Dŵr Cymru Welsh Water

IAP Response

Ref B.22.WSH.CE.A1

Wastewater Growth IAP Response [WWS2 – Lines 25, 26 and 30]

1 April 2019

Contents

1. Ofwat's cost efficiency challenge

We have carefully reviewed Ofwat's approach to modelling Wastewater Growth expenditure. Ofwat have combined the costs for new developments and growth, growth at sewage treatment works and reducing risks of sewer flooding into one wastewater growth assessment, stating that these areas are interlinked with each other and are driven by population increase and demand growth.

Our review has demonstrated that the results of the modelling are materially skewed by the inclusion of a significant outlier in Hafren Dyfrdwy. In addition, the modelling does not adequately account for all the drivers of the expenditure. In particular expenditure to reduce the risk of sewer flooding is driven by the low probability-high impact effects of climate change and urban creep rather than population increase or demand growth.

In conclusion, we firmly believe that the full funding of our programme is fully justified and essential if we are to achieve our sewer flooding targets.

2. Summary of our response to the Initial Assessment by Ofwat

There are three strands to our challenge to Ofwat's assessment of wastewater growth expenditure:

1) The model is significantly skewed by the inclusion of Hafren Dyfrdwy. (Section 3)
2) Enhancement expenditure to reduce the risk of sewer flooding is not primarily related to the number of new connections but rather to climate change and urban creep and should therefore be assessed separately. (Section 4)
3) Expenditure related to our rationalisation scheme for the Gwili Gwendraeth river catchment, to meet regulatory obligations, includes expenditure to meet future trade growth in the area. Ofwat's model does not account for growth of this nature as it is not driven by new connections in AMP7. The growth expenditure related to the Gwili Gwendraeth scheme should be assessed via a 'deep dive'. (Section 5)

3. Wastewater Growth Enhancement Model

We have reviewed the enhancement model for Wastewater growth. Expenditure is assessed using two regressions, firstly historical data and secondly using forecast data. The graph below plots the log of costs by the log of connections for the forecast data. There are several outliers in the bottom left quadrant relating to Hafren Dyfrdwy. The inclusion of Hafren Dyfrdwy skews the regression and results in a significantly different assessment of allowed expenditure compared to just using historical data, or forecast data without the outlier. This anomalous result has arisen due to the significantly smaller size and particular operating characteristics of the substantially rural area served by Hafren Dyfrdwy compared to the other ten WaSCs.

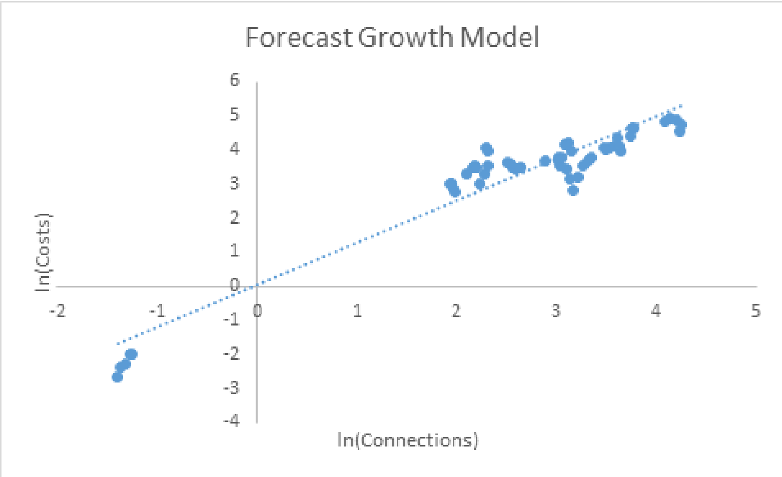


Figure 1: Forecast growth model results of DCWW assessment

3.1. Conclusions

We believe the model should be reassessed excluding Hafren Dyfrdwy. We observe in the IAP Ofwat's precedence for excluding outliers from enhancement models. Ofwat have excluded Thames and Southern from the metering enhancement model as these companies are outliers. Hafren Dyfrdwy and South Staffs and Cambridge have been excluded from the supply-demand balance enhancement model due to their outlying unit costs.

4. Sewer flooding

We believe that Ofwat's wastewater growth modelling does not adequately take account of the drivers of sewer flooding.

Sewer flooding can result from Hydraulic Overload (HO) in the sewerage network (where flow in the sewer exceeds its capacity) and Other Cause (OC) flooding (where something disrupts the free flow of wastewater in the sewerage networks). Other Cause flooding includes sewer blockages and collapses. Expenditure to address the other causes of sewer flooding is included within our base maintenance expenditure and therefore only expenditure on addressing sewer flooding as a result of Hydraulic Overload is considered here.

There are three causes of hydraulic overload flooding:

- Population Growth
- Increased drainage area (urban creep)
- Climate change

Ofwat's modelling does not take account of urban creep nor climate change, which account for 98% of flooding from the hydraulic overload of our sewers.

This section sets out the supporting evidence including:

- 'Future Impacts on Sewer Systems in England and Wales' report produced on behalf of Ofwat by Mott MacDonald in June 2011
- RPS assessment of the finding of the Mott MacDonald Report on Welsh Water's operating area
- A review by Atkins and RPS of our Hydraulic Overload modelling to quantify the contributions of population growth, urban creep and climate change on hydraulic overload flooding

The particular climatic conditions and operating environment in Wales, coupled with the impermeable nature of the geology of many parts of our both rural and urban areas in particular does not allow surface water to percolate into the ground before it runs into our sewers and other drainage systems. This means that we will likely experience a greater relative increase in the volume of surface water runoff flowing into our public sewerage networks that will increase the risk of sewer flooding occurring due to hydraulic overload.

4.1. Causes of Hydraulic Overload (HO) Flooding

There is a finite capacity of a sewer that is related to its size and gradient. Both internal and external sewer flooding due to hydraulic overload occurs where the sewerage network has insufficient pipe capacity to convey the required catchment flow during periods of rainfall. Sewerage capacity is designed based on calculations for upstream catchment flow and properties may become at risk of sewer flooding due to HO as a result of the following causal factors:

Population Growth - *new properties constructed within a sewerage catchment. The increased population associated with new housing development will add new dry weather flows to the system and reduces capacity for storm water.*

Increased drainage area (urban creep) - *the reduction in permeable surfaces within urban areas. Changes including property extensions, construction of conservatories and paving of driveways add additional drained area to a catchment and subsequently result in additional rainwater entering the network. Where the sewer was designed as a foul system this can have a substantial impact. The UK Water Industry Research Ltd (UKWIR) report 'Impact of Urban Creep on Sewerage Systems' contains calculations for estimating urban creep for a sewerage catchment.*

Climate change - *forecast of longer duration, high-intensity storms and more intense summer convective storms. The UK Climate Impacts Programme (UKCIP) was funded by Department for Environment, Food and Rural Affairs (Defra) to help organisations to adapt to climate change. Alongside the Met Office, UKCIP developed a climate change model called UKCP09. UKCP09 provides climate projections for the UK including probabilities for a range of possible outcomes for climate change based on climate model simulations.*

4.2. Ofwat report to assess the relative impact of climate change, urban creep and population growth.

The 'Future Impacts on Sewer Systems in England and Wales' report was produced on behalf of Ofwat by Mott MacDonald in June 2011. The report provides a summary of hydraulic modelling analysis completed to assess the relative impact of climate change, population growth and urban creep up to 2040. The study was commissioned by Ofwat to investigate the change in sewer flooding that may result from these factors.

Ofwat's report concludes that the major contributor to increased flooding is climate change, followed by property creep, with new developments accounting for the smallest contributor to flooding increase.

The study was based on 100 sewer network models supplied by Water and Sewerage Companies (WaSCs). The hydraulic models covered 16% of the population of England and Wales. The study considered four modelled scenarios – population growth only, creep only, climate change only and a combined scenario. Results of the modelling predicts a significant increase in sewer flooding up to 2040, allowing for existing network capacity. This includes an increase in both flood volumes and number of flooding locations. For the combined scenario the three causal factors are combined to produce a greater increase in flooding than the sum of individual changes. Results of the study are summarised within Table 1 and Figure 2.

Population growth estimates were obtained based on population forecasts determined from Office for National Statistics (ONS), Local Authorities and other relevant datasets. Urban creep estimates were based on an UKWIR study which analysed aerial images to form an estimate of potential additional drained area. The climate change impact utilised the UKCP09 medium emissions scenario for 2040 at a variety of percentile rainfall events. For the purpose of the study the medium emissions scenario for 2040 was investigated.

	Median increase in sewer flooding, %		
	10th Percentile	50th Percentile	90th Percentile
Population Growth	-	5	-
Urban Creep	-	12	-
Climate Change	0	27	71
Combined	35	51	100

Table 1: Future Impacts on Sewer Systems in England and Wales - median increase in sewer flooding (%)

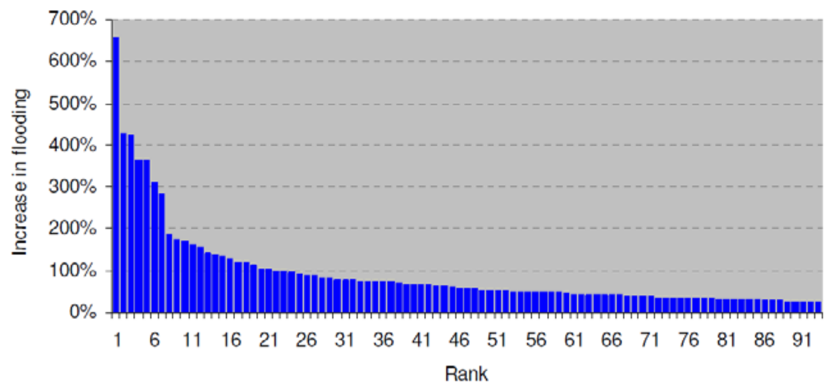


Figure 2: Results for the 50th percentile rainfall combine scenario in rank order

4.3. Ofwat's report adjusted for Welsh Water's circumstances.

In support of our PR19 Business Plan we commissioned RPS to assess how the findings of June 2011 'Future Impacts on Sewer Systems in England and Wales' report apply to our operating area. RPS undertook a high-level assessment of projected increases in flow volumes entering the sewer network over the coming 25 year period. The review focussed on the 85 catchments (133 sub-catchments) that are part of our AMP6 Sustainable Drainage Programme (SDP).

The review concluded that only 1% of the increase to future flow volume in our sewerage network is as a result of population growth.

4.3.1.Population Growth

A forecast of population growth across DCWWs operational area has been made based on available Local Development Plan (LDP) information and historical growth rates. Population within DCWWs operational area is expected to increase by 749,350 over the next 25 years. Assuming an average daily consumption of 180 litres per head per day[1], the increase in daily volume entering DCWW sewers would be estimated to be 134,833 m^3 in 25 years' time, equivalent of 5,620 m^3 per hour.

The population increase over the next 25 years is the same value that is used within our Drainage and Wastewater Management Plan initial screening process. It uses our Local Development Plan (LDP) information held on our GIS system, to forecast population over the next 10 years. The subsequent 15 years is then based on historical connections per year.

[1] This is the standard daily consumption used within our Hydraulic Modelling Assessment Process.

This is in line with the UK population projection for a circa 6 million rise to 2030 (Figure 3 below).

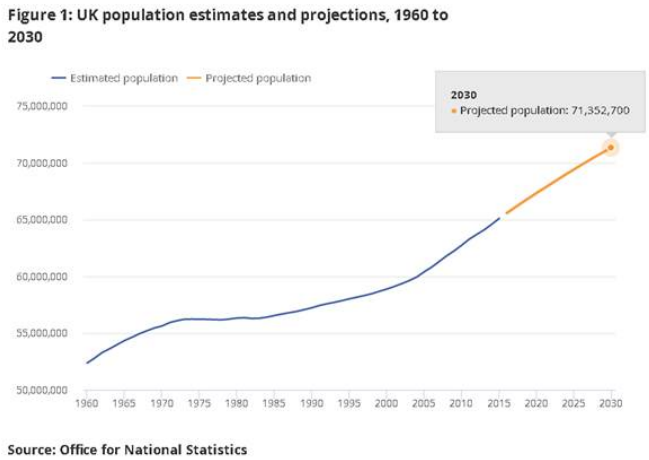


Figure 3: UK population estimates and projections 1960 to 2030

4.3.2.Climate Change

Projected summer and winter rainfall depth increases as a result of climate change have been assessed for Caernarfon, Five Fords, Aberystwyth, Hereford, Merlin's Bridge and Cynon catchments. The catchments were selected based on their spatial distribution across DCWWs operational area. Current design rainfall depths for a 1 in 30 year, 60 minute duration storm have been assessed for each catchment. This is based on key parameters within the hydraulic model. A percentage change in depth was applied to these values based on the UKCP09 medium emissions scenario (2030-2059). A maximum change in rainfall depth of ~3.5 mm is estimated across the 6 catchments (average 2.9 mm).

