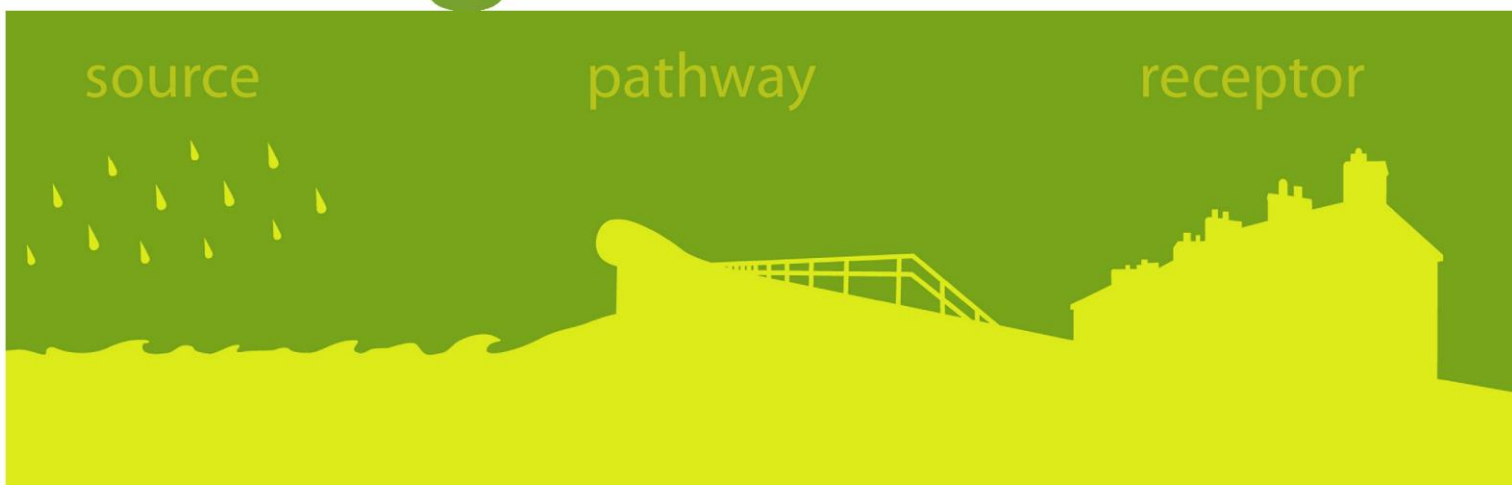


delivering benefits through evidence



Decision-making with probabilistic flood forecasts

Illustrative guide for using decision-support methods

Project: SC090032

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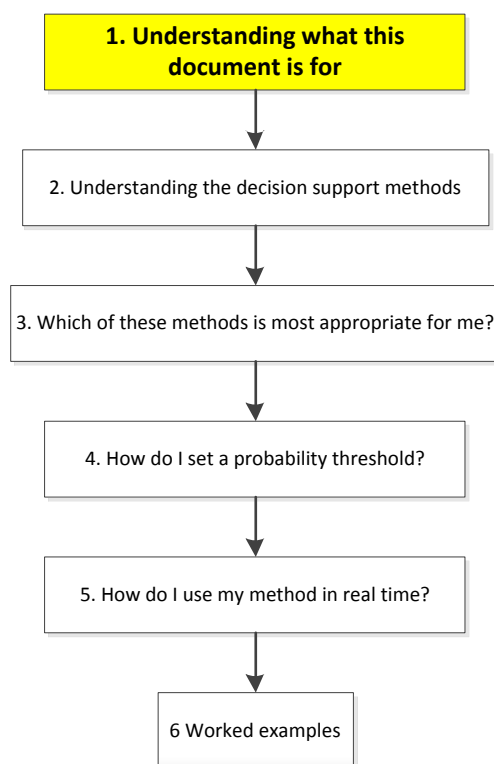
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1 Introduction



1.1 Purpose of this guide

Flood forecasts are uncertain. Unlike conventional, deterministic forecasts, probabilistic flood forecasts try to quantify and represent this uncertainty explicitly. There are a number of ways of making probabilistic forecasts but the most common involves generating multiple possible forecasts of peak water levels, or rainfall intensities, based on slightly different initial conditions so as to reflect the uncertainty about them. While this additional information can improve flood incident management (FIM) by enabling earlier and more proportionate responses to potential flooding, it presents a challenge: what action should be taken when only some of the forecasts predict flooding? (see Figure 1-1).

Probabilistic flood forecasting has a number of benefits. It represents the inherent uncertainties associated with flood forecasts and can improve the utility of forecasts for flood warning in situations of greater uncertainty, such as in convective storms or for longer lead times. Overall, it allows action to be taken earlier in a more informed way and provides a more complete picture of potential flood risk as an event develops.

This guide illustrates a number simple methods which *could be used* to support **clear, consistent, and objective** decisions when using probabilistic forecasts. The methods have been developed and tested on a range of flood locations and types in Environment Agency R&D project *Applying probabilistic flood forecasting in flood incident management* (SC090032). For more details on the project, please refer to the Technical Report (Environment Agency, 2012).

It is worth noting that this is an active research and development area and we expect novel approaches to become available over time. The approaches here

should therefore be seen more as illustrations how probabilistic flood forecasts *could* be used to support decision making and not as fixed and definitive procedures to be followed.

1.2 Who is this guide for?

This guidance is aimed primarily as a resource for Environment Agency Flood Incident Management staff in operational functions. However, it is of interest to anyone involved in making decisions ahead of a flood event when probabilistic flood forecasts are available. Two key providers of probabilistic flood forecasts are Flood Forecasting Centre operational hydrometeorologists and Environment Agency Regional Flood Forecasting duty staff.

1.3 What are probabilistic flood forecasts?

Probabilistic forecasting is a technique that relies on different methods to establish an event occurrence/magnitude *probability*. It is therefore different from a deterministic forecast, which is just one prediction of what might happen. Both probabilistic and deterministic techniques try to predict events but only probabilistic forecasts provide consistent information about the uncertainty by providing a range of possible forecast flood water levels (or rainfall depths). These are often referred to as an ensemble (see Figure 1-1).

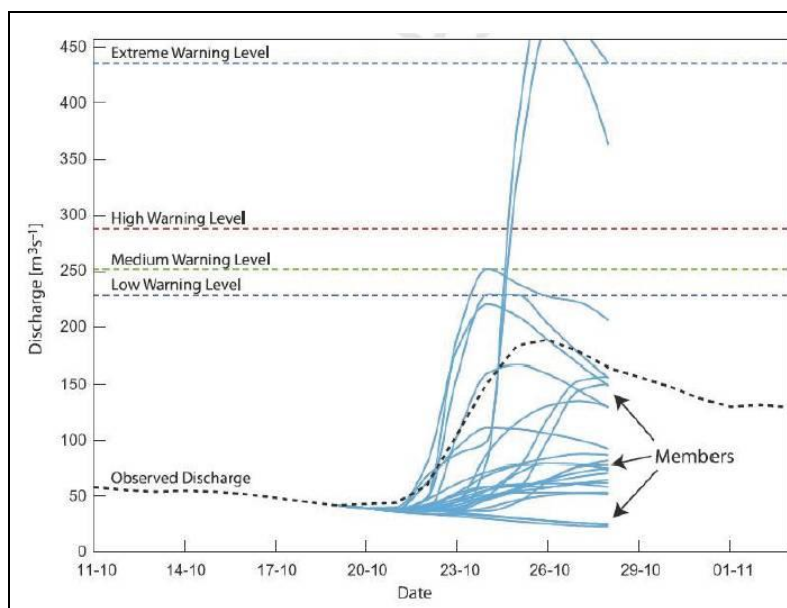


Figure 1-1 Example of probabilistic forecast showing ensemble members (after Cloke et al, 2009, see SC090032 Technical Report for all references)

1.4 How does probabilistic flood forecasting improve my decision-making?

Currently, if you are faced with a set (*ensemble*) of forecast water levels or rainfall amounts, you can use that information in a qualitative way only. In the scenario illustrated by Figure 1-1, two extreme members of the ensemble indicate that an extreme flood warning level might be exceeded, though the majority of forecast ensemble members are well below this. Deciding on the best course of action is,

therefore, subjective – one decision-maker might decide to take an action while another might not.

To help solve this problem, and to allow calculated precautionary action to be taken, this guidance describes systematic decision-support methods developed to assist you in working with probabilistic forecasts. The methods described below, and the tools that accompany them, are designed to be easy to use and suited to the particular flood situation in which they are being applied. Importantly, **their use will not require a significant amount of your time in advance of or during a flood event: using them should be well worth the effort.**

A further advantage of using the decision-support methods is that they will leave a **decision-making audit trail**. After the event, you will have a set of information that demonstrates how and why decisions were taken in response to the information available at the time.

So decision-making is improved because:

- Forecast **uncertainty is captured** (through probabilistic forecasts) enabling earlier and more proportionate responses.
- The approach is more **risk-based** (probability and consequence are captured better) so the costs of actions can be optimized against their potential benefits.
- The approach is **objective** ensuring decisions are based on a consistent and clearly documented process for evaluating the costs and benefits of different FIM options in response to probabilistic forecasts.
- Tools have been developed to make the process of using probabilistic forecasts **simple and quick in real time**.

There are some limitations to the methods. The main limitation is the reliability of the probabilistic forecasts. By reliable we mean that there is a good relationship between forecast probability and observed frequency –meaning that the forecast ensemble members envelop the observed water level as often as predicted. For instance, if the forecast shows a 60% likelihood of a certain event, the observations (over the long term) should show that this event occurred in 60% of the time.

The main assumptions in the methods are that the costs of FIM actions and flood impacts can be estimated satisfactorily. The estimates need not be detailed and precise but should be sufficient to allow a reasonable comparison between cost and benefit (flood impact avoided). A further limitation is that estimating the financial benefits of taking action takes some resource and time. However, this effort is proportional to the relative costs and benefits of that FIM action. For example, where a tidal barrier is protecting hundreds or thousands of properties, a proportionate amount of effort in estimating monetised benefits would be justified; for decision-making on issuing flood warnings for smaller communities, simpler assumptions could be used.

1.5 Definitions

Below is a list of the main terms used in this document, along with their definitions.

Ensemble – A group of individual forecasts that are made at the same time and have slightly different starting conditions.

Flood impact – The negative consequence of flooding. In this report, flood impact is defined in terms of the impact that would occur for a particular flood metric (such as forecast water level on the coast/river or rainfall depth) in the absence of FIM actions. The flood impact is comprised of more than just the financial cost of residential property flooding: aspects such as risk to life, social impact, critical infrastructure, non-residential property and agricultural impact all contribute to the overall flood impact.

FIM action cost – An estimated value in pound sterling (£) incurred when taking a specific flood incident management action as a result of a flood forecast. The costs may those incurred by the Environment Agency and by others including professional partners and the public (in the case of a flood warning). Typical FIM actions are shown below in Table 1-1 (this is not an exhaustive list). For the actions shown, lead time is greatest for category A actions and least for category D actions.

Table 1-1 Typical FIM actions

Category A. Monitoring and forecasting	A1. Enhanced forecasting
Category A. Monitoring and forecasting	A2. Enhanced monitoring
Category B. Event preparation	B1. Additional duty officers put on stand-by
Category B. Event preparation	B2. Open incident room(s) (Area / Region)
Category B. Event preparation	B3. Mobilise staff on-site
Category C. Warning dissemination	C1. Disseminate flood warnings (Flood Watch, Flood Warning, etc)
Category D. On-site actions	D1. Ops activities (e.g. clear blockages at trash screens, culverts, etc)
Category D. On-site actions	D2. Operate active structures as necessary (e.g. close barriers)
Category D. On-site actions	D3. Erect demountable defences

Flood risk – The risk is the product of the flood impact (consequence) and the probability of the flood impact occurring. For example, a medium risk level could be the result of high impact, low probability or low impact, high probability.

Monetised benefit - In this report, the ‘benefit’ is the flood impact avoided. However, benefits can be both monetary and non-monetary. As part of the SC090032 study, a method was developed to convert non-monetary or intangible flood impacts to a monetised value. Therefore, monetised benefit includes an allowance for residential property damage and: loss of life/serious injury; non-residential property damage; social impact; and impact on critical infrastructure.

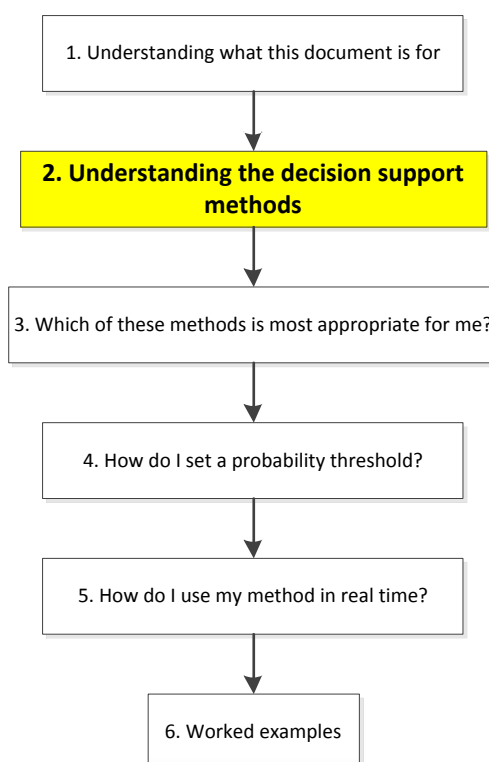
Probability – The likelihood or chance of something happening (such as a flood water level or rainfall depth being exceeded). It is often expressed as a percentage.

Probability threshold – A value (usually a percentage) used to trigger an action. For example, the probability threshold could be set as 35 per cent (probability of the water level exceeding the action level of 5.0 mAOD). If, during an event, the probabilistic forecast predicts a 40 per cent chance of the water level exceeding 5.0 mAOD, taking action (e.g. closing a barrier) would be recommended. Information on setting probability thresholds is provided in Section 4 of this guidance.

Water-level threshold – A water level (or rainfall depth for surface water flood risk) that relates to a particular response, for example: flooding of first property, river bankfull, flooding of critical infrastructure or defence overtopping. The Environment Agency defines action thresholds, result thresholds and information thresholds in the Work Instruction *Threshold setting in flood incident management (55/07)*. See Section 4.2 for more information.

Water level-impact relationship – This relates overall flood impact (the monetised benefit) to different water levels at a flood risk location.

2 How does the decision support method work?



The decision-support methods have been developed so that the effort involved in using each method is **proportional to the costs and benefits** of the decision in question. The methods can be used for different FIM actions and at different lead times ahead of a flood event.

The three methods range from simple to detailed; however, all methods are simple to apply in real time. These are described below.

2.1 Introduction to three decision-support methods

The three methods promote risk-based decision-making, are consistent and are based on quantified evidence supported by local knowledge. The methods are summarised as follows:

- **Basic method** – use a [probability threshold](#) for a specific FIM action based on judgement and local knowledge (e.g. 20, 40, 60 per cent).
- **Simplified method** – use a [probability threshold](#) based on the ratio of [FIM action cost](#) and the [monetised benefit](#) of that action (a cost-benefit approach in the widest sense).
- **Detailed method** – establish a [water level-impact relationship](#) for use in real time and, in real time, determine whether average flood impact of the forecast water levels (if no FIM action is taken) is greater than the FIM action cost.

The methods are described below ([Sections 2.1.1](#), [2.1.2](#) and [2.1.3](#)).

All three methods allow for ‘softer’ factors to influence the decision. These softer factors include local knowledge, recent flood history or historic forecast performance. They are generally ‘intangible’ and therefore are separate to a formal quantified cost-benefit approach. These softer factors are described in Section 2.2. While some softer factors will be subjective (will depend on the views of the duty officer at the time), decision-makers should try to keep softer factors as quantifiable as possible and to ensure that, quantifiable or not, the reasons for making a decision are recorded for audit purposes.

Typical FIM actions that might be taken with probabilistic flood forecasts are shown in [Section 1.5](#). More than one action at a specific location may be taken based on probabilistic forecasts; each FIM action would have its own probability threshold.

2.1.1 Basic method

The basic method requires the setting of a probability threshold as the trigger for taking a specific action. If the water level threshold relates to a relatively high flood impact, a low probability threshold (for example, five per cent or less) could be set to trigger a recommendation to take action, particularly if the cost of taking that action is relatively low. In real time, a probabilistic forecast with a probability of exceeding a threshold that is higher than the pre-set [probability threshold](#) would result in a recommendation to take action. Conversely, if the flood impact is lower, the probability threshold could be set higher. Conceptually, this is represented by the two zones in Figure 2-1.

Probability thresholds for specific FIM actions can be set using expert judgement by those with local knowledge of the flood risk. This method could be useful for low cost FIM actions such as those during the forecasting period (manning incident rooms and so on). For example, three to six days ahead of an event, a 20 per cent probability threshold could be set for taking an action such as setting a rota to man an incident room. The 20 per cent [probability threshold](#) would potentially relate to a flood level threshold such as defence overtopping or first property flooding. An example use of this method is given in Section 6.1.

