A SUGGESTED APPROACH TO FLOOD MAPPING

based on experience in England and Wales

DAVID RAMSBOTTOM, HR Wallingford

1. ABSTRACT

Proactive flood risk management is addressed as much by avoiding the creation of flooding problems as by mitigating them. The identification of flood risk areas by flood mapping provides important information for:

- *Controlling development in the flood plain*
- *Identifying high risk areas for flood alleviation planning*
- *Where a flood warning system exists, flood maps can be used to identify where warnings should be issued.*

In England and Wales, the Environment Agency (as successor to the National Rivers Authority) is required to undertake surveys to define areas which are at risk from flooding, under Section 105(2) of the Water Resources Act 1991. These "Section 105 Surveys" are to be made available to planners and used in the planning process to avoid if possible the risk of flooding of new developments, and restrict development which may increase flood risk elsewhere.

The outputs of Section 105 Surveys are flood maps of specified return periods (for example, the estimated 1 in 100 year flood). This is a fundamental change from previous practice, where flood maps were based on historic flood information.

This paper gives the background to Section 105 Surveys and outlines different approaches to flood mapping.

2. BACKGROUND

2.1 Introduction

Flood plains often present attractive places to live and work, and this legacy has produced demands to alleviate the flood risk to which the occupants found themselves exposed. All too often, planners and developers were either unaware of or ignored the fact that major floods, although relatively infrequent, could affect property some distance away from and often out of view of the river. In heavily urbanised areas, the flow characteristics of relatively small watercourses have been changed by development. The result is that their relatively innocuous appearance for most of the year can be changed to a damaging torrent under the influence of rainfall from convective summer storms.

As the need for new development land continues to grow, there is increasing pressure to develop land which is at risk from flooding. In addition, expected sea level rises and possible increases in storm severity resulting from changes in weather patterns may lead to a gradual worsening of the potential flooding situation. There is therefore a need to ensure that planning decisions take account of flood risk.

These decisions need to be based on a consistent approach, in order that those involved can make comparisons and prioritise between alternatives, knowing that they do so on the basis of good information that is free from local standards and interpretation. This can be achieved using flood maps with a consistent flood return period. Ideally the methodology should also accommodate future changes in risk.

Control of new development is generally the responsibility of local planning authorities (LPAs), who are responsible for both development plans and development control. The Environment Agency (the "Agency") exercises general supervision over flood defence matters in England and Wales (Section 105 of the Water Resources Act, 1991). In addition, the Agency is a statutory consultee on planning matters.

In order to address the need to consider flooding in the planning process, it was decided that the Agency should produce flood maps. The requirement to undertake surveys to define areas at risk from flooding is contained in Section 105(2) of the Water Resources Act 1991. Hence the flood maps are referred to as "Section 105 Surveys".

It should be noted that, in addition to development planning and control, flood maps have other important uses including:

- Identifying high risk areas for flood alleviation planning and the development of flood alleviation schemes.
- Where a flood warning system exists, flood maps can be used to identify where warnings should be issued.

2.2 Circular 30/92

Guidance given to planning authorities for ensuring that planning decisions take account of flood risk include the Department of the Environment Circular 30/92 (Welsh Office Circular 68/92 and MAFF Circular FD 1/92). This approach is central to the Ministry of Agriculture, Fisheries and Food (MAFF) "Strategy for Flood and Coastal Defence in England and Wales" (MAFF 1993) which sets out, inter alia, flood defence priorities. Circular 30/92 is in the process of being updated by Planning Policy Guidance Note 25 (PPG25).

In general terms, the Government looks to local authorities to use their planning powers to:

- Guide development away from flood risk areas
- Restrict development that would itself increase the risk of flooding or interfere with the ability of the Agency or other bodies to carry out flood control works and maintenance.