The relative proportion of paved and roof area connected to the network has been assumed based on the proportions within the Hereford catchment hydraulic model. The values are determined based on background mapping, impermeable area surveys, flow survey data and hydraulic model analysis. For Hereford 22% of the total paved area is assumed to drain to the combined network and 38% of the total roof area. We also have a breakdown of the total paved and roof areas within the 85 SDP catchments from OS mapping. Based on these values, estimates can be made for estimated flow increases as a result of climate change. These are shown in Table 2.

	Total Area - 85 sample catchments (ha)	Assumed proportion connected (%)	Estimated total area connected (ha)	Estimated average rainfall change in future winter M30-60 storm (mm)	Estimated increase in volume due to climate change (m^3)
Paved	17863	22	3930	2.9	113966
Roof	10379	38	3944	2.9	114377
Total	**28242**	-	**7874**	-	**228343**

Table 2: Total estimated increase in volume due to climate change

4.3.3. Urban Creep

The UKWIR document 'Impact of Urban Creep on Sewerage Systems' (2009) provides estimated increases in area per property per year based on area property density. Property density was provided by Arcadis for 55,241 postcodes within the 85 SDP catchments (~55% postcodes). Estimations of creep for the next 25 years were subsequently made based on property densities and UKWIR impermeable area increase estimations. For the postcodes assessed, the additional impermeable area in 25 years is estimated to be 1,645 hectares. Assuming an average rainfall depth for a 30 year RP 60 minute duration storm of 31 mm (from climate change assessment), the increase in volume as a result of urban creep could be 509,556 m^3.

Results

A summary of the results is provided within Table 3. Based on the 85 catchments assessed within the high-level review, urban creep is forecast to contribute the most to future flow volume increases over the next 25 year period. This is likely to be due to rural areas being less densely populated, and thus dwellings have more permeable area that allows for future creep, and an increasing trend of existing properties being improved with additional impermeable areas being connected to the sewerage network. Population growth has been estimated to result in minimal increases in flow volumes relative to the other two factors.

	Volume per hour / M30-60 storm (m^3)	% Share Increased Flow Volumes
Population Growth	5,620	1%
Climate Change	228,343	31%
Urban Creep	509,556	69%

Table 3: Forecast future impacts on DCWW sewer volumes (25 years)

4.4. Hydraulic modelling review

In order to quantify the contributions of population growth, creep and climate change on hydraulic overload flooding and to validate the results of the RPS assessment in section 4.3, a hydraulic modelling review has been undertaken on six of Welsh Water's sewerage catchments. This work has been carried out by Atkins and RPS on behalf of DCWW. The approach adopted follows the analysis completed by Mott MacDonald for Ofwat outlined within the June 2011 report. Further information on the specifics of the analysis is captured within technical notes provided by the consultants and appended to this response.

The assessment of future impacts on flooding has been completed for the 2040 design horizon catchment scenario for 1 in 30 year storm events with durations of 60, 240, 480 minutes to maintain consistency with Resilience metric assessment events. The assessment has been carried out for both summer and winter storm events to assess if there is a seasonal influence in the future impacts. As the assessment is to review the impact of each future aspect on HO sewer flooding a 'clean network' hydraulic model scenario (i.e. free of transient sediment and temporary blockages) has been used to predict the impact on hydraulic overloading.

4.4.1 Results

The predicted proportional impact of each contributing factor on flooding can be seen in Tables 4 and 5 and Figure 4. Results confirm that population growth is estimated to have minimal impact on future flooding volumes. They differ slightly from the Mott MacDonald analysis, with the relative importance of urban creep highlighted as the highest contributor to increased flood risk, almost double climate change.

Catchment	Scenario	Average % Increase in Flood Detriment
Cardiff Bay	Population Growth	4.0%
	Urban Creep	8.0%
	Climate Change	13.0%
Cog Moors (Cardiff West)	Population Growth	4.0%
	Urban Creep	13.0%
	Climate Change	38.0%
Aberystwyth	Population Growth	0.1%
	Urban Creep	1.1%
	Climate Change	0.3%
Tregaron	Population Growth	-0.3%
	Urban Creep	121.0%
	Climate Change	44.0%
Porthmadog	Population Growth	0.6%
	Urban Creep	68.0%
	Climate Change	10.0%
Hereford	Population Growth	0.8%
	Urban Creep	35.0%
	Climate Change	18.0%

Table 4: Results of hydraulic modelling analysis (per catchment)

Scenario	Average % Increase in Flood Detriment - all catchments	Proportion - Future Impact Flooding
Population Growth	2%	2.4%
Urban Creep	41%	65.0%
Climate Change	21%	32.6%

Table 5: Results of hydraulic modelling analysis (per scenario)

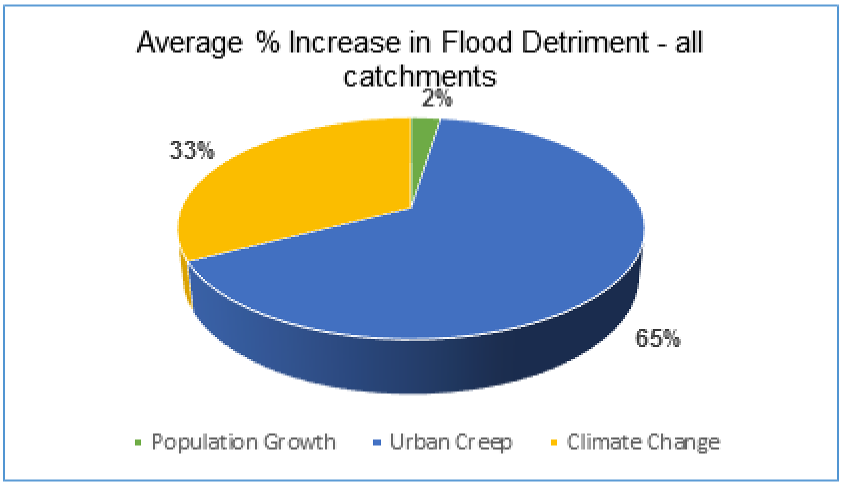


Figure 4: Results of hydraulic modelling analysis (average % increase in flood detriment for all catchments – rationalised)

4.5. Conclusions

Through the overall assessment of 85 catchments and the detailed hydraulic assessment of 6 differing urban and rural catchments, using the same methodology as the 2011 Ofwat report, we are confident that increases in sewer flooding will be caused in the main by climate change and urban creep and that new connections or population growth contributes minimally to changes in flood risk.

Scenario	**Review of 85 DCWW catchments** % Share of Increased Flow Volumes	**Hydraulic assessment of 6 catchments** Rationalised Proportion - Future Impact Flooding
Population Growth	1%	2.4%
Urban Creep	69%	65.0%
Climate Change	31%	32.6%

Table 6: Summary of analysis

As a consequence Ofwat's growth model will significantly underestimate the future funding required to prevent future increases in the HO flooding of customers' properties and Ofwat needs to allow the full enhancement expenditure we have included for reducing the risk of sewer flooding.

5. Gwili Gwendraeth growth

Ofwat's modelling of wastewater growth does not take into account the new connection growth beyond AMP7 that the Gwili Gwendraeth scheme (included in Ofwat's growth assessment) provides nor the disproportionate impact of non-household connections on the network.

In our Business Plan, we outlined our proposed investment in the Gwili Gwendraeth scheme to meet our customer outcomes and new legal obligations in this operational area (document 5.8P.1 Gwili Gwendraeth Investment Case). The key driver for this investment is discharge permit changes at our assets to improve river water quality in the Gwili and Gwendraeth rivers in Carmarthenshire, South West Wales. These new legal obligations, are included in National Resources Wales' (NRW) National Environment Programme (NEP). However, there are other drivers for the scheme:

- Significant Growth – the region is experiencing rapid industrial, commercial and population growth that is forecast to continue, with a 56% increase projected population equivalent between 2016 and 2036;
- Running costs – stricter compliance limits and increasing plant complexity are driving up the costs for processing wastewater, beyond that which is cost effective at a small scale.

To achieve our customer outcomes and meet new legal obligations reliably in the future, we need to invest in the wastewater treatment works (WwTWs) in this operational area. We have looked at the various options, including catchment management, and have identified that the long-term least cost option for our customers is to invest in a new treatment works.

The Gwili Gwendraeth Wastewater Treatment Scheme is proposed to replace seven of the eight WwTWs that discharge treated effluent into two of our most environmentally sensitive rivers and lead to the improvement of 38km of river, supporting achievement of WFD "good" status. The seven treatment works will be replaced with a single works discharging into a tidal estuary. This offers a lower whole life cost solution with significantly better environmental outcomes than upgrading the existing sites together with continuing to support the much needed economic development in this area.

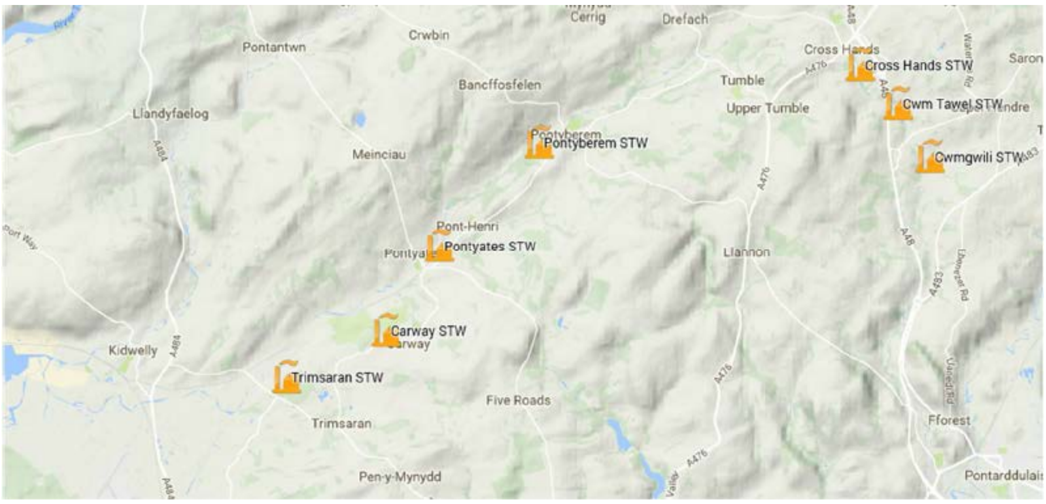


Figure 5: Location of the 7 works on the Gwili Gwendraeth proposed for rationalisation to 1 works

5.1. Scheme cost breakdown.

	Total Capex (post efficiency) £	Base £	Growth £	Quality £
Network – sewage pumping stations and transfer mains	**23,487,000**	704,610	6,341,490	16,440,900
Wastewater Treatment Works	**28,373,983**	851,219	7,660,975	19,861,788
Total	**51,860,983**	1,555,829	14,002,465	36,302,688
% scheme cost		3%	27%	70%

Table 7: Summary of proposed expenditure

5.2. Growth element of Gwili Gwendraeth scheme

5.2.1. Assessment against number of new connections

Our Business Plan, set out the number of new connections (Table WWS3, lines 1 & 2), for AMP7. A total of 44,379 new connections across our whole region is forecast, including 43,245 household (residential) connections and 1,134 non-household (business) connections.

These forecasts of new connections have been used as cost drivers in Ofwat's modelled allowance for wastewater growth expenditure. The forecasts do not take account of the growth in new connections beyond AMP7 nor for the disproportionate impact of non-household connections on the network.

5.2.2. Assessment of actual population change

The Gwili Gwendraeth region is experiencing rapid industrial, commercial and population growth that is forecast to continue, with a 56% population equivalent increase projected between 2016 and 2036;

The proposed scheme has been assessed to be the lowest cost long term option (document 5.8P.1 Gwili Gwendraeth Investment Case) to address both the new legal obligations and the future growth.

Population change and economic development in the area of the 7 Gwili Gwendraeth works mean that significant capacity improvements will be required to meet future demand in this new proposed catchment. Projected growth in Carmarthenshire's population is 8.3% from 2016 to 2036, one of the highest growth rates in Wales[2]. By 2036, the overall population equivalent served by the WwTW, covering the Gwili and Gwendraeth Fawr river catchments, is forecast to increase by approximately 56%[3].

[2] Wales's growth rate from 2016 to 2036 is 6.5%.

[3] Based on 2018 analysis of housing and trade population equivalent growth rates, MMB Growth memorandum in relation to Gwili Gwendraeth WwTW, 2nd January 2019.

	Committed remaining housing on LDP, units	Associated residential increase, PE	Trade area committed LDP, hectares	Associated trade increase, PE	Total increase to 2036. PE	June return 2018, total PE	% population increase from 2018 baseline
CARWAY	6	14	None	None	14	861	2%
CROSSHANDS	172	396	21.2	7,403	7,799	4449	175%
CWMGWILI	64	147	None	None	147	1208	12%
CWMTAWEL	None	None	None	None	None	68	-
PONTYATES	266	612	None	None	612	2710	23%
PONTYBEREM	590	1357	10.2	1,262	2,618	10037	26%
TRIMSARAN	426	980	None	None	980	2584	38%
TOTAL	1524	3506		8665	12170	21917	56%

Table 8: Summary of growth levels in each of the 7 catchments

71% of the new catchment's population equivalent increase is attributed to trade increases, particularly in the Cross Hands sub-catchment which has grown rapidly as an industrial and commercial centre. Continued growth is expected in the catchment as Cross Hands becomes a major regional hub and a growth zone linked to the Swansea Bay Region City Deal.

