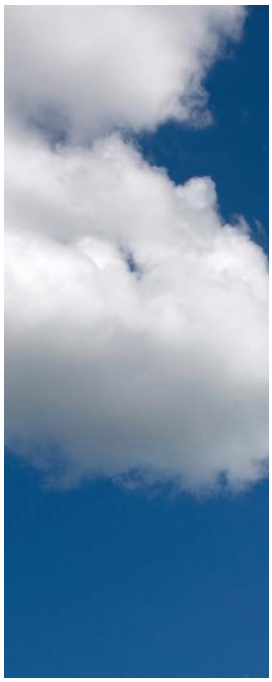

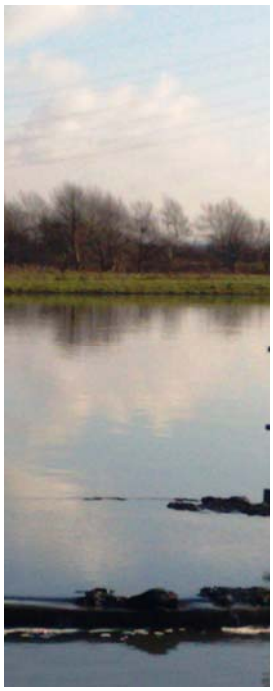

Future Impacts on Sewer Systems in England and Wales

Summary of a Hydraulic Modelling Exercise Reviewing the Impact of Climate Change, Population and Growth in Impermeable Areas up to Around 2040

June 2011

A report prepared for Ofwat

Mott MacDonald

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Ofwat

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Content

Executive Summary

Introduction

Sewer flooding is highly undesirable and causes distress and hardship to many households in England and Wales every year. A total of 4,709 properties are currently registered by the wastewater companies as being at risk of internal flooding at least once every ten years[1].

The ten water and sewerage companies ("companies") have invested over £4bn in the public sewerage system and have reduced the risk of sewer flooding to more than 15,000 properties since 2000. But climate change, increases in drained area, and new housing and industrial development are expected to increase the amount of water in sewers, leading to more flooding problems in the future.

The BIS 'Future Flooding[2]' foresight report identified a risk of increasing intra-urban flooding, commenting that existing tools for urban flood modelling are weak. It stated that urban flooding could increase four-fold over the century, but that a small change in rainfall might be absorbed by spare capacity in the sewers. The conclusions of the current study support the predicted increase in flooding but do not appear to support the view that spare capacity is available.

Ofwat commissioned this study to investigate the change in sewer flooding that may result from climate change, increasing drained area (creep), and new population and housing (growth) up to about 2040. It uses mathematical models of sewer networks, which the companies use to analyse performance and to inform future investment plans.

The results of the modelling for this study predict a significant increase in sewer flooding after allowing for existing network capacity. Each of the three modelled changes – climate change, creep, and growth – leads to an increase in flooding, except for the driest rainfall scenario. In the 'combined' scenario the three changes work together to produce a greater effect than the sum of the individual changes. The results are summarised in table i.

Table i: Median increase in sewer flooding predicted by the modelling scenarios (summer and winter models together)

Median increase in sewer flooding, %	50th percentile
Population growth	5
Property creep	12
Climate change	27
Combined	**51**

The Sewer Flooding Problem

Every millimetre of rainfall deposits a litre of water on each square metre of land. A day of even modest rain can deposit several million litres of water on a town. Rainwater landing on rural areas such as fields

[1] Ofwat summary of water company sewer flooding at risk registers, 2010.

[2] Future Flooding department for Business, Innovation and Skills, 2003.

and forests soaks into the ground or slowly makes its way overland to join rivers. Rainwater landing on urban areas cannot soak into the ground and has traditionally been managed by providing roof gutters and highway gullies that rapidly drain the rainwater to sewer networks.

In some locations a separate surface water sewer discharges rainwater to a nearby drainage ditch, stream, river, or the sea. Otherwise the rainwater enters the sewer carrying domestic and trade wastewater, which then flows to a sewage treatment works where pollutants are removed before the water is returned to the environment.

In rural areas, rainwater is more likely to drain informally from the sides of roads, and from roofs and paved areas to ditches, streams, or soakaways. But even in rural areas, property owners might connect roofs and paved area drainage to the sewer network, if it appears to provide an easy option for drainage.

Every sewer has a finite capacity to carry flow, but the volume of rain that can fall on a paved or roof surface is effectively unlimited. When too much flow tries to pass through the pipe the upstream water level in the pipe will increase. If the flow cannot be accommodated in the full pipe it will escape through gullies or manholes, causing flooding, or through overflow relief points directly to rivers or the sea. Overflows can cause pollution when sewage is also present.

Method

This study used a selection of 100 sewer network models belonging to the companies. The models studied cover 16% (8.9 million people) of the population of England and Wales in a wide range of catchment sizes.

The simulations were commissioned by the water companies and summary results submitted to this study. A modelling protocol was agreed at a workshop of the water companies, so that the models were run on a consistent basis. The models were run to assess the individual effects of growth, creep and climate change, as well as combining all the effects. The changes would not normally occur in isolation but it was important to understand the relative contribution of each one.

The climate change impact was taken from UKCP09 medium emissions scenario for 2040, at the 50th percentile winter rainfall event. Companies with sufficient time or modelling resource also simulated the 10th and 90th percentile. Summer storms have also been a concern and so an allowance was made for an increase in convective storms, so that the response to a summer storm could be modelled.

Population growth estimates were taken from the water companies' population forecasts for 2033. These in turn are based on a mix of Office of National Statistics, local authority, and other data. We assumed the full implementation of Planning Policy Statement 25, which controls the addition of surface drainage to the sewer network.

The urban creep estimate was based on a methodology published recently by UK Water Industry Research Ltd. The UKWIR study analysed aerial images of about two million properties to calculate the increase in roof and paved area. The result allows an estimation of potential additional drained area, based on the current housing density, for 2033.

Growth and urban creep estimates were applied relative to population, which is only modelled on the foul system. Therefore the impact on storm sewers is likely to be underestimated.

We took the inputs as a reasonable scenario for 2030-2040, given the variability in predictions of each of the three changes.

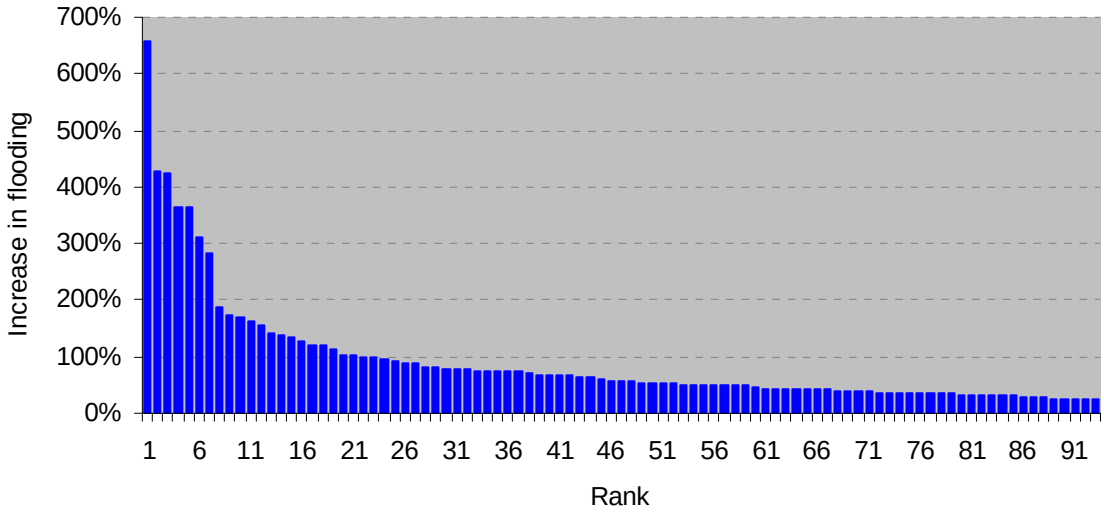
Results

The models predict a significant increase in flood volumes and the number of flooded locations, with a median increase in flood volumes of about 51% and a mean (average) increase of about 92%.

Any of the three changes – climate change, urban creep, and growth – increase the flood volume and number of flood locations, except for the 10th percentile rainfall. None of the models showed a reduction in flooding in all scenarios, the reductions being confined to the 10th percentile rainfall event. The 10th percentile rainfall was run for 66 catchments. Of these, flooding reduced in 57 catchments if there were no other changes. But when combined with the other changes – a more realistic scenario – 45 of the 57 catchments (79%) still showed an increase in flooding.

The results for the 50th percentile rainfall combined with creep and growth are shown in rank order in Figure i. Of the 100 models, the results of four were discarded because of problems with model stability. Of those, three showed no increase and one a reduction in flooding.

Figure i: Results of the combined scenario with 50th percentile winter rainfall, ranked in order of the increase in predicted flooding.



Above: The ranking shows the net increase in flood volume after accounting for spare capacity in the network.

Implications for England and Wales

The pressures of more houses, urban creep that increases the drained area of existing and new properties, and climate change each lead to an increase in the number of flood locations and the volume of flood water from the sewer network, except in the case of the 10th percentile winter rainfall, which lead to a reduction in some catchments.

Sewer models tend to be most up-to-date for catchments already having a flood problem and this may bias the study towards worse performing catchments. However, the study provides an indication of the potential range of the change in sewer flooding that may be expected by 2040.

There was no geographic trend and no trend linking the change in flooding to the population of the existing catchment. The change in flooding is a factor of the current capacity in the network, taken together with the combined effect of the three changes. No catchments can be expected to see a reduction in flooding unless climate change reduces inputs by more than the increase from creep and population growth – which the currently available data suggests to be unlikely.

If nothing is done, it is reasonable to expect a significant increase in the number of flooded properties across England and Wales, as well as an increasing frequency of flooding for those already at risk.

Suggestions for Adaptation Strategies

Drawing on the results of the study we suggest the adaptation strategies listed below. Some will require changes in government policy or legislation. Enforcement powers will have to be adequate and implemented with adequate resources if they are to be effective.

1. Preventing all future connections of rainwater drainage from roofs, paved areas, and highways to the foul or combined sewer network. Significant investment will still be required in foul/combined systems to accommodate the additional foul flows resulting from growth.

2. Ensuring that wastewater capacity is developed in line with the growth of towns. This may involve towns being more closely involved with company asset management plans, and companies providing more information about sewer network capacity for urban strategic plans.

3. Removing or attenuating existing rainwater connections, from roofs, paved areas and highways, from the foul or combined sewers. This should be prioritised to the most vulnerable catchments, and individual schemes according to the marginal cost of abatement of rainwater flows. This should be an integral part of surface water management plans, thus ensuring dialogue with other stakeholders in the built environment. It will require the ending of the right to connect drainage to foul and combined sewer networks, as recommended by the Pitt review.

4. Improving the condition of sewers in vulnerable catchments with above average infiltration (seepage of ground water into sewers), to reduce the infiltration of water from the ground or after

heavy rain and so effectively improve both the capacity and resilience of the system. It should be recognised however that there are limits on how much infiltration can be removed economically.

5. Providing additional sewerage capacity to accommodate the new flows. This could include diverting flows between catchments, providing more storage, or adding new surface water sewers to convert a combined system into separate rainwater and foul water networks.

6. In all the options for change it will be necessary for the companies to work with land owners, councils and drainage authorities such as the Highways Agency or the internal drainage boards to identify the most appropriate strategy for each catchment. All of these parties should already be involved in the preparation of surface water management plans and therefore this would appear to be an ideal forum in which to address any problems.

7. It may be appropriate to develop some measure of companies' performance in drainage management and report on this regularly.

Conclusions

1. Any one of the three changes modelled (growth, urban creep, climate change) are likely to cause an increase in flooding if not addressed. Each of the change scenarios investigated implies a significant increase in the volume and extent of sewer flooding throughout England and Wales by 2040. The exception is the 10th percentile winter climate change scenario, which may reduce flooding in a minority of catchments, especially if there is no population growth or urban creep.

2. When considered in a combined change scenario the volume and extent of flooding is further increased. All three changes are based on sound evidence. It is extremely unlikely that only one change will occur whilst the other two remain the same. The climate, population and the connected area will change: the only uncertainty is by how much they will change.

3. There is a wide range of change predicted across the catchments modelled, from a slight reduction in flooding to an increase to more than four times the current level. The increase will take the form of more flood locations as well as a greater volume of flood water, more often.

4. Housing and industrial development adds new flow and reduces the capacity for draining rainwater. If not properly accommodated, housing growth will lead to an increase in sewer flooding. The median increase in 1:10 year flooding across 97 catchments was 4.8%, compared with current predicted flooding.

5. Urban creep results in more rainwater entering the network in every storm event. It will lead to an increase in sewer flooding. The median increase in 1:10 year flooding across 97 catchments was 11.5%, compared with current predicted flooding.

6. Climate change has the potential to bring longer, heavier spells of winter rainfall. Summer convective storms are not predicted by the UKCIP09 weather generator, but also have a significant

impact on rainwater volumes in some catchments. Climate change therefore has the potential to bring a significant increase in sewer flooding. The median increase in 1:10 year flooding across 97 catchments, at the 50th percentile weather simulation under the medium emissions scenario, was 27%, compared with current predicted flooding.

7. The combined effects of the three drivers lead to a median increase in 1:10 year sewer flood volumes of 51% by about 2040 compared with current predicted flooding.

Recommendations for Further Work

This study has provided an evidence base of over 80 sewer catchments which shows the likely scale of effects on sewer flooding from future climate change, population growth and urban creep.

It provides a foundation from which to investigate the likely costs and effectiveness of different options for preventing an increase in sewer flooding or reducing existing flooding.

Drawing on the experience of this study we recommend that further phases work should include:

1. With the industry and relevant stakeholders, agree a 'design storm' with climate change built in, to use as a common basis for decision analysis. Currently it is possible to design solutions to identified problems for 1:30, 1:40 or 1:50 year storms depending on the water company, and which is based on historic rainfall series which by their nature are backward-looking. A better common basis for design would also allow an easier comparison of network performance between regions.

2. Identify the 'traditional' modifications to the wastewater network that would be required in order to prevent flooding in 2040. These would take account of the combined effects of the three change scenarios of climate change, urban creep and population growth.

3. Estimate the current cost of delivering the network modifications described above, together with likely carbon emissions resulting from the modifications.

4. Identify 'sustainable' modifications to the catchment that would reduce or avoid the need to modify the network, together with the phasing of work that would deliver these changes in time to prevent an increase in flooding. These could include disconnecting existing rainwater drains from the network and providing alternative rainwater drainage, or changing the location of new development.

5. Estimate the current cost of delivering the network modifications described above, together with likely carbon emissions resulting from the modifications, and if practicable construct an estimate of the marginal cost of abatement of climate change.

6. Compare the cost effectiveness of each pair of solutions compared with doing nothing.

7. Suggest an approach to catchment management that would encourage delivery of the most cost-effective solutions to prevent future sewer flooding.

8. Assess the implications of the above for policy making.

Introduction

1.1 Purpose of the Study

Sewer flooding is a highly undesirable failure of the infrastructure, causing distress and hardship to many households in England and Wales every year. A total of 4,709 properties are currently registered by the wastewater companies as being at risk of flooding at least once every ten years[3].

The ten water and sewerage companies (”companies”) have improved the infrastructure to reduce the risk of sewer flooding to some 15,000 properties since 2000. But climate change, increases in drained area, and new housing are expected to increase the amount of water in sewer systems, leading to further flooding problems in the future.

The BIS ‘Future Flooding’ foresight report identified a risk of increasing intra-urban flooding, commenting that existing tools for urban flood modelling are weak. It stated that urban flooding could increase four-fold, but also that small increases in climate change might be absorbed by spare capacity in the sewer network. Sewer flooding is not necessarily the same as urban flooding, but may be linked especially during severe weather.

An alternative to piped drainage has been promoted in recent years, namely Sustainable Drainage Systems, which seek to slow the movement of rainwater from urban areas to rivers or allows it to infiltrate into the natural landscape.

Sustainable drainage systems may improve the longevity of existing infrastructure by reducing the amount of rainwater entering pipes, leaving the capacity free for foul water.

Sustainable drainage systems may improve the longevity of existing infrastructure by reducing the amount of rainwater entering pipes, leaving the capacity free for foul water. New developments – and many existing towns – include separate rainwater management systems, where two pipe networks are used to drain foul water and rainwater. The capacity of storm sewers is also limited and contributes to sewer flooding. It is not clear if it would be cost-effective to modify existing sewer systems to remove the rainwater.

Ofwat commissioned this study to provide an evidence base on the change in sewer flooding that may result from climate change, increasing drained area (creep), and new population and housing (growth). It looks at long term trends in some of the parameters that most affect the performance of foul and combined sewer networks.

[3] Ofwat summary of water company sewer flooding at risk registers, 2010.

The specific purpose of this phase of the study is to:

Estimate projected changes in rainfall, population and paved/roof areas for a selection of towns and cities throughout England and Wales up to 2040

Quantify the effect of these changes on volume of sewer flooding and the number of flood locations in the selected towns, by using computer models of the sewer systems.

This work makes use of mathematical models of sewer networks, which the companies have built to help them to understand network performance and to plan future investment.

Future phases of the study may consider the likely costs of addressing the changes, using 'standard' and 'sustainable' solutions.

1.2 Background

Every millimetre of rainfall deposits a litre of water on each square metre of land. A day of even modest rain can deposit several million litres of water on a town.

Every millimetre of rainfall deposits a litre of water on each square metre of land. A day of even modest rain can deposit several million litres of water on a town. Rainwater landing on rural areas such as fields and forests soaks into the ground or slowly makes its way overland to join rivers. Rainwater landing on urban areas cannot soak into the ground and has traditionally been managed by providing roof gutters and highway gullies that rapidly drain the rainwater to sewer networks.

In some locations a separate surface water sewer discharges rainwater to a nearby drainage ditch, stream, river or the sea. Otherwise the rainwater enters the sewer carrying domestic and trade wastewater. It will then go to sewage treatment works where pollutants are removed and the treated wastewater is discharged to rivers.

In rural areas, rainwater is more likely to drain informally from the sides of roads, and from roofs and paved areas to ditches, streams, or soakaways. But even in rural areas, property owners might connect roofs and paved area drainage to the sewer network, if it appears to provide an easy option for drainage.

Every sewer has a finite capacity to carry flow.

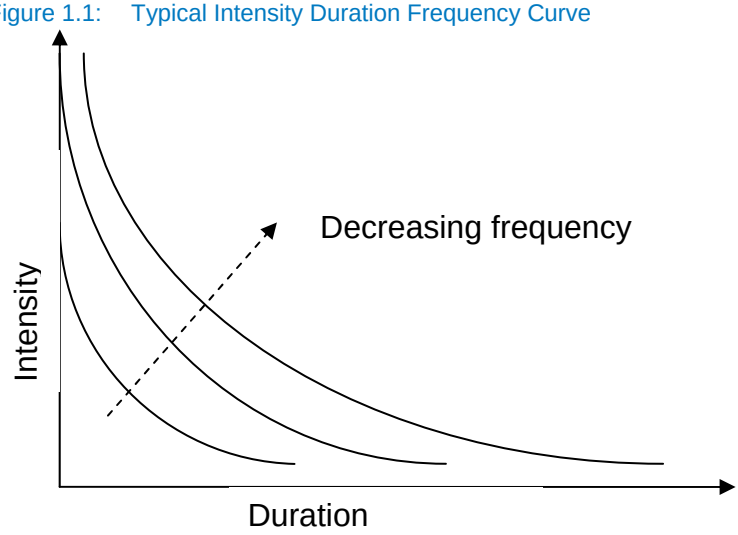
The quantity of water (flow) that can be carried by a gravity sewer is determined by its size, the slope of the pipe and to some extent its depth below ground. Every sewer has a finite capacity to carry flow. When too much flow tries to pass through the pipe the upstream water level in the pipe will increase. If the flow cannot be accommodated in the full pipe it will escape, through gullies or manholes causing flooding,

or through overflow relief points directly to rivers. Overflows can cause pollution where sewage is also present.

Whilst the hydraulic capacity of the pipes is limited, the volume of rain that can fall on any paved or roof surface is effectively unlimited.

Whilst the hydraulic capacity of the pipes is limited, the volume of rain that can fall on any paved or roof surface is effectively unlimited. There is however a relationship between the volume and intensity of rainfall and the frequency of rainfall events. Generally speaking high intensities occur for relatively short durations, whilst low intensities can occur for much longer durations. In addition, the longer the duration at a high intensity, the less frequently this occurs. This is illustrated in Figure 1.1 below.

Figure 1.1: Typical Intensity Duration Frequency Curve



Source: Mott MacDonald

The capacity of the pipe is therefore chosen to carry the flow generated from a certain frequency (or 'return period') of rainfall event. Typically the frequency chosen is between once in twenty and once in fifty years, whilst the duration of rainfall is varied to cause the greatest flow at that point in the sewer network.

The ability of different sewers to cope with severe rainfall is not the same, even within one town.

The frequency of the event chosen for the pipe design can be considered a balance between the construction cost of the sewer network with the cost and frequency of flooding damage when a more severe event occurs. But the design process has been inconsistent over the last 100 years, with variation between towns and over time. Therefore the ability of different sewers to cope with severe rainfall is not the same, even within one town.

The nature of sewer design and construction means that sewers are not easily adapted to the gradual changes and developments of towns.

The nature of sewer design and construction means that sewers are not easily adapted to the gradual changes and developments of towns during their working life, which can be over 100 years.

This study looks at three gradual changes that can affect sewer flooding:
Climate change;
Population or housing growth and;
Urban or drained area creep.

Of these, only population growth can be considered to have been investigated as a matter of course in previous regulatory periods, although more through proposed developments than long term trends.

Both climate change and property creep have been identified as issues in the past ten years.

Both climate change and property creep have been identified as issues in the past twenty years. However it is only relatively recently that sufficient research has been carried out to enable even an approximate prediction of long term change for these, although some companies have included urban creep in their designs since privatisation.

In 2009-10, 2,331 internal flooding events were reported as being caused by overloaded sewers, of which 741 (32%) were attributed to severe weather. Of the 6,300 external flooding events in the same year, 718 (11%) were attributed to severe weather. 'Severe weather' is a storm with a statistical return period longer then once in 20 years.

1.3 Climate Change

Climate change is expected to bring drier summers, wetter winters and longer high-intensity frontal rain, together with more intense convective storms.

Climate change is expected to bring drier summers, wetter winters and longer high-intensity frontal rain, together with more intense convective storms[4]. These effects could be important when investigating the frequency and extent of sewer flooding. Even foul sewer systems – not designed to convey large amounts of rainfall – have a proportion of stormwater flow associated with them as a result of incorrect connection of gullies or roof gutters.

Defra has funded the UK Climate Impacts Programme (UKCIP) which was set up to help organisations to adapt to climate change. In turn, UKCIP helped to develop a climate change model in association with

4 Flood and Coastal Defence Appraisal Guidance, FCDPAG3 Economic Appraisal, Supplementary Note to Operating Authorities - Climate Change Impacts, October 2006 and PPS25 "Development and Flood Risk"

the Met Office called UK Climate Projections (UKCP09)[5]. The UK Climate Projections are intended to be used to inform climate change adaptation plans. The projections show a range of possible outcomes for climate change and the probability of each outcome, based on how much evidence there is for different levels of future climate change.

1.4 Population and Property Growth

Population growth directly affects the quantity of domestic flow that enters sewers through washbasins, baths, showers and toilets. It affects sewer networks either through new developments, re-development of existing sites or increased numbers of people living in existing properties.

Population growth directly affects the quantity of domestic flow that enters sewers through washbasins, baths, showers and toilets. It affects sewer networks either through new developments, re-development of existing sites or increased numbers of people living in existing properties. Companies currently spend approximately £55 million per annum on capital schemes to accommodate new development[6].

In areas with combined sewers, an increase in the population served will reduce the space in the sewer for storm flow, before flooding occurs. The change that can be accommodated may be small depending on the design of the sewer and the changes that have taken place since its installation.

In sewers that are designed to only carry foul flows there is less scope for accommodating additional flow. New developments have the potential to increase flows significantly, compared with the existing or design flow.

In addition to domestic flows, new developments and re-developments result in additional paved and roof areas which must also be managed.

In addition to domestic flows, new developments and re-developments result in additional paved and roof areas which must also be managed. Where possible this is generally kept separate from domestic sewage and is taken directly to watercourses or allowed to soak into the ground.

The Office for National Statistics (ONS) analyses information from the National Census carried out every ten years, plus immigration/emigration statistics to forecast the future population of the country. This information is already used by the companies to estimate long term changes in drinking water demand.

[5] Source: http://ukclimateprojections.defra.gov.uk/

6 June Returns

1.5 Drained Area Creep

The urban landscape is constantly changing. These changes can affect the capacity of the sewer network, such as the extension of properties, the building of conservatories and the paving of driveways.

Drained area, or urban, creep is defined as the loss of permeable surfaces within urban areas. The urban landscape is constantly changing. These changes can affect the capacity of the sewer network, such as the extension of properties, the building of conservatories and the paving of driveways.

If these additional areas drain to the sewer network through gullies and roof gutters, the extra volume of rainwater can overload the network. This is especially important if drains are connected to a foul sewer which was not designed for rainwater flow.

'Urban creep' can occur also in relatively rural areas once properties are connected to a main sewer system, as the sewer appears to provide an easy solution to property drainage where problems occur due to poor performance of other forms of drainage.

An UKWIR report reference 10/WM/07/14 called "Impact of Urban Creep on Sewerage Systems" was recently published that describes techniques for estimating and projecting this change based on historical rates of change. This is considered in more detail in section 2.6.

1.6 Acknowledgements

This study depended on sewer network models built by the companies. The models were run for this project at the expense of the water companies.

The authors acknowledge and are grateful for the cooperation of, and assistance provided by, the ten water and sewerage companies of England and Wales. Their support enabled this work to be completed in a short timescale during a busy period in the investment cycle.

Approach

1.7 Method

Mathematical sewer models mimic the flow in sewers and allow engineers to assess their performance.

Mathematical sewer models mimic the flow in sewers and allow engineers to assess the performance of sewer networks, overflows and pumping stations during severe events. As modelling software has evolved over the past 25 years it has been possible to include a greater level of detail with each revision. Models can now be constructed of a town's entire public sewer network, leading to more accurate prediction of flooding locations.

The accuracy of models can never be absolutely guaranteed. A thorough process of verification is applied, involving field measurement of rainfall and of flows in strategically chosen sewers. The measured rainfall is input to the model and the flows predicted by the model are compared with the measured flows. Adjustments are made to the model only where justifiable and are independently confirmed, for instance, through further surveys. Severe events are modelled and predicted flood locations are compared with known flooding problems to confirm the model is performing adequately.

Even after calibration and verification, the model remains an approximation of the network and its predictions are not a perfect replication of actual performance.