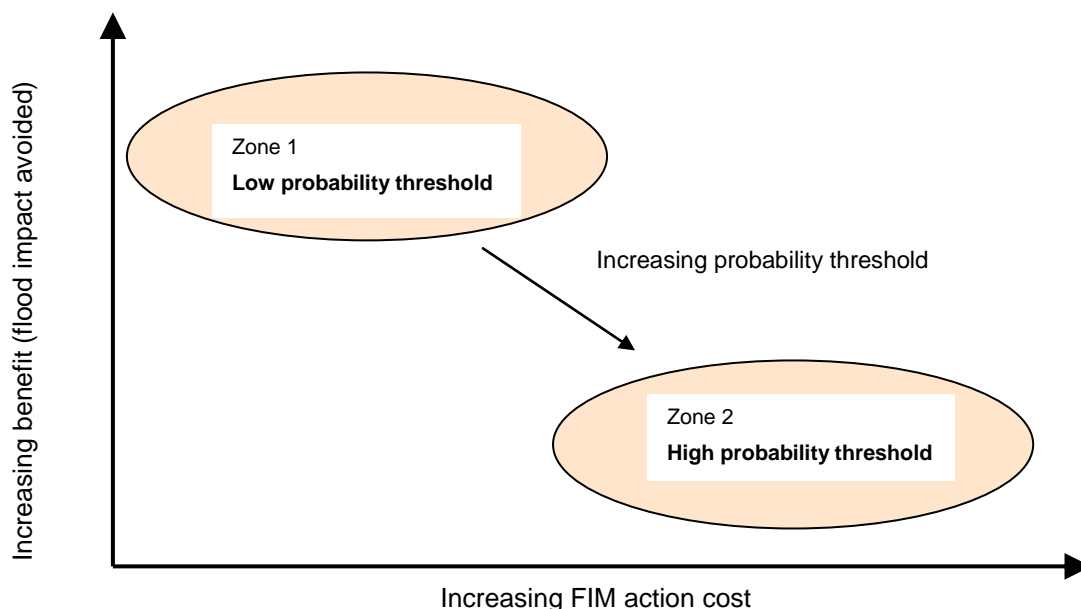


Figure 2-1 Cost-benefit concept for probability threshold setting

2.1.2 Simplified method

In the simplified method, the probability threshold is based on information on costs and benefits (flood impact avoided). For example, if the estimated cost of a FIM action is £10,000 (Environment Agency costs and those incurred by professional partners and the public as a result of the action) and the average benefit (flood impact avoided) from historic events is estimated to be £50,000, the cost/benefit ratio (C/B) is $10/50 = 20$ per cent. Hence, the [probability threshold](#) for this FIM action is 20 per cent. In a real-time forecast if, for example, there is a 21 per cent probability that the flood level will be exceeded, the method would recommend taking the FIM action. However, this would represent a marginal case (20 and 21 per cent are very close) and the decision-maker would be advised to check the 'softer' decision making factors (see Section 2.2 below) before deciding whether to take action. For example, there may have been a recent spate of false alarms, suggesting the forecasts are over-predictions and the public may become desensitised, so it may be better not to issue the warning.

An example use of this method is given in Section 6.2. Further information on the method is given in Appendix 1 of the Technical Report.

2.1.3 Detailed method

The third method is a little more detailed as it calculates the flood impact for each ensemble member from the probabilistic forecast and takes the average of these, which it uses to estimate the [monetised benefit](#). Therefore, it deals with extreme ensemble members in a more risk-based manner than the basic and simplified methods. An example of such a case is illustrated in Figure 1-1, in which there are two 'extreme' ensemble members. In the basic and simplified methods the predicted flood impact is the same as if two of the 24 exceedance members were 1.5 m above the water threshold. But in the detailed method, the flood impact would be significantly higher; the two very high forecasts would raise the average flood impact value significantly, thereby increasing the expected [monetised benefit](#) (flood impact avoided).

The average impact (benefit) can then be compared with the [FIM action cost](#) and if the benefit is greater than the cost, the decision-support method would recommend taking action. As with the other methods, softer factors also need to be considered, particularly in cases where the cost-benefit ratio is marginal.

In this method, initial information and data gathering is needed to establish a [water level-impact relationship](#) in which the overall flood impact is assigned a monetary value for a range of water levels. The steps to doing this are described in Section 4.2.

Once a water level-impact relationship has been derived, this method is simple to use in real time: a prototype tool enables users to load in forecast data for all ensemble members, assign a benefit value to each ensemble member, take the average and compare this value to the FIM action cost. A snapshot of the tool's operational panel, using an example for the Colne Barrier in Anglian Region, is shown in Figure 2-2. The forecast benefit value is calculated from the average benefit of all ensemble members' peak water levels, as shown in Figure 2-3. An example use of this method is given in Section 6.3.

Date	24/06/2011	Time	13:29:05
Team	Anglian FF Team	User	Joe Bloggs

Site/Community	Colne Barrier
	Load Probabilistic Forecast Result Data
Potential FIM action	D2. Operate active structures as necessary (e.g. close barriers)
Action cost	£4,000
Forecast benefit	£101,144
Initial recommendation	Take action

Soft factors influencing the decision include:

1. Do you want to use this event as a practice or training event or as a PR exercise? [could change a 'No' into 'Yes']
2. Is the community at risk in danger of being desensitised (i.e. too many false alarms?) [could change a 'Yes' into 'No']
3. Is this a highly sensitive location with recent flooding? [could change a 'No' into 'Yes']
4. Have there been any missed flooding events (not forecast) at this site ? [could change a 'No' into 'Yes']

Final action decision	Close Barrier
------------------------------	---------------

Justification

B-C ratio is very high, softer factors considered

¹ Forecast benefit comprises monetised impact of reduction in risk to life/serious injury, social impact, residential properties damage, business/agriculture damage and infrastructure disruption.

Figure 2-1 Prototype real-time decision-support tool, using Colne Barrier and FIM action of barrier closure as example

Probabilistic Forecast Data

	Level (mAOD)	Flood impact avoided by action (£)	Exceeding threshold?
Ensemble 1	3.297	£0	0
Ensemble 2	3.296	£0	0
Ensemble 3	3.264	£0	0
Ensemble 4	3.277	£0	0
Ensemble 5	3.317	£208,981	1
Ensemble 6	3.318	£224,816	1
Ensemble 7	3.285	£0	0
Ensemble 8	3.331	£386,912	1
Ensemble 9	3.330	£376,332	1
Ensemble 10	3.288	£0	0
Ensemble 11	3.291	£0	0
Ensemble 12	3.336	£442,730	1
Ensemble 13	3.297	£0	0
Ensemble 14	3.296	£0	0
Ensemble 15	3.264	£0	0
Ensemble 16	3.292	£0	0
Ensemble 17	3.302	£25,561	1
Ensemble 18	3.342	£513,820	1
Ensemble 19	3.292	£0	0
Ensemble 20	3.288	£0	0
Ensemble 21	3.310	£124,276	1
Ensemble 22	3.310	£124,032	1
Ensemble 23	3.272	£0	0
Ensemble 24	3.284	£0	0
Expected Action Benefit (£)		£101,144	
Action Level Threshold (mAOD)			3.3
Exceeding probability			38%

Figure 2-2 Automatic calculation of monetised benefit for each ensemble member water level peak (prototype real-time decision-support tool)

2.2 ‘Softer’ decision making factors

Although important, costs and benefits are not the only aspects affecting decisions made during floods. ‘Softer’ factors such as local or informal knowledge, recent flood history or historic forecast performance at a site are all relevant when deciding on the best response. A list of possible softer factors is provided in Table 2-1¹.

In real time, consideration of ‘softer’ factors may result in the overruling of an action recommended purely through cost-benefit relationships. For example, a decision to raise demountable defences from a cost-benefit perspective could be reversed after other factors are considered – if, say, recent forecasts have been overestimating peak water levels, in this marginal case it may be best not to raise the barriers to save money. Alternatively, a marginal cost-benefit recommendation not to raise the barriers could be overruled where public relations and operational staff training could benefit from raising the barriers.

In some cases there might be transient factors, for example a camp site or festival located in a flood risk area for a short period that would increase the benefit of a

¹ These softer factors were collated from the user consultation workshop in March 2010, project board meetings and discussions with Environment Agency and Flood Forecasting Centre staff.

particular FIM action during that time. In such cases, consideration of this factor would need to be made in real time, so that a marginal recommendation not to take action might be reversed.

The consideration of softer factors allows precautionary action to be taken as necessary.

In these overruling cases it is important to record, for audit purposes, that the cost/benefit recommendation has been overruled and the reason for this.

A further set of factors, known as intangible impacts, are considered within the setting of probability thresholds for each of the three methods, described in Section 4. For example, risk to life and the social impact of flooding are captured with the [monetised benefit](#) estimate. The way this is done is described in Section 4.

Table 2-1 Examples of ‘softer’ decision making factors in FIM decision-making

FIM action category	Example soft decision making factor	Example scenario
Monitoring and forecasting or event preparation (longer lead time)	<p><i>Internal (Environment Agency staff) training/event practice</i></p> <p>At longer lead times, actions such as setting shifts in incident rooms can be taken when cost-benefit information or probability threshold crossings might not recommend them.</p>	<p>A probability threshold for staff mobilisation at 72 hours prior to an event is set at 10%. A probabilistic forecast suggests a threshold exceedance of eight per cent. A decision to mobilise staff could be taken (overriding the strict application of the threshold) as the costs of doing so are negligible and there are training benefits in taking action.</p>
On-site actions or warning dissemination (shorter lead time)	<p><i>Practice/public relations</i></p> <p>Taking action for the benefit of training staff and reassuring the public.</p>	<p>Although the water level is not expected to result in flooding, putting up demountable defences could provide training for operational staff and reassurance to the public.</p>
	<p><i>High rate of false alarms</i></p> <p>If the community at risk has experienced a high proportion of false alarms and might be becoming desensitised as a result, a ‘yes’ recommendation to take a FIM action could be reversed.</p>	<p>A particular site might have a flood forecasting catchment model that is known to over-predict (high probability of detection [POD] but also high false alarm ratio [FAR]). Hence a recommendation to issue a flood alert through the cost-benefit method could be reversed, particularly if it is a borderline case. If no false alarm data exist, this could be a decision taken on local knowledge of the community and judgement. (There may be a need to adjust the probability threshold or improve a forecast model to account for a known bias in the forecasts.)</p>
	<p><i>Community flood sensitivity</i></p> <p>Recent high profile flooding in or near a location could mean that a more precautionary approach is taken than recommended by the cost-benefit approach.</p>	<p>A community has recently experienced serious flooding. A marginal cost-benefit recommendation not to take action could be reversed, following consultation with Environment Agency staff, depending on the potential flood impact.</p>
	<p><i>History of missed events</i></p> <p>If there is evidence/local knowledge of flood events that were not forecast and warnings that were not issued (on time or at all), there may be benefit in marginal ‘no’ recommendations being overridden.</p>	<p>The POD at a site is below 50% and there is a marginal recommendation not to close a barrier. Due to the low POD, the decision-maker might want to be more precautionary and close the barrier. (As above, there may be a need to adjust the probability threshold or improve a forecast model to account for a known bias in the forecasts).</p>
	<p><i>Timing/special events</i></p> <p>A bank holiday weekend or special event, like a musical festival, might bring many more people into the area than normal and so alter the cost/benefit ratio on which decision thresholds were originally set.</p>	<p>With more people at risk the potential impact is higher, hence action at a lower probability threshold would be justified.</p>

3 Which method should I choose?

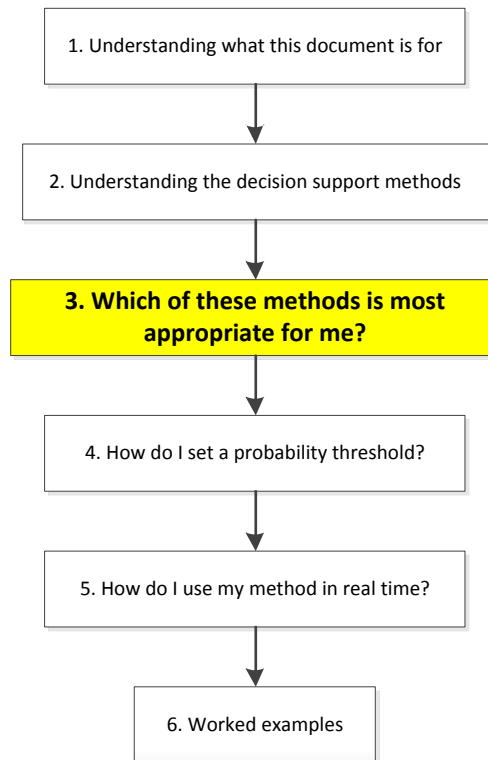


Figure 3-1 shows a flow chart to help you decide which of the three methods is best suited to your site. Choosing the appropriate method is an activity that would happen off-line, not in real time.

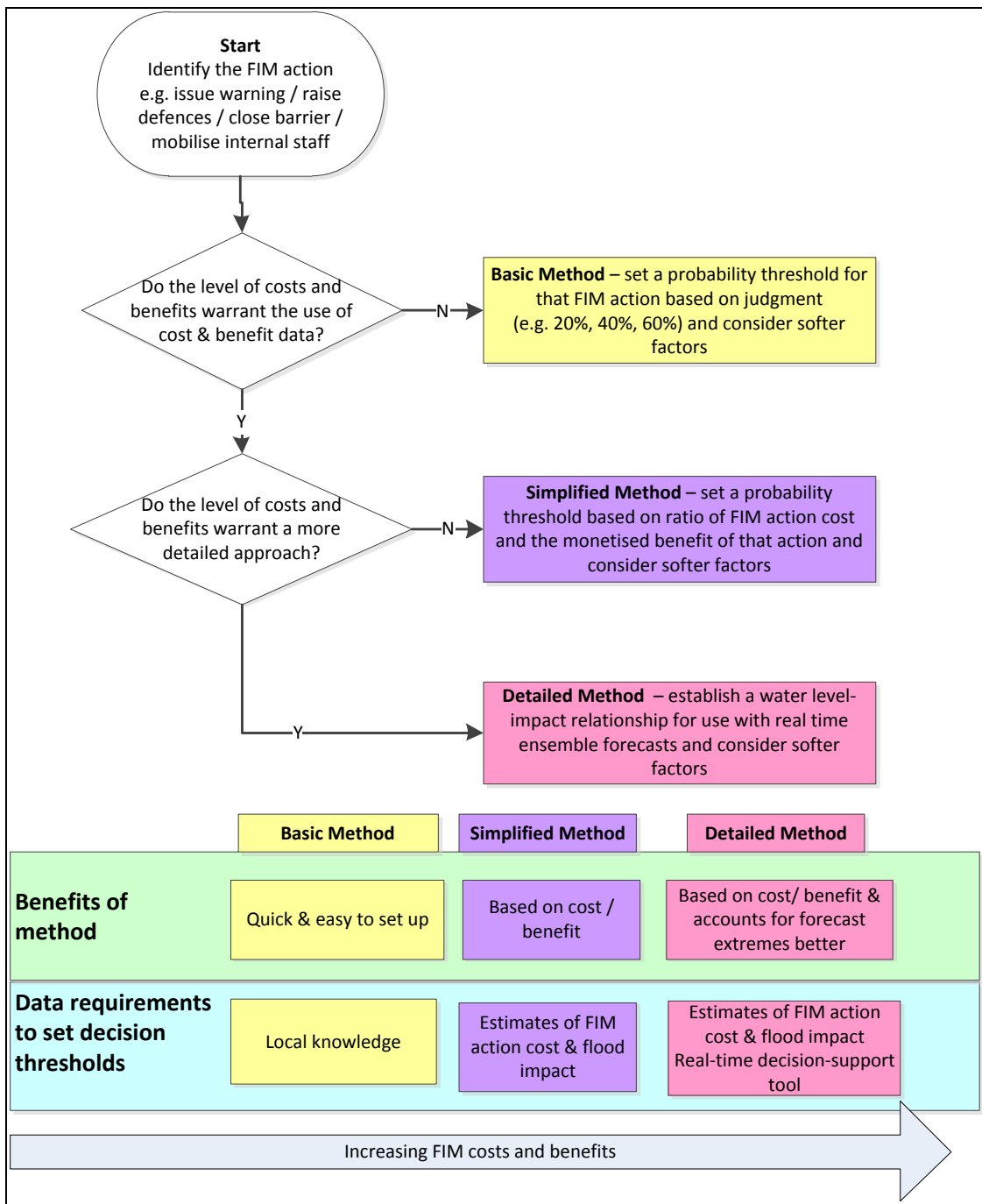


Figure 3-1 Flow chart for selecting decision-support method, showing benefits and data requirements of each method

Suggested applications of the different decision-support methods for different FIM actions are shown in Table 3-1. These offer examples of how different FIM actions might be applied logically to each method, rather than being strict rules for categorising FIM actions into methods.

Table 3-1 Suggested methods for different example FIM actions

	Basic method	Simplified method	Detailed method
	<i>Probability thresholds set by judgement</i>	<i>Probability thresholds set through ratios of cost to benefit</i>	<i>Average benefit of all forecast ensemble members compared with cost</i>
Examples of possible FIM action	Taking 'heads-up' forecasting actions in fluvial, coastal or surface water flood risk situations, such as deciding to staff the flood incident room, holding of teleconference calls, awareness raising with professional partners*.	Closing minor tidal gates that have a flood risk management role. Issuing surface water flooding alerts or setting surface water flooding risk level in the Flood Guidance Statement (cost/benefit method can be used to set individual probability thresholds for different FIM actions).	Closing major tidal gates/barriers that have a flood risk management role. Raising demountable defenses on river banks or coastal locations. Deriving operating rules for flood storage basins.
All methods could be used to support the issuing of flood warnings ²			

* In the case of such 'heads-up' forecasting actions, these would be likely to occur at multiple sites; it is unlikely that such actions would be justifiable at one individual site.