The Cross Hands Strategic Employment Site is set to become the next major employment zone in Carmarthenshire, providing 600 jobs. There are 21.2 hectares of employment land identified in the LDP supporting this hub, which equates to a population equivalent increase of 7,403 to 2036, a 175% change.

This expansion of trade growth is also expected to spill over into the Pontyberem catchment, which also shows signs of significant growth. This growth is significantly above Welsh averages, in the catchment of one of the most sensitive river valleys in Wales. Plans to further develop the Ffos Las racecourse site are expected to significantly increase loads at the Trimsaran WwTW. The development will include housing, hotel and leisure facilities and will result in a 38% increase in the population equivalent served at Trimsaran WwTW.

Our investment in this area will not only ensure our compliance with legal obligations in the National Environment Programme and provide a secure, long-term least cost solution to the tightening environmental permits, it will support the economic development of the region for the benefit of our customers and the Welsh economy.

5.3. Conclusions

The growth element of the Gwili Gwendraeth scheme is unusual due to the large industrial, commercial expansion of the area, most of which is driven by trade growth in the area. The impact of this trade growth is disproportionate to the number of new housing connections in the area.

A 'deep dive' assessment of the growth related expenditure of the Gwili Gwendraeth scheme should be made given these specific circumstances. The consequences of us not being able to continue to support the expansion in trade growth in this area could lead to much wider economic implications including the potential risk of existing traders being forced to relocate to other areas, a risk which was narrowly avoided a decade ago in this catchment.

Appendix 1 – Supporting technical information for assessment of the basis for HO Flooding

Future Impacts on DCWW Sewers

Atkins Future Impact on Flooding Cardiff Bay

Atkins Future Impact on Flooding Cog Moors

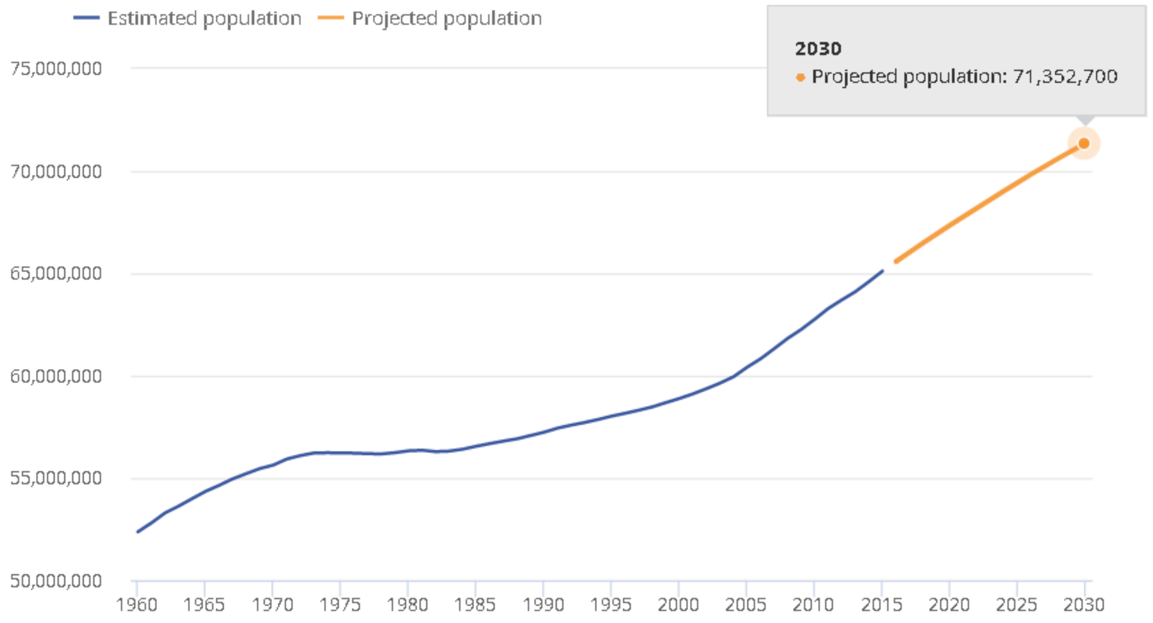
RPS Growth, Creep, Climate Change Assessment

FUTURE IMPACTS ON DCWW SEWERS

19th March 2019

GROWTH

Figure 1: UK population estimates and projections, 1960 to 2030



Source: Office for National Statistics

Image source: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/overviewoftheukpopulation/mar2017, accessed 19/03/2019

Forecast population changes across DCWW's operational area

- Based on combination of LDP data and historical growth rates, population across DCWW's operational area is predicted to increase by **749,350** over the next 25 years.
- Increase in daily volume entering DCWW sewers estimated to be **134,883m^3** in 25 years' time.
- Over one hour, this would be **5,620 m^3**

CLIMATE CHANGE

Rainfall depths across Welsh Water

- **Depth (mm)** is total predicted rainfall depth in a 30 year return period, 60 minute duration storm. Various methods/confidence, dependent on hydraulic model.
- **Change (%)** is UKCP09 predicted increase in rainfall on wettest day to 2030-2059 based on medium emissions scenario, following process determined by DCWW for AMP5 Sustainable Drainage Plans.
- **Change (mm)** is predicted depth in 2030-2059, calculated from Depth (mm) x Change (%), minus current rainfall depth.
- Based on these sample catchments, following changes in depth could be estimated for a 30-year return period, 60-minute duration storm in 2030-2059:
  - **Minimum approx. 0.8 mm**
  - **Maximum approx. 3.5 mm**

Caernarfon

	Depth (mm)	Change (%)	Change (mm)
Winter	31.87	10	3.2
Summer	30.97	10	3.1

Five Fords (Wrexham)

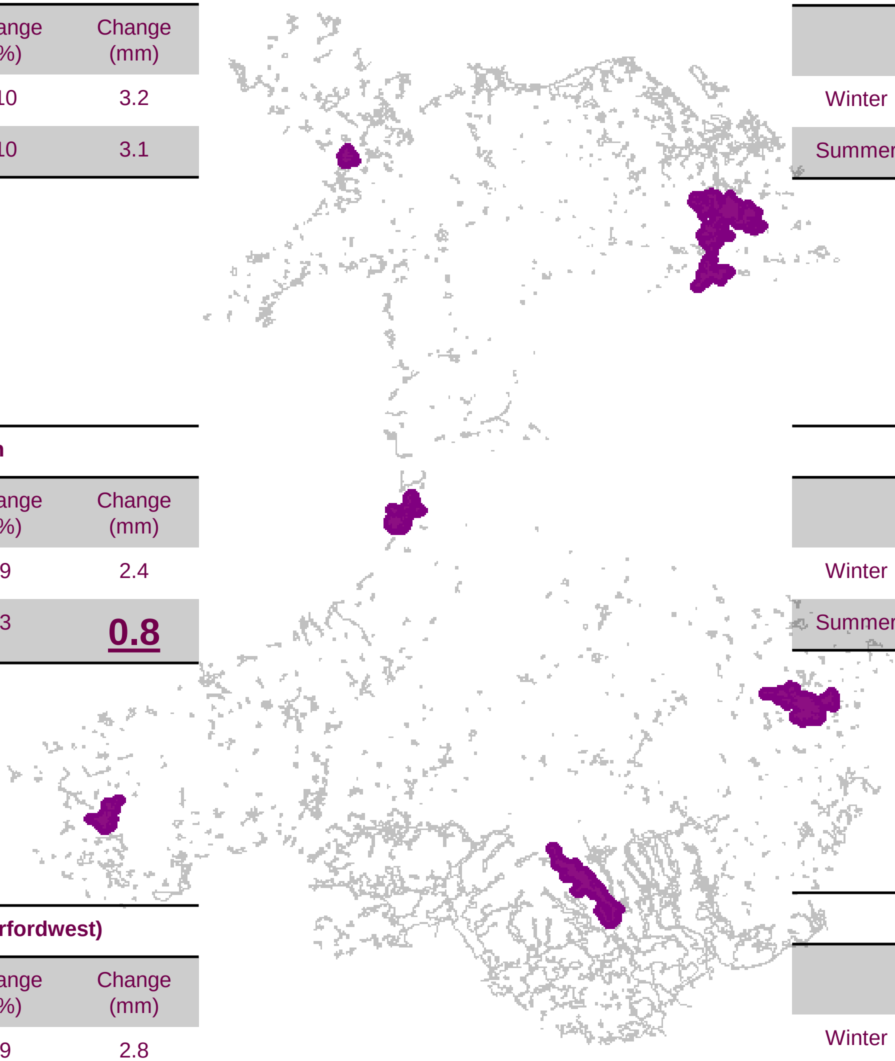
	Depth (mm)	Change (%)	Change (mm)
Winter	30.24	9	2.7
Summer	29.38	Unknown	Unknown

Aberystwyth

	Depth (mm)	Change (%)	Change (mm)
Winter	27.08	9	2.4
Summer	26.31	3	**0.8**

Hereford

	Depth (mm)	Change (%)	Change (mm)
Winter	28.42	9	2.6
Summer	27.61	8	2.2



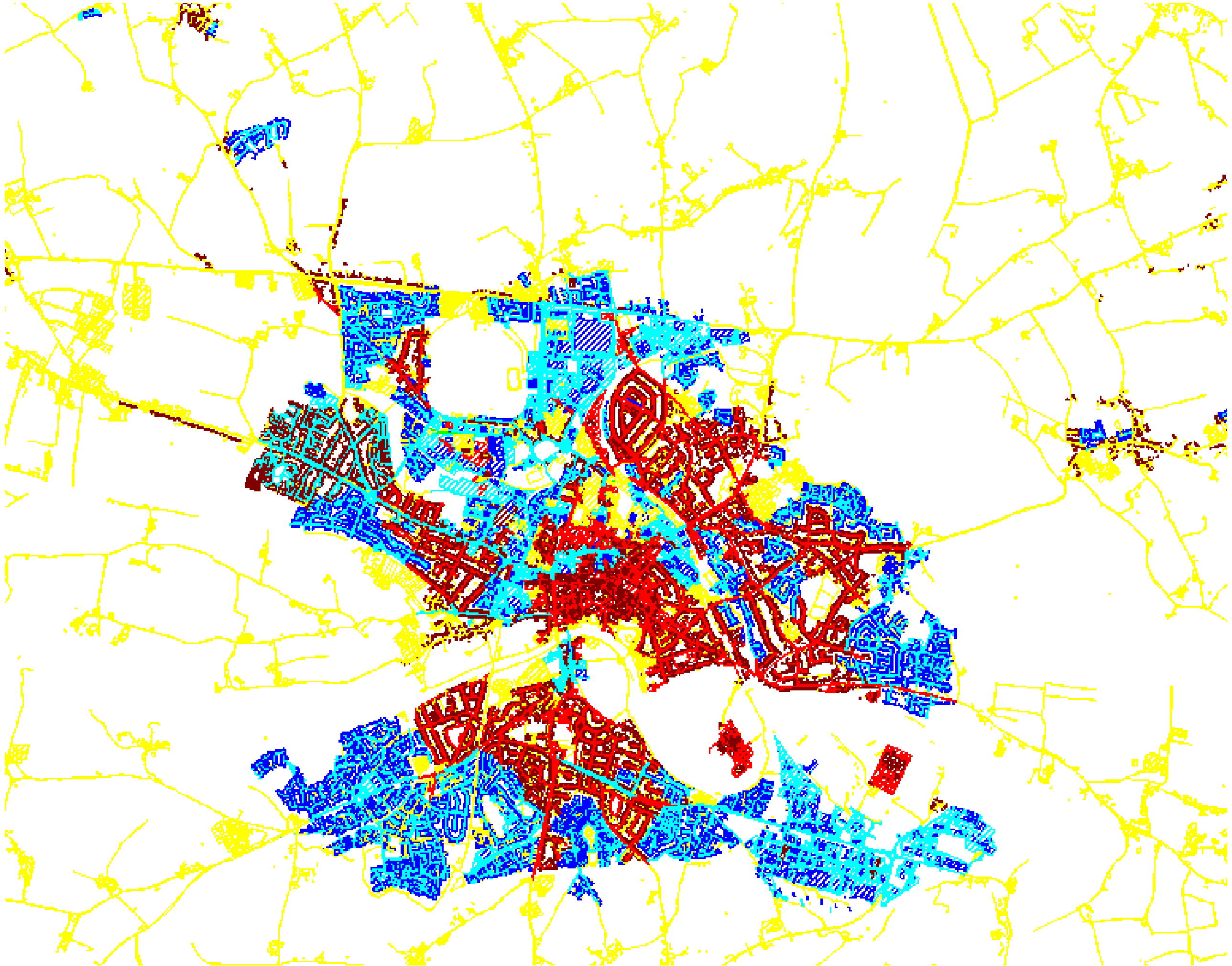
Merlin's Bridge (Haverfordwest)

	Depth (mm)	Change (%)	Change (mm)
Winter	31.52	9	2.8
Summer	30.62	3	0.9

Cynon

	Depth (mm)	Change (%)	Change (mm)
Winter	39.03	9	**3.5**
Summer	37.92	Unknown	Unknown

DRAFT



How much impermeable area is there connecting to DCWW's sewer network?