Even after calibration and verification, the model remains an approximation of the network and its predictions are not a perfect replication of actual performance. During severe events the network may perform differently compared to the relatively small rainfall events used to verify the model. This occurs for a variety of reasons such as flood water from one part of the network flowing down a hill and re-entering the network at a different location, which would not occur during the smaller events and would therefore not necessarily be predicted by the model. In addition, individual house connections to sewers are rarely modelled unless a specific problem has already been identified. To include all house connections is considered an excessive level of detail given that little information is currently available for house connections and relatively few properties flood within a catchment. It is however a very useful planning tool which gives a good indication of the changes in performance that may be expected if conditions change.

In conjunction with the predictions of climate change, population growth and urban creep it is therefore possible to assess the likely long term impact on performance the sewer network.

There are many other variables in a sewer network model which will vary with time. In most cases these are assumed to remain constant for the purposes of this study. The most significant of these variables and the reason for maintaining the values currently modelled are explained below.

Sewage pumps (which are occasionally required e.g. to get flow over a hill) gradually deteriorate over time, resulting in pump flow rates also gradually reducing. Over time, however the pumps will be replaced in the course of normal maintenance and as a result the performance of the pumps should not be significantly affected.

The sewer network deteriorates over time.

The sewer network also deteriorates over time. Cracks in pipes and opening of joints occur due to a small amount of movement of the surrounding soil, allowing water to seep in from the surrounding damp soil when the pipe is empty (as is often the case when there is no rain, or at night). This is called infiltration and can be a significant proportion of the flow in a pipe. If not repaired eventually the deterioration of the pipe condition will cause the pipe to collapse, at which point the pipe will be replaced, also reducing the infiltration in the process.

High infiltration rates relative to domestic flow can show where the network is in poor condition.

Infiltration flow rates from individual pipe lengths are generally low, but the cumulative effect can be significant for larger systems. It does however make it disproportionately expensive to eliminate infiltration as this requires some form of sewer repair. As the worst condition pipes are most likely to have the highest infiltration rate it is therefore effectively capped by repairing pipes in poor condition. Logically, high infiltration rates relative to domestic flow show where the network is likely to be in poor condition.

Typical infiltration rates are about 40% of domestic flow. Some catchments can benefit from a reduction in infiltration; however this will require an increase in expenditure generally by the water companies on sewer repair. Companies need to consider if the benefits of reducing infiltration outweigh the costs. For this study we have assumed that infiltration rates remain at the current rate.

Silt can build up in pipes due to the suspended solids in sewage, which can settle out if the flow is slow-moving, which then reduces the flow that can be carried.

Silt can build up in pipes due to the suspended solids in sewage, which can settle out if the flow is slow-moving, which then reduces the flow that can be carried by the pipe. This is normally included in models of the system to accurately reflect the current performance of the network. Silt was excluded from the models for the purposes of this study, to ensure that the maximum performance of current assets could be assessed.

The companies use two computer programmes – InfoWorks and HydroWorks – to model their sewer networks. Both are produced by Innovyze (formerly Wallingford Software).

1.8 Catchment Selection

Each of the ten companies was asked to provide a list of 15 sewer network models which it considered to be of suitable quality and relevance to this project.

From the 150 models offered, we selected 100 for inclusion in the study. Selection was conducted by ranking the 100 models by population served, then discarding every third catchment from the list. In the case of one company this resulted in models all built by the same supplier, and so a substitution was selected at random from the five discards for that company.

Sewer models tend to be most up-to-date for the catchments experiencing problems, or where significant change needs to be assessed.

Sewer models are expensive to build and so tend to be most up-to-date for those catchments experiencing problems, or where significant change needs to be assessed. It was not therefore practicable to conduct a fully randomised study as that would have included older models, built to a lesser level of detail than more recent models. As well as being much less accurate the data would have had to be updated at considerable time and cost.

It is not possible to therefore consider the sample to be entirely representative of England and Wales. It is more likely to represent 'stressed' catchments than those with spare capacity, because if a catchment has no problems, it is less likely to have been modelled recently to the highest standard. In some catchments the models do not include surface water sewers, which may cause sewer flooding and are equally susceptible to urban creep and climate change.

The models selected for this study covered 16% of the population of England and Wales.

However our sample of 100 catchments from across England and Wales covers a range of towns and rural areas with the population served ranging from about 300 to over a million. Overall the models covered the networks serving some 16% of the population of England and Wales.

A list of catchment models used is included in Appendix A.

1.9 Defining the Modelling Scenarios

A workshop with the companies was held on 09 December 2010 to agree the number of scenarios and projections that could be accommodated within the scope and timescale of the project. The scenarios shown in Table 2.1 were discussed. The table shows that in addition to the current model being run for the 'central estimate' of climate projection, five additional scenarios could be run, for three

climate change projections the 10th, 50th and 90th percentile projections. This is reflective of the climate change model, which was run 20,000 times and produced 20,000 results. This is because there are random variations generated in various parameters. The 10%ile projection means 10% of the model outcomes are less than or equal to this value (in this case the worst seasonal day of rainfall). Similarly the 50%ile means half of the model outcomes are less than this value and so on.

Table 2.1: Initial Proposed Scenarios

Scenario	10%ile Projection	50%ile Projection	90%ile Projection
Current Model		Current rainfall	
Scenario 1 - Population (modified water resources plan figures)	✓	✓	✓
Scenario 2 - Property Creep - UKWIR report published	✓	✓	✓
Scenario 3 - Rainfall – UKCP09	✓	✓	✓
Scenario 4 - Tidal - UKCP09	✓	✓	✓
Scenario 5 – All four variables above applied	✓	✓	✓

The approach to modelling climate change was discussed in terms of its influence on rainfall and on tidal height seen in storm surges.

The approach to modelling climate change was discussed in terms of its influence on rainfall and on tidal height seen in storm surges.

The companies considered that tidal influence was not sufficiently significant to merit investigation as a separate scenario. This is because relatively few discharges would be constrained by tide height. It was agreed that where tidal influence was considered significant it would be included in conjunction with the changes in rainfall depth.

Some companies felt unable to model the effects of the 10%ile and 90%ile climate projections in the timescale. Therefore it was agreed that these runs would only be carried out where time was available. The 50%ile projection was to be given priority so that it was covered by all companies.

Information on low and high projections for urban creep and population were not readily available therefore these were also given a low priority in carrying out this phase of the study.

The workshop agreed to include summer and winter climate change impacts in the modelling scenarios as shown in Table 2.2.

Table 2.2: Final Proposed Scenarios

Scenario	10%ile Projection	50%ile Projection	90%ile Projection
Current Model		✓	
Scenario 1 – Population		✓	
Scenario 2 – Creep		✓	
Scenario 3 – Climate change	Where possible	✓	Where possible
Scenario 4 – All three variables above applied	Where possible	✓	Where possible

A note of the workshop was produced, detailing the agreed approach. It is included in Appendix C.

1.10 Climate Change

The United Kingdom Climate Impacts Programme (UKCIP) provides a range of tools, methods and guidance to help organisations identify how they might be affected by climate change and what they can do to minimise their risks or exploit the opportunities. UKCIP is principally funded by the Department for Environment, Food and Rural Affairs (Defra), and hosted at the Environmental Change Institute (ECI), Oxford University.

UKCIP gives climate projections for the UK up to the end of this century, based on simulations from climate models.

UKCIP gives climate projections for the UK up to the end of this century. Its projections are based on simulations from climate models. The workshop agreed that the UKCP09 outputs would be the most appropriate climate change data to apply to the catchment sewer models.

Because of the short timescale of this study, the workshop agreed that only the medium emissions scenario for 2040 would be investigated, with three levels of certainty within that scenario, namely the 10th, 50th and 90th percentiles. As shown in Table 2.2 the 10th and 90th percentile projections were to be carried out where time allowed.

A procedure was developed for collecting the data on the relevant rainfall change from the UKCP09 website, appropriate for this high level analysis. The percentage change (uplift) for the area being modelled

was then applied to the Multiplying Factor field in the relevant model rainfall file.

An adjustment was required for summer storms, because the UCKP09 data does not reflect likely changes in convective summer storms.

An adjustment was required for summer storms, because the UCKP09 data does not reflect likely changes in convective summer storms accurately. This is noted on the UKCP09 website[7]:

> *"There are limitations to the rainfall extremes that can be simulated by the UKCP09 Weather Generator, particularly in the case of hourly rainfall extremes. The UKCP09 Weather Generator underestimates summer hourly rainfall because of a simplified equation used to derive hourly rainfall.*
>
> *Daily information is used to drive the weather generator. In order for the weather generator to generate hourly information it uses a fixed relationship between daily and hourly rainfall statistics. This relationship comes from the observed climate statistics. Using this relationship in the future projections is limiting because it does not allow for a simulation in the increase of convective rainfall events. Convective rainfall is driven by thermal heating, causing evaporation; therefore, one would expect hotter summers to lead to more convective rainfall. However, in the weather generator, hourly rainfall is obtained from the daily values so it is difficult to project changes in the hourly intensity of rainfall.*
>
> *The projections for summer show overall decreases in daily rainfall therefore these will be associated with decreases in summer hourly rainfall. This simplification is clearly not consistent with the possibility of an increase in infrequent, but intense convective events. Therefore, in locations such as south east England where summer convection dominates the extreme rainfall, a low confidence should be placed in estimates of future hourly extremes.*
>
> *Although the UKCP09 weather generator provides insight into future projections, caution should be taken particularly when examining future extremes. This is because the UKCP09 Weather Generator uses a record of climate observations (35 years; 1961-1995) as the baseline climatology to "train" the weather generator. Therefore, it is unreasonable to assume that extreme events, outside of the range of those previously*

[7] Source: http://ukclimateprojections.defra.gov.uk/content/view/1207/620/

observed, can be accurately simulated in future time series, regardless of how many years of output are simulated."

In response to the limitations above, the workshop agreed to model the effects of an increase in the intensity of summer storms. Where the summer uplift was predicted to be less than 10% a minimum value of 10% above current values would be used. In the absence of clear guidance from the UKCP09 output, the workshop agreed that the baseline of 10% would be used a consistent baseline. The actual change in summer storms is likely to be some other value and may vary between the regions. The 10% figure is in line with figures quoted in previous Defra guidance[8], and is also used in the PPS25 document "Development and Flood Risk"[9].

The workshop agreed that the winter rainfall intensity would not be changed from those provided by the UKCP09 weather generator, even where negative.

The choice of summer uplift is only significant where it has a greater effect on predicted flooding than the winter rainfall scenario.

It is important to remember that the climate change projections are not confident forecasts of future weather events. So, it cannot be said that the modelled rainfall events will certainly occur in 2040 given the range of predicted outcomes from the climate model. The projections do however provide the best available data for future scenarios, with which to model the sewer network's response.

1.11 Population and Property Growth

Information on population growth is provided by the Office for National Statistics (ONS), which is the executive office of the UK Statistics Authority, a non-ministerial department which reports directly to Parliament.

[8] Department of the environment, food and rural affairs 2006: Flood and Coastal Defence Appraisal Guidance, FCDPAG3 Economic Appraisal, Supplementary Note to Operating Authorities - Climate Change Impacts.

[9] Department for communities and local government: 2010: Planning Policy Statement 25, development and flood risk.

Population forecasts are prepared regionally, but growth is not uniform across the whole of a regional area.

Population forecasts are prepared regionally, but growth is not uniform across the whole of a regional area. Some towns will have more growth, others less. Growth occurs mostly through new developments as approved at a local level; therefore the regional figures must be reconciled with the proposed development at a local level.

For example, a housing development might be built on one side of a town, with little or no development elsewhere. Some towns might even expect a reduction in population.

Towns often compete to attract new developments and the sum of expected development may exceed the demand forecast for the region.

Within the local areas where population is expected to grow, the rate and extent is hard to predict. Towns often compete to attract new developments and the sum of expected development may exceed the demand forecast for the region. The timing of new development is also hard to predict as it is linked to other economic activity. Consequently, the population change period is shorter-term than other factors in the study.

The companies were asked to use the best population forecast data available for each model. They decided how to place the development within each modelled catchment, and the extent that it was spread around the catchment. A range of measures to manage surface water for the new developments was assumed for each development, based on simple parameters such as the type of existing network (e.g. separate or combined), the distance to nearby watercourses (which would allow a separate direct discharge) and other such assumptions as noted in the methodology in Appendix C.

At worst, only the equivalent of green field surface runoff flow rates (5 litres per second per hectare of development) was allowed to discharge from a planned development to the foul/combined sewers in addition to the calculated domestic flows.

Local plans prepared by the local councils were used to extract details of developments local to the catchments being modelled.

Local plans prepared by the local councils were used to extract details of developments local to the catchments being modelled. Local guidance was used in allowing for the new development flows (e.g. properties per hectare, persons per property, water usage per person).

It is important to note that the location of developments is a modelling assumption and not necessarily where development will eventually take place. The intention is to understand the response of the sewer network to defined events. It would therefore be wrong to take detailed model outputs and rely on the results for individual properties.

1.12 Drained Area Creep

An UKWIR report reference 10/WM/07/14 called "Impact of Urban Creep on Sewerage Systems" was recently published. This was the first large scale study in the UK and high resolution aerial imagery from two periods for five sample locations (Leicester, Maidstone, Chester, Norwich and Newcastle-Upon-Tyne) was used with each sample area covering 100km^2. Advanced processing technology was used to identify changes in paved and roof areas. This technique was particularly successful in identifying changes in rear gardens which in previous studies was not accessible.

The UKWIR study analysed over 34,900 samples, equating to about 2 million properties. It was found that the average rates of urban creep were between 0.4 and 1.1m^2/house/year depending on the city. A sophisticated statistical analysis of multiple variables was undertaken and the results enable modellers to predict the urban creep and increases in flooding.

The UKWIR study analysed over 34,900 samples, equating to about 2 million properties. It was found that the average rates of urban creep were between 0.4 and 1.1m2/house/year depending on the city.

Before the UKWIR study little consideration had been given to urban creep, because of the difficulty in quantifying how much could occur. Some companies simply allowed a set 5% increase in impermeable area, others did not allow for any change.

Before the UKWIR study little consideration had been given to urban creep, because of the difficulty in quantifying how much could occur.

A method was proposed for calculating creep based on one approach used in the UKWIR report, using a smoothed logarithmic curve to relate current property density to annual creep per property per year in a similar manner to that shown in the UKWIR report. The property density was calculated from the sum of 'address points' within the subcatchment divided by the overall area of the subcatchment.

Whilst this method of calculating the area of creep could be easily used to calculate the overall increase in paved/roof area, there were a number of assumptions made as to how the additional area would be drained:

Where combined sewers were present, most of the companies assumed that all additional area would drain to this sewer.

In areas where both foul and surface water sewers are present, the additional area should in theory connect to the surface system, however in practice when building work is carried out the additional area is not always connected to the correct sewer for a variety of reasons. Assumptions were then applied, from 5% of the new area to 50% connected to the foul sewer. The range reflects differences between the water company experience or judgement and the sewer system characteristics around the country.

Whilst a cap of 5% total creep over the next 25 year period was recommended, this was not rigidly adhered to by water companies. Rural catchments tended to be prone to high predictions of creep due to the relatively low density of housing.

1.13 Running the Models

Models generally consist of several sub-files within a database, some of which describe the physical attributes of the catchment e.g. the sewer network; others describe the external influences on the physical attribute such as the rain that falls on the catchment or a tidal influence on an outfall.

Models generally consist of several sub-files within a database, some of which describe the physical attributes of the catchment e.g. the sewer network; others describe the external influences on the physical attribute such as the rain that falls on the catchment or a tidal influence on an outfall. These are then combined to generate a time varying simulation of the resultant flow through the sewer network. The simulation result is held within the database and can be used to show where flooding occurs or to draw a graph of flow or water velocity/depth in a pipe.

Initially the base models were run to check the critical duration of storm relative to the maximum total flood volume and the maximum number of flooding manholes. Often these do not coincide therefore up to three different storm durations were chosen as the appropriate durations to run for the four scenarios. This ensured that the ‘realistic worst case’ was simulated for each catchment, since that is of interest to this study.

The modelling data files for rainfall, population and impermeable area were then adjusted to include the climate change, population, and urban creep, and the models re-run to create the various scenarios.

The majority of the companies sub-contracted the modelling work to between one and five engineering consultants. Mott MacDonald was appointed by some of the companies to run some of their models for this study.

1.14 Results

1.14.1 Scenarios Modelled

Scenarios

A range of scenarios looking towards a 2040 horizon was considered under each influencing factor in producing the models:

Growth - one population growth scenario based on Local Plans and Office of National Statistics figures

Urban Creep – one urban creep scenario based on UKWIR report

Climate Change – medium emissions scenario was adopted.
Scenarios were run for 10th, 50th and 90th percentile storms.

Summer and winter scenarios were run for each of the three factors and for climate change, these were run for each of the three percentiles. The percentage change in rainfall/population/property creep was plotted against the change in flood volume or number of flooded manholes for each scenario.

The number of model runs for each scenario is listed in Table 2.3.

Table 2.3: Number of Model Runs

Scenario	10%ile Projection	50%ile Projection	90%ile Projection
Current Model		512	
Scenario 1 – Population growth		504	
Scenario 2 – Property creep		512	
Scenario 3 – Climate change	328	512	328
Scenario 4 – All three variables above applied	328	510	328

Current Model - 4 results queried/questionable, 18 nr of flooded nodes missing

Scenario 1 - 21 nr of flooded nodes missing

Scenario 2 - 18 nr of flooded nodes missing

Scenario 3 - 1 result queried/questionable, 54 nr of flooded nodes missing

Scenario 4 - 15 results queried/questionable, 54 nr of flooded nodes missing

Some inconsistencies and gaps were found in the data provided by the companies. These are relatively minor as noted above.

Population Covered

The models run covered a total population of 8.87 million, effectively covering 16.2% of the current population of England and Wales.

The models run covered a total population of 8.87 million, effectively covering 16.2% of the current population of England and Wales (54.8 million[10]). Catchments ranged in population size from approximately 150 to 2,500,000.

The development assumptions in this study increased the modelled population to 10.31 million, an increase of 16.2% by 2040. This compares well to the projected 17.4% increase in population for England and Wales calculated in 2008[11] (54.5 million to 64.0 million).

10 Source: ONS Population Estimates, June 2010, Table 2

11 Source: ONS Statistical Bulletin: 2008-based National population projections, Table 1

Modelling of Flooding

The hydraulic models are able to simulate flooding as both
water ponding above ground which then returns to the sewer after the storm, and
water lost from the system (e.g. spilling downhill to enter a river).

There are also direct, controlled discharges to rivers from overflows in the system. These were not considered as part of this study following the workshop due to time constraints in extracting the relevant information from the models, although it is anticipated that there will be increases in spills from these for each scenario. This could be extracted from the model runs and quantified at a later date.

The maximum flood volume is calculated for each node during the storm for both types. In the second case this is simply the total spilled from the manhole.

A table summarising the maximum flood volumes for each manhole was extracted for each model run. The total flood volume and total number of flooded nodes for each model run was then calculated.

For each scenario the results were compared with the equivalent run for the current model scenario and a percentage change calculated. The maximum change for winter and summer storms was calculated for each scenario.

Analysis of Model Results

The results show that the number of predicted flood locations increases, broadly in line with the predicted increase in flood volumes.

The results show that the number of predicted flood locations increases, broadly in line with the predicted increase in flood volumes. In addition to new flood locations, existing flood volumes increase in almost all locations.

The increase in flood volumes is likely to lead to an increase in the frequency of flooding that already occurs. This is because the volume that currently causes 1 in 10 year flooding is exceeded in the future scenarios. The current flood volume is therefore reached more quickly in the future, and so will occur under lesser storm conditions.

An analysis of the change in return-period was outside the scope of this study, which focussed on 1 in 10 year events. It could be included in future studies by varying the return period of the simulated storm event for the various scenarios, and noting the point at which known flooding is predicted to occur under each scenario. This form of analysis is

typically carried out when companies develop solutions to flooding problems, to check that schemes will provide a suitable reduction in flood risk.

Hydraulic models require careful checking to ensure the calculations and simulations are within normal parameters. Our initial review of the results files identified some erroneous results, for example where model simulations may not have completed correctly. Where possible within the timescale of the project, the companies adjusted and re-ran the models for inclusion in the review. Where our queries have not been resolved, the results have been omitted from the analysis. If time and budgets allow, the queried and missing data should be corrected (where appropriate) and included in any subsequent phase of the study.

The results are presented as graphs for individual scenarios across all catchments comparing % increase in rainfall/population/impermeable area versus % increase in flood volume/number of flooded nodes. These are included in Appendix B.

Figure 2.1: Results For Current Summer Rainfall With Growth Scenario.

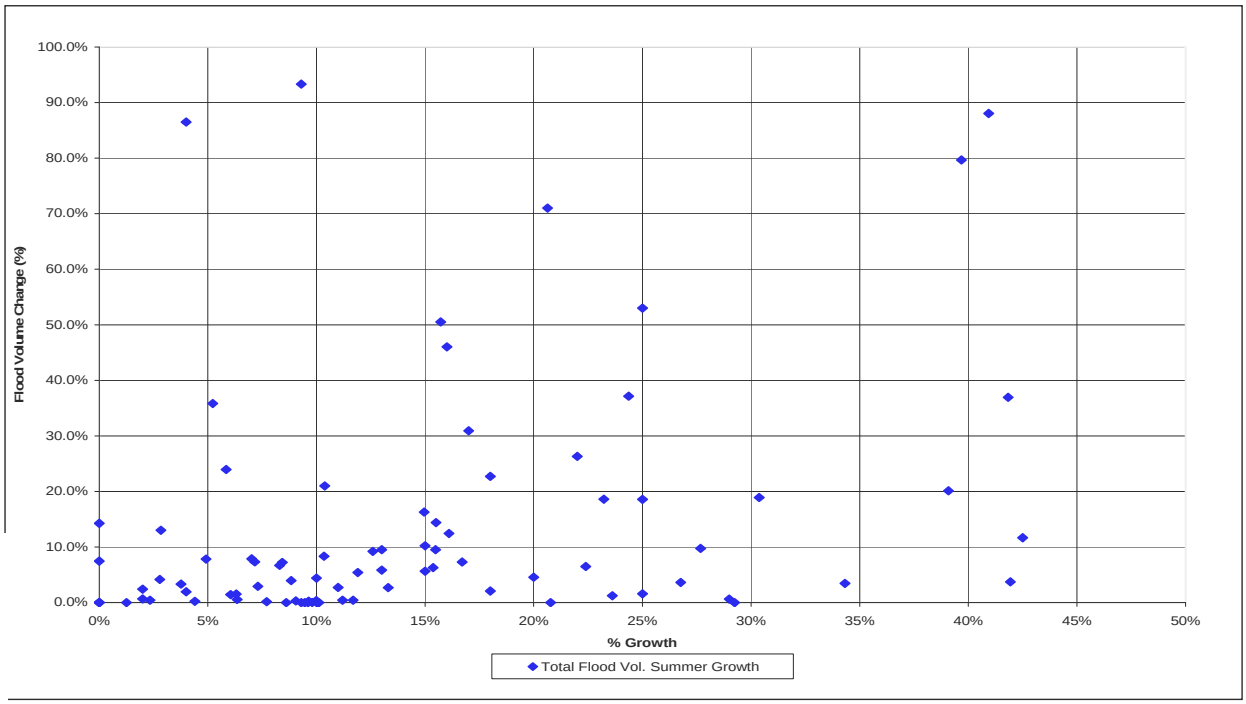


Figure 2.1 shows the spread of results from the scenario that modelled only population and property growth. The percentage increase in flood volume compared to the current model is plotted against the percentage increase in population. No increase was applied to the rainfall.

Figure 2.2: Results For Current Winter Rainfall With Urban Creep Scenario.

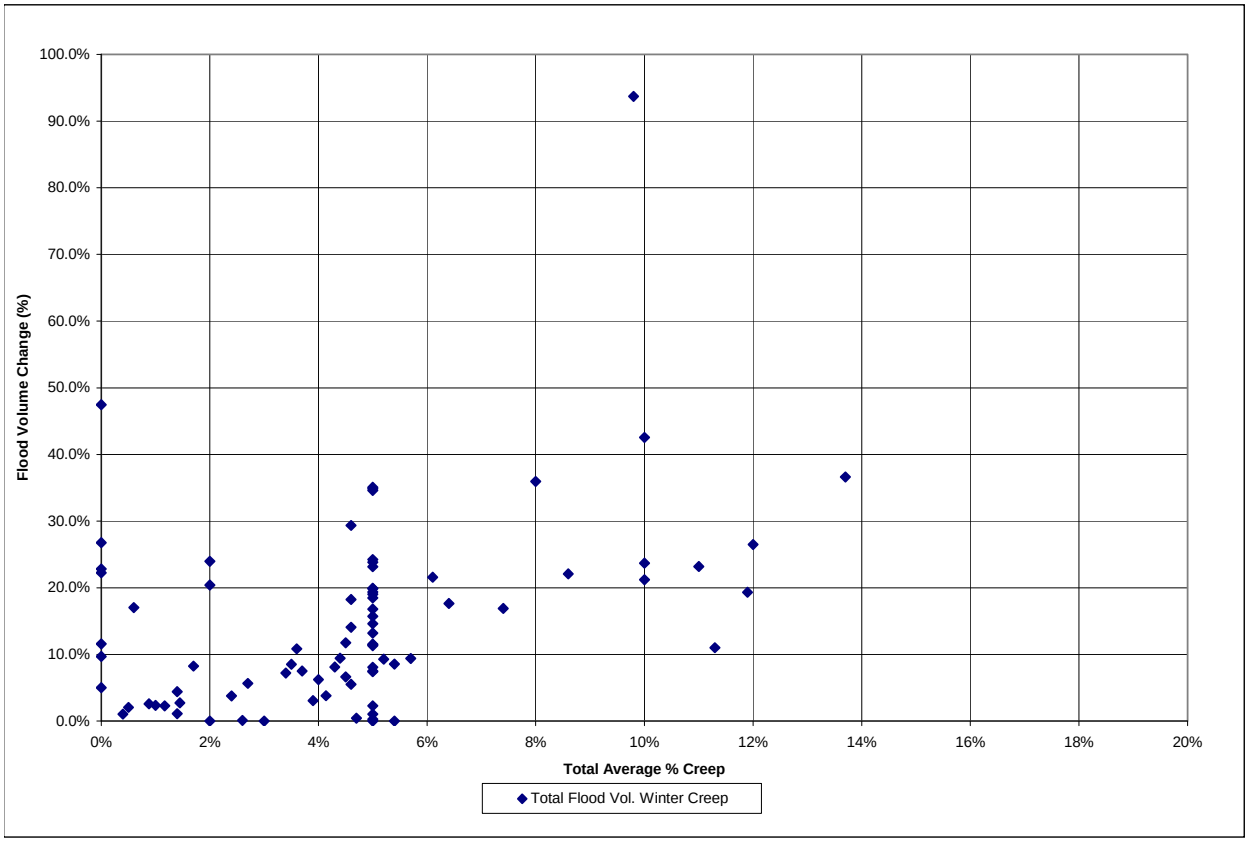


Figure 2.2 shows results for the urban creep scenario. This plots the percentage change in flood volume against the percentage increase in modelled impermeable area. Where companies felt that urban creep was likely to significantly exceed 5% they included in their models,

rather than using the deafult 5% for urban creep. No increase was applied to the rainfall.