Where development in flood risk areas cannot reasonably be avoided, flood defence engineering works can reduce the risk of flooding, for example by the provision of flood storage. However, it is important to appreciate that the risk can never be completely eliminated. Indeed, the sudden onset of flooding resulting from overtopping or failure of flood defences can have a far more severe impact than the gradual rise in flood level that would occur if no flood defences were present.

Through the development plan and development control process, developers need to be made aware of flood risks and consequent constraints on development. The Agency's document "Policy and Practice for the Protection of Floodplains" (EA 1997a) sets out model policies for LPAs accompanied by explanatory notes to help both planners and developers. The Agency seeks to avoid the provision of flood alleviation works to protect developments which could have been placed outside the flood risk area.

2.3 Existing flood risk area information

Prior to undertaking Section 105 Surveys, the available information on flood risk areas included:

- Section 24(5) Surveys (c1976) required under Section 24(5) of the Water Act 1973.
- Standards of Service Surveys
- Records of recent flood events

Further details of these methods are given in Appendix A. They have been used to produce flood maps for many rivers in England and Wales but they do not fulfil the requirements of Section 105 because they are generally based on historic events and do not have a consistent return period. In addition, coverage using historic data is not complete.

3. "SECTION 105 SURVEYS"

3.1 Purpose

The Government intended Section 105 Surveys to be the main Agency input into development plan

preparation. The surveys should also enable the Agency to respond efficiently to development proposals, thus influencing development patterns in a positive rather than reactive way.

The Section 105 Surveys are to be copied to LPAs in order to inform their development plan and development control functions. The surveys indicate to planners the extent of land which is liable to flood to a consistent standard, specifically, for non-tidal rivers, a flood event with a return period of 100 years. Circular 30/92 states that the results of Section 105 Surveys and other information provided by the Agency should be taken into account by planning authorities as they prepare their structure and local plans (including mineral and waste plans). In addition, development plans should include policies relating to development in flood risk areas.

Circular 30/92 states that "...because the surveys are indicative rather than specific..." LPAs will need to consult the Agency on individual applications. This implies:
(a) that whilst the surveys will give a good indication of specific flood envelopes they should not be regarded as definitive, and
(b) an acceptance that absolute precision is difficult to achieve despite the modelling techniques now available.
In addition to providing information to planners, Section 105 Surveys will enable the Agency to advise immediately whether proposed developments are in flood risk areas.

3.2 Scope

Section 105 Surveys are intended to cover the following in due course:

- Main river (ie watercourses under the jurisdiction of the Agency)
- Non-main (or "ordinary") watercourses
- Tidal and coastal waters

The surveys are required to provide mapped flood envelopes to a consistent standard, as follows:

- 100 year minimum in non-tidal areas.
- 200 year minimum in areas subject to tidal inundation.

The surveys are required to provide flood envelopes for the following:

- Unprotected areas
- Protected areas (ie areas protected by defences)

3.3 Progress

Progress on Section 105 Surveys has been slow, and the surveys are far from complete. Following the floods of Easter 1998, the Government required the Environment Agency to produce flood risk maps by September 1999. This was achieved by mapping all currently available information including completed Section 105 maps, historic flood outlines, and very approximate national flood maps (NERC 1996).
Section 105 Surveys for coasts have not commenced, and are not covered by this paper.

4. FLOOD MAPPING METHODS

4.1 Introduction

There are fundamentally two types of flood risk maps:

- Those based on historic information, where the return period of floods will vary from river to river, and also along the length of any particular river.
- Those based on a standard flood return period (or probability of occurrence).

Relative advantages and disadvantages are as follows:

<u>Flood maps based on historic information</u>

Advantages
Flood envelopes difficult to dispute

Relatively easy to prepare

Disadvantages
Probability of floods is not consistent (ie return period varies)
Coverage incomplete
Future floods can exceed limits by unknown amounts
Takes no account of physical changes since the flood took place

Flood maps with a consistent return period

Advantages
Consistent approach
Complete coverage
Can be updated

Disadvantages
More difficult to produce
Results could be disputed
Flood limits could be exceeded (but risk smaller than for historic flood method)

4.2 Flood maps based on historic information

Producing flood maps from historic information involves collection of all relevant information and plotting it on maps. It is recommended that this be done electronically for ease of updating and management of data. Hard copies of the maps should be kept for record purposes.