- Background mapping tells us which surfaces are impermeable.
- Hydraulic models indicate how much of this impermeable area drains into Welsh Water's foul/combined network.

- For Hereford, 22% of the total paved area in the catchment is thought to drain to the combined network, based on flow survey data, impermeable area surveys, analysis of building ages and hydraulic model analysis.
- For Hereford, 38% of the total roof area in the catchment is thought to drain to the combined network.

- Across a sample of 85 DCWW wastewater catchments, we have worked with Arcadis to estimate that there is 17,863 ha of paved and 10,379 ha of roof area in total. Calculation uses OS background mapping.

- We could therefore estimate:

	Total area – 85 sample catchments (ha)	Assumed proportion connected to DCWW network (%)	Estimated total area connected to DCWW network (ha)
Paved	17,863	22	3,930
Roof	10,379	38	3,944

DRAFT

Total estimated increase in volume due to climate change (85 sample catchments)

	Area	Depth		Volume = area x depth	
	Estimated total area connected to DCWW network – 85 sample catchments (ha)	Estimated minimum rainfall change in M30-60 storm in 2039-2059 (mm)	Estimated maximum rainfall change in M30-60 storm in future (mm)	Estimated increase in volume due to climate change - minimum (m^3)	Estimated increase in volume due to climate change - maximum (m^3)
Paved	3,930	0.8	3.5	31,438	137,542
Roof	3,944	0.8	3.5	31,551	138,037
TOTAL	**7,874**	**-**	**-**	**62,990**	**275,579**

CREEP

Impermeable Creep by Property Density	
Property Density*	Increase in Impermeable Area (m2/house/year)
0 to 25	0.629
26 to 50	0.562
51 to 75	0.508
76 to 100	0.387
101 to 125	0.329
126 to 150	0.323
151 to 175	0.209
176 to 204	0.228
205 to 229	0.134
230 to 250	0.167
251 to 275	0.035
276 to 300	0.031
301 to 325	0.065
326 to 350	0.032
351 to 525	0.002
526 to 1000	0.03

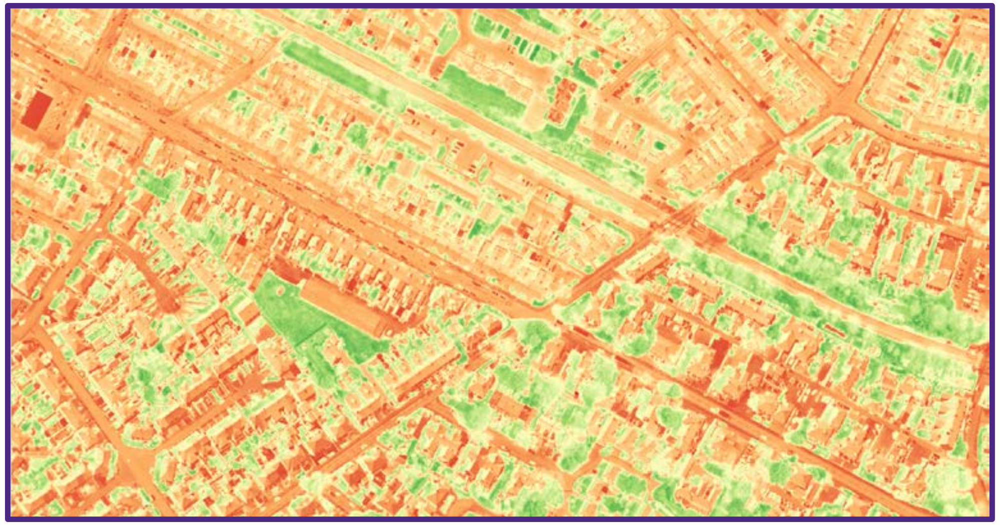
Urban creep - UKWIR - Impact of Urban Creep on Sewerage Systems (2009)

How much creep?

- Increase in impermeable area draining to foul/combined network through construction of patios, extensions, etc.
- 2009 UKWIR paper provides estimated increase in area per house per year, based on property density (see table left).

Considerations

- There isn't always space for creep – ***values given in table can lead to over-estimates***.
- RPS undertaking analysis of aerial photography for Anglian Water to assess whether 2009 creep estimates are still valid.



How much creep?

- Using postcode and address point data, Arcadis have estimated property densities for 55,241 post codes across DCWW's operational area.
- By combining these property densities with creep estimates from slide 9, we have estimated the potential increase in impermeable area connecting to DCWW's network over the next 25 years.
- For the 55,241 post code regions analysed, the additional area is estimated to be **1,645 hectares**.
- Assuming a rainfall depth of 31mm* suggests that the increase in volume due to creep only could be **509,556 m^3**.

*31mm is average of rainfall depths for 30 year return period 60-minute duration storms from slide 5.

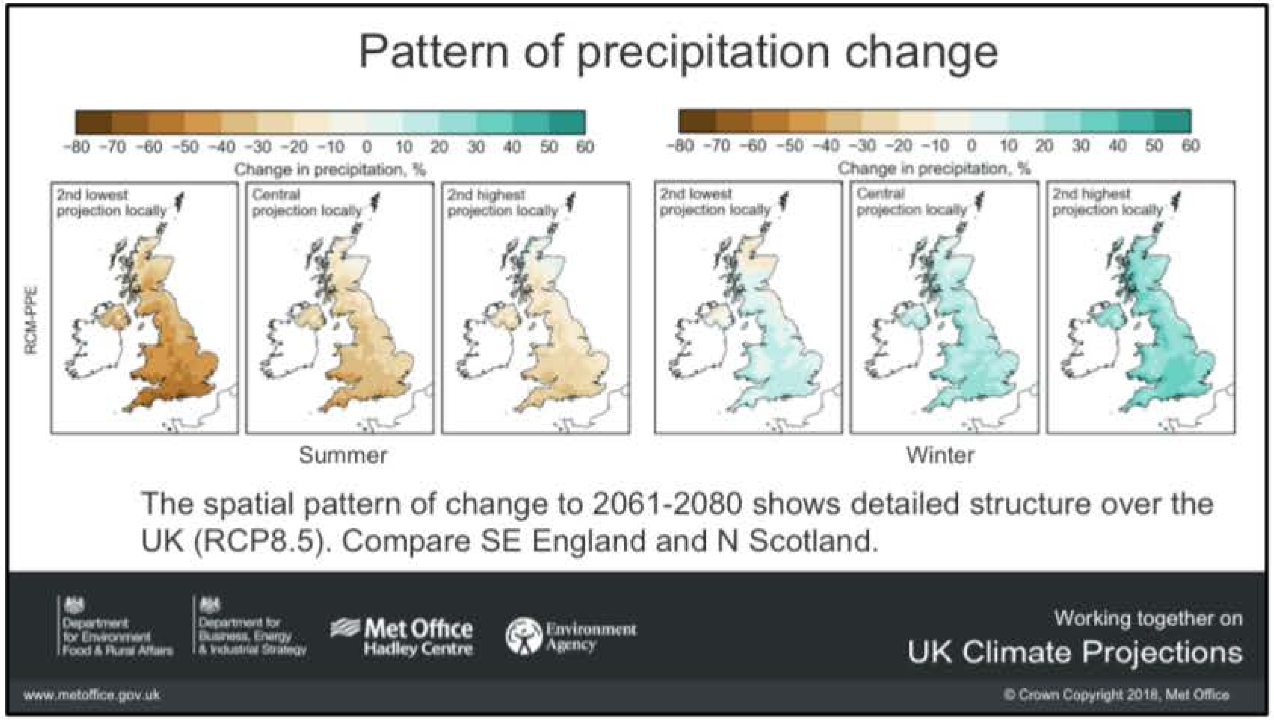
WHAT IS THE BIGGEST THREAT?

- **Growth** is predicted to increase flows arriving in DCWW's sewers by approximately 5,620m^3 per hour on average.
- For a one hour storm, **climate change** could increase the volume of flows arriving in the sewers in 85 sample wastewater catchments by 62,990-275,579m^3
- **Creep** could increase the volume of rainfall entering DCWW sewer network by 509,556 m^3 in a 30-year return period storm.
- *See recommendations following.*

RECOMMENDATIONS

- Please note that the numbers given in this presentation have not undergone quality checks at this stage due to the short time frame for delivery – further checks are recommended.
- Confidence is variable in each estimate – sensitivity testing is recommended, in line with guidance in the Drainage and Wastewater Management Plan framework.
- The amount of creep that can occur is dependent on available space, property age, house ownership trends, etc. The values quoted are based on research from 2009 and could be overestimated.
- UK-wide analysis could be undertaken to understand how Welsh Water's operational areas differ from the rest of the UK. See screenshots in 'Further information' section for initial indications of regional variations.
- Consider latest climate change forecasts from UKCP18, and sensitivity testing to understand confidence in forecasts. UKCP09 now outdated.
- Further assessment of Ofwat cost model and potential variations across UK?

FURTHER INFORMATION



Rainfall patterns across the UK are not uniform and vary on seasonal and regional scales and will continue to vary in the future.

Next summer will see the launch of a further set of results from UKCP18 which will provide very high-resolution projections of rainfall over the UK, fine enough to be able to resolve individual convective storms.

This will allow us to provide more detail around projections of localised heavy rainfall for flood risk assessments.

Summer and winter changes by the 2070s

Summer rainfall change	Winter precipitation change	Summer temperature change	Winter temperature change
For a location in central England			
41% drier to 9% wetter	3% drier to 22% wetter	No change to 3.3 °C warmer	-0.1 °C cooler to 2.4 °C warmer
57% drier to 3% wetter	2% drier to 33% wetter	1.1 °C warmer to 5.8 °C warmer	0.7 °C warmer to 4.2 °C warmer
For a location in central Scotland			
30% drier to 6% wetter	4% drier to 9% wetter	-0.1 °C cooler to 2.8°C warmer	-0.3°C cooler to 2.7°C warmer
40% drier to 8% wetter	3% drier to 12% wetter	0.6 °C warmer to 4.8 °C warmer	0.6 °C warmer to 4.5 °C warmer
For a location in central Wales			
39% drier to 3% wetter	2% drier to 19% wetter	No change to 3.3°C warmer	0.1 °C warmerto 2.4 °C warmer
56% drier to 2% wetter	No change to 29% wetter	0.9 °C warmer to 5.9 °C warmer	0.7 °C warmer to 4.1 °C warmer
For a location in central Northern Ireland			
28% drier to 6% wetter	3% drier to 17% wetter	No change to 2.8 °C warmer	0.1 °C warmer to 2.2 °C warmer
38% drier to 3% wetter	2% drier to 25% wetter	0.8 °C warmer to 4.9 °C warmer	0.6 °C warmer to 3.9 °C warmer

Low emission scenario (blue rows) *High emission scenario* (orange rows)

*All results are for the 10th-90th percentile range for the 2060-2079 period relative to 1981-2000

[redacted]

Technical Note

Project:	5136869 DCWW AMP6 SDP		
Subject:	Future Impacts on Flooding -Cardiff Bay		
Author:	Dean Jeffery		
Date:	19/03/2019	Project No.:	5136869
Distribution:	Jonathan Beddoe Dean Jeffery Paul Black Tom Boichot	Representing:	DCWW ATKINS ATKINS ATKINS

Document history

Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	First Issue	DJ	JP			22/02/2019
Rev 2.0	Inclusion of wider Cardiff Bay catchments	DJ	PB	TB	TB	19/03/2019

Client signoff

Client	Dwr Cymru Welsh Water (DCWW)
Project	5136869 DCWW AMP6 SDP
Project No.	5136869
Client signature / date	

Executive Summary

To support Dwr Cymru Welsh Water (DCWW) in response to OFWAT on the proposed PR19 business case ATKINS have assess the impact of future drivers on the Cardiff Bay wastewater treatment works catchment. The assessment has been made to compare and proportion the respective contribution to hydraulic overload flooding from Population Growth, Urban Creep and Climate Change.

Through the investigation it has been concluded that Climate Change is the most significant future impact, increasing predicted flooding by 13%, proportionally 51% of the predicted future impact. Urban Creep results in an 8% increase in predicted flooding, proportionally 34% of the predicted future impact. Population Growth has the least significant impact, increasing predicted flooding by 4%, proportionally 15% of the predicted future impact.

1.1. Future Impacts on Flooding

Dwr Cymru Welsh Water (DCWW) have requested ATKINS support to quantify and proportion the contributions of future impacts on hydraulic overload (HO) flooding. This request is to support DCWWs response to OFWAT on the PR19 Business Case. The assessment has been carried out on the 33875 – Cardiff Bay WwTW catchment to review the impacts of the following factors:

- Population Growth – Catchment Population growth and catchment development population as defined in the Local Development Plan (LDP)
- Property Creep – Increase in catchment impermeable area contribution to the sewer network due to increases misconnections and increase in impermeable surfaces.
- Climate Change – Increase in rainfall intensity of 10% as per UKCP09 forecast impact.
- Combined - Growth, Creep & Climate Change applied together.