3.1 What data and work are required to apply each of the methods?

As well as the potential flood impact on the at-risk community affected by the FIM action, another consideration in selecting the method is the human and data resources available to apply the method. In cases where available human and/or data resources are low, the basic method is likely to be a good starting point, allowing users to set a judgement-based probability threshold to trigger a specific action from a probabilistic forecast. After time, and practice using probabilistic flood forecasts, the simplified or detailed methods could be developed at the same site as more information or resources become available.

In deciding between the simplified and detailed methods, users should bear in mind that although the simplified method is less complex, it makes less use of the information in the forecasts. The simplified method uses a count of the number of ensemble members above a threshold, taking no account of how much the forecasts exceed the threshold by. By contrast, the detailed method exploits all the scenario information from each ensemble member on how severe the flood impact might be. So, for example, the detailed method might recommend taking action for a low probability of a severe flood where the simplified method would not; equally the detailed method could recommend not taking action for a high probability if the flood would have a very low impact.

Table 3-2 provides information on the data and work (effort) required to use each method for each forecast site at which the method is applied. The work requirements are split into off-line and real-time work requirements.

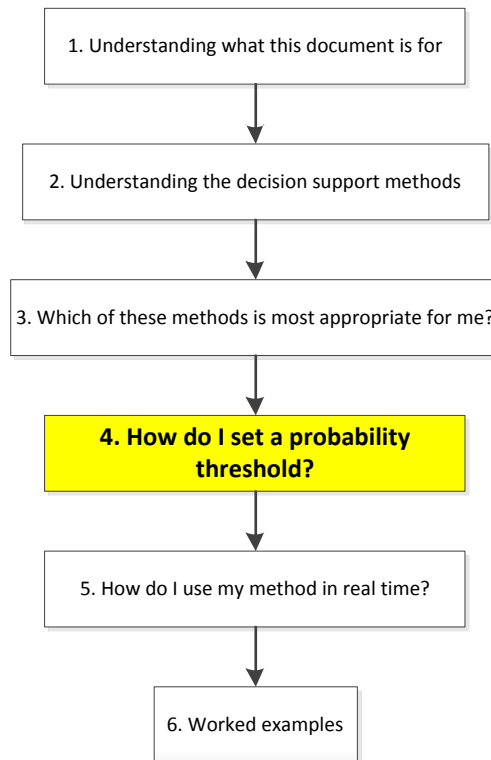
² Community consultation should be considered when setting probability thresholds to issue flood warnings so that communities have a say in threshold setting and are not separated from this process— e.g. for example, asking 'at what probability of flooding would you like to be warned?'

Worked examples that show how data and information have been applied for different decision-support methods are included in [Section 6](#).

Table 3-2 Data and work requirements for each decision-support method

	Basic method	Simplified method	Detailed method
Data requirement per individual FIM action	<p>Local knowledge of:</p> <ul style="list-style-type: none"> the site and its history; the level of potential flood impact; the accuracy of historic flood forecasts; the approximate costs of taking specific FIM actions <p>(see Section 2.1.1).</p>	<p>Estimates of FIM action cost and flood impact:</p> <ul style="list-style-type: none"> An estimate of FIM action cost (derived from factors such as staff time, operational costs, costs incurred by professional partners and the public). An estimate of average flood impact (£) derived from historic high water level/flood events. These estimates enable the cost/benefit ratio to be calculated and a probability threshold set (see Section 2.1.2). 	<p>Estimates of FIM action cost and flood impact:</p> <ul style="list-style-type: none"> An estimate of FIM action cost (derived from factors such as staff time, operational costs, costs incurred by professional partners and the public). The derivation of a water level-impact relationship (estimated from number of properties flooding at different water levels and includes allowance for other flood impacts). Population of the cost estimate and water level-impact curve into the real-time decision-support tool (see Section 2.1.3).
Estimated work requirement per individual FIM action (off-line)	<p>Approximately 0.5 day of local flood risk specialist with review by manager + 0.25 day to configure thresholds within the National Flood Forecasting System (NFFS) (or less if configured in batches). Roughly 0.25 day to update manuals and procedures.</p>	<p>Approximately two person days of local flood risk specialist with review by manager + 0.25 day to configure thresholds within NFFS (or less if configured in batches). Roughly 0.25 day to update manuals and procedures.</p>	<p>Approximately two to five person days of local flood risk specialist (depending on level of detail to develop water level-impact curve) with review by manager + 0.5 day to configure real-time decision-support tool into NFFS (or less if configured in batches). Roughly 0.25 day to update manuals and procedures.</p>
Estimated work requirement per FIM action (real time)	<p>Under one minute – operated through NFFS with automated probabilistic forecast information + five minutes consideration of softer factors.</p>	<p>Under one minute – operated through NFFS with automated probabilistic forecast information + five minutes consideration of softer factors.</p>	<p>Under one minute – operated through NFFS with automated probabilistic forecast information and use of real-time decision-support tool + five minutes consideration of factors.</p>

4 How do I set a probability threshold?



For the basic and simplified methods two types of threshold are required:

1. Water level (or rainfall depth) thresholds that relate to a particular flood water level or flood impact.
2. Probability thresholds – a percentage value that acts as the trigger for taking an action.

Water level (or rainfall depth³) thresholds can be set through standard methods, consistent with the Environment Agency Operational Work Instruction: *Threshold setting in flood incident management* (Number 55_07). These are used for both deterministic and probabilistic forecasts.

Probability thresholds are specific to probabilistic forecasts and the SC090032 project has produced a simple prototype tool to set the threshold for a specific location and action over a specific time window prior to a potential flood peak. This is a separate tool to the prototype decision-support tool described in Section 2.

The probability threshold is decided in advance so that a pre-set threshold is available in real time during a forecast potential flood event. The tool developed is Excel-based and is shown in Figure 4-1.

³ The prototype threshold setting tool was developed to use probabilistic forecasts of peak water level (for coastal surge or river level). Decision-making from probabilistic rainfall forecasts (e.g. for surface water flood risk or rapid response catchments) is undertaken by the Flood Forecasting Centre (FFC). However, the concepts within the threshold setting tool can also be applied to probabilistic rainfall forecasts.



 FIM Probability Threshold Setting Tool 	
Name of flood risk location	<input type="text"/>
Flood Incident Management Action	<input type="text"/>
Time window for deciding on FIM action (hours or days ahead of event)	<input type="text"/>
Estimated cost of taking FIM action* (£'000)	<input type="text" value="25"/>
Estimated monetised benefit of taking FIM action**	<input type="text" value="190"/>
Appropriate probability threshold	<input type="text" value="13%"/>
Data entered by (name) on (date)	<input type="text"/>

Figure 4-1 Prototype probability threshold setting tool

In the threshold setting tool (see Figure 4-1) the probability threshold is set by dividing the estimated FIM action cost by the monetised benefit of taking that action. For example, if a probability threshold of 20 per cent is set for a specific FIM action, a forecast probability of exceeding a specified water level of over 20 per cent (such as five ensemble members or more out of 24) would trigger that FIM action, based on the cost and benefit information used. Other factors will determine whether to overrule the recommendation. These are considered in the real-time environment. Two worked examples of setting a threshold using the prototype tool are provided at the end of this section.

The tool is designed for FIM actions that lead to a direct flood impact reduction. This tool relates to the use of the simplified method.

The cost can be estimated by summing standard staff cost rates of operational Environment Agency staff and costs incurred by others (professional partners and the public) who take action. Two worked examples of how costs can be estimated are outlined below.

The [monetised benefit](#) of taking the FIM action can be estimated in a number of ways. One approach is to broadly assess the number of properties that would benefit from the action and then scale up this value to allow for non-property related impacts. Data from the 2007 summer floods suggests that the economic costs of non-household damages were 1.6 times the costs of household damages⁴. In the report on these floods, household economic costs (buildings and contents) were estimated at £1.2 billion and the cost estimate for other impacts (including businesses, vehicles, infrastructure, utilities, public health/fatalities, agriculture) was £2.0 billion: a ratio of 1.6 (or scaling factor of 2.6).

A more rigorous approach is to carry out a local analysis of the main flood impacts that would benefit from the action. A multi-criteria analysis tool was developed on a

⁴ *The cost of the summer 2007 floods in England*, report, SC070039/R1, Environment Agency, 2010

Halcrow study for SNIFFER⁵ and adapted as part of this project. The multi-criteria analysis tool enables non-residential property damage to be compared with other flood impacts and allows these to be monetised by apportioning weightings to each of the flood impact criteria. If important local sites (a hospital or school, for example) are at risk, these may need to be considered separately in the benefit estimate. An example of this is described in the worked example in Section 6.3.

Choosing between the scaling factor of 2.6 or the multi-criteria analysis tool will depend on the level of cost and benefit of the actions. The choice should be proportionate to the cost and benefit and the resources available to carry out the analysis. A sensible approach would be to start with the simpler scaling-up approach, test this and if experience suggests it is not giving suitable results, run the fuller analysis or plan to do so at a later date.

The following two examples illustrate how threshold setting would work for closing a structure or issuing a flood warning. In the first example, closure of a flood control structure assumes that the impact is reduced to zero (the benefit = 100% of impact if no action is taken). However, in the second example, inundation still occurs and therefore the benefit is only part of the impact if no action is taken (the example assumes a nine per cent saving due to mitigating actions taken by those at risk of flooding⁶).

4.1 Building in a factor of safety

Where forecast reliability is less than ideal (model error is greater than the spread in the forecast), it may be useful to build in a 'factor of safety' into the threshold setting. There are two options for doing this:

- i) Reduce the water level threshold used (so if a water level of 5.0 m relates to first property flooding, a water level threshold of 4.8 m could be used (providing a 200 mm factor of safety). This is similar to an ACTCON threshold used in existing Environment Agency procedures.
- ii) Set a probability threshold as described above, and then lower that probability threshold to be more conservative (so a starting probability threshold of 20% could be lowered to 10% for a particular FIM action).



However, applying factors of safety may increase the number of false alarms, while increasing the probability of detection.

In some cases the probabilistic forecast may allow use of a smaller factor of safety than is required with deterministic forecasts.

⁵ *Assessing the benefits of flood warning* (UKCC10A & UKCC10B), study for SNIFFER (Scotland & Northern Ireland Forum for Environmental Research). Project involved the Environment Agency.

⁶ Flood Hazard Research Centre (FHRC), Middlesex University, *The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques - 2010 (Multi-coloured Manual)* (2010)

Worked Example 1: Decision to close a flood control structure

 FIM Probability Threshold Setting Tool 	
Name of flood risk location	ABCD
Flood Incident Management Action	Closure of sluice X
Time window for deciding on FIM action (hours or days ahead of event)	T+ 24 to T+6 hours
Estimated cost of taking FIM action (£'000)	6
Estimated monetised benefit of taking FIM action (£'000)	300
Appropriate probability threshold	2%
Data entered by (name) on (date)	AN Other

Process for entering cost & benefit estimates

Cost estimate:



- standard staff cost rates of operational EA staff: 3 ops staff @ £27/h * 8h * 1 day = £648; proportion of forecasting staff time @£27/h * 6 = £162; fuel, incidentals c.£100 (total [rounded] = £1,000)
 - allowance for disruption caused due to sluice closure: £5,000
- Total cost = £6,000

Benefit estimate:

10 properties at risk of flooding: $10 * £12,720^1 * 2.6$ (factor for non-property damage impact) = £330,720 (rounded to £300,000)

¹ figure derived from Environment Agency report: The costs of the summer 2007 floods in England Project: SC070039/R1 - calculated as £24,000 per household * 53% (factor to convert financial loss to economic loss to the nation and reduction of VAT)

Worked Example 2: Issuing of flood warning

 FIM Probability Threshold Setting Tool 	
Name of flood risk location	WXYZ
Flood Incident Management Action	Issue of Flood Warning message to Community X
Time window for deciding on FIM action (hours or days ahead of event)	T+ 12 to T + 2 hours
Estimated cost of taking FIM action (£'000)	10
Estimated monetised benefit of taking FIM action (£'000)	45
Appropriate probability threshold	22%
Data entered by (name) on (date)	AN Other

Process for entering cost & benefit estimates

Cost estimate:

- standard staff cost rates of operational EA staff: Additional time input for duty staff and manager input £40/h * 15 * 2 staff = £1,200
 - estimated costs incurred by others (professional partners and the public) who take action:
 - Public & Businesses - 100 people receive warning, assume 50% take action, assume action costs are £100/person = £5,000
 - Prof. Partners - assume 5 management staff affected @ £40/h * 4hours and 10 operations staff from council @ £27/h * 8 hours + £500 fuel and incidentals = £800 + £2,660 = £3,460
- Total cost = £9,660 (rounded to £10,000)

Benefit estimate:

15 residential properties at risk of flooding; £12,720¹ / property * 2.6 (factor for non-property flood impact) * 9% (effectiveness of flood warning estimate²) = £44,647 (rounded to £45,000)

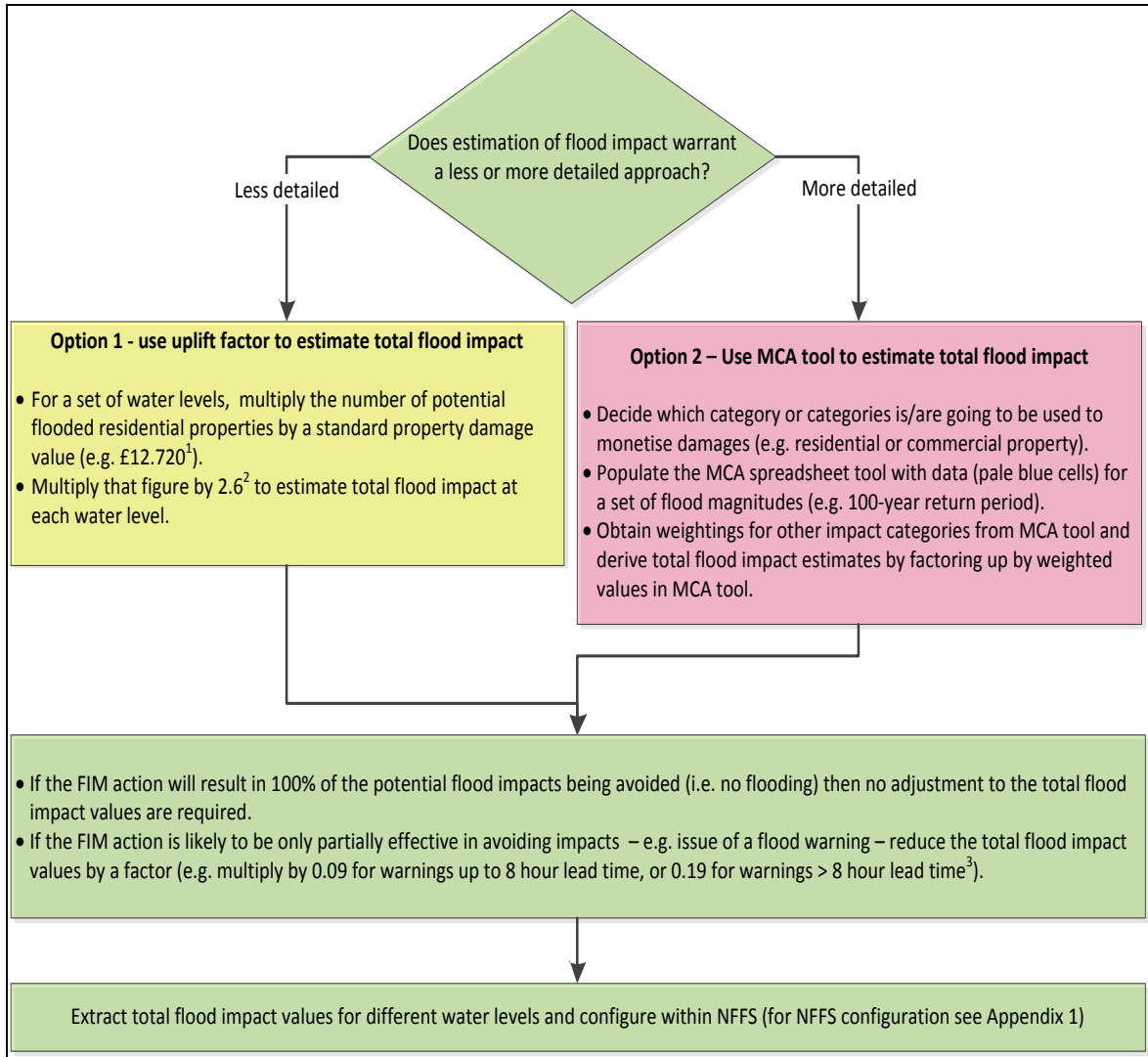
¹ figure derived from Environment Agency report: The costs of the summer 2007 floods in England Project: SC070039/R1 - calculated as £24,000 per household * 53% (factor to convert financial loss to economic loss to the nation and reduction of VAT)

² source: Flood Hazard Research Centre (FHRC) Middlesex University - The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques-2010 (Multi-coloured Manual) (2010), 9% applied to warning lead times of <8 hours, 19% applied to warning lead times > 8 hours

4.2 Developing a water level-impact relationship

If using the detailed method, a water level-impact relationship is required to accompany the water level threshold. As described in Section 2.1.3, this enables a monetised flood impact value to be estimated for all flood water levels. Once completed, a flood impact can be estimated for each forecast ensemble member, from which the average value is taken and compared with the estimate of FIM action costs.

Two suggested methods for establishing the water level-impact relationship are shown in Figure 4-2.



