# Developing a local flood risk management strategy
# Annex 1: Flooding, flood sources and flood defences


## Pennine Water Group, University of Sheffield in collaboration with the partners of the FloodResilienCity and MARE projects



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# 1 Flooding and flood risk

The EU Flood Directive[1] defines "flood" as the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems. The exclusion of floods from sewerage systems is concerned with operational or managerial failures, often in dry weather, **but sewer flooding caused by rainfall is not excluded**.

"Flood risk" is defined in the directive as the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event.

[1] DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 on the assessment and management of flood risks

The definition of "flood" within the Directive does not distinguish between the physical processes that have shaped the natural world around us and those which occur as a result of human kind's interaction with water. The reality is that "flood risk" is seldom a natural problem and it is almost entirely caused by the decisions of people in their relationship with water.

# 2 Sources of flooding

There are two basic sources of flooding;

- Inland, where the interaction between rainfall, the earth's surface and its underlying geology can counter the pull of gravity, resulting in so much runoff that areas which are normally dry become submerged
- Coastal, where "spring" tides can combine with surges driven by low atmospheric pressure and wind to overcome the effect of gravity, resulting in extreme high water levels and large waves.

In addition to these there is a third category which can be termed as incidents. Examples of these include Tsunamis in coastal regions, and snow melts and ice blocks that can contribute to inland flooding.

The boundaries between inland and coastal flooding are shown in Figure 1.

Both sources of flooding can be subdivided.

## 2.1 Inland flooding

Inland flooding can be divided into four sources:

- Flooding from rural and urban areas including flooding from; exceedence pathways, surface water and soil, groundwater and drainage infrastructure.
- Artificial water bodies including; drainage channels, canals, reservoirs and artificial lakes and ponds.
- Streams and ponds, whose response times are too small for meaningful flood warnings to be given.
- Rivers and lakes, whose response times are sufficient to give meaningful flood warnings.

Each of these sources can be further sub divided as detailed in Table 1.

## 2.2 Coastal flooding

Coastal flooding can be divided into four categories:

- Open sea
- Estuaries, which are influenced by the interaction of coastal and inland flooding
- Deltas, where the interaction between coastal and inland flooding affects large areas of low lying land.
- Fjords and inlets, where the proximity of land modifies the behaviour of the open sea and where the mixing of fresh and saltwater leads to brackish conditions.

## 2.3 Incidents

A list of incidents relevant to coastal and inland flooding is given in Table 2.