Figure 2.3: Results For 50th Percentile Climate Change Winter Rainfall Scenario.

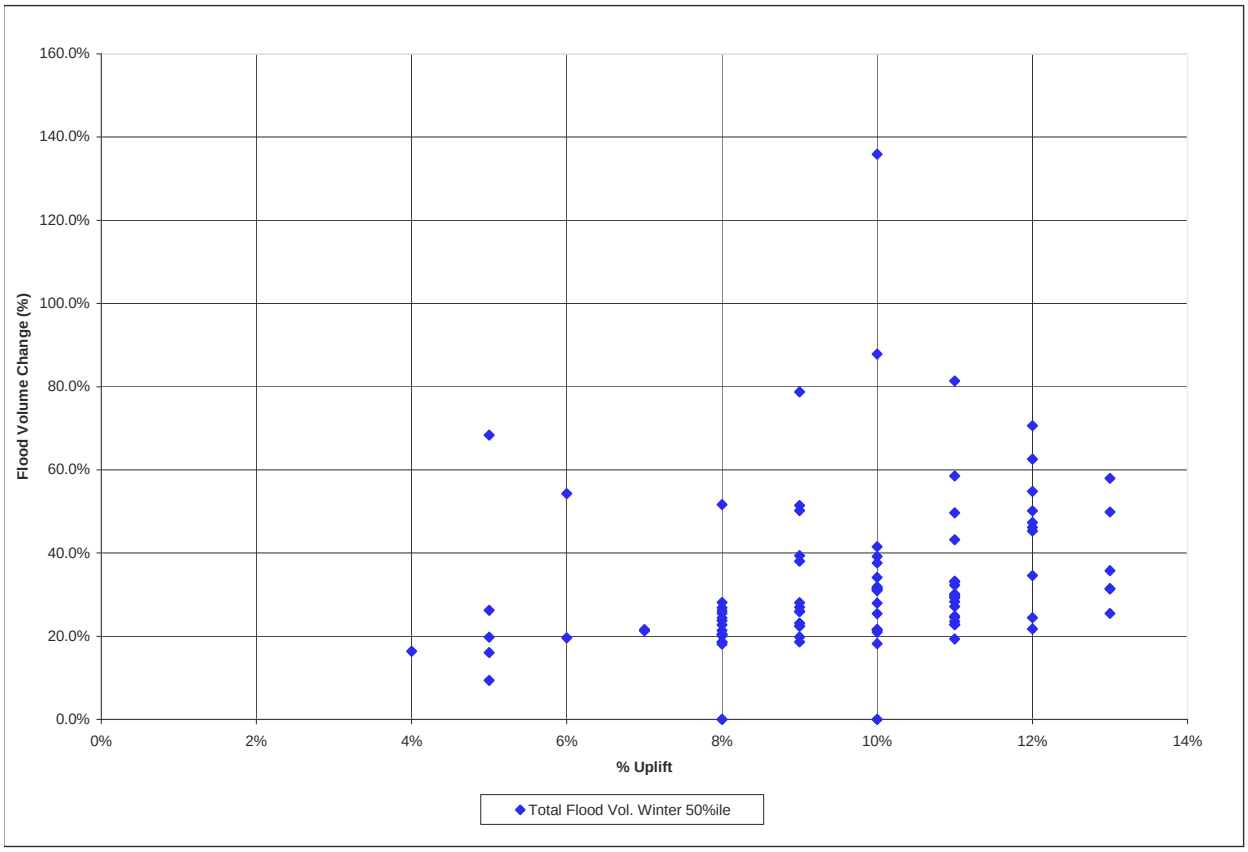


Figure 2.3 shows the effect of winter rainfall under the climate change scenario at the 50th percentile probability. The results show a wide range of responses which reflect the current capacity of the network, and hence its ability to accept additional rainwater.

More results graphs are given in Appendix B.

For some catchments a reduction in winter rainfall means that there is a reduction in flood volume for the 10th percentile scenario.

The 10th, 50th, and 90th percentile rainfall scenarios were also compared for the winter storms, showing a wide variation in the impact. For some catchments a reduction in winter rainfall means that there is a reduction in flood volume for the 10th percentile scenario. The majority of the summer 10th and 50th percentile scenarios resulted in the default 10% increase in rainfall. This is because the UKCP09 weather generator forecast less than 10% increase in rainfall and so 10% was used, to allow for increases in convective rain which outside the scope of the weather generator. There was therefore little variation across the three scenarios and we did not analyse the results further.

Catchments were ranked according to the flood volume increase resulting from the growth, creep, the 50th percentile climate change scenario, and the combined (all changed) scenarios. This is summarised in Table 2.4.

Table 2.4: Summary of Rank By Flood Volume Increase

Number of Catchments	Rank			
	1	2	3	4
41	All	50%ile	Creep	Growth
17	All	50%ile	Growth	Creep
9	All	Creep	50%ile	Growth
7	All	Growth	50%ile	Creep
1	All	Creep	Growth	50%ile
5	All	Growth	Creep	50%ile
17	Awaiting answer to query			
97	Total catchments			

In virtually all cases the model runs show significant increases in predicted flood volumes and flood locations.

In virtually all cases the model runs show that significant increases in predicted flood volumes and flood locations occur. The top two lines of Table 2.4 show that in 58 catchments (i.e. 41+17), the climate change scenario at 50th percentile has the greatest effect on flooding, after the combined scenario. Climate change had the smallest predicted impact on flooding in six of the 80 catchments included in the ranking.

The results for all models (summer and winter) and the winter modelling scenarios are summarised in **Error! Not a valid bookmark self-reference.** and

Table 2.6.

Table 2.5: Summary of median results for all models (summer and winter)

Median increase in sewer flooding, %	10th Percentile	50th percentile	90th percentile
Population growth	-	5	-
Property creep	-	12	-
Climate change	0	27	71
Combined	**35**	**51**	**100**

Table 2.6: Summary of median results for the winter models

Median increase in sewer flooding, %	10th Percentile	50th percentile	90th percentile
Population growth	-	6	-
Property creep	-	14	-
Climate change	27	30	76
Combined	**51**	**51**	**113**

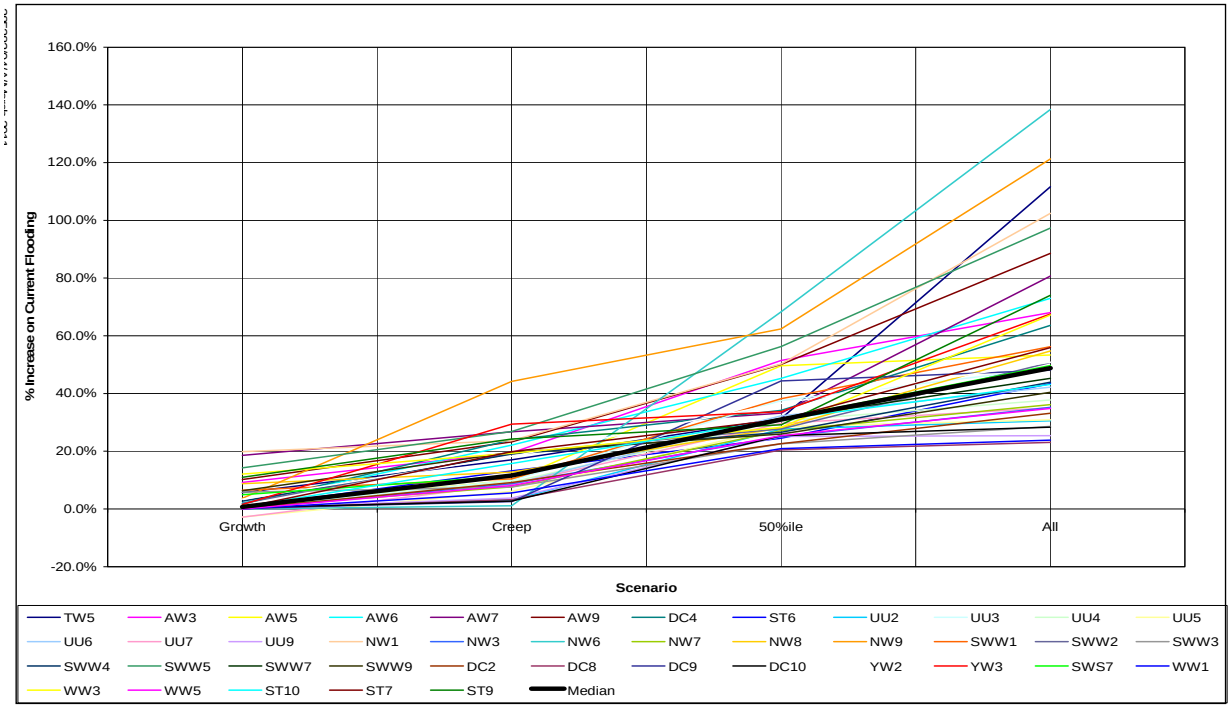
Discussion

1.15 Significant Contributing Factors

As shown in Table 2.4, the most common order of influence when comparing change in overall flood volume, with 41 catchments, is:
Climate change
Urban creep
Growth.

Figure 3.1 shows the overall average impact of the scenarios for the 41 catchments that exactly followed the above ranking (i.e. the catchments in the top line of Table 2.4). Since the impact of individual changes affects a catchment's capacity, the combined scenario can have an effect greater than the sum of the individual changes.

Figure 3.1: Comparison of Flood Volume Increases for Catchments Following Most Common Scenario Ranking



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Growth results in the lowest change in predicted flooding.

Growth results in the lowest change in predicted flooding. This may indicate that the effect is to an extent manageable by limiting rainwater connections in new developments.

Although the rate of growth is never completely predictable, growth forecasts are largely analogous to actual growth and the increase in connections is more predictable because of new housing and connection regulations and greenbelt construction restrictions. The overall median value for growth was a 4.8% increase in flood volumes, whilst the median value for the 41 catchments shown in Figure 3.1 is only 0.7%.

It is important to note that this scenario predicts an increase in flooding as a result of housing growth, even with current PPS25 standards for minimising the connection of new surface water drainage as noted in the methodology in Appendix C. The results show that in order to accommodate the growth currently forecast, either network capacity will have to be increased, or existing rainwater connections will have to be removed.

Urban creep results in a larger increase in predicted flooding than new housing, because it adds more rainwater to the network.

Urban creep results in a larger increase in predicted flooding than new housing. Urban creep is inherently unpredictable and difficult to manage because of less rigorous controls to prevent the public paving driveways and gardens. The rate of increase of drained area is difficult to forecast because it is likely to reflect economic activity in the catchment. It may be driven by property renovation or extension of existing properties. The overall median value for creep was an 11.5% increase in flood volume whilst the median value for the 41 catchments shown in Figure 3.1 is 11.6%. This is greater than the effect of housing growth because it adds rainwater flow, whereas new housing adds ‘dry weather’ flow.

The greater effect of urban creep is because it adds more rainwater to the network, placing further pressure on its capacity for storm flow; whereas new housing does not add as much storm water. However, urban creep will also follow new housing. It is clear from the scenarios modelled here that urban creep will need to be controlled in order to prevent a significant increase in flood volume.

Climate change has the largest impact. Taken across both summer and winter, the median value for the 50th percentile flooding was a 27% increase in flood volume, with little or no change for the 10th percentile case and 71% for the 90th percentile case.

Climate change has the largest impact. Taken across both summer and winter, the median value for the 50th percentile flooding was a 27% increase in flood volume, with little or no change for the 10th percentile case and 71% for the 90th percentile case. Taking the winter rainfall scenario, the median increase was 27% for 10th percentile case, 30% for the 50th percentile, and 76% for the 90th percentile. There is uncertainty within the climate change scenarios but any increase in storm flows will have a direct effect on flood volumes.

Climate change is often discussed in terms of an increase in droughts and the potential for water shortages. It is also important because it has the potential to bring heavier rain in longer storms. These add a much greater volume of rainwater through existing rainwater connections. Whilst the flood volume increases quoted above reflect the worst increase in summer or winter it is noted that in the majority of cases the winter rainfall increase was predominant.

If climate change is combined with the effects of new housing and urban creep, which firstly reduce the capacity for rainwater and then increase the number of rainwater connections, the effect is dramatic.

If climate change is combined with the effects of new housing and urban creep, which firstly reduce the capacity for rainwater and then increase the number of rainwater connections, the effect is dramatic.

To accommodate climate change, either the network capacity will have to be increased, or the overall number of rainwater connections will have to be reduced. There are many ways in which both of these could be achieved, such as storage, overflows, larger pipes, and SUDS.

The differences in uplift predictions are significant, as shown in Table 3.2: Comparison of Uplifts for 50%ile Winter Scenario by Company.

Table 3.1: Range of flood volume change under the various scenarios

Influencing Factor	Range of % Increase in Flood Volume
Growth	-9% to 192%
Urban Creep	-12% to 431%
Climate Change 10%ile	-27% to 95%
Climate Change 50%ile	-10% to 136%
Climate Change 90%ile	30% to 350%
All 10%ile	-47% to 426%
All 50%ile	-27% to 657%
All 90%ile	0% to 378%

The differences are likely to be large as no two catchments are the same. Some have spare capacity and others are already inundated.

1.16 Geographical Variations

The climate change model introduces a variation in rainfall according to geography. To illustrate the effect for one scenario, the uplifts in winter rainfall are summarised by company. This is shown in Table 3.2 below, which shows that the range of uplifts within and between regions is small, although companies in the south have a slightly higher average increase in winter rainfall for this scenario.

Overall the pressures of more houses, urban creep that increases the drained area of existing and new properties, and climate change each lead to an increase in the number of flood locations and the volume of flood water from the sewer network.

Table 3.2: Comparison of Uplifts for 50%ile Winter Scenario by Company

Company	Maximum Uplift	Minimum Uplift	Average Uplift
Northumbrian Water Ltd	11%	5%	8%
United Utilities	11%	6%	8%
Yorkshire Water Services	10%	5%	8%
Dwr Cymru	13%	4%	9%
South West Water	11%	8%	9%
Severn Trent Water	11%	7%	10%
Anglian Water Services	12%	9%	11%
Wessex Water	12%	9%	11%
Thames Water Limited	13%	9%	11%
Southern Water Services	13%	10%	12%

Changes in summer rainfall are difficult to analyse in a similar manner as a 10% minimum uplift was applied to almost all the 10%ile and 50%ile values.

1.17 Overall Implications for England and Wales

Although the results for combined sewer overflows were not analysed, sewer overflow spill frequency and volume are likely to also increase, broadly in proportion to the increase in flood volume.

The pressures of more houses, urban creep that increases the drained area of existing and new properties, and climate change each lead to an increase in the number of flood locations and the volume of flood water from the sewer network, except the 10th percentile winter rainfall, which lead to a reduction in some catchments.

None of the models showed a reduction in flooding across all rainfall scenarios – the reductions were confined to the 10th percentile rainfall event.

Although the results for combined sewer overflows were not analysed, sewer overflow spill frequency and volume are likely to also increase, broadly in proportion to the increase in flood volume.

Mott MacDonald

Since the local topography – the shape of roads, slope of the land and barriers to flood water – is not included in most sewer network models, the likely effect on 'DG5' sewer flooded properties is not quantified by this study. When companies use the models in the design of flood alleviation schemes, they are used to check that proposed investment will prevent water from flooding out of the sewer.

Newer models may consider local topography and predict overland flow pathways, but they were not used in this study. Some of the models did not include surface water sewer flooding.

Even with the absence of detailed topographic studies, it is reasonable to expect an increase in the number of flooded properties, as well as increasing frequency of flooding for those already at risk.

Even with the absence of detailed topographic studies, it is reasonable to expect an increase in the number of flooded properties, as well as increasing frequency of flooding for those already at risk.

A few catchments show a minor reduction in flood volume that is unrelated to reductions in rainfall (as calculated for most 10%ile scenarios). These are generally outliers and are relatively few. There was insufficient time to confirm the cause of all reductions in rainfall but where a reduction is predicted under the 'all change' scenario then an error is highly likely. The climate change predictions do lead to a reduction in winter rainfall in some locations but the trend is for an increase in winter rainfall on all but the 10%ile scenario, which is the least likely of the three rainfall scenarios. We excluded outliers from the graphs but where results were available; we included the results in the analysis.

If the study had been able to use a fully randomised selection of 100 models, from a population of about 3000 models, we could be 95% confident that the results were within about 10% of those that would be obtained from running all the models. The sample may be somewhat pessimistic compared with the whole sewer network, because the better models tend to be built for areas known to, or expected to, have flooding or pollution problems. The study included a wide range of catchment sizes in order to minimise the bias.

Of 57 catchments with a predicted reduction in rainfall from the climate change model, 45 still showed an increase in flooding due to population and property growth plus urban creep for the 'all change' scenario. This suggests that only a small proportion of catchments are likely to benefit from reduced rainfall, if it occurs at all.

The 10th percentile winter climate change plus population and property growth plus urban creep scenario was successfully run on 66 of the catchments, 57 of which used a predicted reduction in rainfall from the climate change model. Of these 57 catchments, 45 still showed an increase in flooding due to population and property growth plus urban creep. This suggests that only a small proportion of catchments are likely to benefit from reduced rainfall, if it occurs at all. It is therefore reasonable to assume that this study indicates the lower range as well as the upper range of changes that would have resulted from modelling all catchments.

Climate change is not something that can be controlled by the companies. This study shows that the effect could range from a slight decrease to a significant increase in flooding, but strongly biased towards an increase.

1.18 Discussion of Mitigation Measures

1.18.1 Population and Property Growth

In order to accept housing growth without a significant risk of increasing sewer flooding, a range of improvement strategies will be necessary to:

Provide additional sewerage capacity, or remove some existing rainwater connections, to cope with the increase in wastewater flow.
Prevent all connection of rainwater drains to foul or combined sewers at the time of construction of new buildings.
Prevent all subsequent creep of the drained urban area around new buildings.
Improve the condition of relevant foul and combined sewers, to reduce infiltration of water from surrounding ground in winter or after heavy rain.
Provide additional capacity, or proactively remove existing surface water connections where practicable, in order to adapt to the effects of climate change.

Modifying the network with construction projects and increased pumping may in itself be unsustainable.

Modifying the network with construction projects and increased pumping may in itself be unsustainable, increasing the energy use, operating costs, and risk of failure compared with a simpler system.

1.18.2 Urban Creep

Urban creep – the gradual increase in drained area from patios, driveways, and extension roofs – represents a significant risk to the sewer network's capacity to cope with either housing growth or climate change.

Urban creep – the gradual increase in drained area from patios, driveways, and extension roofs – represents a significant risk to the sewer network's capacity to cope with either housing growth or climate change.

Urban creep can occur wherever people (or organisations) want to improve their property, whether it is new or old.

Urban creep should be addressed as a matter of priority, to reduce the need for expensive modifications of the foul or combined sewerage system.

Enforcement of existing building regulations, such as those preferring sustainable drainage of new driveways, will help to prevent further urban creep, but might not be enough on its own.

In some catchments, reversing urban creep by proactively removing existing surface water connections could be a more cost-effective, and environmentally sustainable solution than increasing the capacity of the sewer network.

1.18.3 Climate Change

Climate change could have the greatest overall effect on the number of sewer flood locations, the volume of flood water, and the frequency of flooding.

Because the climate change scenarios have such a large effect on the volume of rainwater entering the sewers, climate change could have the greatest overall effect on the number of sewer flood locations, the volume of flood water, and the frequency of flooding.

The current reported flooding from severe weather events shows clearly how flooding could worsen if what we now consider to be 'severe weather' becomes more common. The change in flooding of +14 to +32% from the 90th percentile climate change scenario is comparable with the proportion of events where flooding is currently attributed to 'severe weather'. Taken in the context of existing severe weather flooding, the response to the climate change scenarios is plausible.

We can adapt to climate change by reducing the amount of rainwater that is able to enter the sewers.

We can adapt to climate change by reducing the amount of rainwater that is able to enter the sewers. This can be achieved through:

Ensuring that adequate space is made for wastewater before new properties are constructed. This may require companies to improve the quality of their network models and on-the-ground monitoring of flows and capacity. It will also need to be addressed through a robust urban planning process.

Ensuring that no new rainwater connections are made to the foul or combined sewer networks.

Removing existing rainwater connections from the foul and combined sewer networks. The area of connections that need to be removed could be modelled and then used to drive a programme of prioritised removal such as encouraging the re-development of brownfield sites to reduce connected area, or constructing surface water sewers to separate out storm flows from combined sewers, beginning with the most economic options.

Improving the condition of relevant foul and combined sewers, to reduce infiltration of water from surrounding ground in winter or after heavy rain where infiltration is believed to be high.

As is currently the case, providing additional capacity for rainwater, where it is not possible or economic to separate it from the foul or combined system.

While the actions listed above may be straightforward engineering propositions, they will be difficult to implement. Some will require changes in government policy or legislation. Enforcement powers will also have to be adequate and implemented with adequate resources if they are to be effective.

1.19 Limitations and Future Investigations

Differences in catchment population size, hydrogeology and capacity inevitably limit interpolation of the results to other catchments.

Differences in catchment population size, hydrogeology and capacity inevitably limit interpolation of the results to other catchments. Smaller catchments may appear to suffer dramatically from a small rise in growth, creep or precipitation when expressed as a percentage change. A similar increase in flood volume would be a lesser percentage of a much larger catchment.

The large differences in uplift predictions may appear anomalous when viewing the model results as a whole but it is difficult to determine whether these are anomalous or actual outliers without a more homogenous basis for comparison.

Some separation of models into small and larger catchments may remove some of the more extreme increases from the graphs. These increases however will occur, and reflect the more sensitive nature of smaller catchments to growth and could be investigated in future phases of this study.

It has not been established how much if any reduction in additional flooding there would be if all storm – related development flows were removed, thus defining the absolute minimum flow that must be added from new developments.

With respect to future investigations, it has not been established how much if any reduction in additional flooding there would be if all storm – related development flows were removed, thus defining the absolute minimum flow that must be added from new developments.

It should also be noted that if sewers and storm tanks are to be provided (and still to be allowed) for developments these should be sized with an allowance for creep plus climate change as they will otherwise be under-sized for future flows, causing flooding and/or increased flows in the foul/combined system.

Conclusions and Recommendations

This study set out to model the impact of climate change, housing growth and urban creep on sewer flooding. It used 97 sewer network models built and run by the wastewater companies of England and Wales. The models covered the sewers serving some 16% of the population of England and Wales.

The study used mathematical models to predict the locations and volumes of water that might be expected to flood from the sewer network under certain hypothetical future conditions. It did not provide a forecast of individual properties that will flood.

The scenarios covered forecast housing growth to 2033, urban creep to 2033, and climate change under the medium emissions scenario, at 10th, 50th, and 90th percentile values, to 2040. All the scenarios are considered sufficiently close to represent a horizon of 2040.

1.20 Conclusions

The conclusions are that:

Flooding will increase as a result of either of the future change scenarios, except the 10th percentile winter climate change scenario taken without any other changes.

1. Any one of the three changes modelled (growth, urban creep, climate change) are likely to cause an increase in flooding if not addressed. Each of the change scenarios investigated implies a significant increase in the volume and extent of sewer flooding throughout England and Wales by 2040. The exception is the 10th percentile winter climate change scenario taken without any other changes, which may reduce flooding in some catchments.

2. When considered in a combined change scenario the volume and extent is further increased. All three changes are based on sound evidence. It is extremely unlikely that only one of the three changes will occur whilst the other two remain the same. The climate, the population and the connected area will change; the only uncertainty is by how much they will change.

3. There is a wide range of change predicted across the catchments modelled, from a slight reduction in flooding to an increase to more than four times the current level. The increase will take the form of more flood locations as well as a greater volume of flood water.

4. Urban development adds new flow and reduces the capacity for draining rainwater. If not properly accommodated, housing growth will lead to an increase in sewer flooding. The median

increase in 1:10 year flooding across 97 catchments was 4.8%, compared with current predicted flooding.

5. Urban creep results in more rainwater entering the network in every storm event. It will lead to an increase in sewer flooding. The median increase in 1:10 year flooding across 97 catchments was 11.5%, compared with current predicted flooding.

The combined effects of the three drivers lead to a median increase in 1:10 year sewer flood volumes of 51% by about 2040 compared with current predicted flooding.

6. Climate change has the potential to bring longer, heavier spells of winter rainfall. Summer convective storms are not predicted by the UKCIP09 weather generator, but also have a significant impact on rainwater volumes in some catchments. Climate change therefore has the potential to bring a significant increase in sewer flooding. The median increase in 1:10 year flooding across 97 catchments, at the 50th percentile weather simulation under the medium emissions scenario, was 27%, compared with current predicted flooding.

7. The combined effects of the three drivers lead to a median increase in 1:10 year sewer flood volumes of 51% by about 2040 compared with current predicted flooding.

1.21 Suggestions for Adaptation Strategies

Drawing on the results of the study we suggest the adaptation strategies listed below. Some will require changes in government policy or legislation. Enforcement powers will have to be adequate and implemented with adequate resources if they are to be effective.

1. Preventing all future connections of rainwater drainage, from roofs paved areas and highways, to the foul or combined sewer network. Significant investment will still be required in foul/combined systems to accommodate the additional foul flows resulting from growth.

2. Ensuring that wastewater capacity is developed in line with the growth of towns. This may involve towns being more closely involved with company asset management plans, and companies providing more information about sewer network capacity for town strategic plans.

3. Removing existing rainwater connections, from roofs paved areas and highways, from the foul or combined sewers. This should be prioritised to the most vulnerable catchments, and

individual schemes according to the marginal cost of abatement of rainwater flows. This should be an integral part of surface water management plans, thus ensuring dialogue with other stakeholders in the built environment. It will require the ending of the right to connect drainage to foul and combined sewer networks, as recommended by the Pitt review.

4. Improving the condition of sewers in vulnerable catchments with higher than average infiltration rates, to reduce the infiltration of water from the ground or after heavy rain and so effectively improve both the capacity and resilience of the system. It should be recognised however that there are limits on how much infiltration can be removed economically.

5. Providing additional sewerage capacity to accommodate the new flows. This could include diverting flows between catchments, providing more storage, or adding new surface water sewers to convert a combined system into separate rainwater and foul water networks. It will also be necessary to attenuate flows in order to prevent further downstream flooding.

6. If sewers and storm tanks are to be provided (and still to be allowed) for developments these should be sized with an allowance for creep plus climate change as they will otherwise be under-sized for future flows, causing flooding and/or increased flows in the foul/combined system.

7. In all the options for change it will be necessary for the companies to work with land owners, councils and drainage authorities such as the Highways Agency or the internal drainage boards to identify the most appropriate strategy for each catchment. All of these parties should already be involved in the preparation of surface water management plans therefore this would appear to be an ideal forum in which to address any problems.

8. It may be appropriate to develop some measure of companies' performance in drainage management and report on this regularly.

1.22 Recommendations for Further Work

This study has provided an evidence base of over 80 sewer catchments which shows the likely scale of effects on sewer flooding from future climate change, population growth and urban creep.

This study has provided an evidence base of over 80 sewer catchments which shows the likely scale of effects on sewer flooding from future climate change, population growth and urban creep.

It provides a foundation from which to investigate the likely costs and effectiveness of different options for preventing an increase in sewer flooding or reducing existing flooding.