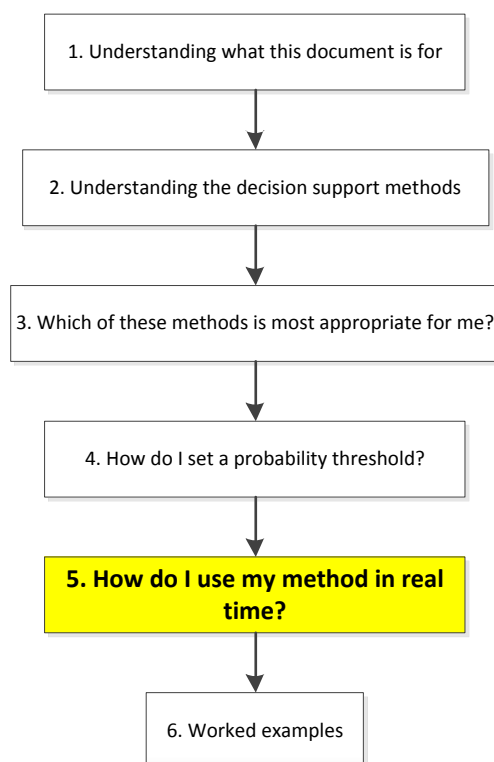
¹ £12,720 is derived from Environment Agency report, *The costs of the summer 2007 floods in England* calculated as £24,000 per household * 53% (factor to convert financial loss to economic loss to the nation and reduction of VAT).

² Economic costs of non-household damages were 1.6 times the costs of household damages in the above-mentioned report, hence multiplying residential damage by 2.6 provides an estimate of total damage.

³ Source: Flood Hazard Research Centre (FHRC), *The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques - 2010 (Multi-coloured Manual)*

Figure 4-2 Establishing the water level-impact relationship – suggested methods

5 Real-time decision support



In real time the three methods will operate as follows for each individual FIM action.

5.1 Basic method and simplified method

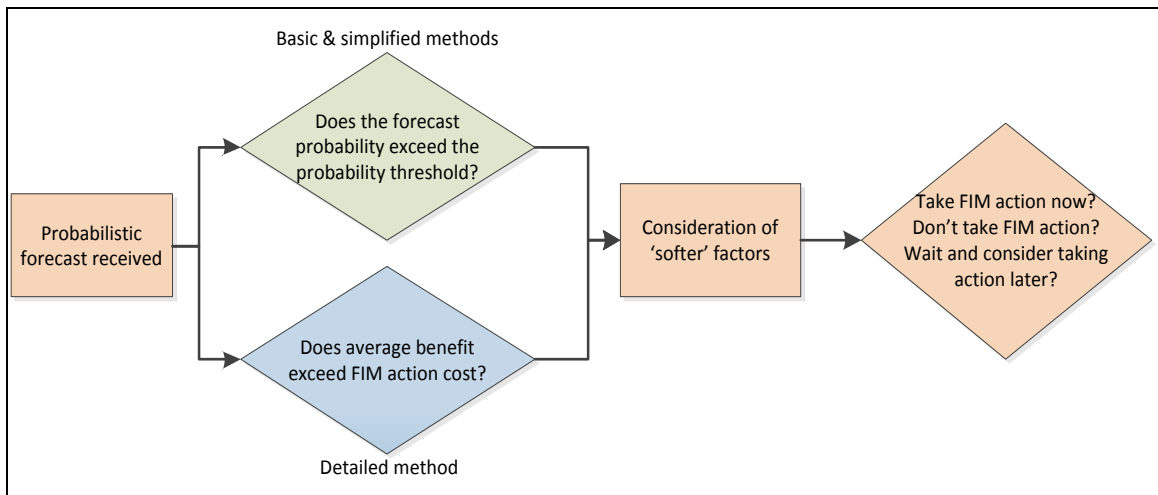
1. A probabilistic forecast is received for a site/location.
2. A pre-set water level (or rainfall depth) threshold is known and a pre-set probability threshold (linked to a specific FIM action) is known.
3. If the forecast probability is higher than the probability threshold, the decision-maker should consider taking the FIM action that is linked to the pre-set probability threshold at the time of the forecast or decide to wait until the next forecast is received, if time allows.⁷
4. Particularly for marginal decisions, the decision-maker should consider 'softer', site-specific factors that might overrule the decision recommended by the cost-benefit calculation.

⁷ For instance, if a threshold to close a barrier is reached two days in advance this might not be actioned until one day or tide cycle in advance; instead, some 'low- regrets' options such as 'enhanced monitoring' could be initiated.

5.2 Detailed method

1. A probabilistic forecast is received for a site/location.
2. The forecast ensemble members are assigned a monetised flood impact value (this is automated within NFFS – the National Flood Forecasting System) by reference to the water level-impact relationship for the site (see Section 4.2).
3. The cost of the FIM action is compared with the average monetised flood impact – if the impact is higher than the cost, the online tool (within NFFS) will recommend taking action at the time of the forecast, or the decision-maker could decide to wait until the next forecast is received, if time allows.
4. Particularly for marginal decisions, the decision-maker should consider ‘softer’, site-specific factors that might overrule the decision recommended by the numerical calculation.

The real-time decision making process is shown schematically below.



5.3 Configuration of the methods on NFFS

A pilot configuration study was undertaken using the Colne Barrier in Essex during the period November 2011 to January 2012. The findings from this configuration are presented in Appendix 1. These should be useful for any teams configuring one or more of the methods onto NFFS.

The configuration process assumes probabilistic flood forecasts are available at the site at which the methods are being configured.

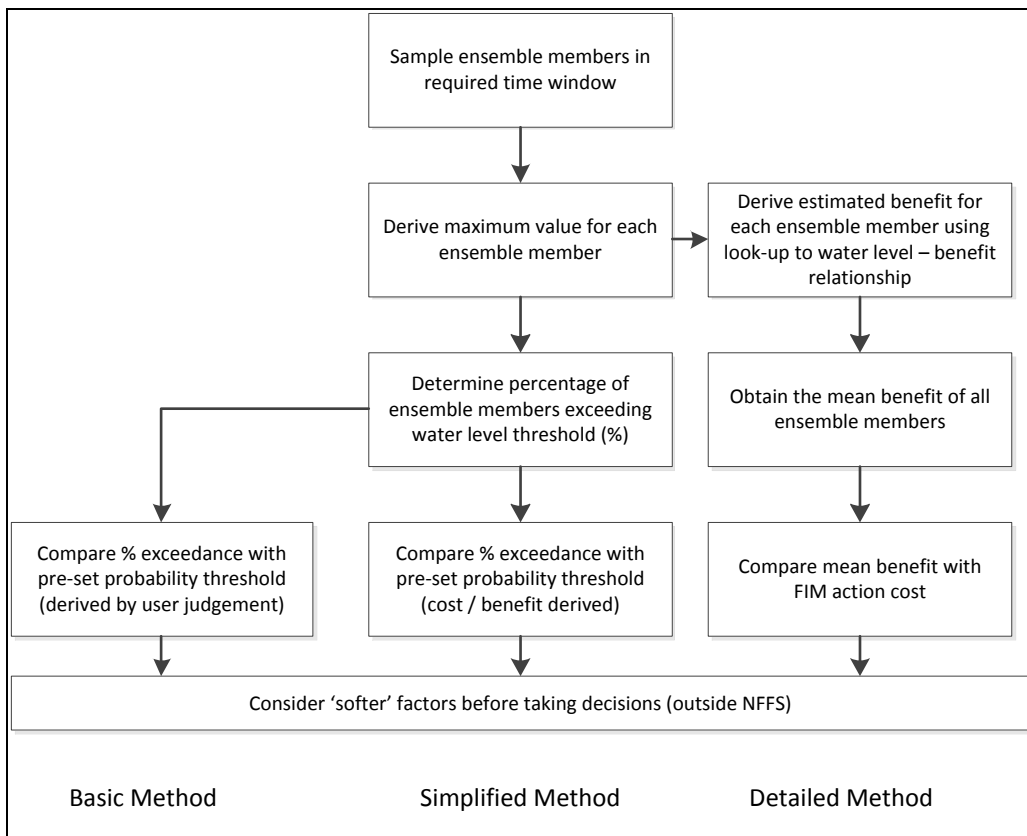


Figure 5-1 Steps to complete configuration of each method within NFFS

The configuration is carried out in the three basic phases: data preparation, calculation and results viewing. The following steps are required for each phase.

Data preparation:

- Configure threshold values for exceedance probabilities (simplified and basic methods) and cost of operation (detailed method).
- Define new parameters for: exceedance (yes [1]/ no [0] flag), exceedance probability (simplified and basic methods), cost and mean cost (detailed method).
- Extract peak values within the time horizon for each ensemble member.
- Ensure that any modules required to calculate values per ensemble member are run in “run in loop” mode.

Calculation:

- Derive exceedance flag (0 or 1) for each ensemble member based on threshold crossing (basic and simplified methods).
- Determine benefit for each ensemble member based on look-up tables or user-defined functions (detailed method).

- Calculate mean of ensemble exceedance flags to determine exceedance probability (basic and simplified methods).
- Calculate mean of ensemble benefit (detailed method).

Results viewing:

- Add outputs to display groups: ensemble peak values and action threshold; exceedance probability and thresholds (basic and simplified methods); ensemble benefit and action cost (detailed method).
- Configure display options for the new parameters.
- Configure options for tabular summary output.

The results available to view in NFFS are the real-time probability of water level threshold exceedance, the probability threshold, and the ensemble peak water levels. For the detailed method, the results shown are the average benefit (of all ensemble members) compared with FIM action cost. This then provides the recommendation for taking action, prior to consideration of softer factors. Figure 5-2 to Figure 5-5 show the proposed format for displaying the decision support data in NFFS. These figures are examples of potential output and not necessarily recommended output. The exact format of the output may be a matter of preference for each region.

Identifying total water peaks when these do not occur on astronomical tide peaks

In the Colne Barrier case, only astronomical highs and lows are available. Hence, it is only possible to calculate the tidal peak (astro + surge) coincident with the astronomical high. For other coastal locations with continuous series for surge and astronomical tides, the tidal peak does not necessarily need to coincide with the astronomical peak. Therefore a scatter of peaks would be available, for the same tide cycle, varying in both time and height⁸. This would also be the case for fluvial locations where the peak could occur at any time within a defined time window.

⁸ Information provided by Alex Minnett, Deltares

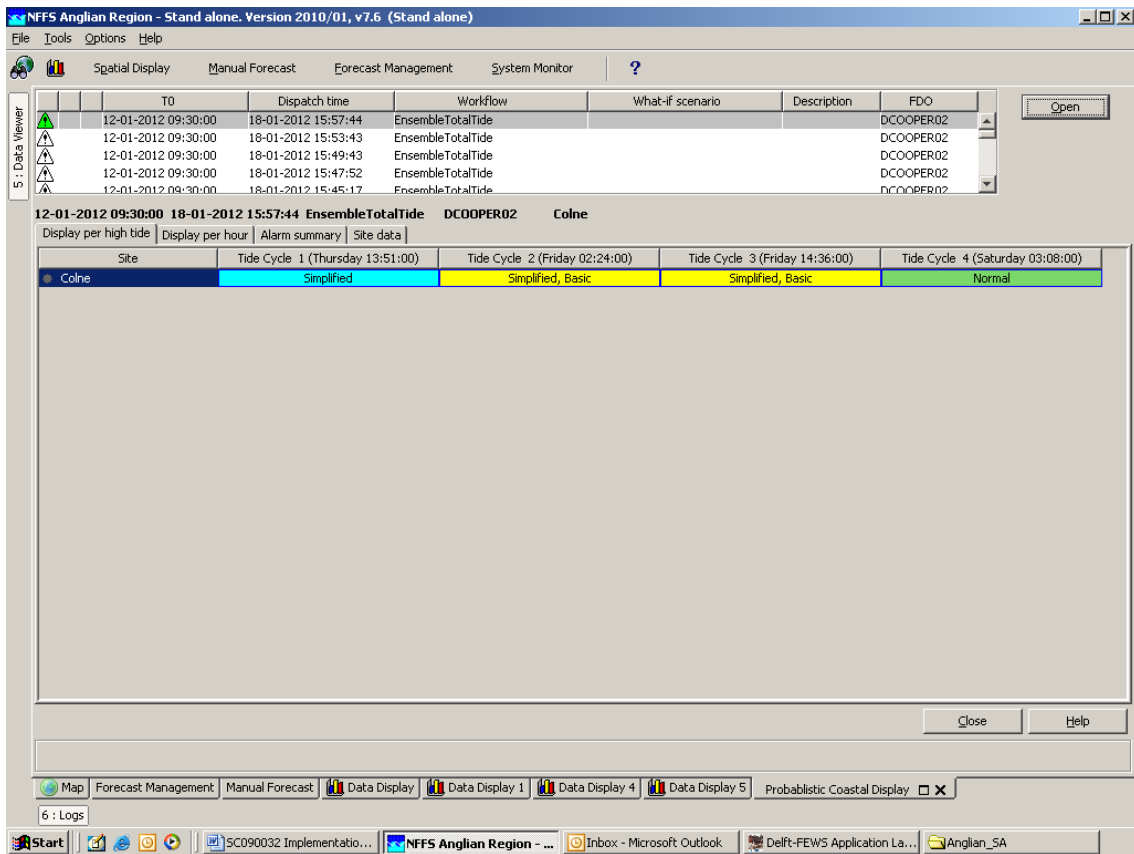


Figure 5-2 Probabilistic Coastal Display – Tab 1 displaying the thresholds exceeded per tide

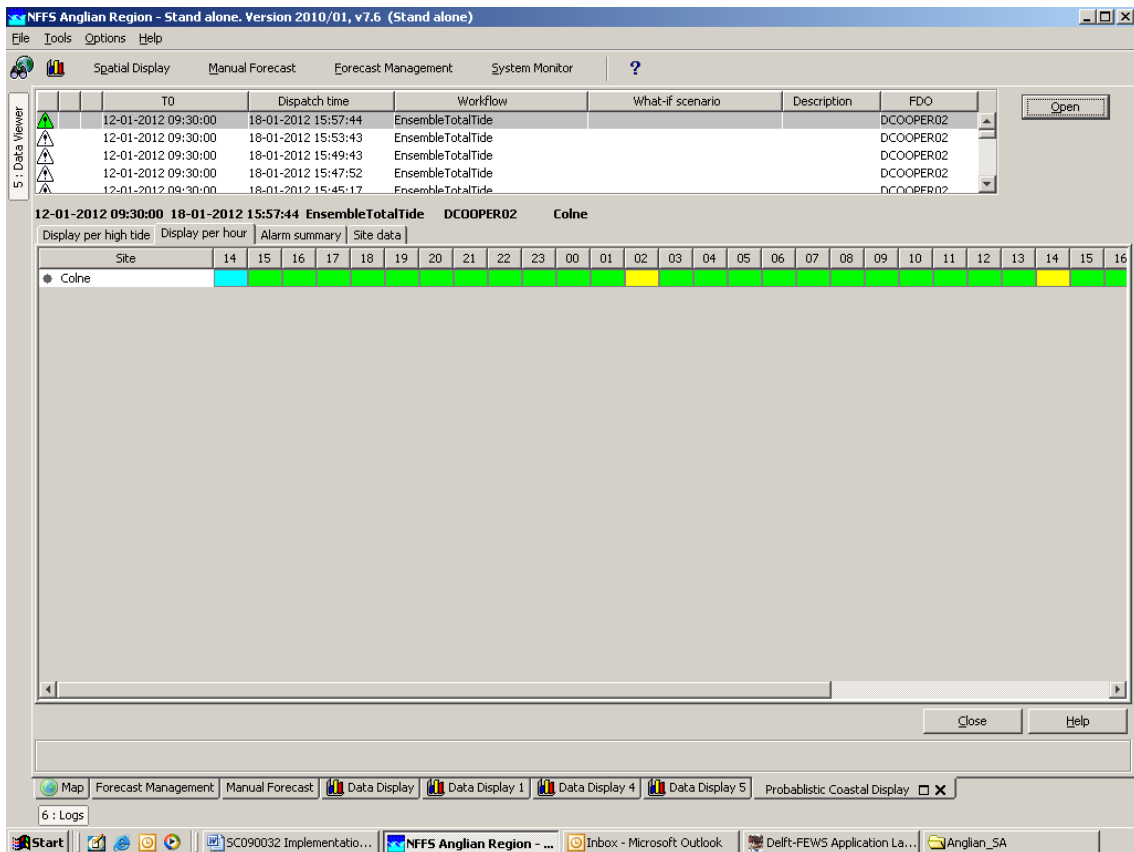


Figure 5-3 Probabilistic Coastal Display – Tab 2 displaying the thresholds exceeded per hour