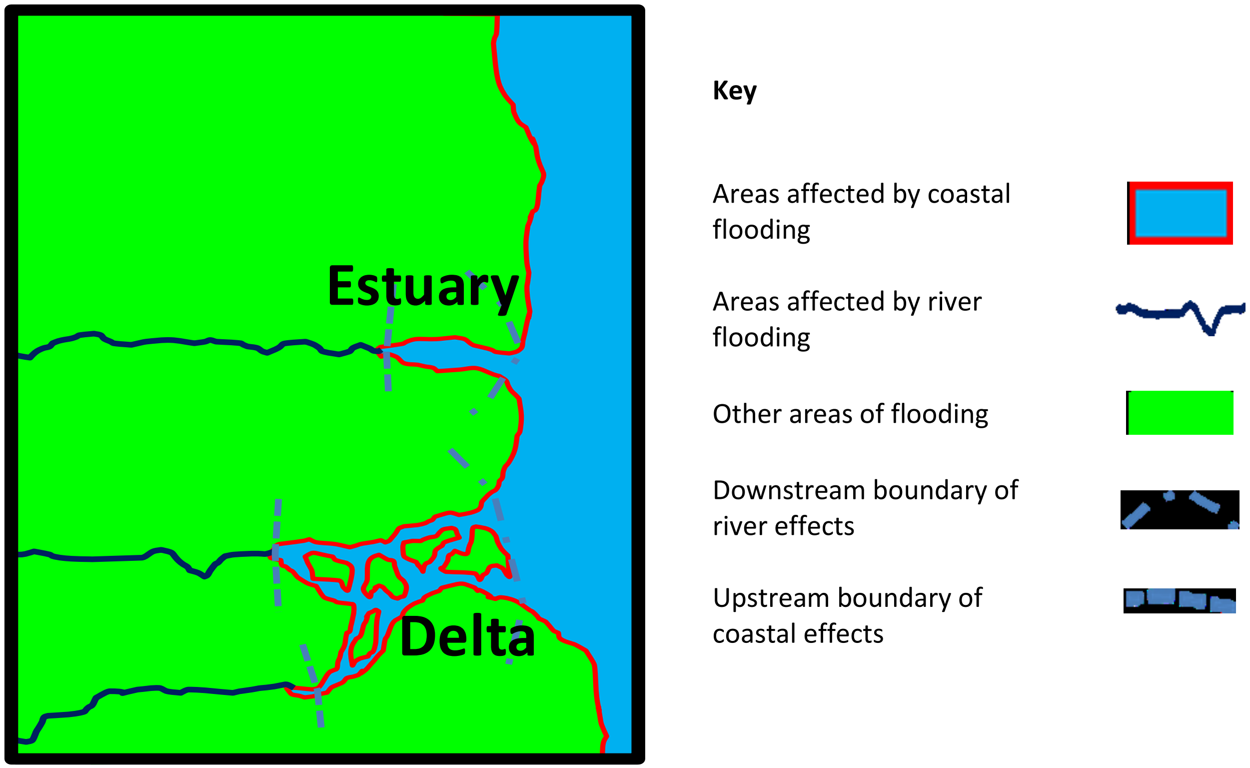


**Figure 1: Illustration of location of flood sources**

**Table 1a: Inland flooding sources**

| Source | Category | Sub category |
|---|---|---|
| Rural and urban areas | Exceedence pathways | |
| | Surface water and soil | Rural green space |
| | | Green space at urban fringe (near urban green space) |
| | | Green space within urban area (urban green space) |
| | | Developed urban surface |
| | Groundwater | Artificial superficial deposits (Made, Worked, In filled, Disturbed or Landscaped Ground) |
| | | Natural superficial deposits |
| | | Bedrock |
| | Drainage infrastructure | Combined sewer |
| | | Surface water sewer |
| | | Foul sewer |
| | | Surface water management systems (SUDS/Source control) |
| | | Pipe drain |
| | | Open Drain |
| Artificial water bodies | Drainage channel | |
| | Canal | |
| | Reservoirs | |
| | Lakes | |
| | Ponds | |
| Streams and ponds | Small Stream[2] | Open |
| | | Piped/culverted |
| | | Built over |
| | Large Stream[3] | Open |
| | | Piped/culverted |
| | | Built over |
| | Ponds | Ponds with outlets |
| | | Ponds without outlets |
| Rivers and lakes | River[1] | |
| | Lakes | Lakes with outlets |
| | | Lakes without outlets (oxbow) |
| | | Salt lakes (inland seas) |

**Table 1b: Coastal flooding sources**

| Source | Category | Sub category |
|---|---|---|
| Coastal | Open sea | |
| | Estuaries | |
| | Deltas | |
| | Fjords and inlets | |

## Notes on inland flooding

River, stream and coastal flooding only occur in limited areas and for relatively short periods of time. In all other areas and at all other times flooding is classified as rural and urban area flooding

1 In this context a river is a body which drains sufficient area and has sufficient time of concentration to make flood warning a viable flood risk management option, whereas flood warning is not a viable option for a stream

2 A small stream is defined as a watercourse which is considered to be too small for inclusion in flood zone mapping required by the EU Flood Directive

3 A large stream is defined as a watercourse which is considered to be sufficiently large for inclusion in flood zone mapping required by the EU Flood Directive

**Table 1: Breakdown of flood sources and categories.**

**Table 2a: Inland flood incidents**

| Source | Category | Incidents |
|---|---|---|
| Rural and urban areas | Surface water and groundwater | Landslides |
| | | Muddy floods from agricultural land |
| | | Snow melt |
| | | Groundwater pumping discontinuation |
| | Drainage infrastructure and water mains | Combined sewer service condition (e.g. blockage) |
| | | Combined sewer structural condition (e.g. collapse) |
| | | Surface water sewer or drain service condition (e.g. blockage) |
| | | Surface water sewer or drain structural condition (e.g. collapse) |
| | | Foul sewer service condition (e.g. blockage) |
| | | Foul sewer structural condition (e.g. collapse) |
| | | Combined sewer overflow service condition (e.g. blockage)/or equipment failure |
| | | Sewer Pumping Station failure |
| | | Sewage treatment works |
| | | Water main burst |
| | | Drainage pipe or sewer freezing |
| Other inland water Sources | Artificial water bodies | Canal breaches |
| | | Land drainage PS failure |
| | | Channel blockage |
| | | Channel collapse |
| | | Reservoir dam breaches structure |
| | | Reservoir dam breaches spillway |
| | | Reservoir overtopping |
| | | Unmanaged reservoir spillway operation |
| | Rivers and streams | Snow melt |
| | | Ice block |
| | | Bridge or culvert collapse |
| | | Bridge or culvert blockage |
| | | Bridge or culvert hydraulic capacity |
| | | Flood defense erosion or collapse |
| | | Flood defense causes flooding in lower risk area |
| | | Locking of drainage systems |
| | | Surface water entrapment behind flood defenses |

