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Development of a semi-Quantitative Risk Based Methodology to Rank Water Industry Assets to their Need of Monitoring in Light of the Impacts of Climate Change

By
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the MPhil and/or the DIC

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I declare that this thesis

Development of a semi-Quantitative Risk Based Methodology to Identify the Monitoring Requirements of the Nomenclature of the Water Industry Assets in Light of the Impacts of Climate Change

is entirely my own work and has not been submitted previously for any other degree. Any material that could be understood as the work of others, it is fully cited and referenced.

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Abstract

Over the course of this century water will become ever more critical to people and business. A growing world population and increasing living standards will drive inexorably rising demand for water, yet at the same time climate change means that our planet will likely to face an increase in both the magnitude and frequency of extreme weather events. Water utility companies are starting to realise the importance of addressing the need of monitoring the impacts of climate change to their assets and ways to adapt.

To date, there is no literature that shows a methodology in which water utility companies can effectively rank their assets in terms of their need of monitoring. This study is targeted to the water industry sector, and uses a semi-quantitative risk approach to assign vulnerability and criticality scores to assets in order to create a total risk score. The scores are presented through a risk matrix, which provides a guidance on assets that are most at risk.

A various based sensitivity analysis was applied to the output, a risk tool, and shows that the final risk scores largely reflect the current literature review on how climate change impacts affect water industry assets.

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Contents

1 The Need to Address the Impacts of Climate Change on the Water Industry

Chapter 1, provides an argument for the importance of addressing the impacts of climate change to the water industry. The argument is created through a narrative, explaining the importance of climate change and its impacts to the water industry. The narrative starts from a broader context and then focuses on the operational impacts of climate change to the water treatment and wastewater treatment processes.

The science of a changing climate tells us that we are likely to face increasingly extreme patterns of weather. There will be more droughts, and more floods, over the decades to come (IPCC, 2013). River flows will be both lower and higher than have been familiar in the past. We are going to have to get used to more unpredictability, more variation, and more extremes (Arup, 2015). The general consensus amongst the scientific community is that climate change is happening as a result of anthropogenic greenhouse emissions (UKWIR, 2007) and according to the fifth Intergovernmental Panel on Climate Change (IPCC) report, it is almost certain that humans are the dominant cause of climate change (IPCC, 2013).

For the last two years, the World Economic Forum's Global Risks report has identified water crises, climate change adaptation and extreme weather events in their top ten most significant risks likely to affect the world, in terms of likelihood and impact. For many, water is regarded as an infinitely available, inexhaustible, free resource. In reality, it is one of the most precious and finite resources that we have. And we depend on it to sustain life, wellbeing, food and farming, much of industry and the ecology of our rivers and lakes.

The impacts of climate change are recognised by the UK water industry and regulating bodies to have adverse effects upon the future supply and demand of potable water. Within the domain of the water utility industry, climate change is set to exacerbate the challenge of supplying potable water and further stressing asset systems for water management, subsequently increasing costs for water companies. UK water utility companies are starting to think strategically about how to minimise the climate risks on fresh water availability, demand and management for the longer term. For example, Anglian Water's '*Strategic Direction Statement 2010-2035*,' (Anglian Water, 2007) recognises that climate change is their biggest business risk over the next twenty five years and that climate change adaptation and mitigation are their highest priorities. In order for Anglian Water to meet their longer term strategy, they have put in place shorter term business plans, as part of their 'Love Every Drop Campaign,' a strategy geared towards revolutionising the way water is thought of and used. Anglian Water understands that a sustainable future, through a fundamental change in their business approach, can only be successfully met through collaborating with the wider stakeholders. As for Anglian Water's shorter business plans, described in their 2015-2020 business plan (Anglian Water, 2012) climate change mitigation has been set as two of their business goals; halving embodied carbon in new assets by 2015 from 2010 baseline and reducing operational carbon by 2015 from 2010 baseline. Climate change adaptation on the other hand is not explicitly mentioned in Anglian Water's 2015-2020 business plan, because it is a culmination of meeting different objectives over a longer period of time in order to minimise the risks of the impacts of climate change.

All major UK water utility companies, like Anglian Water, have recognised the impacts of climate change as part of their 25 year strategy plan. They have realised that climate change poses a big threat to their organisation and customers but have yet to come up with a comprehensive and clear plan as to how they will address these problems for the coming decades. There is no clear-cut solution to climate change. Responses to climate change must be tailored in accordance to the nature of the impact but also the nature of vulnerability (UKWIR, 2007).

1.1 Challenges Faced by Water Utility Companies

Many of the challenges faced by all water utility companies are based around technological and data challenges. The UK water utility companies, as a whole lacks a cohesive data strategy on their assets and for this reason there is a lack of an effective data management system in place. In turn this can hinder the effectiveness of the water utilities risk management system on their assets. The lack of paucity of performance asset data in response to both the short and long term impacts of climate change will lead to an increase of asset cost in addition to a reduction of asset life and its ability to supply potable water during extremities in weather conditions.

The full and complete integration of asset data systems is a considerable, if not currently insurmountable, challenge for a water utility. The importance over time of data acquisition, data logging and data monitoring of water assets has grown in both value and importance to the water industry. Because water infrastructure assets have long life cycles, some of which are over 100 years old, (Mott Macdonald, 2011)*,* this means that data collection were not consistent and so there remains a gap in the databases for these assets. Ambrose et al. (2004) state that water companies have data sets that are often incomplete and/or are of a limited time period, and in some cases are inconsistent for some water infrastructure assets. However, the expanding potential of data acquisition, storage analysis technologies is creating new opportunities and challenges for asset management in water companies. Historically one of the main challenges for data acquisition may have been the lack of technology to gather sufficient data to effectively manage assets on the basis of risk. Using technology to obtain real-time data is an area that is being developed in the water industry. Telemetry systems can capture data in real time and water companies are starting to monitor, measure and analyse assets (Newton, 2010). Although telemetry systems are nothing new, there is a gap in how that data is collated and analysed in the water industry. Today the challenges are largely associated with appropriate use of available technologies. The technology is available, but water utilities are struggling to manage and interpret the data.

Good business decisions are, or at least should be, based on quality data. Good information is dependent on maintaining quality in the acquisition, storage and combination of data and also the appropriate level of analysis and interpretation of data. Definitions of what constitutes information quality vary but 'fitness for use' is the most accepted (Amadi-Ecchendu et al. 2012). However, this may over simplify the many facets of data that determine quality. These have been identified as *'accuracy, reliability, importance, consistency, precision, timeliness, fineness, understandability, conciseness, and usefulness'* (Koronios & Lin 2005).

Challenges for acquisition and analysis of different aspects of data quality have been summarised in Table 1 as below.

Table 1: Asset data quality, acquisition and analysis challenges for water utility companies

Quality aspect	Acquisition challenge	Analysis challenge
Accuracy	Ensuring data is representative	Effective estimation of uncertainty
Reliability	Minimising sources of error	Identifying unreliable data
Importance	Prioritisation of costly data gathering	Prioritisation of analysis
Consistency	Effective maintenance of technology systems and people	Filling missing data
Precision	Ensuring data is representative	Effective estimation of uncertainty
Timeliness	Efficiency of processes	Adapting to changing requirements

Fineness	Appropriate sampling	Effective aggregations / disaggregation
Understandability	Effective metadata	Understanding data acquisition
Conciseness	Appropriate sampling frequency	Finding data
Useful	Collecting the right data	Analysing the right data

The fundamental knowledge gap for water utility companies is based on data acquisition, data management and how data is analysed to provide meaningful information.

For example, as most assets do not exist in isolation, decisions should be taken to optimise value from the asset system as a whole. Monitoring asset data tend to be applied on individual assets. Therefore, there is a knowledge gap on how monitoring data strategies can be applied to an asset system, consisting of two or more assets working together. This will enable a direct comparison in performance between the individual asset and the asset system and weaknesses in the system can be identified more readily.

Water companies also lack the specialist employee skillset to analyse and interpret data scientifically. The Economist (2012) produced a report on the future of water utilities and conducted interviews with water executives, who stated that there is a serious skills gap in the industry.

