debris impact and foundation erosion.

High velocity flows usually occur on the floodplain adjacent to the main river channel and around bends as well as in low-lying gullies where floodwaters break out of the main channel onto a floodplain.

### 4.1.3 Shape and Orientation of Building

The shape or floor plan of the proposed building and its orientation to the direction of flow are factors affecting how it will perform in a flood. In principle, compact buildings offer less resistance to flowing water and are structurally more robust. A square design plan will give the maximum robustness to resist horizontal loading. In areas with significant water velocity, some recommended design features are:

- ratio of the sides less than 1:2 avoiding long and narrow designs or ones which have long projections off the core,
- with “L” shaped houses it is important that the two legs are not significantly different in length - a maximum difference of 1:1.5 in most cases will keep inherent robustness, and
- buildings with long walls are more fragile and if the long wall intercepts the direction of flow, floodwater loading and the vulnerability to debris loading is maximised, (although, this impact may be reduced by using the internal walls as bracing of the long wall).

Figure 41 shows a range of plan configurations that will reduce the pressure of floodwater on the house.

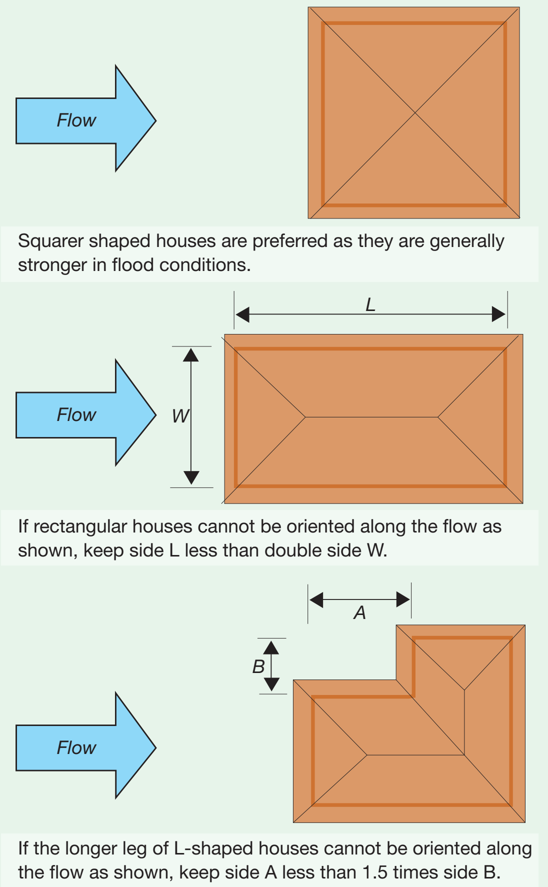
Orientating the house so that the longer wall faces the flow is not desirable. However, as indicated in Section 3.1.2, there are cases where brick side walls on traditional houses can peel away from the house (due to suction) before the front wall collapses inward. Hence having longer

Building on the highest land available decreases the chance of flooding and the period of inundation, and can increase warning time if the site links to high ground via a continuously rising route.

Compact buildings offer less resistance to flowing water and are structurally more robust. Long walls of houses should not face the direction of the flowing flood water.

side walls may be unwise *(NB In this context, the front wall refers to that wall facing the water flow which implies a side wall is parallel to the flow)*. It is possible that brick side walls may collapse at a lower velocity than the front wall, but orientating the house across the flow can reduce the clearance between houses which increases the local velocity around the house. These matters are complex and difficult to analyse because many factors relating to the building structure and flow of water come into play. The impact of structure and water flow are also highly dependent on the individual circumstances. Conventional houses have greater limitations than other types of buildings and are only suitable for areas of relatively low velocity.

***Figure 41*** *Effect of building orientation and shape*




Squarer shaped houses are preferred as they are generally stronger in flood conditions.

If rectangular houses cannot be oriented along the flow as shown, keep side L less than double side W.

If the longer leg of L-shaped houses cannot be oriented along the flow as shown, keep side A less than 1.5 times side B.

## 4.1.4 Build on Well-Drained Ground

Water needs to drain naturally from the site, especially from under the house to allow the area to dry out as quickly as possible. Building in a hollow and creating a hollow under a house should be avoided. Surrounding garden beds should not restrict water drainage.

## 4.1.5 Foundations

Stable foundations are essential, hence it is important to take into account the effect of *soil saturation* as the bearing capacity of some foundation materials is reduced.

Another important consideration is *differential soil movement*. This occurs with the swelling of certain soils (particularly reactive clays) when they are saturated. Different soil properties and rapid site flooding can increase the potential for uneven swelling of foundation soils. This can result in severe cracking in the brickwork.

A range of techniques to minimise problems with foundations is covered in Section 5.1.2.

## 4.1.6 Erosion Control

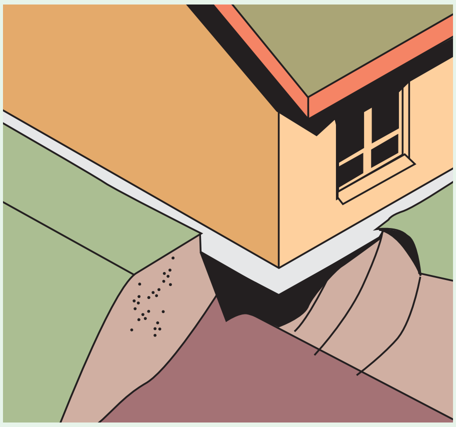
Erosion can be an issue with some soil types and with embankments created by cut and fill. The problem areas are the edge of an embankment or near the corner of a building, (Figure 42). The edges of any obstruction to the flow of water can generate faster currents, which increase the chance of scouring. Depending on factors such as the soil type and vegetation, erosion may develop when these local velocities are as little as 0.2 m/s although more commonly a figure of 1 m/s is a concern.

Embankments should not be steep (with a minimum slope of 2 horizontal to 1 vertical) and have a good vegetation cover year round. Where

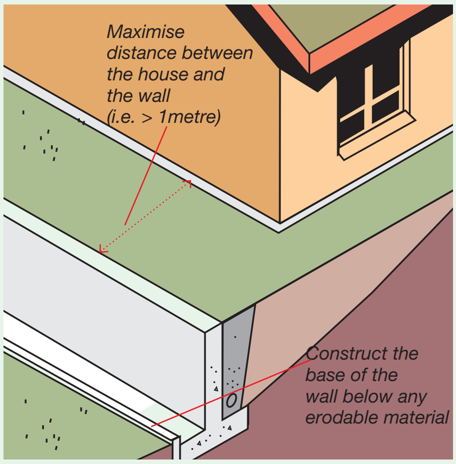
***Figure 42*** *Undercutting from erosion*

Under conditions of deep and prolonged flooding, loss of strength in soils and stability of foundations can cause major failures and expensive repairs.

***Figure 43*** *Protective retaining walls to prevent undermining of the house*



Embankments, especially those constructed from poorly compacted fill, are prone to failure from erosion due to water flowing over the soil or from slumping due to high pore water pressure in the soil.




In areas with flowing water, retaining walls offer better protection against scouring undermining the house.

Where flowing water can cause erosion to embankments, retaining walls can protect the site from undercutting.



such slopes cannot be achieved, or adequate vegetation cover is not possible or where the top of the embankment is less than 2 metres from a house or other structure, consideration should be given to replacing the embankment with a properly designed and constructed retaining or crib walls, (Figure 43).

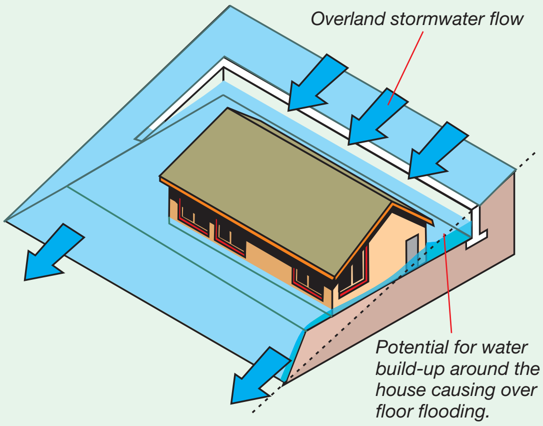
Retaining walls (built with concrete or masonry) and crib walls both need to have their bases below the area that is likely to be affected by erosion. If they are not, full protection is not ensured. Erosion under the toe of the wall could mean the wall will be undermined and collapse, with erosion progressing towards the building's foundations. The depth of the wall below the area likely to be affected by erosion needs to be assessed for each building as it could vary between 200 to 800mm depending on soil types, water velocity and duration of exposure.

In areas of flood flow, cultivated gardens should be kept away from the house especially any corners. The use of concrete paths next to the walls will also increase protection.

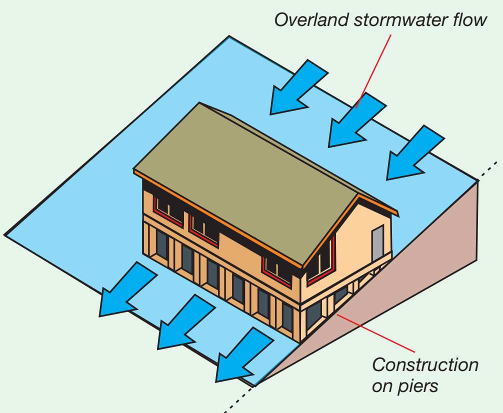
### 4.1.7 Local Drainage Issues

Unless located on a ridge, most houses – even those well away from a river or creek – can be susceptible to shallow inundation from overland flooding. Such conditions can arise during very high intensity rainfall, when the capacity of drainage infrastructure is exceeded or is affected by blockage.

***Figure 44*** *Diverting local run off*




Houses can be affected by stormwater flooding during high intensity rainfall, especially when built in cut and fill situations.




Houses can be protected from overland flows by elevating the ground floor above the surrounding ground level.

Clearly, houses should not be located in potential overland flow paths. Protection from overland flow is best achieved by elevating the floor above the surrounding ground and landscaping the site to shed rather than collect and/or pond local runoff.

## 4.2 HOUSING TYPES

### 4.2.1 Individual Dwellings

There is limited variety in types of house construction due to the conservative nature of the building industry and the lack of awareness by home purchasers of the high flood vulnerability of traditional housing.

Opportunities to reduce flood risk through various building alternatives are often missed with traditional housing seen as the only marketable option.

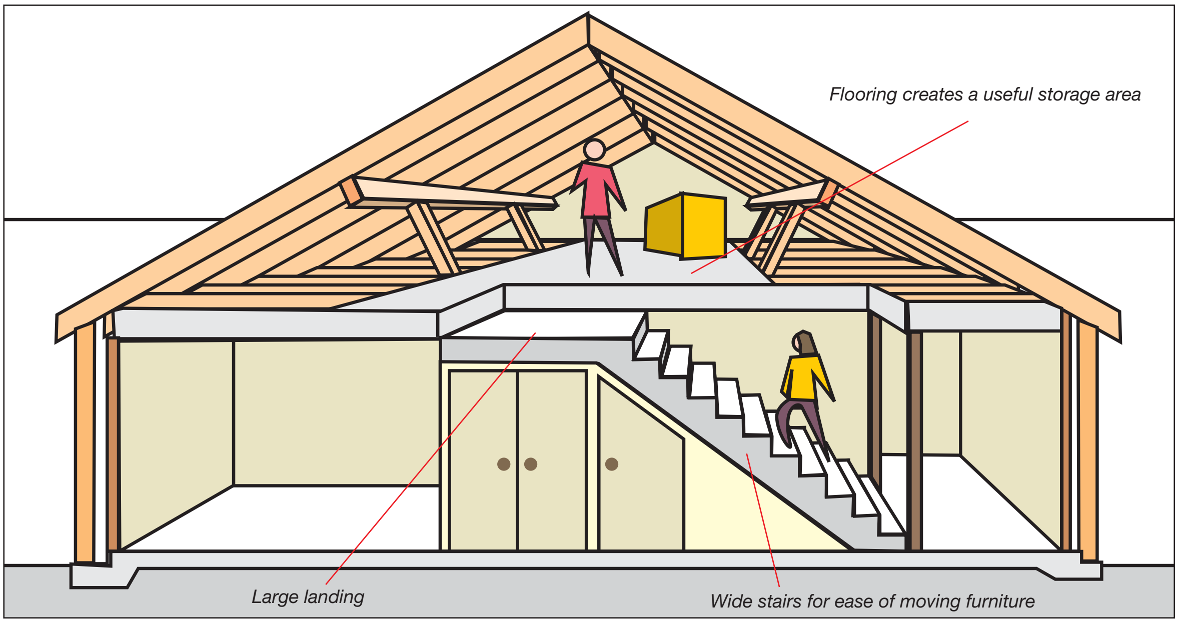
Different housing options can provide substantial opportunities to reduce flood damages both to buildings and contents and therefore control risk exposure through the choice of house construction types and building materials e.g. concrete or full brick.

#### 4.2.1.1 The Single-Storey House

Single-storey houses are suited to areas on the Hawkesbury-Nepean floodplain where there is low flood risk and only shallow flooding.

The disadvantages of a single storey building in areas where there is still potential for deep flooding have been demonstrated many times over in real flood events. Once constructed, a single floor level provides little flexibility for the occupier to give priority during a flood to protecting some assets apart from stacking contents on tables and benches or moving them to another location if there is available time. If flooding reaches halfway up the walls the resident has to accept the loss of virtually all contents and fixtures and that severe structural damage may occur throughout the entire house. There will also be no opportunity to conveniently store goods and furniture and occupy the house safely while reinstatement is in progress.

***Figure 45** Attic space for emergency storage*



One option for a single-storey house is to utilise the roof space to store valuable contents during a flood. A storage attic could be added in the roof space of a single-storey house. (Figure 45) This is not a habitable room, but is sufficient to store house furniture, electrical equipment and belongings in times of flood.

To achieve a useful attic space a gable roof is best with a minimum pitch of 1 in 2.5 (21.5 degrees). The roof structure will require heavier ceiling joists and basic flooring. The access stair to the attic should be wide and straight.

#### 4.2.1.2 The Two-Storey or Split-Level House

The most cost-effective step that can be taken to reduce flood damage to both the house structure and its contents is to elevate vulnerable areas of a building as high as practical. In most cases the extra height gained by a two-storey house would result in either:

- reducing the likelihood of the entire house being flooded, e.g. the relative risk at Windsor is around three times lower for the second storey than the ground floor because it would require a 1 in 300 year flood to reach this higher level, or
- providing a flood free area for storage of valuable contents by locating the upper floor above the PMF level in higher areas.

Two-storey houses also provide an excellent opportunity to use a combination of construction types to improve flood performance and keep additional costs as low as possible. While a two-storey building of full brick construction with a slab-on-ground and a suspended concrete slab on the first floor is highly flood resistant, it is relatively expensive for many home purchasers.

An alternative design that is more affordable combines a flood resistant ground floor with a less expensive upper floor construction. Upper floors can be constructed of brick veneer or an alternative clad frame. Although at some risk from flood damage, a suspended timber first floor is low cost and the extra elevation greatly reduces the probability of it being inundated, (Figure 46).

The functional design of a house can be arranged so that the rooms with the most valuable and vulnerable goods are located at the highest level. If the rooms on the lower floors are used for the more basic purposes (e.g. garages, laundries, second bathrooms) then the opportunity exists to make the lower levels much more flood resistant. For example, the walls could be constructed of concrete blockwork and the floor could be concrete with tiles. Fitted carpets and plasterboard wall linings etc. could be reserved for the habitable rooms upstairs.

A flood-aware two-storey house would consist of a slab-on-ground full brick construction for the ground floor. The second storey could comprise brick veneer or other cladding.



Studies by the Natural Hazards Research Centre at Macquarie University based on flood damage data, show the percentage damage (as a proportion of building value) to the building structure is less for split-level and two-storey dwellings than it is for single-storey dwellings. The data suggests that even split level homes produce lower losses due to inundation than do single-storey dwellings and more significant damage reduction occurs with two-storey dwellings. For this reason, two-storey dwellings and multi-storey residential buildings are a logical choice in areas where deep over floor flooding has a higher chance of occurring.

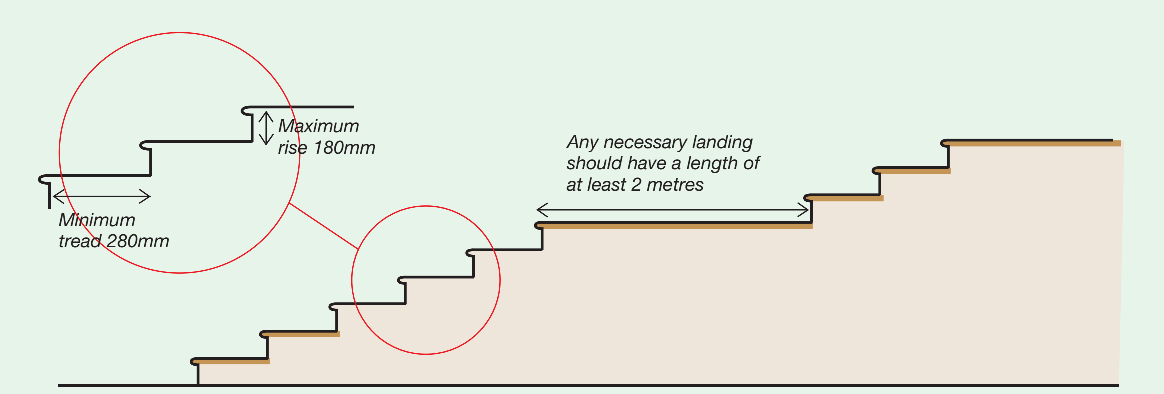
An important factor in the amount of contents damaged in a flood, is their location within the house – small differences in elevation can make large differences in damage. Analysis of damage on a room by room basis indicates that a high proportion of the total contents (and fixtures) value is contained in bedrooms, kitchens and lounge/dining rooms. If these high value contents are located upstairs where flooding is less severe (shallower and shorter duration) and far less likely to occur, then risk can be reduced dramatically. Similar precautionary measures are suggested in a report prepared by the Building Research Establishment Scottish Laboratory.

***Figure 46*** *Two-storey designs to suit areas with potential for deep flooding*

An example of a house design which can reduce flood damage. The lower ground floor was constructed with material not weakened or affected by floodwaters ie. full masonry. The upper floor, which has a much lower chance of being flooded, uses lower cost traditional frame construction and provides an opportunity to reduce damage to contents. The external wall sheeting used on the upper storey walls is both less expensive and easier to repair if damaged.

The three photos show different stages of construction. With good finishing technique both levels of the house have the same appearance.

***Figure 47*** *Stairs in flood-aware housing design*




Stairs that are wide, straight and gently rising make it easier to relocate contents upstairs during times of flood.

***Figure 48*** *The advantage of balconies on two-storey houses*

If residents were unable to evacuate in time, first floor balconies provide easy access for rescue teams.

Although a two-storey house is more expensive than a similar size single-storey house (around 10% more for the same total floor area), the smaller ground floor area of the two-storey house reduces vulnerability to flood damage.

In Sydney the pressure from increasing population, diminishing supplies of new land, and high costs of homes, have altered peoples preferences for housing and two-storey homes have become much more popular than in the past.

Another potential benefit of two-storey houses is that they can have a smaller footprint to increase the clearance between houses, and thus reduce the increase in velocity which occurs as flows are constricted between houses.

To allow furniture to be relocated easily at times of flood, wide, straight stairs, with large landings are desirable in a two-storey house, (Figure 47).

While residents are usually required to evacuate during a flood, there may be special circumstances where emergency rescues are needed for residents trapped by floodwater. First floor balconies are desirable design features on two-storey houses for this reason (Figure 48).

### 4.2.1.3 The High-Set (or Elevated) House

A lower cost alternative to a split-level or two-storey house is to elevate the house on timber, steel or concrete columns or poles. Access can be obtained via either an external staircase or an enclosed smaller ground level area which could also house the laundry, spare bathroom, tool/garden shed etc. The "undercover" area could also be used for car parking, (Figure 49).

High-set houses are technically two-storey although some councils consider a house raised with a clearance of 2.1 metres or less as a single storey house so it does not have as many building controls as a two-storey house. However, as the ceiling is less than 2.4m such areas cannot be used for habitable rooms. These matters would need to be discussed with council before pursuing designs.

***Figure 49*** *Raised house construction provides a high level of protection*

This house is reasonably flood compatible. The elevated living area greatly reduces the chance of flooding.

Steel framing is not affected by immersion and speeds the drying process. Fibre-cement weatherboads minimises water damage to cladding.

High set house.

Footings for high-set houses may be pads or braced posts (possibly with some framed walls between) supporting the house structure above. The use of such supporting posts usually means the house has to be a lighter clad frame structure. This type of construction is particularly useful where the floodwater velocity is likely to damage a standard on-the-ground house. The open ground floor area "substructure" not only reduces the chance of damage to the house but can also minimise the impact of the structure on the flood behaviour. However, it is very important that the substructure be designed to withstand the floodwater and debris forces. It would be prudent for the design to also consider the extra forces which will be imposed should infilling be placed between columns either as part of the initial construction or as a later modification. Such infilling could be designed to fail and breakaway.

Alternatively, especially in areas of low flow velocity, the lower area could be enclosed in masonry. However, more traditional strip footings would be needed so that a single-leaf masonry wall could be built up to floor level and a masonry (brick) veneer wall built around the raised living area of the house.

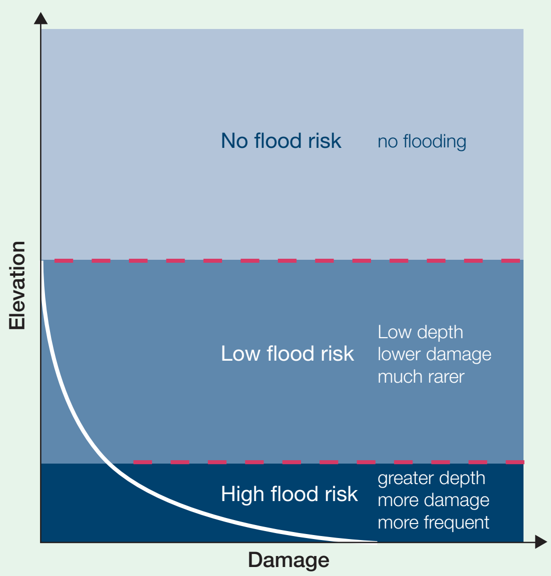
With high-set houses, consideration should be given to having two sets of stairs and useable verandas to provide additional opportunities for evacuation.

### 4.2.2 Larger Scale Housing

Larger scale mixed density developments can provide advantages in:

- areas on the floodplain where there remains potential for very deep flooding above the flood planning level, a higher-set development could greatly reduce the probability of flooding, perhaps even raising the habitable areas above the PMF, (Figure 50). Large scale multi-storey developments provide substantially greater opportunities to adopt more effective measures compared to individual project homes because they can be designed

***Figure 50*** *Higher elevation and lower flood risks*



for specific conditions, are not restricted to materials traditionally used in the construction of individual houses and have benefits from economies of scale, or

- areas where there are added risks from flowing water, the building structure could be designed to resist the higher forces. However, building in areas of high velocity is not sensible because of the reduced safety to occupants and more dangerous conditions for rescue operations.

#### 4.2.2.1 Villas and Town Houses

Depending on the size and topography of the site, villas and town houses may provide an opportunity to:

- locate the buildings in higher areas of the site thereby reducing the probability of flooding, and
- orientate and position the buildings to reduce the obstruction to flood flows and decrease the local velocities between the buildings as well as presenting the stronger wall to the flow to minimise damage.

Conventional villas (single-storey) and town houses (two-storey), with their common walls attached, provide little benefit over their freestanding versions in terms of flood-tolerant construction. Most are of full brick or brick veneer construction using similar materials to a standard house. However, economies of scale from larger development mean that flood-aware designs, materials and construction details can be used.

Some of the more beneficial measures are:

- the use of stronger reinforced concrete or tilt-up panel walls;
- concrete blockwork or brick walls,
- more flood resistant internal linings, or preferably coatings; and
- slab-on-ground and suspended concrete floors as an alternative to more vulnerable first floor/ceiling components such as timber.

#### 4.2.2.2 Multi-storey units

Even greater benefits can be achieved if high-rise unit developments are used in some of the more vulnerable flood prone areas, (Figure 51). Multi-storey units could:

- enable some if not all units to be located above the PMF leaving only garages and common property at the lower levels at risk of flood damage. Confinement of losses to common property represents a substantial reduction in the liability of individual unit owners over the liability of owners of detached houses,
- be specifically designed to resist forces of flowing water using more robust steel or reinforced concrete construction (Figure 52),
- provide a last resort refuge for occupants unable to evacuate in time.

Whilst there are substantial benefits in multi-storey units, it would be unwise to increase the overall numbers of dwellings on the site above that considered appropriate for safe and effective evacuation consistent with the SES's evacuation

Large scale mixed density developments provide substantially more opportunity to adopt many of the more effective flood-aware measures than in individual project homes.

4

***Figure 51** Multi-storey units*

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.

*Parking and shops at ground level*

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

***Figure 52*** *Materials used in multi-storey construction*

*Concrete walls and floors*

*Brick load bearing walls*

*Carpark construction*

*Internal non-load bearing partition wall*

The materials predominately used in multi-storey construction e.g. metal, glass, brick/block work and reinforced concrete have a high resistance to water damage and remain structurally sound after flooding.

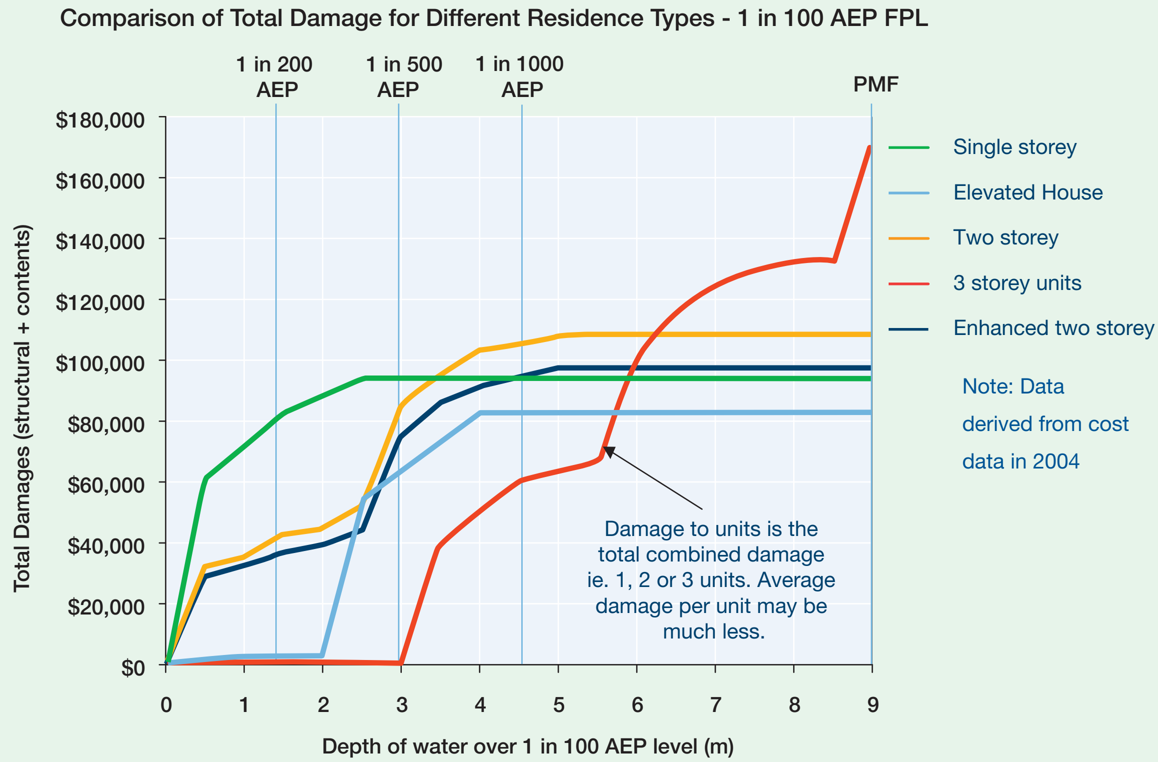
plan for the area. Although the units may provide an opportunity for refuge within the building, it is generally preferable that residents be evacuated from hazardous areas particularly if long periods of inundation are predicted.

The additional cost to increase flood protection in a high-rise unit development should be minimal due to the fact that most advantages come from the elevation of the individual units. The lower areas (carparking, common areas, etc) can be made as flood resistant as possible.

### 4.2.3 Damage Cost Comparisons

Buildings with raised floors such as two storey and elevated houses, town houses and multi

***Figure 53*** *Damage cost comparisons*



storey home units can provide a number of flood damage reduction benefits over single storey on ground houses:

- Greater opportunity to achieve more efficient use of flood resistant (ie. able to withstand immersion and potential out of balance forces) design by reducing the need to utilise flood resistant materials throughout the house by confining this to the lower levels. Use of masonry walls on the ground floor area will involve repainting the walls after the flood rather than replacing the wall linings;
- Allowing the use of cheaper but more easily damaged building materials at higher elevations to minimise the risk of costly repairs and replacement;
- Allow a high proportion of habitable areas and contents to be at higher and therefore less likely flooded elevations; and
- Provide some high level temporary storage area for moveable contents from downstairs areas.

Curves on Figure 53 highlight the lower combined structural and contents damage costs of alternative housing types such as 2 storey or multi – storey units for floods which moderately exceed the ground floor FPL. This damage information helps to define the socio – economic merit of each alterative and would therefore need to be considered when planning for any new or redevelopment. However, it should be noted that these curves do not directly reflect other possible benefits of these alternatives such as reduced trauma and quicker recovery from severe flooding.

## 4.3 CONSTRUCTION MATERIALS

### 4.3.1 Selecting Appropriate Materials

#### 4.3.1.1 Component Materials

In the selection of materials, three basic physical characteristics should be kept in mind:

- Materials that are weakened when wet should be used with caution – particularly if they are used in structural components which support loads on the building. If they are permanently damaged after a flood, they would need to be replaced.
- Materials that are stable when saturated but are porous and readily absorb moisture – should only be used in locations where good, flow-through ventilation will dry them effectively.
- Materials that are not adversely affected by water (is dimensionally stable and does not deteriorate or lose structural integrity when flooded) and do not absorb water readily – are ideal for use in building on flood prone land.

Tradition and cost often inhibit the use of materials in the third category. There can be a tendency to conclude from research into building damage that home builders should be discouraged from using materials that need replacement following a flood such as particle board in floors and in cupboards. In the case of structural components such as the floor this would make sense because its structural properties to support loads can be severely compromised. The floor would also be very difficult and costly to replace and there are cost competitive alternatives. Conversely, the selection of particle board cupboards may be appropriate and cost effective because its application is non-structural and therefore not critical and replacement can be the cheapest, quickest, and easiest option.

Hence, particular attention must be paid to components that perform a load bearing function within the structure of a house. In this situation, materials which weaken or distort when wet must either not be used, especially if there are residual problems even after drying, or an appropriate allowance made for the distortion or loss of strength, (Figure 54).

Distinction should also be made between components that can be readily replaced and those which can only be replaced at great expense. It is therefore imperative that difficult to access elements such as framing and fixtures in wall cavities are flood-resistant, while it is not so important that internal cladding be flood resistant as the extent of damage is very evident and it can be readily repaired or replaced, (Figure 55).

Table 4.3.1.2 organises common construction materials in a two-dimensional matrix according to their absorbency and susceptibility to damage.

It is imperative that difficult to access elements such as framing and fixtures in wall cavities are flood resistant.

***Figure 54*** *Testing of building components*

An understanding of the consequences of immersing various products in water has been gained from CSIRO testing. This information can suggest possible modifications or allowances to maintain the performance of the product when flooding occurs.

The above example shows a test on the effects of flooding on manufactured support beams which are increasingly used as an alternative to solid timber beams because of weight and cost savings.

The purpose of this table is to assist in the selection of flood resistant materials. As the table consists of rather broad categories to simplify the information, some materials do not strictly satisfy any one particular category and have therefore been placed in the most relevant area. In some cases, more than one category may be appropriate depending on the circumstances e.g. one-off wetting of bright steel is likely to cause light rust spots which may or may not progress depending on the future exposure conditions.

The placement of material in Class B and C does not necessarily indicate an increased risk of damage. Thus in any given flood, Class B material may be damaged (if subject to impact when wet) and Class C material undamaged (if dried out quickly), or vice versa, depending on the nature of the flood and post-flood conditions.

Materials in the top left corner of Table 4.3.1.2 are highly absorbent but will not be damaged by immersion. They are stable, but will dry slowly, (Figure 56). Care needs to be taken in combining these materials with others that are damaged by long-term exposure to moisture as these can take up to 3 months to dry out.

In contrast, materials of moderate absorbency take about one month to dry. However they too should not be combined with materials that are highly sensitive to relatively short periods of high moisture (Class D).

***Figure 55*** *Selecting appropriate materials*

The location and construction detailing of structural systems which utlilise a combination of materials with both high moisture absorbancy and potential for deterioration after flooding requires greater care in order to prevent decay and building failure. For example, particle board flooring may be damaged by prolonged floods and will be extremely difficult to replace.

Table 4.3.1.3 presents a range of alternative materials for a given building component in order of preference for resistance against a medium duration flood. This table considers only how well the individual material performs and not its impact on the building system. Thus, if selection is made on the basis of Table 4.3.1.3, it is advisable to cross-reference with Table 4.3.1.2 to check whether the selection has any implications.

It is important to note that the preferential ranking of the building materials provided in Table 4.3.1.3 applies only for the performance of the materials under flood conditions where relatively long-term immersion in dirty water can be expected. The ranking is in no way meant to suggest that the lower ranked materials are not totally suitable for normal non-flood house construction.

***Figure 56*** *Masonry walls and absorbency*

Masonry walls have high absorbency, but are not significantly weakened by moisture and therefore suffer minimal damage.

Consideration also needs to be given to termite protection. Chemical anti-termite treatment, for example, may be diluted or washed away. Physical termite barriers under floors or in walls may be bridged by flood-deposited silt and if not cleaned provide a path for termites to enter and destroy house timbers and fittings.