Experience has shown that historic data does not provide a full description of flood limits, even in urban areas. In addition, information can be conflicting and difficult to interpret. The approaches to flood mapping using historic data in England and Wales are summarised in Appendix A.

4.3 Flood maps with a consistent return period

This is the approach adopted for Section 105 Surveys. In 1995 a study was carried out to identify modelling needs for Section 105 Surveys of rivers (HR 1995). The study identified a range of possible methods for the production of flood maps. These may be broadly categorised as follows:

- Methods that produce flood envelopes directly.
- Methods that produce flood levels directly.
  These methods do not require flow data but they must be combined with topographical information to produce flood envelopes.
- Methods that require flow data to produce flood levels.
  These methods must be combined with a method for estimating flow and topographic information to produce flood envelopes.

The relationship between the methods is shown on Figure 1.

Methods that produce flood envelopes directly
Direct estimates of flood envelopes may be obtained by interpolation and extrapolation using historic flood outlines. However, these are often only available for a small proportion of rivers.

For some lowland rivers, it is possible to estimate the flood plain envelope as the lines where the flat flood plain meets the valley sides. For example, the detailed flood envelope for the Lower River Severn correlated closely with these lines, although this simple approach would not be accurate enough for detailed delineation of flood envelopes in villages and other built-up areas (HR 1991).

Methods that produce flood levels directly

There is a range of methods that produce flood levels directly. These include

- Plotting of historic data on a longitudinal section of the river, and interpolating return period flood levels.
- Estimation of flood depth above average bankfull level from an analysis of flood level data for different types of rivers.

The outcome is a longitudinal profile of the river showing the estimated flood levels for the required return periods.

These methods must be combined with topographical data to obtain flood envelopes. It is normally assumed that the water level at the edge of the flood plain is the same as in the river channel. Methods of obtaining flood plain topographical data range in cost and detail and include:

- Digital Terrain Model (DTM) data from various sources including the Ordnance Survey and satellite data.
- Various degrees of topographic survey, ranging from detailed ground or photogrammetric survey to a range of options involving reduced amounts of ground survey.
- Methods using laser or radar. These involve the use of an aircraft to collect survey information (for example LIDAR, see EA 1997b).

All these methods require ground survey for control purposes and data for the river channel. For methods that require topographical survey, the cost of the survey is a major component of the overall cost.

Methods that require flow data to produce flood levels.

These methods use flow data to predict flood levels, and also require topographic data to produce flood envelopes. They include:

- Full hydraulic model (steady or unsteady flow, calibrated or uncalibrated).
- Simplified hydraulic model with fewer sections, including typical section methods where single sections are used to represent complete river reaches. Rating curves derived from the section are used to produce water surface profiles for the reach. Backwater effects may be superimposed, or the whole procedure may be carried out computationally.

Methods of producing flow data include rainfall-runoff and statistical methods based on the Flood Estimation Handbook (FEH). These methods may either be calibrated or uncalibrated, although there is considerable uncertainty where calibration is not possible. One of the main problems with flood analysis is often the complete lack of hydrological and hydraulic data to calibrate models.

The process of flood mapping using a full hydraulic model involves the following steps:

- Survey of river channels, flood plains and hydraulic structures.
- Collection of model calibration data (if not available already).
- Model planning and construction.
- Model calibration.
- Selection of events for flood mapping (eg 100-year flood).
- Run events on model and output flood levels.
- Construct flood plain DTM.
- Combine flood levels with DTM to produce flood maps.