Not only do the data analysis skills within the water industry need to develop, but the skills of analysing and implementing a robust risk management system need to develop as well. Water companies need to fully understand the implications of risks and the uncertainties of infrastructure assets – these can last for decades - and the importance of risk management and how it can have huge investment consequences if mismanaged

A sudden need to enhance capital performance to address high priority issues can lead to isolated asset data systems. Where appropriate, isolated asset data need to be integrated with other asset data – another example of a data knowledge gap for water utilities.

1.2 The Impacts of Climate Change faced by Water Utility Companies

This section provides a high level overview of the operational treatment process impacts of climate change on water company's assets. The impacts of climate change on water resource assets in addition to all other type of assets as described in Table 2 will be reviewed. This chapter splits the impacts of climate change into two themes:

1. A continuous (but gradual) increase in temperature and sporadic rainfall over the coming decades
2. Intense weather extremities, i.e. flash floods over the coming decades

A plethora of information is available on the impacts of climate change on land, urbanisation, rivers, and social infrastructure and has been widely studied and documented. Not only has the effects of climate change been extensively investigated in itself but has been done so in combination with other factors such as urban creep, agriculture and population growth. In this context, the water industries asset nomenclature refers to water infrastructure, non-infrastructure, and wastewater infrastructure and wastewater non-infrastructure. Table 2, below summarises the assets.

Table 2: Categorisation of type of water industry assets

Category	Type of asset
Water Infrastructure	Drinking water distribution assets
Water non-infrastructure	Drinking water treatment assets
Wastewater Infrastructure	Sewer assets
Wastewater non-infrastructure	Wastewater treatment assets

The cause of the impacts of climate change on water utility assets is multidimensional because the impacts on water utility assets are so complex and non-linear. The cause of many operational or performance controls of assets cannot be attributed to only changes in rainfall or temperature. Many impacts are because of a combination of both, changes in temperature and rainfall, leading to changes in physical, biological and chemical processes, which ultimately impact the asset in some way. For this reason this section does not aim to explicitly categorise each impact to a single climate change parameter.

1.2.1 Climate Change Parameters

There is no standardised definition for 'climate change parameters,' within the field of environmental science. Different studies have called this somewhat ambiguous term, different names. Astaraie-Imani et al. (2012) studied the impacts of climate change on receiving river quality and chose rainfall to be the 'climate change indicator,' and the indicator was represented by using the following two parameters; rainfall depth and rainfall intensity. Mimikou et al. (2000) assessed the impacts of climate change on water resources by identifying and quantifying key future climate change parameters through the use of general re-circulation models (GCMs) and emission scenarios and applied these results to hydrological models to determine the resultant impacts. According to this study the input parameters that were applied to the hydrological model were defined as precipitation, temperature, relative humidity, sunshine duration and wind speed. These parameters could be interpreted simply as weather changes, however, what differentiates them is the measure of time. Weather is what conditions of the atmosphere are over a short period of time whereas climate is how the atmosphere "behaves" over relatively long periods of time. Therefore in this context, a climate change parameter describes a pattern or trend that takes place over a larger period of time, i.e. 100 years.

Numerous studies have approached the impacts of climate change phenomena on water company assets in a similar fashion to that of Mimikou et al. (2000) and all have shown to have identified identical climate change parameters. For example a number of authors (Koutroulis et al., 2013, Tong et al., 2012, Whithead et al., 2006) all adopted a similar approach to assess the impact of climate change on the water resources and nitrogen levels in low lands and for all three studies it is found that the key identified climate change parameters that is intrinsic to their work, were precipitation and temperature. What differentiates one study to another is the applied GCM, hydrological model and emission scenario, however the underlying principle of identifying and inputting the climate change parameters remain the same.
Secondary climate change parameters such as evapotranspiration and soil moisture were also identified (Whithead et al., 2006) however they are the antecedent effects of changing rainfall patterns and temperature. Park et al. (2009) states that changes in temperature and precipitation, in addition to extreme weather events, can lead to changes in land surface geomorphic or hydro-biogeochemical processes as well as deterioration in water quality. Therefore, for this study, precipitation and temperature will be taken as the principle climate change parameters and here on climate change parameters refer to increased precipitation and temperature.

1.2.2 The Water Utility Cycle

This section focuses on the impacts of the 2 main climate change parameters (rainfall and temperature) on the key areas of the water utility cycle; combined sewer overflows (CSOs), urban catchments, rivers and wastewater treatment

CSOs and urban catchments

Rainfall events, in conjunction with CSOs are known to increase the level of multiple water quality parameters such as organics, turbidity, suspended solids and microorganisms (Gasperi et al., 2008; Fong et al., 2010) that can enter surface waters. Studies have also shown that the impact of rainfall events, and subsequently CSOs and storm water discharge impacts, can lead to higher concentrations of water borne enteric viruses (Le Guyader et al., 2006; Ashbolt et al., 2010). Hata et al. (2014) investigated the effects of rainfall events and water quality, based on the detection of viruses in river water samples. It found a negative correlation between suspended solids, generated from the impacts of storm water runoff and viruses, although found that concentrations levels of enteric viruses were generally higher during rainfall affected periods compared with dry weather periods.

Semadeni-Davies et al. (2008) assessed the potential impacts of climate change in a combined sewer and used a similar approach as Koutroulis et al. (2013), Tong et al. (2012), Whithead et al. (2006) and Mimikou et al. (2000), as described in section 2.2.1. In that particular region, Helsingborg, rainfall and storms are the drivers for overflows of untreated wastewater to the coastal receiving waters, causing major pollution problems. Climate change will only exacerbate the problem, through heavier and more intense rainfalls. The main conclusions of the work were that: "*the impact of climate on inflows to the WWTP was seasonally variable due to changes in the snowmelt cycle; and renovation to the system with respect to sewer infiltration has a potential to change inflows which is at least as great as climate change."* The study identified sewer infiltration, overflow of combined sewers and pumping station overload as the main impacts of climate at the WWTP. Overflows will inevitably increase ammonia and pollutant loads.

Urban catchment areas have their own unique set of problems. In urban areas, where there are impervious surfaces, storm water runoff can increase the concentration of harmful organic water pollutants that can be detrimental to water quality in rivers. Storm water runoff combined with high temperatures on a typical summer's day can further impact local surface waters and wastewater treatment plants. Sabouri et al., (2013) assessed the warming effect of the impervious surfaces on storm water runoff temperature in urban catchment areas. Thermal pollution from urban runoff is a significant contributor to the degradation of cold water ecosystems (Herb et al., 2008) as it decreases levels of *dissolved oxygen* (DO). Lower concentrations of DO can potentially kill aquatic life and in areas where fertilisers are used by farmers, algal blooms can potentially occur (Misra et al., 2011). Dead aquatic species found in abstracted water caused by thermal pollution because of urban storm water runoff impacts overall water quality (Guyader et al., 2006).

Therefore the impacts of rainfall and possibly rainfall combined with high temperatures can potentially create problems when abstracting water from rivers for municipal drinking water. Sometimes, river water that contains wastewater discharge upstream is used as a water resource downstream. In such circumstances when there is heavy rainfall, water contamination is higher due to CSO and storm water overflow and subsequently water treatment and wastewater sites are under more stress. On a micro scenario, a water cycle becomes apparent. Omitting the natural hydrological cycle, or when water abstracted is abstracted from surface waters where water is directly fed from mountain glaciers, there is an emergent water cycle that is depicted below in Figure 1.