***Table 4.3.1.2** Material Absorbency*

| ABSORBENCY | | | | |
|---|---|---|---|---|
| CLASS | HIGH | MODERATE | LOW | NIL |
| A | • masonry<br>• concrete | | • solvent-based neoprene adhesives<br>• two-part epoxy adhesives<br>• rubber based sealants silicone sealants | • copper<br>• brass<br>• plastic membranes and sheeting<br>• nylon fittings<br>• glass<br>• glass bricks |
| B | • plasterboard | • plywood<br>• hardwood | | |
| C | | • low durability timbers<br>• good quality adhesives<br>• low quality tiles<br>• water-based paints | • high durability timbers<br>• good quality tiles<br>• rubber-based adhesives<br>• epoxy putty sealants<br>• stone epoxy formed in place | • galvanised steel<br>• aluminium |
| D | • insulation<br>• building paper<br>• wall paper<br>• ceiling plasterboard*<br>• normal particle-board | • hardboard<br>• dry area adhesives<br>• water-based acrylic adhesives<br>• water-based urethane adhesives<br>• water-based acrylic sealants<br>• PVA emulsion cements<br>• lino, carpets, cork | • oil based paints | • bright steel |

*A minimal damage under most circumstances*
*B susceptible to physical damage when wet, otherwise no long-term damage*
*C subject to damage after prolonged immersion, but will recover when effectively dried*
*D subject to permanent damage if subjected to relatively short periods of wetness*
** plasterboard fails due to increased weight and weakened state*

***Table 4.3.1.3** Materials for 96-Hour Immersion*

| COMPONENT | SUITABLE* | MILD EFFECTS* | MARKED EFFECTS* | SEVERE EFFECTS* |
|---|---|---|---|---|
| FLOOR, SUB-FLOOR STRUCTURE | • slab-on-ground<br>• suspended concrete | • timber T&G (with ends only epoxy sealed and provision of side clearance for board swelling) or plywood | • standard grade plywood | • timber floor close to the ground and particleboard flooring close to the ground |
| WALLS SUPPORT STRUCTURE | • reinforced or mass concrete | • full brick/block masonry cavity brick | • brick/block veneer with venting (stud frame) | • inaccessible openings<br>• large windows low to the ground |
| WALL AND CEILING LININGS | • fibre cement sheet<br>• face brick or blockwork<br>• cement render<br>• ceramic wall tiles<br>• galvanised steel sheet<br>• glass and glass blocks<br>• stone, solid or veneer<br>• plastic sheeting or tiles with waterproof adhesive | • common bricks<br>• solid wood, fully sealed<br>• exterior grade plywood<br>• fully sealed<br>• non ferrous metals | • exterior grade particleboard<br>• hardboard<br>• solid wood with allowance for swelling<br>• exterior grade plywood<br>• plasterboard | • particleboard<br>• fibreboard or strawboard<br>• wallpaper<br>• cloth wall coverings<br>• standard plywood<br>• gypsum plaster |
| ROOF STRUCTURE | • reinforced concrete<br>• galvanised metal construction | • timber trusses with galvanised connections | • traditional timber roof construction | • inaccessible flat floor<br>• ungalvanised structural steelwork<br>• unsecured roof tiles |
| DOORS | • solid panel with waterproof adhesive<br>• flush marine ply with closed cell foam<br>• aluminium or galvanised steel frame | • flush or single panel marine ply with waterproof adhesive<br>• painted metal construction<br>• timber frame, full epoxy sealed before assembly | • standard timber frame | • standard flush hollow core with PVA adhesives and honeycomb paper core<br>Note: lowest cost and generally inexpensive to replace |

| COMPONENT | SUITABLE* | MILD EFFECTS* | MARKED EFFECTS* | SEVERE EFFECTS* |
|---|---|---|---|---|
| WINDOWS | • aluminium frame with stainless steel or brass rollers | • timber frame, full epoxy sealed before assembly with stainless steel or brass fittings | | • timber with PVA glues<br>• mild steel fittings |
| INSULATION | • plastic/ polystyrene boards<br>• closed cell solid insulation | • reflective foil perforated with holes to drain water if used under timber floors | | • materials which store water and delay drying<br>• open celled insulation (batts etc) |
| BOLTS, HINGES NAILS & FITTINGS | • brass, nylon/ stainless steel, removable pin hinges | • galvanised steel, aluminium | | • mild steel<br>** see Note below |
| FLOOR COVERING | • clay/concrete tiles<br>• epoxy or cementitious floor toppings on concrete<br>• rubber sheets (chemically set adhesives)<br>• vinyl sheet (chemically set adhesive) | • terrazzo<br>• rubber tiles (chemically set adhesives)<br>• vinyl tiles (chemically set adhesive)<br>• polished floor & loose rugs<br>• ceramic tiles | • loose fit nylon or acrylic carpet (closed cell rubber underlay) | • wall to wall carpet<br>• wall to wall seagrass matting<br>• cork<br>• linoleum |

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** KEY*

***SUITABLE***

***these materials or products are relatively unaffected by submersion and flood exposure and are the best available for the particular application.***

***MILD EFFECTS***

***these materials or products suffer only mild effects from flooding and are the next best choice if the most suitable materials or products are too expensive or unavailable.***

***MARKED EFFECTS***

***these materials or products are more liable to damage under flood than the above category.***

***SEVERE EFFECTS***

***these materials or products are seriously affected by floodwaters and have to replaced if inundated.***

*** Note: For nominal fixings in timber framing, AS 1684.2 requires nails used in joints that are continuously damp or exposed to the weather to be hot dip galvanised, stainless steel or monel metal.*

For infrequent flooding (i.e. above the 1 in 100 AEP flood planning level) the degree of corrosion in heavier gauge mild steel nails and bolts used in timber framing and structural steel connections is unlikely to be critical to require avoiding mild steel. However, for all nails used for framing anchor and straps, AS 1684.2 requires corrosion protected flat head connector nails irrespective of their exposure to moisture.

#### 4.3.1.2 Fastenings and Adhesives

The level of corrosion protection required for fixing hardware (nails, screws, hinges, etc.) depends on a number of factors. Better quality hardware should be used where:

- subject to frequent and/or prolonged wetting,
- it is structurally critical and at risk of severe corrosion,
- the hardware is difficult to examine periodically after a flood,
- the hardware is difficult to replace if severe corrosion does occur,
- inundation by seawater can be expected, and/or
- there is little cost difference involved.

Given that flooding is a relatively low probability in the life of a building placed above a flood planning level such as a 1 in 100 AEP event, most of the heavier mild steel gauge bolts, nails and screws used in structural applications such as timber framing or connecting steel beams do not warrant corrosion-free alternatives. Unless there is constant or prolonged wetting, corrosion should be limited and restricted to the surface.

In a more corrosive environment or in critical areas, consideration could be given to using galvanised or stainless steel hardware. The definition of critical areas is somewhat subjective but they could be those satisfying one or more of points above.

Adhesives and sealants that are available for construction are made from a wide range of materials and their performance, when immersed in water, will not generally be obvious. Most perform poorly in this regard and great care should be taken in their application. Of the more common materials solvent-based neoprene adhesives are the best, followed by rubber-based adhesives.

Of the less common materials two-part epoxies and polysulphide epoxy resins perform well.

Among the common wood glues resorcinol-based glues perform better than melamine urea formaldehyde. PVA glues are the most common wood glues; however, they absorb water and lose their strength.

Sealants are also used for their bonding properties. Common sealants in order of greatest water resistance are:

- polysulphide sealants,
- silicone sealants,
- rubber-based sealants,
- epoxy putty,
- polyurethane joint filler (bitumen impregnated), and
- water-based acrylic.

### 4.3.2 Types of House Construction

#### 4.3.2.1 Traditional House Construction

The vast majority of houses are constructed from:

- brick veneer (a brick wall outside a frame structure),
- light-clad frame (a frame structure directly covered with materials such as timber, aluminium, vinyl, or fibre cement sheet or boards), or
- full brick (two brick walls separated by a cavity). Also referred to as double or cavity brick.

Brick veneer and light-clad frame houses normally use a timber or light gauge steel frame which commonly has internal plasterboard lining. They are readily constructed by the building trades, such as carpenters and bricklayers, and are often the most cost-effective forms of construction especially for detached houses because the industry and market are geared to this product.

Brick ties and other components that are embedded in mortar are a special case. It is well established that components in mortar corrode at a significantly higher rate than those in the air spaces within the building envelope. This is particularly the case if the mortar beds have been immersed in saline or brackish water. Thus it is a wise precaution to ensure that stainless steel or other high durability materials are used for brick ties.

All these forms of construction use a wall cavity, which have problems following a flood, such as trapping silt and retaining moisture in any wall insulation. These issues and possible solutions are discussed in Section 5.4.

#### 4.3.2.2 Concrete Panel Housing

Construction techniques normally associated with commercial and industrial developments are now being used for unit, townhouse and other medium/high density residential developments, (Figure 57). The panels are durable, but depend on the connections to stay in place. If the connections are not appropriately designed and protected they may fail under load or may corrode over time.

Concrete Panel Housing (CPH) comprises external walls and often internal walls made of vertically positioned concrete panels. These can be either precast on site (tilt up construction) or made in a factory and transported to site for placement (precast construction), (Figure 58).

The flood performance of CPH is excellent, due to its inherent strength and imperviousness. When used as an isolated concrete wall, i.e. without external cladding or internal lining, this form of construction will suffer no damage and will only need a hose and scrub down or, at the worst, repainting.

Many of the recommendations in these guidelines are applicable to CPH construction. As CPH is engineered for a specific design and constructed by specialists, these guidelines do not include detailed advice on CPH specific flood-effective designs. The principles of these guidelines can be easily applied in their design to suit floodplain conditions. Some important applications to be considered are:

- CPH is usually built with slab-on-ground floors, so in flood prone areas consideration should be given to raising the slab above the surrounding ground level with compacted fill (see Section 5.1.2). It is also practical to have CPH built with raised, suspended floors, using timber or steel framed flooring or suspended in situ or precast concrete slab floors.

***Figure 57*** *Concrete panel houses*

- As the panels are reinforced concrete, the simplest approach is to design the walls to resist hydrostatic forces. If this is uneconomic, then it is vital to have near-floor level openings for the entry of

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Concrete panel houses can be designed to resist unbalanced hydrostatic (still water) forces.

***Figure 58*** *The advantages of concrete panel housing*


An example of precast concrete panel construction in unit development (top right). As there is no cavity, this form of wall construction avoids problems of silt in the cavity, which occurs in more traditional forms of construction. Being built from concrete it also has the benefit of durability and resistance to any form of damage which may be caused by inundation.

rising floodwaters to prevent unbalanced hydrostatic forces forming (see Section 3.2.1). Section 3.2.1.3 gives advice on the provision of sufficient water inlets which can also allow outflow of receding floods. Construction details of openings are best left to the designer, but consideration should be given providing efficient floodwater entry and exit while also providing a thermal, vermin and intruder barrier.

- Minimum repairs are needed when the concrete panels are not lined or clad but rather have appropriate external and internal finishes applied. Acrylic painting of the wall is the simplest internal finish. CPH walls can also be lined internally with plasterboard placed either directly on the wall or on battens (or furring channels) attached to the wall. Battened lining can be used in conjunction with insulation in locations requiring additional thermal insulation, (Figure 59).

  While battened linings result in the formation of a cavity and a moisture trap, it does not reduce the flood advantage that CPH offers because the structural performance of the concrete wall will not deteriorate. Additional insulation should be incorporated in the wall itself in the form of sandwich construction, (Figure 60).

  For the best flood performance, it is recommended that internal walls also be constructed from solid concrete rather than lined frames.

  Where internal linings are used over concrete panel walls, allowance should be made for water entry and exit near the skirting. Also where battens support the wall lining, they should be placed vertically wherever practical, to provide better drainage of floodwaters and an improved drying environment. The skirting should be removable or have perforations in water-resistant material.

The use of metal door frames should enhance resistance to water damage.

Currently, CPH is economic in unit type developments where repetition and mass production of the panels reduces costs. However, CPH can be used for larger two-storey houses where CPH can be cost competitive with double brick construction.

***Figure 59*** *Plasterboard lining on concrete panel walls*

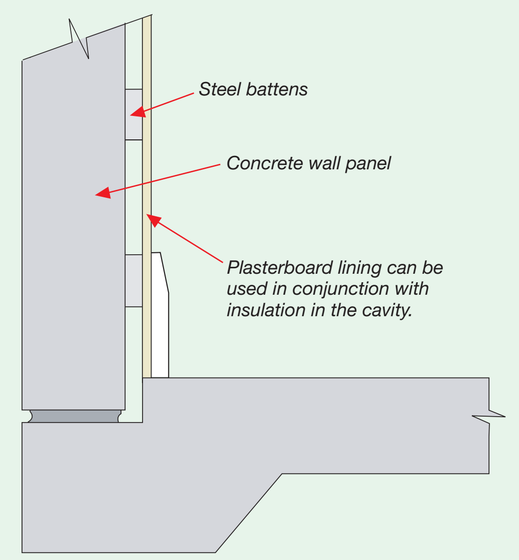
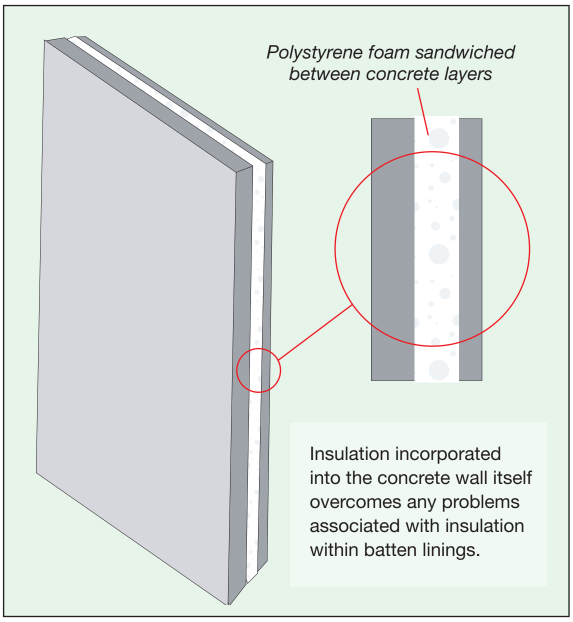


***Figure 60*** *Insulation incorporated into concrete panels*




More information on Concrete Panel Housing is available in the Cement and Concrete Association of Australia's publication "The Concrete Panel Homes Handbook", which can be downloaded from the website: www.concrete.net.au.

### 4.3.2.3 Blockwork Construction

The two most common forms of residential blockwork construction are:

- autoclaved aerated concrete (AAC) blocks, and
- concrete blocks.

Lightweight AAC blocks commonly used in residential buildings are very porous. If immersed, they can absorb a high volume of water and this can lead to damage of other components. The waterproof coatings usually applied on the exposed wall surfaces are to protect against light wetting, e.g. rainwater, rather than protecting against water immersion over several days. Wherever they are laid below ground, the usual recommendation is that they should be imperviously sealed e.g. with bitumous sealant. Thus without special treatment, they may not be suitable in flood prone areas, (Figure 61).

AAC blocks are not recommended for use in flood prone areas, while concrete blocks can perform well.

In contrast, concrete blocks will not be damaged by floodwaters and can be easily cleaned after a flood. A house constructed of single-leaf concrete masonry and concrete floors, metal door frames with no skirting boards has very low vulnerability to water damage.

In some climates the presence of empty cores in the blocks may not provide sufficient thermal insulation and they may need to be lined or clad thereby increasing flood repairs (see Section 5.4.1 for problems with wall cavities).

***Figure 61*** *Concrete blockwork houses*

*Concrete blockwork houses can be highly resistant to water damage and can be reinforced to withstand higher forces against the wall.*

*Interior block walls can be painted directly to avoid damage to linings.*

*Single leaf wall construction eliminates problems with moisture and silt trapped in a wall cavity.*

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Concrete block walls also have the benefit that they can be reinforced to increase their strength in bending, which brick constructed walls are unable to resist. Reinforced concrete or concrete block walls can also be used to provide extra strength to walls at risk from debris and flow velocity.

#### 4.3.2.4 Other House Construction Types

There are a number of alternative construction methods and materials, including:

- mud brick,
- rammed earth,
- reverse masonry veneer, and
- straw bale.

As these types of construction are relatively uncommon in the Sydney metropolitan area, they are not considered in these guidelines. Key considerations about their flood performance include:

- structural integrity of the material upon immersion,
- how the product and installation will affect drying time,
- the potential for deposition of floodwater contaminants in cavities, and
- the behaviour of the material in relation to other components.

The most important consideration is the effect of immersion for extended periods on the material. It is vital to realise that waterproof coatings may be sufficient to stop rain water from entering and/or damaging the integrity of the material, but quite often will not prevent damage when immersed in water.

### 4.3.3 Minimising Water Retention and Absorbency

The main factors influencing water damage are the duration of a flood, the length of time components stay wet, the materials used and the detailing.

Water can be retained in all sorts of traps and hollows that are a problem in flood prone areas. These include:

- hollows around foundation piers and against sub-floor brick walls
- the space between the underside of kitchen cupboards and the floor
- the base of built-in wardrobes and similar areas
- undrained brick cavities in full-brick construction
- the base of brick chimneys
- under bathtubs and prefabricated shower trays
- sealed cavities in double-sided plasterboard walls and hollow core doors
- the spaces immediately above any ceiling, including the void between a ceiling and the floor immediately above in multi-storey construction.

Water that is retained in these places can delay drying out and promote corrosion in metal items and fungal decay in timber or other organic materials.

A long duration flood allows water to soak into materials and sealed cavities, saturating them and maximising the potential for damage. For example, timber will become fully saturated and swell, the pore structure in concrete will become saturated, while the voids in hollow core doors and sealed stud and plasterboard cavities will fill up with water.

The drying time for a building that has been immersed for a prolonged period is measured in months. The damage caused can vary, from mechanical damage caused by timber swelling through to the disintegration of some materials and the onset of fungal decay and corrosion. This will be worsened by the presence of trapped silt and/or absorbent wall and ceiling insulation.

The following four steps will minimise the potential for water absorption and water damage:

1. Choose materials and construction details that are critical to the minimisation of these effects.

2. Choose materials that are not affected by water.

3. Avoid moisture traps in house designs and during building by ensuring clean and tidy construction e.g. wall cavities kept free of building debris and waste.

4. Seal porous materials against water entry. For example, sealing the end grain of timber can significantly decrease water absorption as the open end grain can absorb water at a rate up to 10 times that of the side grain. Some tests have shown that perhaps the best end grain sealer is two-part polyurethane filler or two coats of oil-based primer. The latter is likely to be slightly less effective but easier to apply. Other products may be satisfactory but, because of the problems with reapplying the sealer once constructed, a check should be made with the manufacturer that the product has been proven to provide long-term protection against water absorption without cracking or peeling.

Section 5 addresses in more detail what can be done for the individual components within a house.

### 4.3.4 Maximising Drying Rates

Ensuring rapid drying of house components after flooding is very important to minimise:

- the chance of structural damage to timbers used for framing, flooring systems, etc.,and
- the risk of damage to finishes and finishing.

Houses cannot be reinstated until any permanent loss of strength to structural components is addressed and everything in the house is completely dry. Replacement of plasterboard, carpets etc. should only occur after the adequacy of the post flood structure is certified.

*Typical Drying Times*

The times required for building components to dry out can be substantial and thus the time required before repairs can be made will also be substantial. In Table 4.3.4, estimates of the drying times required for components and the waiting times prior to repair are given for solid brick, brick veneer and timber clad structures.

These drying times are for Sydney during winter and Figure 62 contains a diagram with correction factors. These factors are presented as a function of maximum daily temperature and 3 pm relative humidity. Thus, the average 3 pm relative humidity and the average maximum daily temperature in Sydney during winter are 52% and 17°C respectively, and the correction factor is 1. In contrast, the conditions for Richmond (NSW) during summer are significantly drier and hotter, with the average maximum daily temperature being 30°C and average 3 pm relative humidity 47%, and thus the correction factor is 0.5 so that all the suggested drying times could be halved.

These drying times are provided only as a guide and such factors as post-flood weather conditions, house aspect, ventilation details, etc will influence the times. For example, following a flood, extreme weather patterns may persist. Under these circumstances, it would be advisable to adopt a slightly more conservative correction factor to cover this variability.

Instances where components have not dried after the suggested drying time has elapsed, may simply reflect differences in house type, microclimate variability etc. Where components remain wet after the elapse of twice the proposed drying time, suggests that there may be factors, such as trapped moisture or restricted ventilation, which can delay drying.

A long duration flood allows water to soak into materials and sealed cavities, maximising the potential for structural damage.

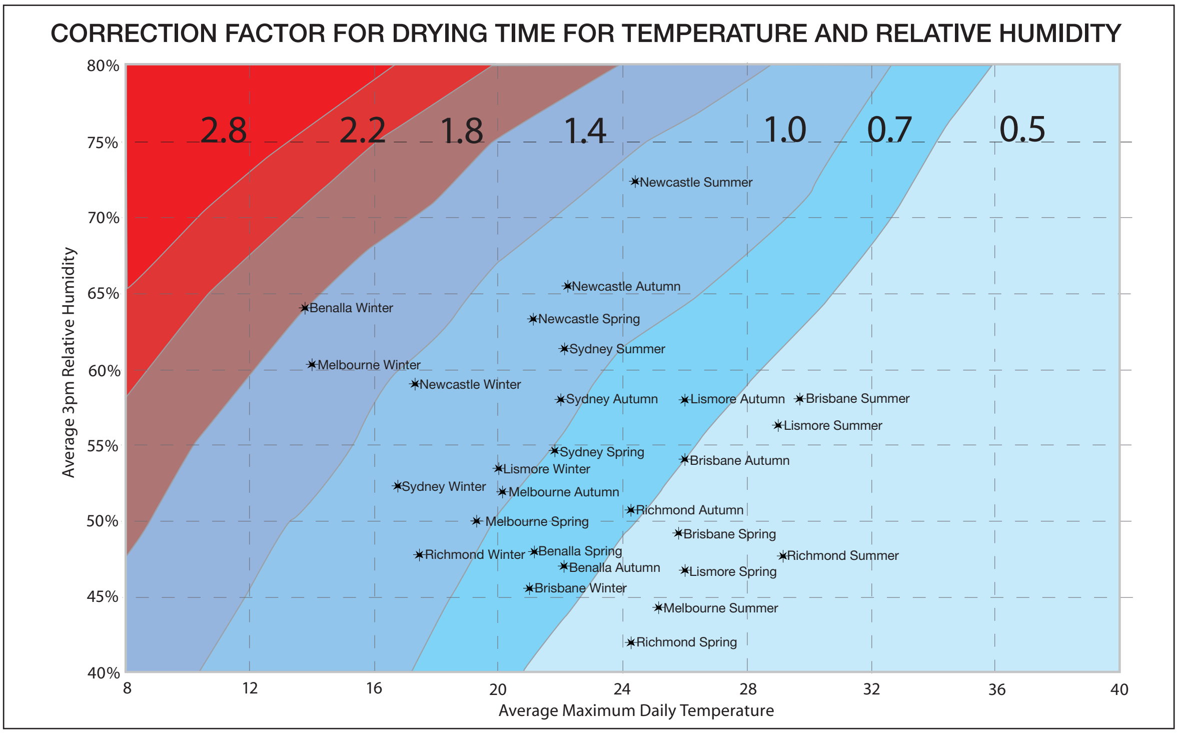
Water is absorbed through the end grain of timber up to 10 times faster than through the side grain.

***Table 4.3.4** Estimated drying time for components and cavities during winter in Sydney*

| COMPONENT | HOUSE TYPE | DRYING TIME (WEEKS) |
|---|---|---|
| **Concrete slab** | | 3 plus |
| **Floor beams** | Timber clad | 10-14 |
| | Brick veneer | 15-20 |
| | Solid brick | 15-25 |
| **Floor joists** | Timber clad | 5-7 |
| | Brick veneer | 15-25 |
| | Solid brick | 15-25 |
| **Solid timber flooring** | All types | 8 |
| **Plywood flooring** | All types | 8 |
| **Particleboard-flooring** | All types | 5 |
| **Tongue-and-groove - first floor** | All types | 10-12 |
| **Floor tile adhesive** | Slab-on-ground | 20-25 |
| **Brickwork** | Brick veneer | 10-15 |
| **Brickwork** | Double brick | 10-20 |
| **Exterior timber cladding** | Timber clad | 4 |
| **Wall cavity** | Timber clad | 3-8 |
| **Wall cavity** | Brick veneer | 6-9 |
| **Wall cavity (with bracing)** | Brick veneer | 9 |
| **Wall cavity** | Solid brick | 7-11 |
| **Bracing - plywood** | All types | 10-20 |
| **Bracing - hardboard** | All types | 4 |
| **Timber framing** | Weatherboard | 5-7 |
| **Timber framing** | Brick veneer | 9-22 |
| **Plasterboard** | All types | 3-5 |
| **Roof space (open)** | Brick veneer | 1-5 |
| **Roof space** | All types | 2-7 |

*Source: CSIRO*

***Figure 62** Correction factors for drying rates*




*Maximising Drying Rates*

Drying rates depend on ventilation more than any other factor. Though heating and forced ventilation can be used to accelerate drying, there is no substitute for cross-flow ventilation both under the floor, inside the house and in the roof space. Some materials permanently lose strength if they are wet for a long time. The longer the weakened materials are in that state, the higher the probability that they will be damaged.

To ensure effective cross-flow ventilation, adopt an open plan design wherever possible and insert vents in doors, ceilings, and enclosed areas such as pantries, toilets and laundries.

House designs should be uncluttered and windows should be situated on opposing walls of the house to promote cross flows through every room.

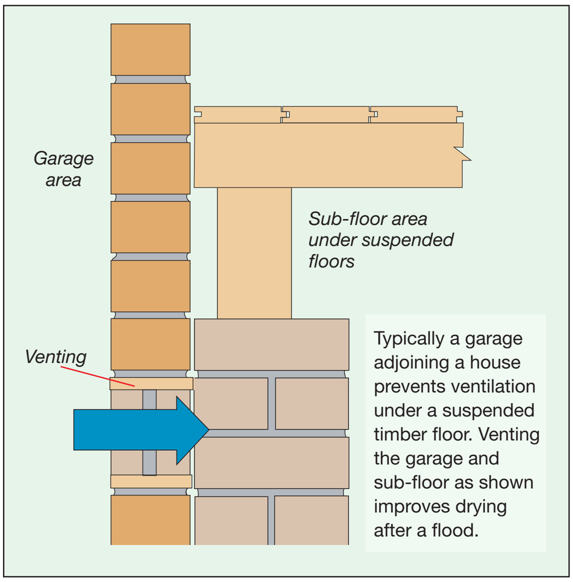
Under-cupboard and under-bathtub spaces should be open. (These units should be supported on freestanding legs.)

Experience has shown that moisture problems after floods are common in wet areas. Bathrooms tend to be small and poorly ventilated. They also contain moisture traps under baths and shower trays.

Another common problem area is where the garage adjoins a house with a suspended timber floor. Usually the garage prevents sub-floor ventilation on that side of the house and hence the sub-floor area dries very slowly. Venting the garage and the sub-floor space can assist in solving this problem, (Figure 63).

More advice on ensuring better ventilation is provided in many of the “Structural Component Design” subsections of Section 5.

***Figure 63** Venting a garage and sub-floor to assist drying*




4

# 5 STRUCTURAL COMPONENT DESIGN

Whilst Section 4 presents basic design and construction principles for the reduction of flood damage to buildings, this section provides more specific advice regarding materials and details for particular areas of building construction.

This section is structured according to the major building elements:

- Foundations and slabs-on-ground
- Suspended floors
- External brick walls and cladding
- Wall frames and external and internal wall cavities
- Insulation
- Internal wall linings
- Ceilings
- Roofs

Some of the major potential problem areas are shown in Section 2.1.

For each building element, information and advice is provided under four headings:

**Problems**

Briefly covers the flood related problems which can be associated with components of this building element.

**Design Suggestions**

Recommends methods of designing and detailing the building elements to overcome problems.

**Material Selection**

Recommends materials for use in the building element which may perform better when inundated. In several instances, it is difficult to distinguish between a design and material issue so there is some overlap.

**Comparative Costs**

Provides an indication of the likely cost of adopting the recommended designs and materials compared with more traditional methods. Any costs provided are representative of mid-2005 costs. Obviously there is a price range associated with any component and the costs change over time so these figures should be considered more as indicative and comparative, rather than absolute costs.

These guidelines are intended to provide an insight into the problems associated with the flooding of houses. Whilst an attempt is made to explain the necessary concepts, they are not intended to provide extensive background knowledge of all facets of residential building construction.

## 5.1 FOUNDATIONS

### 5.1.1 Problems

Foundations are the first part of the house structure to be affected by flooding and failure of the foundations can lead to very costly damage which can result in the total loss of the house.

The two issues of principal geotechnical concern discussed in detail in Section 3.4 are:

1. the threat of foundation failure due to erosion of supporting materials, and
2. foundation failure due to unacceptable settlement.

The soil map shown in Figure 64 for the Hawkesbury Nepean valley is divided into four main geotechnical units – alluvial gravels, alluvial sands and silts, alluvial clays, and residual clays. Table 5.1.1 considers these typical soils and identifies their likely problems.

# HAWKESBURY – NEPEAN SOIL MAP

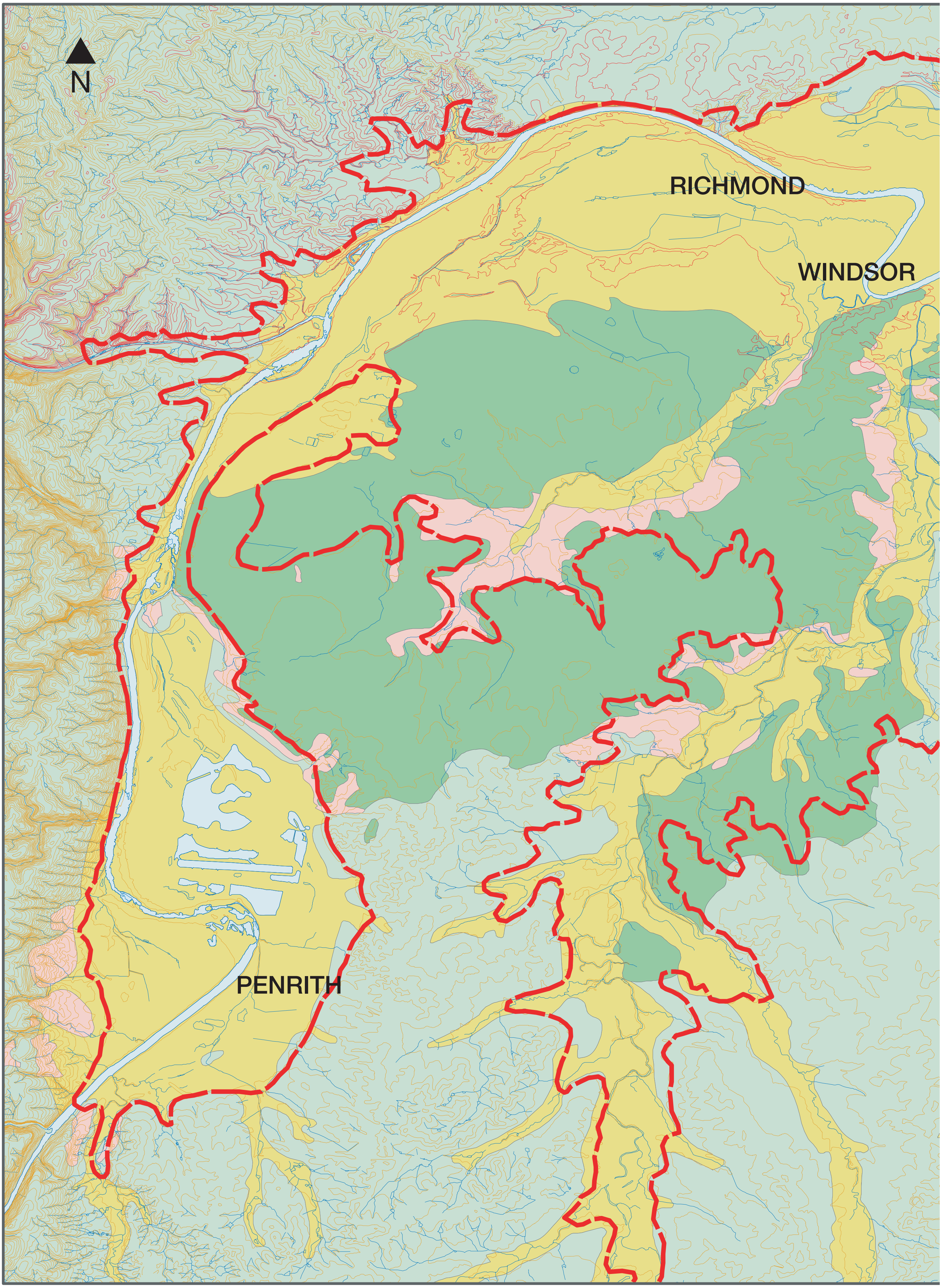
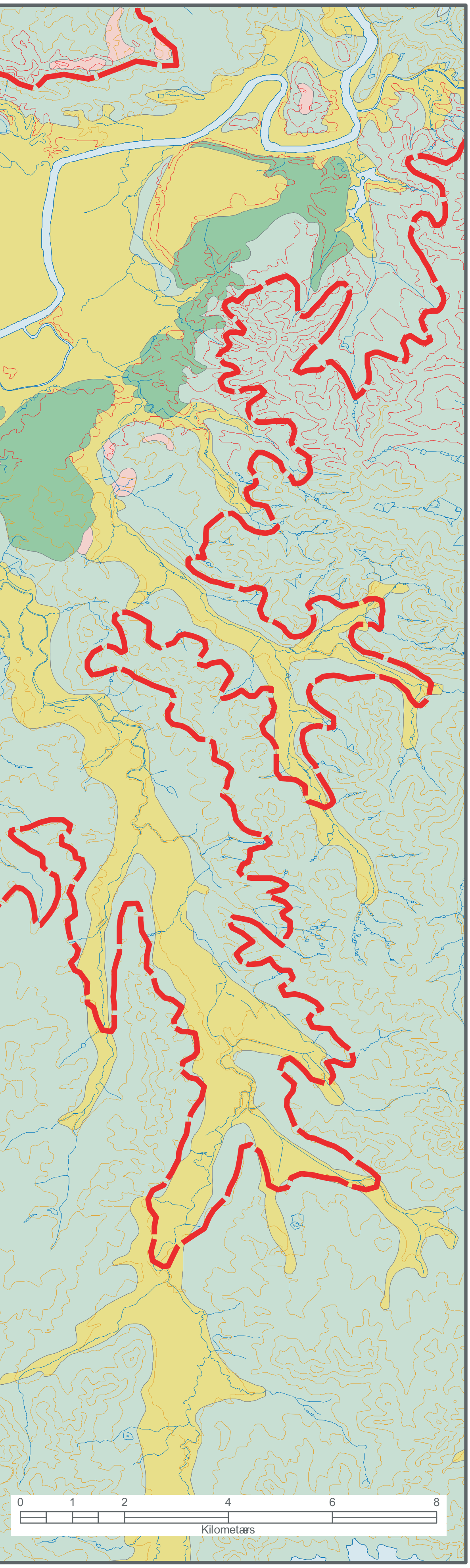


***Figure 64*** *Hawkesbury-Nepean soil map*




KEY

- Alluvial gravels (Unit A)
- Alluvial sands and silts (Unit B)
- Alluvial clays (Unit C)
- Residual clays derived from weathered shale and sandstone (Unit D)
- General limit of mainstream flooding

***Table 5.1.1** Potential Geotechnical Issues with Soils in the Hawkesbury-Nepean Area*

| GEOTECHNICAL UNIT | POTENTIAL GEOTECHNICAL ISSUES |
|---|---|
| **Unit A**<br>**(Alluvial gravels)** | • Gravel materials of this unit are expected to be erodible where water velocity is in excess of 3m/sec although some gravels may erode at much lower velocities.<br>• Relatively permeable nature of the gravels facilitates drainage of the materials following inundation.<br>• Low shrink-swell potential.<br>• Minimal loss of strength on saturation. |
| **Unit B**<br>**(Alluvial sands and silts)** | • The sandy and silty nature of the materials in this unit, may be erodible where water velocity is in excess of 0.2m/sec to 0.6m/sec. These soils are therefore the most erodible of all soils within the project area.<br>• Relatively permeable compared with Units C and D.<br>• Low shrink/swell potential.<br>• Minimal loss of strength on saturation. |
| **Unit C**<br>**(Alluvial clays)** | • The essentially clayey soils are erodible where water velocity is in excess of 1.5m/sec<br>• Relatively impermeable.<br>• Loss of strength on saturation.<br>• Susceptible to shrink/swell movements. |
| **Unit D**<br>**(Residual clays derived from weathered shale and sandstone)** | • The essentially clayey residual soils in this unit, are erodible where water velocity is in excess of approximately 1.5m/sec.<br>• Relatively impermeable.<br>• Loss of strength on saturation.<br>• Susceptible to shrink/swell movements. |

## 5.1.2 Design Suggestions

Given the significant variability in site conditions and flood behaviour, advice provided in this section can only be regarded as of a general nature and not a substitute for investigating actual site conditions.

Structural designers should obtain site specific geotechnical advice and be aware of the potential problems with flooding of the foundation material including landfill.

### 5.1.2.1 General Foundation Issues

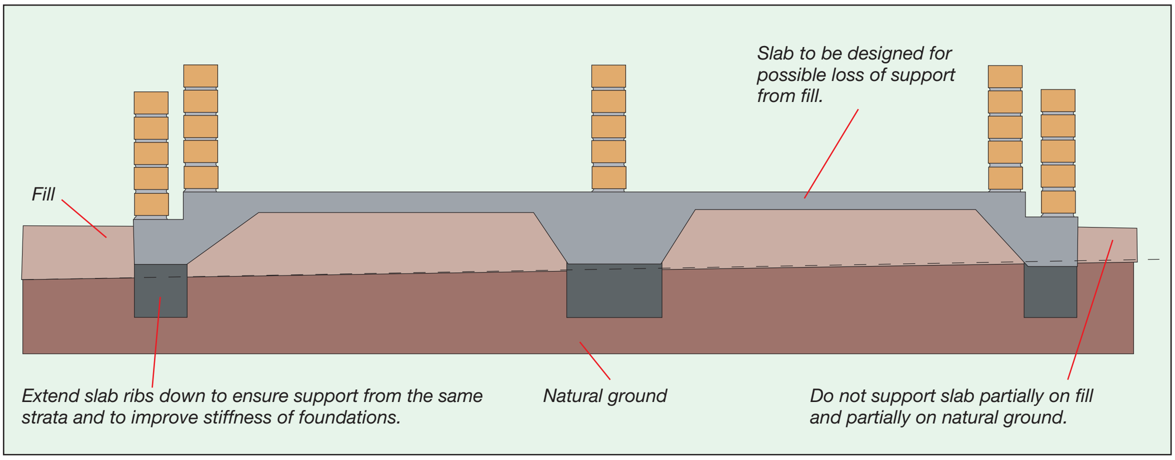
Measures to address the typical soil issues in the Hawkesbury Nepean are discussed in the following Table 5.1.2.

