Developing and Trialling Wastewater Resilience Metrics

Final Report for Water UK

7 November 2017

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Objectives

Infrastructure resilience is recognised by the UK Government and the National Infrastructure Commission as a prime driver for investment to ensure that future challenges can be met. Ofwat has been given a statutory resilience duty with a requirement to ensure that the water industry is planning for the long-term and investing appropriately to maintain the integrity of its assets and levels of service to its customers and the environment. Achieving this resilience outcome will require partnership working between the water industry and a broad range of stakeholders to ensure the delivery of integrated solutions.

In developing its approach to its next price review, PR19[1], Ofwat has set out in a consultation on its proposed methodology, two proposed options for a metric designed to measure the resilience of sewerage undertakers in respect of their drainage systems. The metric is a single hazard, single consequence measure and has been designed with a view to assessing existing and future resilience to an extreme wet weather event causing sewers to flood.

Under the auspices of Water UK through the 21st Century Drainage Programme, this project has been established to review the options proposed by Ofwat and, if appropriate, revise and produce an alternative resilience metric that would have broad industry and stakeholder support as:

- An early stage metric that can be implemented in a consistent manner by all ten Water and Sewerage Companies in England and Wales at PR19 as a common performance commitment and with potential to be adopted by the rest of the UK.
- Avoiding unintended consequences.
- Consistent with the Drainage Strategy Framework established by Ofwat and the Environment Agency.

The outputs presented in this report have been developed with extensive engagement of a Project Steering Group comprising the ten Water and Sewerage Companies of England and Wales, Scottish Water, Ofwat, the Environment Agency, Defra, CCWater and Water UK.

Conclusions and Recommendations

The metrics proposed by Ofwat have been reviewed and a revised metric is proposed. The revised metric is a hybrid, with elements that incorporate engineering judgement and modelled outputs. The proposed metric:

- Incorporates the principles behind Ofwat's Options 1a and 1b with a view to providing a wide coverage of Companies' catchments and populations.
- Takes a proportionate and pragmatic approach in the development of a baseline position.
- Provides a risk-based approach using engineering judgement to assess vulnerability.
- Utilises nodes predicted to flood as the modelled measure as it better reflects the vulnerabilities being assessed and is likely to be more relevant to customers.
- Is, on balance, consistent with Ofwat's criteria for a common performance measure and is aimed at driving and recognising positive behaviours from Companies.

[1] Ofwat regulatory duties include setting the price, investment and service package that customers receive. This includes controlling prices companies can charge their customers. Ofwat currently carries out a review of these price limits every five years; the next Price Review will be in 2019 (PR19) which will cover the period 2020-2025.

- Provides a means for Companies to engage with their customers in respect of sewer flooding arising from extreme wet weather events.

In respect of how this revised metric is taken forward, there are two broad options that could be considered, depending on whether the aim is to use the metric at PR19 or PR24. Both options would allow a period for companies to build confidence in their data and approach by using 'shadow reporting', where information from the metric was not published but was shared in an appropriate manner amongst water sector stakeholders to provide transparency (for example companies, regulators and the consumer body).

If the aim was to use the metric at PR19, then there could be 'shadow reporting' until 2019-20, to allow for it to be used in PR19 when it would be published with any relevant commentary on the data limitations. If a longer period of shadow reporting was deemed appropriate to build trust and confidence in the robustness of the metric, then shadow reporting could be extended beyond 2019-20 with the expectation that the metric would move from shadow reporting to being publicly available in sufficient time to support and inform PR24. Which approach is taken is a matter of judgement.

Several recommendations have been made in respect of review and future development of the metric. Key to this is the need for the metric to be integrated within the Drainage and Wastewater Management Plans that are currently being proposed for development.

Benefits

The metric is a single hazard, single consequence measure; however, it is designed to reflect Companies' performance against an impact that is of significant concern to customers. In addition to measuring outcomes, the metric is aimed at providing Companies with a means to prioritise investment, engage more extensively in partnership working (to derive better value to customers) and with customers, and, importantly, to focus the development of long-term planning strategies with a view to reducing the chances that domestic and business customers will be flooded in future.

1. Introduction

1.1. Background

Infrastructure resilience is recognised by the UK Government and the National Infrastructure Commission as a prime driver for investment to ensure that future challenges can be met. Ofwat has been given a statutory resilience duty with a requirement to ensure that water industry is planning for the long-term and investing appropriately to maintain the integrity of its assets and levels of service to its customers and the environment.

The Water Act 2014 introduced a new primary duty on Ofwat to "*secure the long-term resilience of …. sewerage undertakers' sewerage systems as regards environmental pressures, population growth and changes in consumer behaviour*". This means that the water industry also now has a specific duty in respect of the resilience of its systems. The new duty on both regulator and industry has led to, and built on, a range of interconnected activities designed to enable both parties to be in a position to develop more integrated long-term strategies that will cement resilience at the heart of the water sector. These include:

- The establishment by Ofwat in 2015 of a Task and Finish Group to help inform and challenge the sector on resilience, and advise Ofwat on how they should respond to their new duty;
- The set-up of the Water and Wastewater Resilience Action Group (WWRAG) (one of the key recommendations of the Task and Finish Group) with a remit to "*define qualitative standards, look at the picture across England and Wales and share best practice*" (Ofwat, 2015a);
- Development of the Drainage Strategy Framework (DSF). Published in May 2013 by Ofwat and the Environment Agency, the DSF sets out guidance and best practice for water and sewerage companies to follow to meet long-term sewerage and drainage needs (Ofwat and EA, 2013).

The work being undertaken in all areas is designed to ensure that the water industry can respond to the long-term challenges that its resilience duty demands. Recent publications from the UK Government (UK Govt., 2017) and the National Infrastructure Commission (NIC) (NIC, 2017) have assessed national infrastructure requirements and reinforced the need for the industry to be engaging in long-term drainage planning (beyond the AMP cycle) to meet the future needs of its broad customer base.

Activities undertaken to take forward the principles of the DSF has led to the development of a high-level approach to assessing the available capacity in the UK's drainage systems to accommodate the flows expected in the future - *The 21st Century Drainage Programme Capacity Assessment Framework*. The Framework sets out the processes to enable UK sewerage undertakers to assess how much capacity is currently available in each drainage system, how much capacity will be available in the future and the scale of intervention required to ensure that the performance of the drainage system does not deteriorate (Water UK, 2017). Gaining knowledge on capacity constraints is a core element in understanding system resilience.

Tied in with the need to understand system resilience is the question around how can it be measured. In order to help with this, the first part is to define what it is. Ofwat has adopted the following definition of resilience (Ofwat, 2015b):

"*Resilience is the ability to cope with, and recover from, disruption, and anticipate trends and variability in order to maintain services for people and protect the natural environment, now and in the future.*"

The primary driver is the need to maintain service to customers and to protect the environment. In respect of the sewerage system, the key impact on customers and the environment is when flows exceed capacity; this can result in sewers flooding, treatment works becoming overloaded not treating to the required Permit standards, and combined sewer overflows (CSOs) spilling prematurely to watercourses. The hazards that can cause flows to exceed capacity are multiple (e.g. lightning strikes causing power outages at pumping stations, illegal dumping in sewers causing blockages) but perhaps the most relevant, and easily understood by customers, is the impact of extreme wet weather events (UKWIR, 2017).

Sewer systems are generally designed to operate effectively under a range of conditions; the fact that systems are not running full all the time means that there is some spare capacity to act as storage under wet weather conditions which enables sewers to effectively convey wastewater to treatment works without impacting on customers. However, there is a limit to the amount of spare capacity that can be reasonably (considering both engineering and financial constraints) included into a sewer system. Coupled to an erosion in capacity over time from, for example, population growth, this does mean that sewers can become overloaded more frequently during extreme wet weather events, with flooding a consequence.

Extreme wet weather events do not mean that all sewers will flood. Catchment characteristics (e.g. topography) linked to previous interventions (e.g. to manage historic flooding issues) will likely dictate where, and to what extent, systems will be impacted. In order to understand and 'measure' the extent of resilience within a system, it is important to understand the vulnerabilities, and the probability that those vulnerabilities could lead to flooding and ultimately, as a consequence, the population that might be at risk from such flooding.

In its PR19 methodology consultation document (Ofwat, 2017), Ofwat has proposed two options (Options 1a and 1b) for a metric that are aimed at providing an understanding of the resilience of sewerage systems and hence the potential risks to customers from sewer flooding arising from extreme wet weather events. These options came out of initial work undertaken by the 21CD Programme and the WWRAG. Ofwat is proposing that the metric, however finally defined, is applied and reported by all the England and Wales sewerage undertakers as a common performance measure for PR19. The regulator has defined a common performance measure as one which is:

- relevant to customers of all companies;
- able to be used to engage effectively with customers;
- relevant to what is trying to be measured so that the metric can be used to drive company behaviour in the right direction;
- able to be used to track a company's progress;
- quantifiable, with available data and a clear definition;
- comparable;
- reproducible (yields a consistent result if the correct method is followed); and
- able to be used to set stretching performance commitment levels.

This project has been established by Water UK under the auspices of the 21CD Programme with a view to developing a clearer understanding of the proposed metrics and, where appropriate, to refine them. Any revisions need to be considered within the context of the requirements for a common performance measure and the need for the metric to be consistent with, and integral to, the future development under the 21CD Programme of Drainage and Wastewater Management Plans (DWMPs). DWMPs will represent a major step forward in embedding multi-stakeholder, integrated long-term planning at the heart of Companies' wastewater investment plans; the water sector's commitment to such developments is wholly supported by the UK Government and the NIC.

1.2. Project aims and objectives

The key objectives of the study are to produce a wastewater resilience metric based on the work of the 21CD Programme and the WWRAG that would have broad industry and stakeholder support as:

- An early stage metric that can be implemented in a consistent manner by all ten Water and Sewerage Companies (WaSCs) in England and Wales at PR19 as a common performance commitment and with potential to be adopted by the rest of the UK;
- Avoiding unintended consequences;
- Consistent with the Drainage Strategy Framework.

The outputs presented in this report have been developed with extensive engagement of a Project Steering Group (PSG) comprising the WaSCs of England and Wales, Scottish Water, Ofwat, the Environment Agency, Natural Resources Wales, Defra, CCWater and Water UK.

1.3. Report structure

Section 2 outlines the steps taken in reviewing the metrics as proposed by Ofwat and initial activities to refine the metric.

Section 3 details the revised metric and presents a protocol for Companies to follow in its application.

Section 4 considers some of the mechanisms that could be utilised in customer engagement.

Section 5 presents a summary of the key project outputs.

Additional detail is provided in the appendices to support the sections.

2. Review, assessment and refinement of Ofwat's proposed metrics

The detail of Ofwat's proposed metric options can be found in Appendix 3 of their consultation document (Ofwat, 2017a; Ofwat 2017c). The two options both follow a similar pattern; a characterisation step to provide a high-level indication of the vulnerability of the catchment followed by a more detailed assessment based on either a more granular understanding of catchment characteristics or modelled outputs. For clarity, a catchment is defined here as covering all pipes, and associated population numbers, that drain to a single wastewater treatment works.

The following sections (Sections 2.1 to 2.3) provide an initial review of the actions defined under the Ofwat approach and, where appropriate, provides recommendations as to how these could be improved or revised to more accurately reflect what the measure is trying to achieve.

2.1. Catchment characterisation

The initial characterisation step is common to both Options 1a and 1b. The step involves an assessment of each catchment against descriptive text and selecting the high-level vulnerability risk grade based on that text. Even if that vulnerability impacts only a small element of the catchment the whole catchment defaults to the highest grade.

The characteristics, the descriptive text, approach and resulting high-level vulnerability grade were developed through activities undertaken by the WWRAG and involved all England and Wales sewerage undertakers. It is therefore considered that there is general agreement across the relevant Companies as to those factors from which catchment vulnerability can be inferred.

While considered an appropriate approach to providing a high-level assessment of vulnerability, concerns were expressed that comparisons with the descriptive text were not straightforward. As an alternative, but in-line with initial WWRAG thinking, the primary vulnerability characteristics relevant to the impacts of extreme wet weather events have been drawn out into single descriptive elements against which a vulnerability grade has been assigned. The grade is consistent with the WWRAG considerations. In addition, the principle that the highest vulnerability identified for the catchment, even if only in a small part, represents the default grade for the whole catchment has been retained.

To avoid repetition and to put the approach into context, the detail of the revised methodology is outlined in Section 3.2.

2.2. Option 1a

The following outlines the metric as proposed in the Ofwat consultation document (Ofwat, 2017c).

- Step 1: *Assign a level of risk (1 to 5) to the catchment in question using the table* (see Section 2.1)
- Step 2: *Calculate the residual population at risk in each catchment to rainfall with a return period of 1 in 50 years.*

Please note that Option 1a is not a fully completed metric. Guidelines are needed to ensure companies complete the spreadsheet (schematic shown in Ofwat, 2017c) *and steps consistently. In particular some more work is needed to:*

- *characterise catchments - this should include clarity on definitions and risk assessment methodologies; and*
- *standardise the approach to calculating residual population at risk.*

As indicated above the key issue is that Option 1a is not a fully defined metric; the approach to calculating residual population at risk has, as yet, not been considered. The implied approach appears to be based on engineering judgement in respect of vulnerability / risk given that Option 1b utilises modelled outputs. This does make sense given that not all catchments will be modelled and there does need to be some mechanism that enables vulnerability of non-modelled catchments to be assessed (this would be expected by customers).

A method to derive a population (from hereon in population will be referred to as population equivalent (pe)[2]) that is potentially vulnerable/'at risk' based on a non-modelled approach has been developed. The method builds on that initially developed by the WWRAG. To avoid repetition and to put the approach into context, the detail of the revised methodology is outlined in Section 3.4.

2.3. Option 1b

The following outlines the metric as proposed in the Ofwat consultation document (Ofwat, 2017c).

- Step 1: *Assign a risk grade (1 to 5) to the catchment in question using the table* (see Section 2.1).
- Step 2: *Use the risk grade from the table to dictate the rainfall return period that should be used as an input into the drainage capacity model for the assets in the catchment* [detail provided in Section 2.3.1]. *Companies can include catchments in the lowest risk category, but this is not mandatory for practical reasons due to lower need to prioritise getting data for low risk catchments. It should either include all level 1 catchments or exclude all level 1 catchments for all years.*
- Step 3: *This step is an adaptation of the drainage capacity model enhanced method outlined in workstream 2 (WS2) of the 21st Century Drainage programme (21st CDP).*

For each catchment follow the methodology described, but only use the design storm for the catchment determined in step 1. A variety of durations must be used to determine the critical storm. For each catchment determine the pipes that surcharge in the critical storm. For all pipes in a catchment that surcharge weight results using population equivalent.

$$\frac{\text{Population equivalent upstream of all pipes that surcharge}}{\text{Population equivalent upstream of all pipes}} \times 100$$

Where there is no data, and the risk grade of the catchment is 2 to 5, the pipes in that catchment should be assumed to surcharge. This will highlight where companies do not have good models or data.