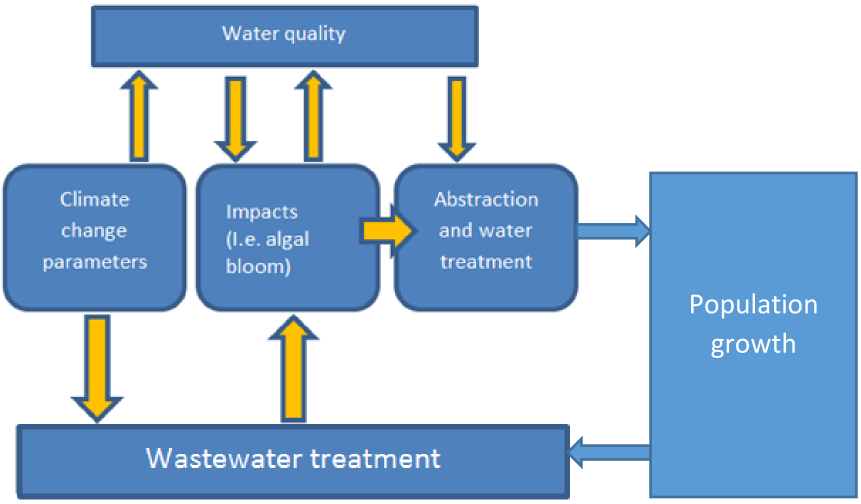


Figure 1: Interactions of the water cycle

Figure 1 illustrates the various interactions between water quality, climate change parameters, drinking water and wastewater and how they are all interrelated. Population growth only exemplifies the impacts through the provision of higher supply and demand of water. Climate change parameters, i.e. changes in temperature and rainfall is the driving force of all impacts such as increased DO, algal blooms, thermal pollution that cause water quality issues and subsequently the need for high level of wastewater and potable water treatment. As for potable water treatment- abstracted water from rivers that may carry CSO discharge only several miles upstream, during heavy rainfall, may potentially pose as a threat to the receiving water treatment plant. Rainfall can potentially increase the concentration of enteric viruses found in surface waters, and through storm water increase concentration levels of suspended solids and metals. The culmination of the increase of loads will stress water treatment sites for municipal water. Wastewater treatment sites are also subjected to potential threats of intense rainfall. Extreme rainfall can generate large quantities of storm water, which can enter the wastewater collection system via sewer manholes, ground infiltration, faulty connections, and leaky or broken pipes (Droste, 1997).

During periods of intense rainfall, not only can storm water carry higher amounts of pathogens, but it also increases the flow rate to the wastewater treatment plant and in many instances, the flow rate exceeds the plants' treatment capacity and can impact treatment performance (McMahan, 2006). Discounting the effects of impervious surfaces on storm water, extreme rainfall can also cause erosion and landslides that increase turbidity of river water and influent wastewater. Conversely, rainfall can also dilute sewage waste, lowering concentrations of biological oxygen demand (BOD) and chemical oxygen demand (COD) in conditions where it is not mixed with storm water. This can easily be perceived to be an advantage for the wastewater treatment site, however during high hydraulic inflows, the treatment plant simply cannot keep up and as a result CSO overflow occurs. Furthermore, the inflow of water may carry storm water runoff and hence more levels of suspended solids and inorganic pollutants, which will cause blockages in the primary treatment processes, i.e. screening. McMahan (2006) and Mines et al. (2007) concluded that on average total volumetric flow, BOD and total suspended solids increased during rainfall at wastewater sites that also had storm water runoff as the influent.

The stability and efficiency of biological phosphorus removal (BPR) processes for wastewater treatment can be disturbed by several factors. The main reason for deterioration of BPR under low COD loading regime is excessive aeration of activated sludge. One of the main factors is heavy rainfall and higher hydraulic loading which temporarily causes lower sewerage loading and increases DO. Under such conditions, BPR efficiency is reduced (Brdjanovic et al., 1998). BPR efficiency decreases during aeration of activated sludge therefore affecting the water quality of the effluent. In addition, as mentioned above, dead aquatic species found in abstracted water caused by thermal pollution and in some cases, algal blooms, because of urban storm water runoff.

<u>River Water Quality</u>

Although many impacts of river quality has also been mentioned, this section solely focuses on the direct impacts of river water quality and it's composition because of climate change effects UKWIR (2006) used a catchment hydro model in conjunction with UKCIP 1998 medium-high emission scenarios for the 2080's to predict the impacts on UK rivers. Nitrate, water temperature, dissolved organic carbon (DOC), BOD*,* phosphorus concentrations were all projected to increase, while ammonia concentration to decrease. The conclusion from this report was that climate change has a noticeable effect on river water quality. Consequently treatment costs would increase and changes in water quality would cause a change in reservoir water dynamics.

Astaraie-Imani et al. (2012) found that rainfall depth, relative to rainfall intensity, had the greater significance on river water quality. The study used DO and ammonia as measurable parameters to represent water quality and concluded that both will exceed the allowed threshold, however DO would be more severe and frequent than ammonia. It also found that the maximum outflow rate from the sewer system to the combined sewer is the most significant operational control parameter in terms of complying with the DO standard in the river under the climate change. This operational parameter was also found to have direct impact the water utility treatment works and therefore the ability to significantly drive water company's costs up.

Mimikou et al. (2000) assessed the impacts of climate change on river water quality in Pinios river basin, central Greece using GCM-based climate change scenarios over a 12 month period. It concluded that BOD and ammonia values increased, while DO decreased. Van Vliet et al. (2008) investigated how droughts effects river water quality using a time series analysis based on existing water quality data and confirmed water quality deterioration in River Meuse during droughts. What is interesting perhaps is that most studies on climate change impacts and river quality tend to yield similar results in increases in contaminants, except for DO. This may be due to rivers having different geographical-landscapes and environments or it may have to do with the inherent uncertainty involved in the models and simulations used by different studies.

Algal Blooms

A strong relationship has been identified between climate change parameters and algae growth, George (1991). Algae blooms can potentially create both chemical and physical concerns for water treatment works. Not only can it create nutrient and DO fouling but it can also create filter blockages and odour issues. An increase of algal concentrations can create serious operational problems for water treatment plants and increase the cost involved in the provision of potable water (Alameddine, 2012).

While algal bloom occurrence is a complex and nonlinear phenomenon, which is governed by a variety of physical, chemical and biological processes (Chen et al.,2014a), from a macro perspective the main contributors to algae growth are only influenced by water composition, pH level, nutrient composition, salinity but also temperature and sunlight.

The effect of temperature on algal blooms and toxicity is complex (Graneli et al., 2012). Different species react differently to temperature and other parameters, when combined with temperature, such as water salinity, also have implications on algal growth (Baker et al., 2009). Patino et al. (2014) found salinity to be the most important known variable influencing algal growth in inland waters however Baker et al. (2007) found no interaction between sunlight, salinity and temperature. Studies agree that on average, most algal species favour temperature rise (George, 1991, X. Lui et al., 2011, J. Baker et al., 2007, Hunter et al., 2003). Nutrient composition is another important variable that can affect algal growth. Higher temperatures will increase mineralization and releases of nitrogen, phosphorus and carbon from soil organic matter (Delphi et al., 2009) and algal growth is expected to rise due to higher levels of nutrients. Under all emission scenarios, it is expected that temperatures will rise during summer months coupled with lower rainfall leading to reduced river levels in some water bodies and therefore make them more prone to experiencing algal blooms. Considering the expected increase in sunlight would also aid the photosynthesis of the algae (Alameddine, 2012). Chen et al. (2014b) conducted a controlled experiment that demonstrated the link between toxic algal blooms and light-shading measures. It was found that harmful algal could be controlled by light-shading, with water quality being partially improved.

On average, temperature rise, lower precipitation and more sunlight will exacerbate algal growth and deteriorate water quality in reservoirs and lakes and will ultimately drive operational costs up.

Dissolved organic carbon, (DOC)

Tong (2010) studied the potential effects of climate change on quantity and quality of DOC. His conclusion was that short term draught events, combined with gradual temperature increase and consequently low flows may mean increased DOC concentrations that have potential to impact water quality. As a result DOC increase will stress water treatment works operations and risk future incompliance with regulatory water quality standards.

Delpla et al. (2009) and Evans et al. (2005) confirmed that DOC concentrations were expected at higher temperatures and higher rainfall. A combination of various factors affect trends on DOC, however regarding climate change drivers and water quality, erosion and runoff of low flows during droughts are one of the reasons why DOC levels are expected to rise.

The impacts of higher DOC level to the drinking water treatment works are that it is aesthetically undesirable. It causes colour and odour in the water, which in turn will increase treatment costs and chemical use. Tong (2010) states DOC can be measured by UV absorbance at a wavelength of 254nm. The higher the DOC the more coloured water with increased UV absorbance. Chlorine is the most cost effective and popular disinfection method use by water companies. The cost of chlorine disinfection is likely to go up as DOC levels increases in the future and as a result the formation of trihalomethane (THM) will also increase and this has significant implications for treatment and poses a health risk to customers (UKWIR, 2011a).

The majority of the above impacts effects surface water quality and consequently water treatment operational works. Overall, raw water quality for drinking water is expected to degrade, causing water utility companies to experience more challenges with water treatment. Temperature rise and heavy rainfall events (extreme storms) are expected to raise dissolved organic matter, micro pollutants and pathogens. Water borne diseases are also highly potentially linked to climate change impacts (Delpla et al., 2009). Delpla et al. (2009) illustrates a high level view of the impacts on water quality parameters, using temperature and rainfall as the principle drivers.