Drawing on the experience of this study we recommend that further phases work should include:

1. With the industry and relevant stakeholders, agree a 'design storm' with climate change built in, to use as a common basis for decision analysis. Currently it is possible to design solutions to identified problems for 1:30, 1:40 or 1:50 year storms depending on the water company, and which is based on historic rainfall series which by their nature are backward-looking. A better common basis for design would also allow an easier comparison of network performance between regions.

2. Identify the 'traditional' modifications to the wastewater network that would be required in order to prevent flooding in 2040. These would take account of the combined effects of the three change scenarios of climate change, urban creep and population growth.

3. Estimate the current cost of delivering the network modifications described above, together with likely carbon emissions resulting from the modifications.

4. Identify 'sustainable' modifications to the catchment that would reduce or avoid the need to modify the network, together with the phasing of work that would deliver these changes in time to prevent an increase in flooding. These could include disconnecting existing rainwater drains from the network and providing alternative rainwater drainage, or changing the location of new development.

5. Estimate the current cost of delivering the network modifications described above, together with likely carbon emissions resulting from the modifications, and if practicable construct an estimate of the marginal cost of abatement of climate change.

6. Compare the cost effectiveness of each pair of solutions compared with doing nothing.

7. Suggest an approach to catchment management that would encourage delivery of the most cost-effective solutions to prevent future sewer flooding.

8. Assess the implications of the above for policy making.

Appendices

Appendix A. Summary of Company Models

Table A.1: Summary of Company Models Used

Company	ID	Population			Urban Creep	Climate Change Summer			Climate Change Winter		
		Existing	Forecasted	increase	% applied	10%	50%	90%	10%	50%	90%
Thames Water Limited	TW2	2,599,407	3,107,594	20.0%	3.0%	No Calc	10%	No Calc	No Calc	9%	No Calc
Thames Water Limited	TW5	747,643	831,313	15.0%	0.6%	No Calc	10%	No Calc	No Calc	10%	No Calc
Thames Water Limited	TW4	542,663	624,445	11.0%	0.4%	No Calc	10%	No Calc	No Calc	12%	No Calc
Severn Trent Water	ST2	399,096*	482,025*	20.8%	5.0%	10%	10%	23%	-4%	10%	27%
Thames Water Limited	TW6	354,116	417,764	16.0%	0.5%	No Calc	10%	No Calc	No Calc	11%	No Calc
Southern Water Services	SWS2	308,158	319,747	3.8%	2.8%	10%	10%	25%	0%	13%	29%
Anglian Water Services	AW8	221,253	294,274	25.0%	No Calc	10%	10%	32%	-2%	12%	29%
Anglian Water Services	AW9	218,436	258,025	15.0%	11.0%	10%	10%	31%	-3%	12%	30%
Thames Water Limited	TW7	183,520	231,155	18.0%	1.4%	No Calc	10%	No Calc	No Calc	12%	No Calc
Dwr Cymru	DC3	155,000	191,000	23.2%	10.0%	10%	10%	26%	0%	10%	23%
Dwr Cymru	DC4	154,000	154,000*	0.0%	2.0%	No Calc	10%	No Calc	No Calc	10%	No Calc
Southern Water Services	SWS1	133,447	141,266	5.9%	4.8%	10%	10%	26%	-2%	11%	27%
South West Water	SWW7	129,043*	129,043*	0.0%	5.0%	10%	10%	10%	-1%	10%	22%
Southern Water Services	SWS5	126,679	135,750	7.2%	3.9%	10%	10%	25%	-1%	12%	28%
Anglian Water Services	AW10	122,735	148,805	18.0%	No Calc	10%	10%	25%	-4%	10%	27%
Severn Trent Water	ST4	109,692*	132,330*	20.6%	5.0%	10%	10%	22%	-6%	9%	26%
Anglian Water Services	AW2	105,882	110,073	4.0%	No Calc	10%	10%	23%	-1%	11%	27%
Anglian Water Services	AW7	100,980	134,273	25.0%	No Calc	10%	10%	23%	-3%	11%	28%
Thames Water Limited	TW1	97,069	125,376	29.0%	61.9%	No Calc	10%	No Calc	No Calc	13%	No Calc
Severn Trent Water	ST1	87,070*	122,712*	40.9%	5.0%	10%	10%	21%	-6%	7%	23%
Anglian Water Services	AW5	85,875	88,040	2.0%	No Calc	10%	10%	15%	-2%	11%	26%
Wessex Water	WW8	77,534	89,552	15.5%	5.0%	10%	10%	12%	0%	11%	25%
Severn Trent Water	ST10	76,856*	84,530*	10.0%	5.0%	10%	10%	31%	-3%	10%	26%
Severn Trent Water	ST8	75,557*	101,490*	34.3%	5.0%	10%	10%	26%	-4%	8%	21%
Thames Water Limited	TW8	69,696	80,693	25.0%	1.7%	No Calc	10%	No Calc	No Calc	11%	No Calc
Southern Water Services	SWS4	66,744	73,058	9.5%	4.7%	10%	10%	22%	-3%	10%	25%
Northumbrian Water Ltd	NW5	63,736	67,463	5.8%	8.0%	10%	11%	27%	-2%	9%	21%
Anglian Water Services	AW3	62,406	70,262	12.6%	No Calc	10%	10%	24%	-1%	9%	21%
Anglian Water Services	AW4	50,841	58,772	13.0%	1.0%	10%	10%	15%	-3%	11%	26%
Southern Water Services	SWS3	50,025	52,483	4.9%	4.1%	10%	10%	25%	0%	13%	29%
Wessex Water	WW7	49,239	61,236	24.4%	2.6%	10%	10%	17%	-1%	11%	24%
Northumbrian Water Ltd	NW6	48,017	48,620	1.3%	1.4%	10%	10%	19%	-8%	5%	20%
Severn Trent Water	ST3	46,926*	53,026*	13.0%	5.0%	10%	10%	23%	-6%	8%	24%
Southern Water Services	SWS7	45,014	46,269	2.8%	5.0%	10%	10%	25%	0%	13%	29%
Wessex Water	WW10	43,604	56,850	30.4%	5.0%	10%	10%	13%	-1%	10%	24%
United Utilities	UU7	41,932	46,222	10.2%	5.4%	No Calc	10%	No Calc	No Calc	9%	No Calc
Southern Water Services	SWS6	40,893	42,052	2.8%	5.0%	10%	10%	25%	-1%	12%	28%
Northumbrian Water Ltd	NW8	38,726	42,733	10.3%	11.3%	10%	10%	19%	-8%	5%	20%
Northumbrian Water Ltd	NW4	38,690	42,705	10.4%	4.5%	10%	10%	23%	-7%	7%	24%
Wessex Water	WW4	38,593	41,301	7.0%	2.7%	10%	10%	22%	0%	11%	24%
Severn Trent Water	ST5	37,876*	43,542*	15.0%	5.0%	10%	10%	20%	-3%	11%	28%
Yorkshire Water Services	YW8	36,414	39,913	9.6%	5.0%	No Calc	No Calc	No Calc	No Calc	10%	No Calc
Northumbrian Water Ltd	NW3	34,271	33,941	-1.0%	3.7%	10%	10%	16%	-2%	11%	27%
Severn Trent Water	ST9	31,726*	40,508*	27.7%	5.0%	10%	10%	28%	-4%	11%	28%
Dwr Cymru	DC2	30,000	33,000	10.0%	4.0%	10%	10%	26%	0%	10%	23%

Company	ID	Population			Urban Creep	Climate Change Summer			Climate Change Winter		
		Existing	Forecasted	increase	% applied	10%	50%	90%	10%	50%	90%
United Utilities	UU5	29,716	30,756	3.5%	2.7%	No Calc	10%	No Calc	No Calc	8%	No Calc
Northumbrian Water Ltd	NW2	29,280	30,809	5.2%	12.0%	10%	11%	27%	-2%	9%	21%
United Utilities	UU8	27,143	29,179	7.5%	3.6%	No Calc	10%	No Calc	No Calc	8%	No Calc
Anglian Water Services	AW6	25,319	26,306	4.0%	2.0%	10%	10%	14%	-3%	12%	29%
Dwr Cymru	DC10	25,107	25,692	2.3%	1.2%	10%	10%	36%	-6%	5%	17%
Severn Trent Water	ST7	24,340*	26,686*	9.6%	5.0%	10%	10%	26%	-3%	10%	25%
Yorkshire Water Services	YW2	23,629	29,210	23.6%	4.6%	10%	10%	17%	-7%	5%	18%
United Utilities	UU1	23,338	25,275	8.3%	4.6%	No Calc	10%	No Calc	No Calc	6%	No Calc
Southern Water Services	SWS9	22,009	24,055	9.3%	5.0%	10%	10%	25%	-1%	12%	28%
United Utilities	UU2	21,111	23,180	9.8%	3.9%	No Calc	10%	No Calc	No Calc	8%	No Calc
Wessex Water	WW3	21,010	29,940	42.5%	11.9%	10%	10%	14%	0%	11%	24%
Yorkshire Water Services	YW1	20,533	22,585	10.0%	6.7%	10%	10%	27%	-2%	10%	23%
United Utilities	UU6	19,989	22,208	11.1%	3.5%	No Calc	10%	No Calc	No Calc	11%	No Calc
Yorkshire Water Services	YW10	19,822	21,827	10.1%	5.0%	No Calc	10%	No Calc	No Calc	10%	No Calc
Yorkshire Water Services	YW5	19,536	20,963	7.3%	5.0%	No Calc	3%	No Calc	No Calc	8%	No Calc
Wessex Water	WW2	19,148	24,747	29.2%	4.5%	10%	10%	11%	-1%	9%	22%
Dwr Cymru	DC9	19,123	19,964	4.4%	0.9%	10%	10%	24%	-6%	4%	14%
United Utilities	UU4	18,949	20,408	7.7%	5.2%	No Calc	10%	No Calc	No Calc	6%	No Calc
Yorkshire Water Services	YW9	18,766	20,346	8.4%	5.0%	No Calc	10%	No Calc	No Calc	8%	No Calc
United Utilities	UU10	17,451	20,261	16.1%	5.7%	No Calc	10%	No Calc	No Calc	9%	No Calc
Northumbrian Water Ltd	NW7	16,869	17,940	6.3%	3.4%	10%	10%	24%	-5%	11%	29%
Dwr Cymru	DC1	16,347	19,943	22.0%	8.6%	10%	10%	20%	-1%	9%	21%
Dwr Cymru	DC6	13,505	15,628	15.7%	10.0%	10%	10%	24%	10%	13%	30%
Yorkshire Water Services	YW3	12,605	13,400	6.3%	4.6%	10%	10%	17%	-6%	5%	18%
Yorkshire Water Services	YW6	12,269	17,402	41.8%	5.0%	No Calc	2%	No Calc	No Calc	10%	No Calc
United Utilities	UU3	12,225	13,594	11.2%	4.4%	No Calc	10%	No Calc	No Calc	10%	No Calc
South West Water	SWW8	12,108	14,131	16.7%	5.0%	10%	10%	10%	-1%	8%	19%
United Utilities	UU9	11,686	12,831	9.8%	2.4%	No Calc	10%	No Calc	No Calc	8%	No Calc
Wessex Water	WW6	11,099	14,069	26.8%	4.7%	10%	10%	16%	-1%	11%	25%
Severn Trent Water	ST6	11,097*	12,394*	11.7%	5.0%	10%	10%	20%	-3%	11%	28%
Dwr Cymru	DC8	10,082	11,092	10.0%	1.5%	10%	10%	33%	-5%	8%	23%
South West Water	SWW10	9,825	10,714	9.0%	7.2%	10%	10%	10%	-2%	8%	20%
South West Water	SWW3	9,167	10,258	11.9%	5.0%	10%	10%	10%	-2%	8%	20%
Anglian Water Services	AW1	8,459	8,670	2.0%	No Calc	10%	10%	15%	-4%	10%	23%
South West Water	SWW6	8,456	9,203	8.8%	9.8%	10%	10%	10%	-1%	8%	18%
Yorkshire Water Services	YW7	8,163	11,354	39.1%	5.0%	No Calc	10%	No Calc	No Calc	10%	No Calc
Northumbrian Water Ltd	NW1	7,672	8,860	15.5%	10.0%	10%	10%	23%	-5%	9%	26%
Southern Water Services	SWS8	7,642	7,829	2.4%	5.0%	10%	10%	16%	-3%	13%	32%
Thames Water Limited	TW3	7,371	8,666	17.0%	7.4%	No Calc	10%	No Calc	No Calc	12%	No Calc
South West Water	SWW2	6,914	7,332	6.0%	5.0%	10%	10%	10%	-2%	8%	20%
Wessex Water	WW5	6,768	6,768	0.0%	4.3%	10%	10%	17%	-3%	10%	25%
South West Water	SWW9	5,845	6,743	15.4%	6.4%	10%	10%	10%	-1%	8%	20%
Northumbrian Water Ltd	NW10	4,980	5,443	9.3%	13.7%	10%	10%	16%	-3%	9%	24%
Dwr Cymru	DC7	4,500	4,500*	0.0%	2.0%	No Calc	10%	No Calc	No Calc	9%	No Calc
Yorkshire Water Services	YW4	2,952	3,206	8.6%	5.0%	10%	10%	28%	-2%	8%	19%
Wessex Water	WW1	2,538	2,538	0.0%	4.6%	10%	10%	16%	-5%	10%	27%
Dwr Cymru	DC5	1,890	2,640	39.7%	14.2%	10%	10%	22%	10%	10%	26%
South West Water	SWW4	1,579	1,789	13.3%	5.0%	10%	10%	10%	-2%	9%	24%
Wessex Water	WW9	1,371	6,587	380.5%	5.0%	10%	10%	18%	-1%	12%	28%

Company	ID	Population			Urban Creep	Climate Change Summer			Climate Change Winter		
		Existing	Forecasted	increase	% applied	10%	50%	90%	10%	50%	90%
South West Water	SWW1	527	645	22.4%	1.7%	10%	10%	10%	-2%	8%	20%
South West Water	SWW5	523	523*	0.0%	6.1%	10%	10%	10%	0%	11%	26%
Northumbrian Water Ltd	NW9	155	220	41.9%	5.4%	10%	10%	23%	-5%	9%	26%
Total or Median		**8,869,589**	**10,310,541**	**10%**	**5%**	**10%**	**10%**	**22%**	**-2%**	**10%**	**25%**
Maximum		**2,599,407**	**3,107,594**	**380%**	**62%**	**10%**	**11%**	**36%**	**10%**	**13%**	**32%**
Minimum		**155**	**220**	**-1%**	**0%**	**10%**	**2%**	**10%**	**-8%**	**4%**	**14%**

Note: * - Numbers are extracted from Severn Trent initial submission prior to modelling or assumed for other numbers

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Appendix B. Graphs

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Comparison of Catchments Grouped by Scenario Rank Order

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Figure B.1: Comparison of Scenarios Rank Series A

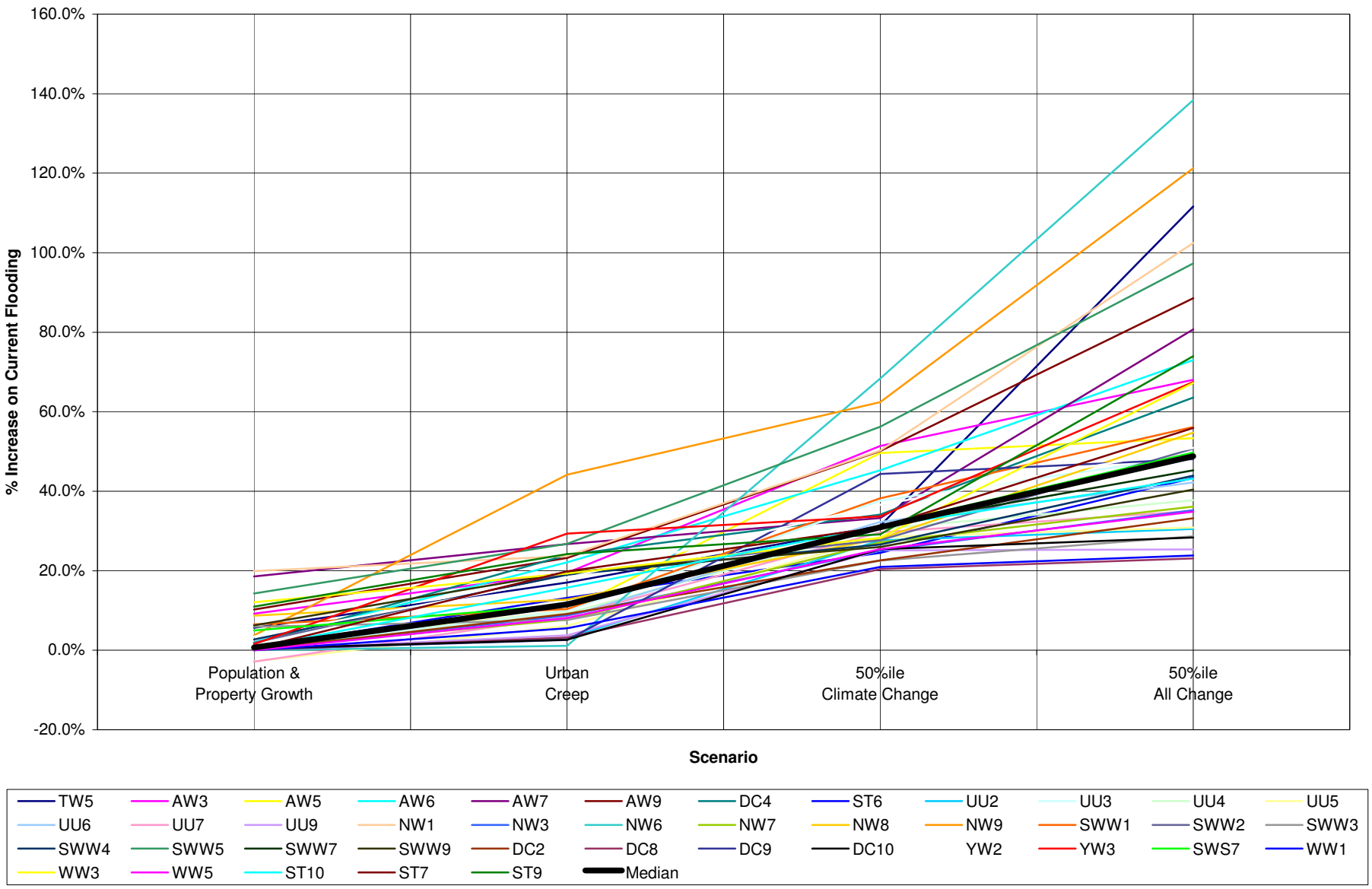

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Figure B.2: Comparison of Scenarios Rank Series B

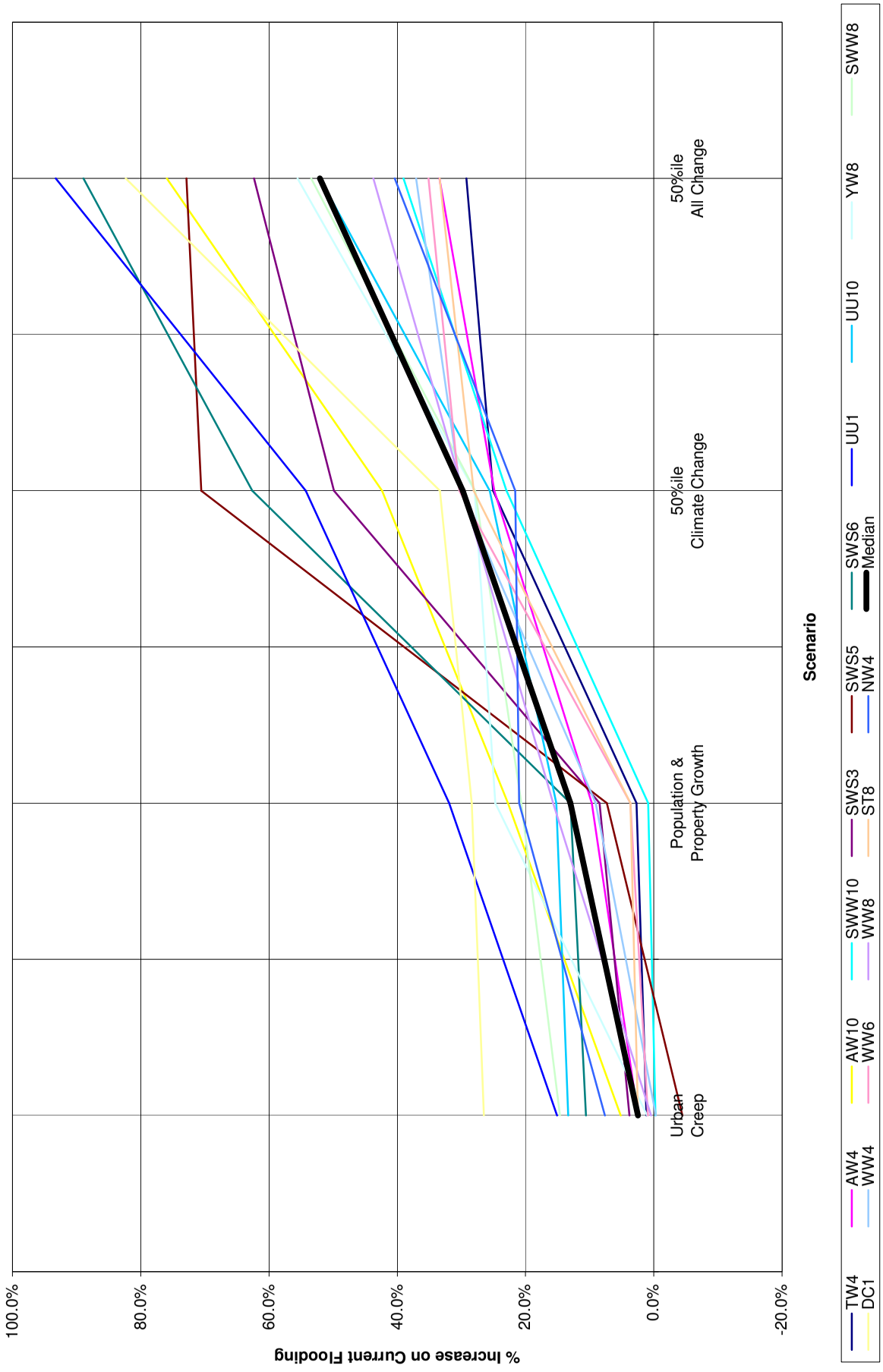

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Figure B.3: Comparison of Scenarios Rank Series C

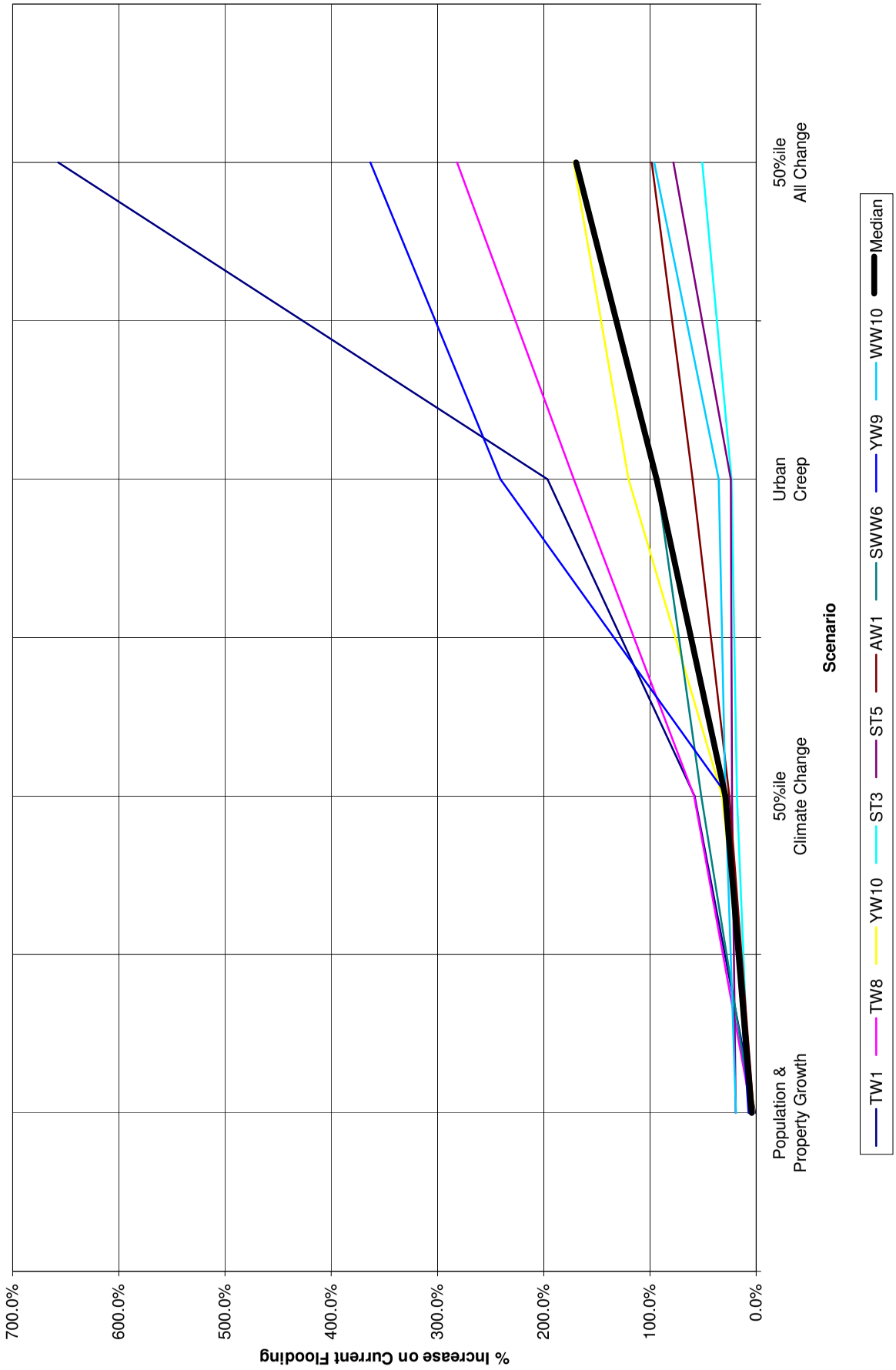

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Figure B.4: Comparison of Scenarios Rank Series D