***Table 5.1.2*** *Possible Actions to Minimise the Impact of Foundation Problems*

| GEOTECHNICAL UNIT | POSSIBLE ACTIONS TO MINIMISE IMPACT |
|---|---|
| **Unit A**<br>**(Alluvial gravels)** | • This unit is the least susceptible with respect to erodibility and foundation failure of all units in the project area.<br>• Other than good engineering practices, there are no specific geotechnical requirements or constraints for developments in this unit. However, if the soil is considerably free draining, water may be able to apply significant pressure to the underside of slabs and some check on the buoyancy uplift forces may be required. |
| **Unit B**<br>**(Alluvial sands and silts)** | • In areas where higher water velocities are anticipated, and where the banks and beds of drainage channels are particularly prone to erosion, protection measures, such as rock filled gabions, mattresses, and grassing should be considered. Where possible, buffer zones between residences and water courses may have to be provided to minimise damage to structures.<br>• Discourage the use of sandy/silty materials as fill in construction of building platforms and other bulk earthworks. Encourage the use of clayey materials, adequately compacted at moisture contents up to approximately 2% wet of optimum moisture content. On the upstream side, and in some locations the downstream side (areas of turbulence) of raised building platforms, protection by rockfill or rockfilled gabions or mattresses may be warranted. |

| GEOTECHNICAL UNIT | POSSIBLE ACTIONS TO MINIMISE IMPACT |
|---|---|
| **Unit C**<br><br>**(Alluvial clays)** | • These soils are the least erodible of all the soils (i.e. not including gravels) in the project area. However, they are the most susceptible to shrink/swell movements. The soils may also loose strength on saturation, leading to progressive failure of some shallow foundations, including houses, road pavements and railway subgrades.<br><br>• Cut and fill sites may fail immediately following drainage due to excess pore pressures in the clayey soils. Encourage use of clayey soils adequately compacted at moisture contents up to approximately 2% wet of the optimum moisture content.<br><br>• Other than standard protection by grassing, cut and fill batters in clayey soils should be no steeper than 2(H):1(V) to minimise the chance of slope failures.<br><br>• Consideration could be given to adopting a lower foundation strength for the soils, and providing thicker pavements in susceptible areas. |
| **Unit D**<br><br>**(Residual clays derived from weathered shale and sandstone)** | • These soils are more resistant to erosion than the more sandy and silty soils of Unit B, but are not as erosion resistant as Unit C material.<br><br>• Cuts and fills in these materials may fail immediately following drainage, due to excess pore pressures in the clayey soils. Encourage use of clayey soils adequately compacted at moisture contents up to approximately 2% wet of the optimum moisture content.<br><br>• Other than standard protection by grassing, cut and fill batters in clayey soils should be no steeper than 2(H):1(V) to minimise the chance of slope failures.<br><br>• Consideration could be given to adopting lower allowable bearing pressures for the soils, and providing thicker foundations and slabs in susceptible areas. |

***Figure 65*** *Deepening foundation ribs in shallow fill*




Doubling the stiffness of a foundation system can reduce flood related damage by 90 percent.

### 5.1.2.2 Slab-on-ground and Raft Foundations

Measures to minimise damage from differential settlement are well documented in *AS 2870-1996 Residential Slabs and Footings*. However, some matters require closer attention where there is the added risk of site flooding.

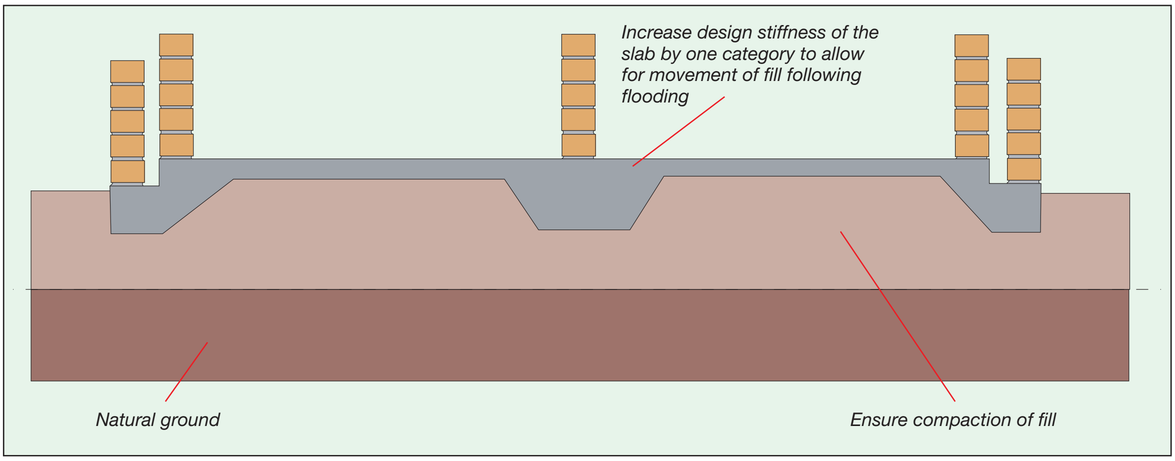
Slabs should be supported on the same strata. Sites employing cut and fill can introduce differential settlement problems in the event of flooding and measures such as extending the slab supports (i.e. ribs, edge beams and piers) to reach the original ground should be considered. Where slabs are placed entirely on fill, then good compaction is essential, (Figure 65 and 66).

Raft foundations tend to perform better from a structural viewpoint than strip and pad foundation systems in flood conditions. Their loading on the soil is significantly lower than strip footings, because it is spread over a greater area, thus the risk of any resultant settlement from weakening of the soil from saturation is reduced. Post-flood observations indicate that raft foundations or slabs-on-ground tend to maintain more uniform moisture content in the supporting soil thereby evening out differential soil swell. Also these types of foundation can be effectively stiffened to minimise differential movements to acceptable limits. This can be achieved by deepening the foundation ribs.

It is recommended that the design stiffness adopted for a flood prone site be increased by one category over that defined in the code (i.e *AS 2870-1996*) to cater for exaggerated movements caused by the immersion of a site. Doubling the stiffness of a foundation system can reduce flood related damage by 90 percent.

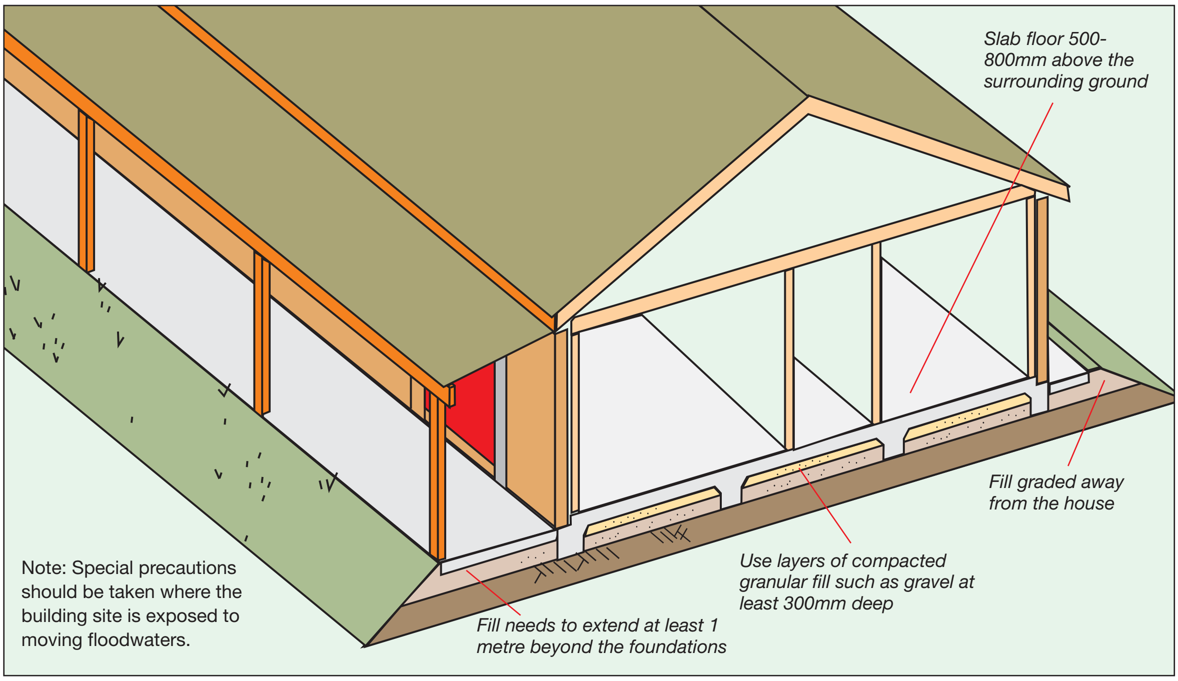
Where concrete slab floors are used, consideration could be given to raising the slab above the surrounding ground level by placing it on fill, (Figure 67). This has been very successful in overcoming problems associated with flooding due to overland flow and where it is impractical to

***Figure 66*** *Design stiffness of slab on floodplains*



Raising the slab will reduce the probability of the house flooding and prevent ponding around the walls.

***Figure 67** Raising the slab on alternative fill*




size the drainage infrastructure to cope with run-off from very high intensity storms and blockages in flow paths. Raising the slab is a more desired solution which will reduce the probability of the house flooding, prevent ponding against the walls, and improve the drainage around the house. Fill should be at least 300mm deep and extend one metre beyond the foundations of the house. As an alternative to standard soil, the fill material could consist of coarse granular material, such as gravel, which is relatively stable.

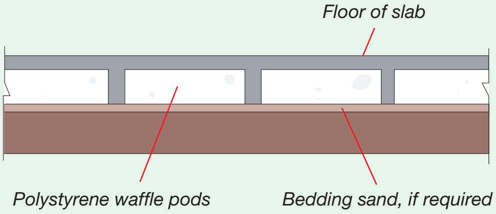
The raised fill may support a surrounding path then be graded gently away from the walls. Topsoil with planting is used to cover the exposed gravel. A layer of geotextile fabric may be required under the topsoil to prevent movement of the topsoil into the gravel fill. The use of such fill should be based on geotechnical advice specific to the conditions at the site.

Raising of the slab could also be achieved using waffle pods, (Figures 68 and 69).

Waffle pods can be constructed using polystyrene or similar blocks as permanent formwork. This can also assist with insulation of the underside of the slab. However, consideration needs to be given to the extra buoyancy that will be associated with the blocks. In some rare cases, this additional buoyancy may result in flotation of the house or create stresses not allowed for in the slab.

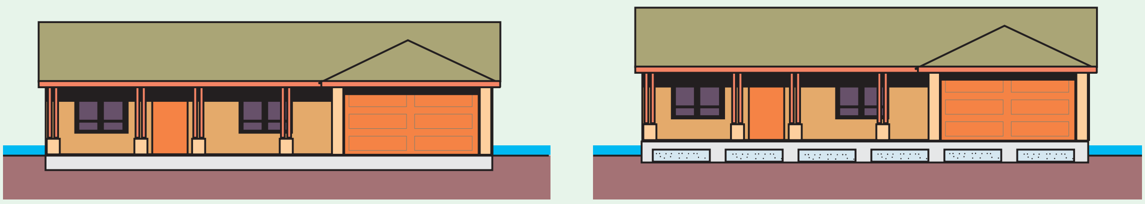
***Figure 68** Waffle pod construction*

Using waffle pod construction has the advantage of raising the floor slab above the surrounding ground. This can substantially reduce the possibility of flood damage in areas of shallow flooding and at risk from overland flow.




Raising the slab via fill or waffle slabs needs additional attention where flow velocities may lead to erosion of the fill and possible undermining of the house.

***Figure 69** Raising the slab using waffle pods*



Raising the slab 500-800mm on waffle pods (right) is very effective in reducing the possibility of the house being innundated in situations of overland flooding and where there is greater risk of the drainage infrastructure being overwhlemed by intensive localised flooding and blockages.

Pier and beam construction should be considered ahead of cut and fill foundations on floodplains.

One issue with slab-on-ground floors is that because of the absence of air circulation beneath the slab, they may take longer to dry out after flooding than suspended floors. This can delay the replacement of floor coverings and the re-occupation of a flooded house. However, with reasonable above slab ventilation, well-compacted concrete slabs with a good surface finish may take 3-4 weeks to dry sufficiently for the relaying of floor coverings. Waterproof coatings can be applied after construction to reduce the amount of water absorbed. Other issues relating to drying are covered further in Sections 4.3.4.

Where climatic conditions require a slab-on-ground to be insulated, the use of polystyrene boards around the edge of the slab is acceptable. However, some additional fixing may be appropriate to resist the tendency for the boards to float when immersed.

#### 5.1.2.3 Pier and Beam

In locations where cut and fill foundations would normally be used, pier and beam construction should be considered on floodplains. There are a number of issues to consider when using this option:

- The bearing must be on a common stratum as this is critical to minimise the potential effects of differential swelling.
- The possible reduction in bearing capacity due to the depth of the floodwater may require larger footings.
- Brick walls should contain articulated panels so that the brickwork can accommodate the differential movement without unacceptable cracking. Section 5.3.2 provides further advice on the use of articulated panels.
- As a rule, close centred columns (3 to 4 m) will give better performance than columns spaced at wide distances (5 to 6 m).
- If the piers are exposed, they will need to be designed to resist the forces caused by the water velocity and any related debris impact. These forces should also make allowance for any load on the infill panels supported by the piers

#### 5.1.2.4 Bored piles

In areas susceptible to excessive settlement or erosion potential, consideration should be given to the use of deep bored piles or similar footings to overcome foundation problems.

### 5.1.3 Material Selection

As potential problems with foundations can be addressed by proper site investigation and appropriate design, material selection is not an issue. However, it is important that any fill used is suitable under flood conditions.

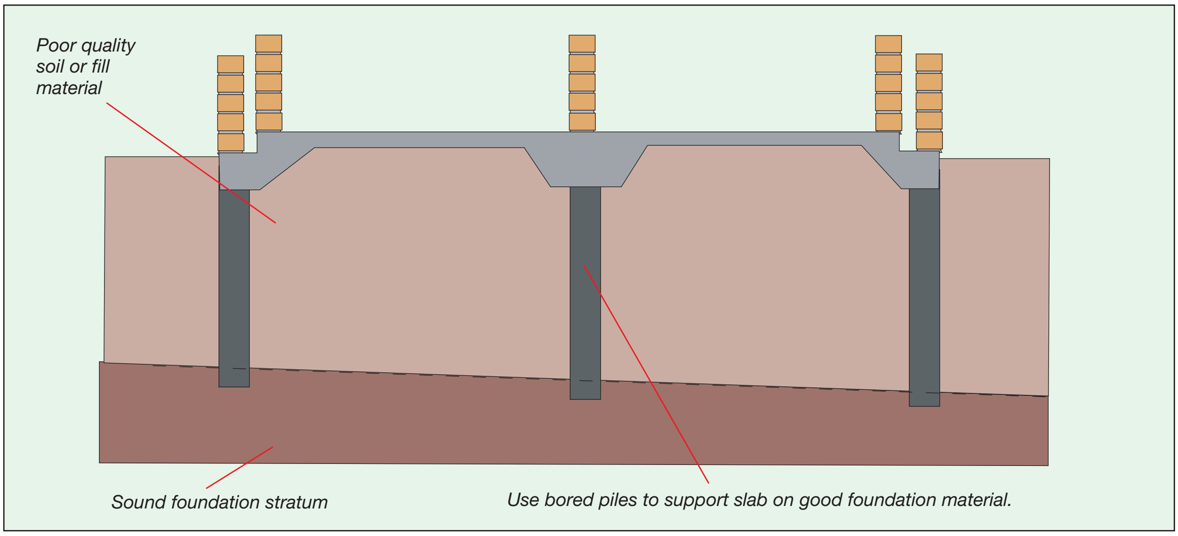
### 5.1.4 Comparative Costs

Selection between various foundation options will mainly be on the basis of the most economical solution to meet the performance requirements, taking into consideration the loadings, the soil properties and the site elevations. Consequently, the site specific nature of this decision makes a comparison of the costs of different systems of limited value.

## 5.2 SUSPENDED FLOORS

*NOTE: This section applies to suspended floors, at ground floor level and those at first floor and higher levels.*

***Figure 70*** *Use of bored piles*




## 5.2.1 Problems

Immersion has little effect on concrete floors, but it affects all timber flooring systems, either by weakening them during and/or after flooding and can cause temporary or permanent deformation. Some main problems are:

- Both particleboard and plywood lose about 50% of their strength after 96 hours of immersion. Consequently, caution has to be taken when reloading such a floor especially if still wet .
- Particleboard floors may have to be entirely replaced. Depending on the period of immersion, particleboard will have a residual strength loss of 25% after drying.

  Plywood sheeting regains most of its normal strength after drying.
- Strip flooring recovers its full strength. However, while it is wet it may buckle and cup, "popping" its nails. It can also swell to such an extent that it pushes surrounding walls out of position, (Figure 71).

Moisture absorbent underlays can be responsible for many floor problems after flooding. Other major problems for floors are the:

- decay of timbers due to moisture in flooring or support timbers. It may not become evident for up to a decade after flooding. Experience has shown that moisture levels may remain high under floors for months even if the area is well drained and ventilated.
- corrosion of steel in moist underfloor environments.
- presence of moisture in the concrete and masonry surrounding steel support beams can lead to destructive, expansive corrosion. Similarly, permanent exposed steel-sheet, concrete formwork/ reinforcement systems can also gradually corrode in these environments, leading to the eventual failure of the floors.
- some engineered timber support beams can be weakened by immersion.

## 5.2.2 Design Suggestions

The critical issue for floors is the quality of sub-floor drainage and ventilation.

### 5.2.2.1 Sub-Floor Drainage

There should be no hollows under the house which may hold water and maintain high moisture

***Figure 71*** *Cupping of strip flooring after immersion*

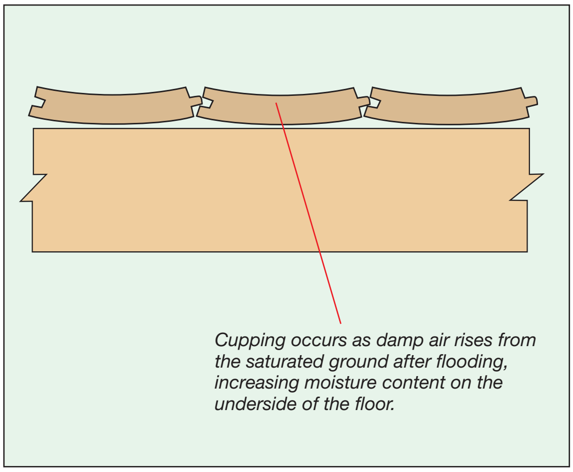
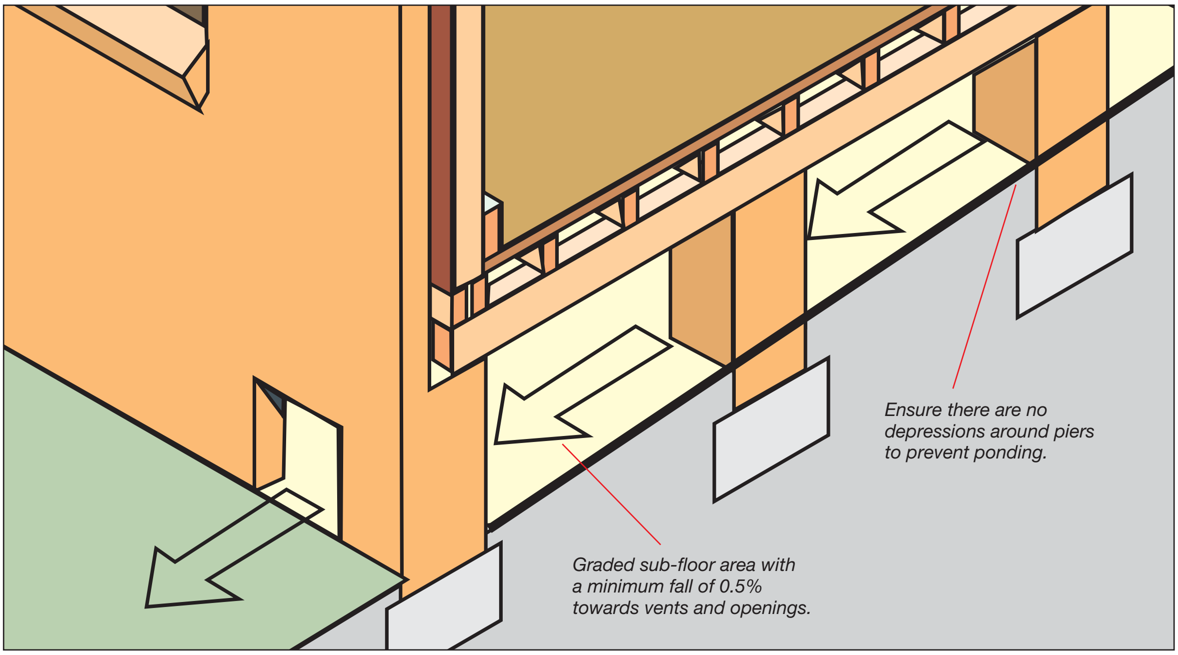


***Figure 72** Graded sub-floor area to prevent ponding*




In flood prone areas, the number of external vents for ventilation should be double that recommended by the Building Code of Australia to approximately 1 brick per metre.

levels. These are often created when strip footings are not backfilled. The sub-floor area must be filled and levelled to ensure that it is highest at the centre and drains to the edges. During floods, hollows can be scoured by fast flowing water, (Figure 72).

Gardens and built up landscaping mounds may restrict the free drainage of the sub-floor area. Careful landscape design is required to ensure that free drainage around the house is achieved.

#### 5.2.2.2 Sub-Floor Ventilation

Building Code Australia (BCA) stipulates that 7300mm$^2$ per metre should be allowed in all walls for vents, both external and internal (approximately half brick per metre). This should be at least doubled to improve the ventilation in flood prone conditions.

Clearance between the underside of joists and the ground needs to be generous in flood affected areas. The BCA stipulates 350mm. However, this clearance should be increased to 450mm where possible in areas likely to be flooded.

It is also important that there are no obstructions to airflow under the house. Continuous concrete or brick walls supporting floor bearers or joists should be avoided, but if used, they should have significant vents to permit some airflow. If the underfloor can dry out quickly, the chance of damage to timber and steel members will be reduced.

#### 5.2.2.3 Insulation of Floors

If insulation of suspended timber floors is required, it is recommended that polystyrene boards, or similar, be installed between the floor joists and held in place by wire mesh. Alternatives are reflective foil stapled to the underside of the joists, or polystyrene boards laid under the flooring, (Figure 73).

Polystyrene boards can be fixed to the underside of suspended concrete slabs.

All these installations will impact significantly on the drying times of the floor. After a flood if there are ventilation problems, consideration should be given to temporarily removing the insulation until the floor is thoroughly dried to avoid greater damage and the increased chance of rotting.

Refer to Section 5.5 for more advice on the use of insulation in flood prone houses.

### 5.2.3 Material Selection

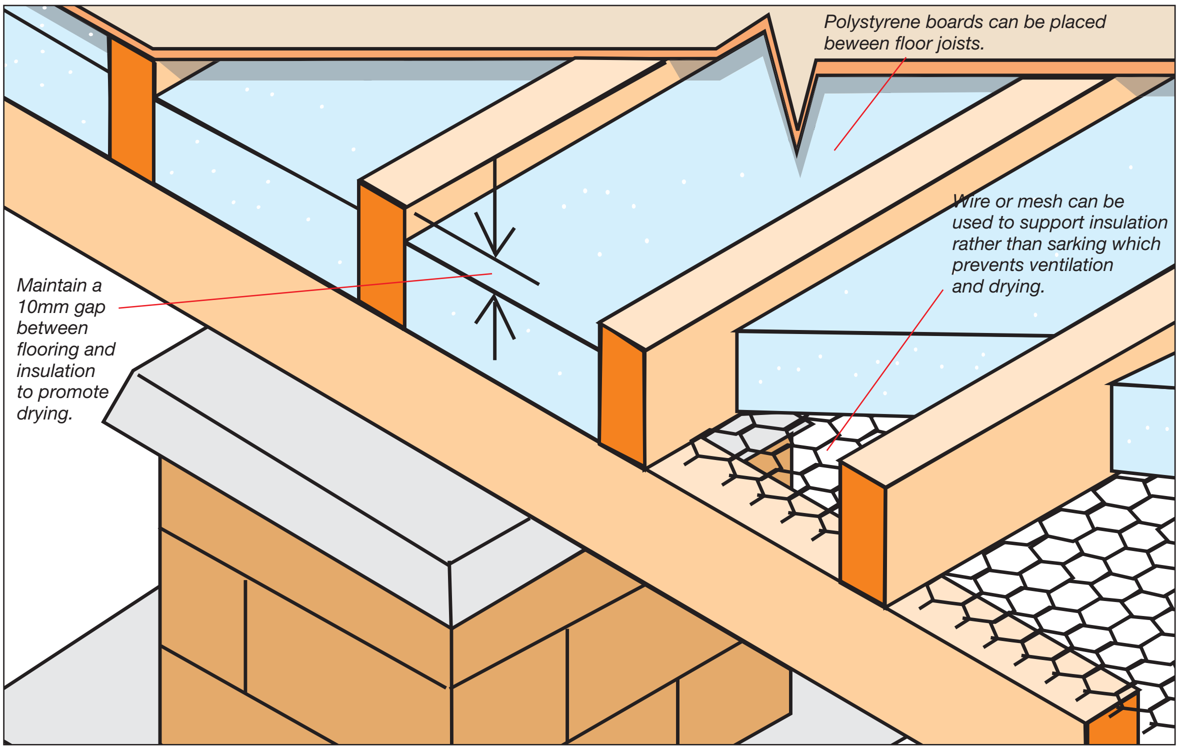
The risk of damage to flooring can be reduced by careful selection of the materials used for both the supporting members and the flooring itself.

#### 5.2.3.1 General

Timber used in sub-floor structural members and in flooring should be Class 2 (durable) or preferably Class 1 (highly durable).

Timber used in the sub-floor should be Class 1 or 2 to resist moisture problems.

***Figure 73*** *Under floor insulation*




For example, rather than using untreated radiata pine (Class 4, non-durable), or brush box (Class 3, moderately durable), there are likely to be advantages of less swelling and shrinkage in using spotted gum or blackbutt (Class 2, durable) or mountain ash or white cypress pine (Class 1, highly durable). Alternatively, treated timbers to hazard level 3 (AS 1604-1993) could be used.

Consideration should be given to factory sealing all ends of support timbers and flooring materials. Where timber members are cut to length on site, the end grain should be sealed before installation as water is absorbed through the end grain up to 10 times faster than through the side grain.

Nails used in the sub-floor should be galvanised or of equivalent corrosion resistance if moisture levels are likely to remain high for long periods.

### 5.2.3.2 Supporting Members

As indicated in the above section, more durable species (Class 1 or 2) should be used for traditional timber beams and cut ends sealed against moisture entry.

*Engineered timber beams*

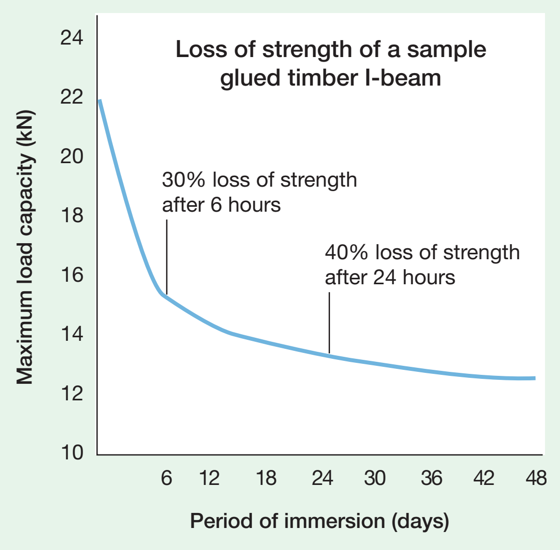
Increasingly, engineered timber beams are being used instead of the more traditional solid timber beams for suspended first floors. Examples of these beams include glued I-beams, timber trusses with metal plate connectors, metal web timber trusses and laminated timber veneer beams. These are becoming more popular as a result of their decreased weight, more efficient use of timber and lower cost.

Engineered timber beams perform well in normal non-flood prone housing. However, testing by CSIRO has indicated that some engineered beams, after a day or more immersion in water,

***Figure 74*** *Suspended concrete floor*

Suspended concrete floor formed with precast beams and fibre cement sheets overcomes the need for formwork and can be used economically at ground and higher floor levels.

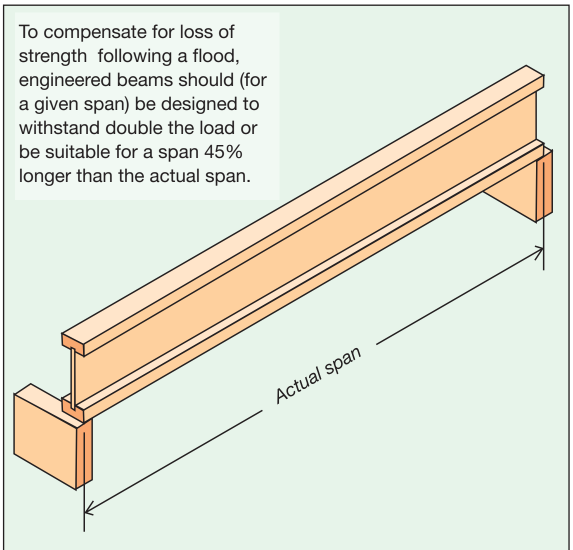
***Figure 75** Loss of strength of a sample glued timber I-beam*




Some glued timber products can weaken substantially because the bonding fails after prolonged immersion in floodwaters.

can lose significant strength and have an increase in deflection when loaded. For example, glued I-beams with oriented strand board (OSB) webs showed a strength loss of around 45% and metal web timber trusses showed a loss of around 35%. Glued connections can fail and nail plate connectors can release their grip at much lower loads when wet. Recovery of strength after drying depends on the type of engineered beam. For this reason, their use in locations where they may be immersed in floodwater requires special considerations, (Figure 75 and 76).

***Figure 76** Building with engineered timber beams*




It is important to note that the loading on structural members can be increased as a result of flooding. Immediately after the flood peak, building materials and contents supported by the beams, may be saturated and hence substantially increase the load on the floor and beams. In addition, upstairs floors may be overloaded with furniture etc. which have been moved there for protection. Such factors may increase the loading on beams above their dry design loading conditions.

There is a wide range of different types of engineered timber and timber/steel composite beams available and their performance varies when wet, (Figure 77). The limited testing for these guidelines is not to provide advice on specific products, but to examine the types of problem that might be encountered and how they might be alleviated. The following suggestions are made for the use of any beam which has been glued, or has nail plates, punched connector plates or similar connections:

***Figure 77** Beam failure*

This type of manufactured beam in a dry state predominately failed due to buckling of the metal struts. When immersed in water, these beams primarily failed due to the metal struts pulling out of the timber.

- If possible, moisture resistant adhesives (such as resorcinol glues) should be used throughout the beam.
- The allowable span for engineered beams should be reduced to around 70% of that normally used. For example, when providing a beam for an actual span of 5 metres, a beam suitable for a span of 7.2 metres under the same loading should be used. Alternatively, the beam should be

Engineered beams should be designed for a given span to withstand double the load to compensate for loss of strength following a flood.

designed for a given span to withstand double the load. With many different beam types available these suggestions can only be taken as general advice. Details and assurances should be sought from individual manufacturers.

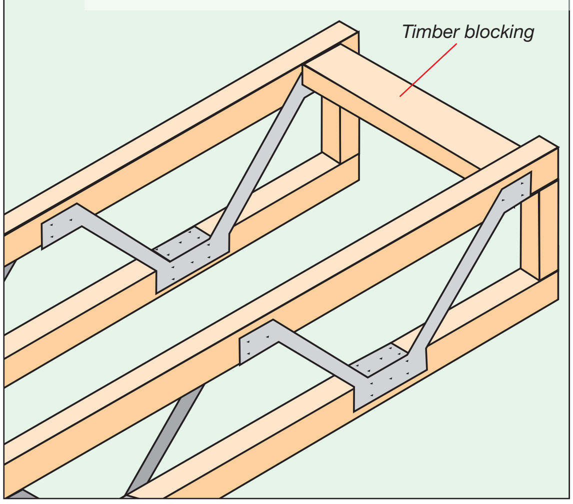
- Where possible, nail plate or similar connectors should be installed with additional grip. This may be achieved by using plates with longer or more teeth (or nails) as normally required or perhaps by "blocking" between the beams bearing on the nail plates to restrict parting of the connector from the timber, (Figure 78). Any measures adopted are especially important in areas of high shear or compression forces, e.g. the first few plates at the end of simply supported spans, and should be undertaken to manufacturer's recommendations or other qualified professional advice.

*Note: As both glued and mechanical connections appear to exhibit significant loss of strength, it is difficult to recommend a preference for either over the other. However, if to be used in critical applications, the manufacturer or product supplier should be consulted on whether their product will perform satisfactorily under conditions of immersion.*

Provided their potential loss of strength concerns are addressed, engineered beams can have advantages including cost effectiveness, they are easy to repair or replace if damaged and quicker to dry out as they absorb less water.

***Figure 78*** *Blocking of nail plates*

Nail plate beams failed primarily due to the metal teeth pulling out of the timber after immersion. This can be resisted by timber blocking at the connections.




*Steel beams*

Many of the problems associated with suspended floors can be reduced by the use of steel support members. As part of steel framing systems, floors are now sometimes supported on light gauge steel beams. Open section steel members are preferred over closed, hollow sections which may trap silt, water and other contaminants, (Figure 79). This material may be hard to remove and may prolong the drying period and increase the risk of corrosion.

There are many propriety brands of metal flooring support systems available. As they are mainly galvanised it is likely that they should perform satisfactorily after one-off flooding. However, when selecting an appropriate system consider the following issues:

***Figure 79*** *Use of steel beams*

Load bearing walls, floor joists and flooring are critical structural components and difficult to repair. Their performance should not be compromised during and after immersion in water. The masonry walls and steel floor joists picured here maintain their strength and dimensions when wet. However, sheet flooring can be weakened with immersion.

- whether all components are adequately protected against corrosion,
- impact of cutting and/or welding on corrosion protection systems,
- whether the members are closed or open sections,
- whether trapped silt or other contaminants or debris may promote corrosion,
- whether the system will be accessible and easily cleaned after flooding.

The flood performance of steel frames is discussed further in Section 5.4.3 of this guideline.

It is recommended that all steel members be galvanised to Z275 AS 4680 to minimise the chance of damage from moisture. If steel members have been inundated by floodwater containing significant contaminants, the members should be thoroughly flushed after flooding. This is particularly important for flooding near the ocean as the water can contain high concentrations of salt which can even damage galvanised steel.

### 5.2.3.3 Flooring

*Strip flooring*

Problems with timber flooring is usually not the fault of the timber but that of a moist environment which can result in cupping of the floor boards or the floor rotting.

Cupping is where the edges of each board lift slightly, leaving a concave centre. Frequently a wooden floor shows signs of cupping when it is covered with an impervious material such as rubber, vinyl or linoleum because the passage of water vapour is restricted. Under the floor, damp air rises from the saturated ground causing an increase in the moisture content on the underside of the floor. This causes the bottom of the boards to expand. The top of the board varies less since it is exposed to a lower humidity normally inside the building.

If the boards are very tight, especially at the bottom side, the expansion can cause the whole floor to lift and become springy as the bearers are lifted off the piers. Where the edge of the floor is closely fitted to the walls, the expansion of the timber can be strong enough to force the walls outwards.

Once the boards have dried out, cupping will subside. After some floods, home owners have sanded flat timber structures only to find that the boards continue to subside giving them a concave final shape. Thus no corrective measures should be taken until the boards are fully dried.

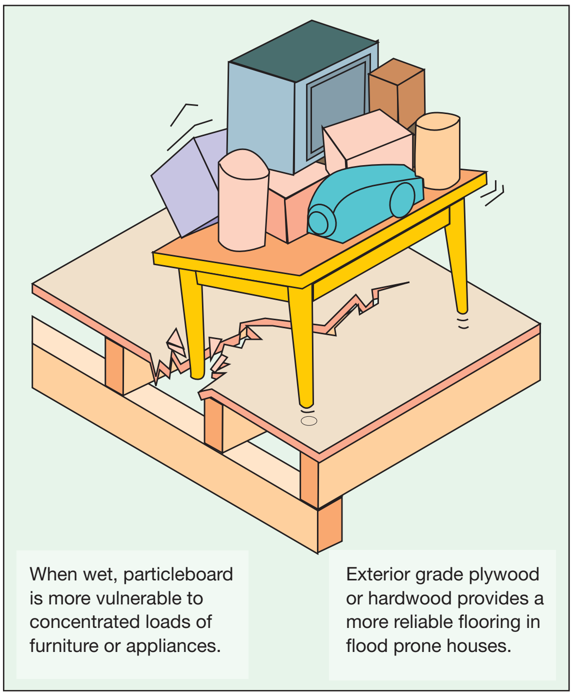
The amount of movement is more related to the timber species and so timbers with a low shrinkage may reduce the amount of cupping experienced. Whilst white cypress exhibits very low swelling and shrinkage, brush box, Sydney blue gum and Tasmanian oak have relatively high shrinkage rates. The flooring supplier should be able to provide more specific advice on timber species which exhibit less shrinkage and movement.