**Table 2b: Coastal flood incidents**

| Source | Category | Incidents |
|---|---|---|
| Coastal | Overtopping of defense | |
| | Defense collapse /failure | |
| | Tide locking of drainage systems | |
| | Surface water entrapment behind defenses | |
| | Tsunami | |

**Table 2: Flood incidents**

## 3 Flood Zones and the European Flood Directive

In Europe, the Flood Directive identifies three different flood scenarios (probability zones); high, medium and low, for which flood risk and hazard maps should be produced.

**High probability** flooding is defined as being more frequent than once in 100 years
**Medium probability** flooding is less frequent than once in 100 years, but still lies within the extreme flood zone.
**Low probability** flooding occurs outside the medium probability zone

These are illustrated in Figure 2 which shows high probability zones for coastal and river flooding in red, medium probability in yellow and low probability in green as the land rises.

Other than the definition of the boundary between high and medium probability flooding, there are no specific definitions of probability within the Directive, so member states have made their own interpretations.

Readers should check the definitions in place within their own countries, but the following are not untypical.

Very high frequency flooding could be considered to occur more frequently than once in 20 or once in 30 years. This equates to what might be termed as the functional flood plain

High frequency coastal flooding could be considered to occur more frequently than once in 200 years. This is because sea water may be considered to be more damaging than fresh water

The boundary between medium and low probability flooding could be considered to be the 1 in 1,000 year probability event.

Within the zone of low probability of river and coastal flooding there will be zones of high and medium probability of flooding from:

- Rural and urban flooding
- Artificial water bodies
- Streams and ponds

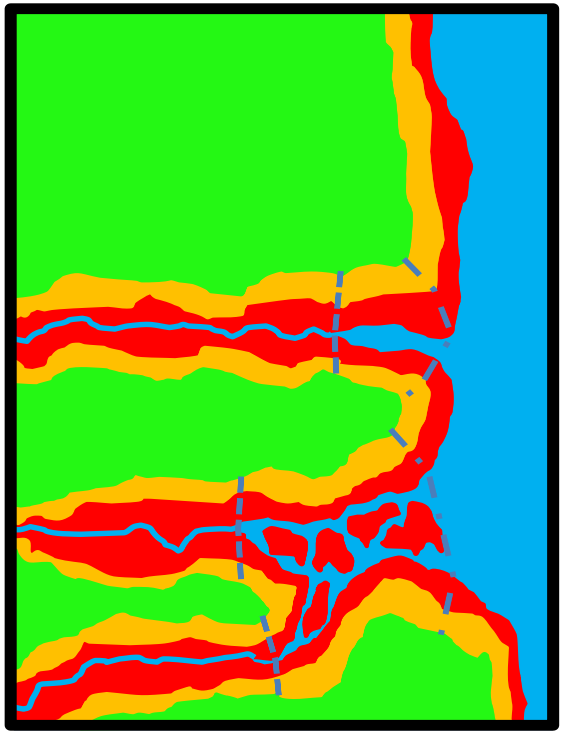

**Figure 2: Illustration of probability zones for coastal and river flooding**

**Key**

| | |
|---|---|
| High probability flood zone | (red) |
| Medium probability flood zone | (yellow) |
| Low probability flood zone | (green) |

# 4 Flooding and flood defence

## 4.1 Coastal flooding

Coastal flooding is caused by raised sea levels resulting from a combination of astronomical and meteorological conditions. Spring tides can combine with surges driven by low atmospheric pressure and wind to result in extreme high water levels and large waves. In addition to this, temperature increases associated with climate change will result in:

- land based ice masses melting and running into the sea and increasing the volume of sea water
- expansion of sea water

These will combine to increase the general sea level over the years

Figure 3 illustrates coastal flood probability zones

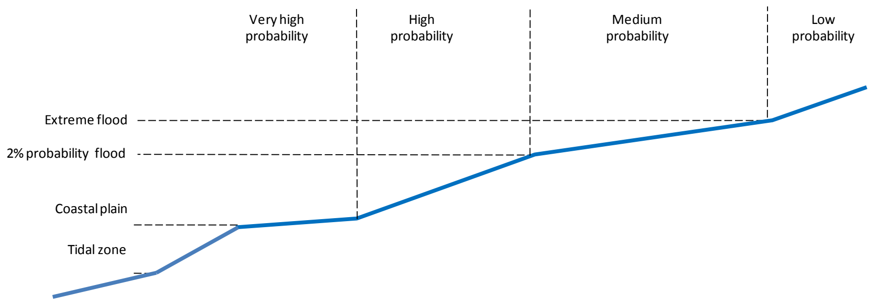


**Figure 3: Typical section of natural coast line and flood zones**

Although the construction of promenades and coastal defences does not affect sea level, they can affect the dynamic effects of wave motion and the way that drainage in the protected areas performs. This is illustrated in Figures 4 and 5