[2] Population equivalent (pe) relates here to the effective population (including trade etc.) vulnerable to the identified risk

The adoption of a modelled metric has the benefit of providing an output that is objective rather than based on engineering judgement. In respect of that proposed several concerns have been raised:

- Ofwat proposes the application of a range of return period[3] events as a function of characterised vulnerability grade *viz.* grade 5 a 1:50 event; grade 4 a 1:30 event; grades 3 and 2 a 1:20 event; and grade 1 a 1:10 event. It is unclear as to the benefit of applying different (lower intensity) storm events as the vulnerability grade reduces. Ultimately the objective is to understand the resilience of systems to events beyond the norm; it is considered that the application of a single hazard (e.g. 1:50 storm event) that represents an event beyond conventional design offers a more reflective and comparable measure of resilience. Section 2.3.1 provides details of work undertaken to assess the impacts of different (above design) return periods.

- The proposed metric utilises surcharge as the primary modelled output and provides a mechanism by which surcharge can be matched to a pe 'at risk'. Given the measure is designed to provide an understanding of flooding potential, the key concern is that a surcharged pipe does not necessarily equate to a flooding risk; a pipe can be surcharging i.e. running with a flow > design, without any risk of flooding. Linking this to a pe 'at risk' gives rise to the potential for significant over estimating of the pe impacted and hence the risk to customers. In addition, there are questions around how surcharge could effectively be communicated to customers given that risk of surcharge does not necessarily mean risk of flood but can act as a lead indicator (Water UK, 2017). Section 2.3.2 provides details of an assessment to examine alternative measures.

- The metric outlines that where there is no data all pipes in the catchment are assumed to surcharge. Ofwat indicates that the objective of this approach is to identify where there are no data or models with a view to potentially focussing Companies' efforts improving their catchment knowledge in the future. The concern is that this approach risks overestimating the pe considered to be 'at risk' and, by applying a blanket assumption, effectively removes these catchments from any kind of resilience assessment. These concerns are addressed further in the development of an alternative metric outlined in Section 3.

While Ofwat's proposed metric is consistent with the 21CD Programme capacity assessment, there are concerns around the fundamental basis of the measure. The following sections provide evaluations aimed at addressing some of these concerns.

2.3.1. Assessment of storm event return period

A key element of the assessment is the application of an appropriate storm event to assess impacts. The Ofwat methodology for consultation outlines that a range of return period events should be applied as a function of characterised risk grade viz. risk grade 5 a 1:50 event; risk grade 4 a 1:30 event; risk grades 3 and 2 a 1:20 event; and risk grade 1 a 1:10 event.

Option 1b utilises modelled outputs and enables, within the constraints of the models, a more specific measure of risk to be assessed. However, concerns have been raised around what event return period provides the most appropriate assessment.

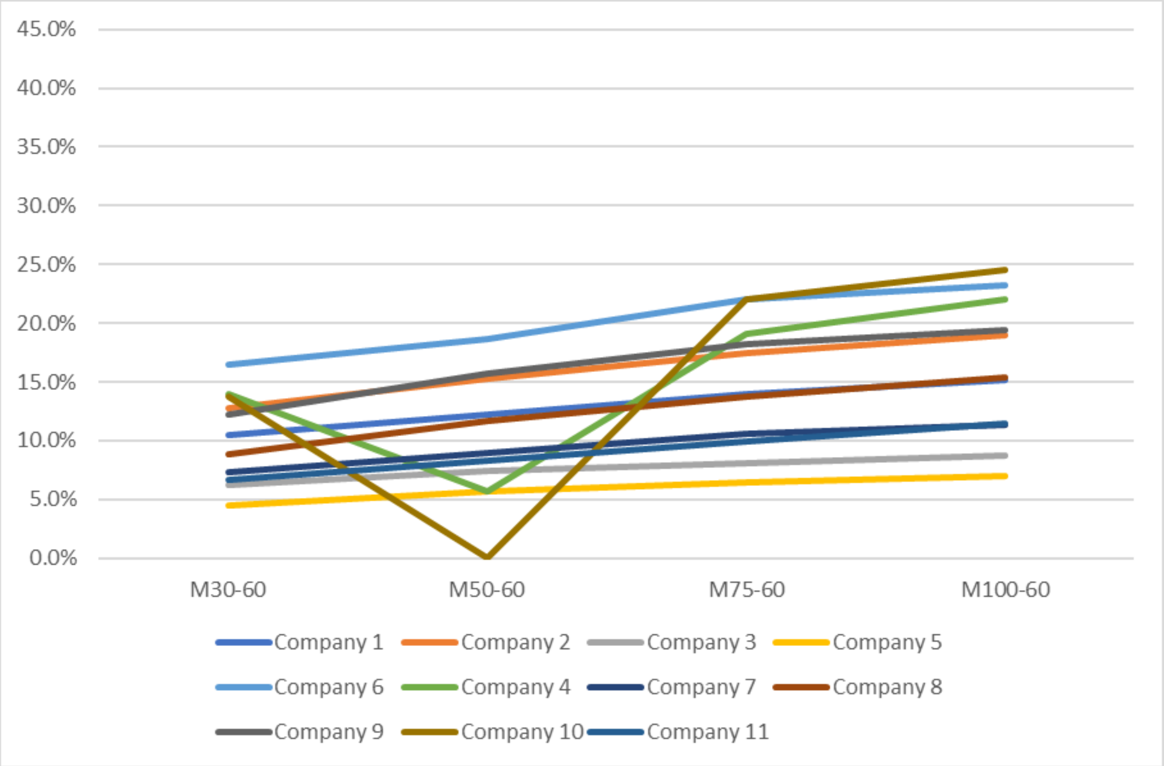
To evaluate these concerns the Companies were requested to provide two catchment models (one preferred and one alternate in case of model run issues). The models or data received (11) were assessed using the following storm events: 1:30; 1:50; 1:75; and 1:100. Durations of 60, 240 and 480[4] minutes were applied to the events with a view to determining a critical duration for each catchment. It should be noted that the 1:30 event was included as a 'baseline' given this is the level on which the design of sewer networks has historically been based or assessed to identify potential needs and trigger interventions.

The impacts, shown in Figure 1, were assessed based on the number of nodes predicted to flood under an event of given frequency and duration. Although there is a limited data set, it can be seen from the figure there is no significant step change in numbers as events increase in severity above the 1:30 level. While the numbers do increase, the lack of step change is likely to be due to an increase in flood volume associated with those nodes that are already predicted to flood which effectively reduces the stress on surrounding nodes. The figure

[3] This report will use return period as 1:x in preference to Annual Exceedance Probability percentages
[4] Range of storm events and durations were agreed by the Project Steering Group

also shows the importance of running more than one duration; for Company 4 there is a clear issue with model runs under the M50-60 scenario (overall flood volume results were in line with the general trend, but with an unexpected drop in the number of nodes predicted to flood) which, if run in isolation, might not have been picked up. For Company 10, the model failed to run under the M50-60 scenario.

Figure 1 Percentage of nodes predicted to flood; range of storms with duration 60 minutes



Given that the relative position and difference between the company examples is relatively constant across the different return periods, ***it is recommended that a 1:50 event is utilised across all vulnerability grades. Companies will still be required to run the three durations outlined previously to determine a critical duration for the catchment.***

Key elements informing this recommendation are:

- A recognition of the limitations of existing models (at higher return periods) which are typically verified using observed events that have significantly reduced intensity (e.g. 1:2 or 1:5). Running the models at more than 1:50 risks introducing significant levels of uncertainty particularly with respect to how surface water flows interact with the sewer system.

- The 1:50 event represents a storm severity above that which is commonly used in design (1:30) and reflects the fact that the water industry as a whole (companies and regulator) has a new resilience duty against which it is required to respond.

- The Capacity Assessment Framework developed under the 21CD Programme utilises storm events with return periods of 2, 5, 10 and 30 years; the 1:50 event proposed under this metric reflects a need to effectively stress test systems beyond any design.

- The recognition that developing mitigation measures against the impacts of a 1:50 event will ultimately require increased levels of partnership working; the utilisation of a multi-agency approach is generally supported by customers and enables a wider range of measures (not just capacity increases) to be considered.

It is anticipated that as models become more sophisticated and extensive, companies and stakeholders will gain a better and more detailed understanding of their drainage networks and the interactions with other pressures on the wider catchment e.g. river levels. This will increase engagement in partnership working to mitigate identified flooding risks from all sources and more holistic drainage planning. Hence, a more stretching storm event (e.g. 1:100) may become appropriate in assessing future risk.

2.3.2. Assessment of metric measure

As outlined in the introduction to this Option 1b, the proposed Ofwat metric utilises surcharge as the primary modelled output and provides a mechanism by which surcharge can be matched to a pe 'at risk'. Given the measure is designed to provide an understanding of flooding potential, the key concern is that a surcharged pipe does not necessarily equate to a flooding risk; a pipe can be surcharging (i.e. running with a flow greater than the design intention), without any risk of flooding. Linking this to a pe 'at risk' gives rise to the potential for significantly over estimating the pe impacted and hence the risk to customers.

To address this concern the models received were run using the range of storm events and durations previously outlined, and the levels of surcharge, surcharge with less than 300mm freeboard, and nodes predicted to flood, assessed. Details of the outputs from all model runs are shown in Appendix B. Table 1 provides details of a typical output.

Table 1 Assessment of metric measures as a function of extreme wet weather event[5]

Company 8	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of modelled nodes	4,277	4,277	4,277	4,277	4,277	4,277
Number predicted to flood	379	213	127	501	279	170
Percentage of nodes predicted to flood	8.9%	5.0%	3.0%	11.7%	6.5%	4.0%
Percentage of nodes with <300mm freeboard	30.2%	20.9%	15.2%	36.1%	26.0%	19.8%
Total number of conduits	4,401	4,401	4,401	4,401	4,401	4,401
Conduits with Surcharge State of 1 or 2	3,251	2,887	2,508	3,432	3,116	2,775
Percentage with Surcharge State of 1 or 2	74%	66%	57%	78%	71%	63%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	4,277	4,277	4,277	4,277	4,277	4,277
Number predicted to flood	586	347	224	657	394	251
Percentage of nodes predicted to flood	13.7%	8.1%	5.2%	15.4%	9.2%	5.9%
Percentage of nodes with <300mm freeboard	41.6%	30.5%	23.6%	44.7%	33.1%	25.4%
Total number of conduits	4,401	4,401	4,401	4,401	4,401	4,401
Conduits with Surcharge State of 1 or 2	3,572	3,274	2,966	3,647	3,361	3,076
Percentage with Surcharge State of 1 or 2	81%	74%	67%	83%	76%	70%

It is considered that, while surcharge does provide a measure of risk as a 'lead indicator' (and is consistent with the 21CD Programme capacity assessment), the extent of surcharge (average across models run of 70%; range 50%-85%) would be an overestimate of the risk and would lack sensitivity and potentially the focus required to drive investment decision. To a lesser degree, the freeboard assessment suffers from similar issues as surcharge.

[5] Surcharge State 1 = Pipe has sufficient capacity to pass forward flow, but is restricted downstream (flow backing up), causing water to level to surcharge above pipe soffit; Surcharge State 2 = Pipe has insufficient capacity to pass forward incoming flow, causing it to surcharge above pipe soffit.

On balance it is considered that, as the metric is designed to provide an understanding of the risk from flooding, ***an assessment based on nodes predicted to flood be adopted as the modelled measure***. While this is different from the 21CD Programme capacity assessment, which utilises a surcharge approach, the objectives are different. The 21CD Programme Capacity Assessment Framework work is about identifying capacity constraints at a local and national level using lead indicator metrics with a view to the development of investment programmes within the context of national planning needs. The resilience metric being derived is more specifically about the vulnerability of systems to flooding from extreme wet weather events; for which nodes predicted to flood is considered to provide a more relevant measure.

In making the metric more relevant to customers and to provide consistency with Option 1a, there is a need to link the measure to a population that could be impacted. Alternatives approaches have been evaluated:

- Applying a buffer zone to the node predicted to flood; all pe in sub-catchments that intersect with the buffer zone would be counted. Measure would be 'pe in sub-catchments impacted divided by total catchment pe'.

- Applying buffer zones to the node predicted to flood; pe in the buffer zone to be obtained from address point data with pe calculated from properties impacted multiplied by the occupancy rate for the catchment. Measure would be 'calculated pe in buffer zone divided by total catchment pe'.

In respect of the former, the assessment is complex and indicated that sub-catchment size can significantly skew outputs with potential for extensive overestimation of the population impacted. In addition, given the variability in sub-catchment size, it is considered that this would impact the ability to reasonably compare between companies. On these grounds, this option was discounted.

In respect of the latter, the assessment is less complex. However, a key consideration is the size of the buffer that should be applied and whether this should be a single value or should vary depending on the predicted flood volume. A single value brings simplicity but, depending on the size, has greater potential to either overestimate (small flood volumes) or underestimate (large flood volumes) the potential impacts. In the initial application of the metric it is recommended that three buffer zone radii are used dependent on the flood volumes predicted:

- Flood volume <25m^3 use a 15m radius buffer

- Flood volume 25-100m^3 use a 30m radius buffer

- Flood volume >100m^3 use a 50m radius buffer

Table 2 shows the outputs from a limited (given time and data constraints) assessment of how the approach would work in practice. Model runs using a 1:50 return event with critical duration of 60 minutes were used to assess volumes at nodes predicted to flood. Details of the approach to determine property numbers impacted are provided in Appendix B.2. Catchment occupancy rates were applied to property numbers to obtain impacted pe (where not supplied an occupancy rate of 2.4 was used).

For clarity, Table 2 shows the properties associated with the node(s) predicted to flood with a described volume; it is not an examination of a single node with a range of volumes applied.

Table 2 Assessment of method for determining populations impacted

		M50-60		
		<25m³ 15m radius	25-100m³ 30m radius	>100m³ 50m radius
Catchment 1	Total number of dwellings affected	1,386	4,018	2,152
Total pop: 153,456	Total number of other properties affected[6]	143	244	282
Percentage of total catchment population impacted: 11.8%	Total population within dwellings affected	3,326	9,643	5,165
	Percentage of population affected	2.2%	6.3%	3.4%
Catchment 2	Total number of dwellings affected	656	717	189
Total pop: 18,676	Total number of other properties affected	0	0	0
Percentage of total catchment population impacted: 18.0%	Total population within dwellings affected	1,394	1,555	411
	Percentage of population affected	7.5%	8.3%	2.2%
Catchment 3	Total number of dwellings affected	509	956	2,036
Total pop: 286,316	Total number of other properties affected	0	0	0
Percentage of total catchment population impacted: 2.9%	Total population within dwellings affected	1,222	2,294	4,886
	Percentage of population affected	0.4%	0.8%	1.7%

While limited, the data does indicate that, in addition to providing an estimate of pe impacted, potentially useful information could be gained on where, within a risk based approach, effort might be focussed to reduce the greatest number of pe affected. The buffer radii have been selected using experience and engineering judgement. However, it is acknowledged that for some models the certainty around small flood volumes is low which could lead to a significant overestimate of pe vulnerability. Ultimately, and depending on model outputs, this could lead to a requirement to develop more accurate models for these catchments. Given the potential issues it is recommended that the buffers are maintained as indicated but that these should be kept under review as the metric is applied.

2.4. Summary of the review and assessment

The review of the metrics proposed by Ofwat has highlighted concerns with both approaches. To address the concerns alternative approaches have been evaluated with a view to revising and developing a more appropriate metric. In summary:

- It is recommended that the initial vulnerability characterisation step is maintained with a revised approach.
- An alternative approach to Option 1a has been developed (outlined in Section 3) that is consistent with the principles of the initial work undertaken by the WWRAG.
- It is recommended that Option 1b is maintained but with a revised approach that utilises:

[6] "Other properties" includes commercial and trade address points, where the address point data is kept separately

- A single storm event of 1:50 (with critical duration to be determined) applied across all modelled catchments.