Temperature effects on biological wastewater treatments

The effects of temperature on secondary, biological treatment has been extensively studied and documented. The secondary wastewater treatment process consists of removing or reducing dissolved organic matter that is left in the wastewater after primary treatment process. Usually, water companies use biological treatment to treat wastewater.

It has been universally accepted that aerobic digestion of wastewater increases within the temperature range of 4-39 degrees Celsius, or otherwise known as the mesophilic temperature range. Within this range, a temperature increase improves total effluent quality (Collins et al., 1978; Eckenfelder et al., 2000; Grady et al., 1999). Biological treatment used in wastewater treatment plants perform most optimally between 26-35 degrees Celsius (Cruikshank et al., 2007).

Table 3 summarises some of the different secondary biological treatment processes and its effect on temperature. Temperature rise does not only benefit biological treatment in wastewater but has also in the water treatment process. Andersson et al. (2001) showed that higher temperatures improve ammonia removal and nitrification in biological granular activated carbon filters used in drinking water treatment.

Table 3: Summary of secondary biological wastewater treatment and how temperatures impacts them

Treatment Process	Effect as temperature rises	Reference
Trickling filters	Biological activity increases as temperature increases. At lower temperatures recirculation is decreased.	McGraw-Hill Professional. (2008)
Anaerobic rotating biological contractor	BOD and COD removal efficiencies are optimum in the upper end of the mesophilic range	C. Lu et al. (1997)
Membrane bioreactor	Sludge filterability deteriorates at lower temperatures,	Krzeminski et al. (2012)

	however improves at higher ambient temperatures	
Moving bed biofilm reactor	Ammonia removal efficiency highest between 35-45°C and effective nitrification at 30°C. No bio-treatment observed at 45°C	Shore et al. (2012)
Anaerobic submerged membrane bioreactor	COD and BOD removal efficiencies close to 90% between 20-35°C.	Martinez-Sosa et al. (2011)
Aeration lanes	Treatment becomes less effective as less oxygen is pumped into wastewater. Increases power requirements	Collins et al. (1978)

Overall, the studies suggest that temperature rise favours the biological treatment of wastewater and consequently improves final affluent quality.

Impacts on physical processes

A part from affecting biological treatment, temperature can also affect physical operations. It affects physical operations in two ways; the viscosity of the water and also the oxygen solubility. Increasing viscosity affects the settling rates of suspended solids in primary treatment and therefore lowers the rate of total suspended solid removal over the final settler, Collins et al. (1978). Increasing temperatures increases the oxygen demand for the aeration of the wastewater. As a result, biological treatment is less effective as there is less oxygen being pumped into the wastewater. Suruco et al. (1988) found that compressibility of activated sludge decreases after 25°C, therefore making the sludge more resistant to dewatering.

Precipitation can also have a physical effect on the water company's assets. The erratic nature of climate weather events may result in soil moisture hydrology changes. Soil property transitions may damage underground pipe infrastructure (Wols et al. 2014). Little research has been studied within this field however an increase in pipe failure rates is observed in summer months (Gould et al. 2011).

Climate extremities

The water industry is an energy intensive business and uses up to 3% of total energy use in the UK (Water UK, 2009). Weather extremities such as intense rainfalls or extreme droughts can seriously interrupt power supply for wastewater and drinking treatment sites.

Severe storms coupled with high winds and rainfall can cause power lines to collapse, and ultimately affecting the supply treated water. The greatest challenges felt at sites where back-up generators failed or weren't available (Francis., 2012).

On the other hand, extreme droughts could also interrupt power supplies through more frequent and intense wildfires with the potential to damage transmission lines and other power infrastructure (Sheehan., 2014). Wildfires are becoming an increasing problem globally, including in the UK. Climate change is likely to mean more summer droughts and more frequent severe wildfires. Not only do wildfires have the capability of damaging power lines, but they can also be detrimental to water supplies. Wildfires that occur near watercourses or reservoirs can have a significant impact on water quality as ash and other pollutants are leached through the soil. Further, wildfires may lead to discolouration of water sources and in more extreme cases may lead to pollution levels exceeding water quality standards (Metoffice, 2013).

Sea level rise is not a direct parameter of climate but more so of a secondary effect of temperature change. The IPCC (2013) estimates global sea level will rise 26 - 82cm. The two main causes are thermal expansion of oceans and melting glaciers due to temperature rise (IPCC, 2013).

Water utility assets that are located near the coast are venerable to effects sea level rise. Extreme storm surges and ocean waves coupled with sea level rise will cause acceleration in coastal erosion, which can damage coastal assets or in the worst case scenario, wipe them out altogether. The east coast of England is particularly susceptible to flooding and recent floods have severely harmed the local population's livelihood as well as infrastructure (McIntyre et al., 2013). Anglian water has identified erosion and site inundation as a high risk and have realised the importance of protecting their coastal assets (Anglian Water, 2011).

1.2.3 Summary of Potential Climate Change Impacts

The UKWIR (2012) report highlights the key impacts of increasing rainfall and temperature. It summarises the impacts across sewers and CSO's, pumping stations, the wastewater treatment site, sludge management and receiving river waters. UKWIR (2011a) provides a high level summary the projected increases and/or decreases in nitrate, phosphorous and sediments as a consequence of climate change. Based on the study, it has identified that the simpler primary treatment systems such as screening, clarification and filtration are the most vulnerable to the effects of climate change, mainly because they're the first point of contact for algae, phosphorous and DOC which are all predicted to increase in the longer term.

Tables 4-6, below, highlights the culmination of all the impacts above and includes some of the impacts in UKWIR (2012) and UKWIR (2011a).

Table 4: The impacts of increased rainfall on the different treatment processes

Category	Treatment processes used	Impacts
Drinking water	• Resources • Screening • Flocculation/coagulation • Sedimentation/clarification • Filtration • Disinfection • Distribution	• BOD/COD, nitrate, prosperous levels increase due to erosion • Increase of TSS, *total suspended solids* (soil erosion), cause blockages • Use of more chemicals, increase cost • Increase of TSS increase sedimentation time • Increase of micro pollutants, more filtration time and backwash • More THM's produced and more chlorine use • Cracked pipes and more stress pumping stations

Wastewater	• Sewer network • Screening and gritting • Primary treatment • Secondary treatment • Discharge • Tertiary treatment and sludge management	• CSO, infiltration • In urban areas create storm water run-off, which increase TSS, increase of algal cause blockages • In urban areas create storm water run-off, which increase TSS and micro-pollutants, increase sedimentation time. Hydraulic flow surpasses treatment works capacity, carrying more pathogens and inorganic pollutant like metals. Primary treatment most at risk (UKWIR, 2011a). • In urban areas create storm water run-off, which increase TSS and micro pollutants, pH levels and ammonia concentration increase. BPR efficiency reduced. Advantage of diluting waste in non-urban areas. • CSO into river. Risk compliance and fines • Longer time for composting

Table 5: The impacts of increased temperature on the different treatment processes

Category	**Treatment processes used**	**Impacts**
Drinking water	• Resources • Screening • Flocculation/Coagulation	• Thermal pollution, algal and DOC concentrations increase

	• Sedimentation/clarification • Filtration • Disinfection • Distribution	• Low flows and TSS, algal bloom, thermal pollution increase causes blockages • More chemical use • Higher sedimentation times • Filtration efficiency lowered • Higher chemical dosing, more disinfection by products (THM's) produced • Higher probability of cracking of pipes, low flows causes septicity and odour issues at pumping stations
Wastewater	• Sewer network • Screening and gritting • Primary treatment • Secondary treatment • Tertiary treatment and sludge management	• Low flow odour and blockages • Low flows and TSS increase, causes blockages • Higher sedimentation times • Lower treatment efficiency for aeration lanes. Advantage, higher treatment efficiency for biological treatment • sludge, septicity and odour issues. Dewatering processes are impacted by compressibility of sludge.