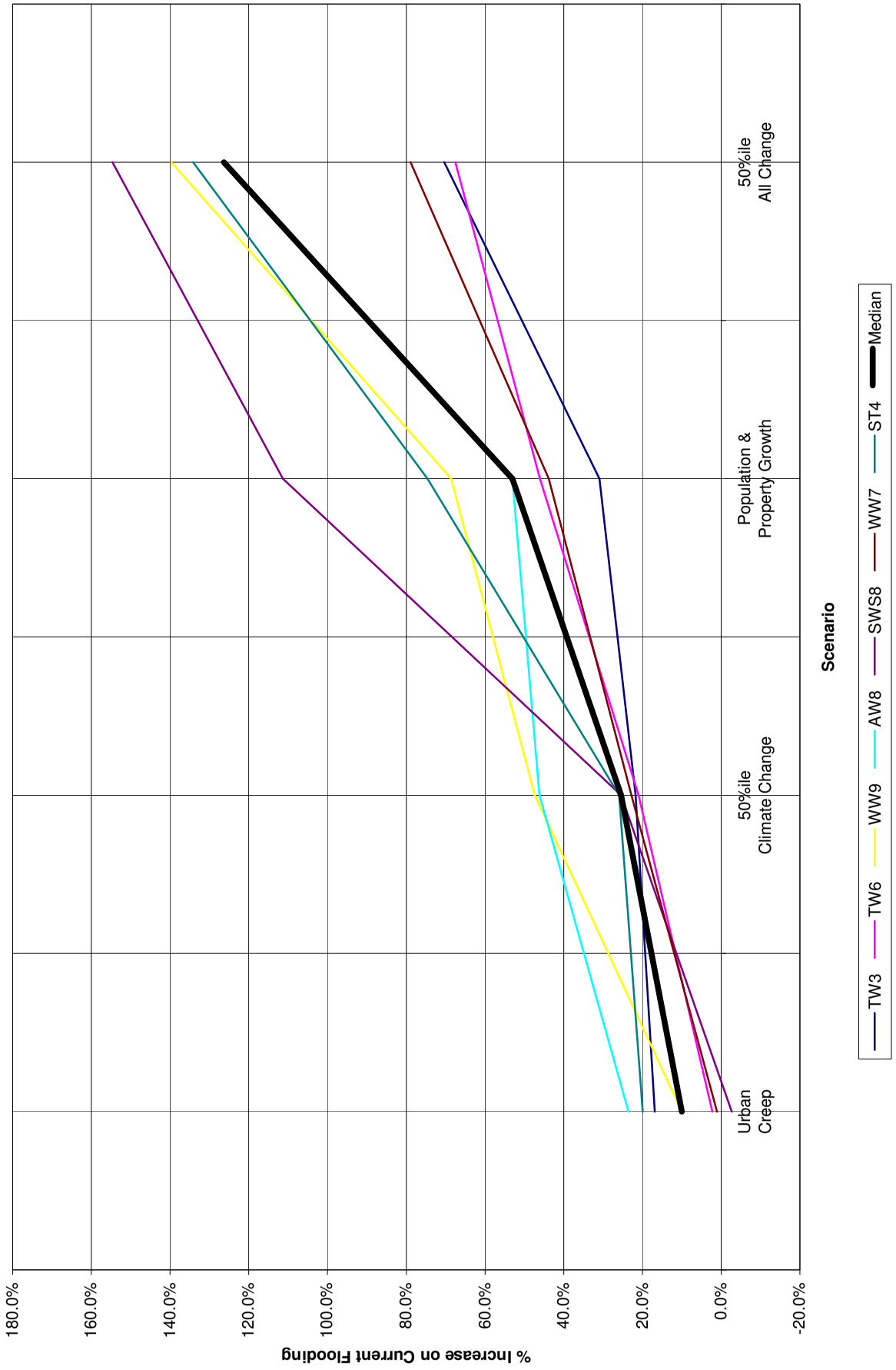

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Figure B.5: Comparison of Scenarios Rank Series E

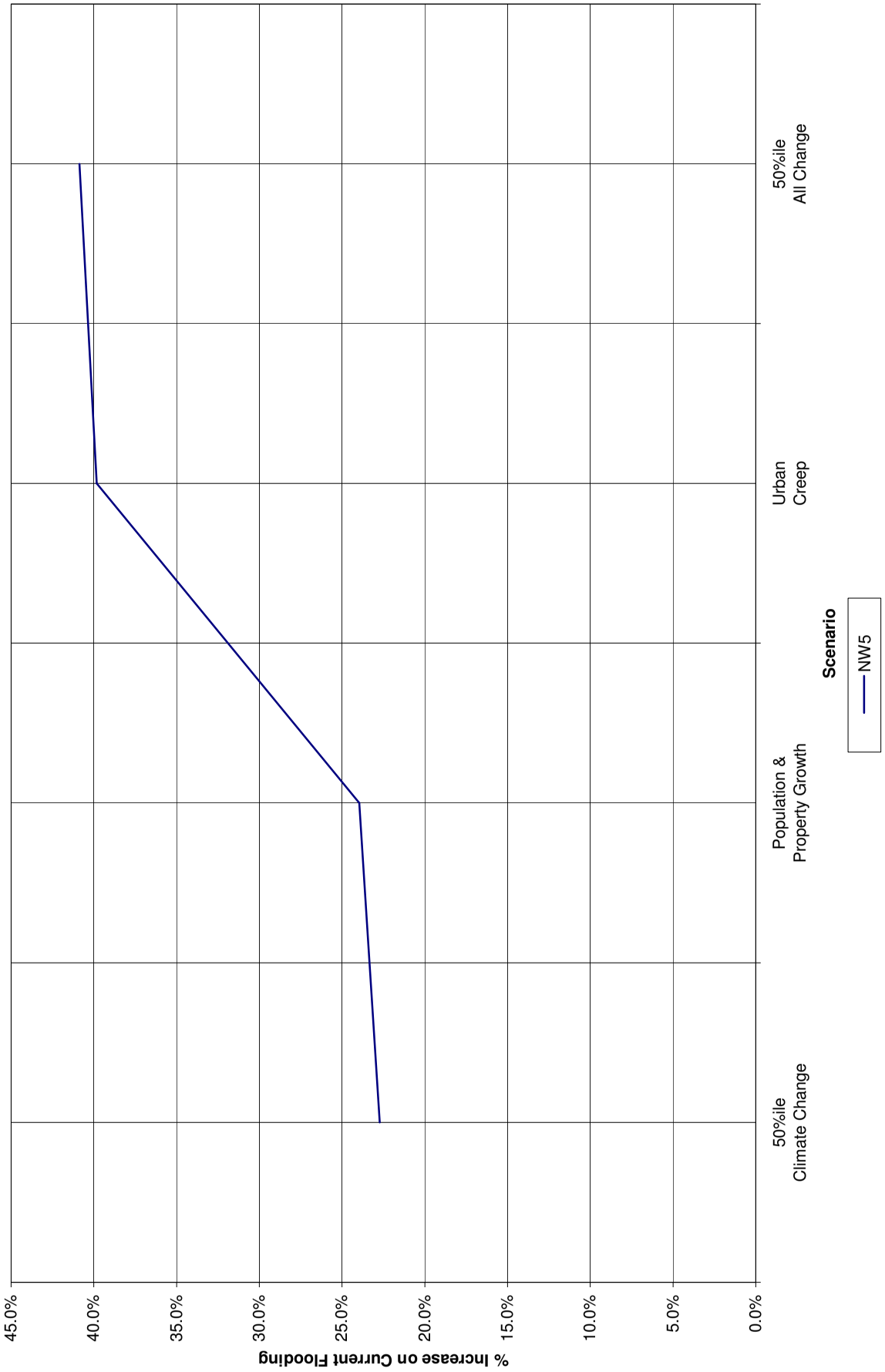

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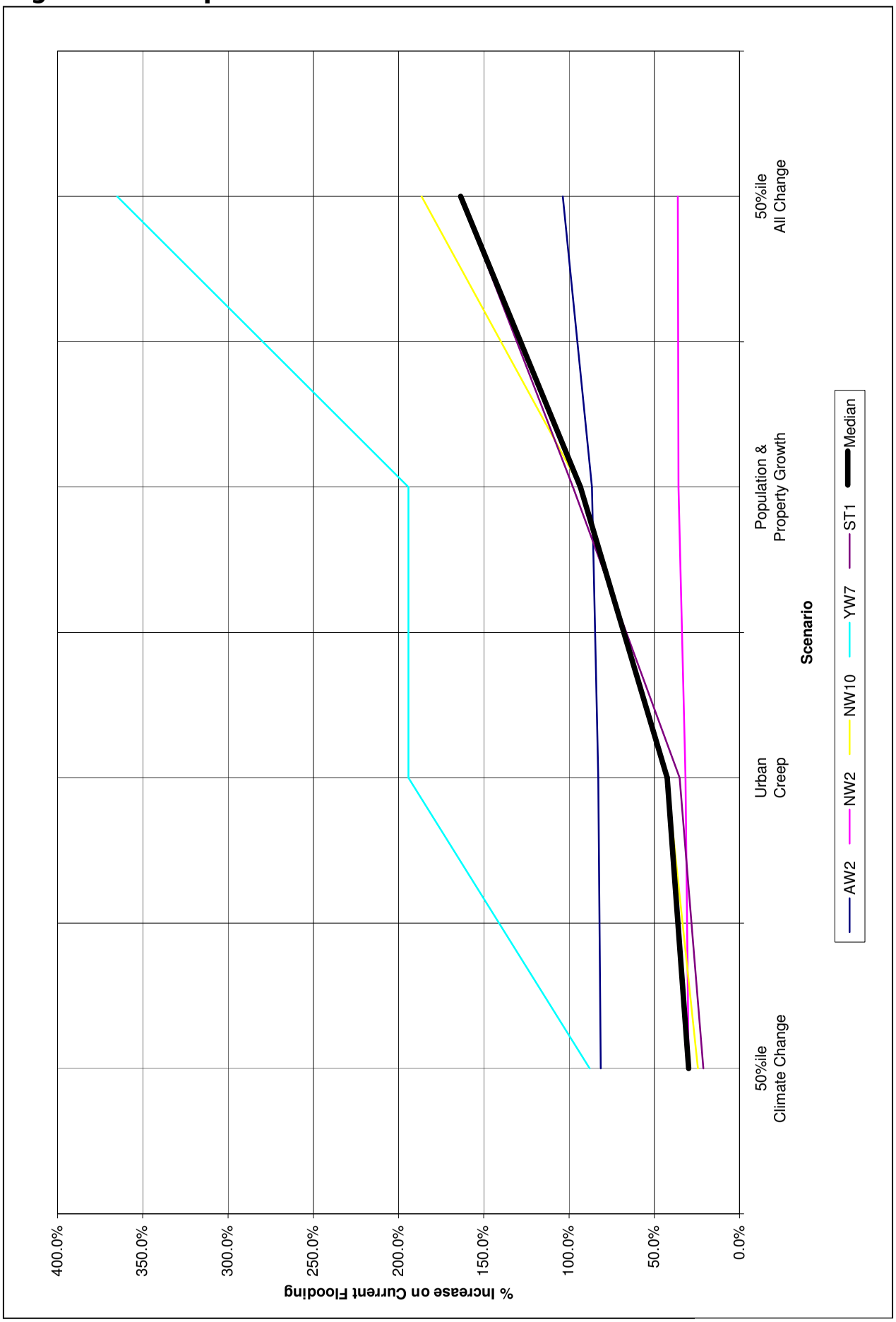
Figure B.6: Comparison of Scenarios Rank Series F



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All Catchments Ranked By Greatest % Increase in Flood Volume (Summer & Winter)

Figure B.7: Population & Property Growth
Figure B.8: Urban Creep Scenario
Figure B.9: 50%ile Climate Change
Figure B.10: 50%ile All Change

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Figure B.7: Population & Property Growth Scenario - All Catchments Ranked By Greatest % Increase In Flood Volume (Summer & Winter)

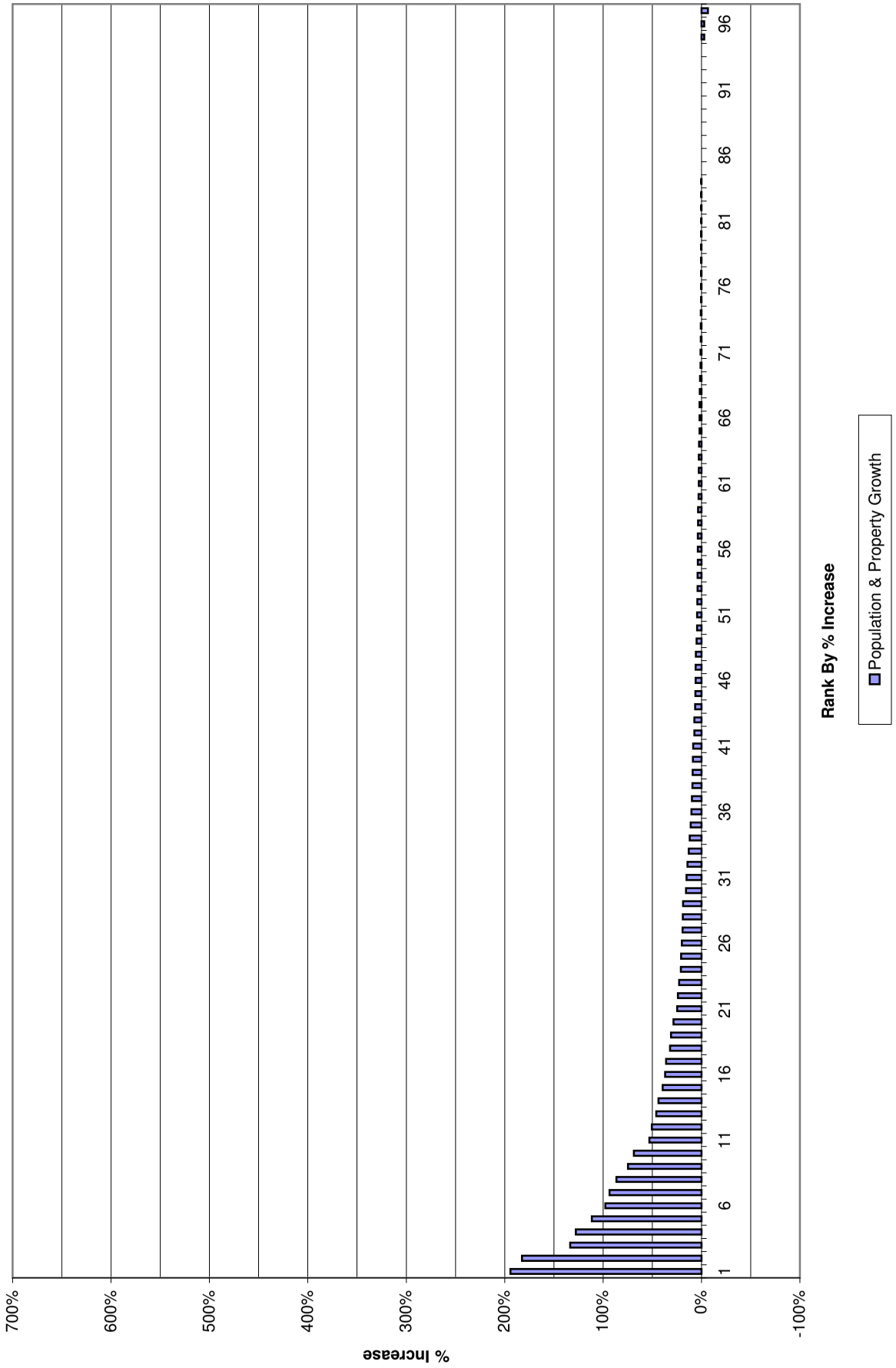

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Figure B.8: Urban Creep Scenario - All Catchments Ranked By Greatest % Increase In Flood Volume (Summer & Winter)

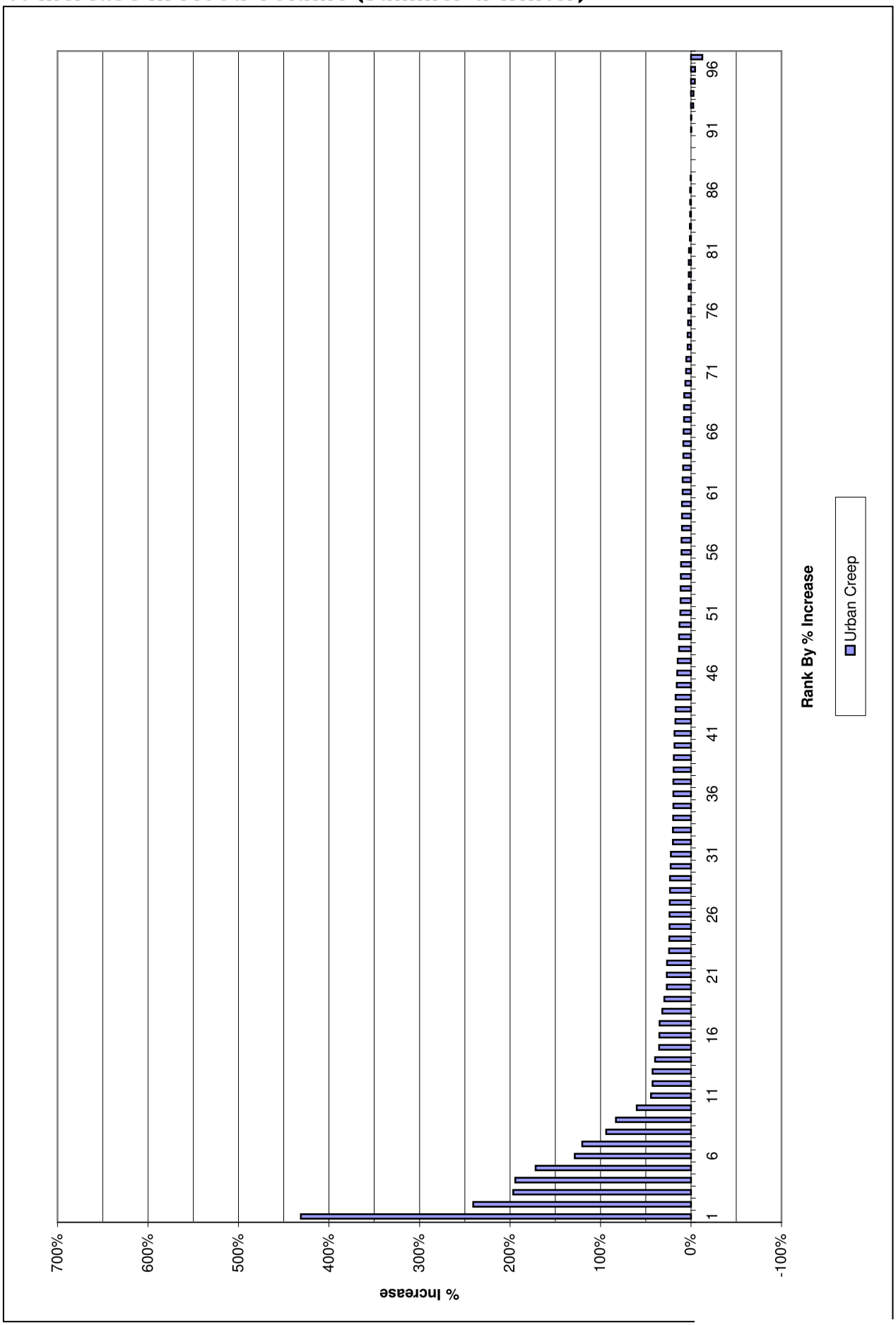

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Figure B.9: 50%ile Climate Change Scenario - All Catchments Ranked By Greatest % Increase In Flood Volume (Summer & Winter)

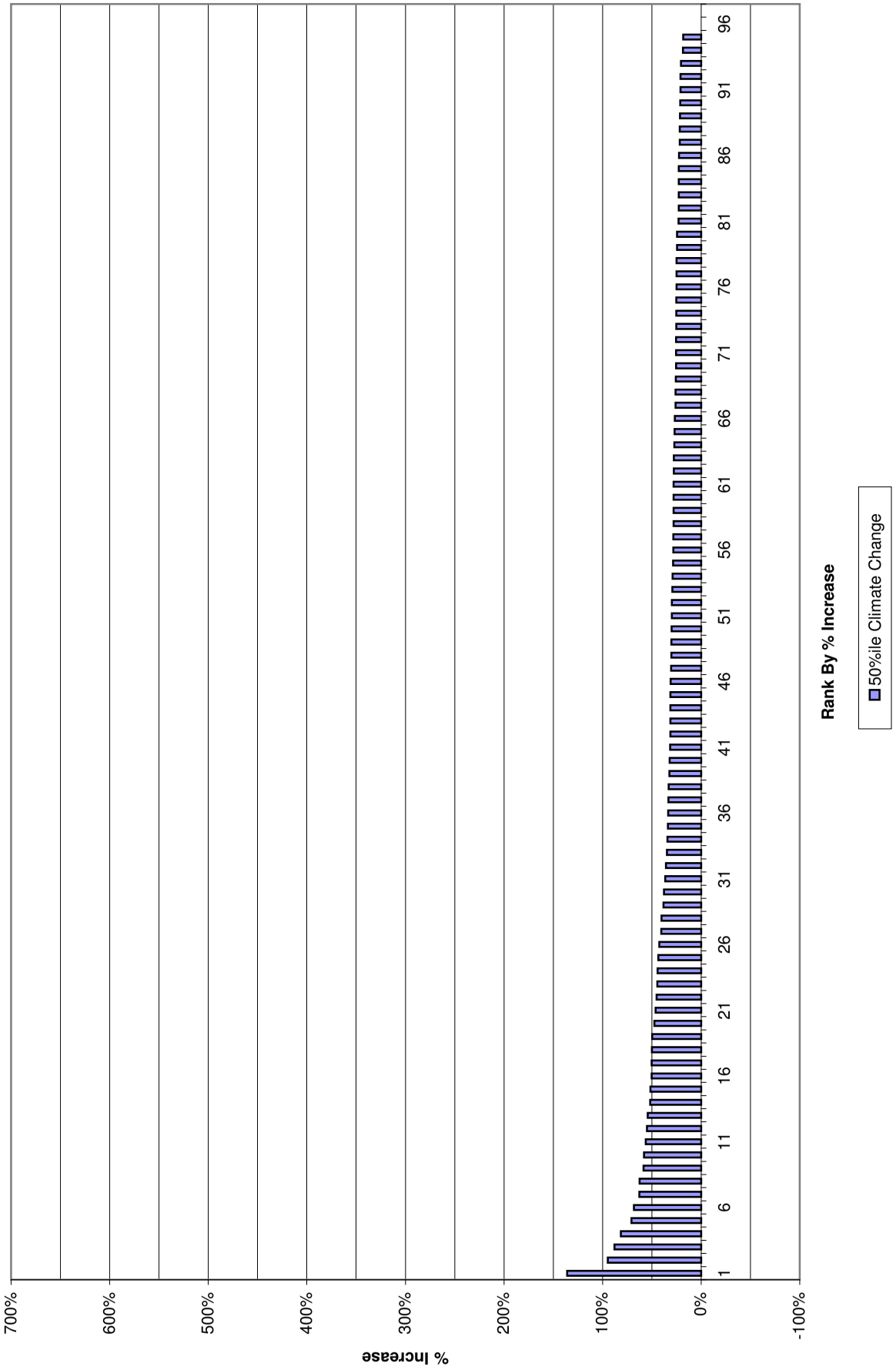

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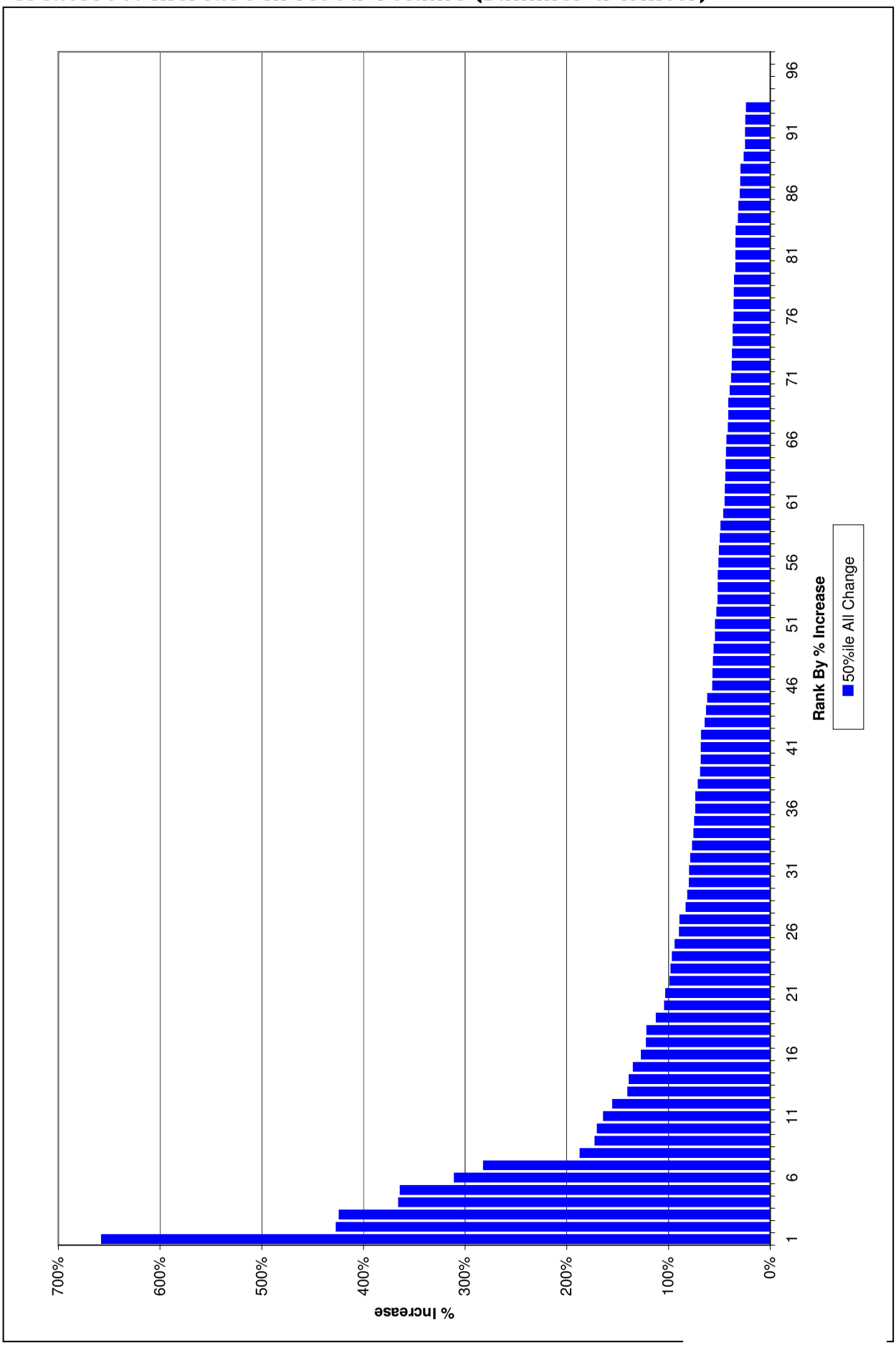
Figure B.10: 50%ile All Change Scenario - All Catchments Ranked By Greatest % Increase In Flood Volume (Summer & Winter)



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Comparison of Climate Change Scenarios

Figure B.11: Comparison of Winter Climate Change Scenarios By Flood Volume (68 Catchments)