With long periods of high moisture content (above 20%), timber becomes susceptible to attack by decay or rotting organisms. The rate of rotting varies with the degree of moisture content and the timber species. Most ordinary hardwoods are durable, but softwoods such as radiata pine can decay quickly. Hence it is essential that good ventilation is provided to allow timbers to dry out.

*Particleboard vs Plywood*

Particleboard flooring cannot be recommended in flood prone houses, when it can be immersed for more than a day or so. When particleboard has been immersed less than a day, it will regain most of its strength and lose most of its swelling when dry (residual swelling is likely to be around 2mm). However, if particleboard has been immersed for more than two days, it is likely to suffer significant residual swelling and strength loss when dry and may need to be replaced.

***Figure 80*** *Concentrated loads*

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Testing by CSIRO indicates that both wet area and dry area particleboard lose more than 50% of their bending strength when immersed for 96 hours hence the bending strength is significantly below the design limit of 16MPa. The sealing of cut edges with adhesive has little effect on the losses and recovery as does the use of wet area particleboard.

Particleboard is even more undesirable in areas likely to be subjected to high furniture and other "dead" (i.e. static) loads. This is especially the case where individual legs of heavy furniture and appliances, e.g. beds and heavy tables, do not effectively spread the load to the floor joists and can punch through a weakened floor, (Figure 80).

Exterior grade plywood is an acceptable alternative to hardwood strip flooring, although it should not be overladen during flooding as it loses considerable strength whilst wet, particularly if immersed for long periods. Plywood will also loose almost half of its strength but given its higher initial strength, it should be above the design limit.

*Floating timber floors*

This type of flooring has become very popular in recent years as an alternative to tiles and carpet. They are placed over a floor but are themselves not a structural component as they do not directly support floor loads.

### 5.2.4 Comparative Costs

Assuming a flat site:

*Ground floor*

- Particleboard floor on a ground floor hardwood floor frame costs from $48/m^2$.
- Plywood floor on a ground floor hardwood floor frame costs from $50/m^2$.
- Hardwood timber strip floor on a hardwood timber frame costs from $130/m^2$.
- Reinforced concrete raft-slab floor costs from $80/m^2$.

*Suspended upper storey*

- Particleboard floor on engineered timber beam joists costs from $60/m^2$, with plywood flooring costing slightly higher.
- Suspended concrete floor costs in the range of $130-$200/m^2$, depending on the distance between supports.

The cost of post-flood flooring repairs and or replacement should be considered when deciding on an appropriate floor. For example, if a particleboard floor requires replacement after a flood, the cost of replacement will be higher than the initial cost and many times the cost difference between a more durable floor material.

## 5.3 EXTERNAL BRICK WALLS AND CLADDING

### 5.3.1 Problems

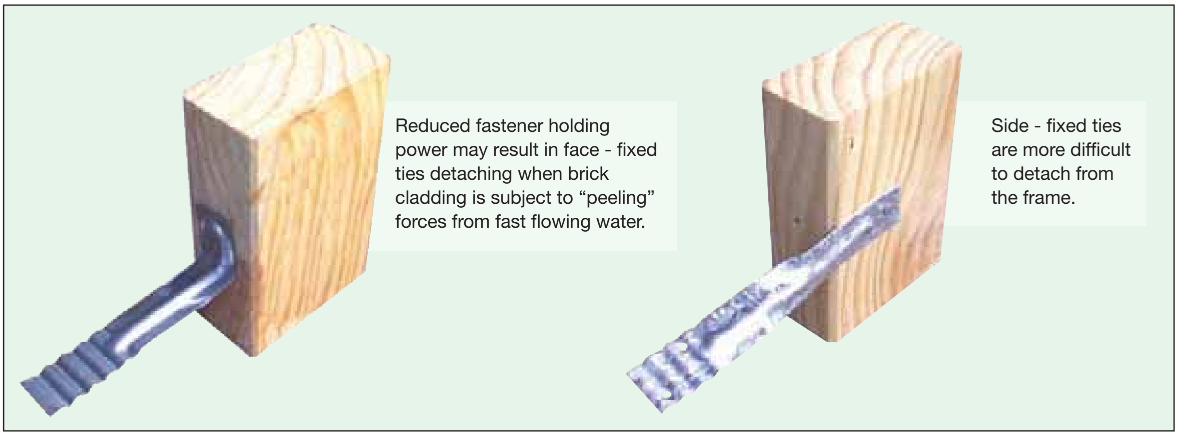
External walls must perform three important functions in a flood situation:

- continue to support vertical loads of any upper structure and the roof,
- withstand the pressure of rising water (both still and moving) and the impact of floating debris, and
- satisfactorily handle the differential movement of the foundations on expansive soils as these initially swell and then shrink as they dry out.

Failure to perform all of these functions can lead to the cladding cracking and possibly even collapse.

Pre-existing cracking in the walls due to settlement or other reasons can weaken the walls and make the house more prone to failure from the water forces.

***Figure 81*** *Preferred brick wall ties*




Side-fixed brick ties will resist pull-out better preventing water forces peeling bricks away from the frame.

## 5.3.2 Design Suggestions

### 5.3.2.1 Resisting Water Forces

Sections 3.1 and Appendix A provide some information on the types and magnitudes of water forces to which a house is subjected during flooding both from still and moving water.

Section 3.2.2.2 provides a method whereby houses can be designed to resist lower velocities using a classification system already adopted for designing against wind forces. However, there are other measures which can be taken to reduce the damage from water forces:

*Brick ties*

Not only can water forces push a brick wall in, they can also peel bricks away from the frame under "negative" pressures which develop when the outside water level is lower than inside the house, see Section 3.1.1. It is important that the number and placement of brick ties satisfy AS 3700-1998 *Masonry Structures* as a minimum.

If ties are inadequate or badly anchored/ embedded in the internal back up wall, then collapse of the veneer could occur. If the net pressures are inward, collapse is less likely unless the inner back up system (stud wall or load bearing masonry skin) also fails. Even if collapse does not occur, there will be serviceability implications from the cracking resulting from wall movements.

As immersion of timber can reduce the holding power of fastenings, especially nails, it is recommended that side-fixed brick ties be used (instead of face fixed) to improve the resistance to pull out as the nails would have to shear for failure to occur, (Figure 81).

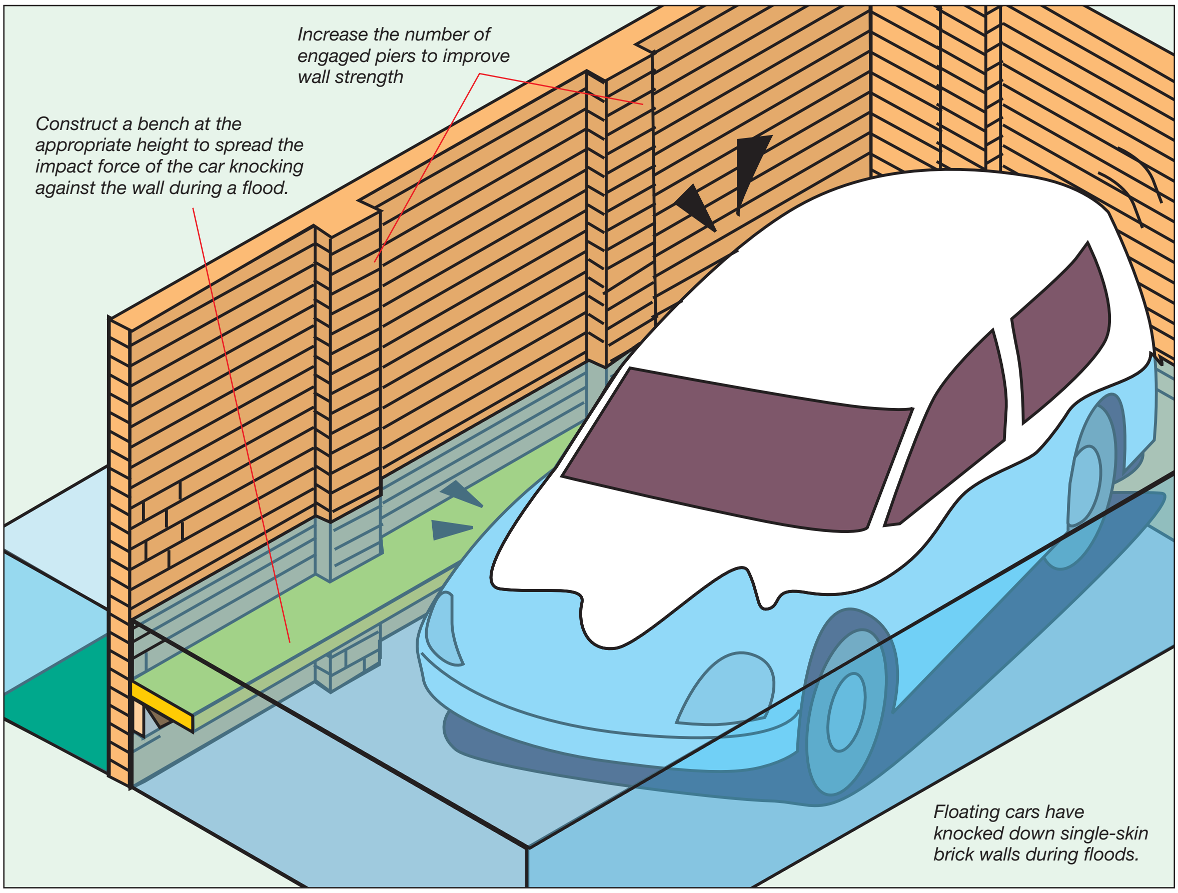
Because of the interaction that occurs between a masonry veneer skin and its back up frame or wall through the wall ties, increasing the number or stiffness of the wall ties does not significantly increase the capacity of the wall system. The correct installation of ties to current requirements is the most important aspect (including the doubling of the number of ties in the top row of veneer construction as required by AS3700).

The presence of sheet wall bracing and/or sheet insulation can interfere with the use of side-fixed ties but the problem is considered too important to ignore. Methods should be employed to overcome this problem or alternative bracing and insulation could be used. Side-fixed brick ties are particularly important in houses subjected to local water velocities greater than 0.5 metres/second. Where the use of face-fixed ties is unavoidable they should be screwed and consideration given to increasing the number of ties to account for any possible loss of connection strength especially where tie fasteners may lose strength or grip as a result of immersion. This step is to increase the reliability of connections rather than increase the capacity of the wall.

*Strengthening garages*

Single skin brick walls on garages sometimes collapse during flooding. A contributing factor to this is that floating cars can impact on the wall. To reduce the chance of this happening, consideration should be given to decreasing the distance between engaged piers or otherwise strengthening or protecting the wall. For example, a workbench could be placed along the wall which would help shed the load to the engaged piers rather than the single skin portion of the wall, (Figure 82).

***Figure 82*** *Protecting garage walls*




#### 5.3.2.2 Differential Settlement of Foundations

Where a house rests on expansive soils, some cracking should be expected once the floodwaters recede. AS 2870-1996, *Residential Slabs and Footings* classify cracking as follows:

Category 2: cracks up to 5mm
Category 3: cracks from 5mm to 15mm
Category 4: cracks from 15mm to 25mm
Category 5: cracks over 25mm wide

It is common for houses supported on other than rock, to suffer Category 2 cracking after a flood. It is expected that 5%–10% of houses will have Category 3 cracks. Category 4 and 5 cracks are unlikely to occur due to soil moisture movement alone and are more likely to be associated with failure of foundations or wall loads caused by very high velocities or debris impact.

If external walls are brick, and the house is situated on expansive soils, the walls must be articulated in panels to disguise movement and minimise uncontrolled cracking as the foundation soils swell and shrink.

Additional information on articulated joints can be found in the Cement and Concrete Association of Australia publication *CCA TN61-1998: Articulated Walling.*

Foundation issues are discussed in Section 5.1 and recommendations are made there for the stiffening of foundation systems.

It is advisable to keep the brick cladding in good repair. Pre-existing cracks can significantly reduce the cladding strength thereby promoting collapse at lower velocities. Such cracks should be repaired to restore as much strength as possible. However, expert advice should be obtained as problems can arise when filling cracks which are a result of normal moisture variations in the foundations.

### 5.3.3 Material Selection

Under normal conditions, the bricks or blocks in walls will not suffer from moisture damage. However, to lessen the chance of mortar deteriorating, it is advisable that in flood prone areas more resistant mortars be used. Mortars are classified by AS 3700 from M1 to M4. In these guidelines, M2 mortars are recommended for non-coastal flood prone areas, and M3 mortars are recommended for marine flood prone areas.

Although rendered brickwork should perform satisfactorily, unrendered brickwork is preferred. Rendered walls may take longer to dry out and could require repainting rather than scrubbing clean.

Wall cladding using *fibre cement, plastic or aluminium* is unlikely to be structurally affected by immersion although some repainting may be required.

Timber cladding, *e.g. weatherboard planking*, is unlikely to be adversely affected by immersion as long as it dries off relatively quickly. For added protection, timber cladding of greater natural durability should be selected, e.g. western red cedar, hardwood and Cypress Pine.

Hardboard planking will swell and buckle in the short-term, but may regain its shape once dry particularly if immersed for less than a day or two. Longer term immersion may result in buckling and significant loss of strength. The use of hardboard is not ideal.

Houses clad using weatherboard, fibre cement, plastic or aluminium cladding can be designed to resist the forces associated with moving water. In areas affected by water velocity, these forms of construction may be better than the more brittle brick cladding and are easier and cheaper to repair. They can also provide better bracing support to the frame. However, they will still be subjected to most of the problems associated with wall cavities which are covered in Section 5.4.

Painted surfaces may require repainting after flooding. This would still be cheaper than repairing damaged brickwork. Water-based paint systems are likely to perform the best with a premium quality acrylic primer under an acrylic top coat performing better than one-coat systems.

### 5.3.4 Comparative Costs

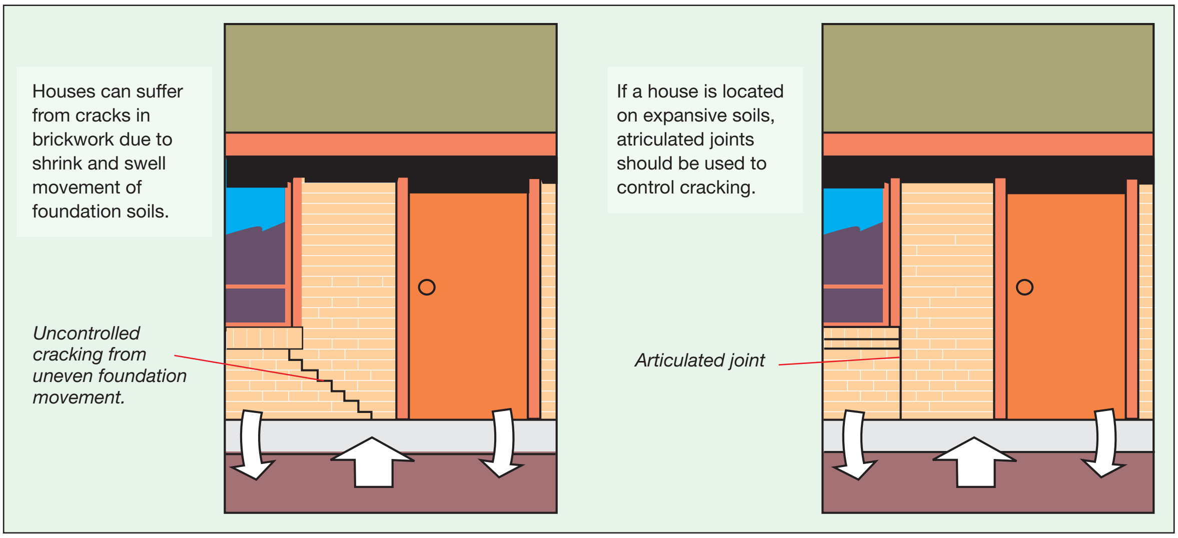
A double skin brick wall, rendered on the inside costs approximately $195/m$^2$.

A brick veneer-timber framed construction with polystyrene insulation and plasterboard inner wall lining is $150/m$^2$. With shallow flooding (i.e. less than 1.2m deep) the bottom sheet of plasterboard may need to be replaced. With deeper flooding both the top and bottom sheeting may need replacing. The cost of replacing plasterboard is around $25/m$^2$. If damaged by prolonged immersion, insulation such as wool fibre may need replacing at a cost of $15/m$^2$.

A framed construction with synthetic planking on the outside and plasterboard sheeting on the inside is $90/m$^2$. (For timber weatherboards add a further $40/m$^2$ to a wall bringing the total cost to $130/m$^2$.)

The costs involved in increasing the strength of the brick cladding need to be considered in light of the very significant costs involved in repairing a brick wall especially if it has collapsed.

***Figure 83*** *Articulated joints*



In areas affected by velocity, weatherboard or fibre cement cladding can resist the forces of water better than bricks.

## 5.4 WALL FRAMES AND WALL CAVITIES

### 5.4.1 Problems

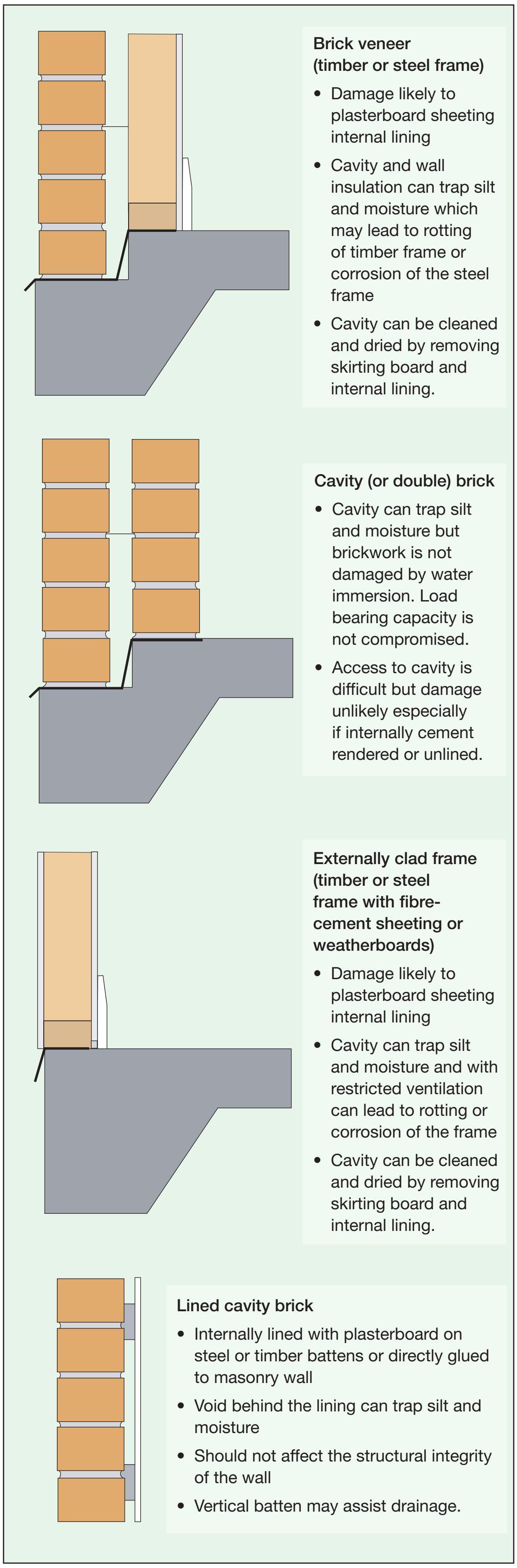
This section looks at the problems associated with the frame itself and the cavity between the cladding and lining when subjected to flooding, (Figure 84). These problems can relate to either:

- the structural adequacy of the wall components to resist the forces, or
- the short or long-term deterioration of the components leading to structural adequacy concerns.

The main problems are:

- The wall can fail (sideways) due to the abnormal water forces particularly if coupled with reduced material strength,
- The timber frame can twist, distort and rot. Metal frames and fasteners can corrode and weaken from prolonged or repeated immersion,
- If insufficient brick ties are used, or if the ties deteriorate or rust, the internal frame cannot effectively support the external brick skin against lateral pressure,
- The linings of internal framed walls (which can have a secondary role in providing additional bracing to the wall frame) can collapse from unbalanced water forces caused by water unable to seep into the cavity, and
- Inadequate ventilation of the wall cavities can lead to deterioration of the frame and internal lining, and promote mould growth.
- Silt can be deposited in the cavity and on the bottom plate and noggings in wall frames as the water recedes. Large amounts of sediment in cavities and stud walls can delay drying. Floodwaters may also leave contaminants from overflowing sewerage systems. Long after a flood has receded, trapped silt in the base of the cavity may continue to have a high moisture content from water entering through weepholes in the bricks. If this silt is deep enough to touch the bottom plate it can promote rot or corrosion of the plate (see Figure 91).

***Figure 84** Problems in wall cavities*



- Wall insulation materials can trap silt and moisture and slow the drying process by restricting air circulation. Some types of insulation may slump when wet, increasing the chance of deformation of the wet plasterboard or contact with the external skin.

### 5.4.2 Design Suggestions

Sections 3.2.1 and 3.2.2 provide information on designing for hydrostatic and hydrodynamic water forces. However, additional measures can be used to reduce the possibility of wall failure.

*Metal nail plate connectors*

With timber frame construction, the connection of the studs to the top and bottom plates is a concern if only end grain nailing into the stud is used. The inadequacy of the top plate connection in transferring horizontal loading on the walls into the ceiling diaphragm has been shown in testing undertaken by the Cyclone Testing Station at James Cook University.

According to the US Federal Emergency Management Agency (FEMA), structural damage to buildings caused by natural hazards – such as strong wind, waves, flooding and earthquakes – are usually not initiated by the timber members breaking under the higher loadings. Structural failure often begins with the connection between the individual timber members as this is normally the weakest point. In many cases, replacing conventional nailing with a sheet metal connector produces a connection over 10 times stronger. Hurricanes and earthquakes have demonstrated repeatedly that for most buildings, good connections often make the difference between survival and severe damage.

In the external timber wall frames, it is thus advisable to use nail plate connectors (framing anchors) to join the studs to the top and bottom plates to create a more robust building by improving the strength of the connection between the walls and the floors and ceilings.

In locations subject to high water velocities and where flooding may exceed eaves level, the roof should be securely fixed to the wall system in accordance with accepted practice for wind design. The appropriate N category can be estimated using the procedure described in Appendix C.

*Bracing*

Some wall bracing materials reduce in strength when wet, in particular hardboard sheet bracing, (Figure 85). The exception is galvanised steel strap bracing, which is unaffected and able to cope with floods longer than flash flooding. Section 5.4.3 provides advice on the best materials for wall bracing. Where sheet bracing is used, it is recommended the spacing between nails be decreased and that the nails be positioned as far as possible from the edge of the bracing. Bracing which may suffer permanent damage increases the risk of failure under high wind or possibly earthquake loading.

*Brick tie design*

Special attention needs to be made to the use of brick ties (see Section 5.3.2) especially where higher velocities are likely.

The design strength of sheet bracing should be downgraded to account for 30% loss of its capacity when wet.

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***Figure 85*** *Durable frame bracing*

Structural wall frame bracing is low-cost, yet it is essential to resist horizontal loads such as those from wind and moving flood waters. Being located within the wall cavity, makes it very expensive to replace and some types of sheet bracing material such as hardboard can lose strength after absorbing water.

Raising all lower plasterboard sheets on internal walls slightly above the bottom wall plate will allow access to the cavity for cleaning after flooding.

***Figure 86*** *Providing internal access to wall cavities*

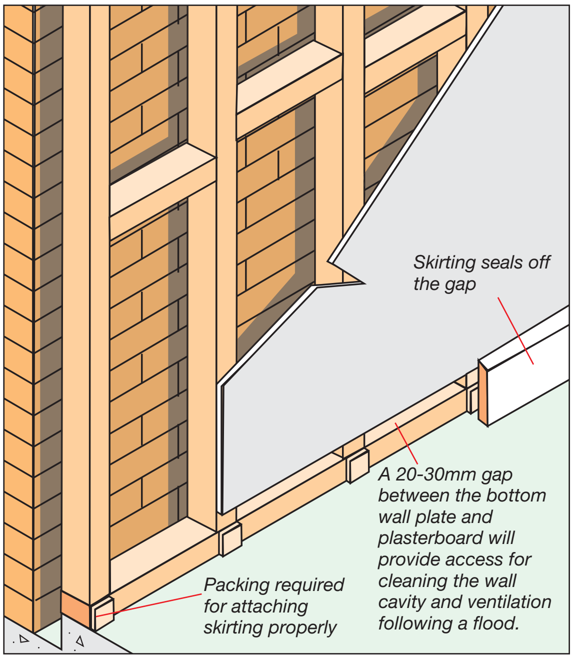
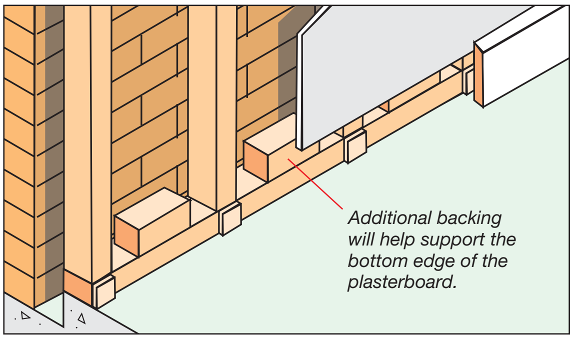



***Figure 87*** *Additional support for elevated plasterboard*




*Internal linings*

Moisture and silt will accumulate in wall cavities unless allowed to drain. In general, mud will have to be actively removed. The simplest way to do this is to remove part of the inner cladding (i.e plasterboard). One way to do this is to remove the skirting and cut the plasterboard below the level of the skirting. Unfortunately, the plasterboard is readily damaged when wet and thus it is difficult to cut without damaging the rest of the plasterboard sheet.

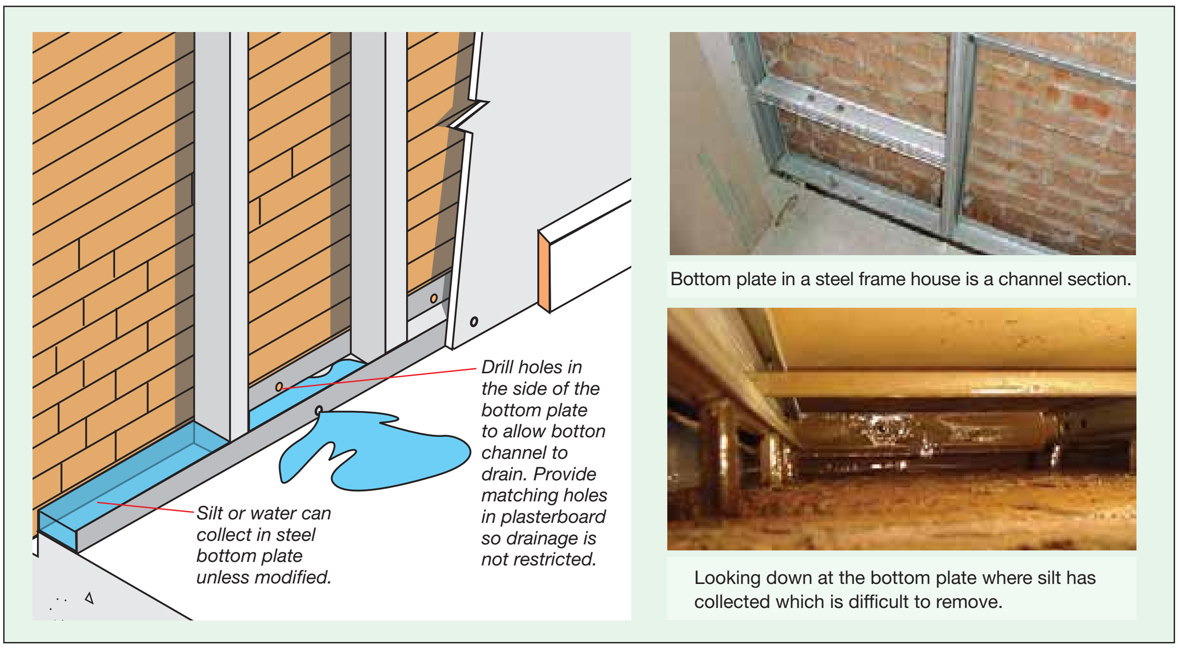
A minor design change can facilitate drainage of the cavity without damaging the plasterboard.

All lower sheets of plasterboard can be attached with a 30mm gap above the bottom wall plate level. This allows access to the cavity following a flood for ventilation and cleaning purposes. Skirtings will cover this gap and packing will be required between the skirting and the bottom plate to assist attachment. Additional backing could be considered in the middle of studs to support the bottom edge of plasterboard, (Figures 86 and 87).

If steel framing is used, holes should be drilled in the side of the bottom plate to allow the bottom channel to drain and to be hosed out, (Figure 88).

A technique of using notches in the lower edge of the plasterboard was also tested, but simply raising the whole sheet to provide a narrow gap was considered quicker and more practical. This also assists with the management of termites by allowing easy inspection of the timber frame.

***Figure 88*** *Drainage of steel frame*




Bottom plate in a steel frame house is a channel section.

Looking down at the bottom plate where silt has collected which is difficult to remove.

*Cavity ventilation*

In the absence of internal vents with only weep holes on the exterior face of walls, ventilation and thus drying rates within the wall cavities can be very slow. Prolonged periods at high humidities can create a range of problems for internal lining, bracing and framing.

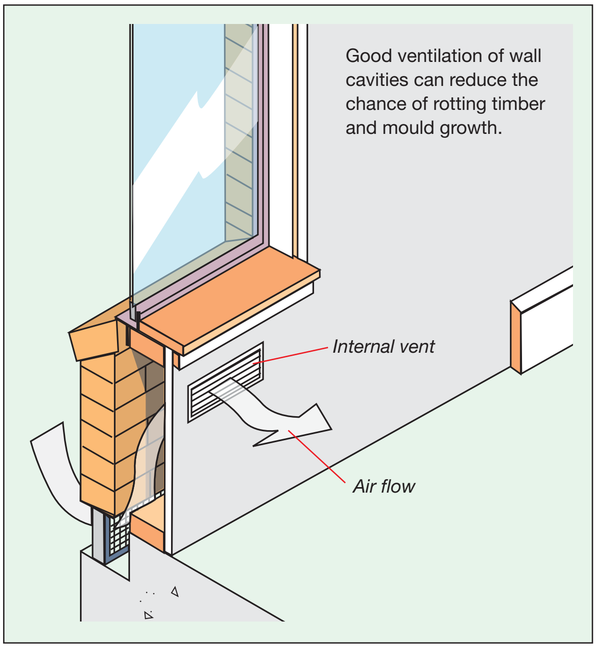
Good ventilation of the external wall cavities is thus very important to reduce the chance of rotting of the timber frame and growth of mould. In brick veneer walls on concrete slabs, additional standard sub-floor vents should be installed in the external walls above the flashing to provide extra venting to the cavity (see Section 5.2.2.2). These should be installed at approximately 1.8 metre spacing, providing 7300mm$^2$ per vent.

Such vents should be provided under long windows as experience has shown that these areas act as moisture traps and dry out very slowly after a flood, (Figure 89).

Vents that are relatively easy to remove give easier access to better clean the wall cavity after flooding. These vents can also assist in allowing water to enter the cavity to balance water forces (see Section 3.2.1.1).

As wall cavities will take a significant time to dry out, it is important that materials and design details be selected firstly to avoid unnecessary moisture uptake and secondly to limit material degradation.

***Figure 89*** *Venting under windows*




*Silt in cavities*

All floodwaters carry silt which includes suspended soil particles, sewage and other substances which would be very diluted but may still be harmful to health. This silt settles out of relatively still water as it fills the house and cavities. Whilst this silt can be removed from the house relatively easily, it is much more difficult to remove it from cavities.

Ventilation of the external wall cavity is critical to reduce the chance of the frame rotting.

The quantity of silt deposited in cavities is normally much less than that deposited inside the house because of the smaller volume of floodwater in the cavities. An indication of whether there is considerable silt in the cavity may be gained from how much there is in a room. The amount depends on a number of catchment factors including vegetation cover, land use patterns, catchment size and flooding characteristics. In most highly urbanised catchments, silt levels in the cavity are likely to be less than 3mm. In most cases it is probably not necessary to remove this small quantity. Flushing out the cavity may be undertaken especially if the silt is suspected of carrying harmful materials such as sewage.

Experiments undertaken by the University of NSW on a range of wall systems, suggest that in areas of slow backwater flooding away from the river there is unlikely to be more than a few millimetres of silt deposited. In contrast, ponding areas adjacent to the Hawkesbury-Nepean River where there is potential for a rapid decrease in velocity would pose a problem. High silt loads picked up by fast flowing flood waters would be continuously deposited in these areas much like a sedimentation pond.

It is possible that in some locations where high upstream velocities persist over a prolonged period, excessive amounts of silt and bed load can be collected and deposited downstream in relatively still waters in the house and the cavity. The local council may be able to identify such an area. Successive floods can also add to the thickness of silt deposits.

Substantial silt lying on noggings would take longer to dry out and could be susceptible to re-wetting especially if there are leaks in the cladding

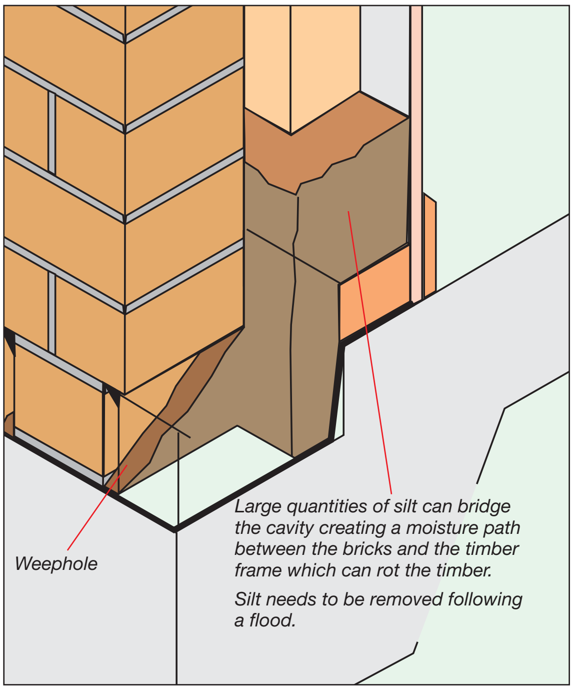
The design strength of sheet bracing should be downgraded to account for 30% loss of its capacity when wet.

***Figure 90*** *Internal linings*

Internal brick walls are unlikely to be damaged by water contact. Rendered walls will only need repainting once completely dry.

Stud walls can suffer extensive flood damage to the wall structure and the linings. Damaged plasterboard linings have been removed to clean out silt and assist drying to prevent decay of the timber frame.

***Figure 91*** *Problem of silt trapped in wall cavities*




or roof, or high levels of condensation due to the climatic conditions. This could lead to rotting of the noggings, (Figure 91).

In locations with a severe silt problem, linings may need to be removed to access the cavity so that it can be cleaned out, (Figure 90). The use of more durable internal linings such as fibre cement which are screwed, not nailed and glued, to facilitate removal and re-use are a good option. Alternatively, the use of weatherboard cladding externally could provide an alternative method of accessing the cavity by removing a few boards.

Where large quantities of silt are expected in the base of the cavity, a deeper than traditional rebate in the slab would provide more "storage" to accommodate the silt in the cavity, (Figure 92). This could be incorporated with the raised slab placed on fill as discussed in Section 5.1.2.2.

Keeping the base of the cavity clean from building waste and mortar droppings during construction will reduce the possibility of moisture transfer to the framing, (Figure 93).

***Figure 92*** *How to prevent problems from silt*

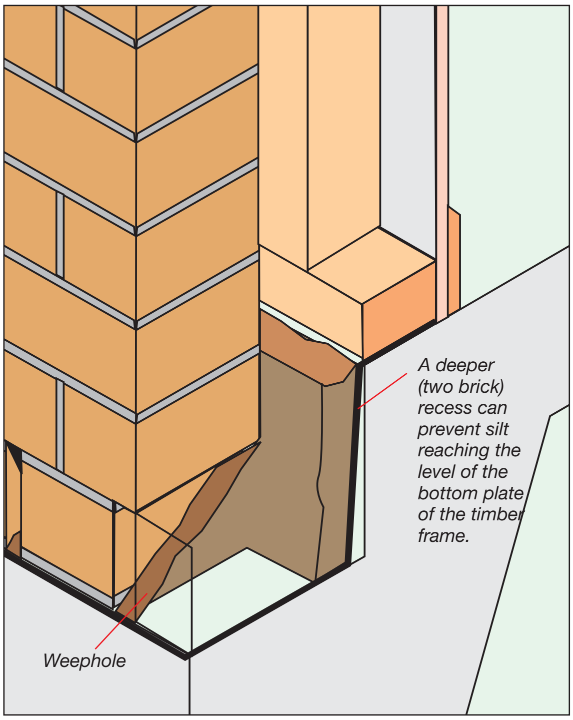


***Figure 93** Careful detailing of weepholes to avoid problems*

Weepholes can be blocked by mortar or other debris so that their effectiveness is decreased.