Table 6: The impacts of extreme weather events on the different treatment processes

Category	Treatment Processes used	Impacts
Drinking water	• Resources • Screening • Flocculation/Coagulation • Sedimentation/clarification • Filtration • Disinfection	• Increased risk of variable flow regimes resulting from storm and drought conditions causing environmental impact • Site inundation • Power outage • Cracked pipes due to climate extremes and hydraulic soil movements
Wastewater	• Sewer network • Screening and gritting • Primary treatment • Secondary treatment • Tertiary treatment and sludge management	• CSO • Site inundation • Power outage • Cracked pipes due to climate extremes and hydraulic soil movements

A high level overview of the impacts of climate change on the nomenclature of water industry assets, as described in Table 2, have been provided. Ultimately, water utility companies will face higher operational and capital costs to adapt to the impacts of the climate change parameters. It is inevitable that climate change will increase operational expenditures to increase in the water industry for the longer term. What differentiates one study to another is the applied GCM, hydrological model and emission scenario, however the underlying principle of identifying and inputting the climate change parameters remain the same. No climate model, no matter how comprehensive it maybe will be able to provide a definitive answer on how the climate will change in the future. All GCMs carry an inherent uncertainty and hence the climate projections are all probabilistic. Uncertainties of the GCM's are a combination of model parameters related to atmospheric and oceanic physical processes, the Sulphur cycle, downscaling and sampling techniques (UKCP, 2012). For this reason, GCMs are not tools that yield completely accurate results, which means that their representation of future climate variability will more likely be imperfect.

2 Reviewing Existing Risk Based Approaches to Investigate the Impacts of Climate Change

2.1 Introduction to Climate Change and Risk

The two main policy approaches to climate change; *mitigation* and *adaptation*, are used to curb the current and future impacts of climate change in order to enable effective and efficient business continuity. Climate change 'mitigation,' relates to reducing the emissions of carbon dioxide as well as other greenhouse gases, as a result of anthropogenic drivers. An example of mitigation can be through renewable sources of energy, such as wind turbines. Climate change 'adaptation,' on the other hand seeks to lower the risks posed by the consequences of climatic changes by anticipating the consequences and taking appropriate action to prevent or minimise the damage in addition to taking advantage of any serendipitous opportunities encountered through climate change. One such example of climate change adaptation could be flood defences in coastal areas that are venerable to floods. Although both mitigation and adaptation are necessary, the former approach has been implemented more so across different industries, mainly due to regulatory drivers and governmental incentives. Such mitigation examples have been demonstrated by many companies who are making strenuous efforts to reduce water use – because it makes not just environmental but also economic sense for them to do so. Sainsbury's have achieved a 50% reduction in water use; Coca-Cola Enterprises' factories in Britain and France are now their most water efficient production plants in the world; and Sunlight, the UK's largest textile rental and laundry organisation, has reduced water usage by 12% in a two-year period (Arup, 2015). While mitigation efforts are crucial to avoid adverse effects of climate change in the latter half of the 21st century; the nature of climate change and its temporal scales mean that we are already locked into climate change over the next 40 years (Defra, 2010). Therefore; some form of adaptation will be required to control the level of risk posed by climate change. However, different industries including the water industry are struggling to find a coherent link between climate change adaptation and their business decisions. This could be attributed to the lack of regulatory direction and support for adaptation only projects which reflects the high level of data uncertainty that underpins the causes (UKWIR, 2007). But why is there a lack of regulatory direction and governmental support? A commentator of the Grantham Research Institute has stated, "*Humans have been adapting to their environments throughout history by developing practices, cultures and livelihoods suited to local conditions – from the Mediterranean siesta to the Vietnamese practice of building homes on stilts to protect against monsoonal rains. However, climate change raises the possibility that existing societies will experience climatic shifts (in temperature, storm frequency, flooding and other factors) that previous experience has not prepared them for*" (Clark, 2012). This suggests climate change adaptation cannot simply be achieved through companies, regulators and the government alone; there needs to be some form of collaboration between all relevant stakeholders, including the general public to control the level of risk and adapt to the impacts of climate change.

The growing recognition of the need to respond to climate change impacts has placed adaptation at the forefront of societal and governmental agendas around the world (Eakin et al., 2014). Slowly, we are beginning to see a transition in economic and business models in both private and governmental organisations. Sustainability is now a key for organisations trying to tackle climate change. Organisations are realising that adapting to climate change and incorporating it in their business decisions will save them money rather than doing nothing (Cogan, 2006). However, adapting to climate change is not a linear task, but is extremely complex and multifaceted. An organisations response to climate change occurs in a variety of dimensions, such as political, technological, social, regulatory and financial. Often, business decisions are entangled with these different dimensions within the organisation in addition to being influenced by external interdependencies. From a macroscopic view, a clear yet complex link can be seen amongst different industries and their need for water. Competition for resources between water, energy, agriculture, livestock, fisheries, mining and other sectors is increasing – with unpredictable impacts for livelihoods and the environment. Climate change is set to only exacerbate these impacts and therefore requires a nexus-based approach – for the water, energy and food sectors to engage in a dialogue and deliberative analysis such as looking for solutions to optimise the interdependencies, and support the equitable and sustainable allocation of natural resources (Hussey and Pittock, 2012; Rasul, 2014). Our agricultural, energy and social infrastructures are reliant on fresh water and these different infrastructures are highly interdependent between one another such that, the decisions made in one industry, often have both implicit and explicit implications on the other. For example 43% of fresh water withdrawal in Europe is used for cooling in the power industry (UN Water, 2014) and at a global level more than 70% of water consumption is used in agriculture (Clay, 2004). Naturally, the linkages between water and the world’s agricultural, energy and social infrastructure are crucial for sustainable socio-economic growth. To date, many studies have used a systems approach to find key relationships, synergies and possible optimisation solutions in the context of water resources and wastewater (Nishanen, 2016; Voulvoulis, 2014). The water-food-energy nexus shows potentially how detrimental the impacts of climate change are to our entire infrastructure (Rasul, 2014). The impacts of climate change are posing a very real threat to our infrastructure and in turn economy, however, a good starting point to show the need of addressing climate change impacts is the water industry.

2.2 Qualitative, quantitative and semi-quantitative risk approaches

Deciphering risk can be done through either one of two ways; qualitatively or quantitatively. It is often the case that qualitative methods are usually used when there is information lacking and quantitative methods are used for when there is sufficient information available. Naturally, the interpretation and management of risk is transformed from a qualitative analysis to a quantitative one. There is no clear cut method to analyse risk as it depends on the nature of the phenomena or system. Sometimes techniques from both qualitative and quantitative methods are combined together to help better understand risk. This combined method is known as, 'semi-quantitative,' and can prove especially useful for complex subject areas such as climate change. This review focuses on existing methods that calculate the risk of the impacts of climate change on the public infrastructure.

The concept of risk is not a new concept but one that has evolved over time. There are various kinds of descriptions about risk in literature. According to the International Organisation for Standardisation (ISO) risk is the effect of uncertainty on objectives and effect is a positive or negative definition from what is expected (ISO 31000, 2009). A more generalised definition of risk is that it embodies both the probability of an event occurring and the level of impact.

A number of studies have attempted to develop qualitative, quantitative and semi-quantitative climate change risk based approaches. Qualitative risk assessments and frameworks tend to take a holistic approach. Surveys, questionnaires, risk indicators and qualitative metrics are commonly used to understand risk. Astles et al. (2006) used a qualitative risk assessment to determine the impacts of fishing. Although this risk assessment method is designed around the fishery industry, many of its features can be transferred to climate change and its impacts on the water industry. Firstly, its key strength is that it can be used on fisheries with little or sporadic fishery data, a similar attribute of climate change modelling. Secondly it combines 2 independent risk variables; a characteristic that can be adapted into the climate change-risk environment as climate can occur in 2 ways, gradual or intense and extreme weather events. Thirdly the risk assessment demonstrated by Astles et al. (2006) is transparent, logical and systematic – a necessary trait that must be present in developing novel risk methodologies for new areas of study.

The outlined stages that were used in the qualitative study were: risk assessment, risk management and risk communication, as depicted in Figure 2 below.