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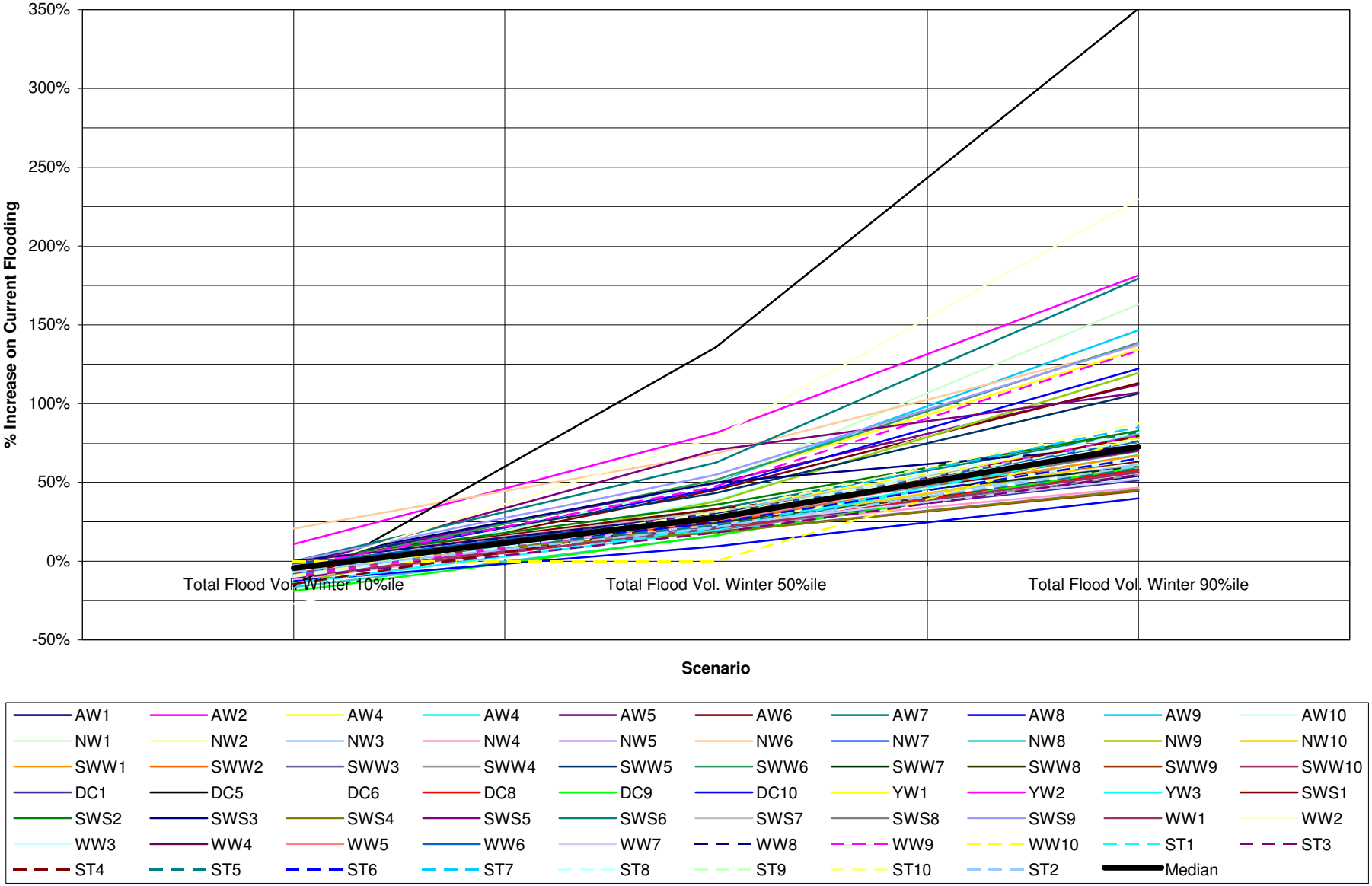
Figure B.11: Comparison of Winter Climate Change Scenarios By Flood Volume (68 Catchments)



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Flood Volume Changes

Figure B.12: 10%ile Winter Climate Change Scenario
Figure B.13: 50%ile Summer Climate Change Scenario
Figure B.14: 50%ile Winter Climate Change Scenario
Figure B.15: 90%ile Summer Climate Change Scenario
Figure B.16: 90%ile Winter Climate Change Scenario
Figure B.17: Summer Population Growth Scenario
Figure B.18: Winter Population Growth Scenario
Figure B.19: Summer Urban Creep Scenario
Figure B.20: Winter Urban Creep Scenario
Figure B.21: Winter 50%ile All Change Scenario
Figure B.22: Summer 50%ile All Change Scenario

Note: 10%ile Summer Climate Change Scenario not included as this is identical to 50%ile Summer Climate Change Scenario

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Figure B.12: 10%ile Winter Climate Change Scenario - Flood Volume Change

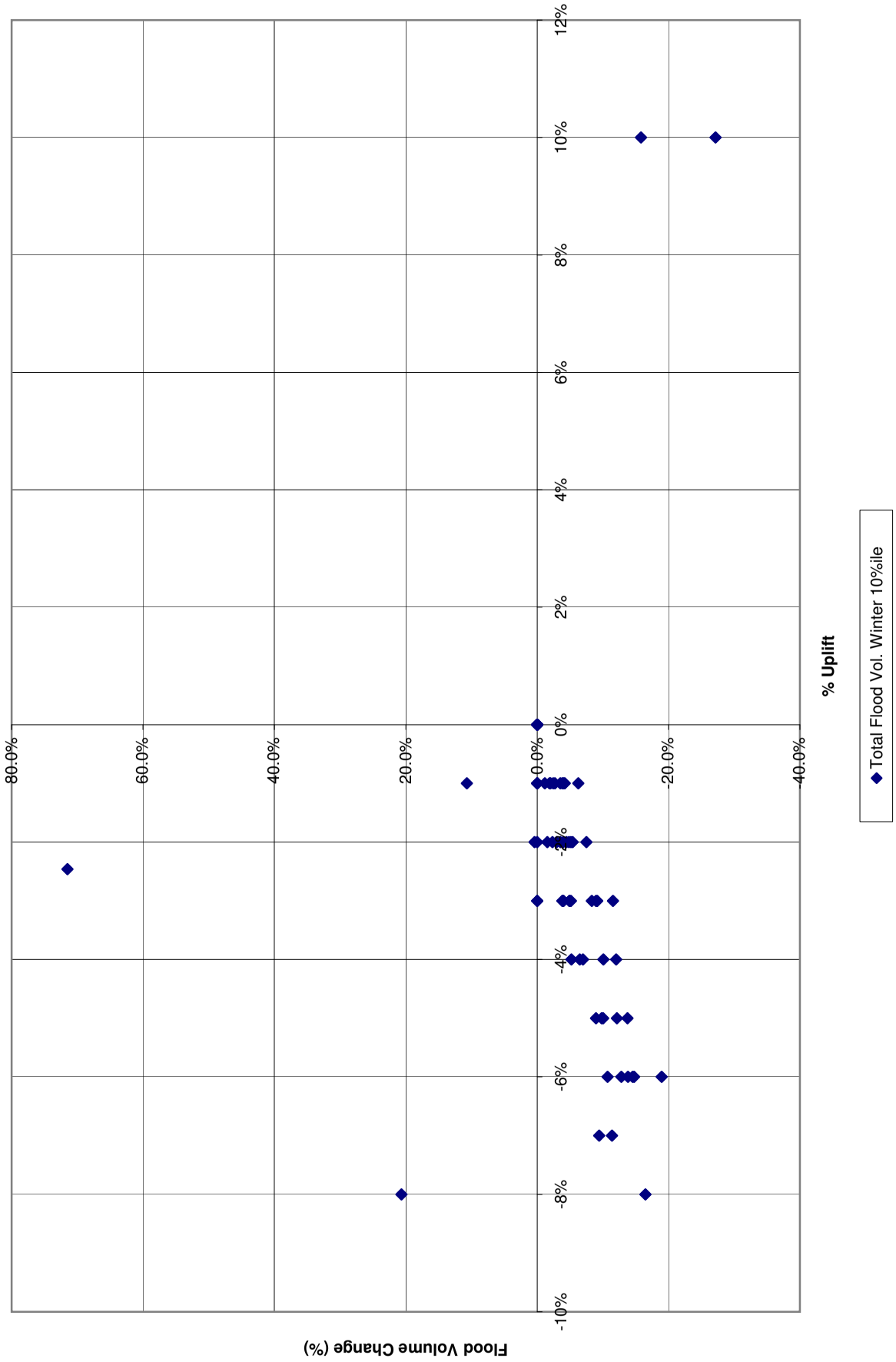

Figure B.13: 50%ile Summer Climate Change Scenario - Flood Volume Change

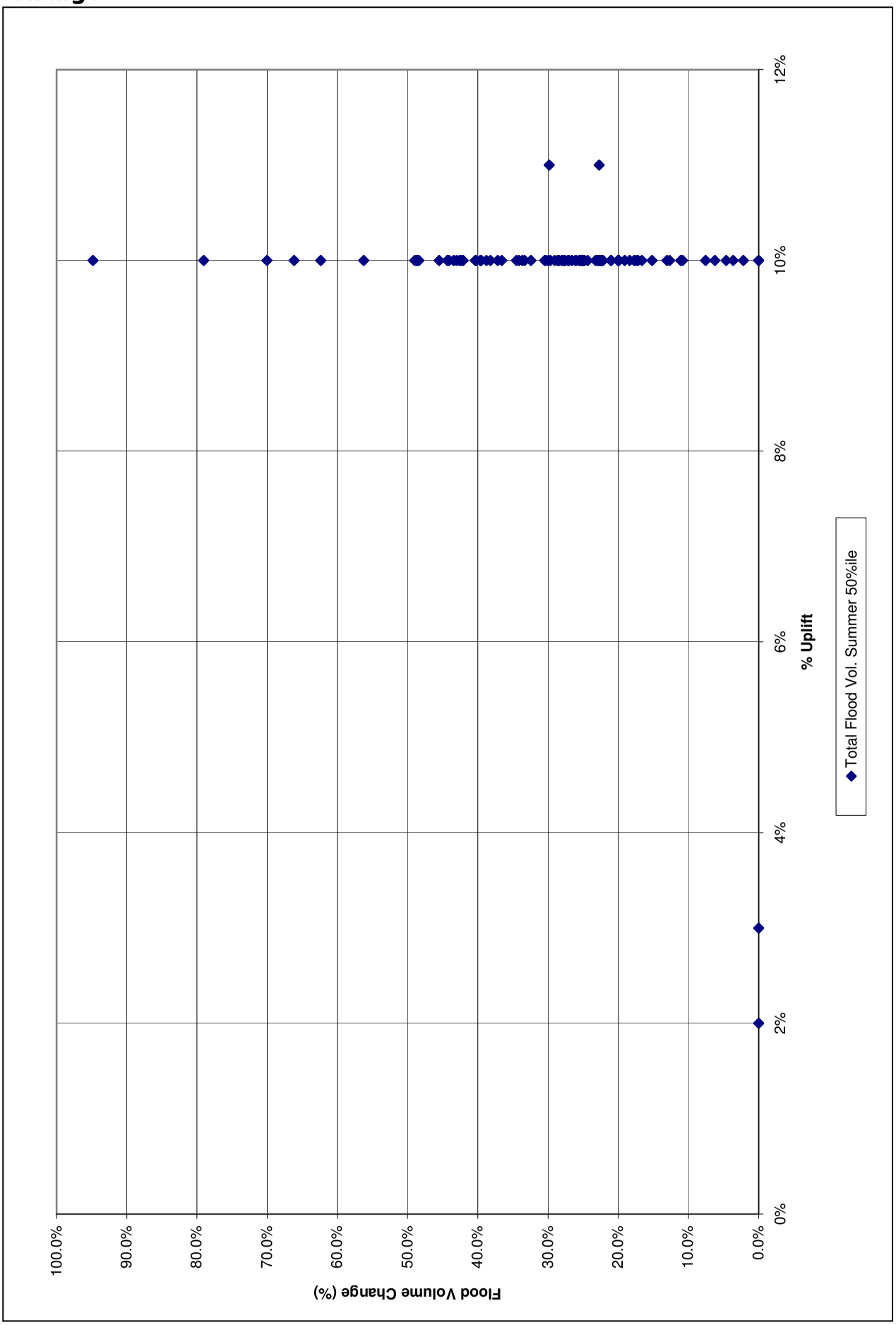

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Figure B.14: 50%ile Winter Climate Change Scenario - Flood Volume Change

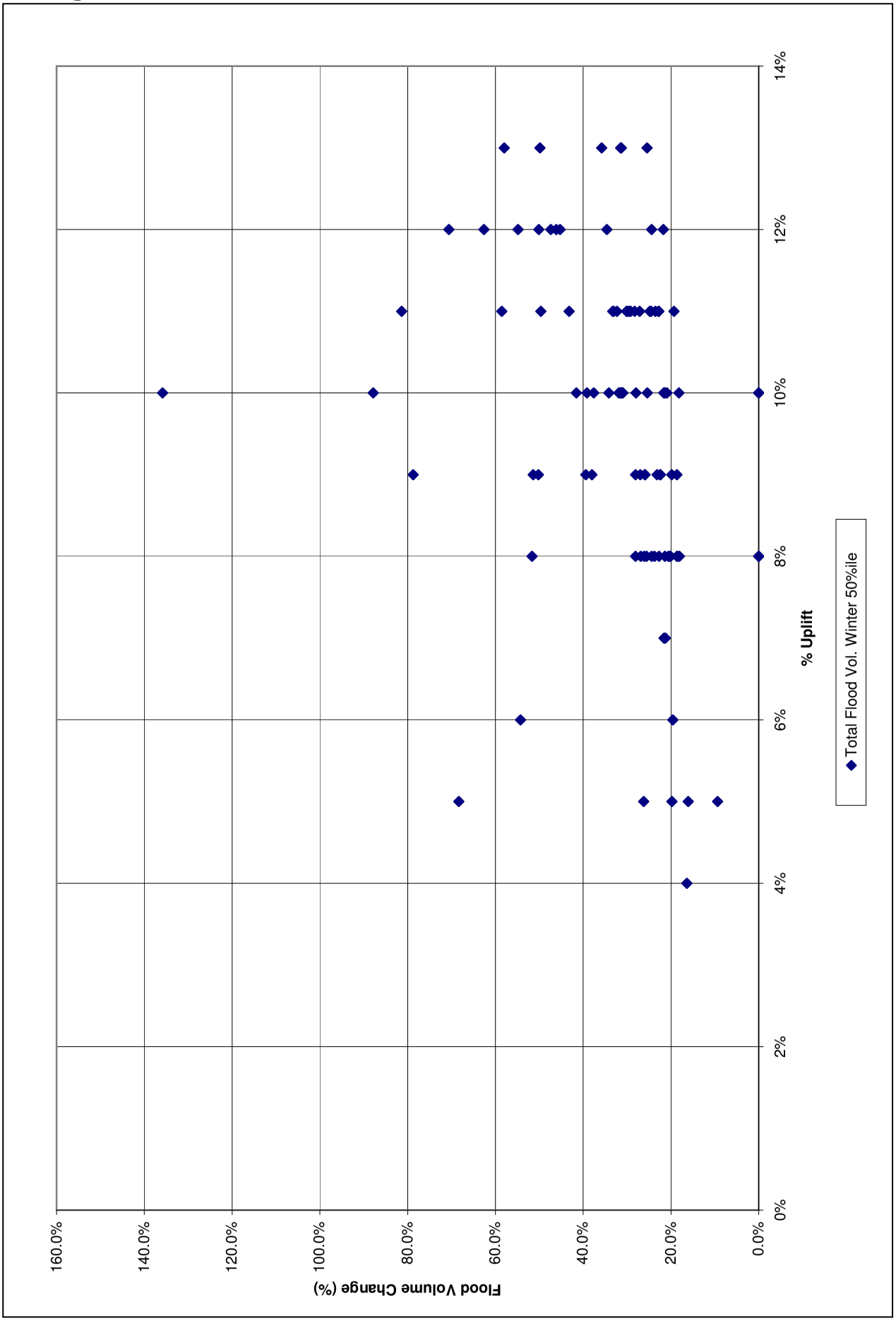

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Figure B.15: 90%ile Summer Climate Change Scenario - Flood Volume Change

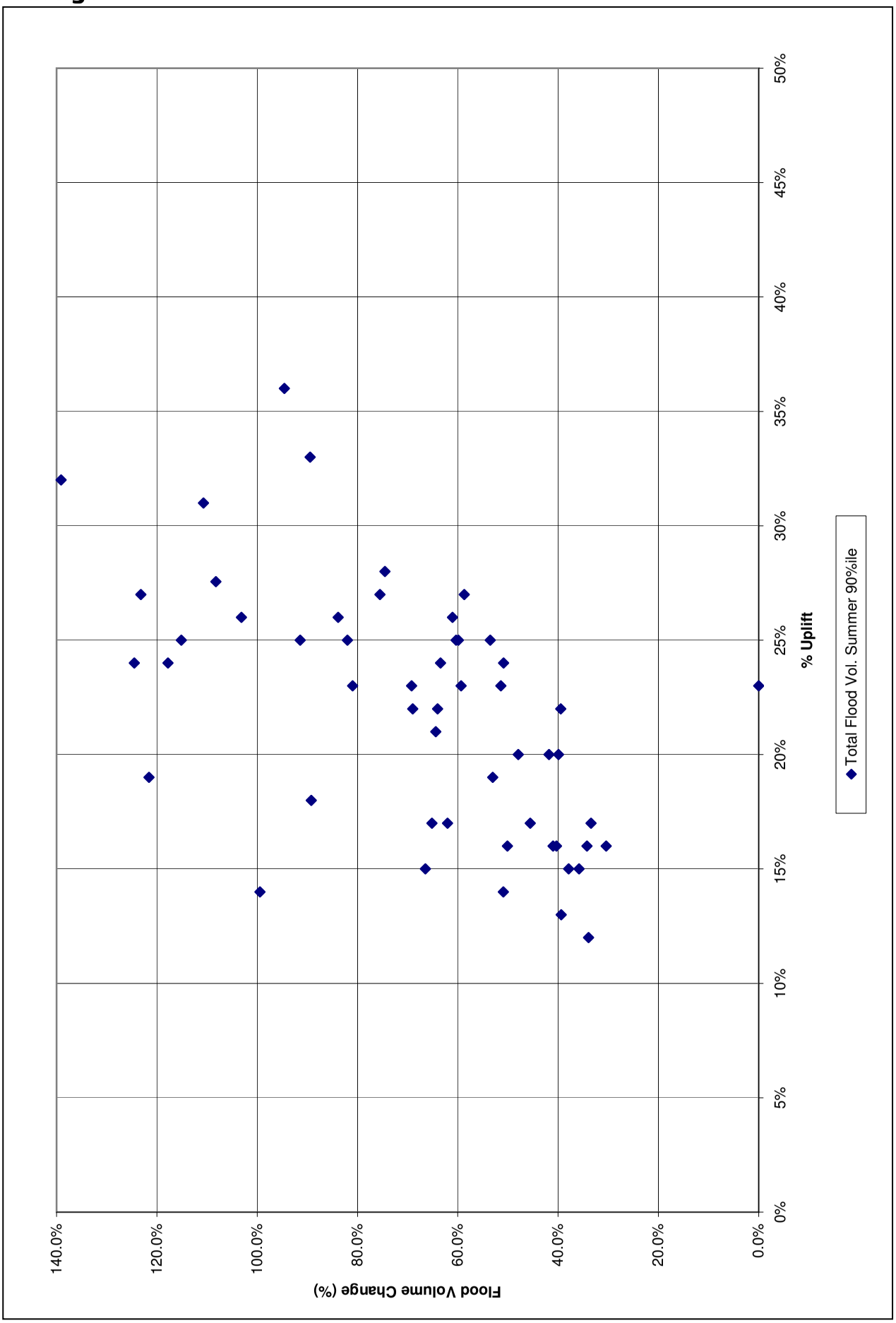

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Figure B.16: 90%ile Winter Climate Change Scenario - Flood Volume Change

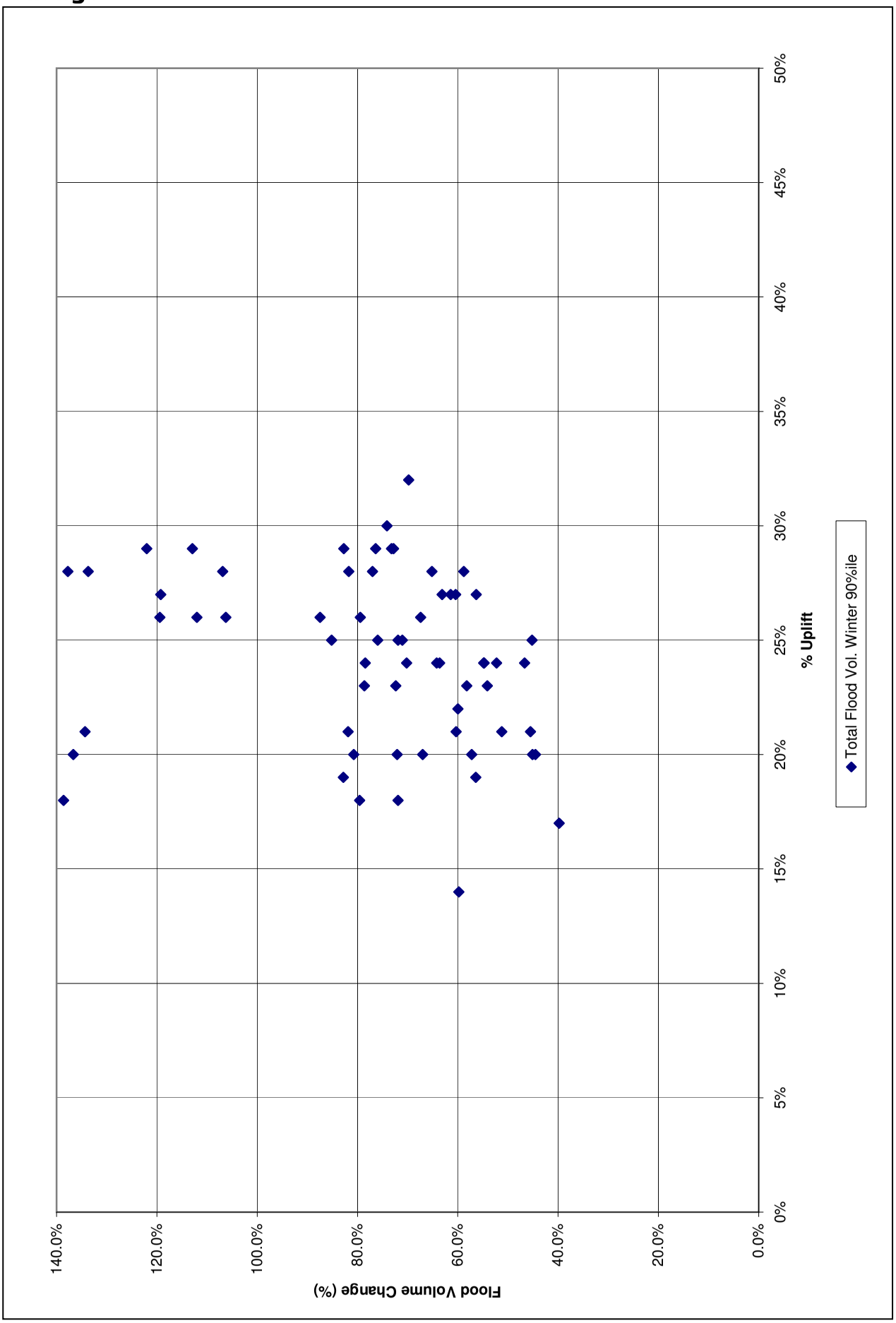

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Figure B.17: Summer Population Growth Scenario - Flood Volume Change

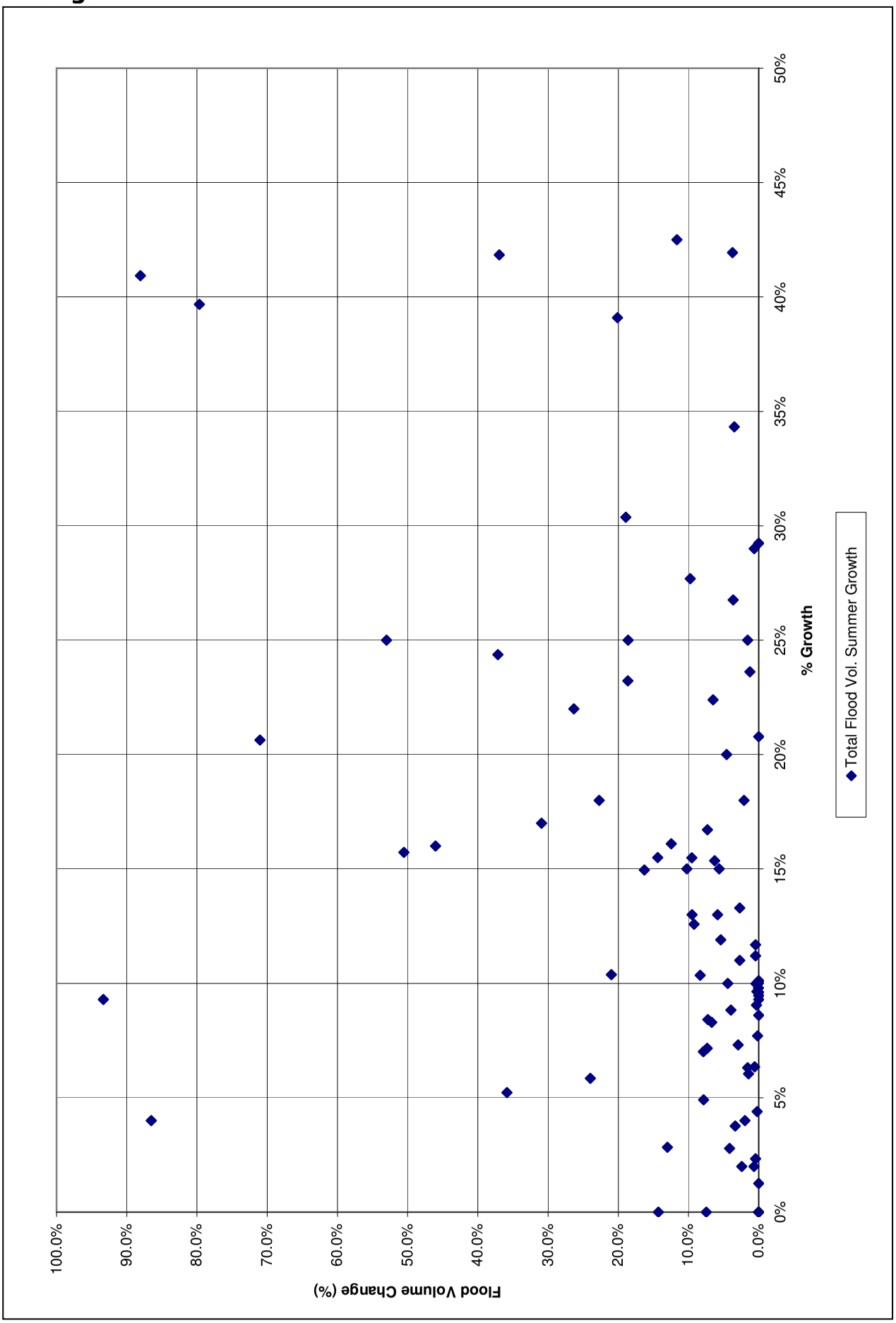

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Figure B.18: Winter Population Growth Scenario - Flood Volume Change