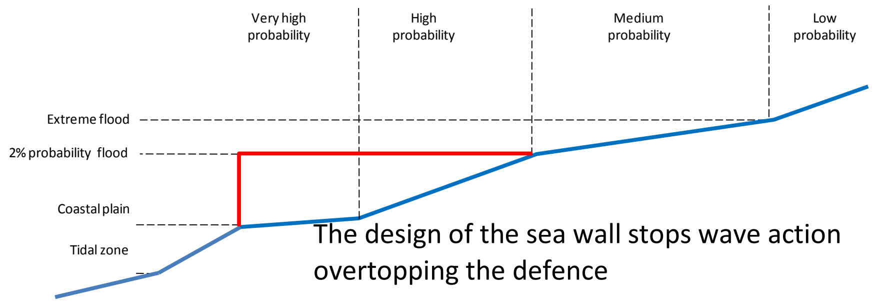


**Figure 4: Typical section through a promenade**

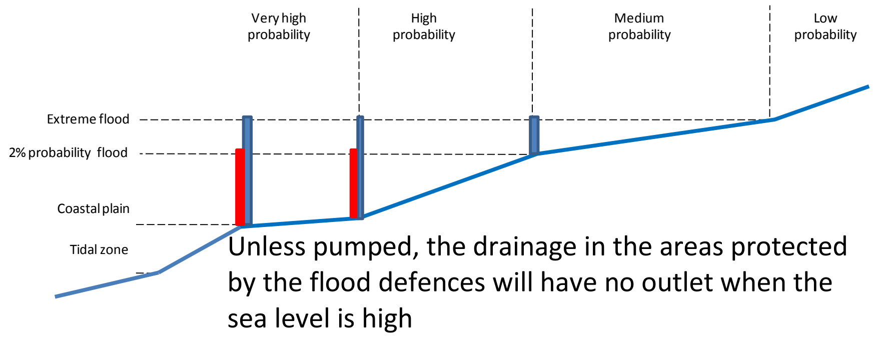


**Figure 5 Typical locations and elevations for coastal defences**

## 4.2 Estuarial flooding

Estuarial flooding is caused by a combination of river and coastal effects which varies between the upstream limits of coastal effects and the downstream limit of river effects. The narrowing of estuaries can increase surge effects.

## 4.3 Delta flooding

In deltas, large areas of low lying land are bounded by river channels and the sea. In these areas, land falls naturally within the flood plain (Figure 6) and may, because of a combination of land reclamation activity and siltation of river channels, lie below the normal river level.  As with Estuaries the balance between river and coastal effects will vary from the upstream to downstream reaches, but it is important to recognise that there are very specific requirements of flood risk management in deltas.

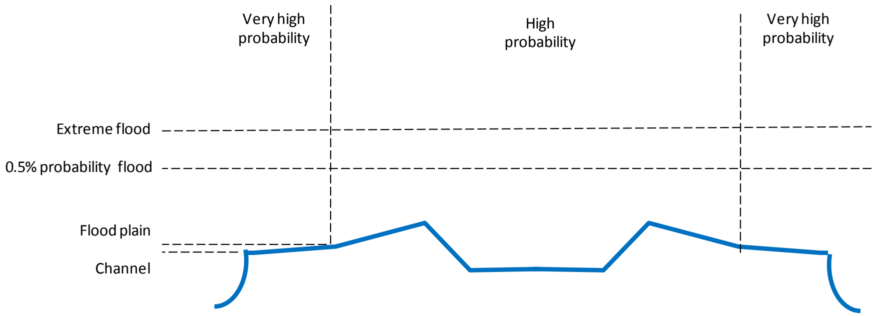


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**Figure 6: Typical flood zones on a delta island**

The location of flood defences diminishes in importance as the river impacts reduce downstream. Nevertheless, sufficient width has to be provided for the impact of surges (Figure 7).