1.2. Hydraulic Model Impact Assessment

The assessment of future impacts on flooding has been completed for the 2040 design horizon catchment scenario for 1 in 30 year storm events with durations of 60, 240, 480 minutes to maintain consistency with Resilience metric assessment events. The assessment has been carried out for both Summer and Winter storm events to assess if there is a seasonal influence in the future impacts.

As the assessment is to review the impact of each future aspect on HO flooding a ‘clean network’ hydraulic model scenario, i.e. free of transient sediment and temporary blockages has been used to predict the impact on hydraulic overloading. The predicted total flood volumes for the scenarios are provided in Appendix A.

1.3. 33875 - Cardiff Bay WwTW Catchment Future Impacts

1.3.1. Cardiff Bay WwTW Catchment

The future impacts on the Cardiff Bay WwTW catchment, Figure 1, has been assessed as this covers 20% of the population of Wales and varies throughout in catchment characteristics. Future Impact assessment of catchments with varying catchment characteristics provides a more detailed understanding and appreciation for the overall impact of Population growth, Urban Creep and Climate change when considered across the whole of Wales.

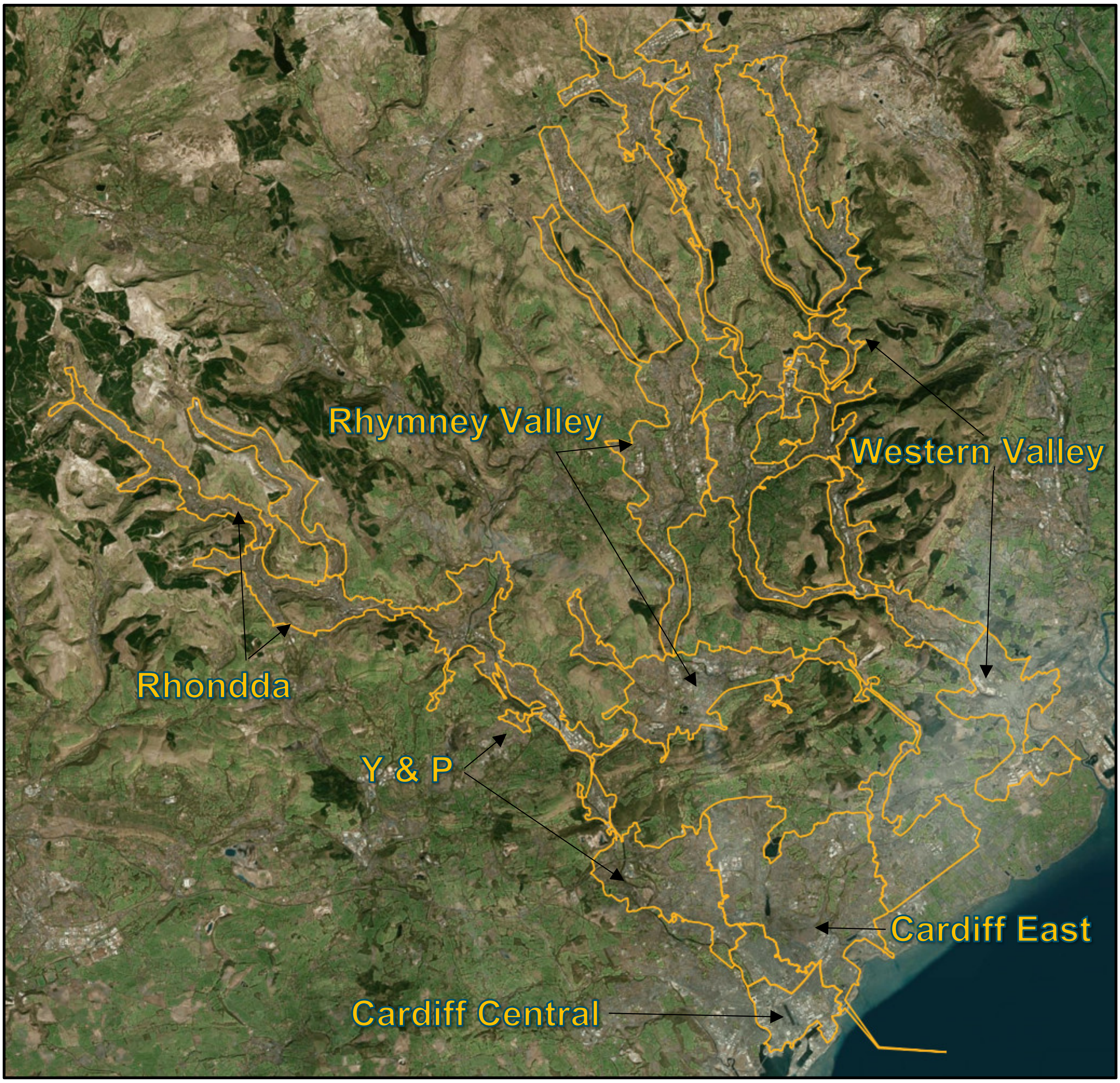


Figure 1: Cardiff Bay WwTW catchment area

The catchment topography and network characteristics in each of the Cardiff Bay sub-catchments are as follows:

- Cardiff Central has an oversized sewer network, (historically to cope with tidal surcharge) and limited capacity for urban creep due to the physical lack of space for expansion. The catchment is low lying with a small number of CSOs.
- Cardiff East generally comprises of small diameter sewers and a high proportion of open space therefore exhibiting a higher potential for urban creep. The catchment is low lying with a small number of CSOs.
- Y&P drainage network contains a large number of CSO's that protect the catchment from flooding. The catchment has a steep valley topography upstream and a low-lying catchment towards the southern end. There are a high number of CSOs which protect both the local network and trunk sewer.
- Rhondda, Rhymney and Western Valley all have a steep valley topography with a large proportion of CSOs protecting the local network before joining the trunk sewer that run through the base of the valleys.

1.3.2. Total Catchment Future Impact

The predicted impact of each contributing factor on flooding in the Cardiff Bay catchment can be seen in Figure 2, from this it is evident that climate change has the most significant impact on hydraulic overload (HO) flooding with a 13% increase in predicted flood volumes across the subcatchments. Urban Creep results in an 8% increase in flood volumes and population growth, a 4% increase. The proportional impact observed is consistent in both summer and winter storm events and across short and long duration events, Table 1.

The combined impact scenario predicted a 23% increase in flooding, this is lower than the sum of individual contributions when considered in isolation due to the influence of catchment CSOs on the overall flow discharged from the sewer network.

The proportional impact of each future factor has been calculated relative to the sum of each factor, Figure 3. The proportional future impact is as follows:

- Climate Change – 51%
- Urban Creep – 34%
- Population Growth – 15%

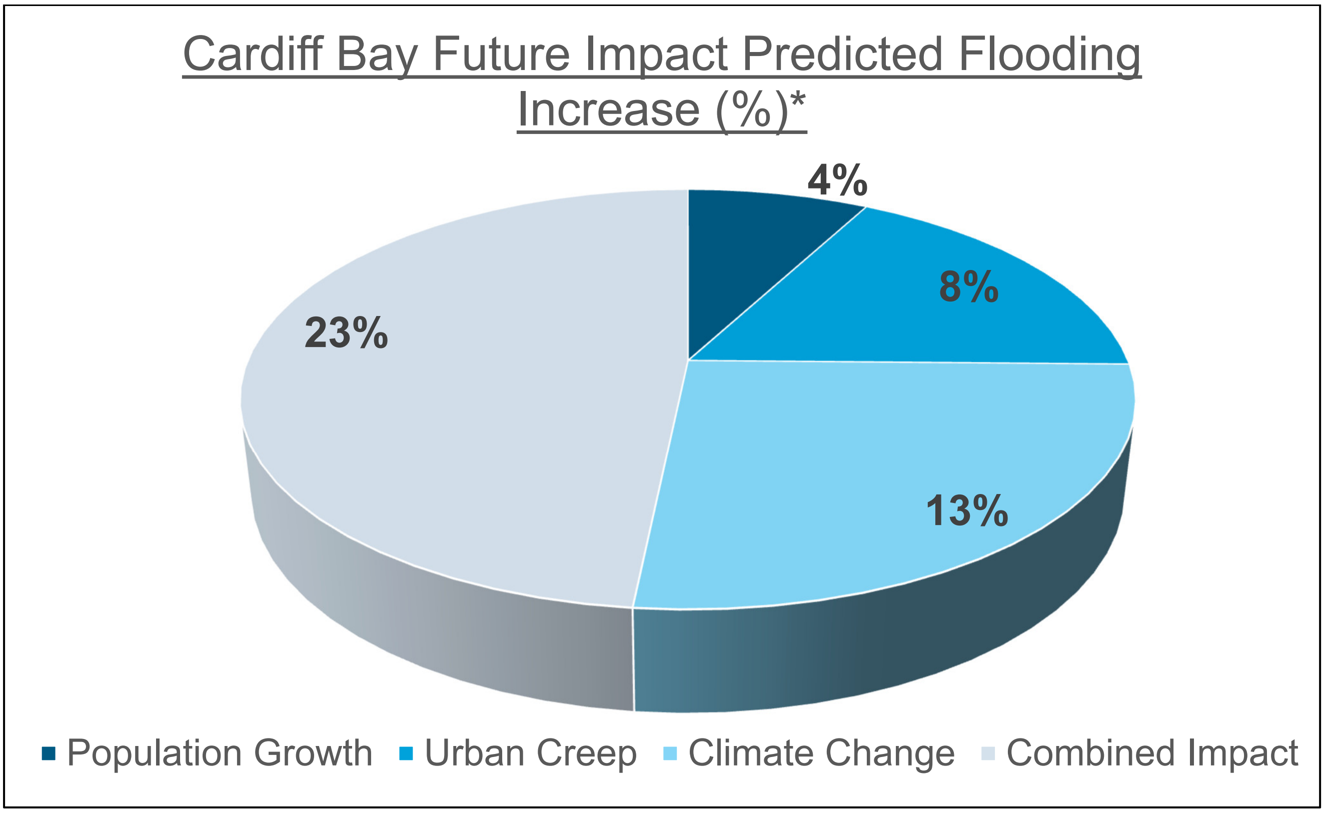


Figure 2: 33875 – Cardiff Bay WwTW predicted increase in flooding

**Excluding Rhymney Lower (Catchment F) see discussion below.*

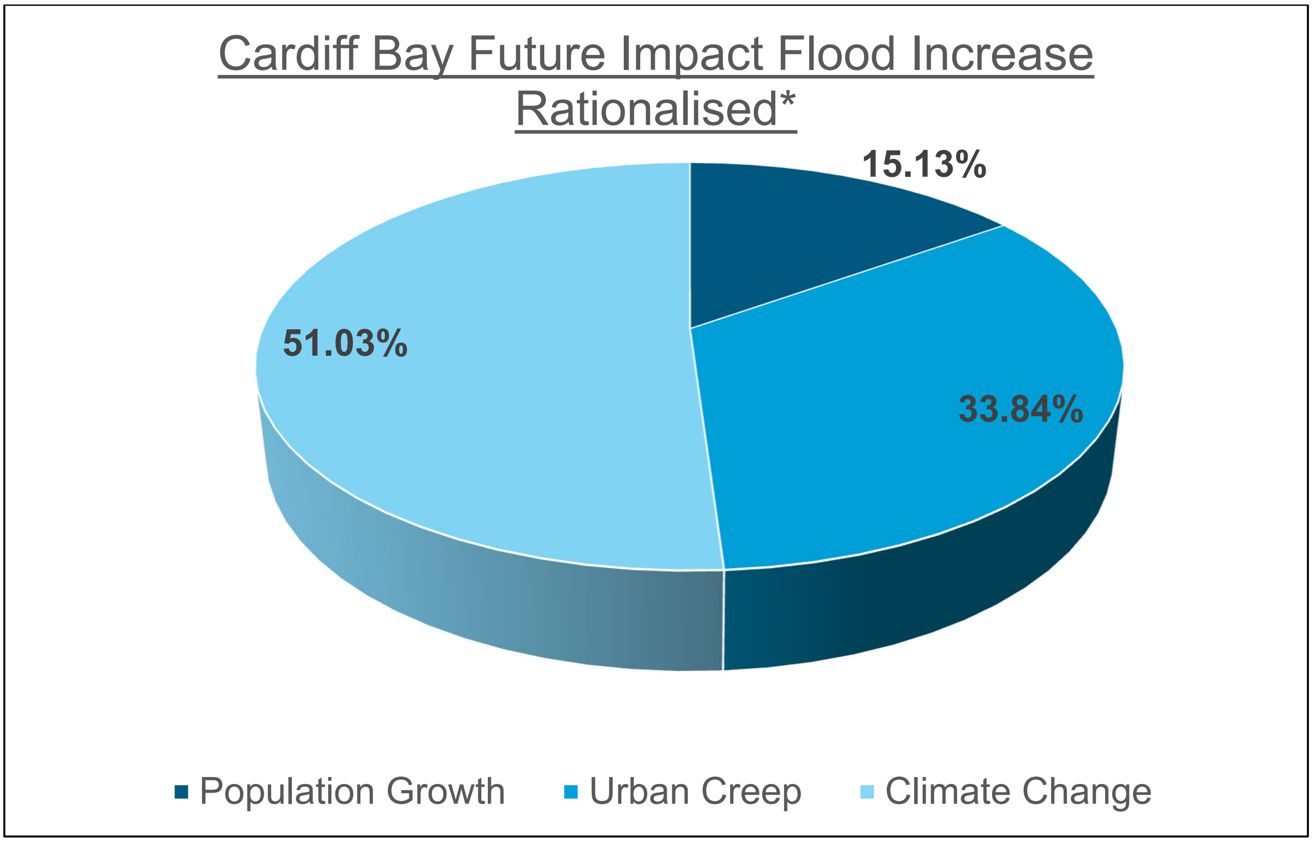


Figure 3: 33875 – Cardiff Bay WwTW Proportional Future Impact

**Excluding Rhymney Lower (Catchment F) see discussion below*

Scenario	1in 30 Year Storm Total Catchment Flood Volume (% increase in detriment)						
	60 S	**240 S**	**480 S**	**60 W**	**240 W**	**480 W**	**Average**
Population Growth	4%	4%	4%	4%	4%	4%	4%
Property Creep	9%	8%	9%	7%	9%	8%	8%
Climate Change	12%	13%	13%	12%	14%	11%	13%
Combined Growth/ Creep/ Climate Change	23%	24%	24%	21%	24%	23%	23%