Wide weepholes that are free from obstructions allow significant flows of water into and out of the house

*Wall insulation*

Refer to Section 5.5 for more information on insulation in flood prone houses.

*Clad frame and brick veneer walls*

Polystyrene boards fitted between the wall studs are preferred. These can be foil-faced to increase the R-value, though this may be reduced slightly due to silt deposits on the reflective surface following flooding.

The buoyancy forces of polystyrene during flooding will require firmer fixing of the boards than in standard installation and they may need to be removed for cleaning or drying the cavity after a flood. The fixing should allow insulation boards to be removed from inside the house by using medium/heavy gauge nails partially driven into the studs at a distance from the lining slightly bigger than the thickness of the polystyrene boards. The boards would then sit between the lining and the exposed portion of the nails. Four nails could be used in each bay formed by adjacent studs and the noggings, (Figure 94).

The use of reflective foil placed between the studs and the cladding or bricks is less effective because it may lose significant R-value with the post-flood deposition of silt and other matter, (Figure 95).

Any reflective foils (or similar) attached to the outside of the wall studs, should not fold over across the cavity at the top of the wall and limit ventilation.

*Cavity brick walls*

As brickwork is relatively unaffected by immersion, cavity brick walls tend to have few problems. The preferred insulation is more a matter of using materials not damaged by immersion. However, polystyrene boards firmly attached to the inner leaf can help with ventilation and drying of the cavity.

***Figure 94** Polystyrene insulation in walls*

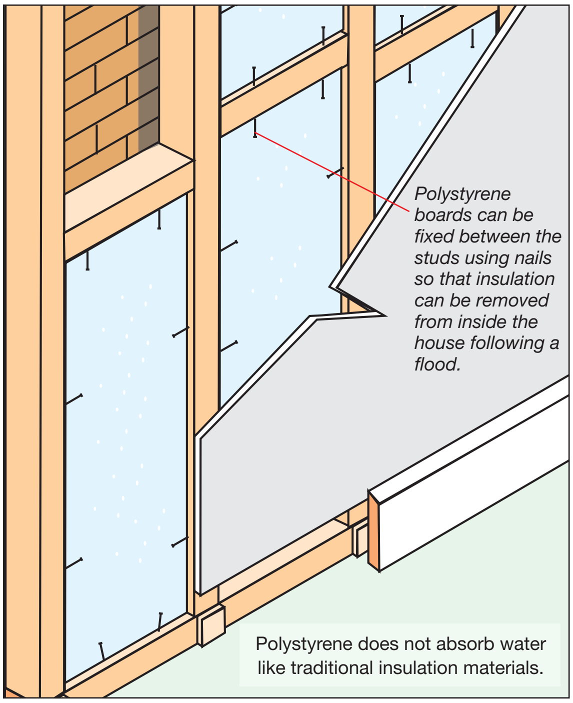
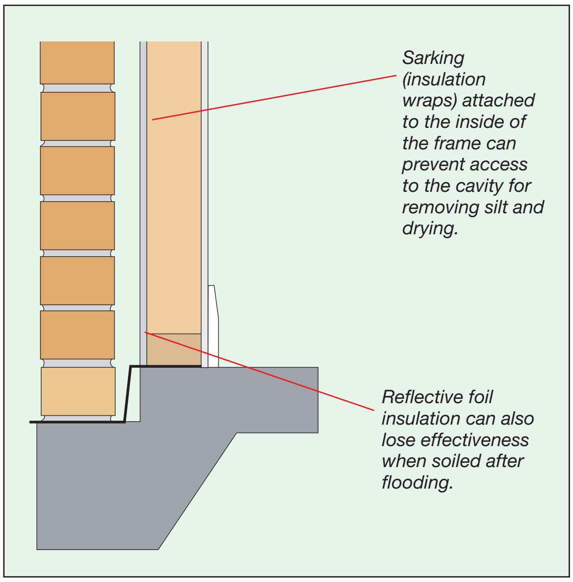


***Figure 95*** *Problems with access to the cavity*




*Solid walls*

Where additional insulation is required for solid walls built from materials such as concrete, concrete block and brick, polystyrene boards can be placed on the inside or outside of the wall. Normally boards are placed between battens (or furring channels) and cladding or lining is fixed to the battens. If foil-faced boards are used, an air gap must be allowed for.

When insulation is used, ideally the number of cavities and joints should be kept to a minimum, the ventilation of any cavity should be maximised and water traps eliminated. Where battens are used, they should run vertically so that water can drain.

In solid concrete walls, the insulation can be built into the wall as a core between concrete layers (see Section 4.3.2.2).

## 5.4.3 Material Selection

Steel framing does not suffer adverse consequences from immersion and will dry more rapidly after inundation. However, if good quality timber and construction methods are used for a timer frame and other recommendations regarding ventilation etc. are followed, the chance of distortion or rotting is slight. Note: that in accordance with Section 3.2.2.2, a higher wind design classification may need to be adopted to allow for the loss of strength associated with immersed timber. Timber used for studs in flood prone construction should be of a higher quality to reduce the chance of distortion when saturated timbers dry after a flood.

Where engineered glued timber products are used in a frame, ensure that moisture resistant glues are used. Resorcinol adhesives are preferable. In particular, finger jointed studs can be weakened and they should be glued with moisture resistant adhesives. Melamine Urea Formaldehyde (MUF) glued studs lose 40% of their bending strength while saturated, though they regain 90% of their initial strength once dry. It is recommended that glued structural components be avoided if possible, especially in areas of significant water velocity. However, where such members are used and are likely to be stressed (as distinct from non-structural members) it is recommended that allowance be made for possible loss of strength in accordance with the principles contained in Section 5.2.3 (Engineered timber beams).

One-off flooding should not cause long-term damage to either timber or steel frames if well designed and constructed. However, timber frames can warp and take longer to dry out while flooding can cause corrosion of steel frames especially if inundated by sea water. Both steel and timber needs to be well vented to permit drying so that corrosion, rot and other problems can be minimised. Open section steel members are preferred over hollow closed or box sections which may trap water, silt, salt and other contaminants, prolong the drying period, and may promote corrosion from inside the members.

Both plywood (exterior grade) and hardboard bracing will lose strength when wet. Tests indicate that both materials lose 30% of resistance to nail pull through when immersed for 96 hours. Similar results occur with fibre cement sheets although this material appears to regain its strength after drying. The eventual failure mechanism for sheet bracing is usually associated to failure around the nail fixing. Having a 30% loss in resistance to nail pull through at the edge indicates that a similar loss of bracing resistance could be expected. In areas where the bracing is required to resist horizontal forces from water flow, this loss of bracing would be critical and indicates that additional bracing should be incorporated to account for the loss of its effectiveness when saturated. These strength losses should be accounted for in design.

Steel bracing should be used wherever possible, but in areas of the wall where sheet bracing is necessary — e.g. in narrow wall section around windows — preference should be given to the more flood resistant fibre-cement bracing (which has a similar cost to other sheet bracing).

### 5.4.4 Comparative Costs

Additional brick vents spaced at 1.8 metres around the outside of the building would add an extra $300 for a standard house.

The cost of hardboard, plywood (exterior grade) and fibre-cement sheet bracing are similar and range between $22 – $24/m$^2$ for material and labour.

For comparison of insulation costs see Section 5.5.4.

## 5.5 HOUSE INSULATION

### 5.5.1 Problems

The need to provide insulation to improve thermal efficiency can conflict with the objective of making a house more flood resistant. Unsuitable insulation can:

- trap and retain moisture as well as delay drying;
- reduce ventilation increasing the possibility of decay and corrosion; and
- obstruct access to and the cleaning of silt deposited in cavities.

Conversely, flooding can affect insulation and reduce its effectiveness. It is important to consider the difficulty and cost involved in replacing flood damaged insulation, (Figure 96). It is much better to use the correct insulation to begin with than have to remove cladding or linings to access flood-damaged insulation. This is particularly important in walls and ceilings attached to roof rafters.

### 5.5.2 Design suggestions

Flood compatible insulation:

- is waterproof;
- is not damaged or does not suffer reduced effectiveness as a result of immersion;
- has negligible absorbance;

***Figure 96*** *Problems with batt insulation*

Batt insulation behind lined walls and ceilings may need to be removed after flooding to enable the timber frame to dry out and prevent decay.

This type of insulation is more appropriate in the upper floors of two-storey houses where the chance of flooding is much less. For example, at Windsor only floods greater than the one that occured in 1867 (a 1 in 250 year event) would reach this level.

- drains and dries quickly;
- is resistant to retaining silt which may attract moisture and/or reduce the effectiveness of the insulation; and
- maintains its shape and is not likely to slump or move out of position.

Consequently insulation should be placed so that it:

- permits the best ventilation possible whilst retaining its insulation benefits;
- allows drainage of floodwaters; and
- is held firmly in position permanently and not displaced by any buoyancy forces.

The installation of insulation can affect the recommended flood compatible structural measures e.g. the use of sheet wall insulation may make the use of recommended side-fixed brick ties (see Section 5.3.2.1) less efficient.

### 5.5.3 Material selection

Insulation can be divided into two main categories:

1. Bulk insulations which basically trap air within their structure. These include:
    - a range of "wool" batts made from materials such as glass fibre, polyester, sheep's wool and rockwool (spun molten rock);
    - loose fill using materials such as cellulose fibre (recycled paper); and
    - polystyrene boards.

In flood prone areas, polystyrene boards or equivalent should be used for bulk insulation as they will not deteriorate, slump or retain silt.

2. Reflective insulations which basically use a shiny surface to reflect radiant heat. These include:
   - reflective foil laminates or sarking i.e. aluminium foil laminated with glass fibre or other reinforcement;
   - concertina-type foil/paper laminates.

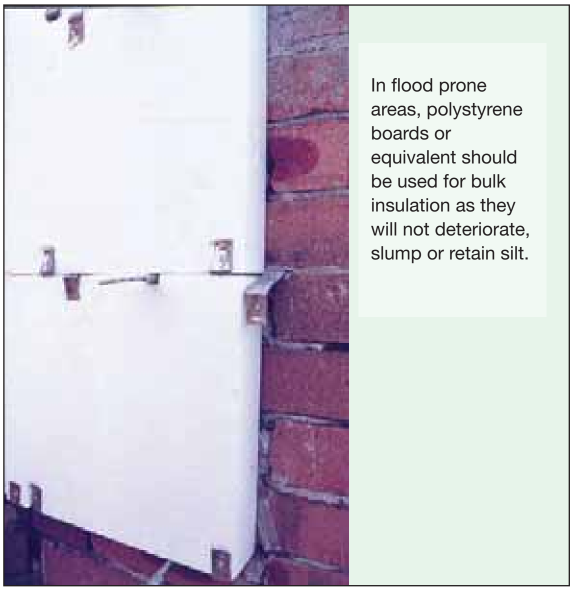
There are some types, normally referred to as composite insulations, which combine both types of insulation. Different types and/or thicknesses of insulation are used to obtain an adequate level of insulation, or R-value, to suit the local climatic conditions.

"Wool" batts are not desirable as they can take extended periods to dry out after immersion. They can lose their shape, slump and retain silt which may significantly reduce their effectiveness. Some forms may even deteriorate as a result of immersion. There are similar problems with loose fill materials especially cellulose fibre which will deteriorate significantly when wet.

It is recommended that in flood prone areas, polystyrene, or similar boards be used for bulk insulation applications as they do not have these disadvantages, (Figure 97).

Although the term polystyrene boards is suggested throughout these guidelines, there are a number of similar boards which could be appropriate. Such boards can be substituted for polystyrene boards provided they are not affected by prolonged immersion, do not overly attract or hold water, and will hold their shape and location when immersed. The manufacturer or supplier should be consulted as to the suitability of their product.

***Figure 97*** *Use of polystyrene insulation*




Reflective laminated insulation, which is capable of surviving long-term immersion, can be used. Reflective foil laminates (using waterproof components) are not damaged and dry quickly after immersion. Reflective insulation requires a minimum air gap of 25mm adjacent to the reflective surface to be effective.

The R-value of reflective insulations can diminish as they become dusty or dirty. Similarly, a layer of silt deposited after flooding can reduce performance. Polystyrene boards would be preferred where silt is expected to be a problem.

Foil-faced boards are also suitable although they too will suffer some loss of R-value if the reflective surface is soiled by floodwaters. Foil-faced boards can be substituted for standard boards although the implications of the minimum 25mm air gap need to be considered.

Section 5.4.2 gives a general indication on how insulation could be placed in wall cavities. It is not the intention of these guidelines to provide detailed advice on insulation. The insulation manufacturer or supplier should be consulted to ascertain the product's appropriateness for the proposed application and for installation details.

The use and installation of insulation should be in accordance with the relevant Australian Standard AS 2627.

### 5.5.4 Cost comparisons

Cost for wall insulation (labour and material) are:

- Aluminium foil costs $8/m$^2$
- Closed cell foam costs $9/m$^2$
- Standard glass or mineral wool fibre costs $10/m$^2$

## 5.6 INTERNAL LININGS TO WALLS

### 5.6.1 Problems

This section looks at the problems of wall lining under flooding. Problems include:

- Plasterboard sheeting is weakened by immersion and wall linings are easily damaged by differences in hydrostatic pressure and by impact from objects (e.g. furniture and appliances) floating in the floodwater. In addition, any assumed contribution to the total bracing capacity of the house provided by the plasterboard lining is likely to be negligible leaving the house more vulnerable to horizontal loading.
- Unless specific water sealing measures have been provided, internal walls (which are lined on both sides) may not fill up with water. This causes the higher outside pressures to push on the lining as the water rises and can permanently deform the lining materials, particularly as water weakens plasterboard and some other materials.
- Moisture trapped within walls could promote rapid mould development.
- Even if it remains functional after a flood, plasterboard may warp and distort upon drying.
- Painted surfaces and wallpaper are inevitably damaged in floods.

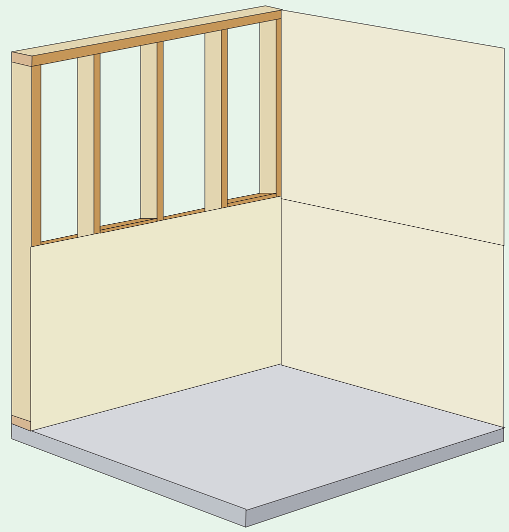
### 5.6.2 Design Suggestions

Exposed face bricks used internally are unlikely to be damaged in a flood. More common cement rendered brickwork is also unlikely to be damaged. However, it will need to be allowed to dry completely before repainting.

Plasterboard will be significantly weakened when wet, but if not damaged in a flood it will regain strength and dimensions when dry. For shallow and short duration floods, there may be little damage.

In the case of potentially deep and long duration floods, whether plasterboard is suitable and how much effort and expense should be put into protecting it from flood damage needs to be determined. Factors to be taken into account in making this decision are:

***Figure 98** Laying of wall lining panels*



Laying the plasterboard lining horizontally limits repairs/ replacement to the lower panels if shallow flooding occurs.

- as a lining, plasterboard is not relied on for structural purposes (its bracing contribution can be compensated for) and therefore it is not critical in protecting the house from failure;
- used in a house placed above a "reasonable" flood planning level (such as the 1 in 100 AEP event), flooding will not be frequent;
- it has a relatively low cost, is easy to remove and install and overall is an economic building product;
- additional measures to protect the plasterboard need to be reliably effective and cost much less than the expense of replacing plasterboard;
- where an open cell wall insulation is used and has been soaked by flooding, the plasterboard will have to be removed and replaced irrespective of its condition; and
- full plasterboard replacement will prolong the recovery period and delay reoccupation of the house.

Plasterboard panels should be laid horizontally rather than vertically (as in normal practice), so that if damaged in shallow flooding, only the bottom panels require replacement, (Figure 98).

Normally, plasterboard linings can be considered to provide a portion of the bracing to resist

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wind and other horizontal loads. However, with plasterboard suffering significant strength loss when immersed, no contribution to bracing should be allowed for with plasterboard linings and other flood resistant bracing should be designed to carry the full loading. Furthermore, it should be appreciated that even if the building survives the flood, any permanent loss of plasterboard strength could see the house more vulnerable to wind or earthquake loading, years after the flood.

### 5.6.3 Material Selection

Plasterboard will need replacing if immersed for several days because:

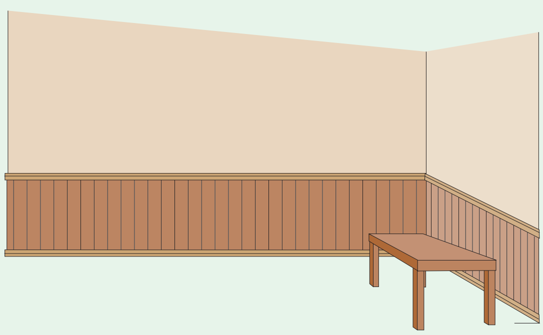
- Wet area plasterboard (used in bathrooms etc) is not specifically designed to withstand full immersion so it can be damaged by severe flooding.
- Plasterboard bonded to insulation can be severely damaged and require complete replacement.

There are alternatives to standard plasterboard for use in flood conditions. For example:

- Impact resistant plasterboard with a reinforcing mesh may also help to hold the plasterboard together after immersion.
- Fibre cement sheeting will not lose its strength to the same extent as plasterboard when wet and will be less prone to damage from floating objects. It is also less likely to be affected by mould.
- Timber boarding and sheeting can resist water pressure and impact from floating objects although it may still be susceptible to deterioration due to immersion unless precautions are taken. Timber products should be exterior grade and preferably sealed on all surfaces, especially the end grains. Obviously to gain the advantage of timber panelling, it would replace the plasterboard and not be placed on top of it.

A compromise can be made using a mix of materials. For example, timber panelling could be used in the lower portion of the wall with plasterboard higher up where there is less chance of flooding. The join could be hidden by a dado rail. The panelling could also be screwed so that it can be easily removed to clean and ventilate the cavity, (Figure 99).

***Figure 99*** *Panelling on the lower wall*



Panelling using more flood resistant materials can be used on the lower section of the wall. If screwed, the panelling can be easily removed for drying and cleaning of the wall cavity.

It is important that the cavities are properly ventilated to encourage rapid drying of the wall components.

Before deciding on the lining material, consideration needs to be given to whether the cavity may need cleaning after a flood and how such cleaning is proposed due to high silt deposition. Unless adequate provision is made, removal of the linings may be required to clean the cavity. It may be possible to re-use timber linings (if screwed and not glued and nailed) and possibly fibre cement linings, but plasterboard linings will most likely need replacing. Access to the cavity can be obtained if the wall linings need to be replaced, thus reducing the need for specific external access provisions (although adequate provision for ventilation is still required).

In most cases, wallpaper will need to be replaced after a flood. Apart from the paper itself deteriorating, the paste tends to promote mould and mildew growth. In regards to decorative surface finishes, good quality, two-coat plastic paint systems tend to perform the best.

### 5.6.4 Comparative Costs

The cost of full brickwork compared to brick veneer construction is given in Section 5.3.4. For wall areas:

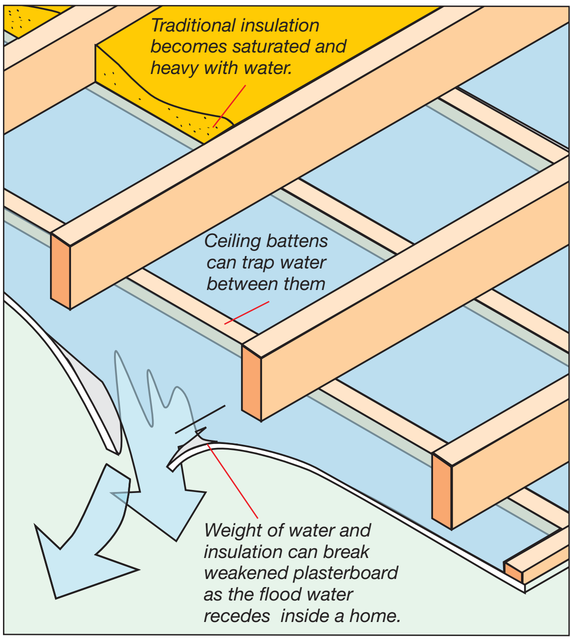
Standard 10mm plasterboard costs $18/m$^2$ fixed.

Wet area plasterboard (10mm) costs $20/m$^2$ fixed.

Fibre cement sheeting (6mm), fully set costs $23/m$^2$.

Timber lined wall panelling costs between $40/m$^2$ and $100/m$^2$ depending on the species of timber used, the fixing details and the finish.

***Figure 100*** *Problems of flooded ceilings*




## 5.7 CEILINGS

*Note: that structural members supporting first floor suspended floors, which form part of the ground floor ceiling, are covered under Section 5.2 Suspended Floors.*

### 5.7.1 Problems

Several problems occur if floodwaters rise above the ceiling level including:

- Plasterboard ceilings may survive relatively short periods of immersion. However, being substantially weakened by longer immersion, they are normally destroyed by their own weight, and the weight of any trapped water and wet insulation as the water level falls. False ceilings are likely to be similarly damaged. Even if the ceiling does not collapse, it is likely that it will suffer permanent sagging, (Figure 100).

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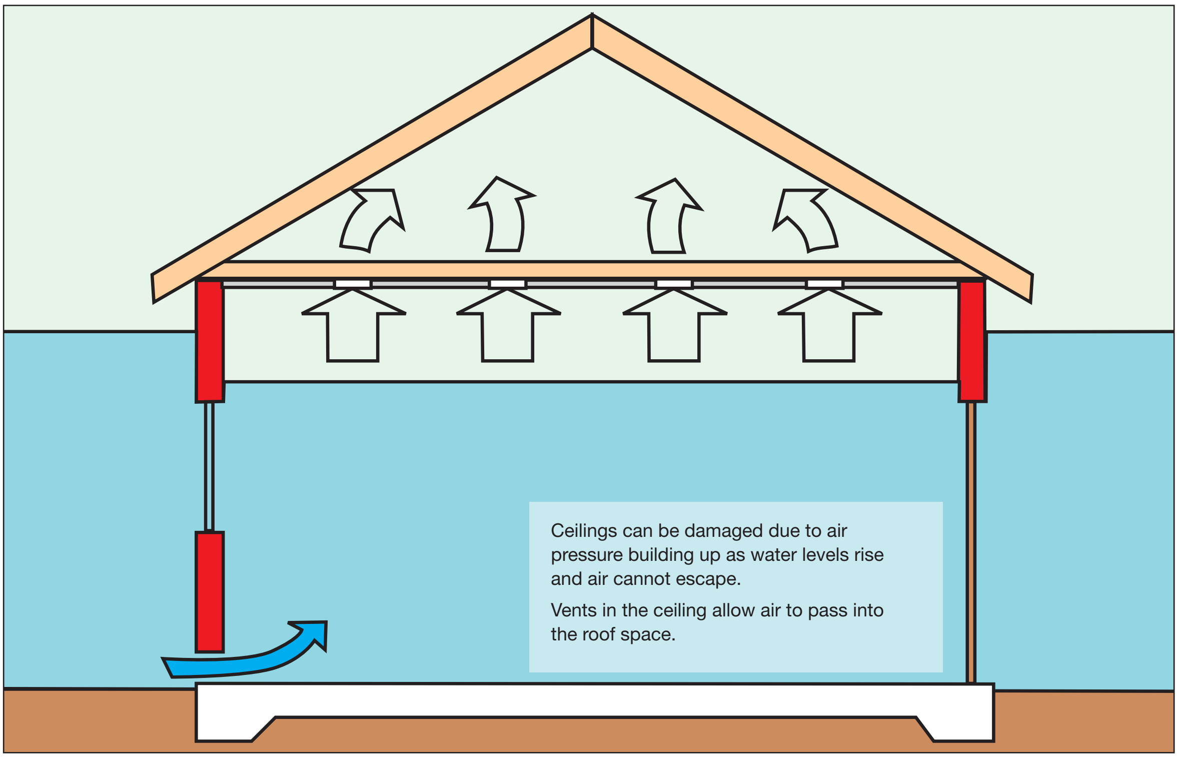
***Figure 101*** *Pressure build-up from trapped air*



Ceilings can be damaged by high pressure forming in the trapped air inside rooms. Venting ceilings can avoid this problem.

- Inappropriate insulation may deteriorate or slow the drying process or promote mould growth by holding moisture.
- As water rises inside the house, air can be trapped between the water surface and the ceiling. It is possible that the air pressure could become sufficient to burst the ceiling. This may occur even if the water does not inundate the roof.

Additional problems are associated with the ceiling of the ground floor in two-storey houses. These include:

- increased likelihood of deterioration of components and mould growth due to the reduced ventilation in the confined area between the ground floor ceiling and the floor above,
- decreased strength of support timbers, in particular engineered timber beams.

### 5.7.2 Design Suggestions

As the ceiling of a house is normally 2.4 metres or more above the floor, damage to ceiling components is not an issue in many river catchments around Australia because it is normally well above the PMF. However, in the Hawkesbury-Nepean and Georges River floodplains, the difference between the 1 in 100 AEP flood planning level and PMF levels means that flooding of the ceiling in severe flood events is a distinct possibility.

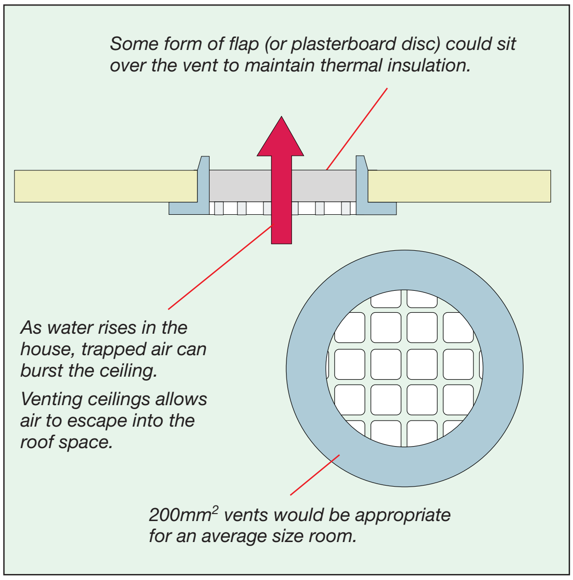
Most of the problems listed in Section 5.7.1 are best addressed by the selection of materials (see Section 5.7.3).

*Protecting against increased air pressure*

To prevent damage by high pressure from trapped air a vent can be provided in the ceiling of each room to allow air to escape into the roof space. The area of the vents need only be small, say 200mm$^2$. If thermal movement is a concern with an open vent, some form of flap could be used to close the vent until opened by the pressure, (Figures 101 and 102).

Provided the vents do not automatically shut, they could also assist in draining water from the roof space as the water level falls.

***Figure 102*** *Ceiling vents to release air pressure*



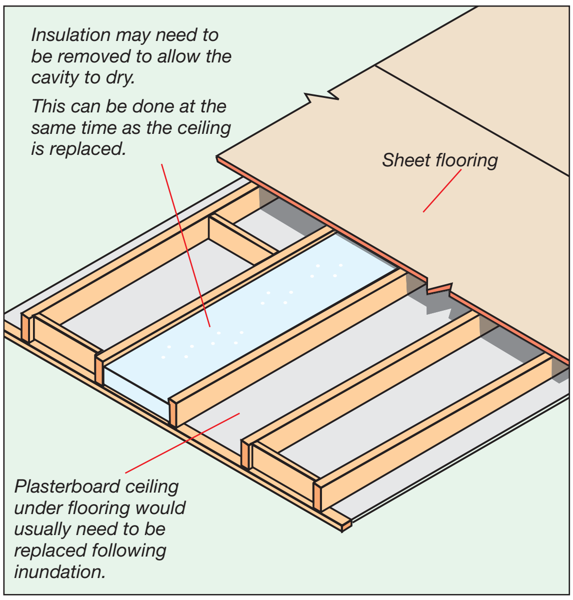

*Ventilation*

It is important that the design of the roof and ceiling area promotes effective ventilation of the area. Methods to improve ventilation are covered in Section 5.8.2.

Due to the long, shallow and confined nature of the area, there are special problems related to the ventilation and drainage of the space between the ground floor ceiling and the first floor in two-storey houses. Such areas will take many months to dry.

Given the extra height of ceilings and hence much lower chance of flooding (about a 1 in 300-year event at Windsor), it is not cost-effective to use alternative materials to plasterboard in the ceiling. If flood waters do reach the ceilings, they will

***Figure 103*** *Repair of intermediate floors and ceilings*



need to be replaced. When the ceiling is removed, access will be available to the ceiling space for cleaning and drying, (Figure 103).

Regardless, it is good practice to ensure that any enclosed spaces are well aired and drained. No impediments should be placed in the way of water draining from the area. Similarly, there should be no blockages to effective ventilation of this space

Reference should be made to Section 5.2 for advice on the use of support timbers in this area.

### 5.7.3 Material Selection

As noted in the previous subsection, the ceiling may need to be removed to permit cleaning and drying of the space between the ceiling and the underside of the upper floors. Accordingly, plasterboard ceilings may be sufficient in this application.

However, in standard single-storey pitched roof houses, the ceiling area can be adequately ventilated and there may be some justification in using more water resistant linings which may survive inundation. These include fibre cement sheeting and timber linings.

Fibre cement sheeting can be used for ceilings as the material will better withstand the weight of water trapped between the rafters and is relatively unaffected by immersion.

Timber-lined ceilings will be less affected as the water will likely leak out between the boards and the timber retains significant strength when wet.

Concrete first floor construction will fully withstand the effects of a flood and should be considered for 2-storey construction although it is considerably more expensive and is normally only used with full brick construction. If used, the most flood resistant underside finishes are those painted or sprayed directly onto the concrete. False ceilings will suffer from the same drawbacks as the space between ceiling and first floor floors as discussed in the previous subsection.

Where flooding can rise above the ceiling, the ceiling insulation will be affected. The most common form of ceiling insulation are batts placed between the ceiling joists. Once again the preferred material for buildings in lower parts of the floodplain is polystyrene boards.

The choice of insulation in traditional pitched roofs is less critical than in most other locations in the house because it can be reasonably accessed for repair or replacement. As it is also less prone to immersion due to the additional height, the use of other forms of insulation such as batts or loose fill can be considered. These will need removal after flooding to reduce the damage to the ceiling components. However, it is possible that the ceiling may collapse as the water level falls below the ceiling level due to the additional weight of wet insulation combined with the significantly reduced plasterboard strength. This is far less likely to occur with polystyrene boards as they are light and do not absorb significant amounts of water.

Refer to Section 5.8.2 for situations where insulation is used in ceilings which closely follow the roof line and access to the ceiling space is limited. The principles in this section are also applicable to the area between ceilings and first floor floors.

Refer to Section 5.5 for more advice on the use of insulation in flood prone houses.

### 5.7.4 Comparative Costs

A simple cost comparison cannot be made between a suspended concrete slab and a timber first floor and a plasterboard ceiling underneath, as the concrete slab is normally associated with full brick wall construction.

If the floor/ceiling system comparison is based on a four metre span:

The cost for a timber joist and particleboard floor with a 10mm plasterboard ceiling is between $60 – $80/m$^2$.

The cost of a concrete slab with a set plaster ceiling is $200/m$^2$.

The cost of a plasterboard ceiling is $21/m$^2$.

The same ceiling in fibre cement sheet is $26/m$^2$.

A timber lined ceiling would cost between $50/m$^2$ and $100/m$^2$ depending on the timber species, the fixing details and the finish.

## 5.8 ROOFS

### 5.8.1 Problems

This section looks at the problems associated with roof cavities and materials. These problems include:

- Water can be retained in moisture traps and ventilation can be poor in roof cavities.
- High moisture levels could initiate rot in roof and ceiling timbers and the corrosion of connectors. This is particularly a problem in the area adjacent to the ceiling where water can pond and elements can remain moist for long periods. The above problems can be greatly exacerbated by insulation that can hold moisture and hinder drying.
- Roof tiles can be dislodged by floodwaters.
- Whilst the upper surface of a roof tile has a degree of water resistance. The under surfaces of some tiles may absorb water which could significantly increase the weight of tiles after prolonged immersion in water. This extra tile weight could overload rafters and other roof members already weakened by immersion.

### 5.8.2 Design Suggestions

As flooding of the roof is likely to be rare, elaborate measures to reduce flood damage become less economical and difficult to justify. However, good practice can help reduce damage in severe events, (Figure 104).

When considering appropriate measures for making the roof area more flood resistant, the following matters are relevant:

- Some roof designs (e.g. hip) resist forces from flood waters better than other designs such as gable roofs.
- Due to its higher level the roof area has a much lower, perhaps even zero, probability of flooding compared with the living quarters of the house.
- As traditional pitched roofs normally have relatively easy access (compared with wall cavities and under floor areas), post-flood inspection, repairs, drying and ventilation can be readily undertaken.
- With the likelihood of the collapse of the ceiling if inundated, or at least the need for its removal and replacement, complete drying of the roof members can be achieved prior to restoration.

In houses with a rectangular floor plan, the roof rafters and ceiling joists are usually perpendicular to the long wall to create shorter roof spans. In the case of a gable roof, the end wall of the house can be the most critical under horizontal loads from floodwater because the top plate has no roof rafter and ceiling joist restraint to transfer resistance through the wall ties to a brick veneer wall. This can allow greater inward deflection of the wall frame and early failure of a brick wall. In this regard, houses with hip roofs have a strength advantage.

Ventilation of the roof space is critical both for the roofing components and the ceilings.

While unsarked tiled roofs have ample ventilation, it is possible that metal clad roofs, and sarked tiled roofs, need additional ventilation using either roof ventilators or air vents on gable walls. Good connection with the wall cavity ventilation will help air flow up the wall cavity and out of the roof space. This will assist drying of the wall cavity as well as the roof space. As ventilation is very important, situations where the ceiling is fixed to the underside of the roof rafters are to be avoided. This occurs in near flat roof construction and where a sloping ceiling follows the roof pitch.

In traditional pitched roofs, reflective foil (also referred to as sarking) is often provided under the roofing as a weather seal and insulation. This is frequently used in conjunction with ceiling insulation to provide the required insulation R-value.

There may be a silty film remaining after a flood and this could reduce the effectiveness of the foil.

In houses where the ceiling follows the roof line e.g. cathedral ceilings and skillion roofs, both the bulk and reflective insulation have to fit into a small space. Due to the difficulty of replacing insulation in such spaces, it is recommended that flood compatible insulation be used. The installation approach could be to place sarking under the roofing material with foil-faced polystyrene boards placed between the roof rafters. Wherever foil is used, the minimum 25mm airgap must be included. As with other insulation it is important that the boards be firmly held in place to avoid movement as a result of the buoyancy forces. If using battens, they should be placed so as not to interrupt water flowpaths and trap water.

Consideration should also be given to ensuring good ventilation in the confined roof space to reduce the chance of rotting and mould growth.

Refer to Section 5.5 for more advice on the use of insulation in flood prone houses.

In areas subject to high flood velocities, it may be necessary to fix individual roof tiles down to the battens to prevent them being lifted off the roof. The increased loading due to water flow is not as critical as with walls since roof coverings can generally accommodate higher deflection limits. The load capacity of a roof should typically resist water velocities up to 2 metres/second.

Reference should be made to Section 5.4.2 which recommends strengthening the roof to wall frame connection where higher velocity flows can exceed the eaves level.

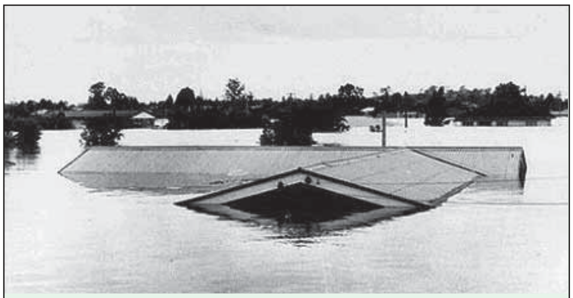
### 5.8.3 Material Selection

Similar to sub-floor areas, moisture and corrosion resistant materials should be selected for roofs susceptible to flooding.