- The use of number of nodes (manholes) predicted to flood as the primary output. The utilisation of buffers (applied radii being a function of flood volume) around the nodes predicted to flood to determine properties impacted; and occupancy rates to derive a pe assessed as vulnerable.

Consideration has also been given to the issue under Option 1b that where there is no data/model then effectively all pe in the catchment should be recorded as being vulnerable. The process developed, and outlined in more detail in Section 3, takes a more risk based approach and entails:

- A size exclusion principle that is considered proportionate and pragmatic in this initial phase of development. However, there is a caveat in that exclusion is permitted 'unless there is good reason not to' and as such requires that companies give due consideration to the vulnerability of all catchments.

- Catchments classified in vulnerability Grades 1 and 2 are reported directly with no further detailed assessment. Again, this is considered proportionate and pragmatic in this initial development stage.

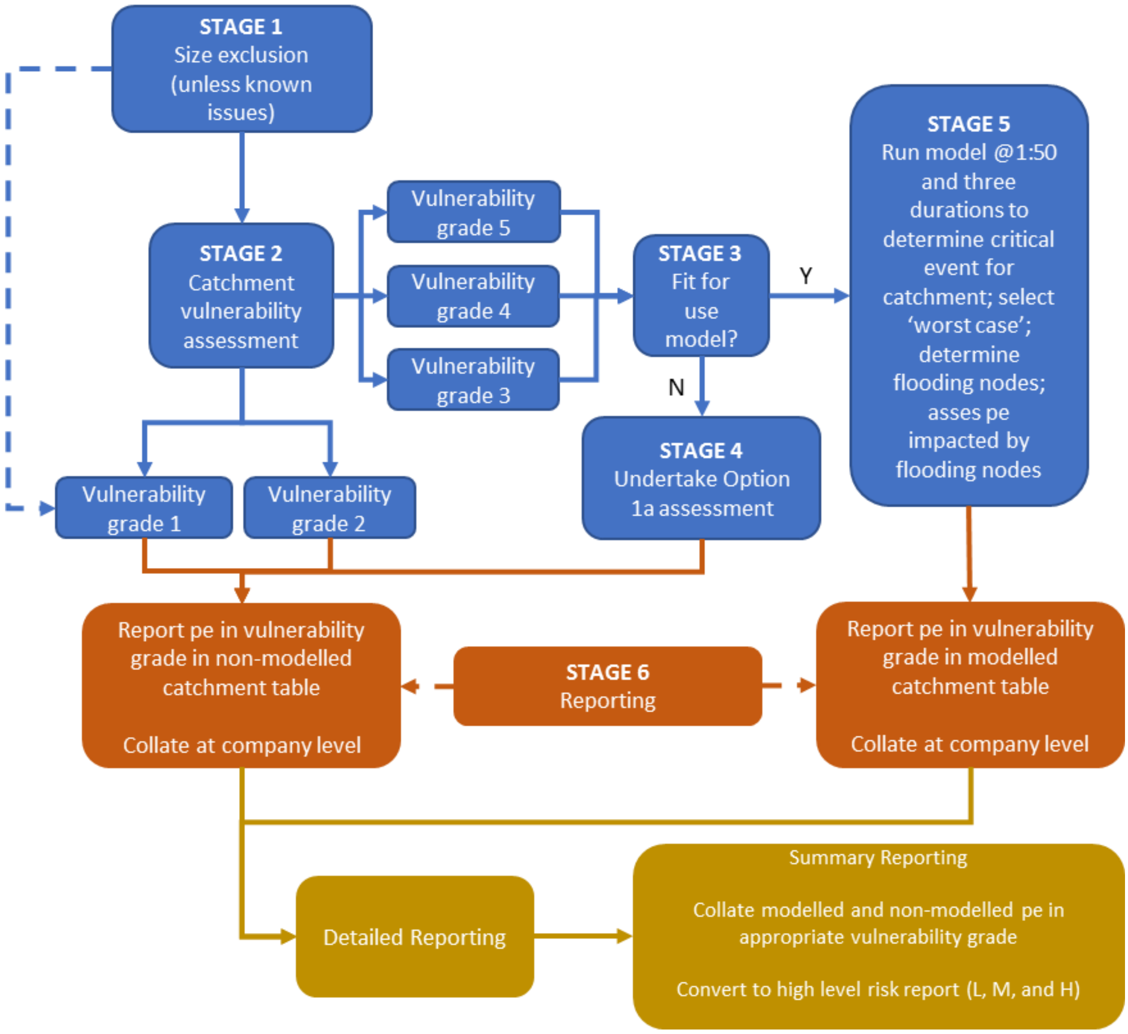
- A requirement that, where there are no models/data and the catchments are classified in vulnerability Grades 3, 4 or 5, as a minimum an Option 1a type assessment needs to be undertaken.

The review and refining process has led to the development of what is effectively a hybrid metric that utilises the principles of both Options 1a and 1b.

3. Proposed revised metric

As outlined in Section 2, a hybrid metric has been developed that makes use of both the principles developed for Options 1a and 1b (i.e. a mix of engineering judgement and modelled outputs). Figure 2 provides a high-level process diagram for how it is envisaged the metric would work. The sections that follow provide more detailed guidance on the relevant stages. A worked example that covers all elements is included as Appendix C.

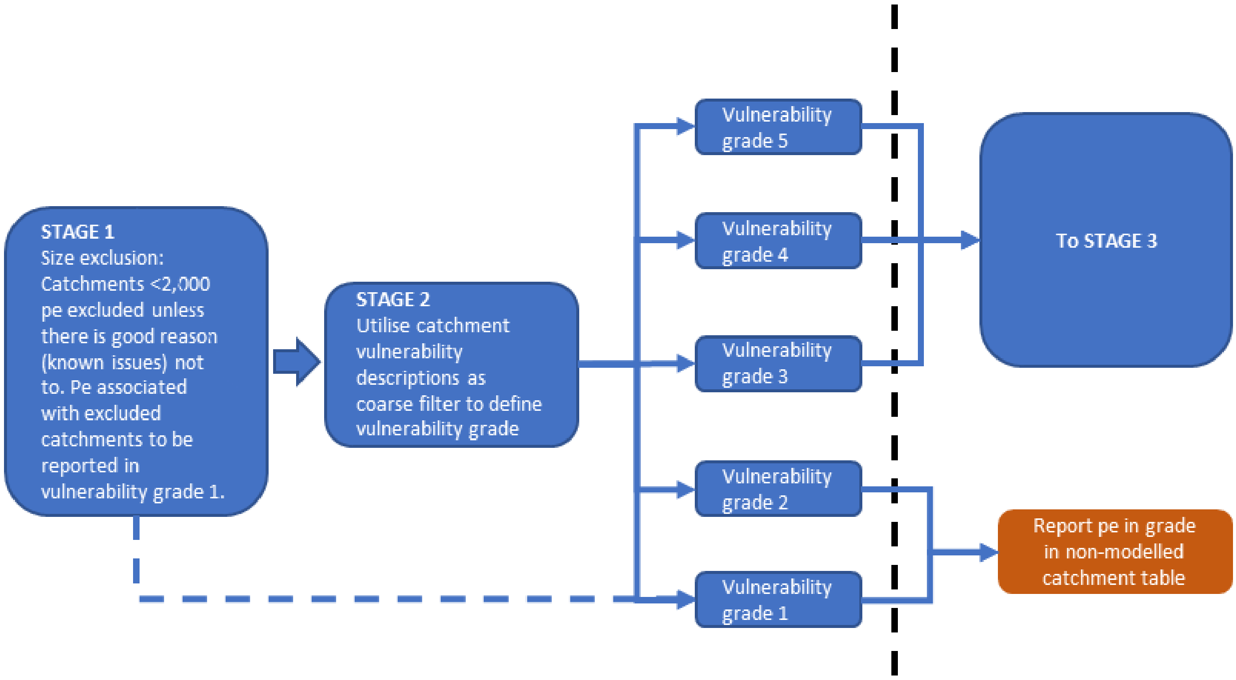
Figure 2 High-level metric process diagram



3.1. Stages 1 and 2 – Initial catchment assessments

Figure 3 outlines the initial assessment stages; Sections 3.1.1 and 3.1.2 provide further details.

Figure 3 Schematic outlining Stages 1 and 2



3.1.1. Stage 1 – Size exclusion

In the initial stage of metric application, it is recommended that Companies exclude catchments below 2,000 pe from the more detailed assessments. It is not a blanket exclusion; where Companies are aware of issues with smaller catchments (e.g. historic sewer flooding issues), these should be passed through to the more detailed assessments. Companies can also decide to include all smaller catchments in the more detailed assessment as a matter of course.

The size exclusion element has been included in the metric as a proportionate and pragmatic measure in this initial phase of development. However, the principle that the exclusion is permitted 'unless there is good reason not to' requires that companies give due consideration to all catchments. It is recommended that in moving forward to PR24 all catchments will be assessed within the more detailed metric processes.

3.1.2. Stage 2 – Catchment vulnerability assessment

The catchment vulnerability assessment is a key element of the process. It is aimed at providing a mechanism for Companies to assess the vulnerability of their catchments against a range of characteristics relevant to what is being measured i.e. the impact of an extreme wet weather event on sewer capacity. Table 3 lists the characteristics considered most relevant. These have been derived from initial work undertaken by the WWRAG. The full list alongside a description of the characteristics to aid Companies in their assessments is provided in Appendix A.

It is important that measures already implemented to address vulnerabilities are recognised. To address this, Companies can reduce the vulnerability grade where appropriate. Grade reductions have been recommended which recognise investment but also reflect that a residual vulnerability (against the hazard in this metric) will exist. For example, provision of additional storage to manage topography funnelling issues will reduce the risk grade (recommended from 5 to either 4 or 3) but unless the storage has been designed for an extreme event greater than 1:30 then there will be a residual vulnerability in the system. Details of recommended reduction for specific vulnerabilities are provided in Appendix A.

Table 3 Vulnerability characteristics and associated grading

Vulnerability description	Vulnerability grade
General catchment geographic topography funnelling all flows into one area	5
Catchments with a rapid response	5
Unknown asset data	5
Only drainage system in catchment / high proportion of combined sewers	5
Sewer flooding risk from historic reported incidents	4
Repeated blockage risk from historic reported incidents	4
Urban density (high population concentration)	4
Proximity to sea / river level	3
Large complex networks with many dependencies	3
Dependence on pumping	3
Proximity to water table	3
Growth potential (unplanned)	3
Consequence of flood risk management by others	2
Growth potential (planned)	2
Catchments with a slow response - flat sewers and septicity	2
Where no key issues identified	1
The list is not exhaustive; companies can put forward their own vulnerability characteristic and score (e.g. for one outlier catchment with its own problems)	

In practice, it is envisaged that Companies will:

- Select catchment;
- Collate known information on the catchment;
- Assess known information against vulnerability characteristics;
- Assess extent of any mitigating measures implemented up to the end of AMP6;
- Select the vulnerability grade (or mitigated grade) that reflects the highest impact characteristic taking on board any mitigation measures implemented.

In addition to some information being available at a business level, the assessment does rely on Companies having personnel with local knowledge; activities to inform the assessment could include (but are not limited to) a questionnaire or workshop approach involving local catchment managers (dependent on how Companies are structured).

The objective is to determine the characteristic which implies the highest level of vulnerability in the system while taking on board any mitigation measures. It may be that the highest vulnerability is restricted to a small part of the catchment; in line with the WWRAG work, the default position should be that highest grade is applied to the whole catchment.

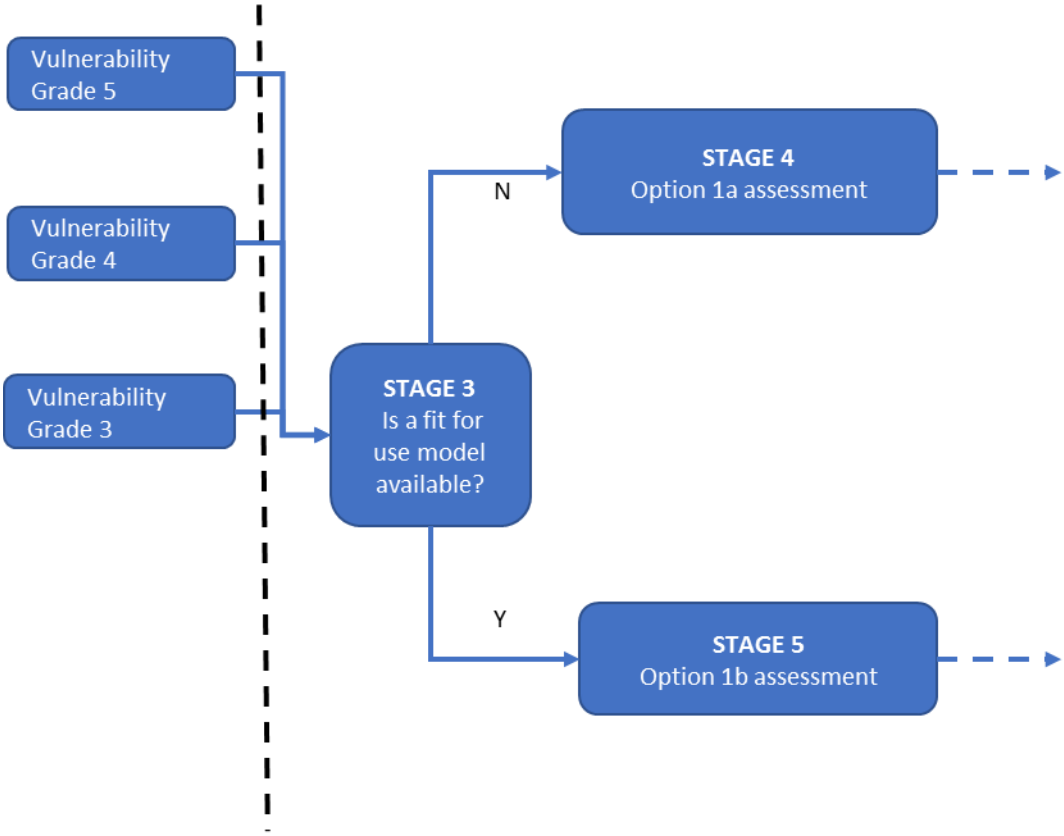
Note that having many vulnerable catchments is not necessarily a negative (the characteristics that make the catchments vulnerable could be beyond the control of the Company). Stages 3 and 4 are designed to test in more detail the predicted/assessed catchment risk. A vulnerable catchment could have a low level of risk associated with it. This would indicate that either the original system design or Company and/or third-party interventions have been such as to mitigate against the vulnerabilities.

For catchments that are assessed as vulnerability grade 1 or 2, the pe associated with the catchment should be reported directly into the catchment non-modelled table. As for the size exclusion, this is considered as a proportionate and pragmatic approach in this initial phase of development. Moving forward to PR24 it is anticipated that all catchments in vulnerability grade 1 or 2 following this stage would be taken forward for more detailed assessment (either the revised Option 1a assessment or the Option 1b assessment if companies are moving towards the development of models across all catchments).