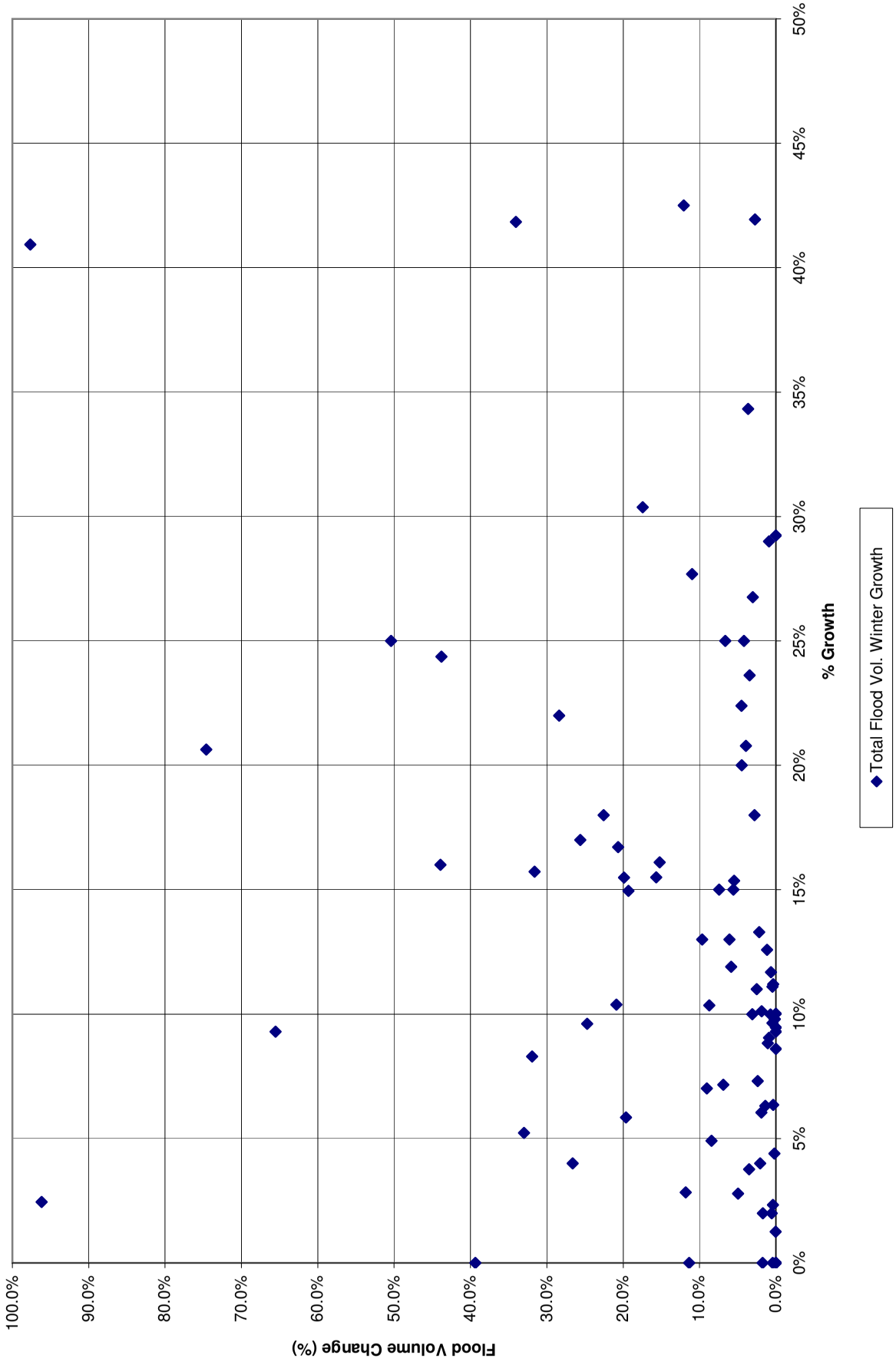

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Figure B.19: Summer Urban Creep Scenario - Flood Volume Change

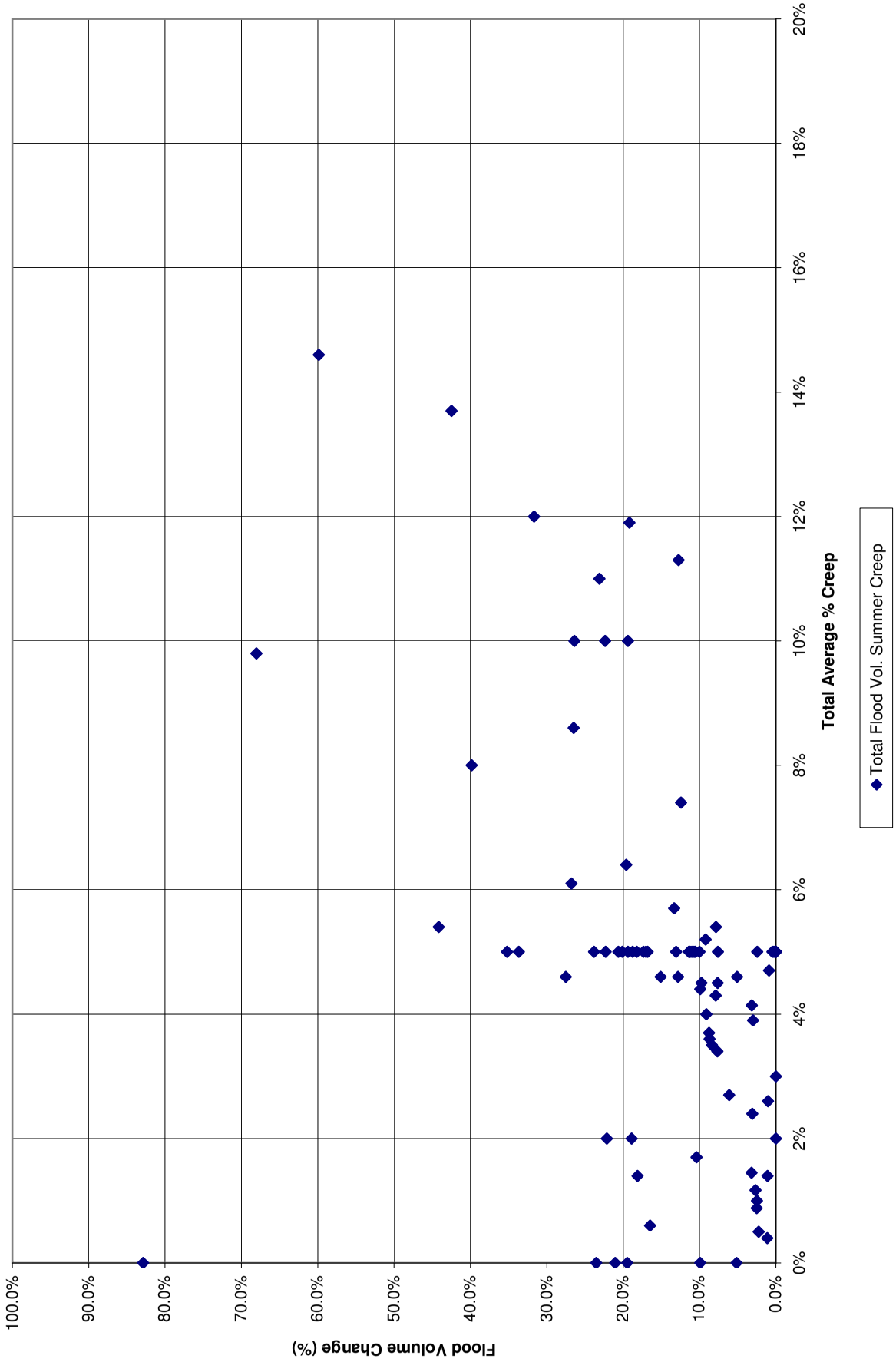

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Figure B.20: Winter Urban Creep Scenario - Flood Volume Change

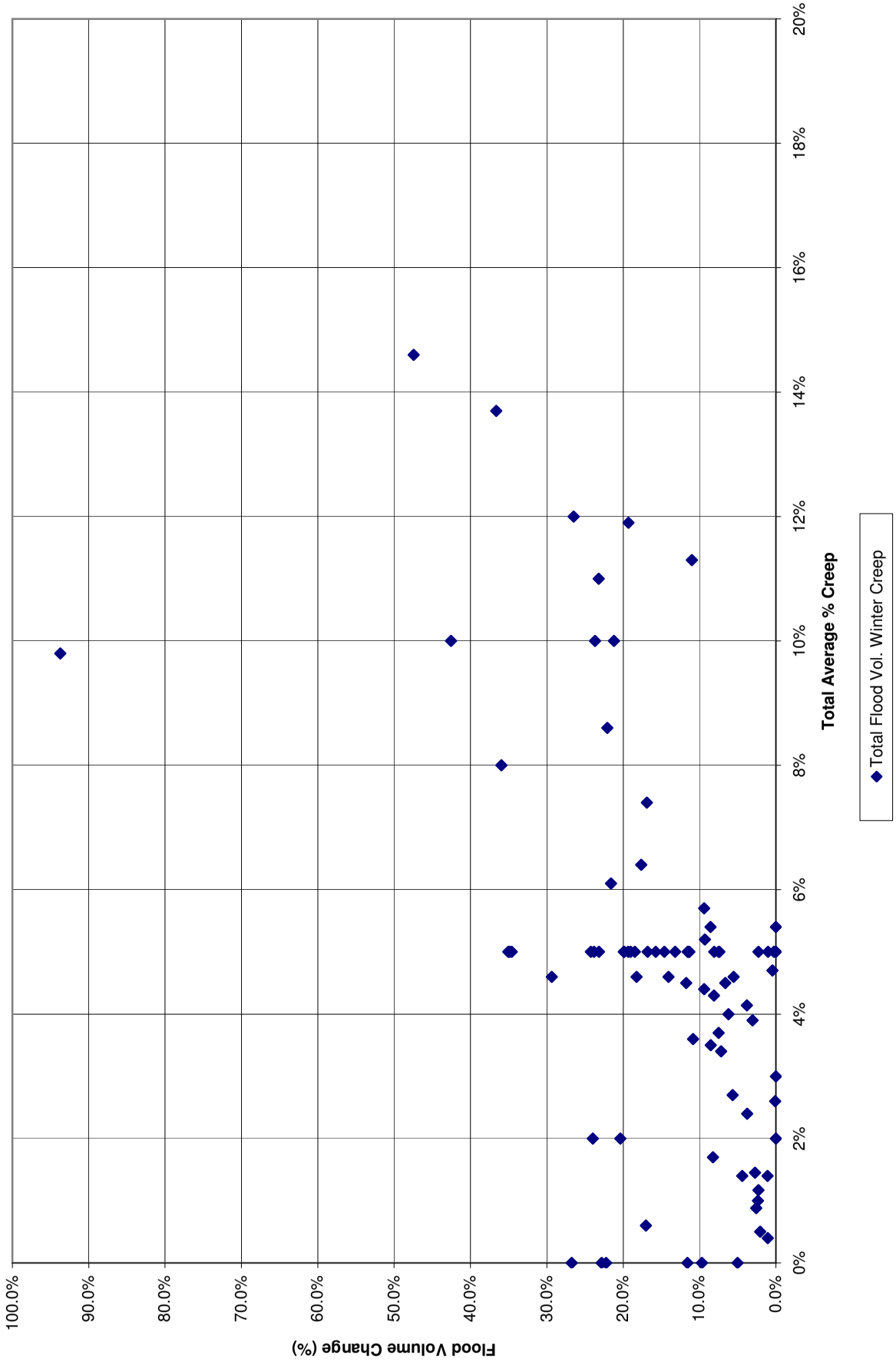

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Figure B.21: Winter 50%ile All Change Scenario - Flood Volume Change

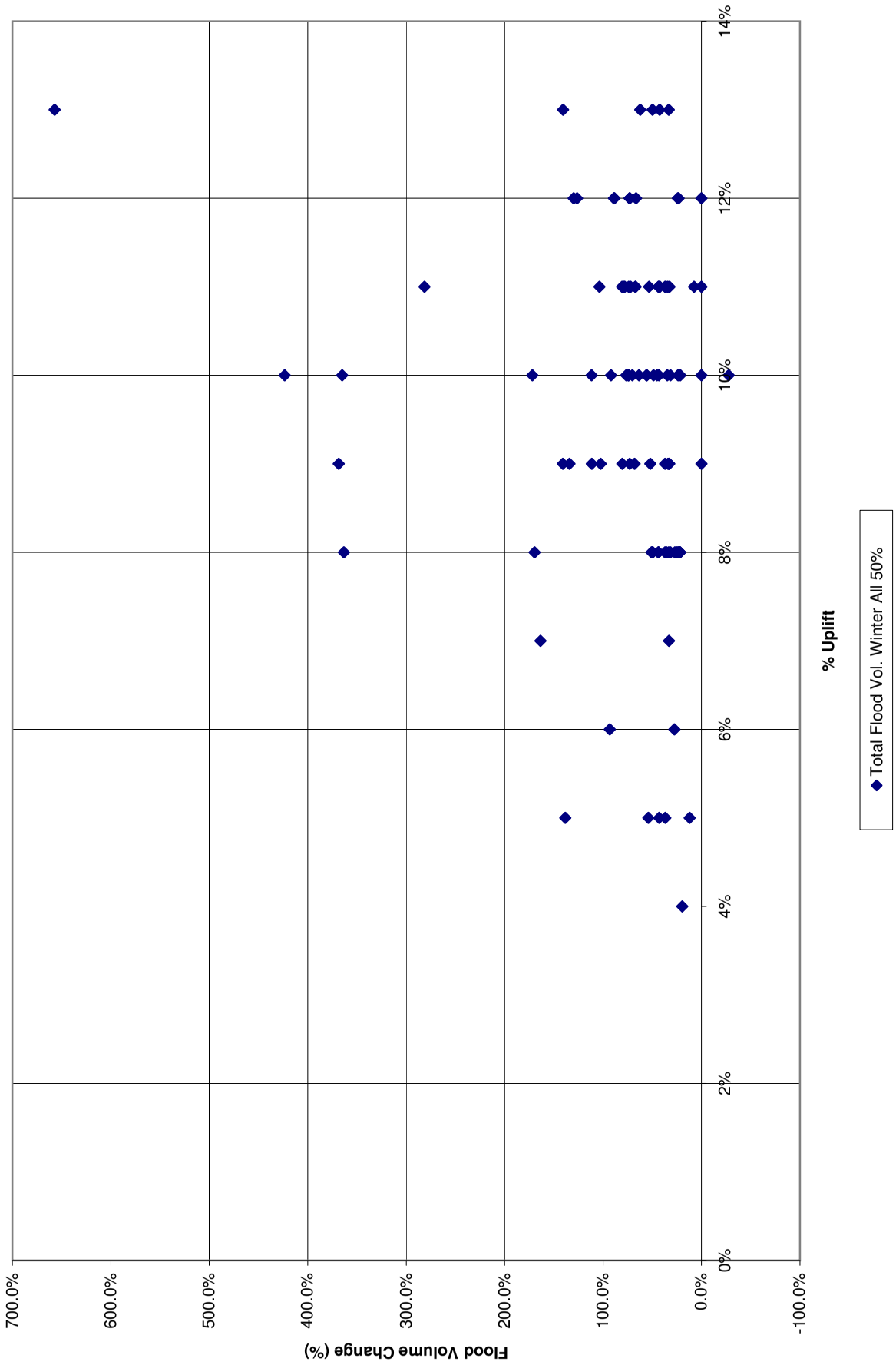

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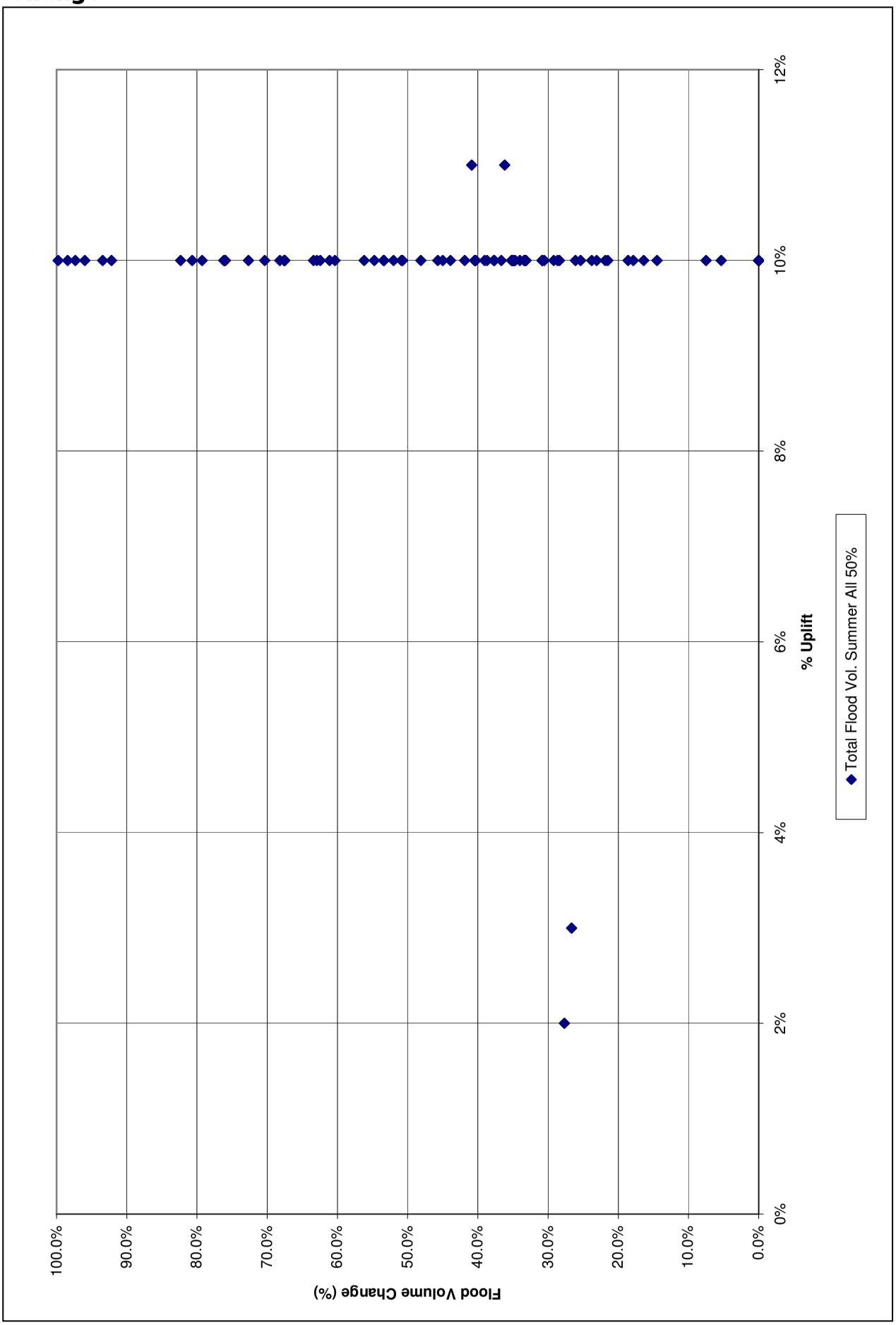
Figure B.22: Summer 50%ile All Change Scenario - Flood Volume Change



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Change in Number of Flooded Manholes

Figure B.23: Winter 50%ile Climate Change Scenario
Figure B.24: Summer Population Growth Scenario
Figure B.25: Winter Population Growth Scenario
Figure B.26: Winter Urban Creep Scenario
Figure B.27: Winter 50%ile All Change Scenario
Figure B.28: Summer 50%ile All Change Scenario

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Figure B.23: Winter 50%ile Climate Change Scenario - Change in Number of Flooded Manholes

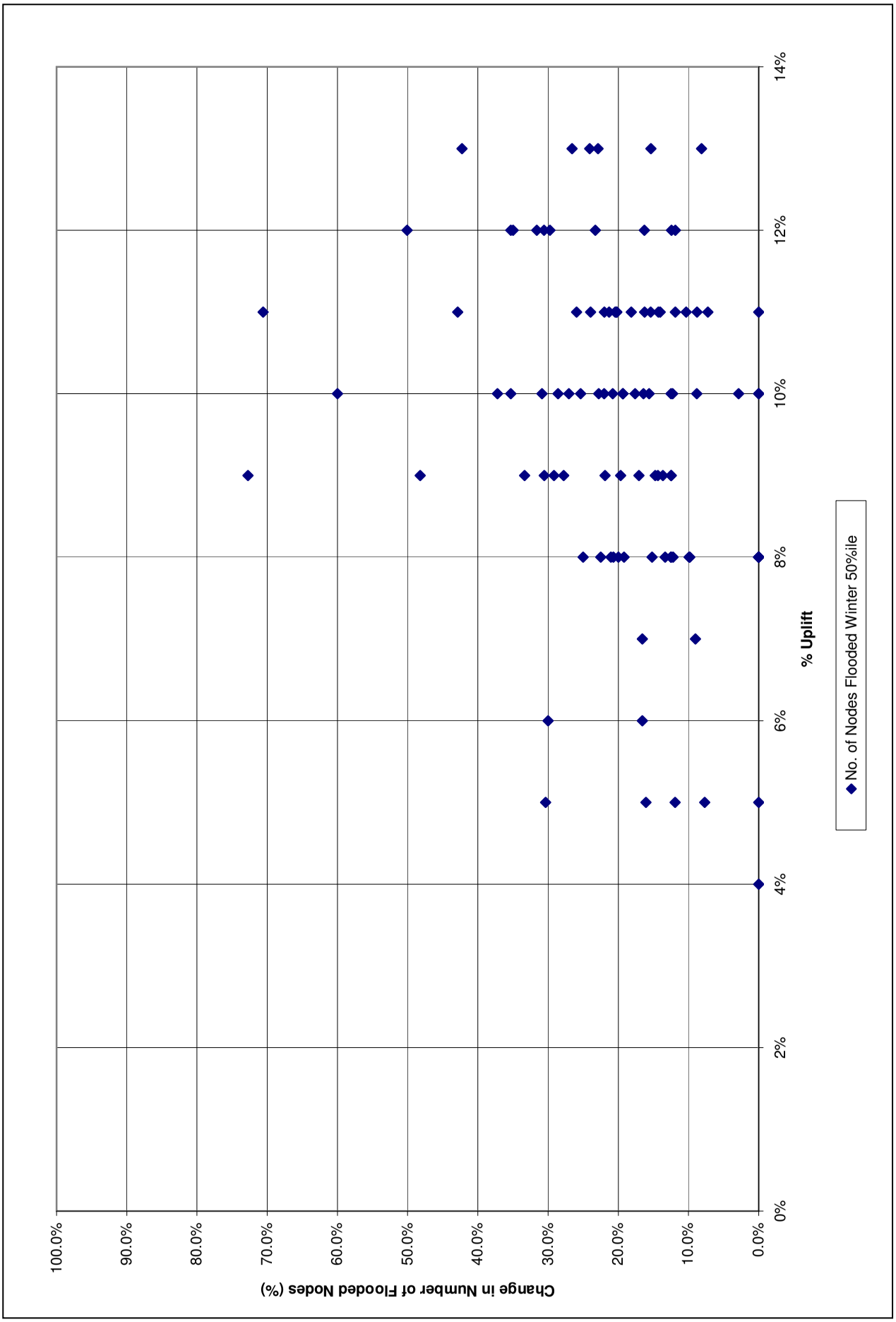

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Figure B.24: Summer Population Growth Scenario - Change in Number of Flooded Manholes

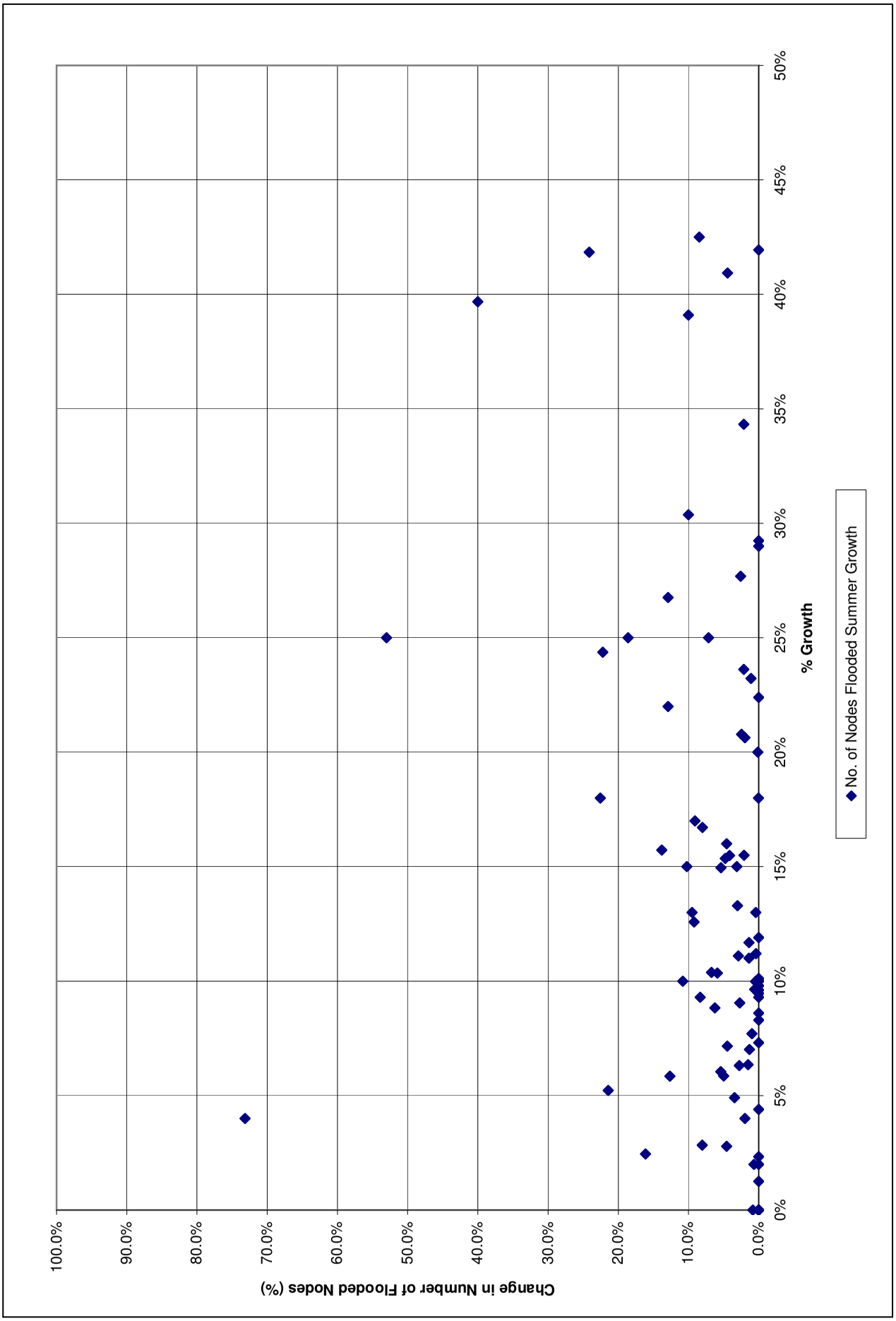

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Figure B.25: Winter Population Growth Scenario - Change in Number of Flooded Manholes