Adhesives in timber products should be moisture resistant. If inundation of the roof is possible, the design of any engineered timber beams should follow the strength reduction recommendations provided in Section 5.2.3.2. Roof insulation should be as recommended in the previous subsection.

As with wall framing, steel roof framing is unaffected by immersion. However, good quality timber and construction methods with adequate ventilation should reduce risks of distortion or rotting. In accordance with Section 3.2.2.2, a higher wind design classification may need to be adopted to allow for the slight loss of strength associated with immersed timber.

***Figure 104*** *Roof design is important in resisting forces from flood waters*



Some roof designs (e.g hip) resist forces from flood waters better than other designs such as gable roofs.

Where prolonged immersion of roof tiles may occur, the chance of overloading roofing members with heavier water laden tiles can be avoided by using sheet steel roofing. This would also remove the chance of tiles being lifted and removed by flowing water. However, as tiles by different manufacturers and materials may exhibit a wide range of water absorption, this issue should be discussed with the manufacturer to determine specific tile porosity, which needs to be based on total immersion not just rainfall. The likelihood of extended immersion also needs to be considered as does that of roofing members being weakened.

### 5.8.4 Comparative Costs

The roof/ceiling system comparison is based on a four metre span.

The cost for a timber joist and metal deck roof with a 10mm plasterboard ceiling and an insulated cavity is $80/m$^2$.

The cost of a concrete tiles on a pitched timber frame with a plasterboard ceiling is $130/m$^2$.

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# 6 NON-STRUCTURAL COMPONENT DESIGN

## 6.1 JOINERY AND FITTINGS

The priority with measures contained in these guidelines is to improve protection of the building from damage to the structural (i.e. load bearing) components so that it can continue to be occupied safely without major reconstruction being necessary.

Protection of fixtures has not been a focus as:

- Components such as doors, skirtings and architraves are relatively low cost and can be easily replaced.
- Higher wear and tear items such as floor coverings and ovens/hotplates have a high depreciation and are actually replaced at least a couple of times over the life of a building.
- Built-in furniture such as kitchen cabinets and bathroom vanity units have a short service life compared with the house structure and are updated at least a couple of times throughout the life of the house. Damage to such components would not prevent the reoccupancy of the house to the same degree that severe structural damage would.

### 6.1.1 Problems

Fixed joinery and built-in furniture are often flood damaged. They include:

*Joinery*

- skirting boards
- architraves around windows and doors
- doors and door jambs (internal and external)
- windows and window frames
- staircases or steps in two-storey or split-level houses.

*Built-in furniture*

- kitchen cabinets
- built-in wardrobes
- vanity units
- laundry cupboards
- shelving (e.g. pantry, linen press).

Built-in furniture items are often delivered as prefabricated units and installed in such a way that moisture traps are created under or behind them.

The adhesives and materials used in the manufacture of these items can also be a major problem when flooded. Certain materials are very susceptible to delamination and warping when immersed. It is quite common to use reconstituted timber products, such as particleboard, MDF and hardboard for many of these items.

### 6.1.2 Design Suggestions

It would be unrealistic to expect that damage to a majority of these items can be avoided cost effectively. In many cases, they should be removed to provide access to damaged walls or to assist drying. However, there are steps to reduce the impact of floodwater on or by these items. They should be detailed to avoid moisture traps, making sure that water drains from them and around them easily. Further, to ensure that the materials in these units and in the surrounding structure dry out quickly, good all round ventilation is essential.

Key design and production issues:

- avoid false floors in cupboards and wardrobes,
- build units on legs to allow for cleaning and free flowing air underneath,
- provide holes for drainage and ventilation to closed-off areas and hollow components,
- construct joints so they shed water,
- avoid grooves and hollows that can collect water, and
- use supports at closer centres with hardboard and ply panelling to limit permanent distortion (position supports at less than 500mm centres).

Some items can be omitted altogether e.g. it is practical to omit skirting boards completely in houses built from “solid” walls such as double brick, concrete blockwork, precast concrete.

Such construction also permits the use of steel door frames which require no architraves, (Figures 105).

***Figure 105** Reducing timber skirtings and architraves*

Face brick or rendered brick without skirting boards can significantly reduce wall damage. Steel door frames will further reduce the repair costs.

Traditional timber stairs can include enclosed areas which are difficult to clean and dry. A simpler approach is to have an open-tread solid timber stair. As a staircase may have to be used to move large furniture items quickly prior to a flood, the stairs should be wide and easily negotiated. It is recommended to have 1 metre clear between balustrades, or wall and balustrade and to have treads at least 280mm wide and risers of no more than 180mm high (see Figure 47).

One difficulty with kitchen cabinets, vanities and wardrobes is that they are placed closely against the wall which restricts ventilation. Another aspect that requires attention is the area behind the kickboard and under the bottom shelf. This is usually an inaccessible void space about 150mm deep between floor, wall and cupboard. Floodwater and debris can enter this area and provision must be made to be able to clean and dry this space. One solution is to use a removable kickboard and support the base of kitchen cupboards off the floor on short metal or plastic legs, (Figure 106).

Built-in wardrobes that have full-height doors and a common floor surface with the room will avoid a boxed-in void at the bottom of the wardrobe.

Ceramic pedestal-type units or hand basins in benches with metal or plastic legs rather than vanity units will better resist flood damages. If metal legs are not fitted and a standard kickboard is used, it is advised to have this as a screw-fitted removable section to clean and dry under the unit. Wall-mounted units can provide alternative storage space.

### 6.1.3 Material Selection

#### General

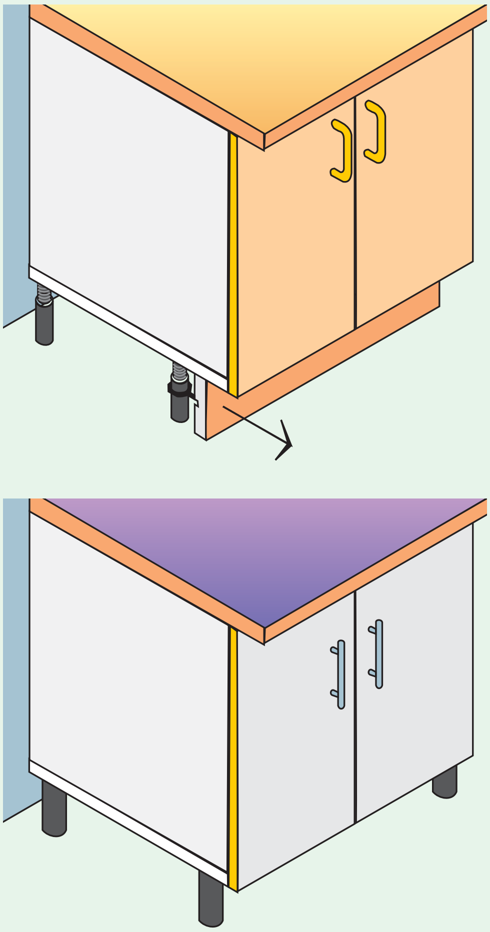
Wherever possible, materials that will have optimum performance in flood conditions should be used.

Longer-term immersion can affect and permanently damage timber-based products. However, well designed and built timber products can be expected to survive moderate flooding. Whilst a number of factors will affect the performance (e.g. individual timber specimens, different standards of production and manufacturing, application), the following list ranks timber products from best to worst:

- solid timber,
- marine grade plywood,
- exterior grade plywood,
- hardboard and MDF, and
- particleboard.

Products built from well-sealed solid timber with moisture resistant adhesives perform the best in flood conditions. Moisture resistant adhesives must be used in all glued fabrications.

***Figure 106** Access beneath kitchen cabinets*



Installing kitchen cabinets on legs (with or without a removable kickboard) provides easy access for cleaning and ventilation.

If plywood is used, it should be exterior, or preferably marine, grade and all edges should be sealed. Thin ply veneers should be supported at closer centres than normal to restrict buckling.

## Joinery

*Skirting boards*

Skirting boards made from MDF can be unsatisfactory when exposed to water. Even when painted front and back, water can create problems at corner joints or where there are fixing nails or screws.

Solid timber skirting boards are generally less affected by water damage than MDF skirtings, but may distort.

However in most cases, skirting boards will need to be removed after flooding either to remove the plasterboard, or to clean the cavity through gaps under the lining as mentioned in Section 5.4.2. As skirting boards are usually fixed by nails, they are difficult to remove without damage and would need to be replaced. Exposed-head screws would simplify the removal process without damaging the skirtings.

Removable metal skirting boards can also be considered. They are available in extruded aluminium or coated pressed metal, with metal backing plates or wall clips. These types of skirtings are often used in commercial construction, but are also suitable for residential buildings.

*Architraves*

Architraves will need to be removed if plasterboard linings, doors and windows require repairing. Solid timber architraves may be reused if not damaged by water or by its removal, but MDF will probably need replacement.

*Doors and door jambs*

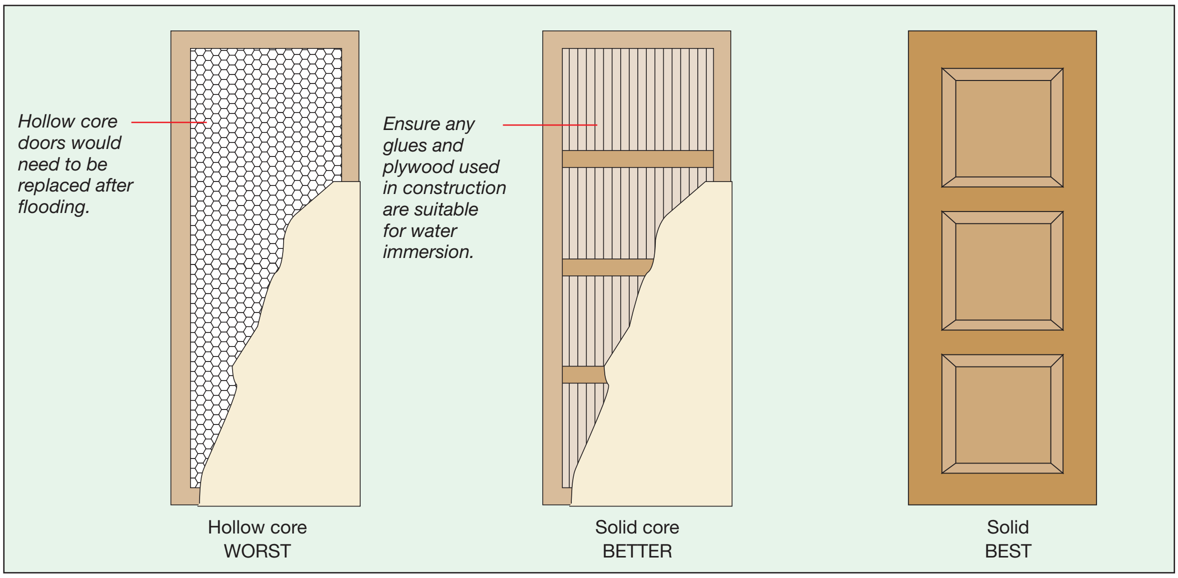
Hollow core doors are badly affected by water and would normally have to be replaced even after a minor, short duration flood event.

On the other hand solid core or solid construction doors can perform better after flooding if the glues and plywood used in the door construction are suitable for extended immersion in water.

Solid timber skirtings and architraves will have a better chance of recovering from immersion.

6

***Figure 107*** *Rating of doors in flood events*




Hollow core doors are relatively inexpensive and their replacement in a severe (though rare flood event) could be far more economic than providing solid doors, (Figure 107).

*Windows and window frames*

Aluminium framed windows are used in the majority of new houses and would not be affected by immersion.

Timber windows absorb water and may result in difficulty opening them until they are dry. It is difficult to ensure that the timber is fully sealed as protection can be lost from rubbing surfaces. Consideration could be given to using windows which have less rubbing surfaces e.g. hopper windows in preference to sash windows, (Figure 108).

It is important to use quality timbers, glues and construction which can withstand immersion without excessive swelling or distortion.

Whilst some glass is more likely to break if immersed due to floating debris and water pressure, the use of stronger glass is not cost effective for the "wet flood proofing" approaches recommended in these guidelines.

## Built-in furniture

*Cabinets and wardrobes*

The most often used material for built-in furniture, including kitchen cabinets, is particleboard coated with plastic sheeting or laminate. Experience shows that particleboard loses its strength, swells and fragments when saturated and will have to be renewed after a flood. Laminated particleboard bench tops are similarly affected. However, an economic alternative (with similar benefits of low-cost, quick and simple construction and ease of cleaning) would be difficult to find, (Figure 109).

***Figure 108*** *Timber window types*

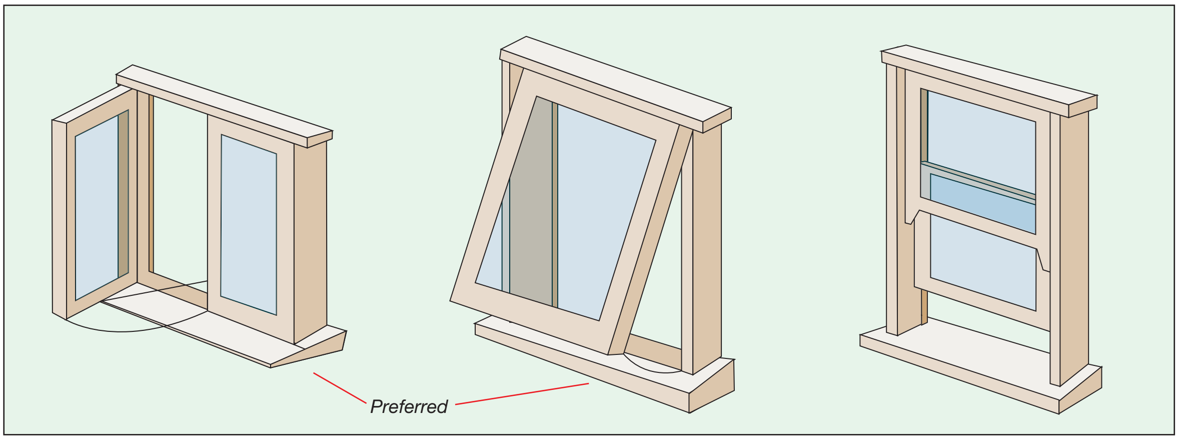
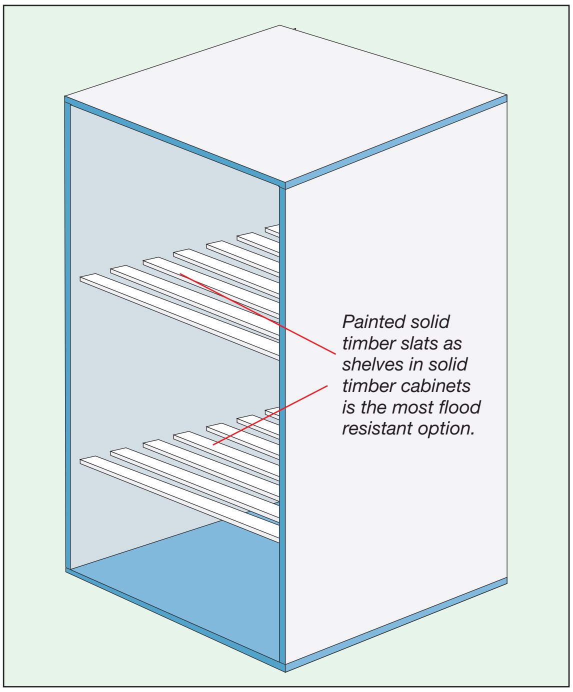


***Figure 109*** *Flood compatible shelving*




## 6.2 FLOOR COVERINGS

### 6.2.1 Problems

There are three issues to be considered in relation to floor coverings:

- the effect water has on the coverings themselves,
- the way the floor coverings inhibit the drying of the actual floor, and
- the extra load on weakened timber floors from saturated coverings.

Floor coverings that contain organic materials such as woollen carpet, grass matting, linoleum and cork flooring will all undergo shrink/swell movement and will be affected by fungal decay (rot) unless they are quickly dried out. Shrinkage can be permanent.

All floor coverings that are not readily removable will have the effect of slowing the drying out of the main floor material.

Hardboard underlay, which is commonly used under cork, linoleum and tiles when they are placed over timber flooring, performs poorly. It swells and retains water and has the potential to cause decay.

Carpets and other floor coverings which retain moisture, weigh much more when wet and will place additional load on weakened suspended timber floors as the floodwater recedes and the support offered by the buoyancy effects on the floor are removed. Wet carpet could represent as much as 10% of the allowable load on a floor. Particleboard, in particular, and, to a lesser degree, plywood flooring may suffer additional deformation or in extreme cases collapse.

### 6.2.2 Design Suggestions

Most measures to reduce damage to floor coverings are related more to the appropriate choice of materials than the design of the house. However, as with much damage, the raised or two-storey house provides more flexibility with the use of materials to reduce damage.

For lower levels that are likely to be inundated, tiled concrete or polished timber are more suitable.

On second storey floors, there is less probability of inundation and a lower risk of damage to wall-to-wall carpet.

### 6.2.3 Material Selection

Consideration should be given to using floor coverings which are removable. Loose carpets such as carpet tiles and loose rugs can simply be lifted above the floodwaters or, if inundated, easily removed for cleaning and drying.

However, it is not recomended that carpets be re-installed without a thorough examination as carpets may contain contaminants, including biological matter, that was spread during the flood.

The most suitable solution for flood prone areas are:

- tiled concrete floors, and
- polished hardwood timber.

Tiles should have limited moisture expansion characteristics (less than 3%).

Tile adhesives should be water resistant but may be either acrylic based or cement based (with polymer adhesives).

Some non-traditional floor coverings that perform well are:

- rubber flooring,
- epoxy, and
- cementitious self-levelling toppings when used over concrete.

Toppings over timber should be avoided as they slow the drying process.

Hardboard and ply underlays are not recommended over timber flooring for the same reasons.

Linoleum backed with hessian is most likely to shrink and cannot be reused while vinyl and rubber sheet can usually be lifted and reused.

### 6.2.4 Comparative Costs

The cost of floor finishes varies widely and needs to be added to the cost of the floor structure and sheeting to get meaningful comparisons.

The cost of a sanded and polished floor is approximately $50/m².

The cost of wall to wall carpet ranges from $35–$60/m² laid.

Floor tiling costs in the range of $80–$90/m² laid depending on the cost of the tiles.

## 6.3 ELECTRICAL SERVICES

### 6.3.1 Problems

Inundation of electrical system components such as meters, fuses, circuit breakers, surge protectors, switches, power points and wiring can cause short-circuits, damage to components, corrosion, malfunction and the possibility of electric shocks.

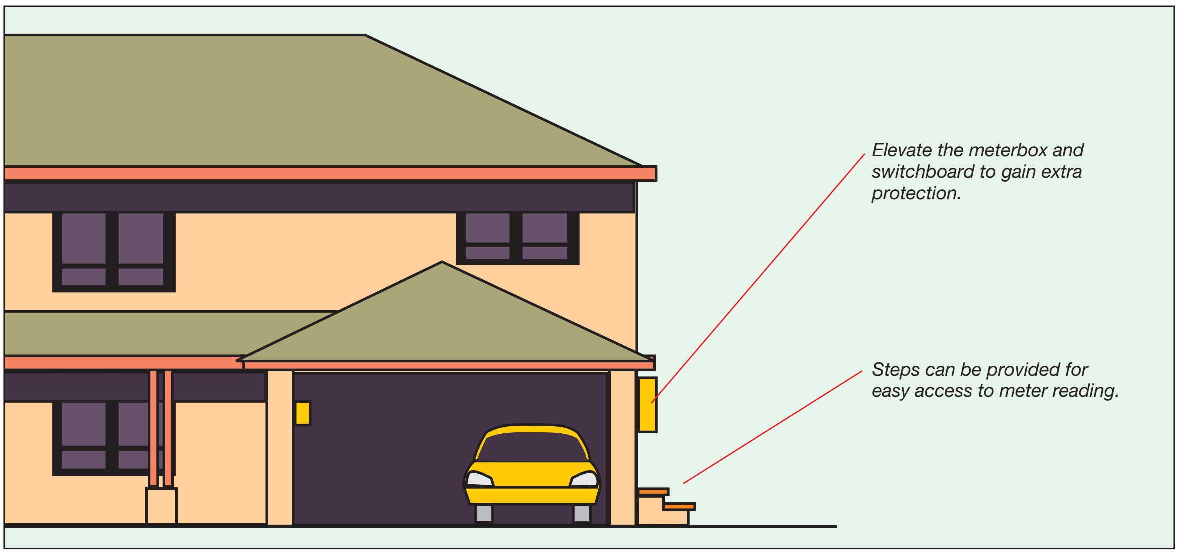
In items with mechanical operations such as circuit breakers and switches, inundation can affect the overall operation of the mechanism through the presence of silt, the loss of lubricants and subsequent corrosion.

### 6.3.2 Design Suggestions

The most effective flood-resistant option for electrical systems in new buildings in flood prone areas is elevation of electrical components to the highest practical or regulatory level.

In some cases major items such as switchboards and meter boxes, which contain easily damaged and expensive to repair or replace items, could be relocated to the upper floor or located higher under the eaves of single-storey houses to gain extra protection. However, it is normal for electricity suppliers to want the meter located close to the ground so it is readily accessible for their inspection and reading. Accordingly,

***Figure 110** Elevated switchboards and meterboxes*



it is desirable to provide appropriate access to the upper floor or, for single-storey houses, to provide a separate raised platform with stairs. The electricity supplier and local council should be consulted to check on any requirements they may have. In addition, individual components should be located as high as possible within the meter box or switchboard, perhaps by making the box wider rather than taller, (Figure 110).

Where possible, house wiring should be located in the roof space and extend down the wall rather than being located in the slab or under suspended floors. Although power points are relatively inexpensive to replace, consideration could be given to raising power points on the wall to reduce the chance of inundation.

It is normal that during severe flooding the mains electrical supply to the house will be cut either intentionally or due to tripping of the mains circuit breakers. In two-storey houses it is worth considering having the lighting and power on each level on separate circuits. During recovery this could allow the damaged lower level to remain disconnected whilst maintaining supply to the upper level if only the lower level is flooded. The advantage is that the upper floors could be reoccupied whilst repairs are undertaken on the ground floor.

Expensive fixed electrical equipment, such as air-conditioners and electric hot water systems, could be mounted high to reduce the chance of inundation.

Where possible, all cable runs should be of one length. If junction boxes are unavoidable, they should be located in easily accessible, yet elevated, locations.

Conduits should be installed in such a manner to ensure any water will drain freely as the floodwaters recede. Similarly, where the mains supply is located underground, it should be installed to ensure that water can drain from the conduit. Sag points in any conduits should be avoided.

### 6.3.3 Material Selection

For obvious reasons, electrical components such as wiring junction boxes, conduits etc. are made from materials which are stable and durable to ensure safe and reliable service over the long term.

While these materials are unaffected by immersion, the connections and switches can be affected and therefore compromise the insulation and safe operation.

Some electrical fittings may be reusable after cleaning and drying, but the majority would require replacement after flooding.

### 6.3.4 Comparative Costs

Correctly installed, electrical wiring should survive inundation. However switches, power points and lights are likely to need replacing. As these are relatively easy to replace and it is difficult to justify using more water resistant components which would be much more expensive. Power points should cost less than $500 to replace.

Main switchboard components will require replacement if inundated. Typically it could cost around $600 to replace the switchboard components and the best option is to raise the board as high as allowable by the supplier.

## 6.4 SEWERAGE SYSTEMS

### 6.4.1 Problems

There are two main problems associated with sewerage systems during flooding.

- the back-up of sewage into houses, and
- damage to the system components such as floating or collapsed septic tanks, broken pipes, damaged pumps and electrical systems.

Although floodwaters which typically enter the house can contain sewage, it is normally very dilute. However, back-up of the sewerage system in the bathroom through the toilet, baths, drains, etc. can be a concern as it has the potential to concentrate the contaminants inside the house and may require a more thorough clean-up.

## 6.4.2 Design Suggestions

Sanitary ware inside a house is generally not damaged by flooding and it is impractical to elevate sewerage components normally placed below ground. It is important though that external components be designed to resist any likely velocity and buoyancy forces.

### 6.4.2.1 Backcharging of Sewerage System

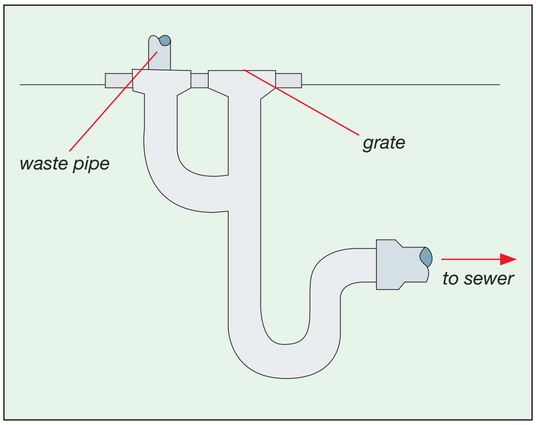
For the majority of houses, the normal practice is to provide a gully trap (disconnector gully) outside the building and low to the ground. This prevents sewage from spilling into the house when there is a backcharge in the main drain such as from tree roots penetrating the pipe joints. Similarly, backcharging should also occur from the top of the trap to prevent sewage entering the house drainage system. It is also normal practice for the gully trap to be well elevated above the main receiving system to help prevent surcharging at the trap itself, (Figure 111).

Sewage back-up is commonly raised as an important concern in many overseas flood guidance publications, particularly those from the USA. In most cases, the recommendations include installing either a non-return or gate valve in the service connection pipe, or a combination of both valves.

Non-return valves allow waste to flow in only one direction from the house to the sewer in normal operation. Flow from the opposite direction during flooding is prevented by automatic shutting of the valve. These valves require regular checking and maintenance to ensure correct operation as obstructions can occasionally block the valve in the open position thereby rendering the valve ineffective.

A gate valve overcomes the blockage problem, but needs to be closed manually before the back-up occurs. If the occupier is not present, or does not know about or remember to shut the valve, the back-up problem remains.

***Figure 111*** *Use of disconnector gully and grate to prevent backcharging of sewage*




Valves need to be in a small pit located outside the house between the sewer main, adding further to the cost.

### 6.4.2.2 Damage to Septic and Sewerage System Components

The main causes of damage to exposed components such as tanks and pipes are the forces associated with buoyancy, water velocity and/or debris impact. These forces should be accounted for in their placement.

Buried components can also be at risk from buoyancy and scour. Tanks associated with septic systems can float due to the buoyancy forces. This is particularly the case for holding tanks which are regularly pumped out. They may be relatively empty at the time of a flood and therefore more susceptible to uplift. All tanks should be designed to resist these uplift forces and more advice is provided in Section 6.6.2.

Any lightweight access covers to tanks and pits should be secured or tethered to prevent their loss during a flood.

Exposed pipework may be damaged, dislodged, or broken by velocity flow, wave action, and debris impact. Where possible, such pipework should be securely fastened to the downstream side of a solid support such as a wall or column. They can also be enclosed in a strong casing with provision for drainage of any trapped water.

The buried distribution pipes in the absorption trenches could be liable to damage if the backfill material is scoured. These should be located in areas of low velocity below the likely depth of scour.

When designing absorption trench systems, consideration needs to be given to ensuring that higher water levels occurring within the soil during a flood can drain quickly as the system will back-up unless the effluent can filter through the soil.

### 6.4.3 Material Selection

Sewerage system components are designed for immersion or contact with contaminated water so there is no need to use alternative materials. Consideration may need to be given to the impact of immersion on some components not normally submerged, for example, power supply and pump equipment.

### 6.4.4 Comparative Costs

Prevention of back flow into the house is provided by a gully trap which is a normal installation in sanitary plumbing for houses and no additional costs would be involved. Where this is not the case, it should be the preferred option as it is likely to be the most cost effective as the cost of installing a non-return valve in a suitable pit in the ground is estimated to be around $1200.

Most buried tanks and pipes should already be designed to resist uplift forces and so there should be no additional cost involved. The additional cost associated with restraining above ground tanks is dictated very much by the size of the tank etc. and would need to be assessed on an individual basis.

## 6.5 WATER SUPPLY

### 6.5.1 Problems

Associated problems of the water supply during and after flooding include:

- Problems of contamination arising with both town water and local rain water tank supplies, which can make the supply unsafe, and
- Damage to exposed and buried components of the water supply systems including pipes and storage tanks from scour and floating debris, (Figure 112).

### 6.5.2 Design Suggestions

There is little that the individual house owner can do to prevent contamination of the town water supply. Precautions must be relied upon when using town water supply after a flood.

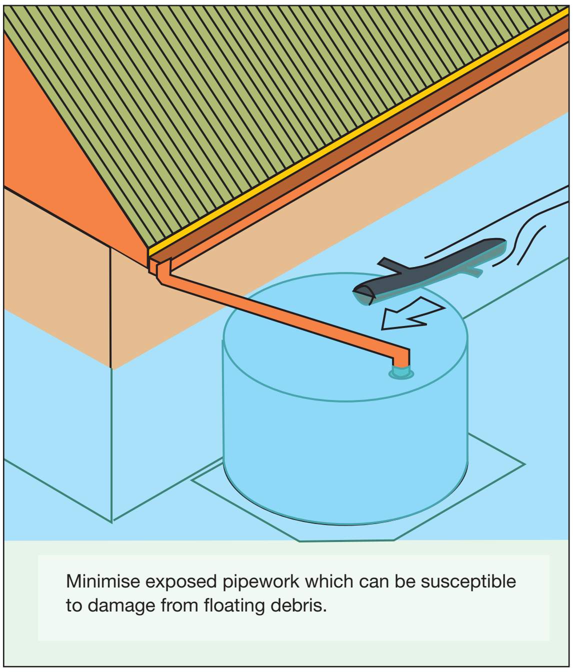
To reduce the possibility of the water in rainwater tanks becoming contaminated, the inlet should be located as high as possible so it does not become submerged, (Figure 113).

Exposed components or pipework at risk from flowing water and debris should be securely fastened or located in sheltered areas to reduce the chance of damage.

Hot water heaters are likely to need replacing if immersed in water and should be mounted as high as practical.

In local flooding situations, rainwater tanks are usually filled with the rainwater causing the

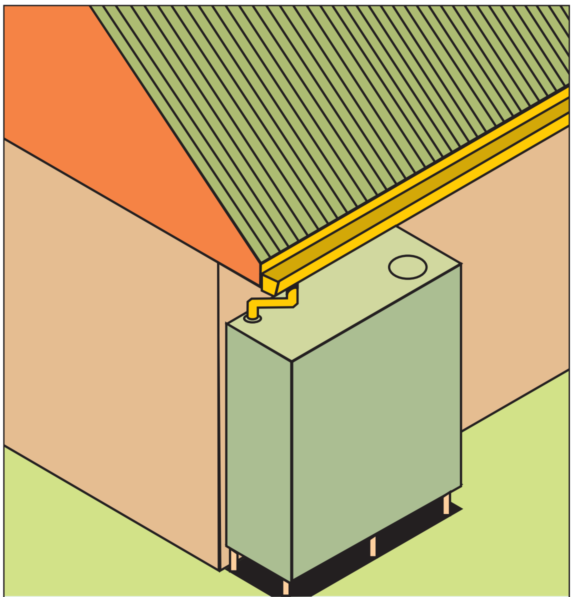
***Figure 112*** *Exposed pipework*



flood. In large catchments they may be empty and consideration should be given to designing against flotation especially in large tanks which are more vulnerable and can be costly to replace.

Regardless of whether they are full or empty, rainwater tanks may need to be restrained to resist dynamic forces if exposed to high flow velocity. The design of tanks is covered further in Section 6.6.2.

***Figure 113*** *Rainwater tanks*



Elevate the inlet of the rainwater tank as high as possible to avoid contamination in the event of a flood.

## 6.5.3 Material Selection

Water supply components are flood compatible. The only components likely to be damaged through immersion is the electrics associated with the water heater and pumps for water tanks. This possibility can be reduced by mounting the heater and pumps as high as possible.

## 6.5.4 Comparative Costs

The only real options available to decrease the flood risk is the raising of rainwater tanks and water heaters. The additional cost associated with this is likely to be reasonably small.

# 6.6 STORAGE TANKS

## 6.6.1 Problems

Tanks (e.g. heater oil, septic, water heaters, rainwater, air ducts) may float, pop out of the soil, break away, or be damaged by floating debris. As well as damaging the system itself, this could also cause other damage due to impact or contamination from leaked contents. Associated pipes can break under dynamic forces especially where they pass through walls or are connected to equipment, (Figure 114).

## 6.6.2 Design Suggestions

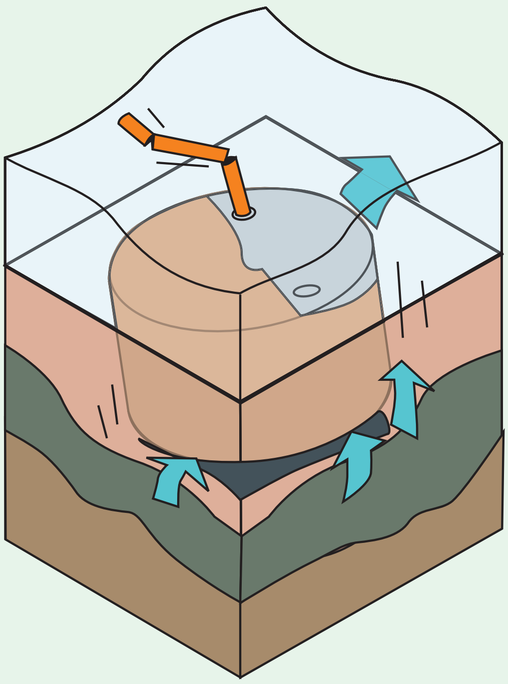
Both above and under ground tanks need to be designed for any likely buoyancy forces. All tanks need to be designed with appropriate hold down capability and to resist impact loads from debris. Any restraints should be of corrosion resistant material to reduce the chance of corrosion weakening the support. The number and capacity of these restraints required can be calculated after determining the net buoyancy force:

> *Net buoyancy force* = Tank buoyancy (FB) – Tank weight – Equivalent weight of saturated soil
>
> Where Tank buoyancy force (FB) = Tank volume (assuming the tank is empty) x specific weight of water ($\gamma_w$) x Factor of safety (around 1.3)

Soil conditions can dramatically affect buoyancy forces. Residents should always consult with a geotechnical engineer or other experienced professional who is familiar with the local soil conditions when designing anchors to counter buoyancy forces.

Where feasible, above ground tanks should be elevated as much as possible to reduce the buoyancy forces but the support structures need to be designed to resist the forces. The supporting posts or columns should have deep concrete footings embedded below expected erosion and scour lines, (Figure 115).

***Figure 114*** *Flotation of buried tanks*



Tanks above and below ground are subject to similar buoyancy forces.

Underground tanks need to be designed with appropriate anchors.

In low velocity locations, elevation can also be achieved by using compacted fill to raise the level of the ground and by strapping the tank onto a concrete slab at the top of the raised ground. Consideration still needs to be given to the buoyancy forces. Alternatively, the tank can be secured to an elevated platform support by piers.

If high velocities are expected in an area, flow deflector walls can be constructed around the tank to protect it from debris impact and the forces of velocity flow. The walls should be as high as practical but they do not have to be watertight. Should they fully circle the tank, there must be drainage holes at the base of the walls for rain and floodwater to drain.

During a flood, settlement of a structure, especially those placed on fill, can occur due to soil saturation. This can lead to breakage of pipework and or the connections. Accordingly, pipework connections should have some flexibility to reduce the chance of breakage.

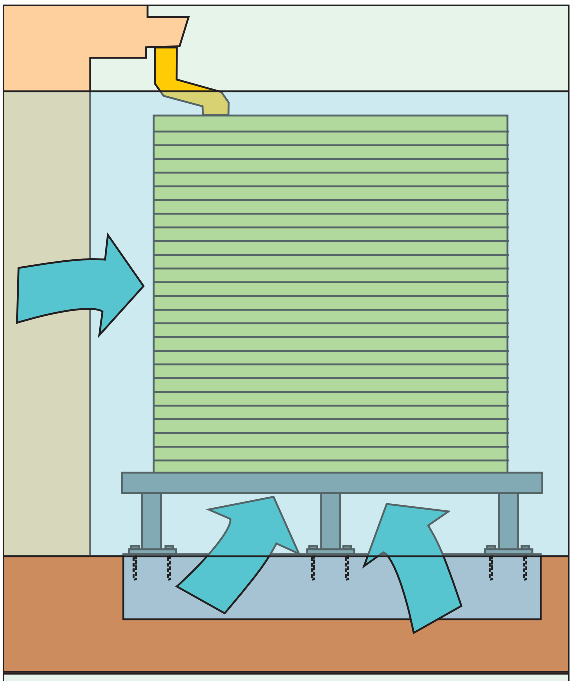
## 6.6.3 Material Selection

Materials used in support structures and the fasteners securing tanks and pipework to those structures should be corrosion resistant and any reduction in strength of components due to immersion should be allowed for.