3.2. Stage 3 – Metric route

Catchments with vulnerability Grades 3, 4 and 5 following Stage 2 will be subject to a more detailed assessment. This is outlined in Figure 4.

Figure 4 Stage 3 - Metric route



The metric route to be followed is solely a function of the availability of a model that is fit for use. In this case fit for use is defined as a model to which can be applied an extreme storm event with varying duration and which can be used to assess nodes predicted to flood.

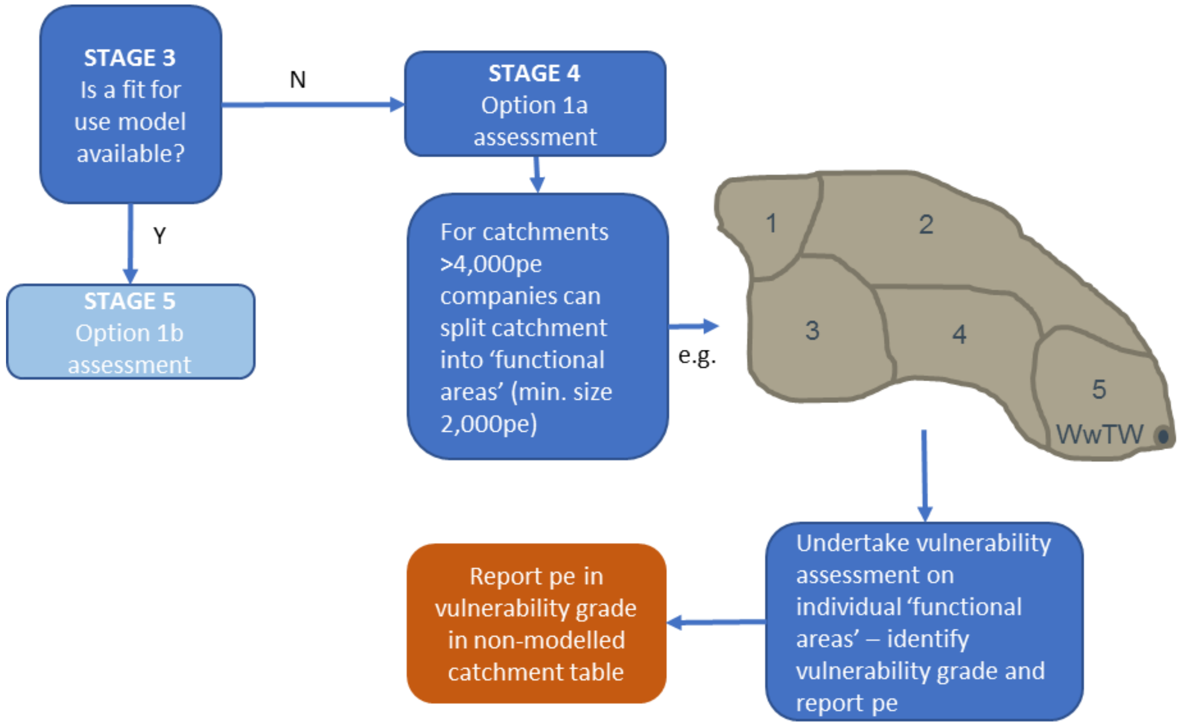
- If a suitable model is available proceed down the revised Option 1b route; or
- If no suitable model is available proceed down the revised Option 1a route

3.3. Stage 4 – Option 1a assessment

While the Stage 2 vulnerability assessment is around characterising a catchment on the basis of the highest vulnerability, the Option 1a approach aims to provide a more critical assessment of vulnerability and risk at a catchment and 'sub-catchment' level. Figure 5 provides a high-level schematic of the proposed approach.

The Ofwat methodology for consultation indicates that the assessment should consider the impacts from a hazard defined as a 1:50 storm event. As the metric has a high level of engineering judgement associated with it and is based on an understanding of the nature and condition of the catchment/network, it is not considered that having a stated 'event return period' provides an appropriate means of understanding vulnerability and the associated risks. It is recommended that the approach adopted by the WWRAG in its considerations is employed *viz.* ***consideration of catchment / network vulnerability and potential flood risk against an extreme weather event greater than 1:30***.

Figure 5 Stage 4 - Option 1a assessment



The key steps are:

- Define the level of granularity for the assessment. This can be whole catchment; however, it is recommended that for catchments larger than 4,000pe Companies should consider breaking down the catchment into more discrete 'functional areas'[7] (unless there is good reason not to i.e. whole catchment can be evidenced to be subject to same level of vulnerability). It is recommended that the minimum size of the functional areas be set at 2,000 pe. No maximum size of functional area is recommended; size will be a function of the decisions around how the catchment can logically be split. Regardless of split all functional areas should be assessed.

- Assess the vulnerability/risk of the functional area against the outlined previously in Section 3.1.2. Note that vulnerability and risk are effectively being considered together; ultimately the objective is to understand the extent to which the hazard impacts on customers as a result of system vulnerabilities.

- For each functional area determine the highest vulnerability taking on board any mitigation measures that have been, or will be, put in place by the end of AMP6; assign the grade (or mitigated grade) associated with that vulnerability to the functional area.

- Determine the pe for the functional areas and report in the Option 1a catchment table.

In respect of annual reporting, outputs should be recorded in the form shown in Table 4 for each catchment. Reporting at business level is considered further in Section 3.6.

[7] Companies employ several different descriptions for drainage areas within catchments; the term 'functional area' has been utilised here to try and avoid being too term specific.

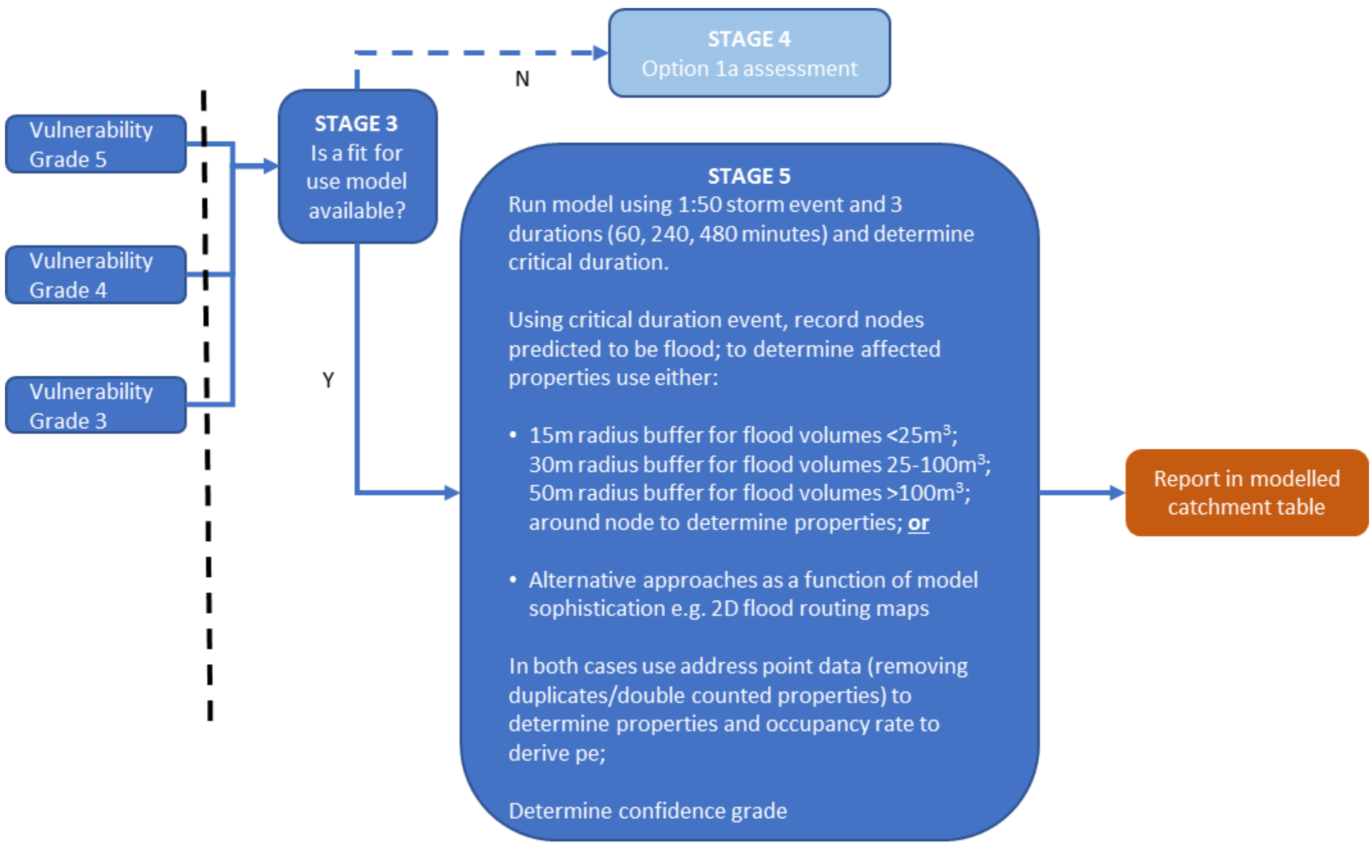
Table 4 Option 1a catchment report (example data included)

Catchment id	High-level vulnerability assessment	'Functional area' id	Detailed vulnerability risk grade	pe in 'functional area'	Percentage of catchment pe
A	3	1	1	2,000	7%
		2	1	3,000	11%
		3	1	7,000	26%
		4	4	10,000	37%
		5….	5	5,000	19%
			Total catchment pe	27,000	

3.4. Stage 5 – Option 1b assessment

The Option 1b assessment should be carried out for all catchments with vulnerability Grades 3, 4 and 5 and for which a suitable model is available. Figure 6 shows schematically the proposed approach.

Figure 6 Stage 5 - Option 1b assessment



As outlined in Section 2.2 the following are recommended inputs and outputs for the modelling assessment (further details are provided in Appendix C):

- Utilisation of a 1:50 storm event; for each catchment durations of 60, 240 and 480 minutes should be run to determine the 'worst case' event/duration.
- The number of nodes predicted to flood should recorded alongside the total number of nodes modelled.

- For each node predicted to flood either:
    - Apply a buffer zone that reflects predicted flood volume (<25m^3 use 15m radius; 25-100m^3 use 30m radius; >100m^3 use 50m radius). Use address point data to identify properties impacted and apply appropriate occupancy rates for the catchment to determine the potential pe impacted. Where nodes are sequential it is important that overlapping properties are removed to avoid the risk of double counting.
    - Utilise 2D flood routing maps (or alternatives) to determine properties impacted; use GIS address point data to determine number of properties impacted and apply appropriate occupancy rates for the catchment to determine the potential pe impacted. Where nodes are sequential it is important that overlapping properties are removed to avoid the risk of double counting.
- Assign confidence grade to the model. In the first instance, it is recommended that the Ofwat confidence grading approach is utilised. This uses a data reliability band (letters A-D) and an accuracy rating (number 1-6 or X). It would be anticipated that all new verified and updated models would be A with an accuracy rating 3-5; older unverified or updated models would be B with an accuracy 3-6. Companies should expose their approach to confidence grades in any commentary that accompanies the tables. As other industry guidance on confidence grades is implemented, then these can be adopted in the future.

Outputs from the modelling assessment should be included in a catchment level record. An example structure is as shown in Table 5.

Table 5 Option 1b catchment report structure (example data included)

Catchment id	High-level vulnerability grade	Number of nodes modelled	Number of nodes predicted to flood	Percentage of nodes predicted to flood	Catchment pe	Total pe associated with flooding nodes	pe associated with flooding nodes as a percentage of catchment pe	Assessed model confidence grade
E	5	3,802	465	12.2%	18,000	3,361	19%	A3

Once completed, the Option 1b catchment level data should be collated for reporting at Company level. Examples are as outlined in Section 3.6.

At this stage in the metric development it is proposed that the residual catchment pe (19% of pe associated with nodes predicted to flood, giving a residual 81% in the case of the example in Table 5) be reported under vulnerability grade 1 in any summary table.

It is possible that future developments in the metric could involve mechanisms to more reflectively classify the residual pe. For example, including an assessment against nodes with freeboard less than 300mm in addition to those predicted to flood could, using the same buffer approach, be used to identify a residual pe that might be classified in vulnerability grade 4 (rather than grade 1 as currently proposed). Similarly, an assessment using surcharge as the measure could be added that might reflect a pe in vulnerability grade 3. Such an approach would provide a graduated assessment of vulnerability. However, as indicated, and to keep the assessment simple at this stage of development, the binary approach (i.e. pe not related to nodes predicted to flood classified as vulnerability grade 1) is recommended.

3.5. Interventions and assessment of improvements

The metric and the information gathered to inform the overall reported figures, is aimed at providing a means to identify priority areas for interventions. As these are undertaken it is important that the assessment for the specific catchment is repeated to be able communicate the difference the intervention has made. Ofwat has been clear in its consultation document that initially it will "*expect companies to show a stable or improving trend over the five year period*" (Ofwat, 2017b).

On this basis, it is not expected that all catchments will be assessed in detail annually. Companies will be expected to report outputs for all catchments annually but the assessment need only be repeated where:

- Interventions to reduce the risk to customers that have been deployed on the ground;
- Detail and knowledge has improved.

In the initial phase of application, it is envisaged that Companies will seek to improve knowledge of their catchments. This could involve further investigation that would lead to changes in: the vulnerability assessment; the Option 1a assessment; the quality of existing models; and the development of new models. While all such activities can be considered as positive steps within the context of resilience, it does need to be recognised that activities which reduce the probability and consequence (e.g. response/recovery) of impacts on customers should be considered as priority interventions.

To minimise the risk that Companies may invest more in improving knowledge than actual risk reduction, it is envisaged that any commentary that accompanies the reported metric is clear about how any movements in the measure have come about and that the metric is subjected to appropriate assurance. In addition, this issue reflects the importance of Companies being able to input the appropriate effort to define the baseline situation in a robust manner; the more robust the baseline, the less likely that any movements will solely reflect changes in baseline information.

3.6. Presentation of outputs

The metric is based on some complex information; as such, it is proposed that two levels of reporting be considered. Tables containing detailed information for those informed stakeholders seeking to understand vulnerability at a higher level of granularity; and a summary table that provides a more high-level assessment of vulnerability.

3.6.1. Detailed information for informed stakeholders

It is recommended that in providing a more detailed level of understanding the outputs from the Option 1a and 1b assessments should be reported separately. While both options are designed with a view to providing an indication of population that could potentially be impacted, the assessment methods are very different. It is considered that reporting separately would provide a more meaningful way for cross company comparisons to be made and for the direction of travel in respect of improvements to be determined. Tables 6, 7 and 8 provide examples of how the metric could be reported.

Table 6 Detailed reporting - metric coverage (example data included)

Total pe served	Total pe in excluded catchments	Percentage of total pe in excluded catchments	Total pe Option 1a	Percentage of total pe Option 1a	Total pe Option 1b	Percentage of total pe Option 1b
128,000	10,000	8%	40,000	31%	78,000	61%

Table 6 provides an indication of the split between the size exclusion/engineering judgement process and the more robust modelled approach. As and when Companies develop wider model coverage the percentage reported under Option 1b will increase and that under Option 1a will decrease.