Table 1: Future Impacts Flood Volume Comparison (S = Summer, W= Winter)

The impact of future urban creep, population growth and climate change are influenced by the catchment topography and protection provided by the network, Section 1.3.1 reviews the impact on each of the Cardiff catchments.

1.3.3.

1.3.3. Catchment Variation

The catchment topography and network characteristics influence the impact of Population Growth, Urban Creep and Climate Change on a catchment. The Cardiff Bay sub catchments cover a diverse range of topographic and network characteristics, from the upper reaches in the Valleys to the urban centre in Central Cardiff, this provides a good representation of the impact variance in catchment. Individual catchment characteristics are discussed in section1.3.1 of this report.

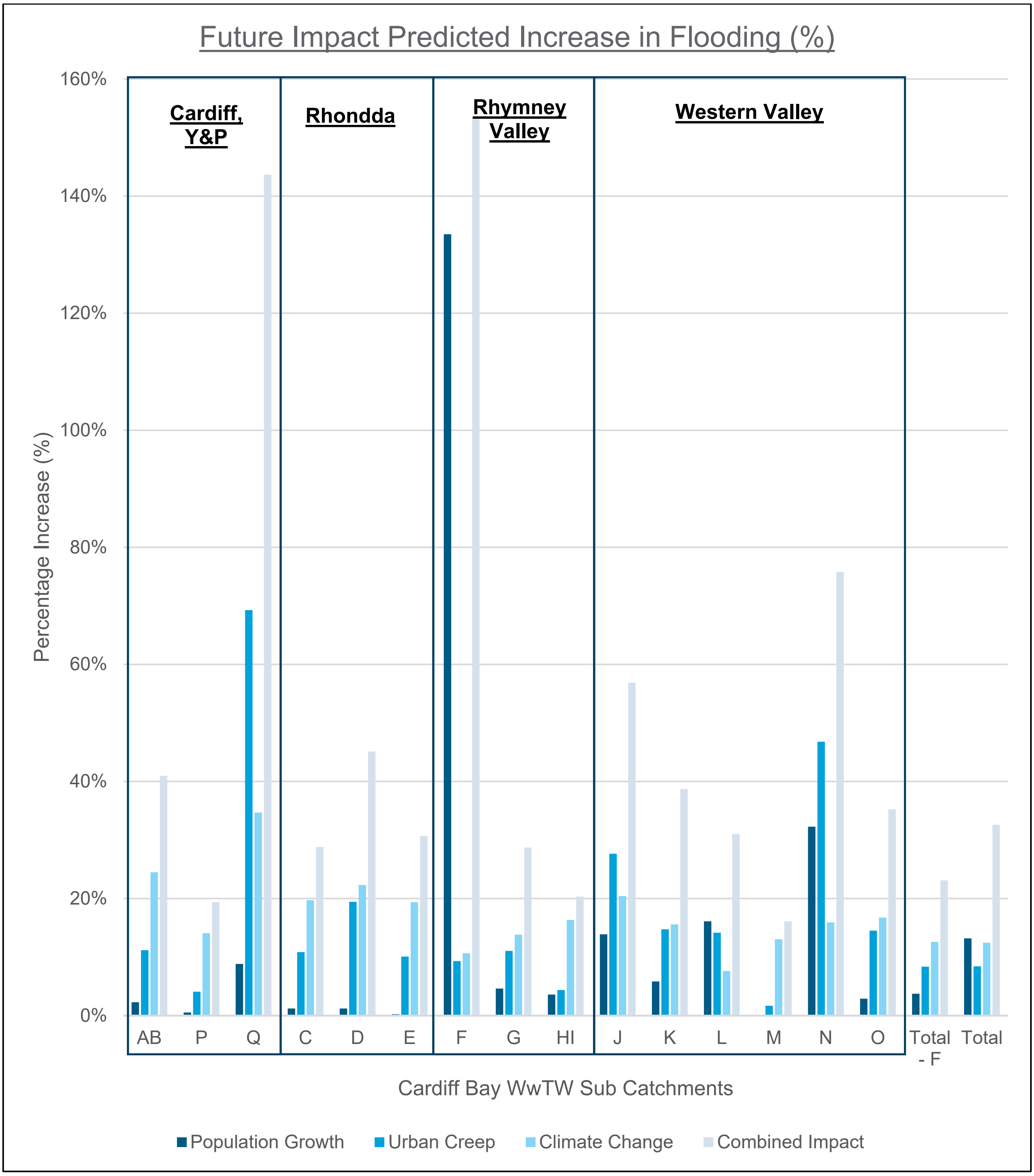


Figure 4: 33875 – Cardiff Bay WwTW Predicted Future Impact per subcatchment

The trend predicted across the total Cardiff Bay catchment can be observed throughout the majority of subcatchments, Figure 4. Several anomalous results have been assessed in further detail to determine the level of confidence in the predicted impact:

- Cardiff Central (AB), Y&P (P), Rhondda (C, D, E) Rhymney (G, HI) Western Valleys (K, M, O) follow the trend predicted for the total Cardiff Bay catchment.
- Cardiff East (Q) – Flooding detriment in Cardiff East is disproportionally high due to the high potential for urban creep. A large catchment area with low housing density and small capacity sewer network results in a greater impact from urban creep.
- Rhymney Lower (F) – A disproportionate response is predicted from population growth, upon further investigation this is due to coarse model representation of a large trade development of 22.5 Ha, Cardiff Parkway, connecting to a small capacity local sewer network. The network representation and impact of this development is currently under assessment through a Hydraulic Model Assessment. In reality the development is not likely to point load one sewer line and would most likely bypass the Rhymney Tanks and flow directly into the Interceptor Tunnel. This has been observed in the proposals for the Plas Dwr, Cardiff West development, refer to 'Future Impact on Flooding Cog Moors (Cardiff West) TN001 v1' for further details. For the purpose of this report the Rhymey Lower (F) catchment has been excluded from the assessment due to low confidence in the Population Growth representation which otherwise would significantly skew the Cardiff Bay catchment results.
- Western Valleys (J, L, M) – There is divergence from the trend of results in these catchments due to the skeletal hydraulic model representation, primarily constructed to represent the conveyance of flows to the trunk sewers. With use of the best data available these results are not perceived to be anomalous and therefore have been included in the assessment of the Cardiff Bay catchment.

1.4. Conclusions

Although variance in the future impact of growth, creep and climate change can occur on a local catchment level due to network characteristics. A general trend is apparent where climate change is predicted to have the most significant future impact on a catchment with respect to flooding, followed by urban creep and then population growth.

2. Appendix A

	1in 30 Year Storm Total Catchment Flood Volume (m^3)					
Scenario	60 S	240 S	480 S	60 W	240 W	480 W
Current	268559	392059	451030	280648	403179	461686
Population Growth	278301	406135	469073	291204	418145	478782
Property Creep	291723	424833	491650	300373	438220	500398
Climate Change	301073	444163	510694	315284	458455	511888
Combined Growth/ Creep/ Climate Change	329320	486372	560122	338973	498720	569343

Table 1: Cardiff Bay Future Impacts Flood Volume Comparison – (Excluding Rhymney F)

	1in 30 Year Storm Total Catchment Flood Volume (m^3)					
Scenario	60 S	240 S	480 S	60 W	240 W	480 W
Current	287672	423402	490681	301007	436035	503282
Population Growth	333340	475350	549153	347641	488966	560896
Property Creep	312709	459094	534766	322918	473975	545506
Climate Change	322364	479069	554186	337903	494877	557421
Combined Growth/ Creep/ Climate Change	388464	561968	647449	399668	576103	658868

Table 2: Cardiff Bay Future Impacts Flood Volume Comparison – (Including Rhymney F)

SNC·LAVALIN ATKINS Member of the SNC-Lavalin Group

Technical Note

Project:	5136869 DCWW AMP6 SDP		
Subject:	Future Impacts on Flooding -Cog Moors (Cardiff West)		
Author:	Dean Jeffery		
Date:	19/03/2019	Project No.:	5136869
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Document history

Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	First Issue	DJ	PB	TB	TB	19/03/2019

Client signoff

Client	Dwr Cymru Welsh Water (DCWW)
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Executive Summary

To support Dwr Cymru Welsh Water (DCWW) in response to OFWAT on the proposed PR19 business case ATKINS have assess the impact of future drivers on the Cog Moors (Cardiff West) wastewater treatment works sub catchment. The assessment has been made to compare and proportion the respective contribution to hydraulic overload flooding from Population Growth, Urban Creep and Climate Change.

Through the investigation it has been concluded that Climate Change is the most significant future impact, increasing predicted flooding by 38%, proportionally 68.3% of the predicted future impact. Urban Creep results in a 13% increase in predicted flooding, proportionally 24.4% of the predicted future impact. Population Growth has the least significant impact, increasing predicted flooding by 4%, proportionally 7.3% of the predicted future impact.

1.1. Future Impacts on Flooding

Dwr Cymru Welsh Water (DCWW) have requested ATKINS support to quantify and proportion the contributions of future impacts on hydraulic overload (HO) flooding. This request is to support DCWWs response to OFWAT on the PR19 Business Case. The assessment has been carried out on the 33726 - Cog Moors WwTW sub catchment (Cardiff West) to review the impacts of the following factors:

- Population Growth – Catchment Population growth and catchment development population as defined in the Local Development Plan (LDP)
- Property Creep – Increase in catchment impermeable area contribution to the sewer network due to increases misconnections and increase in impermeable surfaces.
- Climate Change – Increase in rainfall intensity of 10% as per UKCP09 forecast impact.
- Combined - Growth, Creep & Climate Change applied together.

1.2. Hydraulic Model Impact Assessment

The assessment of future impacts on flooding has been completed for the 2040 design horizon catchment scenario for 1 in 30 year storm events with durations of 60, 240, 480 minutes to maintain consistency with Resilience metric assessment events. The assessment has been carried out for both Summer and Winter storm events to assess if there is a seasonal influence in the future impacts.

As the assessment is to review the impact of each future aspect on HO flooding a 'clean network' hydraulic model scenario, i.e. free of transient sediment and temporary blockages has been used to predict the impact on hydraulic overloading. The predicted total flood volumes for the scenarios are provided in Appendix A.

1.3. 33875 - Cardiff Bay WwTW Catchment Future Impacts

1.3.1. Cog Moors WwTW (Cardiff West) Catchment

The Cardiff West sub catchment of the Cog Moors WwTW, Figure 1, has been assessed as this has the largest proposed single development in Wales, Plas Dwr, at 15,000 additional population. A hydraulic model assessment and intervention proposals are currently in development for this site, therefore there is high confidence in the hydraulic model representation of the development. Future Impact assessment of catchments with varying catchment characteristics provides a more detailed understanding and appreciation for the overall impact of Population growth, Urban Creep and Climate change when considered across the whole of Wales.