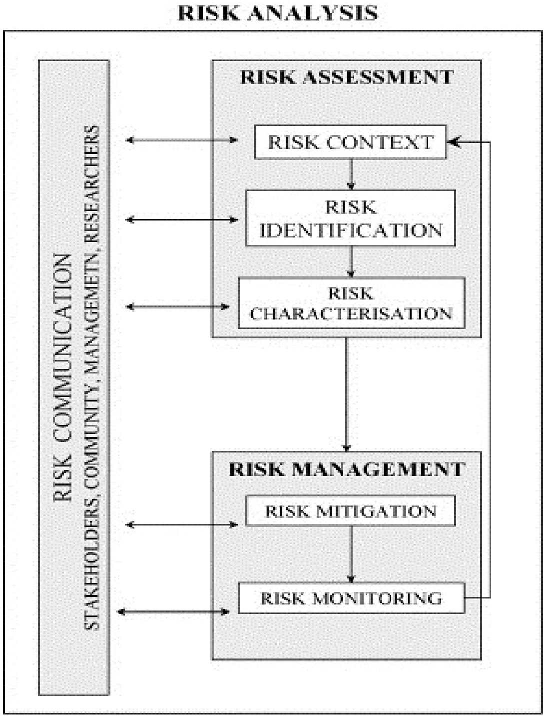


Figure 2: Example of qualitative risk analysis method, adapted from Astles et al., (2006)

Rosendahl et al., (2014) created a qualitative methodology to investigate all possible relations between coastal hazards and the level of vulnerability associated with different typologies of coastal systems. The method was developed for world-wide application and represents risk through five key climate change hazards, described as ecosystem disruption, gradual inundation, salt water intrusion, erosion and flooding. Sample et al., (2016) developed a spatially distributed screening tool to assess climate and land use change impacts on water-related ecosystem services. The method incorporates a range of spatially distributed scenarios of land use and climate, which are used as inputs to a qualitative risk assessment model underpinned by expert opinion. The methodology provides a high-level evaluation encompassing a range of ecosystem services at large spatial scales.

From the referenced literature on qualitative studies there is a common trend on the application context - usually where data is very high level and the phenomena occurs at a large spatial distribution, at a regional-national level. These are the common traits on the application in the referenced literature where qualitative techniques were utilised. Climate change is a phenomena that occurs on a large spatial scale and also occurs at a regional-national level, therefore a qualitative method is a good starting point for creating a risk methodology to investigate climate change impacts on water industry assets.

Quantitative risk methods on the other hand employ sophisticated mathematical models or algorithms to analyse and calculate numeric values associated to each component that result after risk evaluation. For example Jiang et al., (2013) proposed a quantitative risk method using Monte

Carlo simulation and Finite Element Method to help optimise the level of assigned risk for water quality.

Semi-quantitative risk methods provides an intermediary level between the textual evaluation of qualitative risk assessment and the numerical evaluation of quantitative risk assessment, by evaluating risks with a score. Moonis et al. (2010) used a semi-quantitative risk methodology to identify the knowledge and data gaps for the supply of hydrogen fuel and its implications to industry. The study calculated the total risk score by totalling the likelihood score and consequence score, each having their respective assigned definitions and values. Abbas et al. (2013) developed a semi-quantitative risk methodology to investigate primary healthcare service interruption during floods. Here, the total risk score was calculated through three components; hazard, vulnerability and capacity, each being assigned a composite index. What is similar in both studied by Moonis et al. and Abbas et al. is that the final risk score was grouped into the three categories of 'low', 'medium' or 'high' risk. This classification is generally true for most semi-quantitative risk studies, which makes the approach widely applicable. Overall, a semi-quantitative risk approach can offer a more rigorous approach to assessing and understanding risks than does qualitative risk assessment, and avoids some of the greater ambiguities that a qualitative risk assessment may produce. At the same time it does not require the same mathematical skills as quantitative risk methods, nor does it require the same amount of data, which means it, can be applied to such scenarios in which there maybe data gaps, complex interdependencies within that system or where there lies much uncertainty. Therefore complex phenomena such as climate change become an ideal candidate for the use of semi-quantitative risk techniques to help better understand the risks.

Table 7 below summarises qualitative and semi-quantitative risk studies:

Table 7: Past Risk based approaches

Author	Risk Study
Astles et al. (2006)	Qualitative
Rosendahl et al., (2014)	Qualitative
Sample et al., (2016)	Qualitative
Moonis et al. (2010)	Semi-quantitative
Abbas et al. (2013)	Semi-quantitative

2.3 Climate Change and Risk

A plethora of risk management methodologies, frameworks and tools are available to assess, rank, identify, interpret, analyse, monitor and calculate risks. Deciphering climate change risk for natural and human systems has been a particularly challenging topic for academics and commercial organisations alike. There are a multitude of challenges; assigning risk to key climate change vulnerabilities involves substantial scientific uncertainties as well as value judgements. It requires consideration of the response of biophysical and socio-economic systems to changes in climatic and non-climatic (e.g., changes in economy, population or technology) conditions over time that can affect adaptive capacity, value judgements about the acceptability of potential risks and potential adaptation and mitigation measures (Moss and Schneider, 2000). It becomes apparent that many of the challenges stem from the inherent uncertainty of climate change predictions and therefore the inability to accurately calculate climate change risk. It is for this very reason that a purely quantitative risk analysis tool cannot be properly utilised to effectively calculate risk associated with climate change. Finding the right balance between qualitative and quantitative and combining the two data is key to tackle such complex phenomena as climate change. GCMs is a good example of combining qualitative data (emission scenarios) with quantitative data (mathematical approaches to project probability of weather events occurring). Anglian Water (2011) have produced a semi-quantitative tool CCRA using data from UKCP09. What was lacking from this CCRA is that it is too vague to be used as a definitive tool; in the sense that it does not assign risk to each and every asset but instead, to the asset *type*, which is based on the size of the treatment works as described in Anglian Water's climate change adaptation report (2011).

What becomes apparent is that in order to design an effective risk assessment tool to rank the assets with respect to their level of monitoring, a semi-quantitative approach must be taken. The Risk Matrix Approach (RMA) is used by both Moonis et al. and Abbas et al. presents itself as a perfect tool to untangle the complex nature of climate change and its impacts to public sector infrastructure assets. Section 5.4 further describes the RMA.
Although the concept of risk is not a new topic with the field of risk management, it is still important to discuss concepts and methods based around risk before introducing RMA. This is discussed in the following chapter.

2.4 Integrating Climate Change and the Components of Risk

This chapter aims to integrate climate change and risk. As stated in Equation 1, risk is the probability/frequency of an event occurring multiplied by the severity/impact of the consequences.

The ramifications of any potential risk are multidimensional, in that it will have technical, financial and social components.

The source, or the hazard in this context, is the change our world is experiencing in the statistical distribution of the temporal and magnitudinal changes in weather patterns and extremities from climate change. This 'hazard' can be further broken down into the different climatic parameters as described in section 2.2.1. As discussed in this particular section, the two main climate change parameters are precipitation and temperature. This, still, can be broken down further into the different consequences of climate change, i.e. the frequency and severity scales of droughts, extreme storms and so forth. Essentially, climate change poses the ability to cause harm to public sector assets and therefore it is the *hazard*.

The assets are *vulnerable* to the consequences (the climate change parameters) of climate change. The consequences of climate change potentially pose a threat to the performance or even the existence to these assets and it is therefore imperative to take into account the *vulnerability* of these assets to the different climate change parameters.

Thus far, we have linked the hazard or source, climate change to its consequences (climate change parameters) and its impacts to the operational processes of assets (vulnerability). Logically, the next stage is the impacts faced by the organisation or water utility company as a result of these impacted asset(s). Hence, how *critical* these assets that have been impacted by different climate change parameters are to the organisations business decisions is the third important risk element must be taken into account. To summarise there are 3 risk elements:

1. Hazard: Climate change and its different parameters
2. Vulnerability of assets to the different climate change parameters
3. Criticality is the level of potential ramifications that the business as a result of the impacted assets

Figure 3 below illustrates the above.