Table 7 Detailed reporting - Option 1a collated (example data included)

	Detailed vulnerability grade	Number of catchments or 'functional areas'	Total pe in catchments or 'functional areas' at vulnerability risk grade	Percentage of total Option 1a pe
	5	1	2,000	5%
	4	0	0	0%
	3	2	8,000	20%
	2	1	5,500	14%
	1	4	24,500	61%
Totals	-	**8**	**40,000**	

Table 7 highlights that 25% of pe is in areas that have been assessed as medium/high vulnerability. It would be anticipated that, as a priority, Companies would seek to better understand the issues driving the vulnerability particularly to the 5% in Grade 5.

Table 8 Detailed reporting - Option 1b collated (example data included)

High-level vulnerability grade	Total number of catchments	Total number of nodes modelled	Total number of nodes predicted to flood	Percentage of nodes predicted to flood	Total pe in modelled catchments at vulnerability risk grade	Total pe associated with flooding nodes	pe associated with flooding nodes as a percentage of total modelled pe	Assessed overall model confidence grade
5	2	8,079	966	12%	78,000	4,484	6%	A4
4								
3								

In respect of Table 8, as outlined in Section 3.4 in relation to the catchment specific table, it is proposed that any pe not associated with a node predicted to flood is reported as vulnerability grade 1. Future evolutions of the metric could provide a more detailed assessment of the vulnerability of this residual pe; however, at this stage in the metric the binary approach is recommended.

Table 8 also stipulates that in respect of model confidence an assessed overall confidence grade that covers all models used in that vulnerability grade should be determined. Companies will be expected to use their professional judgement in this assessment; however, an option could be to use the median of the confidence grades for the models in the respective vulnerability category. For example, if for 10 models the grades were 5 at A3, 4 at A4 and 1 at A5, then an overall A3 grade could be considered reasonable. If 5 were at A3 and 5 at A4 it is suggested that a precautionary approach is taken and the lower grade is the default.

It is anticipated that Companies will be expected to provide a commentary on the reported figures (expose where movements in the measure have arisen) and, in respect of any assurance, to provide appropriate evidence[8] to support any movements.

[8] This could include, but is not limited to: catchment questionnaires completed by operatives with local knowledge; outputs of workshops; scheme design and implementation reports; reports on operational activities (e.g. pro-active jetting). It is also important that any workbooks/spreadsheets that are developed in support of the baseline and annual reporting show evidence (e.g. QA cover sheets) of check, review and authorisation governance.

3.6.2. Summary information for general stakeholders and consumers

To provide a mechanism to convey sewerage system vulnerability against extreme wet weather to those with a less technical background, it is proposed that a simplified metric table be produced by each company. Key inputs to the table are:

- 'Low' vulnerability grade – total pe obtained from size exclusion stage plus total pe from vulnerability grades 1 and 2 from the Stage 2 and Stage 4 outputs plus pe NOT vulnerable to nodes predicted to flood from Stage 5 outputs
- 'Medium' vulnerability grade – total pe obtained from vulnerability grades 3 and 4 in Stage 4 and 5 outputs
- 'High' vulnerability grade – total pe from vulnerability grade 5 in Stage 4 and pe associated with nodes predicted to flood in Stage 5 outputs

All pe values to be divided by total pe served to give percentage. Table 9 shows the structure of the anticipated reporting table.

Table 9 Summary reporting table (example data included)

Vulnerability risk grade	Percentage of total population[9] served
L	88%
M	7%
H	5%

Table 9 highlights that, based on the assessment undertaken, 5% of the population served live in areas of high vulnerability to sewers flooding as a result of an extreme wet weather event.

It is acknowledged that as the data to be reported in Table 9 incorporates outputs from two different approaches, the numbers need to be considered within the context of what the measure is trying to show. It is important that the messages around the metric reflect that this is about understanding the stresses in the wastewater network if subjected to extreme wet weather events and does not imply that, for example, those in high vulnerability catchments are likely to be flooded. Further consideration of the mechanisms for engaging with customers are outlined in Section 4.

3.6.3. Assurance

Ofwat is clear that it anticipates the metric will be subject to assurance. It is not within the remit of this project to define the organisational structure for such assurance (Appendix D provides guidance to assurers); however, given the use of engineering judgement for certain elements it is suggested that using a limited number of assurers would reduce the risks posed in the interpretation of these elements of the metric.

As a new metric, it is important that internal governance procedures are established early in the process. Evidence of such governance (check, review and sign-off of methods and data) is a primary part of the assurance process and provides Companies' Boards with confidence that the information provided is consistent with the agreed metric process.

3.7. Critique of developed metric

3.7.1. Consistency with Ofwat's criteria for a common performance measure

The process for deriving outputs for inclusion in the metric is based on Ofwat's initial proposals but has been refined to produce a hybrid metric which incorporates elements of both Options 1a and 1b. The objective has

[9] Population used here in preference to 'pe' to reflect the knowledge difference of the stakeholders

been to ensure that, in taking a proportionate and pragmatic approach in this initial stage of development, all catchments and hence customers are considered within the context of the need to understand Companies' wastewater network resilience to extreme wet weather events.

As outlined in the introduction, Ofwat has developed a set of criteria which a common performance measure is expected to address. Table 10 sets out these criteria and considers the extent to which the developed metric meets the requirements.

Table 10 Consistency of the developed metric against Ofwat's criteria for a common performance measure

Common performance commitment requirement	Comment
Relevant to customers of all companies	The metric is relevant to all customers of sewerage undertakers
Able to be used to engage effectively with customers	The metric has been designed to provide a measure of the stress within a Company's wastewater network in response to an extreme wet weather event. While much customer research is still on-going it is suggested that customers do understand resilience (to a greater or lesser degree); sewer flooding is something that most customers can imagine (if they have not been flooded themselves). Moving Option 1b to a prediction of flooding is likely to be easier for customers to understand than surcharge. However, care needs to be taken to ensure that the measure is indicated as a level of stress rather than a prediction of a reality to avoid unintended consequences (e.g. property blight).
Relevant to what is trying to be measured so that the metric can be used to drive company behaviour in the right direction	The metric describes a key element of the resilience of sewerage systems i.e. level of vulnerability (raw and mitigated) and risk with respect to sewer flooding as a result of extreme wet weather events. It is considered that the mechanism for developing the metric outputs will enable a Company to focus its efforts on interventions that have a material impact on customers potentially at risk of flooding. The metric elements enable appropriate mitigation measures to be reflected in a reduction in vulnerability grade and/or pe in a vulnerable position. However, it is likely that there will also be interventions that are more about improving understanding (which can be considered as increasing knowledge of resilience) such as an increase in the quality and coverage of models (reducing the coverage of the 1a assessment). In this initial phase of the metric's development, it is considered that such interventions should be viewed positively; however, it is also considered that ultimately resilience interventions should be those that practically reduce the consequence, and customer impact, of events occurring. It will be important that any movement in the metric is clearly explained by the Companies and is appropriately assured. It is also recognised that the metric cannot take on board all forms of resilience measures; however, it should be able to reflect key interventions that can reduce risk to customers.
Able to be used to track a company's progress	In theory, the metric should enable a Company's progress to be tracked; however, this will need to be tested. There is the potential that, in collating information at a Company

Common performance commitment requirement	Comment
	level, there is a loss in sensitivity. For example, a Company may undertake work in an area to remove 4,000pe from being at high risk based on predicted flooding at several nodes. When collated at a business level the change may not register as being significant despite the Company have made a clear and appropriate intervention. In addition, as described above, in the initial stage of application, movements in the metric may be more about improvements in information rather than measures to address resilience on the ground. It will be important that any movement in the metric is clearly explained by the Companies and is appropriately assured.
Quantifiable, with available data and a clear definition	The catchment vulnerability characterisation and Option 1a assessment do have a high degree of engineering judgement associated with them. There are elements that can be supported with documented information (e.g. historic flooding events) but large parts are based on local knowledge and are therefore open to interpretation. The modelled element of the metric is based on reasonably robust (function of model quality) quantifiable information. While the pe conversion does take an assumed 'at risk' buffer it is considered that the approach reduces the risk of overestimating the potential issues.
Comparable	See discussion in Section 3.7.2 that follows this table.
Reproducible (yields a consistent result if the correct method is followed)	As for both the previous criteria, the catchment vulnerability characterisation and Option 1a assessment do have a high degree of engineering judgement associated with them and, as such, are open to interpretation. The modelled element of the metric is based on reasonably robust (function of model quality) quantifiable information; the process for obtaining outputs is relatively straightforward for competent modellers and, as such, expected to be reproducible.
Able to be used to set stretching performance commitment levels	See discussion in Section 3.7.2 that follows this table.

3.7.2. Comparability and incentivisation

It is considered that until the method has been applied and tested, it is difficult to fully define the extent to which comparisons can be made and that, certainly in the initial stages, caution is required in how the data is interpreted or used for comparative purposes.

Understanding that this is a single hazard, single consequence metric and that Companies' regions will have different levels of vulnerability driven by the nature of land (e.g. topography, and population density and development), it is considered that the relative positions of the Companies can be assessed with respect to:

- Coverage of the metric (size exclusion / Option 1a / Option 1b);
- Option 1a – an understanding of pe vulnerable within identified vulnerability grades – while comparisons can be made this is a generally based on engineering judgement and as such the limitations need to be recognised;

- Option 1b – an understanding of pe vulnerable from predicted flooding in higher vulnerability catchments; the nature of the outputs means that this data is more robustly comparable but confidence grades on models need to be considered.

With respect to the ability to set stretching targets, it is difficult to see at this stage how a financial incentive could be applied without a better understanding and testing of the metric and customer support for resilience investment. On-going work in this area coupled to improved knowledge gained as the metric is applied will inform the extent to which financial incentives could be considered in the future. In the initial testing and embedding phase this would also be true of any comparability approach. However, it is recognised that in the initial learning phase there is a real opportunity to 'polish' the metric to move towards a robust comparator to support and inform PR24.

In respect of how this metric is taken forward there are two broad options that could be considered, depending on whether the aim is to use the metric at PR19 or PR24. Both options would allow a period for Companies to build confidence in their data and approach by using 'shadow reporting', where information from the metric was not published but was shared in an appropriate manner amongst water sector stakeholders to provide transparency (for example Companies, regulators and the consumer body).

If the aim was to use the metric at PR19, then there could be 'shadow reporting' until 2019-20 to allow for it to be used in PR19 when it would be published with any relevant commentary on the data limitations. If a longer period of shadow reporting was deemed appropriate to build trust and confidence in the robustness of the metric, then shadow reporting could be extended beyond 2019-20 with the expectation that the metric would move from shadow reporting to being publicly available in sufficient time to support and inform PR24. Which approach is taken is a matter of judgement.

3.7.3. Summary

In general, the hybrid metric is considered to be consistent with Ofwat's criteria for a common performance measure; it is acknowledged that the use of engineering judgement for some elements of the assessment could lead to issues with comparability and reproducibility. However, as outlined in Table 11, which is based on information supplied by the participating Companies, given the percentage of pe covered by the modelled approach (and likely to be higher in future), it is considered that overall the metric does provide a reasonably robust assessment of resilience against a single but important hazard.

Table 11 Estimated model coverage - foul and combined sewers only (England and Wales)

Model type (10 returns)	Assessment
Total pe covered by verified or partially verified models	46,324,222
Percentage of total pe covered	85%
Number of models/catchments	1,896
Total pe covered by older/lower quality models	5,319,386
Percentage of total pe covered	10%
Number of models/catchments	1,312
Total pe not covered by models	2,956,920
%ge total pe not covered by models	5%

The sensitivity of the metric reported at Company level needs to be tested as there is the potential that, by collating information, movements in the metric resulting from improvements on the ground are not fully recognised. Consideration does need to be given to the number of decimal places and significant figures used as the collated information is reported (being clear that a high number of decimal places does not infer accuracy but sensitivity).

The lack of sensitivity is likely to be a key issue in the Summary reported table given that it is recommended data is further aggregated to provide a report that is more easily understood by customers. The sensitivity issue requires evaluation as and when the metric is applied.

4. Customer engagement

As part of their PR19 customer engagement activities, all Companies will have or will be engaging with customers on the concept of 'resilience'; while historically this would be more likely under the auspices of water resource planning, it is understood that there is a clearer focus on the wastewater systems in the development of the business plans. At the time of the project Companies were unable to provide details of the research they have been undertaking in this area as it was on-going and/or commercially sensitive. As such, it has not been possible to frame the messages around the metric within the context of current consultation outcomes.

However, from information that could be shared[10], there do appear to be some high-level indicators arising from work already completed:

- Customers understand the need to plan for the long term; pro-active spend in the shorter term to avoid leaving potentially greater reactive investment in the longer term.

- Customers have a range of understanding around resilience but generally appreciate that extreme events do occur and it is not always possible to mitigate against the effects; but there is an expectation that Companies will have a plan in place to deal with the consequences of an event occurring. This highlights that having appropriate response/recovery plans developed (and tested) is important to customers. This suggests that customers are willing to pay for a certain level of resilience; what level has yet to be defined.

- Customers view partnership working in general positively; this suggests that resilience work undertaken with other stakeholders (e.g. local authorities, Environment Agency) to manage, for example, run off entering the sewer system, would be viewed in the same light.

- Customers view the Companies as the experts and generally want to see them 'getting on with it'.

In respect of the metric itself there are messages that are considered key. One is likely to be that around return periods for storm events; what does, for example, a 1:50 storm actually look like? The following are suggested approaches to discussion around the chances that flooding will occur:

- Linking equivalent return periods to localised events that people may remember.

- Linking return periods to national events e.g. 1987 'Michael Fish no hurricane' storm had winds with a return period of 1:200.

- Linking return periods to life time events e.g. 'once in a life time', '50% chance of a once in a life time event occurring'; caution is still required with this approach and there is a need to frame this within the context that each year there is a small chance that a 'once in a life time event' could occur.

- Consider adopting the approach used for river, sea and surface water flooding, for example, that there is more than 1 in 30 (3.3%) chance of flooding in any given year.

With respect to what the metric is aimed at showing, the following elements are suggested:

- The metric is looking at the potential for sewers to flood due to extreme rainfall – it does not mean that sewers will flood or that houses will be impacted.

- Population is used as a measure of the stress in the system and does not mean that houses will be flooded should an extreme rainfall event occur (risk of 'property blight' needs to be avoided).

[10] PSG meeting – 4th October 2017

- Models can be viewed as giving definitive answers; there is a need to ensure there is clarity that model outputs are indicative as the nature of catchments means that a lot of assumptions are made (covered area etc.).

- For modelled outputs, using 'manholes predicted to flood' is easier to understand than surcharge; but it is important to reiterate the message that the outputs are indicative of stress in the system and do not mean that customers will be flooded.

- The assessment is designed to identify areas that would possibly be stressed within the system under an extreme rainfall event with a view to focussing effort to better understand the risks to customers; ultimately this will focus effort and lead to prioritising areas for investment spend where needed so that the chance of flooding to homes and businesses is less likely to happen in the future.

It is important to communicate that the metric is a means to help identify areas of stress which will focus work to better understand the risks to customers and will prioritise effort and spend, both in the short and long term, in respect of the need to develop measures to reduce risk. The scale of investment can be significant so robust evidence is needed to make the right choices. Solutions can take time to agree and make happen on the ground, so companies need to plan ahead.