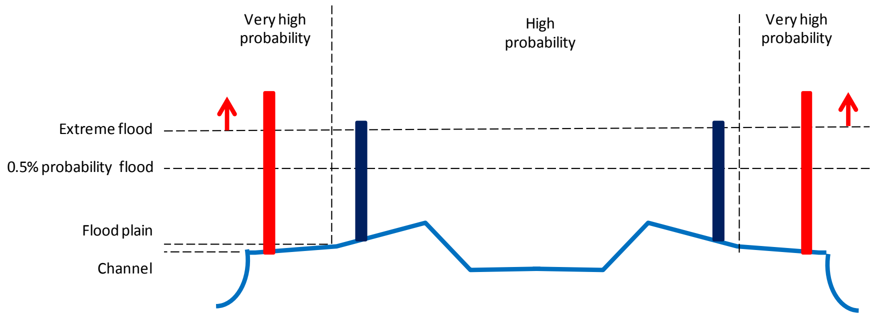


**Figure 7: Impact of defence location on height of extreme flood where river impacts predominate**

## 4.4 River flooding

River flooding occurs along large watercourses which have large catchment areas and slow response times. This means that flood warning systems based on weather forecasts and river flow gauging systems can be sufficiently accurate to make them an effective measure for flood risk management.

River flooding occurs in areas which have a high or medium probability of flooding as defined in Article 6 of the Flood Directive. River flooding may occur in natural or modified river channels as illustrated below.

It is common for flood probability maps to identify the flood extents based on an undefended channel. This is illustrated in the following section (Figure 8).

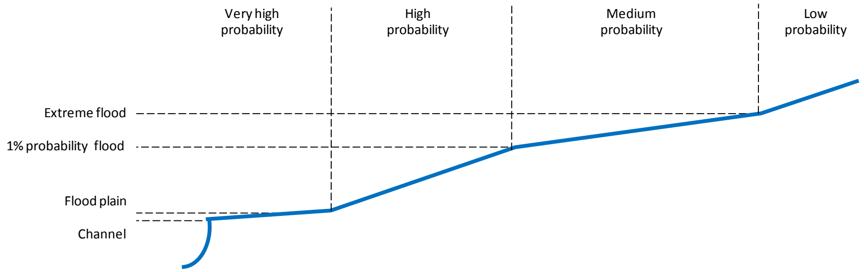


**Figure 8: Typical section of river bank and flood zones**

However, most urban rivers are modified in one way or another and the areas protected by flood defences may be shown on flood probability maps.

Flood defences may be located at any position and at any elevation, but typically would be located at the edge of a channel, aflood plain or boundary between the high and medium probability flood zone as illustrated in Figure 9. Defence elevations might typically be the level of the high probability or extreme flood with an addition for freeboard.

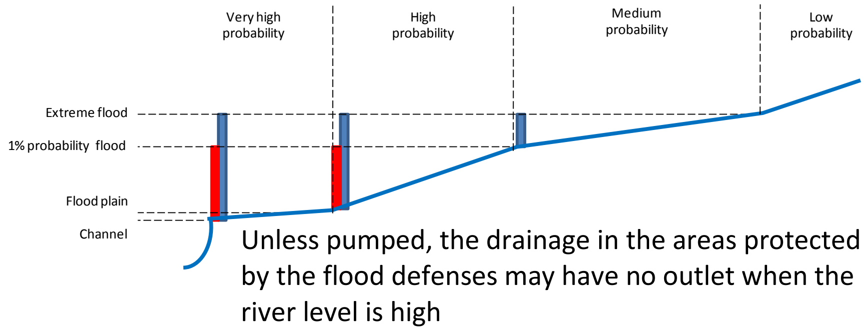


**Figure 9: Typical locations and elevations of flood defence**

By channelling a river and filling the land behind it, high probability flooding can be reduced or eliminated, but the loss of cross sectional area may increase the level of the medium and low probability floods when they occur. This is illustrated in Figure 10.

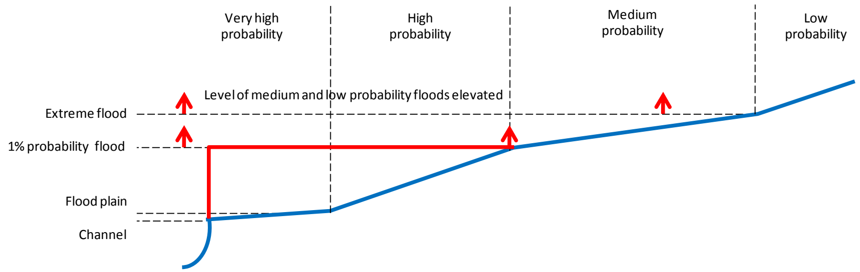


**Figure 10: Effect of elevating bank profiles**

Alternatively a well positioned, moderate flood defence coupled with a widening of the flood plain can significantly reduce flood risk in the medium probability zone as shown in Figure 11.