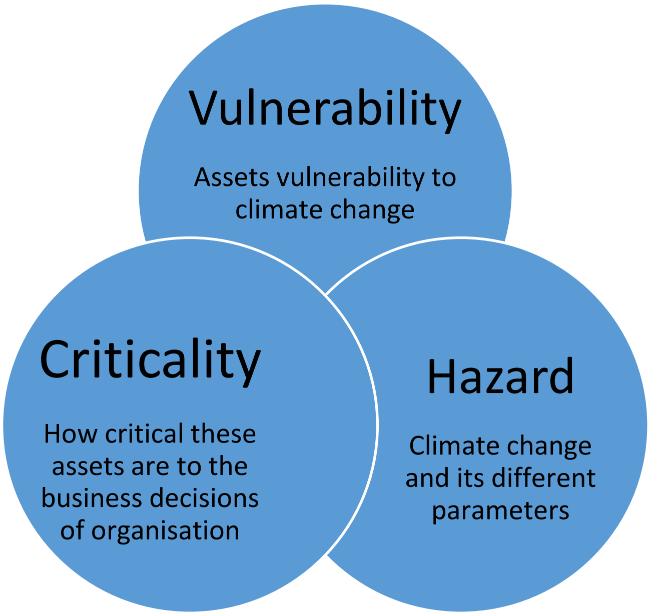


Figure 3: Venn diagram illustrating the different components of risk

From Figure 3, the total risk can be the intersection of all three components- vulnerability, criticality and the hazard.

Similarly, another way to interpret risk is through the combination of exposure and effects. For example, in this context, the assets are exposed to the harmful effects of climate change (climate change parameters) which encapsulate the frequency and severity of these climate change parameters. The effects are the impacts on the asset and the business.

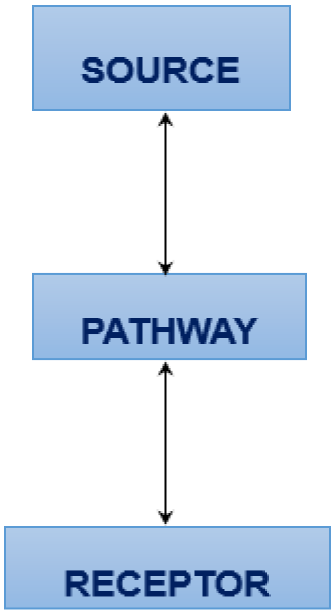


Figure 4: Source, pathway and receptor flow diagram

Figure 4 illustrates the above more clearly. The hazard, or the source in this particular context, is the changing climate over the coming decades. The pathway is the climatic parameters, e.g. surge storms, droughts etc. and its damage to the public infrastructure (assets) and finally the receptor, or output, is the business who owns those assets and the end user, the customers. There can be no risk unless all of these 3 criteria are present.

The output of the probability and severity of a given event occurring is equal to the output of how vulnerable something is to the hazard and how critical it is. Using a semi-quantitative tool such as a risk matrix utilised by Moonis et al. (2010) and Abbas et al. (2013) can be effective in analysing and evaluating risk of water industry assets to climate change.

2.5 Risk Matrix

RMA is a classic semi-quantitative assessment tool to evaluate various kinds of risks. The basis for risk matrix is the standard definition of risk as a combination of severity of the consequences occurring in a certain accident scenario and its probability (Markowski and Sam Mannan, 2008). The severity of consequences, probability and output risk index can be divided into different levels with qualitative descriptions and scales, respectively. The calculation for risk is therefore the multiple of the probability and the severity of the consequences occurring (Ni et al. 2010).

The RMA is widely implemented across different industries in order to assess risk. Moonis et al. (2010) and Abbas et al. (2013) both incorporated a risk matrix as part of their risk scoring methodologies, however Moonis et al. study was aimed towards the energy and commercial industry whereas Abbas et al. area was in the healthcare industry. The UK's public sector, the National Healthcare Service (NHS) extensively utilises the risk matrix as part of a number of their risk studies (AIRMIC, 2002) and have created their own version of what a risk matrix can look like (NHS, 2008) as depicted in Figure 5 below:

	Likelihood				
Consequence	1	2	3	4	5
	Rare	Unlikely	Possible	Likely	Almost certain
5 Catastrophic	5	10	15	20	25
4 Major	4	8	12	16	20
3 Moderate	3	6	9	12	15
2 Minor	2	4	6	8	10
1 Negligible	1	2	3	4	5

For grading risk, the scores obtained from the risk matrix are assigned grades as follows:

1–3	Low risk
4–6	Moderate risk
8–12	High risk
15–25	Extreme risk

Figure 5: NHS Risk Matrix example

In this particular example, the NHS provides a definition as to what the "likelihood" and "consequence" can be (NHS, 2008) and scales them from 1-5. The risk score is simply the "consequence" multiplied by the "likelihood" and is graded from "low risk" to "extreme risk". Ultimately, the NHS wanted to create standardised risk matrix that is simple to use, can be applied to a variety of roles or professions, it should be capable of assessing risk from different areas i.e. financial risk or biomedical risk and should be easily adaptable to meet specific needs.
The RMA is also used in studies more closely related to the water and environment sector. For example Baah et al. (2015) used a semi-quantitative approach, incorporating a risk matrix to assess the consequence and risk of sewer pipe failure for a mid-sized city. The results yielded from the risk methodology adapted in this study can potentially serve as a basis for future planning and decision making as it systematically explains and describes how the total risk score was calculated in a clear and concise way; enabling the reader to easily interpret the risk. The definitions of what constituents as a pipe failure, their associated weighted scores and probability of occurrence were clearly detailed in the study. The development of the risk matrix used the same underlying principles to that of the NHS risk matrix; demonstrating how easily the RMA can be adapted to different industries.

Overall, there are a number of advantages of the RMA, the key points being its features of intuitive graphical expression, easy to understand and easy to apply still make it well received across different industries (Ni et al. 2010). Nevertheless, the RMA does have its limitations- mainly, the non-meticulous classification of risk index and the subjective calculation inputs by the reader and it doesn't carry the same mathematical vigour or technicality to that of a pure quantitative approach. However, deciding whether or not a RMA should be applied to the given case would ultimately depend on the level of existing data and complexity. The limited quantitative data surrounding the impacts of climate change to water infrastructure and non-infrastructure assets (defined in Table 2) only makes the case for employing the RMA to assign risk to these assets stronger.

2.6 Review on Testing and Validating

Climate change models require a validation test to assess system performance. A common approach in validating the model is called a sensitivity analysis. The objective of sensitivity analysis is to identify the contribution of the variability of inputs to the variability in the output, hence to find the most important input factor and also the contribution of the variability input interactions (Cannavó, F. et al., 2012). Various techniques have been developed to determine
how sensitive model outputs are to changes in model inputs.

Most approaches employ a global sensitivity analysis that focuses on the output uncertainty over the entire range of values of the input parameters. Global sensitivity analysis methods have been developed, because they deliver global, quantitative and model independent sensitivity measures. Variance based methods are particularly suited as they capture input interactions in non-linear models and can help rank input variables in order of importance (Sobal et al., 2001).

Sensitivity analysis have been applied in many previous studies that investigates climate change models. Shi et al., (2016) applies a multi-model sensitivity analysis to examine several GCMs response to the rise of greenhouse gases during the last millennium. Sterk et al., (2016) investigated the climate change impacts on infection risks during bathing downstream of sewage emissions from CSOs and WWTPs. The study employed as sensitivity measures on its models through key sensitivity coefficients.

The exact character of a sensitivity analysis depends upon the particular context and the questions of concern. As explained in section 1.2.1, in the context of climate change impacts on water industry assets, the two key independent variables are rainfall and temperature.

3 Aims and Objectives

Aim:

To develop a semi-quantitative risk based methodology based on the vulnerability and criticality of water utility assets to climate change parameters and to the water utilities' business. The developed risk methodology aims to ranks the assets, where the greater the risk, the greater the need for monitoring.

Objectives:

1. Identify the key climate change parameters and understand its effects on a water utility company;
2. Collate the necessary information from a water utility company in regard to their assets to understand how this semi-quantitative methodology can fit into their business and add value. This includes:
    a. How the water utility categorise their entire nomenclature of water utility assets into groups and identify the assets or groups of assets that can be potentially impacted by climate change;
    b. Review their existing asset risk practices or risk managements tools/systems for their assets;
    c. Identify whether they incorporate the impacts of climate change into their existing risk practices or risk managements tools/systems;
3. Link the relationship between the impacts of the different climate change parameters (vulnerability of assets) and the subsequent impacts to the water utility from a commercial standpoint (criticality).
4. Evaluation of past semi-quantitative risk studies on ranking/scoring;
5. Develop a scoring methodology that can calculate the total level of risk to each asset using the components; vulnerability and criticality;
6. Produce a visual tool to help present the found risk data in a meaningful format.