5. Conclusions

The metrics proposed by Ofwat in its consultation document as a mechanism to assess the vulnerability of customers to sewer flooding as a result of an extreme wet weather event have been reviewed and a revised metric is proposed and recommended for application in AMP7. The revised metric is a hybrid that:

- Incorporates the principles behind Ofwat's Options 1a and 1b with a view to providing a wide coverage of Companies' catchments and populations.

- Takes a proportionate and pragmatic approach, at this stage in the metrics initial development, that: permits Companies to exclude small catchments unless there is good reason not to; enables Companies to report low vulnerability catchments directly without them having to undergo detailed assessment.

- Ensures that all catchments that are characterised as medium to high vulnerability undergo more detailed assessment whether or not a model currently exists for the catchment.

- Provides a risk-based approach using engineering judgement to assess vulnerability in those catchments where no models currently exist.

- Utilises nodes (manholes) predicted to flood as the modelled measure as it better reflects the risks being assessed and is likely to be more relevant to customers than a measure based on surcharge.

- Is, on balance, consistent with Ofwat's criteria for a common performance measure.

- Is aimed at driving positive behaviours from Companies; while improving knowledge is a resilience intervention, and is likely to be a key source of change in the metric in the initial stage of implementation, ultimately the metric is about recognising practical efforts to reduce the probability that customers will be impacted and the severity of that impact. It is acknowledged that the metric cannot recognise all forms of resilience intervention as the outputs are limited in what they can show (in particular modelled outputs); however, they do recognise key interventions to reduce, in particular, surface water inputs to the system whether undertaken by the Companies alone or in partnership with other stakeholders.

- Provides a means for Companies to engage with their customers in respect of sewer flooding arising from extreme wet weather events.

In respect of how this revised metric is taken forward, there are two broad options that could be considered, depending on whether the aim is to use the metric at PR19 or PR24. Both options would allow a period for companies to build confidence in their data and approach by using ‘shadow reporting’.

If the aim was to use the metric at PR19, then there could be ‘shadow reporting’ until 2019-20, to allow for it to be used in PR19 when it would be published with any relevant commentary on the data limitations. If a longer period of shadow reporting was deemed appropriate to build trust and confidence in the robustness of the metric, then shadow reporting could be extended beyond 2019-20, with the expectation that the metric would move from ‘shadow reporting’ to being publicly available in sufficient time to support and inform PR24. Which approach is taken is a matter of judgement.

Developing a robust baseline against which change can be measured will be key to the effectiveness of the metric. As the metric is ‘bedded in’ there are issues which will need further evaluation, these include but are not limited to:

- Ensuring that the metric is driving appropriate Company behaviours.
- Assessing the sensitivity of collated data in Company level reported tables; revisions may be required if there is a lack of sensitivity. However, having the catchment specific tables in the background does enable progress at local level to be evidenced even if this is not initially fully recognised at Company level.

Appropriate assurance will be important to minimise the risks to comparability (particularly from the elements of the metric that are based on engineering judgement) and to ensure that the metric is driving the right kind of behaviours.

6. Recommendations

It is envisaged that the metric will evolve over time; the following recommendations are made with a view to enhancing the metric in future:

- The vulnerability criteria have been established as an initial mechanism to develop understanding of catchment vulnerability taking on board any mitigation measures put in place. It is recommended that these are kept under review as the metric is applied with a view to potentially adapting them as required to produce more reflective criteria e.g. is there a more effective way to take on board a range of dwelling configurations notably flats and basements.
- Attempts have been made to provide a modelling approach that can be applied consistently across all companies; however, the difference in level of sophistication of the models requires that the approach is kept under review. In addition, the size of the buffers, the associated predicted flood volumes and the inclusion of ‘lost’ and ‘stored’ flood volumes in the assessment will need to be reviewed to ensure that the risks of overestimation of vulnerable pe is minimised.
- The modelling outputs currently take a binary approach to the pe assessed as being vulnerable i.e. that pe not associated with a node predicted to flood is classified as vulnerability grade 1. Future developments in the metric could involve mechanisms to more reflectively classify the residual pe. For example, including an assessment against nodes with freeboard less than 300mm in addition to those predicted to flood could, using the same buffer approach, be used to identify a residual pe that might be classified in vulnerability grade 4. Similarly, an assessment using surcharge as the measure could be added that might reflect a pe in vulnerability grade 3. Such an approach would provide a graduated assessment of vulnerability. However, as indicated, and to keep the assessment simple at this stage of development, the binary approach is recommended.
- As models become more sophisticated in future it is recommended that such development trends are recorded. Table 11 provides a comparison of the pe coverage based on foul and combined only sewers; what is not clear is the proportion of those models that are integrated with surface water models. Greater levels of integration will provide more robust model outputs.

There are significant developments in drainage system planning proposed; the establishment of Drainage and Wastewater Management Plans (DWMPs) represents a major step forward in integrated system planning and the metric will potentially need to evolve to fully reflect these advances.

7. References

National Infrastructure Commission, *Congestion, Capacity, Carbon: Priorities for National Infrastructure Consultation on a National Infrastructure Assessment* (2017)

Ofwat and Environment Agency, *Drainage Strategy Framework* (2013)

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Ofwat, *Towards Resilience* (2015b)

Ofwat, *Delivering Water 2020: Consulting on our methodology for the 2019 price review* (2017a)

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Ofwat, *Delivering Water 2020: consultation on PR19 methodology Appendix 3: Outcomes technical definitions* (2017c)

UKWIR, *Resilience – performance measures, costs and stakeholder communication UKWIR Report Ref No. 17/RG/06/4* (2017)

UK Govt., *Government response to the Committee on Climate Change 2017 Report to Parliament – Progress in preparing for climate change* (2017)

Water UK, *21st Century Drainage Programme Workstream 2 Capacity Management Guidance Document Water UK Report Ref. No. 21CDP.WS2.CM* (2017)

Appendices

Appendix A. Vulnerability criteria guidance

The table that follows outlines the vulnerability criteria and associated grades, alongside descriptive guidance for companies in undertaking the detailed Stage 1 high-level vulnerability assessment and the more focussed Stage 4 Option 1a. Note that in undertaking the assessment, if mitigation measures have been implemented (including measures up to the end of AMP6) then there is an option to reduce the vulnerability grade. The proposed reduction recognises that in most cases a level of vulnerability will remain.

Vulnerability description	Vulnerability grade	Detailed vulnerability description to aid assessment
General catchment geographic topography funnelling all flows into one area	5	Catchment geographic topography i.e. steep or hilly, is such that all flows are routed to one location creating a high vulnerability area; this may only be in one part of the catchment but indicates that overall the catchment has vulnerability. ***If mitigation measures have been implemented (include measures up to the end of AMP6) that manage the high vulnerability then reduce grade to 4 or 3. A lower grade is not recommended as the cause of the vulnerability still exists.***
Catchments with a rapid response	5	Catchment has a rapid response (assumed time of concentration <1 hour) resulting in high flow routing through the sewer and drainage network. ***If mitigation measures have been implemented (include measures up to the end of AMP6) that manage the high vulnerability then reduce grade to 4 or 3. A lower grade is not recommended as the cause of the vulnerability still exists.***
Unknown asset data	5	Little or no asset data is available for the catchment; this may be because there have never been issues reported. This primarily relates to information associated with critical assets; lack of information on, for example, private sewers that might be peripheral to the catchment are not considered as imparting high vulnerability.
Only drainage system in catchment / high proportion of combined sewers	5	Catchment where there are no natural watercourses; water company is >80% of engineered drainage routes. ***If mitigation measures have been implemented (include measures up to the end of AMP6) that manage the high vulnerability then reduce grade to 4 or 3. A lower grade is not recommended as the cause of the vulnerability still exists.***
Sewer flooding risk from historic reported incidents	4	Catchment has a history of reported sewer flooding incidents; all causes to be considered. ***If schemes have been put in place to manage the risks then reduce vulnerability to grade 3. If schemes have not been put in place, for whatever reason, then vulnerability still exists.***

Vulnerability description	Vulnerability grade	Detailed vulnerability description to aid assessment
Repeated blockage risk from historic reported incidents	4	Catchment has a history of repeated blockages on main sewers that could reduce sewer capacity. ***If operational practices or other interventions (e.g. proactive jetting) have taken place to manage the risks then reduce vulnerability to grade 2. If operational practices or other interventions have not been put in place, for whatever reason, then vulnerability still exists.***
Urban density (high population concentration)	4	Catchment with significant population centres; should flooding occur then this increases the likelihood of customers being impacted. The following guideline values are suggested: high density grade 4 – greater than 55 dwellings per hectare (dw/ha); medium density grade 3 – 30-55 dw/ha; low density grade 2 – less than 30 dw/ha[11]. However, Companies are advised to take on board local planning authority approaches if available. Within the context of urban density consideration needs to be given to the nature of the properties/developments in the catchment e.g. high levels of basements, concentrations of blocks of flats etc., and the extent to which creep could increase surface water flows. In both cases Companies should use professional judgement in applying an appropriate grade that reflects the assessed vulnerability.
Proximity to sea / river level	3	Catchments which could be subject to tidal/fluvial locking causing sewers to back up and flood under storm conditions (link to EA flood risk maps). ***If mitigation measures have been implemented (include measures up to the end of AMP6) that manages the vulnerability then reduce grade to 2 or 1.***
Large complex networks with many dependencies	3	Generally large catchment with significant combined sewers and interactions with surface water drainage systems; some cross catchment flows.
Dependence on pumping	3	Catchment contains one or more critical pumping stations (in-catchment or terminal) where high flows could overwhelm capacity (or cause failure). Asset registers. ***If mitigation measures have been implemented (include measures up to the end of AMP6) that manages the vulnerability then reduce grade to 2 or 1.***
Proximity to water table	3	Catchment with known high levels of infiltration which could be exacerbated by heavy rainfall effectively reducing capacity in system to remove surface/foul flows.

[11] There are no statutory guidelines to cover urban density; the UK Government's Housing White Paper leaves the decision on appropriate density up to local planning authorities and which reflects previous approaches. The figures used are derived from those published in Annex 3 of the draft Planning Policy Statement 3 (PPS3) in 2005 although it is noted that the guideline figures were removed from the final version of PPS3.

Vulnerability description	Vulnerability grade	Detailed vulnerability description to aid assessment
Growth potential (unplanned)	3	Catchments with areas known to have high demand for new housing, are economically buoyant and are highly likely to develop further. Significant risk of infill growth.
Consequence of flood risk management by others	2	Catchment where flood management by others could cause unintended consequences.
Growth potential (planned)	2	Catchments with areas known to have high demand for new housing but risks are generally known.
Catchments with a slow response - flat sewers and septicity	2	Catchments that are generally flat with a slow response.
Where no key issues identified	1	Where none of the catchment vulnerabilities match and there are no alternative catchment specific vulnerabilities then the catchment is to be reported under vulnerability grade 1.
The list is not exhaustive; companies can put forward their own vulnerability characteristic and score (e.g. for one outlier catchment with its own problems)		

Appendix B. Outputs from modelling assessment

B.1. Nodes predicted to flood or surcharge with <300mm freeboard

The following presents the outputs from the modelling assessment examining nodes predicted to flood and nodes with <300mm freeboard.

Company 1	**M30-60**	**M30-240**	**M30-480**	**M50-60**	**M50-240**	**M50-480**
Total number of modelled nodes	3,802	3,802	3,802	3,802	3,802	3,802
Number predicted to flood	398	236	164	465	279	194
Percentage of nodes predicted to flood	10.5%	6.2%	4.3%	12.2%	7.3%	5.1%
Percentage of nodes predicted to flood (>100m³)	0.2%	0.3%	0.2%	0.3%	0.5%	0.4%
Percentage of nodes predicted to flood (25-100m³)	2.8%	1.6%	1.0%	3.4%	1.9%	1.2%
Percentage of nodes predicted to flood (<25m³)	7.5%	4.3%	3.1%	8.5%	4.9%	3.5%
Percentage of nodes with <300mm freeboard	24.9%	17.3%	13.2%	28.1%	19.2%	15.1%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	3,802	3,802	3,802	3,802	3,802	3,802
Number predicted to flood	531	313	224	577	334	241
Percentage of nodes predicted to flood	14.0%	8.2%	5.9%	15.2%	8.8%	6.3%
Percentage of nodes predicted to flood (>100m³)	0.6%	0.6%	0.6%	0.6%	0.7%	0.7%
Percentage of nodes predicted to flood (25-100m³)	3.8%	2.4%	1.7%	4.4%	2.8%	1.9%
Percentage of nodes predicted to flood (<25m³)	9.7%	5.2%	3.7%	10.2%	5.2%	3.7%
Percentage of nodes with <300mm freeboard	30.5%	20.9%	17.0%	31.7%	22.0%	18.1%

Company 2	**M30-60**	**M30-240**	**M30-480**	**M50-60**	**M50-240**	**M50-480**
Total number of modelled nodes	19,364	19,364	19,364	19,364	19,364	19,364
Number predicted to flood	2,469	1,079	596	2,954	1,349	720
Percentage of nodes predicted to flood	12.8%	5.6%	3.1%	15.3%	7.0%	3.7%
Percentage of nodes predicted to flood (>100m³)	0.7%	0.6%	0.5%	1.0%	0.9%	0.6%
Percentage of nodes predicted to flood (25-100m³)	2.8%	1.4%	0.8%	3.4%	1.8%	1.0%
Percentage of nodes predicted to flood (<25m³)	9.3%	3.6%	1.8%	10.9%	4.3%	2.1%
Percentage of nodes with <300mm freeboard	20.6%	10.0%	5.5%	24.2%	12.4%	6.9%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	19,364	19,364	19,364	19,364	19,364	19,364
Number predicted to flood	3,374	1,604	883	3,674	1,798	1,029
Percentage of nodes predicted to flood	17.4%	8.3%	4.6%	19.0%	9.3%	5.3%
Percentage of nodes predicted to flood (>100m³)	1.2%	1.1%	0.8%	1.4%	1.3%	1.0%
Percentage of nodes predicted to flood (25-100m³)	4.2%	2.2%	1.2%	4.6%	2.5%	1.3%
Percentage of nodes predicted to flood (<25m³)	12.1%	5.0%	2.6%	13.0%	5.5%	3.0%
Percentage of nodes with <300mm freeboard	27.0%	14.5%	8.6%	29.2%	16.1%	9.8%

Company 3	**M30-60**	**M30-240**	**M30-480**	**M50-60**	**M50-240**	**M50-480**
Total number of modelled nodes	9,199	9,199	9,199	9,199	9,199	9,199
Number predicted to flood	572	343	217	678	407	266
Percentage of nodes predicted to flood	6.2%	3.7%	2.4%	7.4%	4.4%	2.9%
Percentage of nodes predicted to flood (>100m^3)	0.5%	0.5%	0.3%	0.7%	0.6%	0.4%
Percentage of nodes predicted to flood (25-100m^3)	1.6%	0.9%	0.5%	1.8%	1.2%	0.6%
Percentage of nodes predicted to flood (<25m^3)	4.1%	2.4%	1.5%	4.9%	2.7%	1.8%
Percentage of nodes with <300mm freeboard	21.0%	16.1%	13.2%	24.3%	18.7%	15.3%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	9,199	9,199	9,199	9,199	9,199	9,199
Number predicted to flood	747	456	313	799	488	339
Percentage of nodes predicted to flood	8.1%	5.0%	3.4%	8.7%	5.3%	3.7%
Percentage of nodes predicted to flood (>100m^3)	0.8%	0.7%	0.6%	1.0%	0.8%	0.7%
Percentage of nodes predicted to flood (25-100m^3)	2.0%	1.4%	0.7%	2.2%	1.4%	0.8%
Percentage of nodes predicted to flood (<25m^3)	5.3%	2.9%	2.1%	5.6%	3.1%	2.2%
Percentage of nodes with <300mm freeboard	27.2%	21.2%	16.9%	28.6%	22.7%	18.5%