## 6.6.4 Comparative Costs

The cost associated with making tanks and supports sufficiently strong to resist the likely water velocity forces are specific to the project. However, it is unlikely that such cost would represent a significant increase in the cost of the house.

***Figure 115*** *Protecting above ground tanks*



Above ground tanks should be elevated as much as possible and secured to deep concrete footings to resist buoyancy forces.

6

# APPENDICES

# APPENDIX A

## DAMAGE FROM WATER FORCES

Section 3.1 provides a simplified explanation of hydrostatic (still water) and hydrodynamic (moving water) forces and their order of magnitude. In reality, the calculation of these forces is more complex and requires a rigorous design approach to calculate and account for these forces. This Appendix provides additional information on how water forces occur, and the likely associated damage.

### A.1 Hydrostatic Forces

Every point within a still body of water is subjected to pressure proportional to the depth of water above it. The pressure acts at right angles, or perpendicular, to any object in the water. Therefore on the vertical wall of a house pressure will act horizontally on the wall. The hydrostatic pressure ($P_H$) at any given point, acting on a wall due to a body of water, is given:

$$P_H = \gamma_w H$$

Where $P_H$ is in Pascals or Newtons per square metre, $\gamma_w$ is the specific weight of water (= density of water x acceleration due to gravity = 1000 kg/m$^3$ x 9.8 m/s$^2$ = 9,800 N/m$^3$) and H is the height (in metres) of the water against the wall surface as shown in Figure 116. Pressure increases proportionally with water depth so that pressure has a triangular distribution down the wall. The resultant horizontal hydrostatic force, $F_H$ (in Newtons) acting per metre width of wall is given by the average pressure distribution times the wall area:

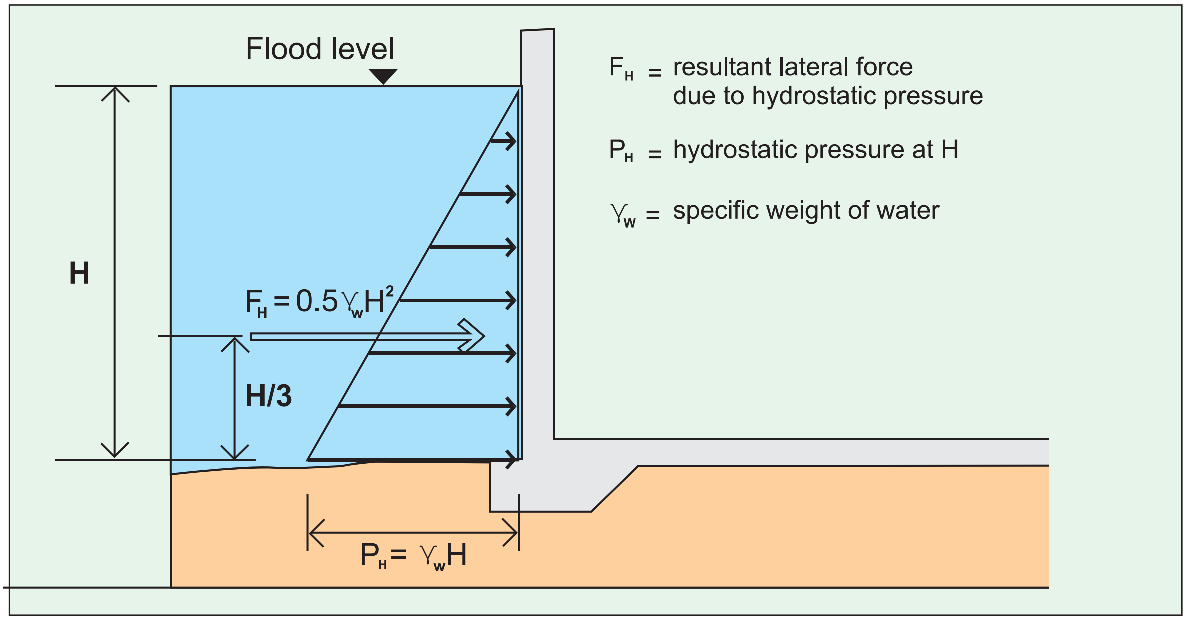
$$F_H = \frac{(P_H)\,H}{2} = \frac{\gamma_w H^2}{2}$$

With a triangular pressure distribution the centroid of $F_H$ is at a distance H/3 from the base of the wall.

In 1 metre deep water the total force is around 4,900 Newtons for each metre along the wall. As the force increases proportionally to the square of the depth of the water, the force for a depth of 2 metres is four times greater, or 19,600 Newtons for each metre along the wall. Water reaching the eaves of a house (usually 2.4 metres high) will exert a force of around 28,400 Newtons.

In a house that is “dry flood proofed” (i.e water is prevented from entering the house), as little as 0.75 – 1 metre deep floodwater outside can destroy a standard brick wall.

***Figure 116** Hydrostatic forces result in a triangular distribution of force up the wall*



Similarly on a horizontal floor, hydrostatic forces will act upwards and can lift and float houses or components if the uplift forces exceeds the weight or dead load of the structure. If water enters under a concrete slab, it is possible in theory that a double brick house could float as a result of water being prevented from entering the house. However, brickwork is brittle and would probably fail before full flotation occurs.

Brick houses with suspended timber floors can also suffer structural damage due to the buoyancy forces on the floor which can be critical at relatively small depths, especially if water cannot enter the house.

The buoyant force ($F_B$) is calculated by determining the volume of water displaced in the submerged or partially submerged object, and multiplying it by the specific weight of water. Figure 116 depicts a house with a slab on ground floor subject to a water level surcharge equal to H. The buoyant force, $F_B$, is then:

$$F_B = \gamma_w AH$$

Where $\gamma_w$ is specific weight of water, A is the area of the horizontal surface e.g. floor, where the loads are acting, and H is the submerged depth of the building below the water surface level.

If the buoyant force exceeds the dead weight of the structure (i.e. submerged and above the water level), uplift forces will occur, which can cause an inadequately anchored structure to float or move off its foundations.

For example, if the external water level reaches 300mm above the floor and water did not enter the house, there would be an upward force on the floor in a 4m x 3m room of around 35,300 Newtons. This force is double the maximum downward force a room is normally designed to carry. So even small differences of water level could severely damage flooring material or dislodge framing members.

An external depth of 1.2m (approximately half-way up the wall) would result in an uplift force of over 141,200 Newtons.

With all houses, designers should consider how individual components or the house structure will be held firmly in place should severe flooding occur. Some forms of failures include:

- weatherboard or sheet clad houses floating as a whole (usually those with suspended timber floors on piers) or the frame separating from the concrete slab,
- suspended timber floors in brick houses shifting, and
- roofs in all types of houses may break away from the supports.

In the majority of the Hawkesbury-Nepean floodplain where inundation can exceed 300mm, wet flood proofing is considered appropriate to reduce the possibility of severe damage due to hydrostatic forces. This requires effective water entry/exit points large enough to ensure internal and external water levels are balanced. (see Section 3.2.1.3)

## A.2 Hydrodynamic Forces

A house located on a floodplain where there is flowing water will be subject to forces additional to those caused by still water.

Pressures and associated forces vary because water levels are not constant when there is flow around a house. Generally the water depth increases on the upstream walls and decreases on the side and rear walls as shown in Figure 117. As long as there are sufficient openings in the walls and floors of the house, the internal water level will be relatively flat (somewhere between the external upstream and downstream levels). The increased water depths on the upstream walls result in an inward force on the wall. Similarly, the decreased water depths that normally occur on the side and rear walls result in an outward force on the wall that tends to strip the wall away from the house.

These pressures vary with house size and shape and with flow behaviour. In fact, as the depth of the flow increases and submerges the house, the pressures can drop significantly as the flow becomes three-dimensional (i.e. in very severe floods it can then flow over the house rather than just around it).

The exact form of these pressures and forces is complex but the following provides a general description on how these forces are developed and an indication of the size of the forces involved.

The inwards force due to flowing water is mainly associated with the afflux that occurs on the upstream side of the house. The afflux is the build up of water on the upstream side of any obstruction placed in moving water. On the other hand, the outward force is similarly related to the reduction of water level. The height of the afflux is proportional to the square of the water velocity. For example, if water flowing at a certain velocity results in an afflux of 50mm, then a flow at twice the velocity will produce an afflux of around 200mm. Afflux can be calculated from the following equation:

$$\text{Afflux} = \frac{C_d v^2}{2g}$$

*v* = *water velocity in metres/seconds*

*g* = *gravitational acceleration (9.8 metres/sec²)*

$C_d$ = *drag coefficient which depends on the shape of the object around which the water flows.*

***Table A.2A** Drag Coefficients*

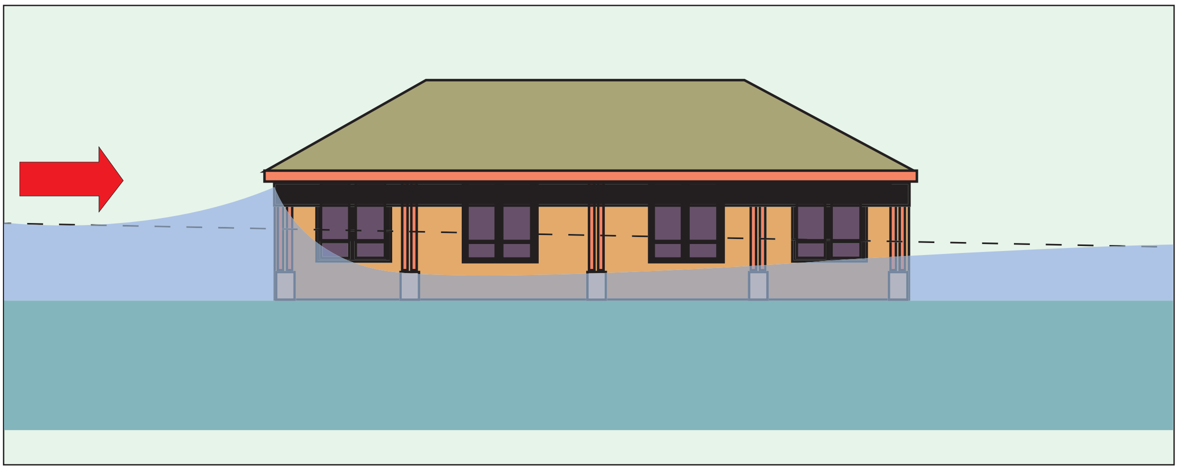
| Width to height ratio w/h Wall on ground | Drag coefficient $C_d$ |
|---|---|
| From 1 to 12 | 1.25 |
| 20 | 1.3 |
| 32 | 1.4 |
| 40 | 1.5 |
| 80 | 1.75 |
| 120 | 1.8 |
| 160 or more | 2.0 |

The drag coefficient, $C_d$, can be determined from the width to height ratio, w/h, where the width is the side perpendicular to the flow and the height is the distance from the ground to the water level. The table above gives $C_d$ values for different width to height ratios for water normal to the face of the structure with its base at ground level.

Where flow velocities are less than 3 metres/second, the force of flowing water is equivalent to this increase in depth of water on the outside of the wall. This results in an unbalanced force, which applies even if the hydrostatic force is balanced.

The additional load due to afflux tends to be uniformly distributed up the wall rather than the triangular distribution associated with hydrostatic forces, (Figure 118).

***Figure 117** Hydrodynamic forces result mainly from the afflux on the upstream wall of the house*



The force due to any afflux is proportional to the square of the velocity of the flow. Ignoring the hydrostatic force, the total force per metre resulting from 2.4 metre deep water on a wall perpendicular to the flow is approximately:

***Table A.2B** Forces on walls*

| Water Velocity metres per sec | Total Force on Wall Newtons per metre |
|---|---|
| 0.5 | 290 |
| 1 | 1,200 |
| 2 | 4,900 |
| 3 | 10,800 |

These velocities and forces are only indicative and are provided merely to give an idea of the magnitude of the forces. These forces are theoretical and can vary depending on the house shape and orientation, the spacing between houses, the general subdivision layout, and flood behaviour. As a comparison against hydrostatic forces, 2.4 metre deep water has a force around 28,400 Newtons per metre of wall.

Flowing water can also cause a reduction in the water level on other walls, principally the side and downstream walls. The resulting lower water level downstream can cause an unbalanced force on the inside of walls. These outward forces can be more damaging to a house than inward forces.

Figure 119 shows the pressures that occur around a house as determined by three-dimensional modelling of the flow around a house. These represent only the hydrodynamic pressures (i.e. the hydrostatic component is excluded) and represent a flow with an approach velocity of 1.5 metres/sec and 2.4 metres deep (eaves level of a single-storey house).

Positive pressures represent inward pressures towards the house whilst negative represent outward pressures away from the house.

Calculating all the forces imposed on a house from flowing water is complex as it depends on a number of variables. It is important to appreciate that the water velocities around a house can be very different when the house is located in a close group of houses or on its own in an open field. Any change in velocity can significantly change the pressures on the walls. This is discussed in more detail in Appendix B.

***Figure 118** Hydrodynamic effects from moving water*

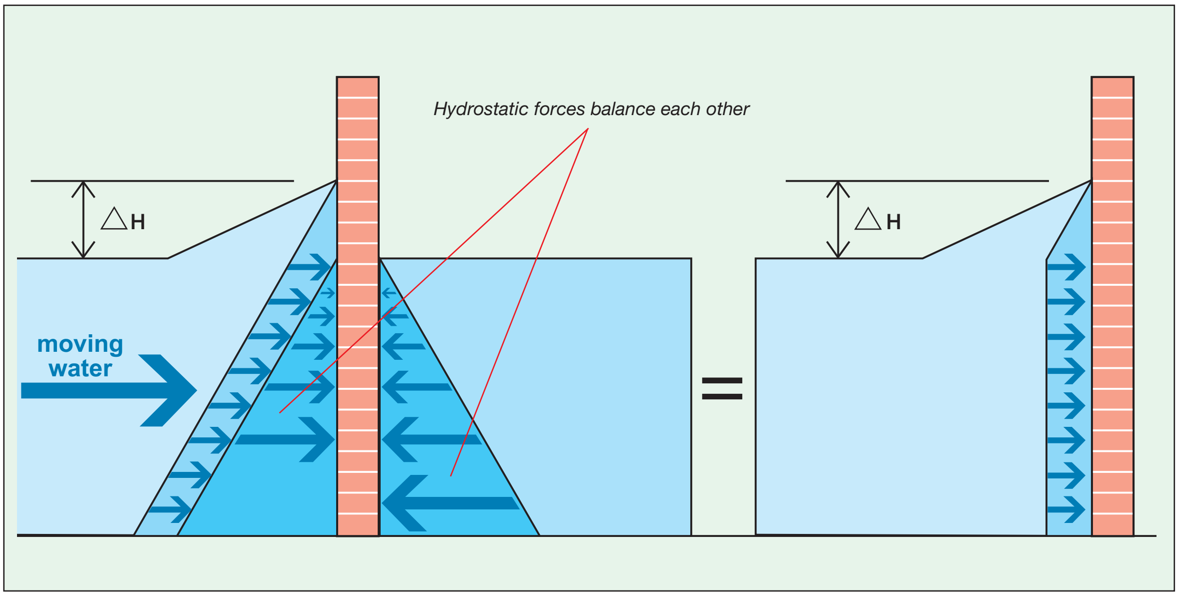
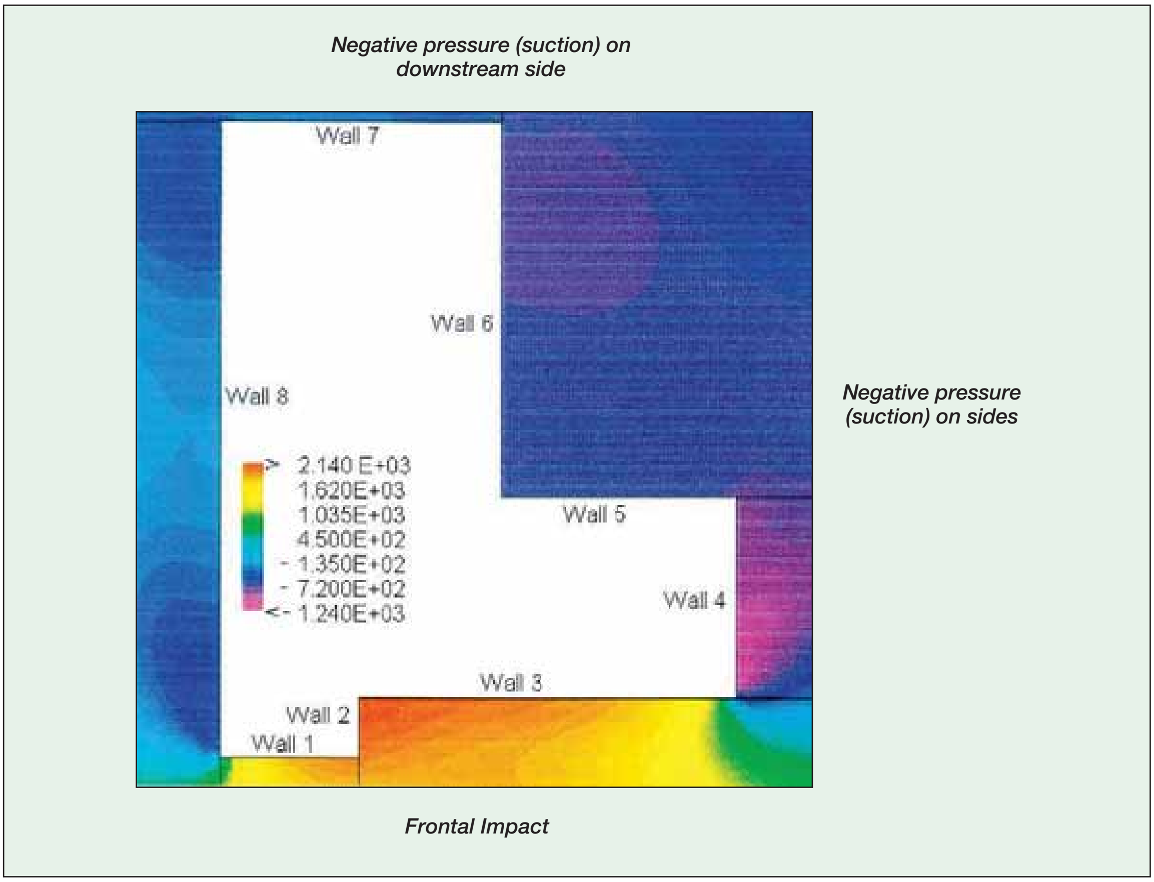


***Figure 119*** *Pressure on walls of a house due to moving water, Water 2.4 m Deep, Pressures in Pascals*




## A.3 Damage from Water Forces

This section is intended to explain the principal failure mechanisms due to both inward and outward water forces which many of the recommendations in these guidelines seek to address.

Whether the load on a wall is due to hydrostatic or hydrodynamic forces is less significant for the potential damage to a building than:

- the number and shape of openings like doors and windows,
- the direction of the load (i.e. inward or outward), and
- the leakage of walls which allows water pressure to bear on different wall components.

It is not practical to cover all the failure mechanisms in these guidelines, but the following provides a brief explanation on how wall components interact and wall failure can occur.

The external brick wall of a house consists of three structural components:

- external brick cladding,
- internal brick wall, or timber or steel frame, and
- ties between the internal and external walls.

External brick cladding provides some structural strength but is mainly for protection from the weather. The cladding is essentially freestanding and connected to the internal structure via ties (normally steel) usually placed at 600mm spacings both up and along the wall.

In full brick houses the internal structural member is another brick wall, but in brick veneer houses this is replaced with a timber or steel frame. The main structural members of these frames are vertical studs normally spaced 450mm or 600mm apart. This internal wall or frame supports the upper floor and roof structure and transmits the horizontal wall forces to the floor or footings and the other walls in the house. The frame is covered with sheeting, normally plasterboard, to provide the internal lining to the house.

The cavity between these walls provides a barrier to moisture transfer and offers some thermal insulation.

***Figure 120** Brick wall bowed inwards due to water force*

The interaction between these components is complex and depends on factors such as the ties used and the size and spacing of the internal frame members. The University of Newcastle undertook detailed research into how brick walls fail due to horizontal pressure, either inward towards the house or outwards away from the house. The findings are summarised as follows (see *"The Effects of Flood Loading on Masonry Housing"*, University of Newcastle, 2000).

### Inward forces

As an inward horizontal load on the *outside* of a brick wall increases, the brick cladding initially carries most of the load with progressive deflection and bowing of the wall likely to result in cracking along the mortar joints and even through the bricks themselves, (Figure 120). The load is also transferred by the brick ties onto the internal support structure - either an inner brick wall or wall frame. As the load increases the ties may compress, bend or disconnect and the cladding may even bear directly onto the internal support frame or wall.

The bowing or deflection may be sufficient to result in vertical cracking at locations where the wall is supported by other walls. For example, the returns at the end of the walls, (Figure 121).

***Figure 121** Vertical cracking at corner due to bowing of adjacent wall*

If the load continues to increase, the internal support will eventually fail by snapping the timber frame, bending the steel frame or collapse of the inner brick wall. Alternatively, the external brick cladding may collapse and transfer the load onto the internal frame or result in the load being applied directly to the inner brick wall.

Evaluation of the structural integrity of brick veneer and concrete block walls was undertaken by the US Army Corp of Engineers through a series of experiments on test wall panels and two houses as well as analytical computations (*"Flood Proofing Tests"*, US Army Corp of Engineers, 1998). The aim of this work was to determine the height of water loads that a building can safely support to help make decisions on acceptable methods of flood protection. An important conclusion from the test results was that it is better to allow water to enter a building than to use flood protection methods that subject it to forces that structurally damage or collapse the walls.

A summary of the tests on different types of walls can provide a useful insight on how hydrostatic loads are resisted.

- *Brick veneer wall 1 – typical end wall of a home*

  Most critical because the top plate has no roof rafter and ceiling joist restraints to transfer resistance through the wall ties to the brick veneer wall.

  Wall deflection increased considerably for small increases in water depth after water reached a 600mm height. The wall began to deflect large amounts for small increases in water load and failure occurred for sustained loading when the water depth was approximately 700mm. Lack of restraints at the top of the stud wall allowed it to continue to deflect and fail.

- *Brick veneer wall 2 – with a 900mm wide door in the centre*

  In general, the wall deflected forward toward the water loading for low water loads then backward as the water depth became greater than 240 to 480mm. The wall deflections were very small for depths up to 600 to 700mm of water above which the wall began to deflect considerably backward for small increases in water depth.

The backward deflection caused failure similar to wall 1. The lintel above the door strengthened the wall at the door opening, thereby causing the opening to have little effect on the final response of the wall.

- *Brick veneer wall 3 – identical to wall 1, but with roof rafter and ceiling joist restraints*

  Total collapse of the brick veneer wall occurred at a depth of 1.45m and at a total applied force of 850 Newtons.

  The roof rafter and ceiling joist restraints caused a changed in the failure mechanism compared to the other walls. The failure mechanism for walls 1 and 2 was deflection and failure of the brick wall, while the failure mechanism for wall 3 was beam failure of the supporting studs and a resulting collapse of the brick wall. Although the wall can withstand greater water depths, it failed suddenly and totally.

- *Concrete block wall*

  The safe water height was found to be approximately the same as for the brick veneer test wall i.e. 600mm.

- *Tests on houses*

  The tests performed on actual houses showed that 600mm of water depth is conservative and a brick veneer house can withstand approximately 900mm of water loading without damage. Wall damage occurred when loaded in excess of 1.2m. Deformation became permanent and the wall had visible cracks in the mortar joints.

**Outward forces**

When the load is due to elevated internal water levels which are not balanced, the outward load is assumed to be applied to the inside of the external cladding. In this case the ties are in tension and the cladding can no longer deflect until it rests on the internal frame or wall. Accordingly the cladding will normally collapse, or "peel away" from the house. Under such forces the ties can fail due to stretching, breaking or disconnecting from either wall or internal frame and so the connection detail is critical.

In addition to the strength of the wall components, it is also important that all members of any frame be adequately secured so that connections between the studs and the top and bottom plates are not dislodged. Section 4.3.1.2 provides more details on secure fastenings.

Vibration associated with moving water is an additional consideration as it can loosen connections especially when coupled with the reduced material strength and nail pull-through resistance due to inundation. For example, the nailed connections of hardboard sheet bracing may weaken and move resulting in a loosening of the house frame.

# APPENDIX B

## DETERMINING THE DESIGN WATER VELOCITY

While it is simple to counter hydrostatic forces by balancing inside and outside water levels, it is possible to calculate these hydrostatic forces with a reasonable degree of accuracy. Unfortunately, the estimation of hydrodynamic forces is much more complex and less reliable.

*Building in any area subject to moving floodwater should be avoided because of the increased risk to both people and property.* However, if this cannot be avoided it is wise to be conservative in the design of houses to resist hydrodynamic forces and to restrict development to land that would experience relatively low velocities.

To design for hydrodynamic forces on a house it is necessary to:

1. determine the pre-development "greenfield" velocity at the site,
2. estimate the influence on the "local velocity" of any subdivision and other obstacles surrounding the house,
3. gain some understanding of the hydrodynamic loading and assess whether the local velocity is likely to damage a house not specifically designed to resist flood flows, and
4. strengthen the house to resist these forces.

This Appendix looks at Steps 1 and 2 that demonstrate how to estimate the water velocity for which a house should be designed.  Steps 3 and 4 are covered in Appendix C.

## B.1 Greenfield Velocity

Computer modelling is commonly used in investigating flood behaviour at potential development sites and often this involves an assessment of pre and post development scenarios. Generally, the modelling results will provide a reliable estimate of the potential flood levels and flow velocities under existing conditions because physical parameters such as roughness, site topography, and flow paths are easier to determine. Sometimes results can be compared against any historical observations. However, these estimates only relate to pre-development or greenfield conditions, where in many cases the sites have been cleared and previously used for agricultural purposes, (Figure 122).

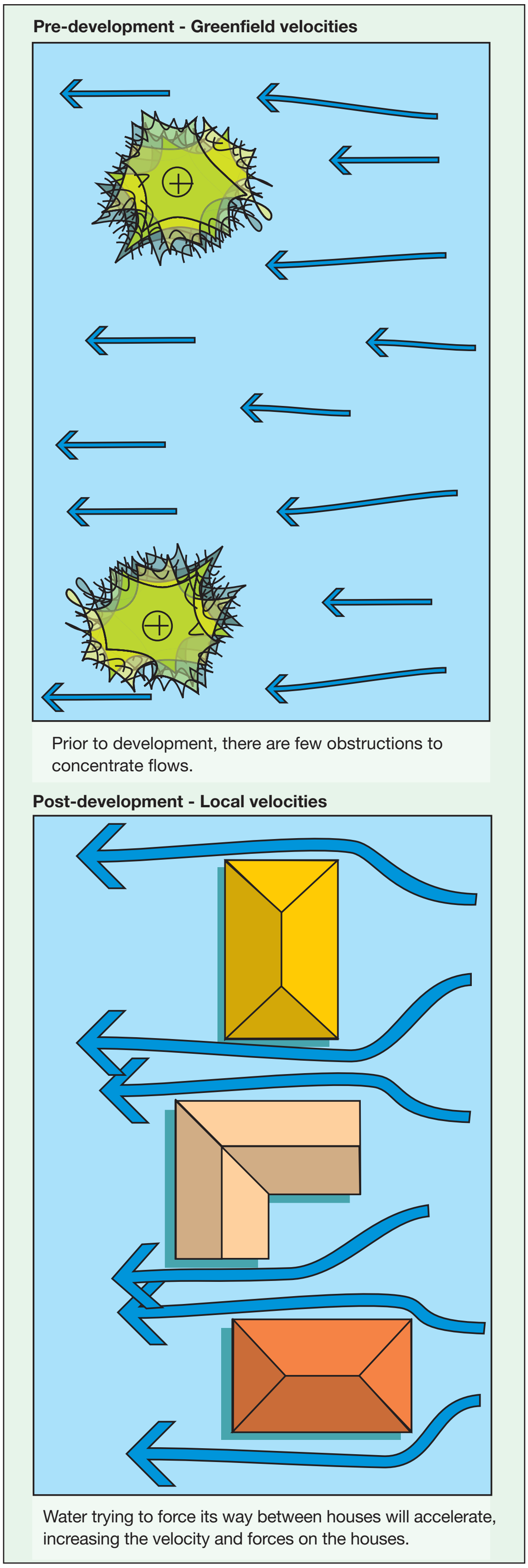
Flood behaviour is likely to change dramatically when the site is urbanised, as flow will only be possible in open spaces such as roadways, parks and recreation areas and will be restricted in between buildings, fences and vegetation. This has a tendency to increase flood heights and flow velocities.

## B.2 Local Developed Velocity

As indicated in Appendix A a house located in moving water is subjected to both inward and outward forces on the various walls and the magnitude of these forces is related to the velocity of the moving water. However, flow around a house is complex and at best it is only possible to get an indication of the scale of the likely surrounding velocity. Given the variability of local velocities around individual houses it is best to design the whole house for the more extreme velocity scenario.

For example, Figure 123 shows the velocities that occur around a single isolated house in a relatively open area with no other obstructions. This demonstrates how the flow accelerates around the house with the velocities around the house up to 60% greater than the "unobstructed" greenfield velocity.

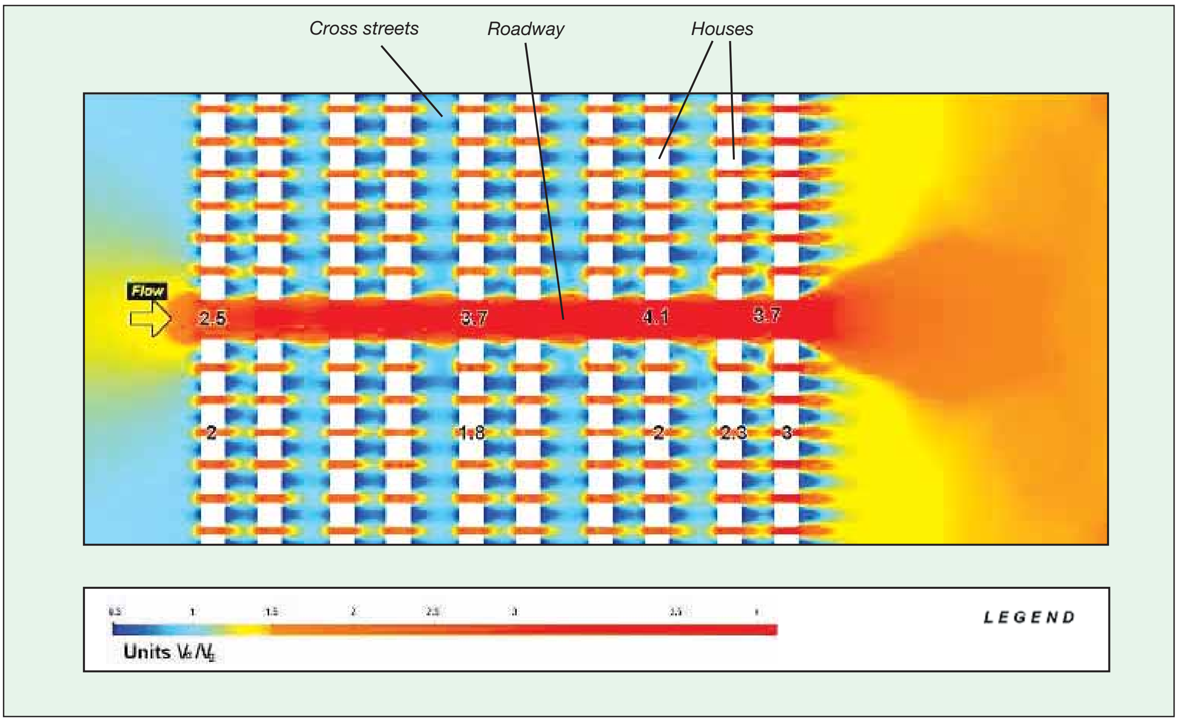
***Figure 122*** *The difference between greenfield and local velocities*




Prior to development, there are few obstructions to concentrate flows.

Water trying to force its way between houses will accelerate, increasing the velocity and forces on the houses.

***Figure 124*** *Increased velocity within developments*




For the same flood, the isolated house is subject to much lower velocities and forces than the same house surrounded by other houses in a subdivision because the obstructions severely restrict flow paths. Water trying to force its way between houses will accelerate, increasing the velocity and forces on the houses. Thus the "local velocity" between houses can be much greater than the greenfield velocity and the forces on the house are increased accordingly.

The more closely-spaced the houses, the higher the velocity. Any analysis of a site should examine the worst case likely to occur throughout the life of the house. Figure 124 shows how the velocity changes between houses and within roadways of a simple rectangular grid layout of houses.

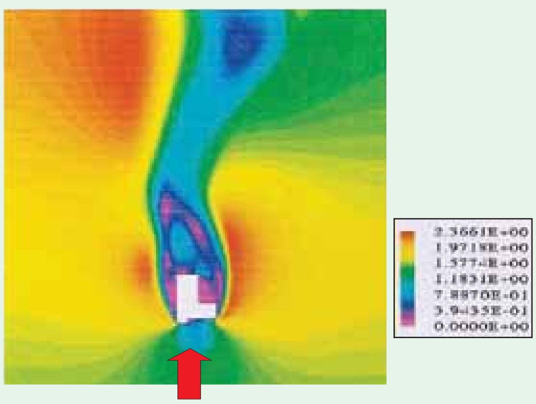
The figure plots values of Vd/Vg (i.e. developed velocity divided by greenfield velocity) with the areas of:

- light blue representing zones with velocities similar to the greenfield velocity,
- dark blue representing zones with reduced velocities e.g. directly in front and behind houses, and
- yellow to red representing zones with increased velocities e.g. in the roadway parallel to the flow and between houses.

This shows that velocities more than 4 times the greenfield velocities can be generated although results would be layout specific. In the above case, the flow passes through the development. Velocities could be reduced if a sufficient by-pass flow path was possible around the development.

Estimation of local velocities likely to occur around houses is site specific. While computer modelling may give an indication of the possible velocities, it would be expensive and only practical on a subdivision scale. In some cases, two-dimensional computer flow modelling may be undertaken by a council as part of their floodplain management risk study, which includes consideration of future development areas.

***Figure 123*** *Flows and loads on an individual house*




*Direction of flow*

Output from CSIRO flow analysis to determine structural loads around a single flooded building. The colours show differences in water velocities around the walls and corners.

# APPENDIX C

## DESIGNING FOR HYDRODYNAMIC FORCES

Appendix B refers to the interrelationships between velocities and the spacing of buildings on a floodplain and the resultant hydrodynamic forces.

This Appendix looks at an approach to resist these increased forces.

### C.1 Damaging Velocities

The ability of a house to withstand hydrodynamic forces associated with moving floodwaters depends on the type of house construction and how its components act to resist these forces.

Houses are not engineered structures in the true sense. The materials and fastening methods used in their construction suit relatively light loadings and however undesirable, there can be large differences in their quality of construction. As such the load limits to which a particular design might survive a flood would be particularly difficult to determine.

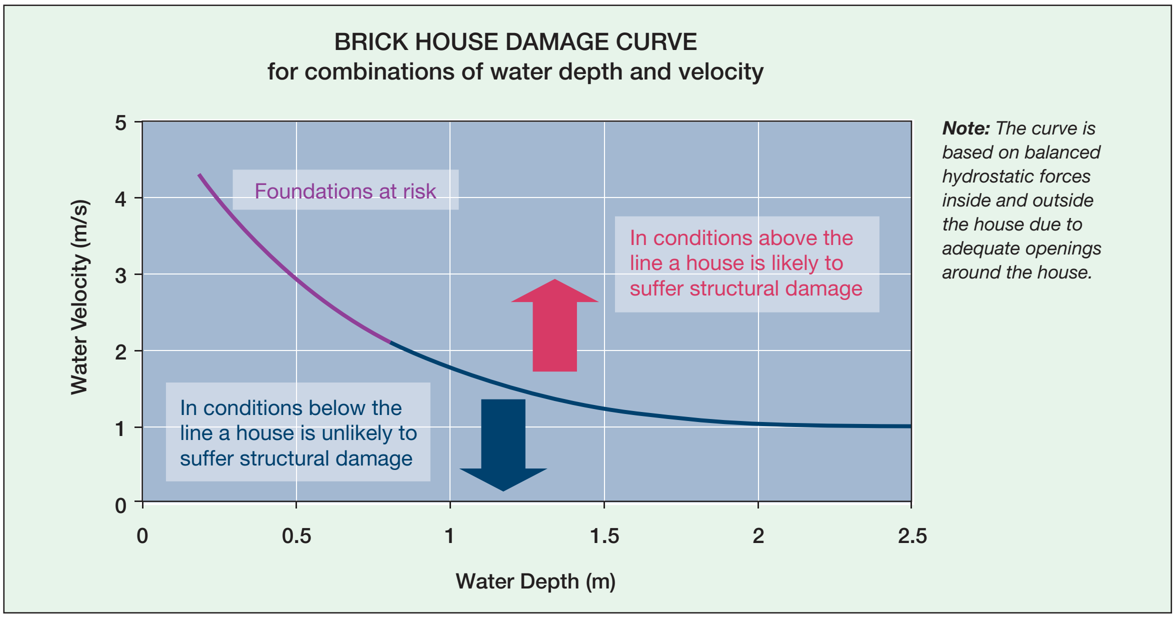
However, as a guide, Figure 125 provides an indication of water depth over the floor and flow velocity which may initiate damage to walls in a typical single storey full brick or brick veneer house.