4.4 The River Cherwell Pilot Study

In order to refine the methodology to be adopted in the Thames Region of the Agency, several of the methods outlined above were used to predict flood envelopes on the lower River Cherwell (HR 1996).

The results of the study are summarised in Table 1. The main conclusions were as follows:

1. Three general approaches to Section 105 Surveys were defined ranging from detailed modelling to relatively simple methods. Choice of method depends on land use and available data.
2. The indicative costs for different methods range from about £st3,000 to £st35,000 for a 10-kilometre reach of river (including survey costs), at 1996 prices.
3. The range of flood levels on the Lower River Cherwell is small. Estimates of the 100-year flood level are generally between one and two metres above bank top level. Simple methods can, in this case, provide reasonable estimates of flood levels.
4. The simple methods gave reasonable flood envelopes where the flood plain is confined. The large deviations in Table 1 are generally in areas where the valley is flat and the flood plain is not clearly defined. In these cases, accurate topography is needed to define the flood limit.
5. Of the simple methods, the use of observed flood outlines gave the best results. Effort should be devoted to the collection of historic data both for application of this method and calibration of other methods. Experience has shown however that, whilst some river reaches are well covered by historic data (for example, the lower Cherwell), the amount of data available for the majority of river reaches is very limited.

5. HOW ACCURATE DO FLOOD MAPS NEED TO BE?

In general terms, accuracy costs money. The Cherwell Pilot Study demonstrated a relationship between cost and accuracy. From Table 1 it can be seen that the least accurate method cost about £4,000 per 10-kilometre reach of river whereas the most accurate method cost about £35,000 per 10-kilometre reach.

Potentially, flood maps could cover thousands of kilometres of rivers and coasts. The level of detail and accuracy needed for flood maps varies depending on location and existing land use. Categories of land use include:

- New development sites (identified in local development plans)
- Existing urban areas
- Rural areas.

New development sites

One of the key issues which affects new developments is shown by the example of a major development in Oxfordshire. The edge of the estimated 100-year flood envelope forms one boundary of the development site. Land on the river side of this flood limit is worth about £4,000 per hectare, whereas land on the development site side of the flood limit is worth about £600,000 per hectare. This is because planning permission has been granted for land outside the 100 year flood limit.

Clearly the location of the flood envelope is of great importance, and in this case maximum accuracy is needed in the determination of flood envelopes. From the planners' point of view, a flood envelope is needed which is acceptable technically to the Agency, the LPA and the developer.

Where there is concern about the potential impact of a particular development in England and Wales, it is normal practice for the developer to be required to demonstrate the impact on flood risk and land drainage. This requirement is unaffected by the production of Section 105 Surveys.

Existing urban areas

Existing urban are subject to constant regeneration and renewal of properties and other assets. Accurate flood envelopes are not only important for planning and development control but also for flood warning purposes. However, even with detailed modelling it is not practicable to take full account of the local complexities of urban areas and their drainage systems.

Rural areas

Land use in rural flood plains is relatively low value compared with existing urban areas and designated development sites. A high level of accuracy and detail is less crucial in these areas. Clearly if developments

occur in rural areas in the future, more detailed studies to improve the accuracy of the flood envelopes could be carried out at that time.

6. UNCERTAINTY

The flood limit obtained using the best available means will have a degree of uncertainty associated with it. This may arise for a number of reasons, including:

- The possibility of a flood occurring in the future which is above the specified standard.
- Uncertainties in the estimates and calculations used to derive the flood envelopes. These include calculations of flood flow and flood level.
- Uncertainties, inadequacies and inconsistencies in historic data used to calibrate models and/or produce flood envelopes for historic floods.
- The impact of climate change and sea level rise.
- Changes in catchment land use and maintenance regimes.
- Assumptions regarding gate openings and structure blockages.

It must therefore be recognised that:

- All estimates of flood envelopes will have an associated degree of uncertainty and that there is no absolutely correct flood envelope.