Company 4	**M30-60**	**M30-240**	**M30-480**	**M50-60**	**M50-240**	**M50-480**
Total number of modelled nodes	2,745	2,745	2,745	2,745	2,745	2,745
Number predicted to flood	382	143	69	156	193	95
Percentage of nodes predicted to flood	13.9%	5.2%	2.5%	5.7%	7.0%	3.5%
Percentage of nodes predicted to flood (>100m^3)	2.6%	1.6%	1.0%	1.8%	1.8%	1.3%
Percentage of nodes predicted to flood (25-100m^3)	3.1%	1.2%	0.5%	1.3%	2.1%	0.5%
Percentage of nodes predicted to flood (<25m^3)	8.3%	2.4%	1.0%	2.6%	3.1%	1.6%
Percentage of nodes with <300mm freeboard	27.5%	14.4%	9.6%	14.3%	17.6%	10.9%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	2,745	2,745	2,745	2,745	2,745	2,745
Number predicted to flood	523	216	133	606	248	156
Percentage of nodes predicted to flood	19.1%	7.9%	4.8%	22.1%	9.0%	5.7%
Percentage of nodes predicted to flood (>100m^3)	3.5%	2.3%	1.6%	4.3%	2.8%	1.8%
Percentage of nodes predicted to flood (25-100m^3)	5.2%	2.2%	0.7%	6.5%	2.6%	1.3%
Percentage of nodes predicted to flood (<25m^3)	10.3%	3.4%	2.6%	11.3%	3.6%	2.6%
Percentage of nodes with <300mm freeboard	35.9%	19.4%	12.4%	38.9%	21.2%	14.3%

Company 5	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of modelled nodes	2,744	2,744	2,744	2,744	2,744	2,744
Number predicted to flood	124	59	37	155	82	45
Percentage of nodes predicted to flood	4.5%	2.2%	1.3%	5.6%	3.0%	1.6%
Percentage of nodes predicted to flood (>100m^3)	0.4%	0.2%	0.1%	0.5%	0.4%	0.2%
Percentage of nodes predicted to flood (25-100m^3)	1.1%	0.6%	0.4%	1.3%	0.7%	0.5%
Percentage of nodes predicted to flood (<25m^3)	3.1%	1.3%	0.8%	3.8%	1.9%	0.9%
Percentage of nodes with <300mm freeboard	11.3%	7.0%	5.0%	13.4%	9.9%	6.3%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	2,744	2,744	2,744	2,744	2,744	2,744
Number predicted to flood	176	101	51	192	121	57
Percentage of nodes predicted to flood	6.4%	3.7%	1.9%	7.0%	4.4%	2.1%
Percentage of nodes predicted to flood (>100m^3)	0.6%	0.5%	0.3%	0.7%	0.6%	0.4%
Percentage of nodes predicted to flood (25-100m^3)	1.7%	0.9%	0.6%	2.2%	1.1%	0.6%
Percentage of nodes predicted to flood (<25m^3)	4.1%	2.3%	0.9%	4.2%	2.7%	1.1%
Percentage of nodes with <300mm freeboard	15.0%	11.5%	7.4%	16.4%	12.7%	8.4%

Company 6	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of modelled nodes	327	327	327	327	327	327
Number predicted to flood	54	24	9	61	35	13
Percentage of nodes predicted to flood	16.5%	7.3%	2.8%	18.7%	10.7%	4.0%
Percentage of nodes predicted to flood (>100m^3)	3.4%	2.1%	0.6%	4.0%	2.8%	1.5%
Percentage of nodes predicted to flood (25-100m^3)	7.3%	2.1%	1.2%	9.2%	3.4%	0.6%
Percentage of nodes predicted to flood (<25m^3)	5.8%	3.1%	0.9%	5.5%	4.6%	1.8%
Percentage of nodes with <300mm freeboard	26%	13%	6%	31%	18%	8%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240[12]**	**M100-480**
Total number of modelled nodes	327	327	327	327		327
Number predicted to flood	72	41	16	76		19
Percentage of nodes predicted to flood	22.0%	12.5%	4.9%	23.2%		5.8%
Percentage of nodes predicted to flood (>100m^3)	5.2%	3.7%	1.5%	5.2%		2.1%
Percentage of nodes predicted to flood (25-100m^3)	9.8%	3.4%	1.5%	9.8%		1.2%
Percentage of nodes predicted to flood (<25m^3)	7.0%	5.5%	1.8%	8.3%		2.4%
Percentage of nodes with <300mm freeboard	34%	21%	9%	37%		10%

[12] Model failed to run

Company 7	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of modelled nodes	3,863	3,863	3,863	3,863	3,863	3,863
Number predicted to flood	284	154	101	347	209	140
Percentage of nodes predicted to flood	7.4%	4.0%	2.6%	9.0%	5.4%	3.6%
Percentage of nodes predicted to flood (>100m^3)	0.2%	0.2%	0.2%	0.4%	0.3%	0.3%
Percentage of nodes predicted to flood (25-100m^3)	1.3%	0.8%	0.4%	1.8%	1.4%	0.9%
Percentage of nodes predicted to flood (<25m^3)	5.9%	3.0%	2.0%	6.8%	3.6%	2.5%
Percentage of nodes with <300mm freeboard	16.7%	10.3%	7.4%	19.8%	13.4%	9.1%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	3,863	3,863	3,863	3,863	3,863	3,863
Number predicted to flood	407	236	178	437	274	192
Percentage of nodes predicted to flood	10.5%	6.1%	4.6%	11.3%	7.1%	5.0%
Percentage of nodes predicted to flood (>100m^3)	0.6%	0.5%	0.4%	0.6%	0.7%	0.6%
Percentage of nodes predicted to flood (25-100m^3)	2.4%	1.7%	1.2%	2.7%	2.0%	1.4%
Percentage of nodes predicted to flood (<25m^3)	7.6%	3.9%	3.0%	8.1%	4.4%	3.0%
Percentage of nodes with <300mm freeboard	22.9%	15.2%	11.0%	24.4%	17.1%	12.5%

Company 8	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of modelled nodes	4,277	4,277	4,277	4,277	4,277	4,277
Number predicted to flood	379	213	127	501	279	170
Percentage of nodes predicted to flood	8.9%	5.0%	3.0%	11.7%	6.5%	4.0%
Percentage of nodes predicted to flood (>100m^3)	0.3%	0.4%	0.2%	0.5%	0.5%	0.4%
Percentage of nodes predicted to flood (25-100m^3)	1.9%	1.3%	0.7%	2.8%	1.7%	1.1%
Percentage of nodes predicted to flood (<25m^3)	6.6%	3.3%	2.0%	8.4%	4.3%	2.5%
Percentage of nodes with <300mm freeboard	30.2%	20.9%	15.2%	36.1%	26.0%	19.8%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	4,277	4,277	4,277	4,277	4,277	4,277
Number predicted to flood	586	347	224	657	394	251
Percentage of nodes predicted to flood	13.7%	8.1%	5.2%	15.4%	9.2%	5.9%
Percentage of nodes predicted to flood (>100m^3)	0.8%	0.7%	0.5%	1.1%	1.0%	0.7%
Percentage of nodes predicted to flood (25-100m^3)	3.3%	2.1%	1.5%	3.8%	2.4%	1.7%
Percentage of nodes predicted to flood (<25m^3)	9.5%	5.3%	3.2%	10.5%	5.8%	3.5%
Percentage of nodes with <300mm freeboard	41.6%	30.5%	23.6%	44.7%	33.1%	25.4%

Company 9	**M30-60**	**M30-240**	**M30-480**	**M50-60**	**M50-240**	**M50-480**
Total number of modelled nodes	581	581	581	581	581	581
Number predicted to flood	71	57	49	91	62	56
Percentage of nodes predicted to flood	12.2%	9.8%	8.4%	15.7%	10.7%	9.6%
Percentage of nodes predicted to flood (>100m^3)	0.2%	0.9%	0.7%	0.3%	0.9%	0.9%
Percentage of nodes predicted to flood (25-100m^3)	1.7%	1.7%	1.2%	2.4%	2.2%	2.2%
Percentage of nodes predicted to flood (<25m^3)	10.3%	7.2%	6.5%	12.9%	7.6%	6.5%
Percentage of nodes with <300mm freeboard	24.4%	16.4%	15.3%	28.6%	18.4%	16.7%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	581	581	581	581	581	581
Number predicted to flood	106	66	62	113	71	63
Percentage of nodes predicted to flood	18.2%	11.4%	10.7%	19.4%	12.2%	10.8%
Percentage of nodes predicted to flood (>100m^3)	0.7%	0.9%	0.9%	0.9%	1.0%	1.0%
Percentage of nodes predicted to flood (25-100m^3)	2.8%	2.9%	2.6%	3.3%	3.1%	2.4%
Percentage of nodes predicted to flood (<25m^3)	14.8%	7.6%	7.2%	15.3%	8.1%	7.4%
Percentage of nodes with <300mm freeboard	33.0%	20.0%	17.9%	34.8%	22.0%	18.2%

Company 10	**M30-60**	**M30-240**	**M30-480**	**M50-60[13]**	**M50-240**	**M50-480**
Total number of modelled nodes	677	677	677		677	677
Number predicted to flood	93	23	5		35	10
Percentage of nodes predicted to flood	13.7%	3.4%	0.7%		5.2%	1.5%
Percentage of nodes predicted to flood (>100m^3)	1.9%	0.4%	0.0%		0.4%	0.0%
Percentage of nodes predicted to flood (25-100m^3)	4.4%	0.7%	0.0%		2.2%	0.3%
Percentage of nodes predicted to flood (<25m^3)	7.4%	2.2%	0.7%		2.5%	1.2%
Percentage of nodes with <300mm freeboard	17.9%	5.5%	1.2%		7.1%	2.2%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	677	677	677	677	677	677
Number predicted to flood	149	46	14	166	54	17
Percentage of nodes predicted to flood	22.0%	6.8%	2.1%	24.5%	8.0%	2.5%
Percentage of nodes predicted to flood (>100m^3)	3.7%	1.0%	0.0%	4.9%	1.9%	0.3%
Percentage of nodes predicted to flood (25-100m^3)	5.8%	2.7%	0.4%	7.2%	2.2%	0.7%
Percentage of nodes predicted to flood (<25m^3)	12.6%	3.1%	1.6%	12.4%	3.8%	1.5%
Percentage of nodes with <300mm freeboard	27.8%	9.2%	3.1%	30.9%	11.5%	3.7%

[13] Model failed to run

Company 11	M30-60	M30-240	M30-480	M50-60	M50-240[14]	M50-480
Total number of modelled nodes	6,448	6,448	6,448	6,448		6,448
Number predicted to flood	428	367	319	538		413
Percentage of nodes predicted to flood	6.6%	5.7%	4.9%	8.3%		6.4%
Percentage of nodes predicted to flood (>100m³)	1.2%	1.4%	1.2%	1.6%		1.7%
Percentage of nodes predicted to flood (25-100m³)	1.8%	1.6%	1.3%	2.4%		1.9%
Percentage of nodes predicted to flood (<25m³)	3.6%	2.7%	2.4%	4.3%		2.9%
Percentage of nodes with <300mm freeboard	16.2%	13.8%	11.4%	20.0%		13.5%
	M75-60	**M75-240**	**M75-480[15]**	**M100-60**	**M100-240**	**M100-480**
Total number of modelled nodes	6,448	6,448		6,448	6,448	6,448
Number predicted to flood	642	586		742	644	535
Percentage of nodes predicted to flood	10.0%	9.1%		11.5%	10.0%	8.3%
Percentage of nodes predicted to flood (>100m³)	2.1%	2.3%		2.6%	2.8%	2.5%
Percentage of nodes predicted to flood (25-100m³)	3.0%	2.9%		3.4%	3.1%	2.5%
Percentage of nodes predicted to flood (<25m³)	4.8%	3.9%		5.6%	4.1%	3.3%
Percentage of nodes with <300mm freeboard	23.3%	19.2%		26.1%	21.1%	16.1%

B.2. Surcharge assessment

Models were run applying the agreed range of storm events and durations. The number of conduits surcharging at either State 1 or 2 were recorded and the percentage of total conduits in the model calculated.

Company 1	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	3,687	3,687	3,687	3,687	3,687	3,687
Conduits with Surcharge State of 1 or 2	2,277	1,793	1,517	2,381	1,922	1,653
Percentage with Surcharge State of 1 or 2	62%	49%	41%	65%	52%	45%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	3,687	3,687	3,687	3,687	3,687	3,687
Conduits with Surcharge State of 1 or 2	2,467	2,013	1,735	2,519	2,091	1,806
Percentage with Surcharge State of 1 or 2	67%	55%	47%	68%	57%	49%

Company 2	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	19,031	19,031	19,031	19,031	19,031	19,031
Conduits with Surcharge State of 1 or 2	10,843	7,216	4,906	11,658	8,112	5,766
Percentage with Surcharge State of 1 or 2	57%	38%	26%	61%	43%	30%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	19,031	19,031	19,031	19,031	19,031	19,031
Conduits with Surcharge State of 1 or 2	12,164	8,859	6,384	12,511	9,351	6,797
Percentage with Surcharge State of 1 or 2	64%	47%	34%	66%	49%	36%

[14] Model failed to run
[15] Model failed to run

Company 3	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	9,256	9,256	9,256	9,256	9,256	9,256
Conduits with Surcharge State of 1 or 2	5,971	5,306	4,669	6,272	5,606	4,965
Percentage with Surcharge State of 1 or 2	65%	57%	50%	68%	61%	54%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	9,256	9,256	9,256	9,256	9,256	9,256
Conduits with Surcharge State of 1 or 2	6,479	5,861	5,210	6,620	5,998	5,369
Percentage with Surcharge State of 1 or 2	70%	63%	56%	72%	65%	58%

Company 4	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	2,719	2,719	2,719	2,719	2,719	2,719
Conduits with Surcharge State of 1 or 2	2,073	1,544	1,242	2,178	1,664	1,364
Percentage with Surcharge State of 1 or 2	76%	57%	46%	80%	61%	50%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	2,719	2,719	2,719	2,719	2,719	2,719
Conduits with Surcharge State of 1 or 2	2,222	1,753	1,433	2,300	1,843	1,491
Percentage with Surcharge State of 1 or 2	82%	64%	53%	85%	68%	55%

Company 5	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	2,678	2,678	2,678	2,678	2,678	2,678
Conduits with Surcharge State of 1 or 2	1,249	990	783	1,344	1,101	879
Percentage with Surcharge State of 1 or 2	47%	37%	29%	50%	41%	33%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	2,678	2,678	2,678	2,678	2,678	2,678
Conduits with Surcharge State of 1 or 2	1,406	1,173	967	1,456	1,222	1,021
Percentage with Surcharge State of 1 or 2	53%	44%	36%	54%	46%	38%