Again, as with all structures, to maximise their performance under extreme loading conditions, it is essential that standards of construction are adequate and structural members have the capacity to attain their predicted strength. This is particularly relevant to masonry housing, where the standards of construction are poor, with lack of attention to detail, incorrect choice and installation of wall ties, and poor standards of bricklaying. This particularly applies to the batching and use of mortar, with incorrect mix proportions, the omission of lime from the mix and overdosing the mix with plasticisers to increase mortar workability. It is well documented that these practices can have a major influence on the durability and bond strength of the masonry, both important properties for long-term performance.

The hydrodynamic load on the walls increases as the velocity or water depth or both increases. For example, a house with water flowing at a velocity exceeding 1.5 m/s, half way up the wall (or approximately 1.2 m deep) could suffer damage to the cladding and/or frame.

Clearly traditional brick veneer houses have limitations and are unsuitable in locations of high velocity. Consent authorities are likely to prohibit, or at least severely restrict, house construction in areas where local velocities exceed 2 m/s for shallow flooding and around 1 m/s where deeper flooding is possible.

***Figure 125*** *Water velocities may cause severe damage to a brick house*



In areas where large flood loadings are expected, the use of partially reinforced single skin hollow clay or concrete masonry construction could be investigated. This system is widely used in Northern Australia in cyclonic regions, with the partial reinforcement providing extra strength and resilience against lateral loads. The added attraction of using single skin construction in flood areas is the potential to minimise post-flooding clean up problems due to the lack of a wall cavity.

## C.2 The Wind/Water Design Approach

No provision is made in the majority of timber framed houses in flood prone areas to account for the higher dynamic forces from moving floodwaters. It is also not practicable for each new house to be subject to a detailed investigation and design to accommodate these abnormal conditions.

In response, the CSIRO has developed an approach to designing houses to resist moving water by equating it to the forces generated by an equivalent wind velocity. Research shows that wind and water create similar forces on the walls of a house. This approach could be adopted in the interim until more research and knowledge become available. It is simple to introduce as the building industry already has an effective procedure for designing the frame of a brick veneer home to resist wind loading.

Australian Standard AS 4055 - "Wind Loads for Housing" adopts a ten-band wind classification system N1 to N6 for non-cyclonic regions and C1 to C4 for cyclonic regions so designs will adequately cover the different wind velocities.

The non-cyclonic N classification system best applies to water velocity and the following wind and water velocities (Table C.2A) create similar wall forces.

***Table C.2A** Wind Velocity Classification and Equivalent Water Velocity*

| Wind Classification AS 4055 | Maximum design gust wind velocity | | Equivalent maximum water velocity* | |
|---|---|---|---|---|
| | m/s | km/hr | m/s | km/hr |
| N1 | 34 | 122 | 0.8 | 2.9 |
| N2 | 40 | 144 | 1.0 | 3.6 |
| N3 | 50 | 180 | 1.2 | 4.3 |
| N4 | 61 | 220 | 1.5 | 5.4 |
| N5 | 74 | 266 | 1.8 | 6.5 |
| N6 | 86 | 310 | 2.1 | 7.6 |

**velocities are based on ultimate limit state design*

Publications including Australian Standards AS 1684 "Residential timber-framed construction" and AS 3700 "Masonry structures" as well as a number of manuals produced by various building material associations are useful in designing for wind loads and designing for the equivalent water velocity.

Table C.2B indicates which basic N classification should be used to design the house, based on the elevation of the house and the water velocity. This classification uses a < 0.001 probability of failure (i.e 1 in every 1000 houses may fail) and may need to be modified in accordance with advice under "Further Considerations" later in this Appendix.

***Table C.2B** Basic Wind/Water Classification Determination*

| Flood Return Period at eaves level (years) | Water Velocity (metres/second) | | | | | |
|---|---|---|---|---|---|---|
| | Up to 0.8 | 0.8 to 1.0 | 1.0 to 1.2 | 1.2 to 1.5 | 1.5 to 1.8 | 1.8 to 2.1 |
| 0 to 100 | N1 | N2 | N3 | N4 | N5 | N6 |
| 101 to 200 | N1 | N2 | N3 | N4 | N5 | N6 |
| 201 to 500 | N1 | N1 | N2 | N3 | N4 | N5 |
| 501 to 1000 | N1 | N1 | N1 | N2 | N3 | N4 |
| 1001 to PMF | N1 | N1 | N1 | N1 | N2 | N3 |

*Table C.2B should be read in conjunction with "Application of this Design Procedure and Cautionary Notes" at the end of this Appendix*

This approach provides a reasonable level of protection against the added hydrodynamic forces of moving floodwaters. As in the case of strong winds, some damage may still occur due to more localised conditions and other factors such as debris loads.

## C.3 Determining the Appropriate Flood Return Period

To apply Table C.2B determine:

- the two flood return periods between which the eaves of the house are located, and
- the flood velocity at the site for above two flood return periods.

In most cases, the local council should be able to provide the flood levels for the 100 year and PMF flood events or at least reasonable estimates of these levels.

The eaves level is adopted for this procedure as water reaching the level of the eaves usually produces the maximum loading on the walls of the house. With increasing depth, the water begins to flow over as well as around the house and the associated three-dimensional flow patterns result in decreased wall pressures.

Different return periods are used in the table as this provides each house with approximately the same probability of failure in a flood (as opposed to probability of the flood occurring). This means houses which have lower floor levels are more likely to flood but, using this procedure, are also designed stronger to resist the forces that occur in a flood. Similarly, the higher the house is, the less strong it will need to be to resist the forces from rarer floods.

With two-storey or multi-storey houses, the higher eaves level means that in reading Table C.2B, such houses would end up with an inappropriate lower level of protection than a single storey house with the same floor level. To correctly apply Table C.2B for multi-storey houses, the ground floor ceiling level should be used instead of the eaves level to determine the lower storey N classification .

The average velocity of floodwaters usually increases proportionally with the depth of flooding. However, in some floodplain terrains, the velocity may actually decrease at greater depths. Allowance should be made for these variations when designing residential development of two or more storeys.

The following can be used as guidance when determining the appropriate N rating(s) for two or more storey dwellings:

- When the velocity at the eaves is higher than the velocity at the intermediate floor level, the design of both the lower and upper storey(s) should adopt the N rating applicable to that higher velocity.
- When the velocity at the eaves is lower than the velocity at the intermediate floor level, the design of the lower storey should adopt the N rating applicable to that higher velocity. The design of the upper storey(s) may adopt a lesser N rating appropriate for the lower velocity.

## C.4 Determining the Appropriate Design Velocity

Some councils may be able to provide an indication of the flood velocity at a particular site. This will usually have been determined by computer modelling and represent “greenfield” velocity prior to development.

In some cases the council may even be able to provide an estimate of the velocity at a particular site for each of the return periods in Table C.2B. It is recommended that the velocity be estimated for a flood at eaves level be obtained by using a pro-rata basis between the two adjacent return periods (see C5).

It is necessary to check whether this “greenfield” velocity is likely to increase as a result of the interaction with the surrounding houses. The velocity that is used in Table C.2B is the “developed” velocity which is usually higher than the greenfield velocity.

## C.5 Example of N Classification Determination

Assume there is a site with the following conditions as illustrated in Figure 126:

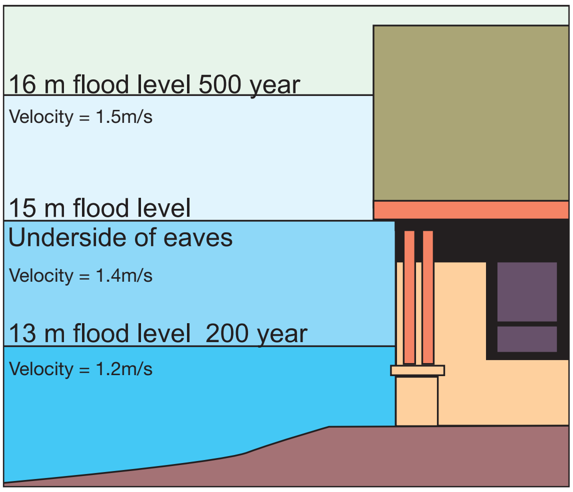
***Table C.5*** *Greenfield velocities and flood level*

| Flood Event | Flood Level (m AHD) | Greenfield Water Velocity (m/s) |
|---|---|---|
| 1 in 100 AEP | 8 | 1.0 |
| 1 in 200 AEP | 13 | 1.2 |
| 1 in 500 AEP | 16 | 1.5 |
| 1 in 1000 AEP | 17 | 1.6 |
| PMF | 18 | 1.8 |

The level of the eaves of the single storey house is assumed to be 15 metres AHD. Hence the eaves of the house fall within the 1 in 200 to 500 AEP. As 15 mAHD is two-thirds of the way from 13 mAHD to 16 mAHD, in the absence of better information we will assume the greenfield water velocity at the eaves is two-thirds of the way from 1.2 m/s to 1.5 m/s i.e. 1.4 m/s.

Furthermore, assume that modelling of the subdivision suggests that the local velocity around the house is about 1.3 times the greenfield velocity. Hence the velocity to be used in Table C.2B is 1.3 x 1.4 = 1.82 m/s.

***Figure 126*** *Example of how velocity can be estimated to select a suitable N-classification*




Using the appropriate return period range and water velocity in Table C.2B, the basic N classification that applies is N5.

*Note: Building in locations with such a high velocity should be avoided wherever possible. Despite an additional 10% cost to build a N5 house, rather than the more common N1 or N2 house, there is no guarantee that serious damage will not occur in a flood. Variables such as the probability and size of floating debris is difficult to allow for. As the debris forces are roughly proportional to the square of the water velocity, the same debris for example produces four times the force in water moving twice as fast.*

## C.6 Further Considerations

The recommendations in this Appendix address the issue of increasing the N classification to account for the loss of strength of certain materials and construction methods due to immersion. Materials and construction methods are addressed in more detail in Section 5 of these guidelines.

### C.6.1 Flood Affected Materials

Due to the reduction in the strength of certain materials when wet, the basic N classification obtained from C.2B requires some modification to accommodate the use of such materials.

The procedure is directly applicable to steel framed brick-veneer houses. However, full brick and timber framed brick-veneer houses should be built to a standard one classification higher e.g. N4 instead of N3.

In general, structural components of various materials would be designed or selected according to the basic construction classification modified as indicated in Table C.6.

***Table C.6** Modification of N classification for construction materials*

| Construction Material | Modified N Classification |
|---|---|
| Steel, concrete and fibre cement | Basic N classification |
| Timber, timber composites, plywood and masonry | One classification above the basic N classification |
| Hardboard bracing * | Two classifications above the basic N classification |

** Note that hardboard bracing is vulnerable to damage in a flood, particularly when immersed for any length of time and when subjected to flowing water. As covered in Section 5.4.3, the use of hardboard bracing is generally not recommended in houses liable to be flooded.*

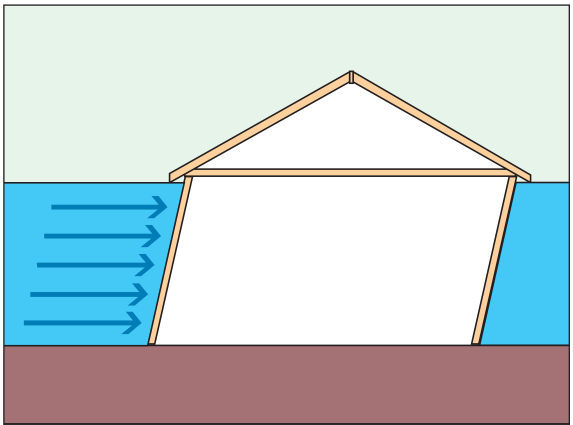
### C.6.2 Roof Design

As mentioned, maximum wall loads occur when the water is at eaves level. Having determined the appropriate N classification on that basis, it is permissible to use the same N classification to design the roof members.

### C.6.3 Racking Forces and Wall Bracing

Racking forces are those which occur in walls parallel to the wind or water direction and require wall bracing to resist (Figure 127).

***Figure 127** Racking forces on a house*



Bracing is required to resist "racking" distortion due to horizontal loads. Without suitable bracing, walls and posts are unable to remain vertical to support the roof and upper floor loads.

Racking forces can generally be reduced by orientating the house along the water flow i.e. to have the least area facing the flow.

The N classification for these components will need to be increased to account for the materials used as indicated in this section.

In normal construction, AS 4055 permits wall linings to be considered as providing some of the structural bracing requirements. However, because of the loss of strength of plasterboard and other linings when wet, it is recommended that 100% of bracing be provided by the purposely designed structural bracing. In addition, some sheet materials traditionally used for structural bracing fixed to the outside of the frame lose strength when immersed and alternatives should be used.

If water affected bracing is used, then it should be modified according to Table C.6. For example, where moisture resistant plywood bracing is used, it should be designed to an N classification one classification higher. Alternative materials, which meet a performance requirement of providing a specified level of resistance after 96 hours immersion in water, would also be acceptable.

Where the maximum N6 basic classification is required, there is no opportunity to use a higher classification so water affected materials should be avoided. The use of some materials will require special design.

#### Sub-floor bracing

Sub-floor bracing is diagonal bracing in the vertical plane attached to posts and stumps supporting the house.

As a consequence of the loss of strength of immersed particleboard* and strip flooring, sub-floor bracing units should be evenly distributed, with the spacing between parallel bracing units, or sets, not to exceed:

- 1.7 times the overall floor width or 10 metres maximum for platform floors, and
- 1.1 times the overall floor width or 6.7 metres maximum for fitted floors.

** Note: alternatives to particleboard flooring should be considered for houses built in flood prone areas.*

### C.6.4 Multi-Storey Houses

The same house dimension limitations apply as those included in Section 6 of AS 4055-1992 "Wind loads for housing". Basically it applies to typical houses of one or two storeys with the underside of the eaves not greater than 6m above ground level and the highest point of the roof not greater than 8.5 m above ground level. However, reference should be made to AS 4055 for details.

Houses not conforming to the constraints identified in AS 4055 should be subject to a special design.

### C.6.5 General Strengthening Details

This procedure covers the main structural design of the house. However, in minimum N1 classification sites some details can be incorporated in normal building practice to strengthen walls with little additional cost. These will improve the capacity of a traditional house to withstand the pressure from relatively low velocity and shallow floods. These are discussed in Sections 5.3 and 5.4 of these guidelines.

For example, nail plate connectors are preferred to strengthen the traditional practice of skew nailing between studs and top and bottom plate in timber construction. This strengthens the capacity to transfer water pressure from the walls into the floor and ceiling. Similarly the use of medium or heavy duty brick ties firmly fixed to the side of the studs can reduce the chance of the cladding peeling from the frame.

## C.7 Application of this Design Procedure and Cautionary Notes

As previously noted, houses designed using AS 4055 (and houses in general for that matter) do not constitute fully engineered structures. Fully engineered structures are reliable but expensive. Housing designed using AS 4055 usually will have adequate resistance to wind loading but due to the nature of the house building industry, the level of reliability will not be the same as that of commercial/industrial buildings.

As well, traditional houses are unsuitable for extreme conditions as is often demonstrated by extensive damage following storms, cyclones, floods etc. There are also too many factors which influence the strength of the house (and in some cases a wide range of load conditions) to be able to provide definitive advice on whether a house will survive a flood.

The wind/water design approach provides a method to increase the likelihood that residents will be able to reoccupy their houses after flooding where there is an additional hazard from moving floodwaters.

Preferably it is only applied in areas where development is of a small scale e.g. infill developments. At this stage, it is not considered appropriate to use Table C.2B to warrant large-scale developments in flood flow areas, and in particular those subject to the higher velocity range.

Building traditional houses in areas where deep flooding and high velocities occur is possible (using designs based on the N4 to N6 classifications), but not recommended. If this is unavoidable then determination of alternative construction or barriers to reduce velocities should be considered.

While comparisons are frequently made to houses that have survived past floods, what is often overlooked is that the buildings, compared to modern houses, are significantly different. Older buildings tend to be more conservative in design and of heavier construction e.g. hardwood framing with thick weatherboard planks which can be durable and have high impact strength.

Modern houses make use of materials in a much more cost-effective manner, and for the vast majority of houses, their performance under flood conditions could lead to structural failure. Problems arise because of two key factors. Water not only subjects buildings to unusual and higher structural loads, but it can also substantially weaken the components which are relied on to withstand these loads. The use of low technology materials in the older houses has in many cases provided them with an advantage of greater durability in floods and often a higher factor of safety as well.

This design procedure covers only the forces imposed by the moving water itself. It is possible that the water will be carrying floating debris, which have the potential to cause significant damage or destroy a house.

## C.8 Designing for Impact Forces

The following examples indicate a method for calculating impact loading:

Assume an object of 450 kg mass moving in water at a velocity of 0.5m per second and impacting on a building at an angle perpendicular to the wall.

**Impact force:** is calculated by multiplying the mass times the initial velocity divided by the duration of impact (or deceleration). The duration of impact is usually assumed to be one second.

$$F1 = \frac{MV}{t}$$

$$= \frac{450 \times 0.5}{1}$$

= 225 Newtons acting on any $0.1m^2$ of surface of the submerged area normal (perpendicular) to the flow.

Where F1 is the normal impact load in Newtons

M is the mass of object in kilograms

t is the time of impact (assume 1 sec)

V is the velocity of flow metres per second

**Special impact force:** 140 kg per metre of length normal to the flow, assume the structure is 10 metres wide.

$$F1 = \frac{MV}{t}$$

$$= \frac{140 \times 10 \times 0.5}{1}$$

= 750 Newtons acting on any 0.3m wide strip of submerged area for the length of the structure.

Where F1 is the normal impact load in Newtons

M is the mass in kilograms per metre length

t is the time of impact (assume 1 sec)

V is the velocity of flow metres per second

# APPENDIX D

## LIMITATIONS

### D.1 Materials and Design

The information contained in these guidelines is based on observations, industry knowledge, research and testing as well as expert opinion. The recommendations on the use of certain materials or products are based on the above research as they are currently manufactured and applied. There is an increasing range of building products available on the market and with a performance-based building industry, there would be no point in evaluating all products for the purpose of these guidelines. Evaluations of the more common building materials are to illustrate relevant issues which will enable the industry to respond with products and building techniques to improve the performance of buildings both during and after a flood. Most of the products and materials could have their flood resistance improved with minor modifications.

Manufacturers should be consulted regarding the performance of their products during and after water immersion.

These guidelines suggest that some materials or products are likely to suffer from immersion, which could result in structural damage. If considering the use of such materials and products there is a need to weigh the probability of severe flood events against the cost of repair. Importantly, the initial cost and difficulty of repairs should also be considered. If the cost of a better performing material is marginal and the difficulty and expense of replacing it after a flood is high (e.g. platform flooring and wall bracing), then major gains can be achieved for little extra cost.

Similarly, the suggestions for design and construction detail to minimise structural flood damage are aimed towards assisting householders to return to their house more quickly. However, there remain many other alternative ways to achieve this aim. It is the responsibility of those applying these guidelines to ensure the requirements of local councils, appropriate codes and accepted building practice are met. The intention of these guidelines is to highlight the problems and provide principles which, if followed, should provide improved protection against damage or failure.

Due to the extensive range of house designs, material applications and a wide variation in flood hazard, no assurances can be made that any recommendations contained in these guidelines will ensure that no damage or failure of components occurs in a flood.

## D.2 The Brick House Damage Curve (see Figure 125)

Appendix C contains a curve showing failure of a typical brick wall under horizontal loading imposed by flowing water. This curve was developed in response to a lack of information relevant for modern brick houses.

Previously, two curves that have been widely used to provide an indication of when house failure may occur due to moving water are:

1. that given in Appendix L of the Floodplain Development Manual (April 2005), and
2. that derived by Richard Black of Cornell University in New York (1975).

The former curve, based on that used by the United States Army Corps of Engineers over 30 years ago, indicates that damage to light structures is possible when the velocity (m/s) times the depth (m) is greater than 1 i.e. VxD>1. There are also limits of a maximum velocity of 2 m/s and a maximum depth of 2m.

The latter curve principally relates to light structures and considers the flotation of lightweight timber-framed houses from pier foundations. Black's work is based on estimates of the horizontal force (and the associated

***Figure 128*** *A floated house typical of that assumed for Black's curve*

water velocity) required to slide a weatherboard house off its piers as this type of flooded house becomes increasingly buoyant with rising water levels. Figure 128 shows the type and approximate size of the house and failure mode to which Black's curve applies. This curve is very house specific and applies only to a house 32 feet long by 24 feet wide (or 7.7 squares) orientated with its long side facing the flow. Rotating the house 90º significantly changes the water velocity required to slide the house. Also a subsequent report by Cornell University (Sangrey et al) suggests Black's curve underestimates the water force by adopting a lower than usual drag coefficient.

Black includes a curve for a brick veneer house but this still assumes flotation/sliding as the mode of failure and simply adds additional weight to allow for the brickwork.

More information on the Black curve can be found in Cornell University reports:

- *"Flood Proofing Rural Residences"* by Richard D Black, May 1975
- *"Evaluating the Impact of Structurally Interrupted Flood Plain Flows"* by D. Sangrey, P. Murphy & J. Nieber, October 1975

Whilst the Black curve may have been appropriate for a rural North American house at that time, it is not considered applicable to modern slab-on-ground brick houses because:

- the curve is very house, and even orientation specific,
- the house size is much smaller than contemporary houses (around 25 squares),
- mode of failure by flotation is not relevant,
- failure of slab-on-ground brick houses is due to collapse of the walls rather than flotation.

The curve given in Appendix B was developed specifically for modern brick houses and utilised 3-dimensional computational fluid dynamics (CFD) computer models to estimate positive (inward) and negative (outward) pressures on individual walls of a house located in flowing water. Using these pressures, another computer model determined at what velocities the individual components of a “standard” brick veneer and full brick wall may exceed their characteristic strength. The results of this modelling by the University of Newcastle were used to produce an envelope of curves covering brick veneer, full brick, inward loading, outward loading, etc. The damage curve in Appendix B represents the lower limit of this envelope and provides a prediction as to when some form of failure is likely to occur. Failure of a wall could mean anything from serious cracking and/or bowing to collapse of a wall. The pressure redistribution associated with the loss of a wall could lead to progressive collapse of other walls or perhaps the collapse of the roof.

As the mode of failure and house types assumed in both the earlier curves are different to the curve in these guidelines, comparison of the three curves is not strictly valid. However, the curve included here indicates a lower velocity is required to cause damage than that derived by Black and higher than that in the Floodplain Management Manual.

As with many design aids, certain assumptions have been made in developing this curve and it is considered indicative rather than definitive. However, it is believed to be considerably more representative of the failure of modern Australian brick houses then the other curves and provides a good basis for further research into this issue.

## D.3 Use of N Classification for Water Velocity Design

Appendix C of these guidelines contains a procedure to assist with designing brick houses to resist the forces associated with flowing water. By equating water forces to wind forces the procedure allows the house designer to determine the appropriate wind classification to use (N1 to N6 as outlined in Australian Standard AS 4055) to resist hydrodynamic forces. The N classification needs to be modified to allow for the loss of strength of some components during and after immersion.

By using the wind classification system, already understood and adopted by the building industry, this procedure greatly simplifies the process of designing a house to resist water forces.

Notwithstanding the effort in developing this procedure, further input would be required before it could be considered appropriate for mandatory implementation. Nevertheless this is a simple procedure which addresses the need for a higher level of protection against the forces of moving floodwater. Again, because of individual circumstances, variation in flood behaviour and quality of construction, there is no certainty that damage will not occur if this procedure is followed. Special designs should be undertaken in cases where a higher level of assurance is required, flood conditions are difficult to determine, or where required by council.

# GLOSSARY

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| Annual exceedance probability (AEP) | The chance of a flood of a given size or larger occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of $500m^3/s$ has an AEP of 5%, it means that there is a 5% chance (1 in 20) of a peak flood discharge of $500m^3/s$ or larger occurring in any one year (see average recurrence interval). |
| Australian Height Datum (AHD) | A common national surface level datum corresponding approximately to mean sea level. It is used to measure height above sea level throughout Australia. |
| Average recurrence interval | The long-term average number of years between the occurrence of a flood the same size as, or larger than, the selected event. For example, flood 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. |
| Articulation joint | A vertical joint placed in a masonry wall to minimise uncontrolled cracking due to foundation movement. The joint divides walls into panels to accommodate movement of the footings by allowing the joint to open and close. |
| Autoclaved aerated concrete | A light-weight concrete manufactured from sand, lime and cement which has been aerated to produce small finely dispersed air spaces and then steam cured under high pressure. Supplied in small blocks as well as reinforced panels that are used for walls, floors and roofs. |
| Batter | A slope, such as the outer face of an embankment, that recedes from the bottom to top. |
| Bearing capacity | The ultimate value of the contact pressure between a foundation mat or footing and the soil which will produce a shear failure within a soil mass. All stability in soils is derived from shearing strength. The soil slips in a complete downward, sideward and upward movement, and allows the footings to settle as a result of the displacement of the bearing material. |
| Blockwork construction | Construction method using concrete building blocks which are usually hollow. |
| Bottom plate | Horizontal member at the base of the wall frame. |
| Bowing | Bending of a wall due to water forces that can result in cracking or even collapse of the wall. |
| Bracing | Bracing is required to prevent racking and distortion of the wall frame due to sideways pressure. Two main forms are steel-strap/angle bracing and sheet bracing. Sheet bracing is used in confined areas such as beside windows or at the corner of a wall. |
| Brick ties | Metal ties built into brick walls at regular intervals to link internal and external portions of a cavity brick wall. |
| Buoyancy forces | Vertical uplift force due to water pressure on horizontal or sloping surfaces such as floors which can lead to a house floating in extreme circumstances. |
| Cladding | Any material used to face a building or structure. |
| Concrete panel housing (CPH) | Comprises external and often internal walls made of vertically positioned concrete panels. CPH is either pre-cast on site (tilt-up construction) or made at a factory (pre-cast construction). |
| Cross-flow ventilation | Flow of air into and out of an enclosed space. |
| Cupping | Where the edges of a timber board (e.g. floorboards) lift and leave a concave centre. |

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| Cut and fill | Earthworks used to provide a level area on a sloping site, where part of the sloping surface is cut away and used to provide fill on the portion of the slope immediately below it. |
| Cut-in flooring | Method of construction where the building's frame and bottom plate are not placed over the floor sheeting (compare platform flooring). |
| Dado rail | A horizontal portion of timber on an internal wall usually concealing the join of two different forms of lining (e.g. timber panels and plasterboard). |
| Damp course or damp-proof course | A waterproof membrane built into brickwork or masonry (usually bitumen-coated aluminium, copper or lead) to prevent moisture rising above. |
| Dead load | A permanent, inert load on a building or other structure due to the weight of its structural members and the fixed loads they carry. |
| Debris or impact forces | The forces acting on buildings and structures when struck by floating objects carried by floodwaters e.g. logs, storage tanks, cars. |
| Differential movement or differential settlement | Refers to uneven settlement of foundations (the soil formations on which a building is constructed) due to influences such as moisture and loadings imposed upon them. Differential movement creates stresses in walls which usually cause cracking. |
| Differential pressure | Net pressure on a wall due to different water levels inside and outside a house. |
| Dry flood proofing | Preventing water from entering a house by using a variety of methods such as seals, walls and levees. |
| Engaged pier | A column (usually bricks) supporting floor beams or bearers, which is then attached to the wall. |
| Engineered timber beams | Manufactured alternative to solid timber beams used for suspended floors. Examples include glued I-beams, timber trusses with metal plate connectors, metal web timber trusses and laminated timber veneer beams. |
| Expansive soil | Soil is described as expansive when it undergoes appreciable volume change as a result of changes in moisture content. This volume change occurs as shrinkage upon drying and swelling upon wetting. |
| Extreme or severe flooding | Where extensive urban areas above a reasonable flood planning level are flooded with severe consequences. |
| Floating timber floor | Non-structural floor covering which is placed directly over a suspended floor or slab as an alternative to tiles or carpet. |
| Flood Planning Levels (FPL) | Are the combinations of flood levels and freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. Usually they relate to the minimum floor level for control of development in a flood prone area. |
| Flood prone land | Land which is likely to be flooded by the probable maximum flood (PMF) event. Flood prone land has the same meaning as flood liable land. |
| 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 damages. (see "dry" and "wet" flooding proofing). |
| Flood of record | The highest flood recorded. Note that flood records are only available for floods since European settlement, though there may be evidence of higher floods having occurred in years prior to settlement. |
| Flood risk | The possibility of something happening to people and/or property as a result of flooding. It is a function of both the likelihood of flooding and its consequences. |

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| Floodplain | Area of land which is subject to inundation by floods up to and including the probable maximum flood event. |
| Foundation material | The material (fill or natural ground) upon which the footings or slab of a building are constructed. |
| Geotextile fabric | These fabrics are available as woven and non-woven types for many different soil engineering applications. The fabric can distribute local soil stresses and increase bearing capacity through its high tensile strength properties or to allow water to pass through the porous fabric while preventing soil loss in retaining walls and drainage systems. |
| Greenfield velocity | Water velocities (usually average velocity) associated with flood behaviour on a site prior to urbanised development, generally in a cleared state for agricultural purposes. |
| Hardboard | A hard wallboard of highly compressed fibre. |
| Hydrodynamic water forces | Pressure exerted by flowing water. |
| Hydrostatic water forces | Pressure exerted by still water. Because these forces are caused by the weight of water, it increases as the depth of water increases. |
| Insulation | Material used in roof or wall cavities as a thermal or sound barrier. The two types of insulation are bulk insulation (such as “wool” batts or polystyrene) and reflective insulation. |
| Intermediate floor | Any floors above ground floor comprising a suspended floor. |
| Levee | Any form of barrier such as an embankment or wall constructed to restrict or control the passage of floodwaters. |
| Lining | The covering of the walls and ceiling of the interior of a building (the most common example is plasterboard). |
| Live load | The load arising from the intended use or purpose of the building or structure (e.g. furniture, contents and people), but excluding wind, flooding or earthquake loads. |
| Local velocity | Water velocity at a particular location or vicinity, which may be influenced by site conditions e.g. buildings or constrictions. |
| Local overland flooding | Inundation by local run-off rather than overbank discharge from a stream, river, estuary, lake or dam. |
| Mainstream flooding | Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam (compare to overland flooding). |
| Medium density fibreboard (MDF) | A type of hardboard made from fine particles of wood fibres glued under heat and pressure. |
| Moisture traps | Areas of a house where water and moisture can be retained following flood such as wall cavities, recesses, intermediate floors, and the sub-floor. |
| Mortar | A composition of lime and/or cement and sand mixed with water in varying proportions to bond bricks. |
| N classification | System used to design buildings to resist wind loads (AS 4055 “Wind Loads for Housing”). Now adapted by CSIRO to help design buildings for varying water velocities. |
| Nail plate connectors | A steel plate with a collection of spikes or nails projecting from one face which are pressed into timber laid end to end to form a joint. |
| Nail pull through | Resistance of sheet bracing to failure around the nail fixing to the timber frame. |

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| Nogging | A horizontal piece of timber fixed between the studs in a framed wall. |
| Period of inundation | Duration of a flood event above a point of reference (e.g. lowest point on the floodplain). In the Hawkesbury-Nepean a 1 in 100 AEP flood will have a 4-7 day period of inundation. |
| Pier and beam | Where the structure is carried on reinforced concrete beams supported on reinforced piers. These piers are anchored in a deeper zone of the foundations where moisture content is stable and movements are insignificant (or in a deeper stratum of stiff clay or rock), when the foundations closer to the surface are not capable of carrying the applied loads safely. Also used when there is variation in soil types across a site or when fill is used. |
| Piping failure | Occurs when water percolates through a soil embankment to a free surface at the downstream base of the embankment, carrying soil particles that are free to migrate. If the pressure causing this seepage is high enough and the pore spaces in the material become large enough, erosion can develop at the downstream side and work progressively through the embankment developing into a stream of liquefied water and particle mixture – moving through the surrounding soil as if it were flowing through a pipe. |
| Plasterboard | A rigid lining board made of gypsum plastercore material encased on both sides by heavy paper cover. |
| Platform flooring | Method of construction where the floor sheeting is laid as a continuous surface over the supporting joists and the wall frame is constructed on top of the completed floor (compare to cut-in flooring). |
| Pore water pressure | When water is trapped in saturated granular soils the pore fluids exert pressure on the surrounding structures such as embankments or walls. |
| Probable Maximum Flood (PMF) | The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum participation. The PMF defines the extent of the flood prone land i.e. the floodplain. |
| R-value | Thermal rating for insulation. |
| Racking forces | Longitudinal sideway forces along the wall, which can force a stud wall to become out of shape and out of plumb. |
| Raft slab | A concrete floor slab foundation designed with an integrated edge and internal beams to support the full load of the building structure above it. |
| Rate of rise | A measure of how quickly a flood rises, usually in metres per hour. The rate of rise is based on historical records or flood studies. |
| Render (cement) | The covering of a brick or masonry wall surface with a hard cement mortar finish. |
| Riser | The vertical board under the tread of a stair. |
| Run off | The amount of rainfall which actually ends up as a stream flow. |
| Sarking | A covering of waterproof building paper beneath the external roof covering or in wall cavities. |
| Single skin brickwork | One vertical layer of brickwork (i.e. brick veneer) as compared to double brick construction. |
| Slump | Collapse of a material due to immersion, particularly cohesive soil as referred to in these guidelines. |
| Span | The clear horizontal distance between the supports of an arch, beam, truss or roof. |

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| Strip flooring | Tongue and groove timber floor boards laid over the top of floor joists after the erection of the walls. |
| Structural damage | Damage to key components of a building which affect the load bearing capacity of the structure and can led to major repairs or even collapse of the house. It does not include damage to contents and fittings. |
| Studs | The vertical structural units in a timber or steel wall frame. |
| Sub-floor area | The area underneath the floor of a house with a suspended ground floor. |
| Sub-floor vents | Vents in the wall to create air flow in the sub-floor area. |
| Suspended floor | Flooring raised above the ground level (i.e on piers and stumps) or on intermediate floors supported on walls. |
| Timber durability | Indicates natural durability and relates to the resistance of the heartwood of the timber species to fungal and insect (including termite) attack. Ranges from Class 1 (highly durable – lasting 25-50 years) to Class 4 (low durability – lasting less than 5 years). |
| Top plate | Timber member placed horizontally at the top of the wall frame. |
| Tread | In a stairway, the horizontal portion of each step. |
| Velocity multiplier | A multiplier used to estimate the likely local velocity based on the greenfield velocity i.e. local velocity = greenfield velocity x the velocity multiplier. |
| Waffle pod system | A form of concrete slab footings which use an arrangement of box-like formers (usually polystyrene blocks) placed above the ground to minimise site excavation and trenching. The depth of the pods and reinforcement required depends on the site conditions and loadings. The system enables significant reductions to be made in quantities of reinforcement and concrete required. |
| Wall cavity | Space in wall usually created between two brick layers (double brick) or one brick layer and a timber or steel frame with an internal lining. |
| Water pressures | Net pressure exerted by water in any direction. |
| Weepholes | Openings left in the perpends (vertical joints) of a brickwork course over flashing, and at the bottom of wall cavities for drainage purposes. |
| Wet flood proofing | Allows water to enter and exit a house through vents, doors and other specially designed openings in order to minimise structural damage. |
| Wind/water design approach | System developed by CSIRO based on designing buildings to resist wind loads and adapted for design of buildings in areas affected by flowing water. |

## RELEVANT AUSTRALIAN STANDARDS

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| AS 1604 | Timber - Preservative treated – Sawn and round |
| AS 1684.1 | Residential timber-framed construction – Design criteria |
| AS 2627.1 | Thermal insulation of dwellings – Thermal insulation of roof/ceilings and walls in dwellings |
| AS 2870 | Residential slabs and footings – Construction |
| AS 3700 | Masonry Structures |
| AS 4055 | Wind loads for housing |
| AS 4680 | Hot-dip galvanised (zinc) coatings on fabricated ferrous articles |
| DR 99463 | Timber flooring – Part 1: Installation (Draft) |

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