- A best estimate of the flood envelope is needed at reasonable cost taking land use and development pressure into account.

The variation in flood level and the impact on flood extent will vary from river to river. For example, in a broad flood plain, the difference in water level between a 50 and 200 year flood event may be less than 0.5m. However, the impact on the edge of the flood envelope could be of the order of 500m. Conversely, in a narrow valley, the level difference between the two events could be a more threatening 2m or more, yet the increase in width of the flood envelope may be less than 50m.

In view of the uncertainty in the estimates of flood envelopes, one possibility to avoid underestimating the flood limit would be to introduce the concept of "freeboard", in which an allowance is added to the flood level and used in the determination of flood envelopes. This approach would lead to an overestimate of flood envelopes and could be challenged by landowners, anxious to maximise the value of their development land.

7. GENERAL APPROACH TO FLOOD MAPPING

From the development point of view, the areas for which flood plain maps are most likely to be required are those where development is proposed. Therefore maps for the whole catchment might not be required. However, in order to produce consistent flood maps it would be necessary to undertake a catchment hydrological study to produce a consistent set of design flows. A general approach might therefore be as follows:

1. Catchment study, to produce consistent design flood flows for the catchment.
2. Detailed study of development areas and, subsequently, other urban areas in the catchment.
3. Flood envelopes for other areas as required.

In order to undertake flood mapping in a cost effective manner, a number of factors must be considered including:

- Accuracy required for different types of land use.
- Availability of existing data.

- Extent of modelling needs.
- Availability of funds and other resources.

A suggested approach to the preparatory work needed to undertake flood mapping is given below.

1. Adopt a catchment wide approach in order to permit the most efficient use of existing data, optimise the acquisition of new data, and ensure that a consistent set of flows is used for all reaches where flow data are required.
2. Locations where different degrees of accuracy are appropriate should be identified.
3. Review all flood envelope and flood level data to identify reaches where methods based on historic data can be applied. These should be areas where good historic flood limits exist for large historic floods.
4. Review previous studies to identify any hydrological and hydraulic data / models that could be used for other areas.
5. Decide which method to adopt for each reach. Guidelines are given below. In all cases the choice will depend on the availability of historic flood information.

Application	Methods
Development sites and urban areas	Full modelling (or use of historic data where quality and coverage is good) and detailed topographic survey.
Intermediate areas	Modelling using reduced amounts of survey data compared with full models.
Rural areas with low land use value	Simple screening; use of previous surveys; simple modelling with minimal survey information.

   An appropriate hydrological study will be needed where methods which require flow data are applied.

6. Estimate total costs of the proposed methods for different river reaches, and adjust the overall approach to match the available budget.

7. Collect additional data. This is likely to require topographical and other surveys.

At this stage, a plan will have been prepared for each catchment, and data will have been collected. It should then be possible to produce the flood limit maps using the approach outlined in points 5 and 6, above.

8. DISCUSSION AND CONCLUSIONS

1. Two possible approaches to flood risk mapping are:
   - Those based on historic information, where the return period of floods will vary.
   - Those based on a standard flood return period (or probability of occurrence).

2. It is generally recommended that a method based on a standard return period is adopted except in areas where good historic data are available for sufficiently large floods. Reasons for this include limited coverage of historic data and the lack of large recorded floods on some rivers.

3. In England and Wales the Environment Agency is required to undertake surveys to define areas

which are at risk from flooding, in accordance with Section 105(2) of the Water Resources Act 1991, in order to assist with development planning and control.

4. All estimates of flood envelopes will have an associated degree of uncertainty and there is no absolutely correct flood envelope. In general terms, a best estimate of the flood envelope is needed at reasonable cost taking land use and development pressure into account.

5. Flooding can occur outside beyond the flood limits shown on flood maps. For example, the annual probability of a 100-year flood envelope being equalled or exceeded is 1%.