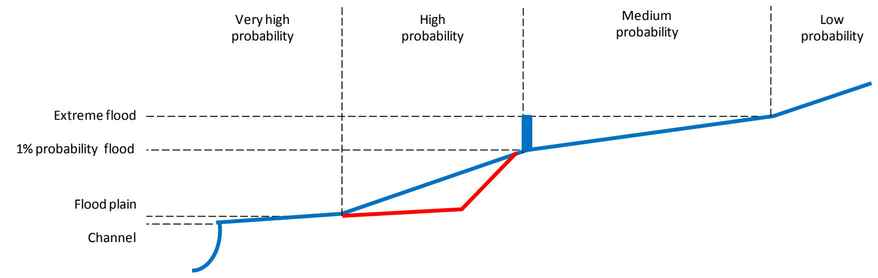


**Figure 11: Effect of increasing flood plain width**

## 4.5 Flooding from streams

Flooding from open streams occurs for the same reasons as flooding from rivers, but because streams are small in size, it is more likely that they will be modified to a larger extent than rivers. Although rivers may be bridged, it is unlikely that they will be culverted for any significant length, whereas this is common place for streams. Figure 12 illustrates the impacts of culverting.

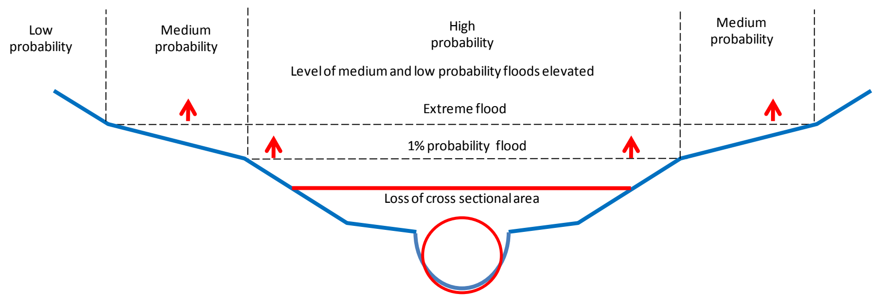


**Figure 12: Effect of culverting**

The impact of culverting is compounded by sedimentation and blockage of the culvert which reduces the capacity of the culvert. There is another impact resulting from the reduction of connectivity between the land surface and the culvert which can cause the surface to flood before the culvert runs full.

Blockage of culverts and their inlets reduces capacity and can generate secondary pathways. This is shown in Figure 13.

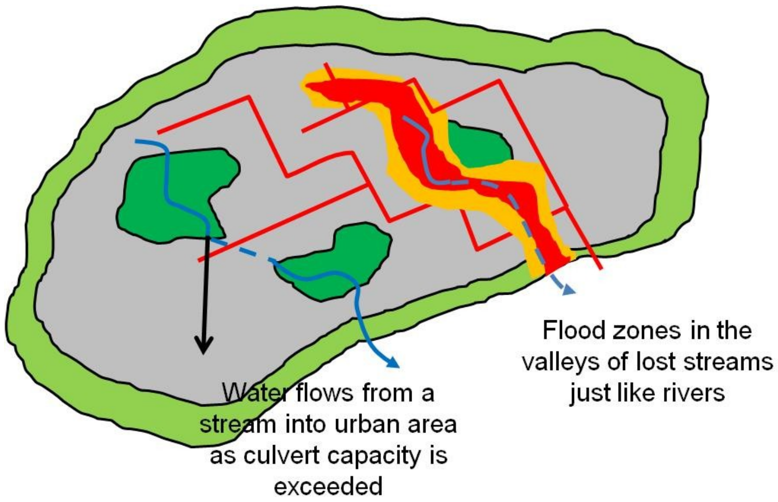


**Figure 13: Illustrations of flooding from streams**

## 4.6 Rural and urban area flooding

This source of flooding includes:

- Surface water and soil,
- Ground water
- Minor drainage systems (sewers, surface water management systems and land drainage)
- Exceedence pathways

These sources of flooding interact in complex ways and are relevant to all areas of land. However, in areas with a high or medium probability of river, coastal, estuarial or delta flooding, there are special requirements for flood management and drainage systems lying behind flood defences, from which water cannot drain when river or sea levels are elevated.