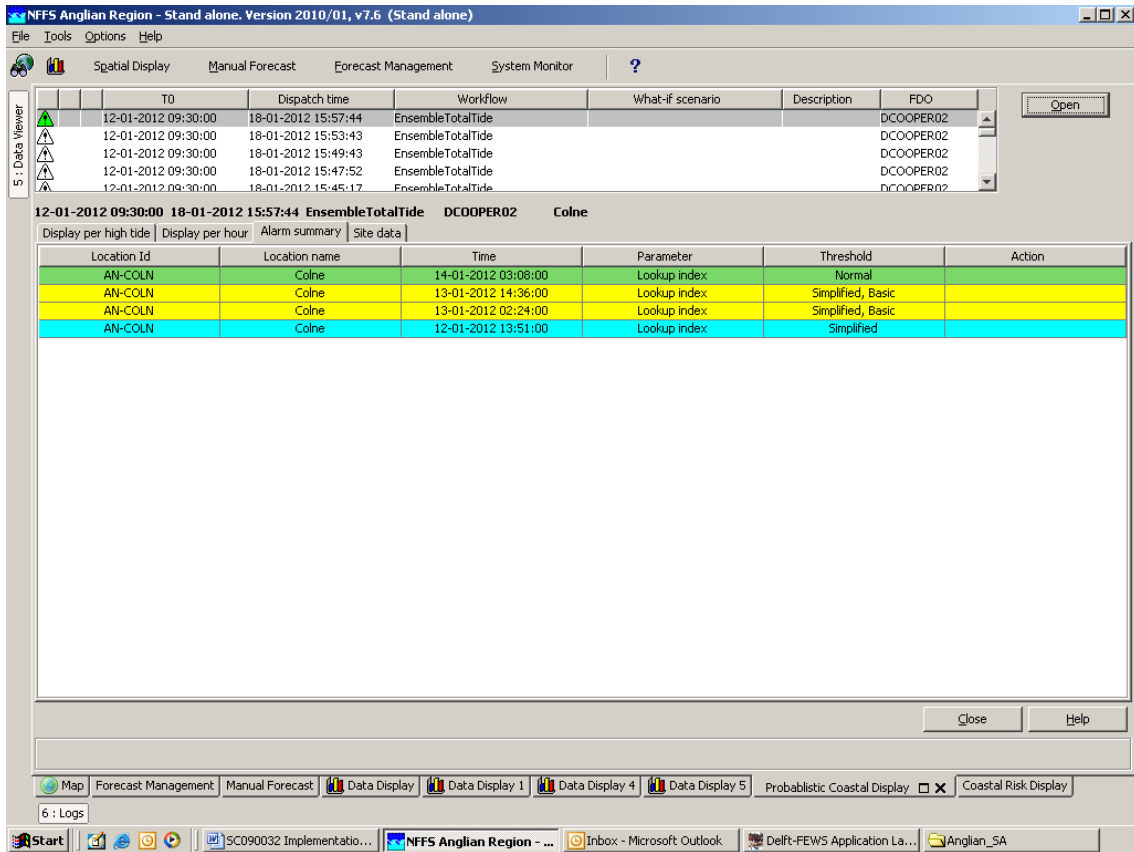


Figure 5-4 Probabilistic Coastal Display – Tab 3 showing alarm summary

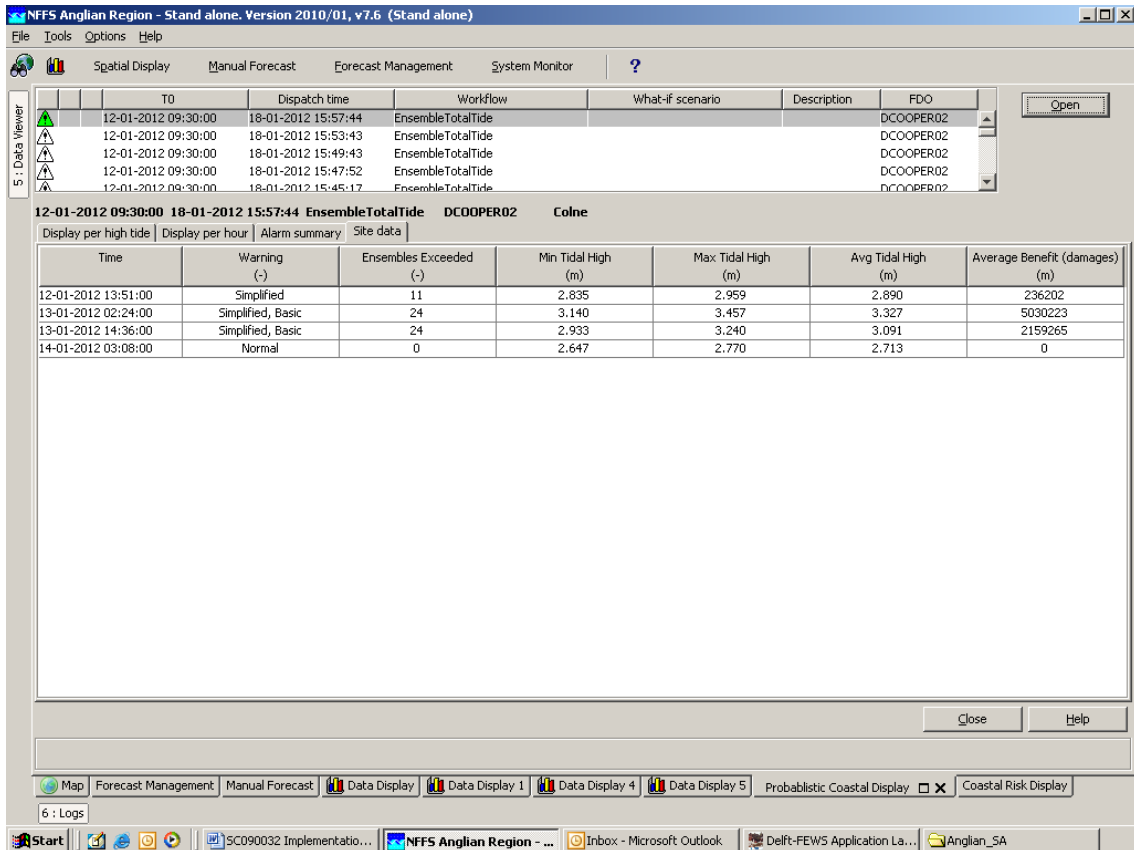
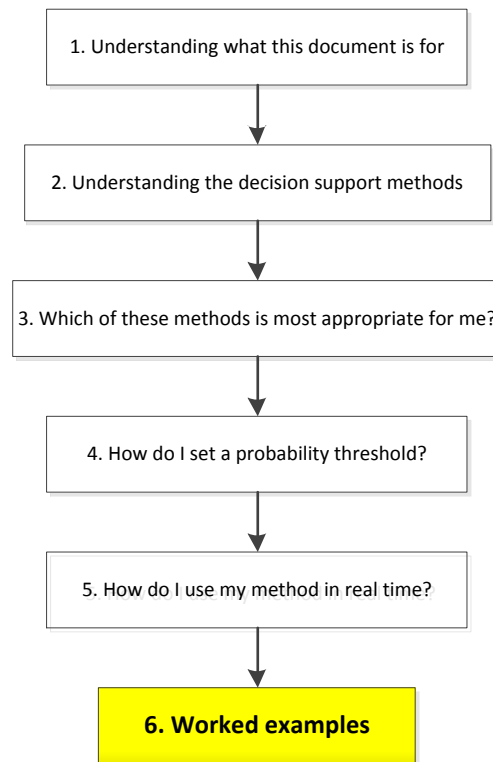


Figure 5-5 Probabilistic Coastal Display – Tab 4 showing site data

Testing

Following configuration a testing phase is recommended to ensure the output on NFFS is useful and the process is working as it should. Section 6 details how this should be carried out.

6 Worked examples



In this section we present worked examples of using each method. These are derived from the case studies covered in the Technical Report (SC090032).

6.1 Basic method example – Colne Barrier (coastal surge)



Figure 6-1 Colne Barrier (aerial view)

6.1.1 Background

Colchester, Essex, is at risk from tidal flooding from the river Colne, but is protected by a barrier at Wivenhoe (see Figure 6-1). The current barrier operation rules are to close the barrier if the deterministic tide-surge forecast exceeds 3.1 mAOD. Flooding is known to start at a water level of 3.3 mAOD. Thus, a 200 mm margin of safety is built into the current threshold for closure.

As well as closure of the Colne Barrier, a number of FIM actions can be initiated at longer lead times. The actions shown in Table 6-1 are those that are likely to be taken at lead times of two to five or even 10 days ahead of a possible high water event that exceeds the water level threshold of 3.3 m (the threshold at which flooding starts).

6.1.2 Offline threshold setting

For actions that should be triggered on a very low probability of possible exceedance (category A actions in Table 6-1) these can be taken for a forecast probability threshold of four per cent or more of exceeding the flood threshold of 3.3 m (one out of 24 forecasts). In other words, the cost is regarded as relatively low and the potential benefit relatively high – a ‘low regrets’ decision.

For actions that should be triggered on a higher probability of possible exceedance (category B actions in Table 6-1) the threshold could be 12.5% (three out of 24 forecasts). These actions have slightly higher costs and importance but would still be worth taking on relatively low probability thresholds.

Table 6-1 List of actions in response to risk of flooding at the Colne Barrier at a) very low probability and b) higher probability of exceedance of 3.3 m water level threshold

Category A actions - triggered on a very low probability of exceedance	Category B actions - triggered on a higher probability of exceedance
'Heads up' conversations with Flood Forecasting Centre over model performance and general weather conditions. Establishing the reason for outliers or ensemble spread. Are the UK Met Office models in line with others?	As for category A.
'Heads up' conversations with Flood Incident Response teams. Communicating the nature of the risk and potential significance of outliers. Depending on the scenario, this may lead to conversations with professional partners.	As for category A.
'Heads up' conversations with Press Office to prepare press releases and respond to enquiries should the risk be picked up by the media.	'Heads up' conversations with Press Office to prepare press releases and respond to enquiries from the media.
Informal checks on availability of forecasting duty staff in the event of having to populate rosters at a later time.	Formal checks on availability of forecasting duty staff in the event of having to populate rosters to cover the period of tidal activity.

6.1.3 Real-time use

In a Colne Barrier probabilistic forecast on 2 November 2010, eight of the 24 ensemble members predicted exceedance of 3.3 m total water level. This forecast was made 6.5 days ahead of a potential surge event on 9/11/2010. In this case, the probability of exceedance would be 33 per cent (8/24). As 33 per cent is well above 12.5 and four per cent (the two probability thresholds) and the recommendation would be to take action in both categories A and B described in Table 6-1. This process would be automated within NFFS directly from the probabilistic forecast. Consideration of softer decision-making factors would also be required.

6.2 Simplified method example - Thames Barrier (coastal surge with fluvial element)



Figure 6-1 Thames Barrier

6.2.1 Background

This example focuses on the flood risk posed to nine riverside areas in west London, rather than the flood risk to central London. Although closure of the Thames Barrier is a relatively expensive but high benefit FIM action, a probability threshold can be derived from 14 previous exceedance events in the record over which probabilistic forecasts are available. Hence, it can be used to demonstrate the simplified decision-support method.

6.2.2 Offline threshold setting

Estimating flood impact (benefit of taking action)

In this case, the flood impact is estimated by examining the average benefit of historic high water events in the data record held by the Environment Agency. Table 6-2 shows the average benefit (flood impact avoided) for four scenarios described below.

Two property threshold scenarios were used: a property threshold level (onset of flooding) of 0.4 m above the bank level and of 1.0 m above bank level. The threshold of flooding is known to be higher than the levels from the digital elevation model used to calculate property levels in the analysis. Hence, these two scenarios were adopted as there is uncertainty over the exact level at which property flooding occurs in these nine locations. These results are presented assuming a zero error allowance (margin of safety) and a 0.3 m error allowance. The case study also assumes that local flood defences and resilience measures in the nine locations will reduce the monetised total flood impact by 50 per cent. Further details on these assumptions can be found in the Technical Report (SC090032).

Table 6-2 Estimates of flood impact; for Scenarios 1a and 1b there are 14 ‘exceedance’ events; when the property level threshold is raised to 1.0 m there are only seven ‘exceedance’ events

Scenario	Average flood impact of all ‘exceedance’ events
1(a) – 0.4 m property level, 0.3 m error allowance	£8,795,000 ÷ 14 = £630,000 (rounded)
1(b) – 0.4 m property level, 0.0 m error allowance	£8,474,300 ÷ 14 = £600,000 (rounded)
2(a) – 1.0 m property level, 0.3 m error allowance	£2,044,600 ÷ 7 = £300,000 (rounded)
2(b) – 1.0 m property level, 0.0 m error allowance	£1,383,700 ÷ 7 = £200,000 (rounded)

Estimating FIM action cost

It is difficult to accurately calculate the marginal cost of closing the barrier. Following discussions with the barrier team and broad assumptions, for the purpose of this example we used an indicative cost per closure of £100,000 (based on whole-life cost considerations).

Table 6-3 uses the average benefit (B) (flood impact avoided) to calculate probability thresholds for the different scenarios (figures in bold type).

Table 6-3 Trigger probability thresholds based on cost-benefit ratio for Thames Barrier closure

Scenario	Cost C (per Thames Barrier closure) = £100,000	
	B (£)	Probability threshold = C/B ⁹ (%)
1(a) – 0.4 m property level, 0.3 m error allowance	630,000	100/630 = 16
1(b) – 0.4 m property level, 0.0 m error allowance	600,000	100/600 = 17
2(a) – 1.0 m property level, 0.3 m error allowance	300,000	100/300 = 33
2(b) – 1.0 m property level, 0.0 m error allowance	200,000	100/200 = 50

6.2.3 Real-time use

If we assume that Scenario 2(b) is the most appropriate, a 50 per cent probability threshold is configured within NFFS to be used with probabilistic forecasts. If the forecast probability is above 50 per cent, the cost-benefit analysis would recommend taking action (closing the barrier). Following this, the decision-maker is encouraged to consider other factors to assess whether the cost-benefit recommendation should be overruled.

⁹ For the case of the Thames Barrier, there may be several trigger probabilities for different water levels for one location. For example, these could be: > 16% of a Southend water level of > 3.4 m and > 4% (one forecast out of 24) of a Southend water level > 3.85 m (the barrier control rule for closure). Therefore, there may be several different thresholds and rules and they all need to be considered together.

6.3 Detailed method example – River Sever at Bewdley (fluvial)



Figure 6-3 Demountable flood defence for River Sever at Bewdley

6.3.1 Background

Demountable flood defences are erected at Bewdley to protect property and people from flood water from the River Sever. The defences need to be brought to site by lorry (they are not stored locally) and require trained operational staff to erect them. Therefore, flood warning lead time is important. Probabilistic flood forecasts provide an opportunity to increase the flood warning lead time and to plan the mobilisation of resources to erect the defences earlier.

The decision to erect the barriers at Severnside North is triggered by a water level forecast of 3.8 m (local datum), even though flooding does not occur until a level of 4.2 m is reached. This allows time for the operational teams to erect the barriers safely.

6.3.2 Threshold setting

Estimating flood impact (benefit of taking action)

For the detailed method, a water level-impact relationship is required that relates a monetised flood impact to different water levels that would cause flooding if the defences were not in place. In this example, this relationship was established using techniques developed by Halcrow in the SC090032 Project. As shown in Figure 6-4, the water level-impact relationship for Bewdley is defined by four values at four water levels and interpolated between these points. The monetary impact values at these four water levels were estimated through consultation with the Midlands Flood Forecasting Team and are described in the SC090032 Technical Report. The impact values are based on property numbers but increased to reflect other less tangible impacts: risk to life, social impact, and impact on business, agriculture and infrastructure.

When applying the detailed method, the water level-impact relationship can be more or less detailed than this example, depending on the degree of potential flood impact and the sensitivity of the values to decision-making.

It may be useful to include ‘softer factors’ in the estimation of flood impact. For example, there is an old people’s home at risk of flooding in Bewdley (Lickhill Manor) with specific water level thresholds for evacuation. As flooding of the old people’s home or evacuation are both undesirable outcomes, the benefit value can be raised to account for this, thereby taking a more precautionary approach. This is an example of a relatively permanent ‘softer factor’ that can be built into the water level-benefit relationship.

Estimating FIM action cost

Costs associated with erecting and managing the demountable flood defences at Bewdley were estimated at £29,592 based on discussions with the Environment Agency Operations and Forecasting teams. The estimate included costs associated with mobilising the barrier, haulage, security costs, and demobilising the barrier and membrane. The figure was rounded to £30,000 for the decision-support tool.

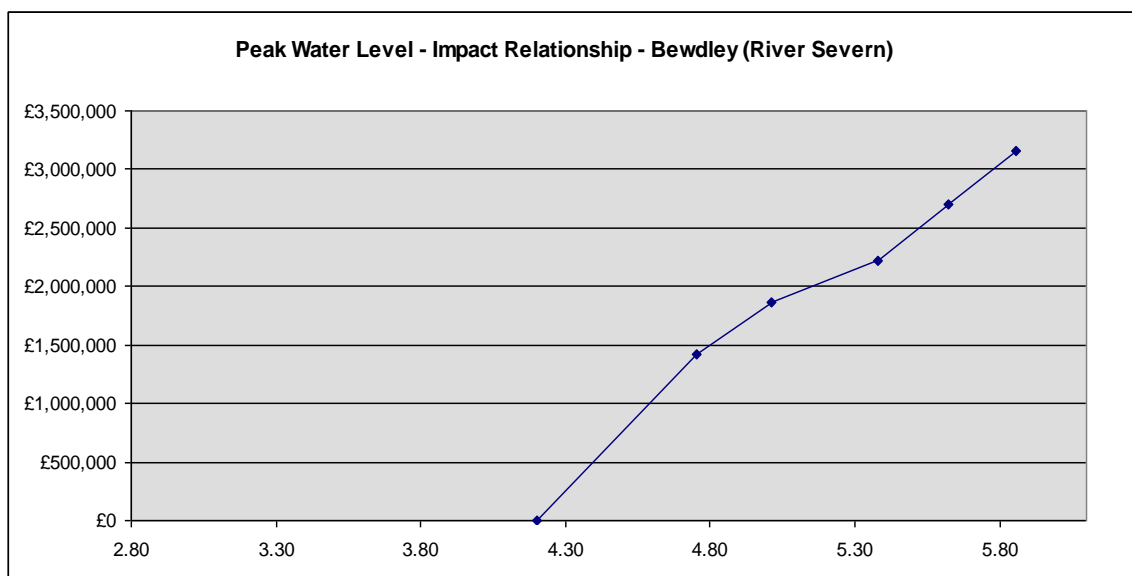


Figure 6-2 Water level-impact relationship for the demountable defences at Bewdley

6.3.3 Real-time use

Once the water level-impact relationship has been defined, and the FIM action cost estimated, the values can be populated within the decision-support tool so that it can be used in real time. The decision-support tool will be configured within NFFS for real-time use.