6. "Section 105" flood maps are indicative and should not be considered to be definitive. It follows that there should be no legal liability for repercussions arising from inaccuracies.

7. Methods for preparing flood maps vary in both accuracy and cost. An approach is recommended which involves the use of a range of methods depending on land use, data availability and budget.

REFERENCES

EA 1997a — Policy and practice for the protection of floodplains. Environment Agency, January 1997.

EA 1997b — Laser Induced Direction and Range: LIDAR. The National Centre for Environmental Data and Surveillance brochure. Environment Agency, March 1997.

HR 1991 — River Severn Flood Plain, Worcester to Avonmouth. Report EX2252, HR Wallingford, March 1991.

HR 1995 — Section 105 Surveys: Modelling needs. Report EX3141, HR Wallingford, 1995.

HR 1996 — Section 105 Surveys: River Cherwell Pilot Study. Report EX 3455, HR Wallingford, September 1996.

MAFF 1993 — Strategy for Flood and Coastal Defence in England and Wales. Ministry of Agriculture, Fisheries and Food, September 1993.

NERC 1996 — Flood risk map for England and Wales. Morris D G & Flavin R W, Institute of Hydrology Report 130, National Environment Research Council, October 1996

RGC 1990 — Flood Defence Levels of Service: Component stages in undertaking an LOS assessment. Robertson Gould Consultants, December 1990.

ACKNOWLEDGEMENTS

The assistance and support provided by the Environment Agency and HR Wallingford is gratefully acknowledged. The views and opinions expressed are those of the authors and not necessarily those of the organisations they represent.

Table 1 Accuracy of flood plain mapping methods

Source: Section 105 Surveys: River Cherwell Pilot Study, September 1996.

Combination of methods	Accuracy		Cost (Note 1)	Time (Note 1)
	Flood levels (mm)	Flood outlines (m)		
Full hydraulic model Calibrated flood hydrographs Full topographic survey Standard method. Other methods compared with results from this method	- (Note 2)	- (Note 2)	35 incl 20 survey	8
Use of historic flood outlines	N/A	0 - 100	2-4 Needs historic data	2
Use of flood level data Ad hoc interpolation 50m topographic data	200	0 - 600	3-5 Needs flood levels	2
Typical sections Peak flood flows Survey sections at 5km spacing	600	0 - 400 (note 3)	10 incl 5 survey	4
Full hydraulic model Un-calibrated flood hydrographs Full topographic survey	450	0 - 100	30 incl 20 survey	8

Notes

1. Indicative costs (£'000) and timescale (weeks) are typical average values for a 10km reach of river. Costs are in £st at 1996 prices.
2. Assumed to be the best method. Accuracy of the order of +/-100mm or greater for level and 0-50m for flood limits depending on quality and quantity of survey data. Accuracy of this method should be added to accuracies of other methods to obtain absolute values.
3. Large but localised errors in flood outlines between survey cross sections. Results would be improved by addition of cross sections at critical locations.