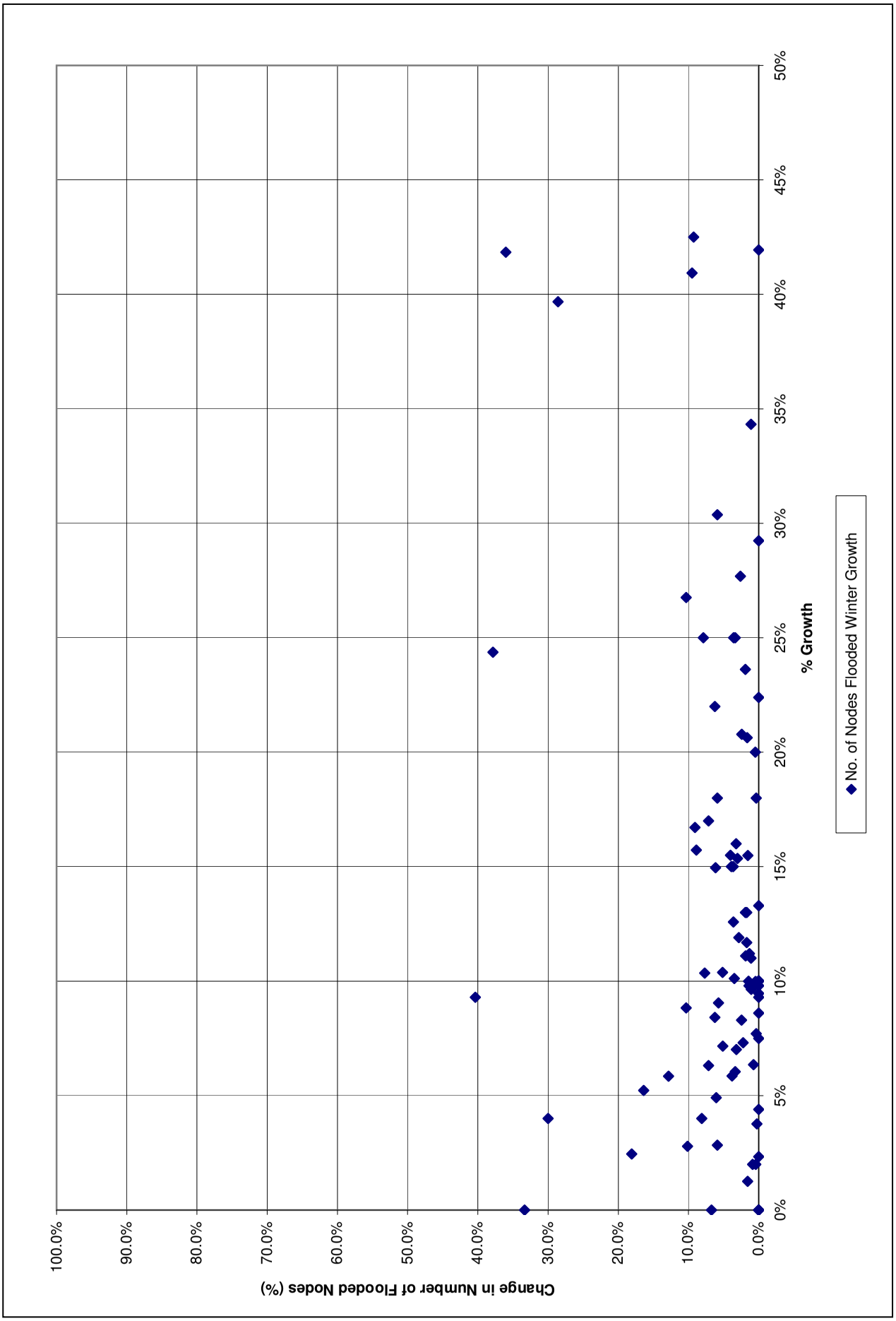

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Figure B.26: Winter Urban Creep Scenario - Change in Number of Flooded Manholes

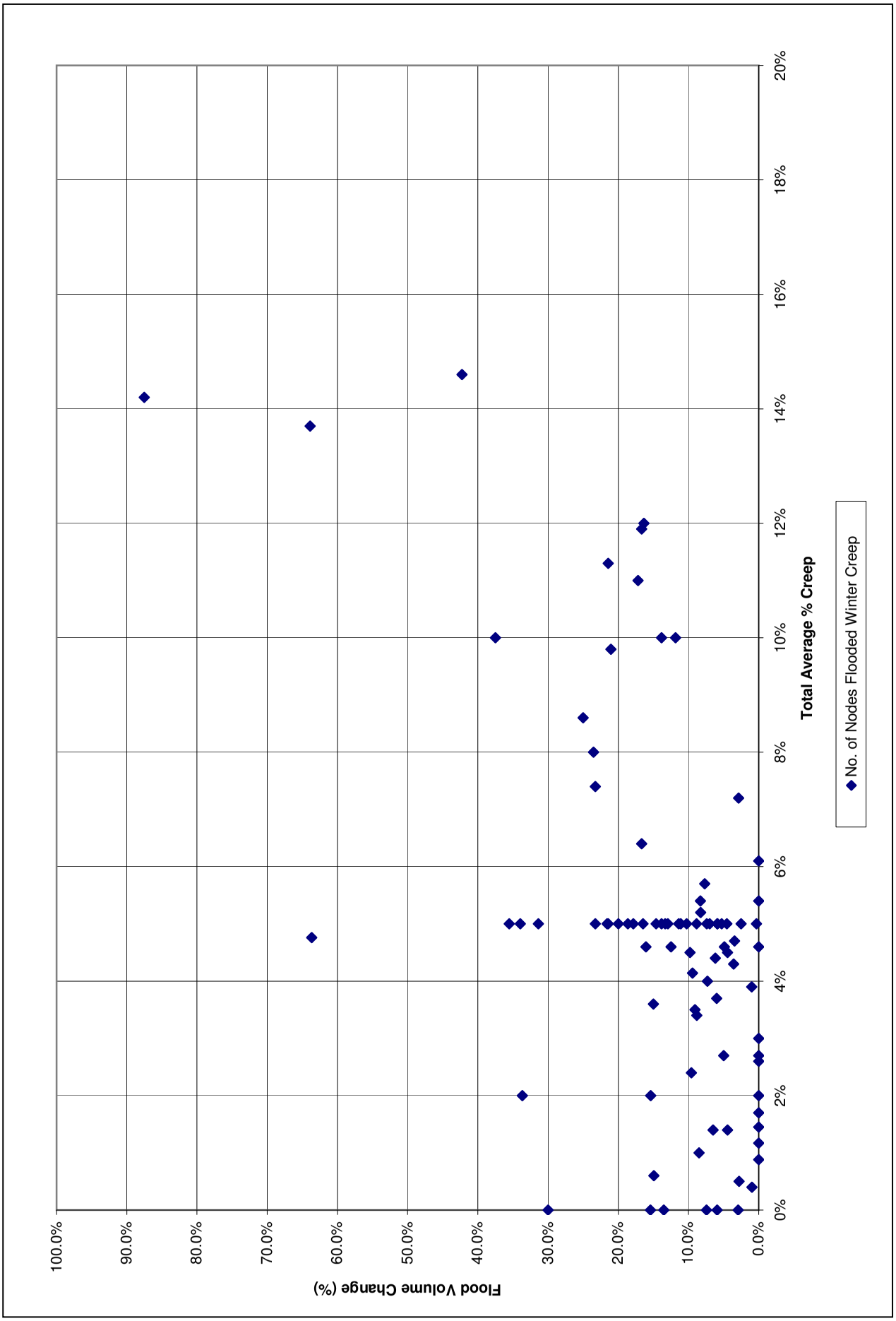

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Figure B.27: Winter 50%ile All Change Scenario - Change in Number of Flooded Manholes

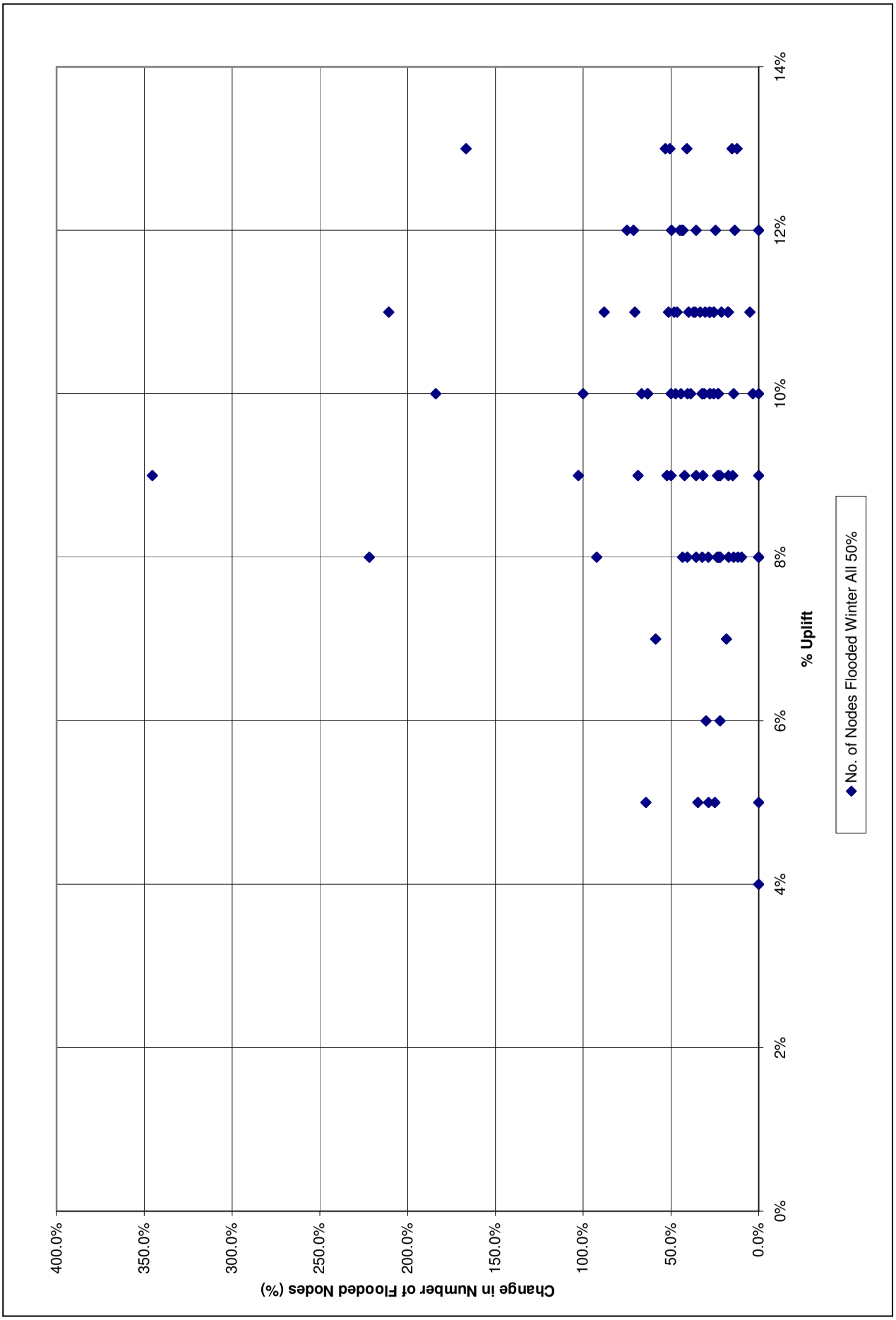

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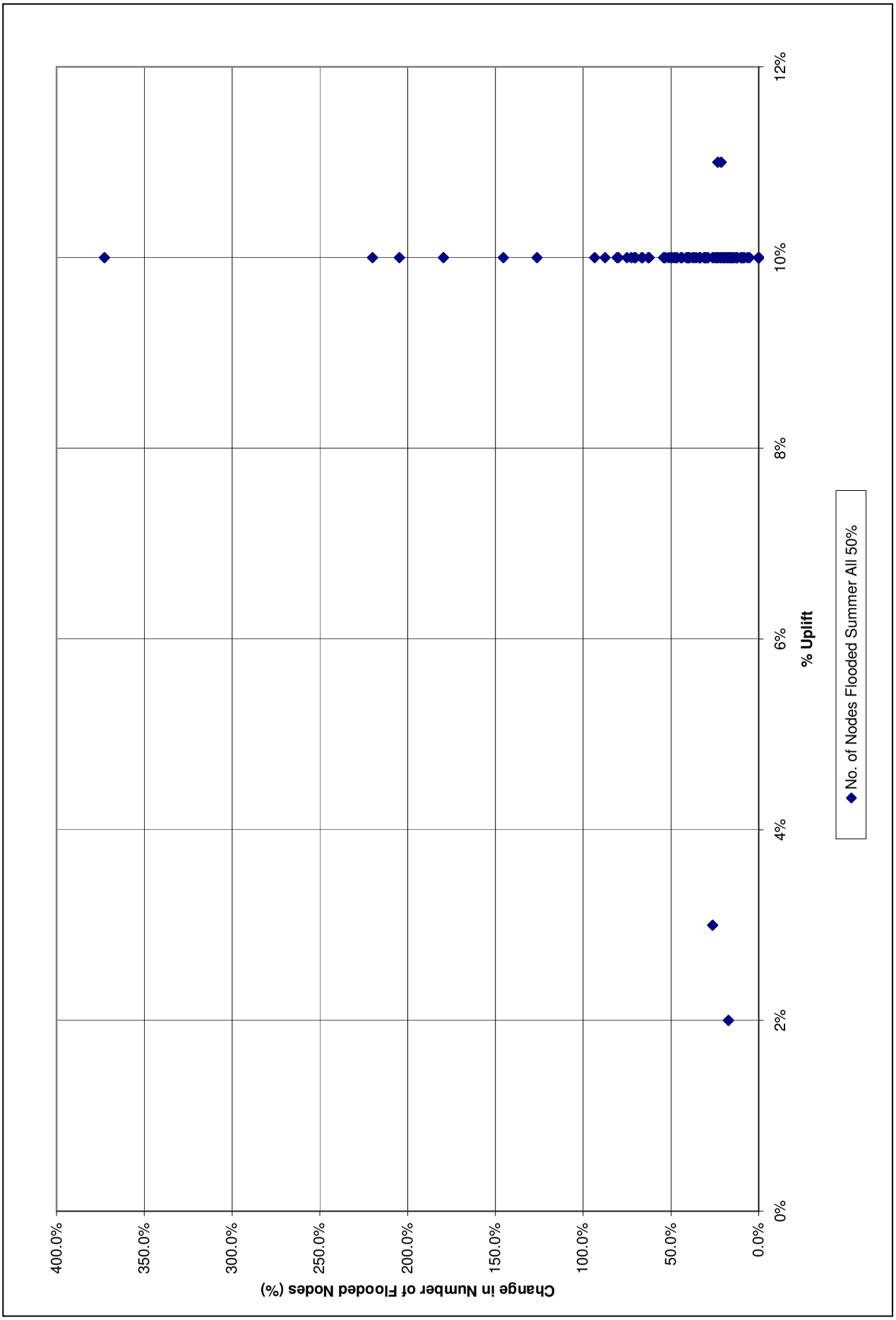
Figure B.28: Summer 50%ile All Change Scenario - Change in Number of Flooded Manholes



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Appendix C. Notes of the workshop held 9th December 2010

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Ofwat Evidence Base for Sustainable Drainage

Method for Selecting Catchments, Scenarios and Running Models

April 2011
Ofwat

Mott MacDonald

Ofwat Evidence Base for Sustainable Drainage

Method for Selecting Catchments, Scenarios and Running Models

April 2011

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Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
A	10/12/10	A Heather	C Wilson	P Chadwick	Draft external issue for comment
B	17/12/10	C Wilson	A Heather	P Chadwick	Final external issue
C	25/04/11	C Wilson	A Heather	P Chadwick	Names removed

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Content

Tables

Executive Summary

It will be important to quantify the impact of unconstrained and constrained growth, so that policy makers can understand the potential benefits of the Flood and Water Management Act.

Unconstrained growth – in which new development is allowed to discharge in accordance with current legislation (PPS25).

Constrained growth – in which we assume full implementation of the Floods and Water Management Act, with greatly reduced additional surface water flows to combined sewers.

Ofwat's 'Evidence base for sustainable drainage' will collate the results of sewer network models to provide a database describing the network's response to possible future changes, including – climate change, population growth, urban creep.

1. Introduction

Ofwat's 'Evidence base for sustainable drainage' will collate the results of sewer network models to provide a database describing the network's response to possible future changes, including – climate change, population growth, urban creep.

A draft method statement was circulated and reviewed by nine of the ten water and sewerage companies, at an expert group meeting at Ofwat on 09 December 2010.

This revised 'final method' is the result of the workshop with comments incorporated.

2. Scenario Definition

2.1 General

There was general agreement at the workshop that uncontrolled demand growth presented the greatest threat to sewer networks, as growth could happen faster and in a more concentrated manner than climate change.

Hence the focus of effort should be on understanding demand factors and their effects.

It will be important to quantify the impact of unconstrained and constrained growth, so that policy makers can understand the potential benefits of the Flood and Water Management Act.

- Unconstrained growth – in which new development is allowed to discharge in accordance with current legislation (PPS25).
- Constrained growth – in which we assume full implementation of the Floods and Water Management Act, with greatly reduced additional surface water flows to combined sewers.

It should be noted that hydraulic models generally do not include sufficient detail to assess basement flooding, (although in some cases where basement flooding has been reported they have been modelled). As a result it is difficult to predict the increased likelihood of flooding in basements when the number of basement properties connected by a gravity sewer to the main sewer is not fully known. The sewer model may predict an increase in surcharge that does not cause flooding at road level but which may cause flooding in a basement property. Basement flooding may therefore be under-estimated using this analysis.

Miscellaneous Actions

- Mott MacDonald to compare a storm from the InfoWorks weather generator with one from the Flood Estimation Handbook CD. (Some companies commented that they wanted to peer review the InfoWorks weather generator.) [This was investigated and is now believed to be an issue with FEH rainfall not accurately representing winter rainfall in the south east rather than issue with the InfoWorks rainfall generator. This is outside the scope of this study.]
- United Utilities to circulate the smoothed graph showing how urban creep varies with property density based on the UKWIR report Impact of Urban Creep on Sewerage Systems. [Sent.]
- Mott MacDonald to revise the catchment data table to include 'Topography' (flat, mixed, hilly) and 'Year of model update' in the table. [Carried out. Flat is defined as an average catchment slope <0.002, with steep defined as > 0.004.]

2.2 Climate Change and Rainfall

2.2.1 Rainfall

2.2.1.1 Background

The UKCIP09 web site provides cumulative frequency distributions of rainfall intensities for individual future decades. The benefit over UKCIP02 is that it takes better account of uncertainty, providing a probabilistic output.

The models have been run for different 'emissions scenarios', which affect the rate of forecast climate change.

Taking three probability scenarios and three emissions scenarios would result in nine modelling combinations.

Companies felt that climate change modelling could be addressed over the longer term for PR14, whereas development policy was more urgent.

However, if only one climate change scenario was modelled, then the benefit of UKCIP09 over UKCIP02 would be lost.

2.2.1.2 Method

- Use UKCIP09 medium emissions scenario for 2040.
- Use UKCIP09 50th centile (most likely) probability.
- Use 10% uplift on summer storms with percentage change in wettest winter day used as winter UKCIP09 rainfall predictions. (Guidance on how to use UKCIP09 website to follow.) Rainfall files for one in ten year storms will be adjusted by the appropriate percentage using the global multiplying factor on the design rainfall files within InfoWorks.
- Use nearest UKCIP09 25km grid square to the catchment being studied.
- Use UKCIP09 10th centile and 90th centile probability if resources can be made available to consider the range of climate change uncertainty. Mott MacDonald to coordinate the inclusion of these additional probabilities, to ensure a range is covered.
- Storm duration – companies to select the critical winter and (where appropriate) summer durations causing the greatest flood volume throughout the current catchment model; preferably including both a long- and short-duration event to run on the various scenarios. Up to three durations is considered preferable however where one is considered sufficient by the modeller this will be acceptable.

2.2.2 Rivers and Watercourses

In some catchments the water level in a river can have a significant effect on overflow discharges and hence on flooding. Whilst it is considered unlikely that average river levels will change significantly the effect of climate change on rivers cannot be easily quantified. However for many catchments river level has little or no effect.

2.2.2.1 Method

- Companies to include river level effects where they consider they are important. In the abscense of information on predicted river level rises, a 300mm increase in river levels should be applied to the modelled river levels. Where no river level has been modelled no further action is necessary.

2.2.3 Tide Impacts

2.2.3.1 Background

Tidal infiltration and saline intrusion are a problem in some catchments.

Sea level rise might have a small effect on existing infiltration, or reduce the operating time of outfalls that are not pumped. The change in tide levels due to climate change is not felt to be sufficiently significant to automatically include at this time.

The group considered there might be an effect in about 1 in 20 catchments.

2.2.3.2 Method

- Companies to include tidal effects in models if they consider it appropriate and to allow for a tide level increase in line with UKCP09.
- Companies to make clear where tidal effects have been included, and state the reason for inclusion.

2.3 Urban Creep

2.3.1 Background

United Utilities plotted a graph of the results of the various methods from the UKWIR methodology. The curve fitted to that allows an estimate of urban creep in m^2/property/year, according to property density per 4ha.

2.3.2 Method

- Companies to take urban creep forecasts from the graph. The files are attached to the email copy of this report.
- Where not able to apply (e.g. because do not have property density data) then assume an increase of 5% on the current connected impermeable area up to the 2040 planning horizon, with a reduction in modelled permeable area accordingly.

2.4 Population Forecasts

Companies have population forecasts for the year 2031 for each WWTW, produced for PR09. The challenge is how to locate the forecast development in the catchment. It was agreed not to allocate population increases evenly across the catchment as this is generally an unlikely scenario and will underestimate the impact of population growth. The scenario with full implementation of F&WMA, so that the impact of the proposed legislation can be understood will be included in later stages of the project.

2.4.1 Method

- Companies to use PR09 population forecasts.
- Do model the realistic worst case – i.e. application of PPS25 only. This will enable understanding of the worst realistic impact on the network.
- If catchment model has detailed locations of proposed developments, use those, connecting to the closest manhole to the development.
- Where development data is known and *in the absence of local guidance/standards*:
  - In separately sewered areas assume development is also separately sewered
  - In partially separate or combined areas, if boundary of development is within 200 metres of a watercourse assume development is separately sewered
  - In partially separate or combined areas, if boundary of development is not within 200 metres of a watercourse assume development is served by a combined sewer
  - For developments served by combined sewers assume 50% impermeable area for unrestricted flows or 5 l/s/ha for attenuated flow
  - Occupancy rate in line with population forecasts (alternatively use 2.5)
  - Per capita consumption in line with per capita consumption locally (alternatively use 155 l/h/d)
  - For infiltration related to development, assume value in line with local infiltration rate (alternatively use 10% of development foul flow rate)
  - For light industry/commerce assume $10m^3$/ha site area/day foul flow
  - For medium industry/commerce assume $20m^3$/ha site area /day foul flow
  - For heavy industry/commerce assume $30m^3$/ha site area /day foul flow

- For office developments assume 1 employee per 10m^2 floor space (if known) and 65 l/employee/day foul flow
- For separately sewered developments assume 5m^2/property of proposed development area as paved area to allow for property creep.
- Assume (Current Population x Projected % Population Increase) – Additional Modelled Development Population = General Increase to Existing Modelled Population. If in the opinion of the modeller a significant increase in the general population is calculated, consideration should be given to creating assumed developments as noted below.

- If no detailed development forecasts exist, then as a last resort assume development is split in three point locations based on areas that could be developed – lower-, mid-, and upper-catchment to the nearest trunk sewer.

The company visits will be used to document the choices made on the above development issues for each catchment.

3. Catchment Selection

3.1 Background

Mott MacDonald proposed selecting a shortlist of 10 catchments from each company, from a long list of data provided by the companies,

Companies have not collated the results of all their models. Therefore, to complete the proposed table, all the models would have to be opened to extract the data: this cannot be achieved in the short timescale for model selection given the project deadline.

Mott MacDonald and Ofwat want to be confident that a representative selection of catchments has been included in the study.

Many companies have not modelled small catchments having no current or forecast flood issues, so it will be difficult to cover the 'good performing' catchments and this might introduce some bias to the study.

Models will not be revised specifically for this study – they will be run as they are.

3.2 Method

- Companies to propose a shortlist of 15 catchments each based on the best available models in the companies' possession.
- Companies to complete the 'catchment data' table for the 15 proposed catchments.
- Mott MacDonald will review the company lists and select 10 from each company, for inclusion in the study.
- During the company visits, Mott MacDonald will review the choices and document the rationale for selection, and potential limitations/results bias that is inevitable given the limited choice of models.
- Run models for the network 'as built' not 'as designed' where available.

4. Simulations and Results

The models used and created for the scenarios should be free of operational problems, e.g. all pumps operational, no silt.

Table 4.1: Scenarios to be Run

Scenario	Low Projection	Most Likely Projection	High Projection
Current Model		✓	
Scenario 1 – Population Forecasts – see Section 2.4	Where possible	✓	Where possible
Scenario 2 – Property Creep – see Section 2.3	Where possible	✓	Where possible
Scenario 3 – Climate change – see Section 2.2	Where possible	✓	Where possible
Scenario 4 – All three variables above applied	Where possible	✓	Where possible

The output from the model to be supplied to Ofwat will consist of a spreadsheet for each scenario and the current model containing manhole numbers and maximum flood volumes for the range of runs as shown below.

Table 4.2: Sample Output

Node Reference	M10-30W	M10-60W	M10-300W	M10-30S	M10-60S	M10-300S
TQ12345678	e.g. 10 year 30 minute Winter	e.g. 10 year 60 minute Winter	e.g. 10 year 300 minute Winter	e.g. 10 year 30 minute Summer	e.g. 10 year 60 minute Summer	e.g. 10 year 300 minute Summer
TQ12345679	10.1	10.2	10.3	15.1	15.2	15.3

Reporting will be limited to the recording of the amendments to the models during the company visits as much as possible.

5. Timescales

In order to contribute to Defra's white paper on water, the project results will need to be available during March 2011.

Ofwat's requirement is for the project report to be completed by the end of March 2011.

The timescale below will provide substantive results in time to contribute to the white paper.

Table 5.1: Timescales

Activity	Responsible	Deadline
Start-up workshop	All	09 December 2010
Confirm final method	Mott MacDonald	17 December 2010
Agree catchments to model	All	07 January 2011
Company meetings with Mott MacDonald to review models	All	Before 11 February 2011
Run models and report results (cut-off)	WaSCs	04 March 2011
Prepare draft report	Mott MacDonald	11 March 2011