An example using an actual probabilistic forecast for the Severn at Bewdley is shown in Figures 6-5 and 6-6. This shows that the average flood impact (benefit) is greater than the FIM action cost, resulting in a recommendation to erect the defences. ‘Softer’ decision making factors also need to be considered before reaching a final decision.

Environment Agency

FIM Decision Support Tool

Date 10/08/2011

Team XXX

Time 09:54:45

User XXX

Site/Community Severn @ Bewdley

Load Probabilistic Forecast Result Data

Potential FIM action D2. Operate active structures as necessary (e.g. close barriers)

Standard cost/benefit method

Action cost £30,000

Forecast benefit £260,694

Initial recommendation Take action

Soft factors influencing the decision include:

1. Do you want to use this event as a practice or training event or as a PR exercise? [could change a 'No' into 'Yes']
2. Is the community at risk in danger of being desensitised (i.e. too many false alarms?) [could change a 'Yes' into 'No']
3. Is this a highly sensitive location with recent flooding? [could change a 'No' into 'Yes']
4. Have there been any missed flooding events (not forecast) at this site ? [could change a 'No' into 'Yes']

Final action decision

Justification

¹ Forecast benefit comprises monetised impact of reduction in risk to life/serious injury, social impact, residential properties damage, business/agriculture damage and infrastructure disruption.

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Figure 6-3 Prototype decision-support tool operation panel showing that the average flood impact of all forecast members (forecast benefit) is greater than the FIM action cost, hence the cost-benefit element would recommend taking action (erecting the demountable defences)

Probabilistic Forecast Data

	Level (mAOD)	Flood impact avoided by action (£)	Exceeding threshold?
Ensemble 1	3.620	£0	0
Ensemble 2	3.795	£0	0
Ensemble 3	3.588	£0	0
Ensemble 4	4.799	£1,499,927	1
Ensemble 5	4.287	£222,949	1
Ensemble 6	3.680	£0	0
Ensemble 7	3.588	£0	0
Ensemble 8	4.126	£0	0
Ensemble 9	5.268	£2,113,999	1
Ensemble 10	3.679	£0	0
Ensemble 11	4.244	£113,655	1
Ensemble 12	3.588	£0	0
Ensemble 13	4.225	£64,140	1
Ensemble 14	3.608	£0	0
Ensemble 15	5.134	£1,982,907	1
Ensemble 16	3.658	£0	0
Ensemble 17	3.608	£0	0
Ensemble 18	4.048	£0	0
Ensemble 19	3.927	£0	0
Ensemble 20	4.074	£0	0
Ensemble 21	4.314	£291,451	1
Ensemble 22	3.994	£0	0
Ensemble 23	3.588	£0	0
Ensemble 24	4.245	£115,708	1
Ensemble 25	5.090	£1,940,767	1
Ensemble 26	3.700	£0	0
Ensemble 27	3.866	£0	0
Ensemble 28	3.593	£0	0
Ensemble 29	3.903	£0	0
Ensemble 30	3.601	£0	0
Ensemble 31	3.597	£0	0
Ensemble 32	3.588	£0	0
Ensemble 33	3.588	£0	0
Ensemble 34	4.243	£110,320	1
Ensemble 35	3.609	£0	0
Ensemble 36	3.694	£0	0
Ensemble 37	4.307	£274,005	1
Ensemble 38	3.588	£0	0
Ensemble 39	3.588	£0	0
Ensemble 40	4.096	£0	0
Ensemble 41	6.144	£3,705,596	1
Ensemble 42	3.588	£0	0
Ensemble 43	4.637	£1,120,648	1
Ensemble 44	3.588	£0	0
Ensemble 45	3.588	£0	0
Ensemble 46	3.945	£0	0
Ensemble 47	3.798	£0	0
Ensemble 48	3.588	£0	0
Ensemble 49	3.685	£0	0
Ensemble 50	4.005	£0	0
Ensemble 51	3.608	£0	0
Ensemble 52	3.861	£0	0
Expected Action Benefit (£)		£260,694	
Action Level Threshold (mAOD)			4.2
Exceeding probability			25%

Figure 6-4 Calculation of forecast flood impact from a probability forecast on 13 January 2007 for Severn at Bewdley, showing average benefit of all forecast members (£260,694)

Appendix 1 – National Flood Forecasting System configuration

This section describes how existing ensembles within an NFFS configuration can be used to provide probabilistic forecasting outputs in association with the recommendations made in the report,;: *Applying probabilistic flood forecasting in flood incident management* (SC090032). This section provides guidance and examples on how to:

1. Prepare ensemble forecast data to analyse.
2. Calculate the probabilistic results from ensemble forecasts.
3. Display probabilistic forecasting results.

Consideration is given to all three methods: basic, simplified and detailed.

A1.1 Pre-requisites

Configuration requires the NFFS release version to be at least DELFT-FEWS 2009.01 with build number 25369. It is assumed that ensemble forecasts will already be present in the current configuration.

A1.2 Data preparation and calculation

Parameters

Because the introduction of probabilistic forecast outputs involves parameters which may be new to the existing NFFS configuration, such as exceedance probability and the financial benefits of taking action, it is necessary to create new parameters in the *RegionConfigFiles\Parameters* file, or to ensure they currently exist for the following:

1. Exceedance flag (basic and simplified methods)
2. Exceedance probability (basic and simplified methods)
3. Exceedance criterion met flag (basic method)
4. Exceedance criterion met flag (simplified method)
5. Damages/benefit cost (detailed method)
6. Mean damages/benefit cost (detailed method)
7. Exceedance number (basic and simplified methods)
8. Minimum ensemble tide
9. Maximum ensemble tide
10. Average ensemble tide

The following configuration extracts from the *Parameters* file give examples of creation of these new parameters.

```

<!-- parameters for ensemble forecast - exceedance flag & probability; flags for probability exceedance
criteria met -->
<parameter id="flag.H.forecast.ensemble.tidal.exceedance" name="Surge Ensemble hilo forecast
exceedance count">
  <shortName>flag.H.forecast.ensemble.tidal.exceedance</shortName>
</parameter>
<parameter id="prob.H.forecast.ensemble.tidal.exceedance" name="Surge Ensemble hilo forecast prop
exceedance">
  <shortName>prob.H.forecast.ensemble.tidal.exceedance</shortName>
</parameter>
<parameter id="Lookup.index.basic" name="Probabilistic FIM lookup - Basic method">
  <shortName>Lookup.index.basic</shortName>
</parameter>
<parameter id="Lookup.index.simplified" name="Probabilistic FIM lookup - Simplified method">
  <shortName>Lookup.index.simplified</shortName>
</parameter>

```

Figure A1-1 New parameters for basic and simplified methods

```

<!-- parameters for damages/benefit cost for prob ff (detailed method) -->
<parameter id="Dam.cost" name="Damages cost">
  <shortName>Dam.cost</shortName>
</parameter>
<parameter id="Dam.cost.mean" name="Mean damages cost">
  <shortName>Dam.cost.mean</shortName>
</parameter>

```

Figure A1-2 New parameters for basic and detailed methods

Amending the existing ensemble module configuration

Since ensemble forecasts are already present in the configuration, we can amend the existing ensemble forecast module to process the data specific to each ensemble, namely the exceedance flag (whether the action criterion is met for each individual ensemble, for the basic and simplified methods), and the benefit associated with taking action for each individual ensemble (detailed method).

The existing module will be run as an ensemble in “run in loop” mode (see section on workflows), ensuring that it is processed for each ensemble member in turn.

The following steps are required as detailed below:

1. Set an exceedance flag if the target water level (or other parameter) is exceeded for each ensemble (basic and simplified methods). This can be performed, for example, by a segmented arithmetic function within a transformation set. Note that this variable has to be defined first, therefore a dummy instance is created initially before setting its value.
2. Calculate the financial benefit from taking action (detailed method). This can be performed, for example, by a segmented arithmetic function within a transformation set, by applying the water level-cost relationship function within each segment. Note that this variable has to be defined first, therefore a dummy instance is created initially.

The following configuration extracts from the module configuration file explain how to create these variables and set the appropriate value. For the basic and simplified methods, the function sets the flag to one if the ensemble peak value exceeds 3.3, and zero otherwise (see highlighted section).

```

<!-- dummy set to instantiate flag.H.forecast.ensemble.tidal.exceedance -->
<transformationSet transformationId="exceedance_dummy">
  <inputVariable variableId="H_astro">
    <timeSeriesSet>
      <moduleInstanceId>ImportAstronomical</moduleInstanceId>
      <valueType>scalar</valueType>
      <parameterId>H.astronomical.hilo</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>external historical</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
      <readWriteMode>read only</readWriteMode>
      <ensembleId>main</ensembleId>
    </timeSeriesSet>
  </inputVariable>
  <arithmeticFunction>
    <segments limitVariableId="H_astro">
      <segment>
        <userDefinedFunction>missing</userDefinedFunction>
        <outputVariableId>H_dummy</outputVariableId>
      </segment>
    </segments>
  </arithmeticFunction>
  <outputVariable variableId="H_dummy">
    <timeSeriesSet>
      <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
      <valueType>scalar</valueType>
      <parameterId>flag.H.forecast.ensemble.tidal.exceedance</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
      <readWriteMode>add originals</readWriteMode>
    </timeSeriesSet>
  </outputVariable>
</transformationSet>

```

Figure A1-3 Initialising the exceedance flag variable

```

<transformationSet transformationId="Exceedance_Colne">
  <inputVariable variableId="H_HiLoEnsemble">
    <timeSeriesSet>

    <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
      <valueType>scalar</valueType>

    <parameterId>H.forecast.ensemble.tidal.hilo</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
      <readWriteMode>read only</readWriteMode>
    </timeSeriesSet>
  </inputVariable>
  <arithmeticFunction>
    <segments limitVariableId="H_HiLoEnsemble">
      <segment>
        <limitLower>3.3</limitLower>
        <userDefinedFunction>1.00</userDefinedFunction>
      </segment>
      <segment>
        <limitUpper>3.3</limitUpper>
        <userDefinedFunction>0.00</userDefinedFunction>
      </segment>
    </segments>
  </arithmeticFunction>
  <outputVariable variableId="H_Exceedance">
    <timeSeriesSet>

    <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
      <valueType>scalar</valueType>

    <parameterId>flag.H.forecast.ensemble.tidal.exceedance</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>

```

Figure A1-4 Setting the exceedance flag for basic and simplified methods

In the example extracts below, for the detailed method, the cost of action is calculated (see highlighted section) as zero beneath the action threshold of 3.3, a linear function between the values of 3.3 and 5.0, and at a fixed value above 5 m.

```

<!-- dummy set to instantiate Dam.cost -->
<transformationSet transformationId="cost_dummy">
  <inputVariable variableId="H_astro">
    <timeSeriesSet>
      <moduleInstanceId>ImportAstronomical</moduleInstanceId>
      <valueType>scalar</valueType>
      <parameterId>H.astronomical.hilo</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>external historical</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
      <readWriteMode>read only</readWriteMode>
      <ensembleId>main</ensembleId>
    </timeSeriesSet>
  </inputVariable>
  <arithmeticFunction>
    <segments limitVariableId="H_astro">
      <segment>
        <userDefinedFunction>missing</userDefinedFunction>
        <outputVariableId>c_dummy</outputVariableId>
      </segment>
    </segments>
  </arithmeticFunction>
  <outputVariable variableId="c_dummy">
    <timeSeriesSet>
      <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
      <valueType>scalar</valueType>
      <parameterId>Dam.cost</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
      <readWriteMode>add originals</readWriteMode>
    </timeSeriesSet>
  </outputVariable>
</transformationSet>

```

Figure A1-5 Initialising the benefit variable for the detailed method

```

<transformationSet transformationId="Damages_Colne">
  <inputVariable variableId="H_HiLoEnsemble">
    <timeSeriesSet>

      <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
        <valueType>scalar</valueType>
        <parameterId>H.forecast.ensemble.tidal.hilo</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
        <readWriteMode>read only</readWriteMode>
      </timeSeriesSet>
    </inputVariable>
    <!-- £0 below 3.3m; linear increase to 5.0m -->
    <arithmeticFunction>
      <segments limitVariableId="H_HiLoEnsemble">
        <segment>
          <limitLower>5.0</limitLower>
          <userDefinedFunction>20995713</userDefinedFunction>
          <outputVariableId>dam_cost</outputVariableId>
        </segment>
        <segment>
          <limitLower>3.3</limitLower>
          <limitUpper>5.0</limitUpper>
          <userDefinedFunction>0+(H_HiLoEnsemble-
3.3)*12350420</userDefinedFunction>
          <outputVariableId>dam_cost</outputVariableId>
        </segment>
        <segment>
          <limitUpper>3.3</limitUpper>
          <userDefinedFunction>0.00</userDefinedFunction>
          <outputVariableId>dam_cost</outputVariableId>
        </segment>
      </segments>
    </arithmeticFunction>
    <outputVariable variableId="dam_cost">
      <timeSeriesSet>

        <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
          <valueType>scalar</valueType>
          <parameterId>Dam.cost</parameterId>
          <locationId>AN-COLN</locationId>
          <timeSeriesType>simulated forecasting</timeSeriesType>
          <timeStep unit="nonequidistant"/>
          <relativeViewPeriod unit="hour" start="0" end="48"
startOverrutable="true" endOverrutable="true"/>
          <readWriteMode>add originals</readWriteMode>
        </timeSeriesSet>
      </outputVariable>
    </timeSeriesSet>
  </transformationSet>

```

Figure A1-6 Calculating the benefit for each ensemble member, the detailed method

Calculating the probability exceedance and mean benefit

Once the ensemble members have been sampled to determine whether the exceedance level has been met (basic and simplified methods) or to derive the benefit obtained (detailed method), they can now be processed to determine the probability of exceedance or mean benefit. The function is essentially the same – a mean of either the exceedance count or benefit. Since this function must be performed after all the ensembles have been processed, it must be run outside of the ensemble loop, therefore a new module must be created to be run after the ensemble processing. For this, one can make use of the ensemble statistics module within a transformation set.

The following configuration example is for a complete module, which calculates both the exceedance probability and the mean benefit in the individual transformation sets.

Note the inclusion of the ensemble ID (highlighted) to ensure the mean is calculated over all ensemble members.

```

<?xml version="1.0" encoding="UTF-8"?>
<transformationSets xmlns="http://www.wldelft.nl/fews" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews http://fews.wldelft.nl/schemas/version1.0/transformationSets.xsd"
version="1.1">
  <transformationSet transformationId="exceedanceProp">
    <!-- proportion of events exceeding (== mean of counts, where 1 is a hit; 0 is a
miss) -->
    <inputVariable variableId="exceedFlags">
      <timeSeriesSet>

        <moduleInstanceld>CoastalCalc_TotalTideEnsemble</moduleInstanceld>
          <valueType>scalar</valueType>

        <parameterId>flag.H.forecast.ensemble.tidal.exceedance</parameterId>
          <locationId>AN-COLN</locationId>
          <timeSeriesType>simulated

forecasting</timeSeriesType>

        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48"

startOverrutable="true" endOverrutable="true"/>

        <readWriteMode>read only</readWriteMode>
        <ensembleId>MOSurge</ensembleId>
      </timeSeriesSet>
    </inputVariable>
    <statistics>
      <function outputVariableId="exceedMean"
inputVariableId="exceedFlags" function="mean"/>
    </statistics>
    <outputVariable variableId="exceedMean">
      <timeSeriesSet>

        <moduleInstanceld>DetermineExceedance</moduleInstanceld>
          <valueType>scalar</valueType>

        <parameterId>prob.H.forecast.ensemble.tidal.exceedance</parameterId>
          <locationId>AN-COLN</locationId>
          <timeSeriesType>simulated

forecasting</timeSeriesType>

        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48"

startOverrutable="true" endOverrutable="true"/>

        <readWriteMode>add originals</readWriteMode>
      </timeSeriesSet>
    </outputVariable>
  </transformationSet>
  <transformationSet transformationId="MeanCost">
    <!-- mean of cost obtained from ensemble WLS -->
    <inputVariable variableId="EnsembleCost">
      <timeSeriesSet>

        <moduleInstanceld>CoastalCalc_TotalTideEnsemble</moduleInstanceld>
          <valueType>scalar</valueType>
          <parameterId>Dam.cost</parameterId>
          <locationId>AN-COLN</locationId>
          <timeSeriesType>simulated

forecasting</timeSeriesType>

        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48"

startOverrutable="true" endOverrutable="true"/>

        <readWriteMode>read only</readWriteMode>
        <ensembleId>MOSurge</ensembleId>
      </timeSeriesSet>
    </inputVariable>
    <statistics>
      <function outputVariableId="EnsembleMean"
inputVariableId="EnsembleCost" function="mean"/>
    </statistics>
    <outputVariable variableId="EnsembleMean">
      <timeSeriesSet>

        <moduleInstanceld>DetermineExceedance</moduleInstanceld>
          <valueType>scalar</valueType>
          <parameterId>Dam.cost.mean</parameterId>
          <locationId>AN-COLN</locationId>

```

Figure A1-7 Module configuration file to calculate ensemble means

Setting an exceedance criterion flag

For the simplified and basic methods, one can create a further module, such as a look-up table, to convert the exceedance probability to a binary flag (one or zero) depending on whether the criterion (which is in general different for the basic and simplified methods) has been exceeded.