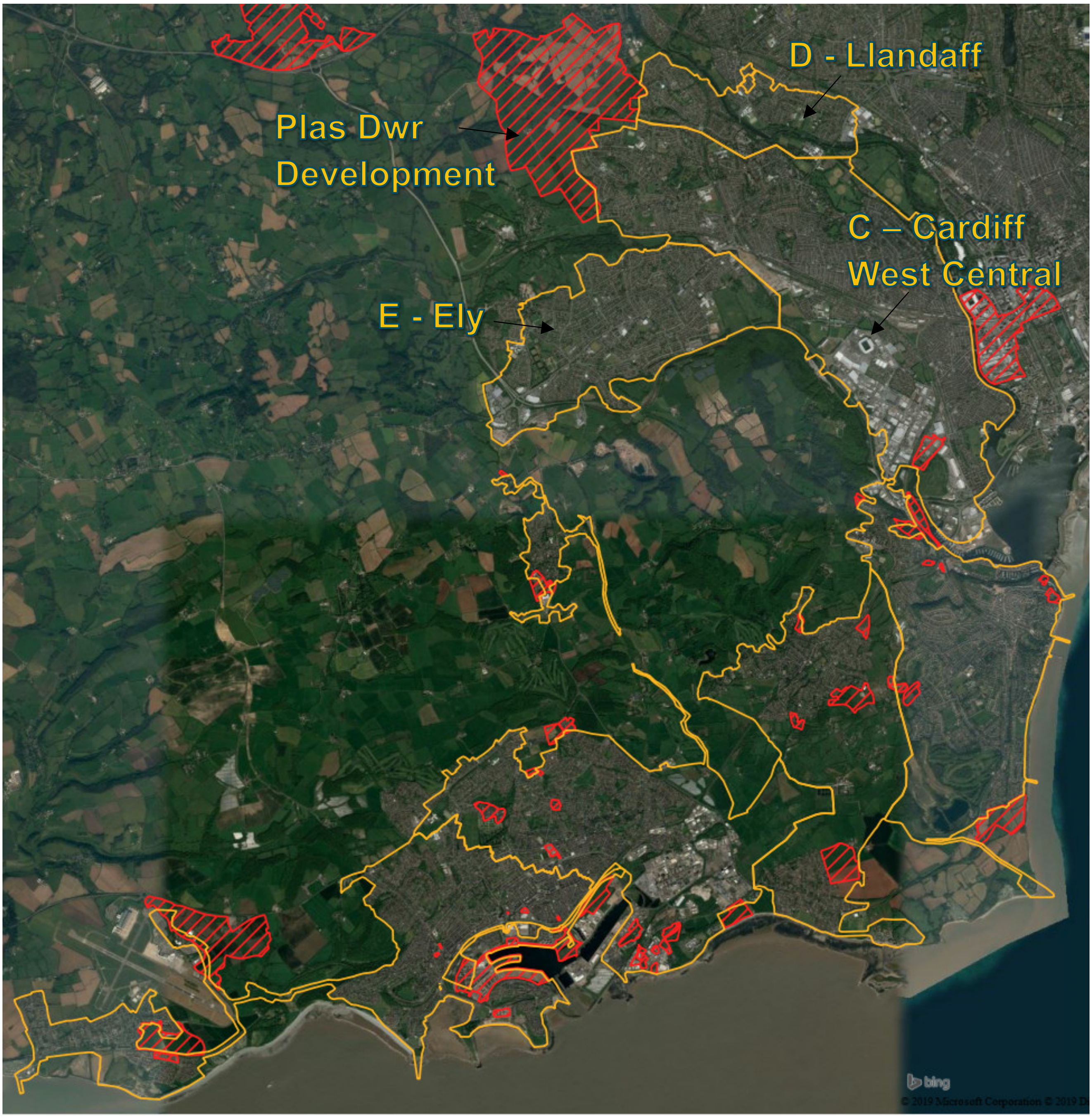

Figure 1: Cog Moors WwTW catchment area

The catchment topography and network characteristics in each of the Cardiff West sub-catchments are as follows:

- Cardiff West Central (C) - has oversized sewer network, (historically to cope with tidal surcharge) and limited capacity for urban creep due to the physical lack of space for expansion. The catchment is low lying with a small number of CSOs.
- Cardiff West Llandaff (D) – generally comprises of small diameter sewers and a high proportion of open space therefore exhibiting a higher potential for urban creep. The catchment is low lying with no CSOs.
- Cardiff West Ely (E) - generally comprises of small diameter sewers and a high proportion of open space therefore exhibiting a higher potential for urban creep. The catchment is low lying with a small number of CSOs.

1.3.2. Total Catchment Future Impact

The predicted impact of each contributing factor on flooding in the Cog Moors (Cardiff West) catchment can be seen in Figure 2, from this it is evident that climate change has the most significant impact on hydraulic overload (HO) flooding with a 38% increase in predicted flood volumes across the subcatchments. Urban Creep results in a 13% increase in flood volumes and population growth, a 4% increase. The proportional impact observed is consistent in both summer and winter storm events and across short and long duration events, Table 1.

The combined impact scenario predicted a 60% increase in flooding, this is greater than the sum of individual contributions when considered in isolation due to the increased flow contributions, limited number of CSOs in the catchment and limited pipe capacity.

The proportional impact of each future factor has been calculated relative to the sum of each factor, Figure 3. The proportional future impact is as follows:

- Climate Change – 68.3%
- Urban Creep – 24.4%
- Population Growth – 7.3%

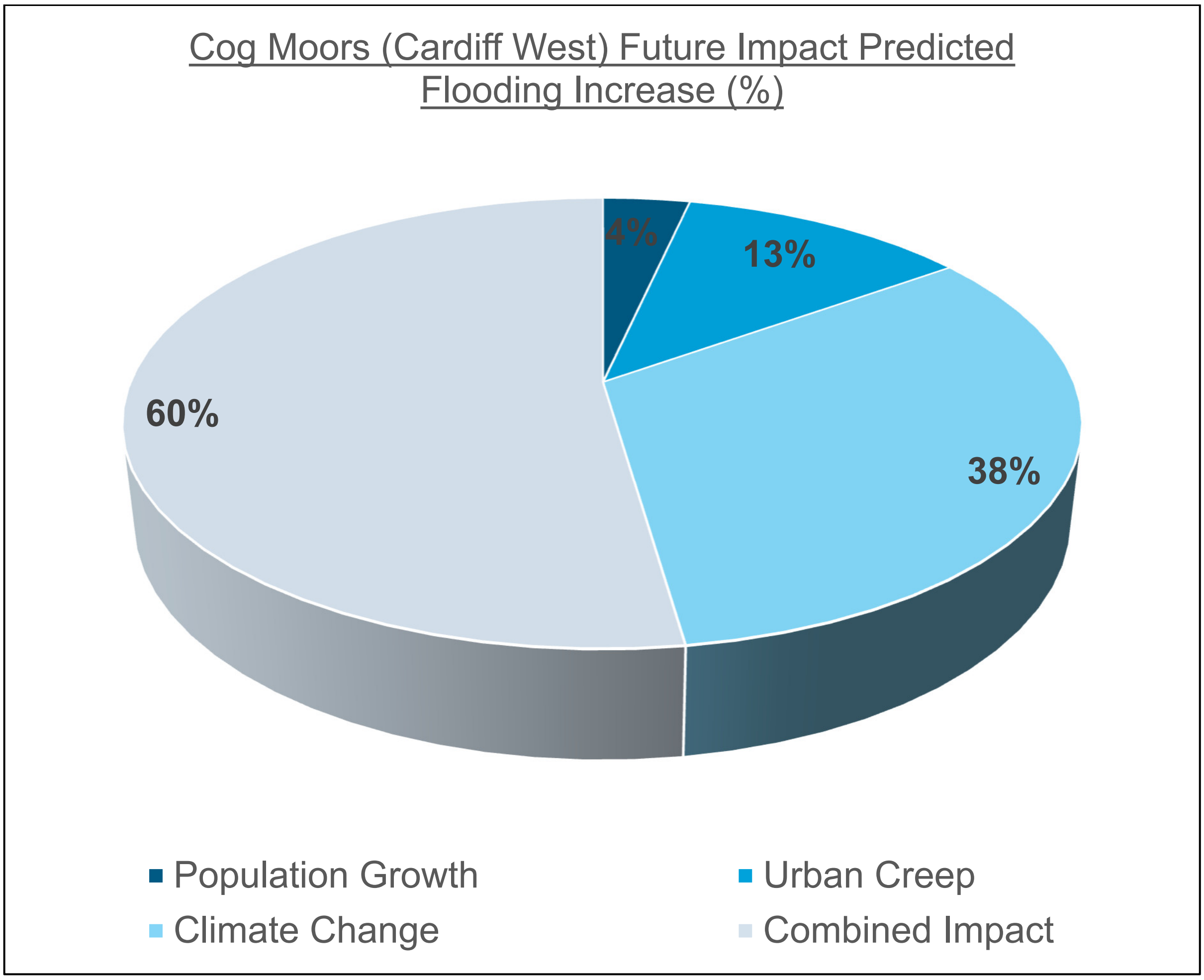

Figure 2: 33726 - CDE– Cog Moors (Cardiff West) predicted increase in flooding

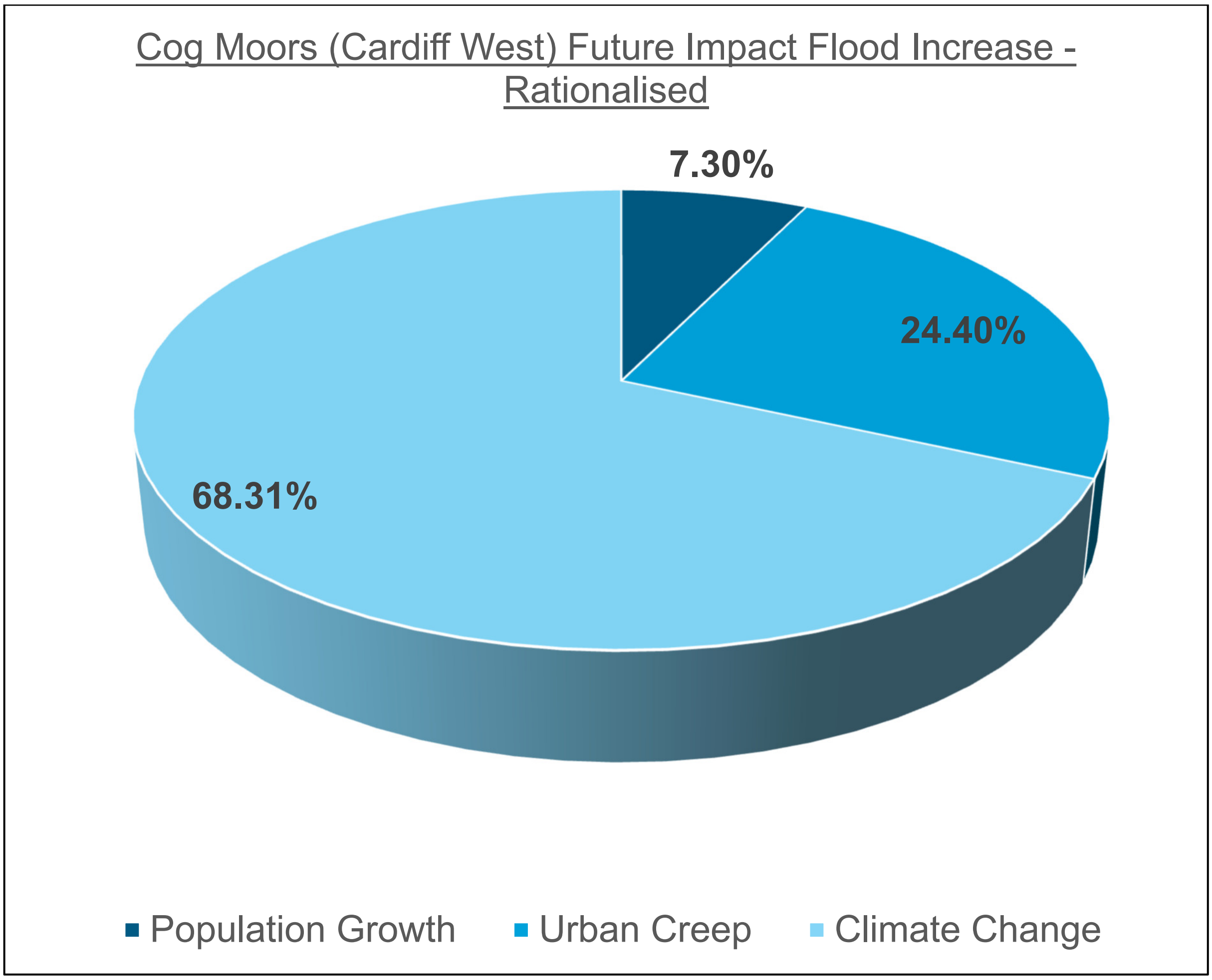

Figure 3: 33726 - CDE– Cog Moors (Cardiff West) Proportional Future Impact

Scenario	1in 30 Year Storm Total Catchment Flood Volume (% increase in detriment)						
	60 S	240 S	480 S	60 W	240 W	480 W	Average
Population Growth	3%	3%	6%	2%	5%	5%	4%
Property Creep	15%	13%	13%	13%	12%	14%	13%
Climate Change	36%	39%	37%	35%	40%	40%	38%
Combined Growth/ Creep/ Climate Change	60%	62%	62%	56%	59%	64%	60%

Table 1: Future Impacts Flood Volume Comparison (S = Summer, W= Winter)

The impact of future urban creep, population growth and climate change are influenced by the catchment topography and protection provided by the network, Section 1.3.2 reviews the impact on each of the Cardiff West Catchments.