Company 6	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	322	322	322	322	322	322
Conduits with Surcharge State of 1 or 2	266	226	179	275	239	188
Percentage with Surcharge State of 1 or 2	83%	70%	56%	85%	74%	58%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240[16]**	**M100-480**
Total number of conduits	322	322	322	322		322
Conduits with Surcharge State of 1 or 2	278	250	201	282		208
Percentage with Surcharge State of 1 or 2	86%	78%	62%	88%		65%

[16] Model failed to run

Company 7	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	3,843	3,843	3,843	3,843	3,843	3,843
Conduits with Surcharge State of 1 or 2	2,512	2,031	1,723	2,644	2,176	1,885
Percentage with Surcharge State of 1 or 2	65%	53%	45%	69%	57%	49%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	3,843	3,843	3,843	3,843	3,843	3,843
Conduits with Surcharge State of 1 or 2	2,739	2,291	2,000	2,790	2,376	2,074
Percentage with Surcharge State of 1 or 2	71%	60%	52%	73%	62%	54%

Company 8	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	4,401	4,401	4,401	4,401	4,401	4,401
Conduits with Surcharge State of 1 or 2	3,251	2,887	2,508	3,432	3,116	2,775
Percentage with Surcharge State of 1 or 2	74%	66%	57%	78%	71%	63%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	4,401	4,401	4,401	4,401	4,401	4,401
Conduits with Surcharge State of 1 or 2	3,572	3,274	2,966	3,647	3,361	3,076
Percentage with Surcharge State of 1 or 2	81%	74%	67%	83%	76%	70%

Company 9	M30-60	M30-240	M30-480	M50-60	M50-240	M50-480
Total number of conduits	571	571	571	571	571	571
Conduits with Surcharge State of 1 or 2	378	278	229	389	306	244
Percentage with Surcharge State of 1 or 2	66%	49%	40%	68%	54%	43%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	571	571	571	571	571	571
Conduits with Surcharge State of 1 or 2	403	322	259	410	333	272
Percentage with Surcharge State of 1 or 2	71%	56%	45%	72%	58%	48%

Company 10	M30-60	M30-240	M30-480	M50-60[17]	M50-240	M50-480
Total number of conduits	668	668	668		668	668
Conduits with Surcharge State of 1 or 2	418	228	127		271	162
Percentage with Surcharge State of 1 or 2	63%	34%	19%		41%	24%
	M75-60	**M75-240**	**M75-480**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	668	668	668	668	668	668
Conduits with Surcharge State of 1 or 2	464	299	186	475	325	199
Percentage with Surcharge State of 1 or 2	69%	45%	28%	71%	49%	30%

[17] Model failed to run

Company 11	M30-60	M30-240	M30-480	M50-60	M50-240[18]	M50-480
Total number of conduits	6,237	6,237	6,237	6,237		6,237
Conduits with Surcharge State of 1 or 2	4,105	3,790	3,444	4,343		3,647
Percentage with Surcharge State of 1 or 2	63%	58%	53%	67%		56%
	M75-60	**M75-240**	**M75-480[19]**	**M100-60**	**M100-240**	**M100-480**
Total number of conduits	6,237	6,237		6,237	6,237	6,237
Conduits with Surcharge State of 1 or 2	4,529	4,216		4,657	4,331	3,952
Percentage with Surcharge State of 1 or 2	69%	65%		71%	66%	61%

B.3. Assessment of property numbers associated with nodes predicted to flood

The following outlines the process utilised for obtaining property and pe numbers associated with nodes predicted to flood:

- X, Y coordinates and system type for each node were transferred into the existing model data export file (.*csv*) for storms (M50-60, M50-240, M50-480).
- A Feature Manipulation Engine (FME – data manipulation software) workspace was created and the export (.*csv*) file imported. The FME was programmed to filter by required flood volumes and set the buffers for each node as a function of flood volume. The filtering process removed any nodes with a recorded flood volume of less than 0m3 (the model results produce negative values for any nodes that do not flood).
- The FME process produced a .*tab* file that was imported to MapInfo. Address point data was also imported to MapInfo.
- SQL select was then be used to produce a table of the addresses which fell within the given buffers.
- The table containing address details was exported to Excel; this was subsequently used to remove duplicate counts of address points where more than one node buffer overlapped.
- The number of properties in each buffer was then multiplied by the catchment occupancy ratio to obtain a pe figure.

Companies can use alternative methods dependent on the systems employed; however, a key element is to ensure that duplicate properties are removed.

[18] Model failed to run
[19] Model failed to run

Appendix C. Modelling criteria

To achieve consistency across companies, a standard modelling methodology is proposed. It is assumed that the majority of the current hydraulic models will be one-dimensional Type II (Drainage Area Planning Models) and that these should be used as standard if available. If more detailed models are available, then these can be used for the purpose of the assessment. Fully integrated catchment models which allow overland flood paths to be mapped in two-dimensions with reasonable accuracy, can also be considered for use as these will allow for much greater levels of certainty in determining the address points likely to be impacted by predicting flooding. Care should be taken to ensure reporting flooding is a consequence of sewer flooding rather than pluvial flooding, fluvial flooding or flooding from other sources which may be built into the model. It is anticipated that as modelling tools improve over time, there will be a greater prevalence of higher quality models available to be used for this analysis, and this will eventually become the standard method of assessment.

The following summarises the key criteria:

- Companies should run the model with a 1:50 storm event with durations of 60, 240 and 480 minutes. In respect of winter / summer models that which results in the ‘worst case’ i.e. greatest number of nodes predicted to be flooding under the conditions outlined, should be selected for pe assessment.

- The number of nodes predicted to flood should be recorded alongside the total number of nodes modelled.

- For each node predicted to flood either:

    - Apply a buffer zone that reflects predicted flood volume (<25m^3 use 15m radius; 25-100m^3 use 30m radius; >100m^3 use 50m radius). Use address point data to identify properties impacted and apply appropriate occupancy rates for the catchment to determine the potential pe impacted. Where predicted flooding nodes are sequential it is important that overlapping address points are adjusted to avoid the risk of double counting.

    - Utilise 2D flood routing maps (or alternatives) to determine properties impacted; use GIS address point data to determine number of properties impacted and apply appropriate occupancy rates for the catchment to determine the potential pe impacted. Where nodes are sequential it is important that overlapping properties are removed to avoid the risk of double counting.

- The assessment should be inclusive of all foul, combined and surface water sewers contained within the model. It is acknowledged that Company’s existing models will vary widely in terms of the percentage of surface water sewers that are included. However, it is considered that models with a higher proportion of surface water sewers already included will be due to known high levels of interaction with the foul/combined network, and/or known flooding issues in the area.

- Blockage data should be considered when looking at overall catchment health; however, it is not expected that companies will replicate blockages in the hydraulic modelling exercise.

- As per the 21CD Capacity Assessment Framework guidance, infiltration, trade flows and diurnal profiles should be used as provided in the existing models.

At this stage, no uplift should be applied for climate change; the 1:50 return event has been agreed as the standard storm for this measure.

Appendix D. Worked example of assessment and reporting

The following provides an example of how it is proposed that metric would operate. The scenario involves six catchments. The following summarises the initial outputs:

Catchment id	PE	Assessed vulnerability grade	Model available	Assessment
A	1,500	1	N	No known issues; <2,000pe so report directly in Option 1a catchment table as vulnerability grade 1
B	5,500	2	N	Having assessed high-level vulnerability grade, report directly in Option 1a catchment table as vulnerability grade 2
C	3,000	3	N	Option 1a assessment
D	30,000	5	N	Option 1a assessment
E	18,000	5	Y	Option 1b assessment
F	60,000	5	Y	Option 1b assessment
Total	**118,000**			

Catchment A

As indicated, no known issues and as catchment is <2,000pe this is reported directly at vulnerability Grade 1:

Catchment id	High-level vulnerability assessment	'Functional area' id	Detailed vulnerability risk grade	pe in 'functional area'	Percentage of catchment pe
A	1	1	1	1,500	100%
			Total catchment pe	1,500	

Catchment B

Catchment has been subject to initial vulnerability assessment and is considered flat with a slow response; no other issues are identified so assessed as Grade 2:

Catchment id	High-level vulnerability assessment	'Functional area' id	Detailed vulnerability risk grade	pe in 'functional area'	Percentage of catchment pe
B	2	1	2	5,500	100%
			Total catchment pe	5,500	

Catchment C

Catchment has been subject to initial vulnerability assessment; issues identified as a dependence on pumping, high levels of infiltration and is in a potential growth area. Catchment assessed as Grade 3 based on highest vulnerability grade. Catchment cannot be split given minimum functional area size requirement. As such, the whole catchment is assessed as Grade 3:

Catchment id	High-level vulnerability assessment	'Functional area' id	Detailed vulnerability risk grade	pe in 'functional area'	Percentage of catchment pe
C	3	1	3	3,000	100%
			Total catchment pe	3,000	

Catchment D

Catchment has been subject to initial vulnerability assessment; issues identified as topography funnelling all flows to one location, rapid response, and in an area where local flood management initiatives risk fluvial locking. Catchment assessed as Grade 5 based on highest vulnerability grade. Company decides to split catchment as vulnerabilities do not apply across all areas. Split is based on discrete areas attached to mains sewers that feed into a trunk main. Individual functional areas have been assessed. Topography and response time only impact areas close to the WwTW. Catchment assessed as follows:

Catchment id	High-level vulnerability assessment	'Functional area' id	Detailed vulnerability risk grade	pe in 'functional area'	Percentage of catchment pe
D	5	1	1	5,000	17%
		2	1	8,000	27%
		3	1	10,000	33%
		4	3	5,000	17%
		5	5	2,000	7%
			Total catchment pe	30,000	

Catchment E

Catchment has been subject to initial vulnerability assessment; issues identified as network being the only drainage system in catchment with a high proportion of combined sewers and historic flooding issues recorded. Catchment assessed as Grade 5 based on highest vulnerability grade. Company has a well-developed model available. Model is run with 1:50 return period with three durations and the critical event identified. Procedure to derive vulnerable pe is followed and the following catchment table developed:

Catchment id	High-level vulnerability grade	Number of nodes modelled	Number of nodes predicted to flood	Percentage of nodes predicted to flood	Catchment pe	Total pe associated with flooding nodes	pe associated with flooding nodes as a percentage of catchment pe	Assessed model confidence grade
E	5	3,802	465	12.2%	18,000	3,361	19%	A3

Outputs suggest that further investigation is prioritised given the percentage of pe assessed as being vulnerable to flooding as a function of extreme wet weather.

Catchment F

Catchment has been subject to initial vulnerability assessment; issues identified as catchment with a high proportion of combined sewers, historic flooding issues recorded and is a potential growth area. Catchment assessed as Grade 5 based on highest vulnerability grade. Company has a well-developed model available. Model is run with 1:50 return period with three durations and the critical event identified. Procedure to derive vulnerable pe is followed and the following catchment table developed:

Catchment id	High-level vulnerability grade	Number of nodes modelled	Number of nodes predicted to flood	Percentage of nodes predicted to flood	Catchment pe	Total pe associated with flooding nodes	pe associated with flooding nodes as a percentage of catchment pe	Assessed model confidence grade
F	5	4,277	501	11.7%	60,000	1,123	2%	A4

Outputs suggest that despite the high vulnerability, the proportion of pe assessed as being vulnerable to flooding as a function of extreme wet weather is low. This could be the result of previous interventions or original sewer design.

DETAILED REPORTING

As outlined on Section 3.6 the following tables are completed:

Metric coverage

Total pe served	Total pe Option 1a	Percentage of total pe Option 1a	Total pe Option 1b	Percentage of total pe Option 1b
118,000	40,000	34%	78,000	66%

Option 1a collated

Note - from catchment	Detailed vulnerability risk grade	Number of catchments or ‘functional areas’	Total pe in catchments or 'functional areas' at vulnerability risk grade	Percentage of total Option 1a pe
D	5	1	2,000	5%
	4	0	0	0%
C, D	3	2	8,000	20%
B	2	1	5,500	14%
A, D	1	4	24,500	61%
	Totals	**8**	**40,000**	

Option 1b collated

High-level vulnerability grade	Total number of catchments	Total number of nodes modelled	Total number of nodes predicted to flood	Percentage of nodes predicted to flood	Total pe in modelled catchments at vulnerability risk grade	Total pe associated with flooding nodes	pe associated with flooding nodes as a percentage of total modelled pe	Assessed average model confidence grade
5	2	8,079	966	12%	78,000	4,484	6%	A4
4								
3								

Note: Company will need to make a judgement on the overall model confidence grade – see main text (Section 3.6.1) for further discussion.

SUMMARY REPORTING

As outlined in Section 3.6.2 it is suggested that the following table is provided for those with a less technical background to provide a high-level understanding of vulnerability:

Vulnerability grade	Percentage of total population served	*Comment (for explanation in the context of this report and not intended for inclusion in the Summary table)*
L	88%	*From vulnerability grades 1 and 2 and pe NOT predicted to be at risk of flooding from Option 1b assessment (catchment pe minus pe assessed as being vulnerable to predicted flooding)*
M	7%	*From vulnerability grades 3 and 4 (Options 1a and 1b combined)*
H	5%	*From vulnerability grades 5 (Options 1a and 1b combined)*

Appendix E. Guidance for assurers

The following is provided as guidance for assurers; it is not prescriptive but the Company and Ofwat need to have confidence that the outputs have been derived in a manner consistent with the metric process and reflects the best information available. Key to this is the provision of evidence of check, review and sign-off of methods and outputs. As a new metric, it is important that internal governance procedures are established early in the process; evidence of such governance is a primary part of the assurance process. Each of the assessment stages are considered in turn:

- Stage 1 Size exclusion – Companies are permitted to exclude catchments with pe <2,000 from any further assessment 'unless there is good reason not to'. Suggested that assurance is based on random check of catchment excluded vs pe in Company systems. In addition, checks of catchments against Company records for historic flooding and blockage incidents should be made; this is considered the primary mechanism for determining whether there is a good reason not to exclude.

- Stage 2 Vulnerability assessment – this is generally based on engineering judgement. It is expected that Companies will be able to evidence the process for determining the vulnerability grade. Examples include: catchment questionnaires completed by staff with local knowledge; workshop outputs where multiple catchments may be considered with staff with local knowledge; and outputs from Companies' systems (e.g. historic reports of flooding/blockages). Suggested that a random number of catchments are selected for more detailed investigation to confirm process and outputs. Companies will be expected to be challenged where evidence does not support grade selected.

- Stage 3 Metric route – process to determine whether an Option 1a or Option 1b assessment should be undertaken. Process and outputs to be confirmed through checking.

- Stage 4 Option 1a assessment – an opportunity for Companies to focus the vulnerability assessment outlined in Stage 2. Depending on catchment size (and guideline values), Companies can split catchments to smaller functional areas to provide the additional focus. Suggested that assurance should focus on:

    - Process for splitting catchments

    - Application of the vulnerability assessment at functional area level (similar to Stage 2 assurance)

- Stage 5 Option 1b assessment – modelling approach; key focus of assurance:

    - Use of 1:50 storm event and three durations

    - Data extracts for nodes predicted to flood ensuring that the critical storm event data is being utilised

    - Process for determining properties impacted (buffer; 2D routing maps) is applied in a consistent manner

    - Process for determining pe applied in a consistent manner

Stage 6 Company level reporting – checks on data carry over to ensure that there is consistency of approach with guidance.

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