The following examples are for complete modules, which process the probability exceedance and convert it to a one or zero based on the critical condition look-up function.

Since this functionality must be performed after all the ensembles have been processed, they must be run outside of the ensemble loop, therefore a new module needs to be run after the ensemble processing.

Note that the look-up set tags can be combined consecutively within the same module file.

```
<?xml version="1.0" encoding="UTF-8"?>
<LookUpSets xmlns="http://www.wldelft.nl/fews" xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance" xsi:schemaLocation="http://www.wldelft.nl/fews
http://fews.wldelft.nl/schemas/version1.0/lookUpSets.xsd" version="1.1">
  <lookupSet lookupSetId="Colne_Basic">
    <inputVariable variableId="Exceedance">
      <timeSeriesSet>
        <moduleInstanceId>DetermineExceedance</moduleInstanceId>
        <valueType>scalar</valueType>
        <parameterId>prob.flag.H.forecast.ensemble.tidal.exceedance</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48" startOverrutable="true"
endOverrutable="true"/>
      <readWriteMode>read only</readWriteMode>
    </timeSeriesSet>
  </inputVariable>
  <!-- set flag to on (1) if target exceedance for basic method (10%) is exceeded -->
  <criticalConditionLookup>
    <criticalCondition ruleIndex="1" rule="1">
      <ruleCriteria>
        <rule operator="ge" variable="Exceedance" value="0.1"/>
      </ruleCriteria>
    </criticalCondition>
    <criticalCondition ruleIndex="0" rule="0">
      <ruleCriteria>
        <rule operator="ge" variable="Exceedance" value="-0.1"/>
      </ruleCriteria>
    </criticalCondition>
  </criticalConditionLookup>
  <outputVariable>
    <timeSeriesSet>
      <moduleInstanceId>ExceedanceLookup</moduleInstanceId>
      <valueType>scalar</valueType>
      <parameterId>Lookup.index.basic</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="48" startOverrutable="true"
endOverrutable="true"/>
      <readWriteMode>add originals</readWriteMode>
    </timeSeriesSet>
  </outputVariable>
</lookupSet>
</LookUpSets>
```

Figure A1-8 Look-up set to convert exceedance probability to binary flag (basic method)

```

<?xml version="1.0" encoding="UTF-8"?>
<LookUpSets xmlns="http://www.wldelft.nl/fews" xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance" xsi:schemaLocation="http://www.wldelft.nl/fews
http://fews.wldelft.nl/schemas/version1.0/lookupSets.xsd" version="1.1">
  <lookupSet lookupSetId="Colne_Simplified">
    <inputVariable variableId="Exceedance">
      <timeSeriesSet>
        <moduleInstanceId>DetermineExceedance</moduleInstanceId>
        <valueType>scalar</valueType>
        <parameterId>prob.flag.H.forecast.ensemble.tidal.exceedance</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48" startOverrutable="true"
endOverrutable="true"/>
        <readWriteMode>read only</readWriteMode>
      </timeSeriesSet>
    </inputVariable>
    <!-- set flag to on (1) if target exceedance for simplified method (4.1% - one member of 24) is
exceeded -->
    <criticalConditionLookup>
      <criticalCondition ruleIndex="1" rule="1">
        <ruleCriteria>
          <rule operator="ge" variable="Exceedance" value="0.041"/>
        </ruleCriteria>
      </criticalCondition>
      <criticalCondition ruleIndex="0" rule="0">
        <ruleCriteria>
          <rule operator="ge" variable="Exceedance" value="-0.1"/>
        </ruleCriteria>
      </criticalCondition>
    </criticalConditionLookup>
    <outputVariable>
      <timeSeriesSet>
        <moduleInstanceId>ExceedanceLookup</moduleInstanceId>
        <valueType>scalar</valueType>
        <parameterId>Lookup.index.simplified</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="48" startOverrutable="true"
endOverrutable="true"/>
        <readWriteMode>add originals</readWriteMode>
      </timeSeriesSet>
    </outputVariable>
  </lookupSet>
</LookUpSets>

```

Figure A1-9 Look-up set to convert exceedance probability to binary flag (simplified method)

A1.3 Workflows

Adding the modules to workflows

It is important to include the module(s) which process each ensemble member individually within an ensemble loop, and those which process the complete ensemble once the loop has been finished.

In the following workflow configuration example, the module CoastalCalc_TotalTideEnsemble processes each ensemble member, and calculates the exceedance flag and benefit for each member. Note the ensemble ID and 'run in loop' mode set (both highlighted) for this.

The module DetermineExceedance calculates the means of exceedance and benefit and ExceedanceLookup converts the probability exceedance to a flag based on the exceedance criteria for each of the basic and simplified methods. Both of these are run outside of the ensemble loop since all ensembles are required to be processed before these functions may be performed.

```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2009 sp1 (http://www.altova.com) by Environment Agency (Capgemini Uk Plc) -->
<workflow xmlns="http://www.wldelft.nl/fews" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.wldelft.nl/fews http://fews.wldelft.nl/schemas/version1.0/workflow.xsd" version="1.1">
  <!-- Calculate observed surge levels -->
  <activity>
    <runIndependent>true</runIndependent>
    <moduleInstanceIcd>CoastalCalc_TotalTideEnsemble</moduleInstanceIcd>
    <ensemble>
      <ensembleId>MOSurge</ensembleId>
      <runInLoop>true</runInLoop>
    </ensemble>
  </activity>
  <!-- calculate means - exceedance probability and mean benefit -->
  <activity>
    <runIndependent>false</runIndependent>
    <moduleInstanceIcd>DetermineExceedance</moduleInstanceIcd>
  </activity>
  <!-- convert exceedance probability to binary flag -->
  <activity>
    <runIndependent>false</runIndependent>
    <moduleInstanceIcd>ExceedanceLookup</moduleInstanceIcd>
  </activity>
</workflow>
```

Figure A1-10 Workflow example, showing modules run inside and outside the ensemble loop

Housekeeping

1. One must remember to define the new modules and workflows in the *ModuleInstanceDescriptors* and *WorkflowDescriptors* configuration files respectively, in the *RegionConfigFiles* folder.
2. Any new parameters should have their default output symbols defined in the *SystemConfigFiles\TimeSeriesDisplayConfig* folder for display plotting purposes.

A1.4 Results – thresholds and visualisation

The primary purpose of visualisation is to indicate when thresholds have been exceeded to inform the forecaster as part of the decision-support process. For the basic and simplified methods, this equates to the probability of exceedance threshold having been exceeded. For the detailed method, this will be when the mean ensemble cost exceeds (a function of) the cost of taking the requisite action.

The thresholds therefore need to be set in the *RegionConfigFiles\ThresholdValueSets* configuration file and related to the quantity to which they pertain. The example below shows typical modifications to this file for each method.

```
<thresholdValueSet id="CB_AN-COLN" name="CB_AN-COLN">
  <levelThresholdValue>
    <levelThresholdId>RES OPS</levelThresholdId>
    <value>4000</value>
    <label>COST OPS COLNE</label>
  </levelThresholdValue>
  <timeSeriesSet>
    <moduleInstanceId>DetermineExceedance</moduleInstanceId>
    <valueType>scalar</valueType>
    <parameterId>Dam.cost.mean</parameterId>
    <locationId>AN-COLN</locationId>
    <timeSeriesType>simulated forecasting</timeSeriesType>
    <timeStep unit="nonequidistant"/>
    <relativeViewPeriod unit="hour" start="0" end="48" startOverrutable="true" endOverrutable="true"/>
    <readWriteMode>editing visible to all future task runs</readWriteMode>
  </timeSeriesSet>
</thresholdValueSet>
<thresholdValueSet id="EXC_AN-COLN" name="EXC_AN-COLN">
  <levelThresholdValue>
    <levelThresholdId>RES OPS</levelThresholdId>
    <value>0.1</value>
    <label>SIMPLIFIED METHOD COLNE</label>
  </levelThresholdValue>
  <levelThresholdValue>
    <levelThresholdId>RES OPS</levelThresholdId>
    <value>0.041</value>
    <label>BASIC METHOD COLNE</label>
  </levelThresholdValue>
  <timeSeriesSet>
    <moduleInstanceId>DetermineExceedance</moduleInstanceId>
    <valueType>scalar</valueType>
    <parameterId>prob.H.forecast.ensemble.tidal.exceedance</parameterId>
    <locationId>AN-COLN</locationId>
    <timeSeriesType>simulated forecasting</timeSeriesType>
    <timeStep unit="nonequidistant"/>
    <relativeViewPeriod unit="hour" start="0" end="48" startOverrutable="true" endOverrutable="true"/>
    <readWriteMode>editing visible to all future task runs</readWriteMode>
  </timeSeriesSet>
</thresholdValueSet>
```

Figure A1-11 *ThresholdValueSets* example configuration

The results can be displayed in graphical or tabular format in a number of ways, which is largely a matter of individual preference.

Graphical methods include:

1. Individual ensemble benefit and mean benefit value against action cost (detailed method).
2. Individual ensemble peaks and mean peak value against action threshold.
3. Exceedance probability against probability exceedance thresholds (basic and simplified methods).

The following examples contain suggested modifications to the *SystemConfigFiles\DisplayGroups* configuration file.

The first example creates a new display group named “Probabilistic forecasts”, with the graph name “Colne (cost-benefit)” which displays the individual ensemble benefit (dam.cost) and the mean ensemble benefit (dam.cost.mean) (detailed method). Note the inclusion of the ensemble ID in the former (highlighted), required in order to output all ensemble members. In conjunction with the threshold value sets, this will also display the cost threshold (COST OPS COLNE). The resultant output is shown after the configuration example (Figures A1-12 and A1-13).

```

<displayGroup name="Probabilistic forecasts">
  <display name="Colne (benefit-cost)">
    <explorerLocationId>AN-COLN</explorerLocationId>
    <subplot>
      <timeSeriesSet>
        <moduleInstanceld>CoastalCalc_TotalTideEnsemble</moduleInstanceld>
        <valueType>scalar</valueType>
        <parameterId>Dam.cost</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="36"/>
        <readWriteMode>add originals</readWriteMode>
        <synchLevel>1</synchLevel>
        <ensembleId>MOSurge</ensembleId>
      </timeSeriesSet>
      <timeSeriesSet>
        <moduleInstanceld>DetermineExceedance</moduleInstanceld>
        <valueType>scalar</valueType>
        <parameterId>Dam.cost.mean</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod unit="hour" start="0" end="36"/>
        <readWriteMode>add originals</readWriteMode>
        <synchLevel>1</synchLevel>
      </timeSeriesSet>
    </subplot>
  </display>
  ...

```

Figure A1-12 Display group configuration showing ensemble and mean benefit

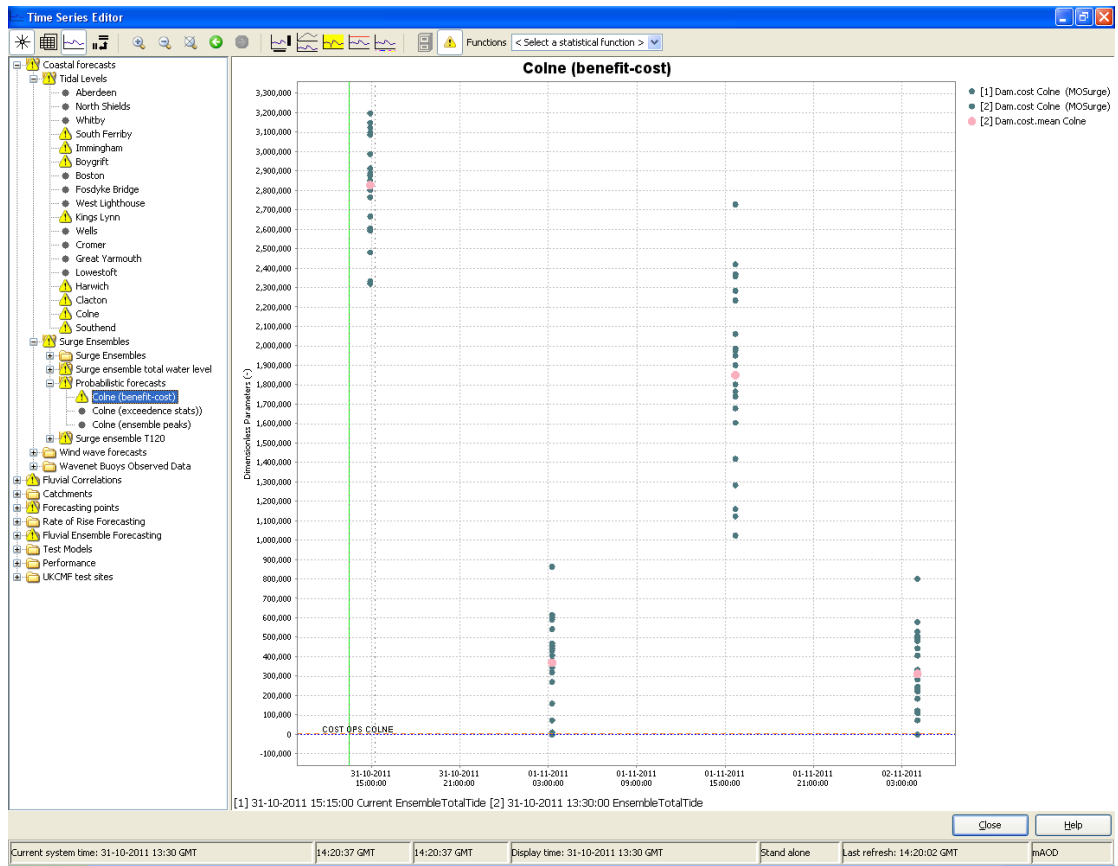


Figure A1-13 Example output displaying ensemble and mean benefit

The next example, which can be added to the same display group, creates the graph named “Colne (exceedance stats)” and displays the exceedance probability from the ensembles. In conjunction with the threshold value sets, this will also display against the thresholds of exceedance for the basic and simplified methods. Example output is shown below after the configuration extract (Figures A1-14 and A1-15).

```

<display name="Colne (exceedance stats)">
  <explorerLocationId>AN-COLN</explorerLocationId>
  <subplot>
    <timeSeriesSet>
      <moduleInstanceld>DetermineExceedance</moduleInstanceld>
      <valueType>scalar</valueType>
      <parameterId>prob.H.forecast.ensemble.tidal.exceedance</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <readWriteMode>add originals</readWriteMode>
      <synchLevel>1</synchLevel>
    </timeSeriesSet>
  </subplot>
</display>

```

Figure A1-14 Display group configuration showing probability of exceedance

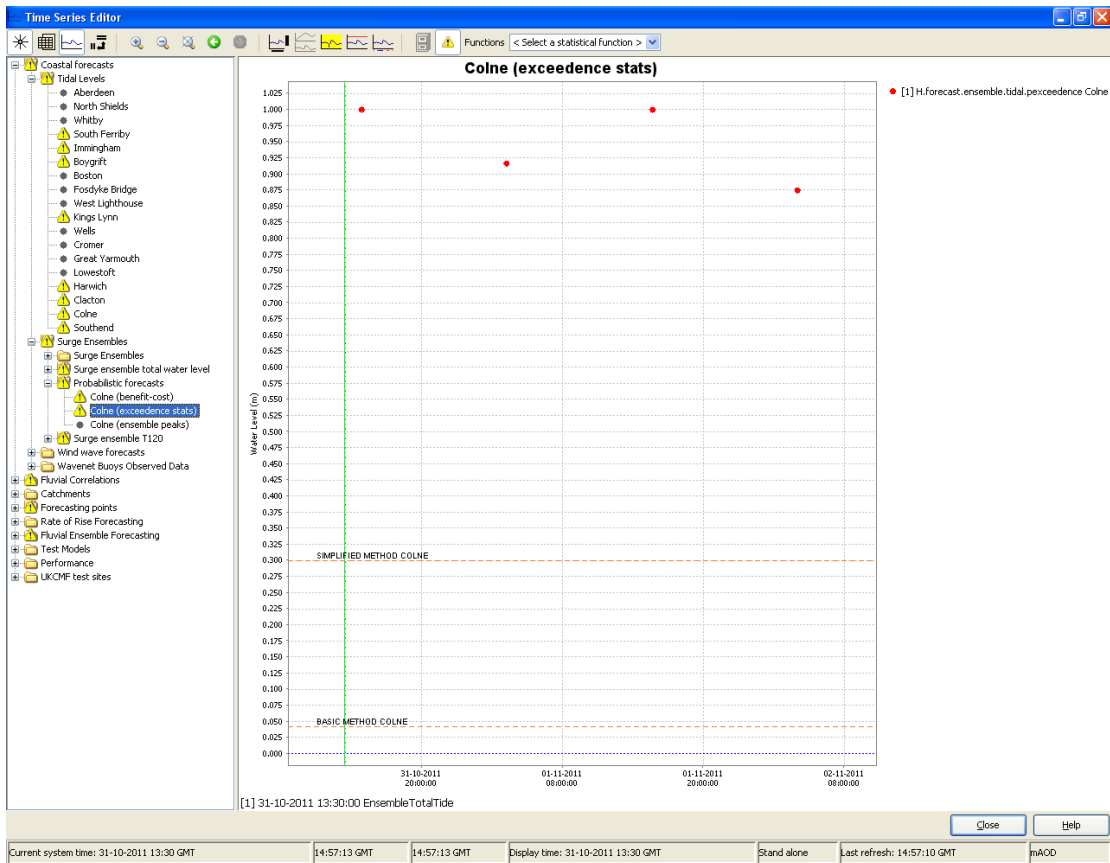


Figure A1-15 Example output displaying probability of exceedance versus threshold levels