1.3.3.

1.3.3. Catchment Variation

The catchment topography and network characteristics influence the impact of Population Growth, Urban Creep and Climate Change on a catchment. The Cardiff West sub catchments cover a range of topographic and network characteristics, individual catchment characteristics are discussed in section1.3.1 of this report.

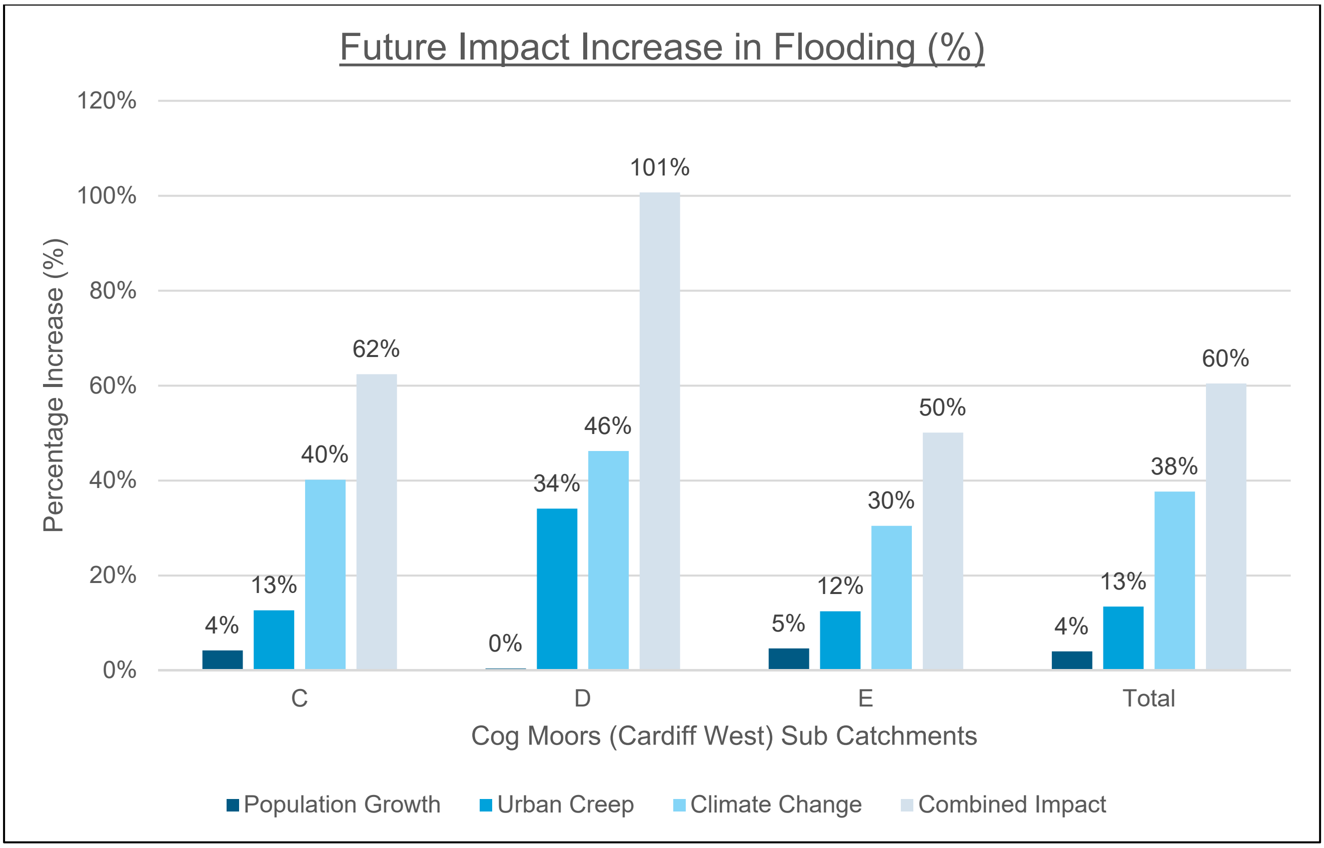

Figure 4: 33726 – Cardiff West Predicted Future Impact per subcatchment

The trend predicted across the total catchment can be observed throughout all of the subcatchments, as shown in Figure 4. In summary:

- Both Cardiff West (C) and Ely (E) follow the trend predicted for the total Cardiff Bay catchment despite high population growth contributions from Plas Dwr.
- Llandaff (D) had a higher impact from urban creep due to the small capacity local network and the high potential for urban creep within the catchment. There is negligible detriment observed from population growth due to limited development in the catchment.

1.4. Conclusions

Although variance in the future impact of growth, creep and climate change can occur on a local catchment level due to network characteristics. A general trend is apparent where climate change is predicted to have the most significant future impact on a catchment with respect to flooding, followed by urban creep and then population growth.

2. Appendix A

	1in 30 Year Storm Total Catchment Flood Volume (m^3)					
Scenario	**60 S**	**240 S**	**480 S**	**60 W**	**240 W**	**480 W**
Current	20390	33616	34302	23180	36930	34651
Population Growth	20948	34726	36191	23749	38673	36533
Property Creep	23389	38116	38858	26233	41540	39405
Climate Change	27812	46603	46923	31340	51547	48341
Combined Growth/ Creep/ Climate Change	32633	54371	55449	36132	58725	56959

Table 1: Cardiff West Future Impacts Flood Volume Comparison

PR19 GROWTH, CREEP, CLIMATE CHANGE ASSESSMENT

CLE10301
PR19 Growth, Creep, Climate Change Assessment
1
19 March 2019

rpsgroup.com

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
1	The purpose of this document is to provide details of the steps carried out to estimate the impact that population growth, creep and climate change have on flooding in different catchments across Wales.	Javier Val	Amy Jones	Amy Jones	19/03/2019

Approval for issue

Amy Jones	Amy Jones	19 March 2019

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Contents

1 METHODOLOGY AND ASSUMPTIONS

The following steps were carried out to understand the impacts that population growth, creep and climate change have on different catchments across Wales. The impacts of each factor were calculated individually.

Based on the model confidence, total population and UKCP09 climate change factor, the following 4 catchments were selected:

- Aberystwyth
- Tregaron
- Porthmadog
- Hereford.

Table 1. Catchments selected for assessment.

Catchment	Current Population	UKCP09 Climate Change Winter Factor	UKCP09 Climate Change Summer Factor
Aberystwyth	19,092	1.09	1.03
Tregaron	884	1.1	1.1
Porthmadog	3,658	1.08	1.02
Hereford	69,097	1.09	1.09

- Models representing current ground conditions were used for every catchment (current scenario models). These models were last updated between 2013 and 2017.

- For every current scenario model, the following additional scenarios were created:

  - 10% increase of population. This increase was applied evenly across the combined and foul subcatchments.
  - 30% increase of population. This increase was applied evenly across the combined and foul subcatchments.
  - 25-year creep based on UKWIR research from 2009.

- Values of population increase were selected after reviewing yearly historical growth data for each catchment and projecting these historic trends 25 years into the future.

- The following storm events, for winter and summer, were simulated for each scenario: M30-60, M30-240 and M30-480. M30-60 is a storm that happens every 30 years and lasts 60 minutes.

- The following storm events, for winter and summer, were simulated representing climate change conditions: M30-60, M30-240 and M30-480.

- Total flooding volumes in each current scenario model were compared against total flooding volumes of the other scenarios.

2 RESULTS

The following tables show the model predicted impact that climate change, creep and increase population have on the catchments above mentioned:

Table 2. Impact of climate change, creep and population increase on Aberystwyth.

Aberystwyth								
Comparison	**Units**	**M30-60s**	**M30-240s**	**M30-480s**	**M30-60w**	**M30-240w**	**M30-480w**	**Average**
Current vs 10% increase in population	**Absolute (m^3)**	25.90	15.60	21.10	-66.20	63.00	50.90	**18.38**
	%	0.01%	0.01%	0.01%	-0.04%	0.03%	0.02%	**0.01%**
Current vs 30% increase in population	**Absolute (m^3)**	49.90	123.10	168.60	91.60	239.30	195.90	**144.73**
	%	0.03%	0.06%	0.06%	0.05%	0.11%	0.07%	**0.06%**
Current vs Creep	**Absolute (m^3)**	**2,052.00**	**2,651.60**	**2,586.90**	**2,111.20**	**2,759.10**	**2,419.50**	**2,430.05**
	%	1.14%	1.20%	0.94%	1.17%	1.25%	0.88%	**1.09%**
Current vs Climate Change	**Absolute (m^3)**	321.60	381.40	289.60	962.40	1,361.60	1,037.00	**725.60**
	%	0.18%	0.17%	0.10%	0.53%	0.61%	0.38%	**0.33%**

Table 3. Impact of climate change, creep and population increase on Tregaron.

Tregaron								
Comparison	**Units**	**M30-60s**	**M30-240s**	**M30-480s**	**M30-60w**	**M30-240w**	**M30-480w**	**Average**
Current vs 10% increase in population	**Absolute (m^3)**	-1.30	0.50	-1.30	0.30	-	-	**-0.30**
	%	-0.45%	0.28%	-2.22%	0.11%	0.00%	0.00%	**-0.38%**
Current vs 30% increase in population	**Absolute (m^3)**	-1.10	0.60	-1.60	0.40	0.80	-	**-0.15**
	%	-0.38%	0.33%	-2.74%	0.14%	0.84%	0.00%	**-0.30%**
Current vs Creep	**Absolute (m^3)**	**210.40**	**199.10**	**157.60**	**217.60**	**187.80**	**72.30**	**174.13**
	%	73.34%	109.94%	269.40%	77.14%	196.03%	0.00%	**120.97%**
Current vs Climate Change	**Absolute (m^3)**	89.10	72.20	51.30	86.70	69.50	-	**61.47**
	%	31.06%	39.87%	87.69%	30.73%	72.55%	0.00%	**43.65%**

Table 4. Impact of climate change, creep and population increase on Porthmadog.

Porthmadog								
Comparison	**Units**	**M30-60s**	**M30-240s**	**M30-480s**	**M30-60w**	**M30-240w**	**M30-480w**	**Average**
Current vs 10% increase in population	**Absolute (m^3)**	5.30	-11.70	11.60	13.60	6.70	13.30	**6.47**
	%	0.15%	-0.25%	0.25%	0.38%	0.15%	0.30%	**0.16%**
Current vs 30% increase in population	**Absolute (m^3)**	19.60	2.00	40.50	22.90	32.40	39.30	**26.12**
	%	0.55%	0.04%	0.87%	0.64%	0.72%	0.88%	**0.62%**
Current vs Creep	**Absolute (m^3)**	**2,195.10**	**3,080.90**	**3,368.10**	**2,257.70**	**3,084.00**	**3,431.50**	**2,902.88**
	%	61.05%	67.13%	72.75%	62.61%	68.35%	77.18%	**68.18%**
Current vs Climate Change	**Absolute (m^3)**	148.20	157.20	189.00	587.40	623.30	772.10	**412.87**
	%	4.12%	3.43%	4.08%	16.29%	13.81%	17.37%	**9.85%**

Table 5. Impact of climate change, creep and population increase on Hereford.

Hereford								
Comparison	**Units**	**M30-60s**	**M30-240s**	**M30-480s**	**M30-60w**	**M30-240w**	**M30-480w**	**Average**
Current vs 10% increase in population	**Absolute (m^3)**	-275.40	-177.30	155.10	-335.80	-213.10	372.80	**-78.95**
	%	-0.45%	-0.29%	0.29%	-0.55%	-0.36%	0.75%	**-0.10%**
Current vs 30% increase in population	**Absolute (m^3)**	1.90	412.30	745.40	-22.40	349.90	981.30	**411.40**
	%	0.00%	0.67%	1.41%	-0.04%	0.59%	1.98%	**0.77%**
Current vs Creep	**Absolute (m^3)**	**15,072.10**	**20,598.40**	**22,391.70**	**15,573.60**	**21,257.50**	**22,637.10**	**19,588.40**
	%	24.68%	33.27%	42.46%	25.29%	35.67%	45.66%	**34.5%**
Current vs Climate Change	**Absolute (m^3)**	10,131.50	10,405.90	11,309.40	10,248.50	9,975.70	10,495.60	**10,427.77**
	%	16.59%	16.81%	21.45%	16.64%	16.74%	21.17%	**18.23%**

3 COMMENTS

Simulations suggest that creep has the biggest influence on future flooding. These results differ from those found by Atkins in Cardiff. A possible explanation for this difference is that, generally, rural areas are less densely populated than urban areas thus, dwellings have more permeable area that may allow for future creep.

In some of the simulations representing population increase, flooding volumes are lower than in the current scenario. This is due to model tolerance and the percentage changes are generally small.

A limitation in this analysis is that the models used have been built and verified as part of DCWW's Sustainable Development Plan (SDP) programme. This implies that there is higher confidence in the parts of the models included within risk areas.