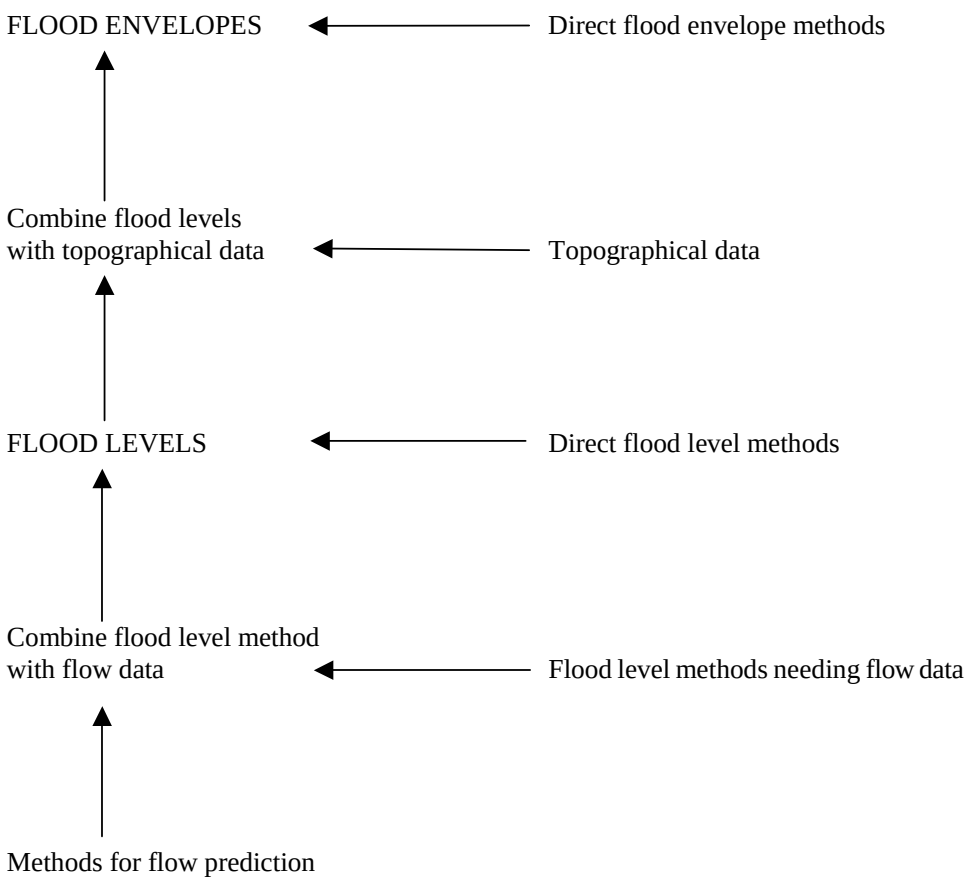

Figure 1 Methods for producing flood envelopes

APPENDIX A

EXISTING INFORMATION ON FLOOD RISK AREAS

Existing information on flood risk areas include:

- Section 24(5) Surveys (c1976) required under Section 24(5) of the Water Act 1973.
- Standards of Service Surveys
- Records of recent flood events

Section 24(5) Surveys

The Section 24(5) Surveys involved collating available information on flooding. In contrast to the Section 105 Surveys, they were not required to produce flood envelopes to a specified standard. They do however provide much useful information. In the agreement between LPAs and the Environment Agency, the first stage of the implementation programme is to re-issue Section 24(5) Survey data, where this has been materially updated, to the local planning authorities. This is an interim measure, to be superseded by the Section 105 Surveys when they are available. The limitations of Section 24(5) maps compared with Section 105 Surveys include:

- They are mostly based on recorded events. The magnitude of the events varied and not all events were covered.
- Flood extents were not consistent and often based on anecdotal evidence.
- Coverage was not complete.

Standards of Service Surveys

The Standards of Service (SOS) Surveys were carried out in the 1980s and early 1990s to determine the value of land use in flood risk areas. Flood envelopes were estimated for main rivers using available information including historic flood envelopes and Section 24(5) Surveys. The river system was divided into reaches of about 5km in length and the value of land use on each bank for each reach was calculated in terms of a unit called the "House Equivalent" (RGC 1990). The SOS surveys were used in the prioritisation of maintenance and other operational activities.

Flood limits on the SOS maps generally refer to historic floods and do not provide a consistent standard in terms of return period. They do not therefore meet the criteria required by the Circular 30/92 agreement. However, they could provide an interim set of flood limit maps for main rivers.

Records of recent flood events

Since the Section 24(5) and SOS surveys have been undertaken, some significant flood events have occurred. The Agency, through earlier survey requirements, has become increasingly aware of the importance of collecting data in such events. Therefore, there is often good quality information recorded immediately after an event.