The final graphical example, which can also be added to the same display group, creates the graph named “Colne (ensemble peaks)” and displays the peaks for each ensemble. Again, note the inclusion of the ensemble ID (highlighted), in order to output all ensemble members. In conjunction with the threshold value sets, this will also display the action threshold(s). The resultant output is displayed following the configuration example (Figures A1-16 and A1-17).

```

<display name="Colne (ensemble peaks)">
  <explorerLocationId>AN-COLN</explorerLocationId>
  <subplot>
    <timeSeriesSet>
      <moduleInstanceld>CoastalCalc_TotalTideEnsemble</moduleInstanceld>
      <valueType>scalar</valueType>
      <parameterId>H.forecast.ensemble.tidal.hilo</parameterId>
      <locationId>AN-COLN</locationId>
      <timeSeriesType>simulated forecasting</timeSeriesType>
      <timeStep unit="nonequidistant"/>
      <relativeViewPeriod unit="hour" start="0" end="36"/>
      <readWriteMode>add originals</readWriteMode>
      <synchLevel>1</synchLevel>
      <ensembleId>MOSurge</ensembleId>
    </timeSeriesSet>
  </subplot>
</display>

```

Figure A1-16 Display group configuration showing ensemble peaks

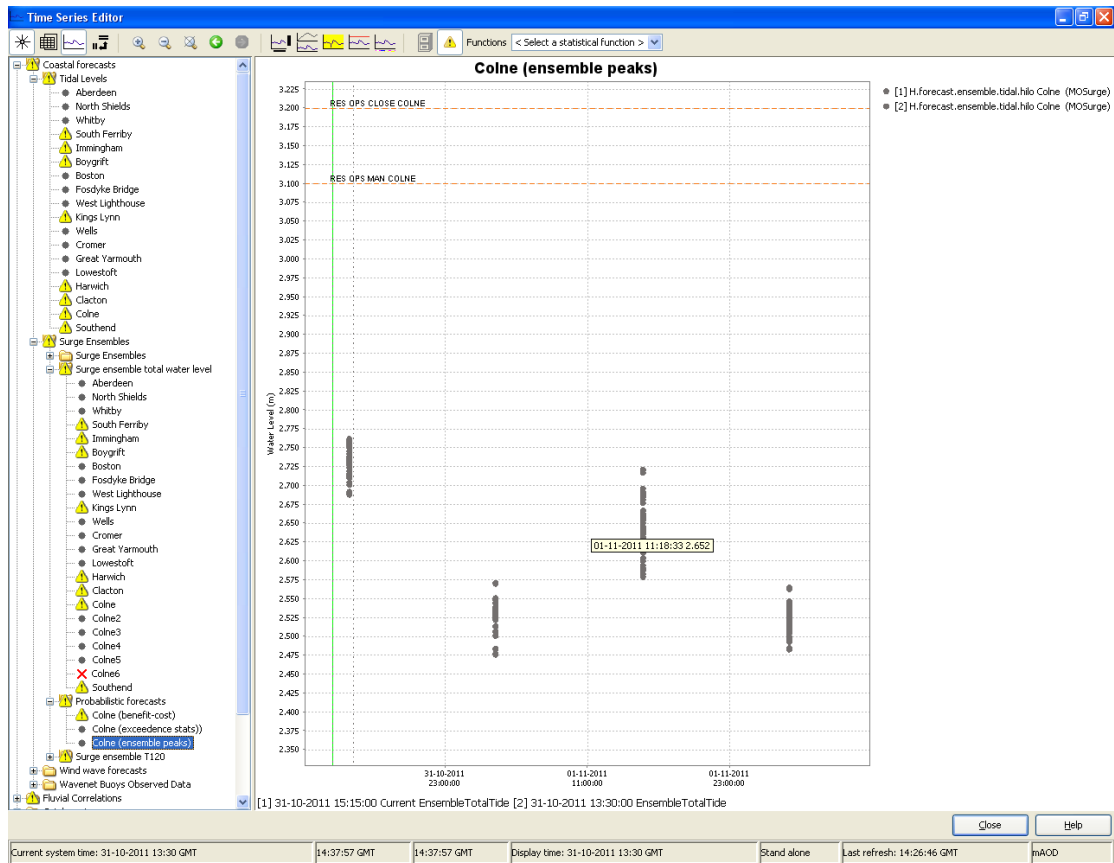


Figure A1-17 Example output displaying ensemble peaks versus action threshold levels

Results – probabilistic coastal display

The existing coastal risk display for Anglian Region was adapted to create the probabilistic coastal display to present the output results. Both of these displays use the threshold overview display plug-in which allows the user to see at a glance which locations have forecasted threshold crossings, a summary of alarms and more detailed information about specific site forecasts (Deltares WIKI). This consists of four tabs.

- Tab 1: Display by high tide – Indicates for the next four consecutive tides whether thresholds for the basic and simplified methods have been exceeded.
- Tab 2: Display per hour – colour coded per hour.
- Tab 3: Alarm summary – This will become more useful if several alarms are assigned to an individual site.
- Tab 4: Site data – This includes useful background information such as warnings for the simplified and basic methods; number of ensembles to exceed the threshold; minimum, maximum and average ensemble high tide; and average benefit/damages for the detailed method.

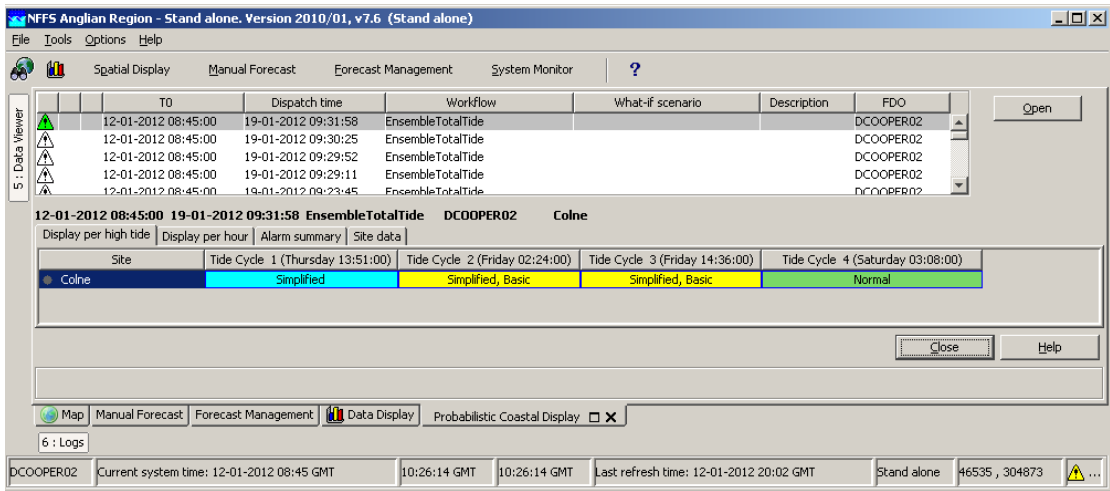


Figure A1-18 Probabilistic coastal display – Tab 1: Display by high tide

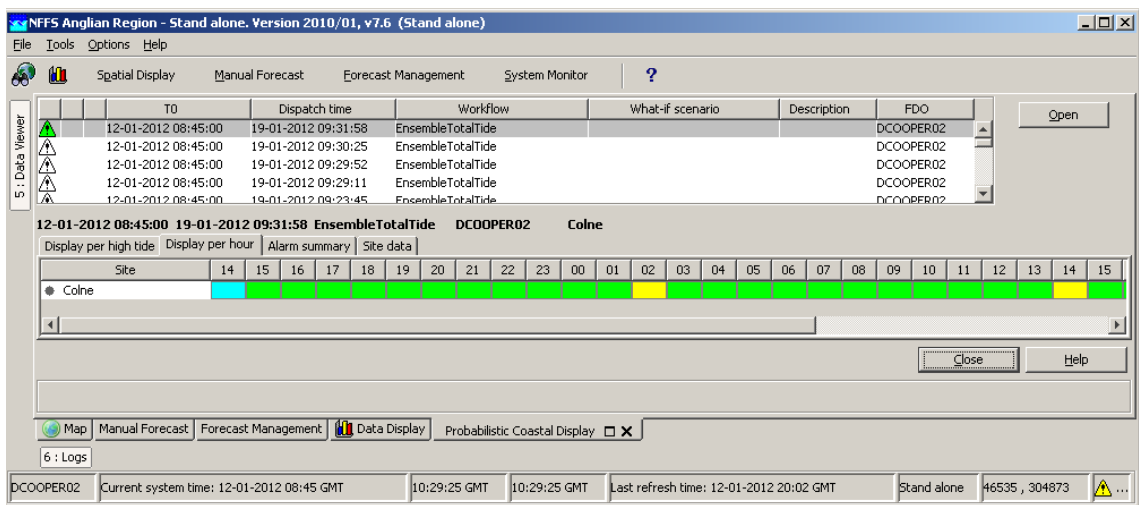


Figure A1-19 Probabilistic coastal display – Tab 2: Display by hour

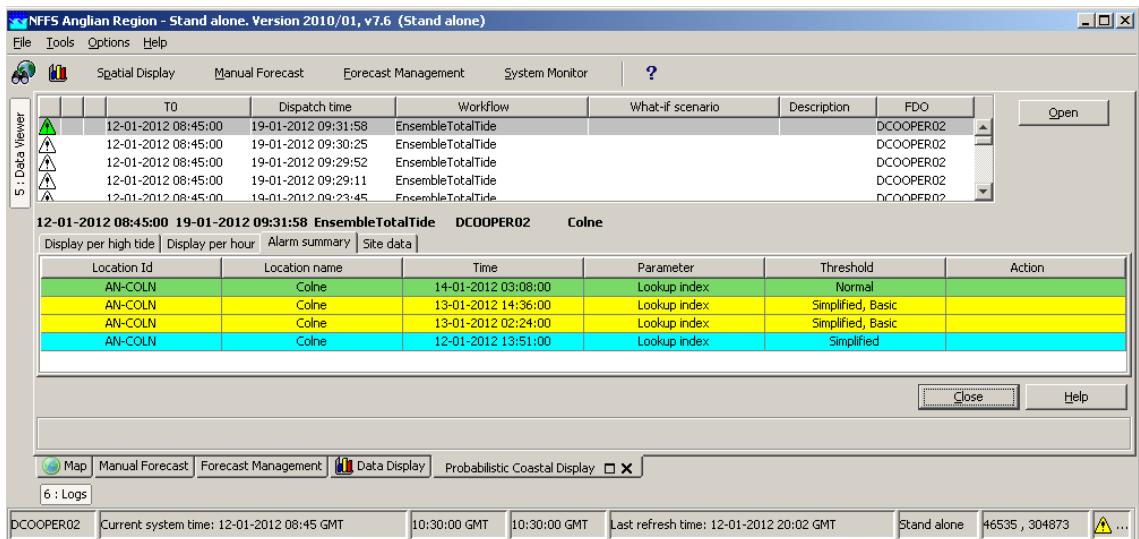


Figure A1-20 Probabilistic coastal display – Tab 3: Alarm summary

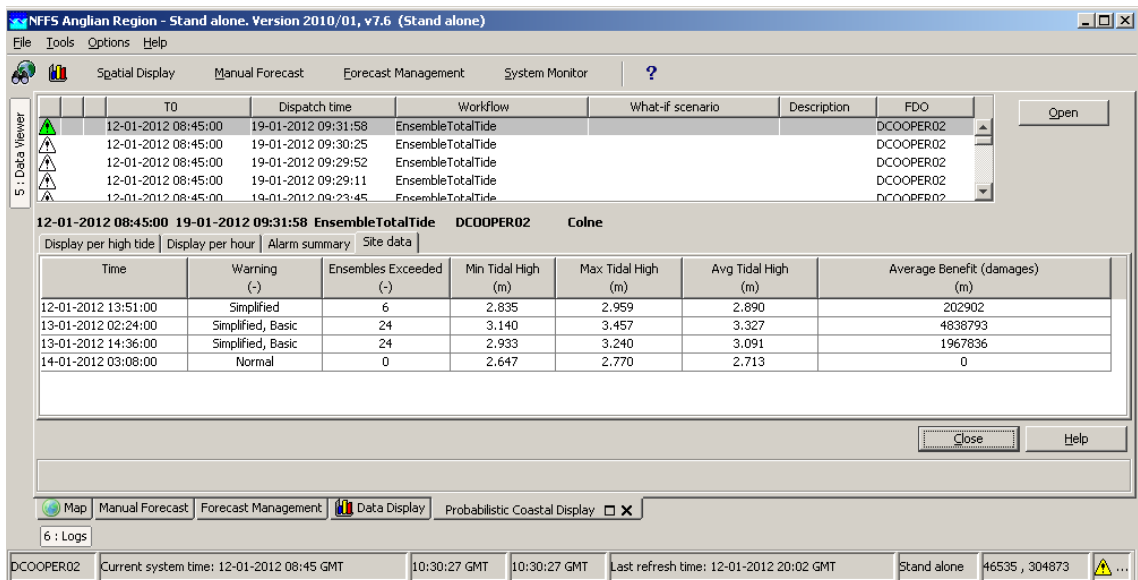


Figure A1-21 Probabilistic coastal display – Tab 4: Site data

As the probabilistic coastal display is adapted from our coastal risk display, it is quite specific to the Anglian Region and as such, it may be more useful for other regions to adapt their existing coastal or fluvial threshold displays. It is more important to describe the time series used to derive the data for Tab 4 (Site data) in the display than to explain the functionality of the probabilistic coastal display.

The configuration for the probabilistic coastal display is defined in the *ProbabilisticCoastalDisplay* module. The number of ensembles exceeded is derived from *DetermineExceedence* module as is the average benefit.

```

<inputVariable variableId="exceedNumber">
  <timeSeriesSet>

  <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
    <valueType>scalar</valueType>

  <parameterId>flag.H.forecast.ensemble.tidal.exceedence</parameterId>
    <locationId>AN-COLN</locationId>
    <timeSeriesType>simulated
forecasting</timeSeriesType>
    <timeStep unit="nonequidistant"/>
    <relativeViewPeriod unit="hour"
start="0" end="48" startOverrutable="true" endOverrutable="true"/>
    <readWriteMode>read
only</readWriteMode>

  <ensembleId>MOSurge</ensembleId>
    <timeSeriesSet>
      <inputVariable>
        <statistics>
          <function outputVariableId="exceedcount"
inputVariableId="exceedNumber" function="sum"/>
        </statistics>
      <outputVariable variableId="exceedcount">
        <timeSeriesSet>

  <moduleInstanceId>DetermineExceedence</moduleInstanceId>
    <valueType>scalar</valueType>

```

Figure A1-22 Display group configuration for number of ensembles exceeded

The warning information is output from the *CoastalLookup_ProbabilityDisplay* module. This module uses the outputs from the *DetermineExceedence* module and assesses these against the simplified and basic method thresholds. These new thresholds need to be defined in the *Thresholds.xml* and the *ThresholdValueSets.xml* files. The colour code for these thresholds is defined in the *ValueAttributeMaps* file.

```
<criticalConditionLookup>
<criticalCondition rule="Simplified, Basic" ruleIndex="18">
<ruleCriteria>
<rule operator="ge" variable="Exceedence" value="7"/>
</ruleCriteria>
<ruleCriteriaLogicalOperator>and</ruleCriteriaLogicalOperator>
<ruleCriteria>
<rule operator="le" variable="Exceedence" value="25"/>
</ruleCriteria>
</criticalCondition>
<criticalCondition rule="Simplified" ruleIndex="17">
<ruleCriteria>
<rule operator="ge" variable="Exceedence" value="1"/>
</ruleCriteria>
<ruleCriteriaLogicalOperator>and</ruleCriteriaLogicalOperator>
<ruleCriteria>
<rule operator="le" variable="Exceedence" value="6"/>
</ruleCriteria>
</criticalCondition>
<criticalCondition rule="NORM" ruleIndex="0">
<ruleCriteria>
<rule operator="ge" variable="Exceedence" value="-0.1"/>
</ruleCriteria>
</criticalCondition>
</criticalConditionLookup>
```

Figure A1-23 Display group configuration to determine the warnings assigned

The minimum, maximum and average ensemble high tides are derived from the *CoastalCalc_TotalTideEnsemble* module.

```

<transformationSet transformationId="Max_Colne">
  <inputVariable variableId="H_HiLoEnsemble">
    <timeSeriesSet>

      <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
        <valueType>scalar</valueType>

      <parameterId>H.forecast.ensemble.tidal.hilo120</parameterId>
        <locationId>AN-COLN</locationId>
        <timeSeriesType>simulated
forecasting</timeSeriesType>
        <timeStep unit="nonequidistant"/>
        <relativeViewPeriod end="156"
endOverrutable="true" start="0" startOverrutable="true" unit="hour"/>
        <readWriteMode>add
originals</readWriteMode>

      <ensembleId>MOSurge</ensembleId>
        </timeSeriesSet>
        </inputVariable>
        <statistics>
          <function function="max"
inputVariableId="H_HiLoEnsemble" outputVariableId="maxEnsemble"/>
          </statistics>
          <outputVariable variableId="maxEnsemble">
            <timeSeriesSet>

              <moduleInstanceId>CoastalCalc_TotalTideEnsemble</moduleInstanceId>
                <valueType>scalar</valueType>

              <parameterId>Max.EnsembleTide</parameterId>
                <locationId>AN-COLN</locationId>
                <timeSeriesType>simulated
forecasting</timeSeriesType>
                <timeStep unit="nonequidistant"/>

```

Figure A1-24 Display group configuration for the maximum ensemble high tide

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