The following illustration (Figure 14) shows an urban area with its drainage system which for the sake of simplicity is not affected by river or coastal flooding. Typical of most urban areas it is surrounded by near urban green space which drains into or is affected by urban runoff. There are pockets of urban green space such as parks and playing fields within the developed urban area. The area is drained by a combination of sewers and small watercourses, but in some areas the process of urbanisation has in effect destroyed the natural drainage system.

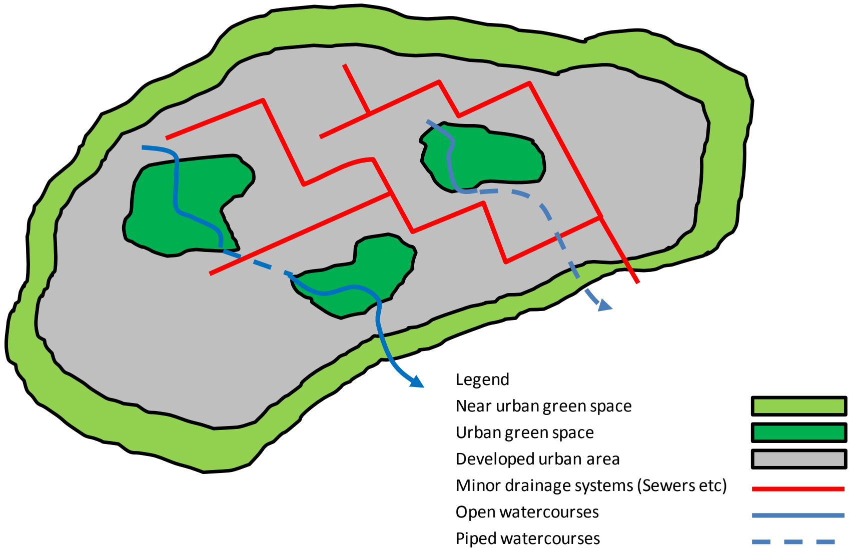


**Figure 14: An urban area within a rural setting**

### 4.6.1 Surface water and soil

Flooding from surface water and soil includes runoff from:

- Undrained impervious areas
- Drained impervious areas when the design capacity of the drainage system is exceeded
- Pervious areas when intense rainfall exceeds the rate at which the water can soak into the ground
- Pervious areas when the ground is fully saturated by prolonged rainfall

These types of surface may be found in:

- Rural green space
- Green space at urban fringes (near urban green space)
- Green space within urban areas (urban green space
- Developed urban surfaces

Runoff from one area of land can flow onto an adjacent area causing overloading of that area and subsequent down-slope areas.

Figure 15 shows runoff migrating through an urban area passing from the near urban green space area into the developed urban area; from the developed urban area into the urban green space and vice – versa and finally, from the developed urban area into the downstream near urban green space. The illustration also shows rural areas, but these may be considered to be buffered from the urban areas by near urban green space.

This simple illustration shows us that in order to manage the complexities of urban drainage; it is necessary to appreciate the complexities of the hydrology of near urban and urban green space as well as that of developed urban areas and how that affects runoff.

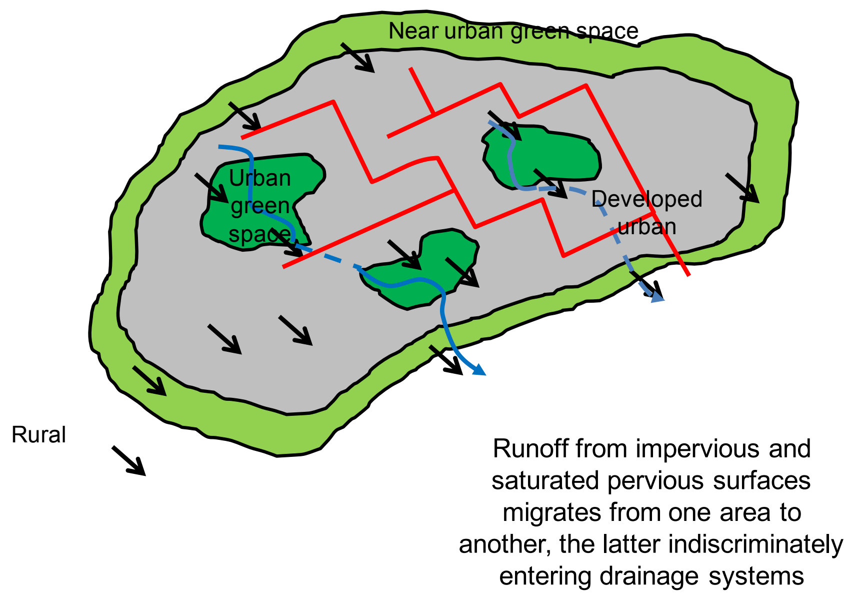


**Figure 15: Illustration of flooding from land**

### 4.6.2 Flooding from groundwater

Flooding from groundwater can arise from:

- Artificial and natural superficial deposits,
- Bedrock

In both cases water moves from below ground to the land surface when the downward migration of water into the ground is stopped by an impervious layer, or a layer which has inadequate permeability to convey the water percolating into the ground. This typically manifests itself as high groundwater levels in flat land or river valleys, or as spring lines on hillsides after periods of prolonged wet weather (Figure 16)

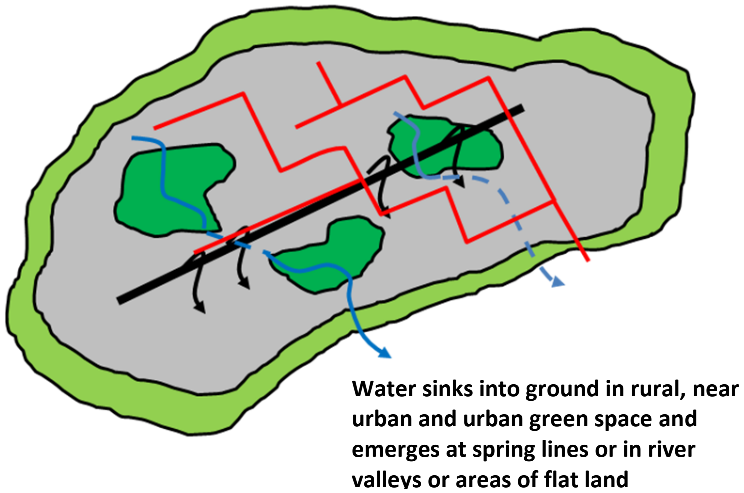


**Figure 16: Illustration of flooding from ground water**

### 4.6.3 Flooding from drainage infrastructure

Drainage infrastructure includes:

- Land drainage
- Sewers
- Surface water management systems (SUDS/Source control)

Expectations of the capacity of minor drainage systems vary, but it is inevitable that the capacity of these systems will be exceeded as it is not practicable to provide capacity for all events. Factors which affect the choice of capacity for a minor drainage system include the degree of urbanisation and the proximity of watercourses. These affect the amount of water that will flow over the surface and the distance that it has to travel and thus affect the likelihood of flooding. The impacts of climate change and urbanisation over the serviceable life of drainage assets are likely to exacerbate inadequacies in capacity towards the end of their life. The difficulty lies in the uncertainty of the predictions of climate change and urbanisation and the cost of constructing additional capacity that might not be needed. Figure 17, illustrates of how capacity might be exceeded due to inadequate provision for runoff from green space and increasing demand because of climate change and urbanisation. In addition, poor operation and maintenance may result in capacity being reduced.

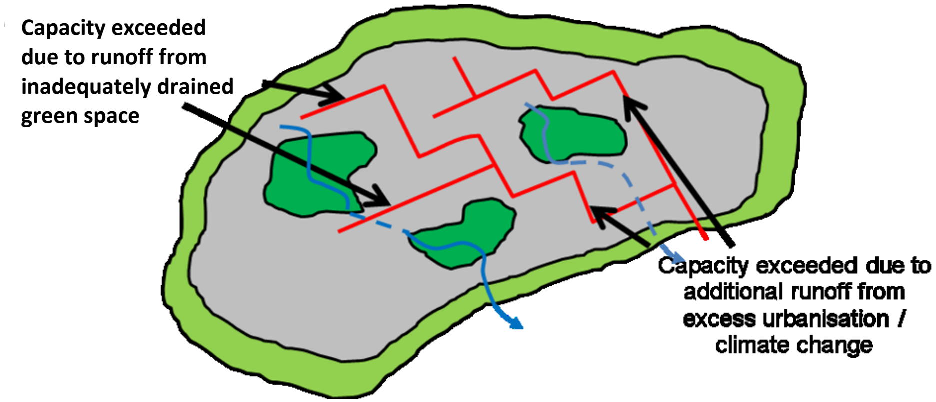


**Figure 17: Illustration of flooding from minor drainage systems**

### 4.6.4 Flooding from exceedence pathways

When flooding from surface water, soil, groundwater, streams and minor systems occur, the flows enter exceedence pathways. These pathways may be natural or built. If the pathways contain the water without causing damage or unacceptable disruption, then this should not be regarded as an inconvenience rather than a problem. **However, if unacceptable damage and/or disruption are caused then this is classed as flooding.**