4 Methodology for Designing a Risk Framework to Rank Assets in Need of Monitoring

The methodology is split into two key parts. The first part is the creation of a narrative that logically leads to the need of addressing the impacts of climate change to the water industry as described in Chapter 1. Using this background knowledge, one may start to assess and review the key business decision making processes or risk management of a water utility company on their assets. Section 4.4.1 provides a case study example of a review of Anglian Water's decision making processes and or management systems regarding their assets.

Once the business processes/management systems have been reviewed, and depending on how much a water utility company integrates the risks of climate change impacts into their organisation, the necessity on whether a risk strategy or framework is feasible or not can be determined.

This creates a case for why a risk strategy or risk framework needs to be created to rank assets in terms of their need of monitoring which leads to the second part of the methodology, which is the creation of a comprehensive risk methodology that assigns risk to the asset, which comprises of the impacts of climate change to that asset and the assets importance to a water utilities business and subsequently ranks the assets in terms of its need of monitoring. A detailed review of the existing literature was undertaken in different areas of study to gather information, identify relationships between assets and risk and identify knowledge gaps in the water industry relating to assets and risk as described in Chapter 2. The cumulative knowledge was combined to create the risk methodology. Finally, the output - the overall risk methodology framework and its associated risk tools, were tested to evaluate the weaknesses and strengths of the risk methodology.

4.1 Detailed Literature Review

A literature review was undertaken in the following stages in order to provide background knowledge and context on:

1. The phenomena of climate change and its overarching impacts to the world;
2. The impacts of climate change the water industry, in particular the technological and data acquisition and management challenges as discussed in section 1.1.
3. The impacts of climate change on a water utilities treatment operational processes and the associated infrastructure and non-infrastructure assets across the utility cycle as discussed in section 1.2.2. This also included a literature review on identifying key climate change parameters as discussed in section 1.2.1.

Overall, Chapter 1 of this thesis provides a literature on the need to address the impacts of the water industry and aids towards creating a business case on whether it is meaningful for a water utility to form a risk based methodology on the impacts of climate change to their assets.

4.2 Review of a Water Utility Company and Its Business Units

Once a detailed literature review on the challenges faced by a water utility company, as a result of the impacts of climate change on both the operational treatment processes and the technological management of asset data, one is equipped to be able to review the business units of a water utility company.

This part of the method, involves the collation and review of information on a water utility company's assets - in particular the review of a water utility company's asset risk management practices and how they group their assets.

A comprehensive review of existing literature on Anglian Water's business processes was carried out to understand how they currently manage asset risk. Section 4.4.1 presents a review of Anglian Water's business decisions and risk management practices on their assets, as an example of why it might be imperative for a water utility to create a link between their assets, their business processes and the impacts of climate change. Through this review, knowledge gaps were found in terms of how and the impacts of climate change and the level of incorporation of these impacts into their business processes on assets. Moreover, relationships between climate change and asset data can be established. Furthermore to the review of existing Anglian Water asset risk management practices; information on how they grouped assets was also reviewed. Reviewing Anglian Water's asset categorisations provided information on the number of assets on each treatment process and how they were grouped – a list of assets identified, is used by Anglian Water and is shown in Tables A.2 and A.3 in the Appendices section. A review on the water industry standard of the nomenclature of water industry assets was also conducted and it was found that the assets are categorised according to UK water industry standard as defined by the UK water regulator, Ofwat. Ofwat divides assets between the terms, 'infrastructure' and 'non-infrastructure.' Infrastructure assets generally refer to any assets below ground, for example the sewage network, whereas non-infrastructure generally refers to anything above ground, for example a pumping station (Mott Macdonald, 2001). These categorisations are used in Table A.2 and A.3.

Overall, the review of climate change impacts on industry from both a physical and commercial standpoint and technological asset data challenges formulates the need to address the impacts of climate change on the water industry. Relationships were identified between how assets are impacted by climate change parameters (i.e. vulnerability) and how important assets are to the business decisions of a water utility company (i.e. criticality). Subsequently, this leads to next part of the method, which is to create a risk methodology.

4.2.1 Anglian Water: A Case Study

Anglian Water is a water company that operates in the East of England and serves approximately 6 million water customers. It is the largest water and water recycling company in England and Wales by geographic area and also operates in one of the driest and low-lying, flat regions in the country. The characteristics of the region make Anglian Water vulnerable to the impacts of climate change and form a good basis on why Anglian Water can be used for a case study and address the need for monitoring assets to aid managing the future risk of the impacts of climate change.

This chapter aims to meet the following objectives:

- Define the concept of decision making in business and their importance in the context of climate change.
- Define asset management and the relationship between Anglian Water's business units, Risk & Opportunity Value (R&OV), Capital Maintenance Models (CMM) and Operational Management Centre (OMC) and asset management.
- Provide a review of each of Anglian Water's business units.
- Identify climate change data or knowledge gaps within the business units.

The purpose of these objectives is to understand how a large water utility company such as Anglian Water make their business decisions in order drive investment for their assets. Also, typically, how a large water utility like Anglian Water manages and processes their data to enable their business decisions and how climate change is currently integrated in all this.

4.2.1.1 Business Decisions

Decision making is a crucial part of good business. For effective decision making, an organisation should consider all available data and information and weigh out the possible options in order to find an optimal solution that aligns with the strategy in which the organisation wishes to steer towards.

There are a vast number of decision making methodologies and frameworks. Each has their own merits and faults, depending on the context of the business organisational culture, and complexity of the business's strategic objectives and aims. Because climate change adaptation is such a complex development, much research has been carried out on combining different and more sophisticated decision making practices, theories, tools and methods. Synergistic approaches such as multi-criteria decision-analysis and Systems Thinking and Adaptive Management practices have been studied to determine how they can be implemented for successful climate adaptation (Schmidt-Thomas, 2013; Maani, 2013).

Decisions made for water use and water management can have significant, multifaceted and far reaching impacts on each other –and these impacts often carry a mix of both positive and negative repercussions. In some cases these repercussions are out of the water utilities control. Decision making in water utility companies are sometimes confined and restricted in what can be done by external forces. Energy prices and power outages are mostly out of Anglian Water's control, and being such an energy intensive industry, this can have serious implications on the business decision making. Other externalities such as the Drinking Water Inspectorate and the Environmental Agency govern certain regulatory and compliance standards that the water utility must adhere to. Ofwat regulates financial and serviceability decisions of water utility companies. These external bodies can too have influence Anglian Water's business decisions.

The impacts of climate change to Anglian Water's assets are overarching and therefore all decision units at different levels, strategic, tactical and operational, within the Anglian Water's organisation are in need, to different degrees, of optimisation in order to adapt to the forthcoming risks of climate change. The underlying challenge is the inherent uncertainty that is present in climate change data and modelling techniques used by GCMs because business decision rely on this data. There is contradiction in long term organisational strategic decision making and the lack of knowledge and experience about future climate scenarios and asset performance response to future climate risks. Knowledge gaps within Anglian Water's business decisions will need to be filled and this can only be done through a deeper understanding of asset response to different climate parameters. Therefore monitoring data for assets will enable a greater understanding of asset response.

4.2.1.2 Asset Management, (AM)

In England and Wales the water sector has physical assets worth approximately £237 billion (Armitage, 2011). It is therefore paramount for water utility companies have a robust and adaptive asset management practice that meet their long term strategic goals. An asset management system is defined as "*systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks* *and expenditures over their life cycles for the purpose of achieving its organisational strategic plan*." (Deadman, 2010).

A good asset management system is very complex and will include many stakeholders within its boundary system, such as regulator, suppliers and customers. As well as stake holders, a good asset management system will also involve tools (data, computers, organisational structures) and clear processes that all work together in harmony. All areas of the organisation need to be linked to one another and work well together for an effective asset management system.

Anglian Water have categorised their assets into nine groups, each called, "Asset Group Strategy." Anglian Water (2011) has identified, based on expert knowledge, the risks and uncertainties for each of their asset groups and has also identified their highest climate change risks in the long term, for each asset group, as shown in Table 8.

Table 8: Long term climate change risks for Anglian Water's assets

Asset Group Strategy	Climate dependency
Water resources	• Impacts until 2035 considered low as most of Anglian Water's water supply is from ground. • >2035, as the frequency of extreme climate events increase, fresh water resources will be less in supply.
Raw water distribution	• Soil condition impacting raw water aqueduct and main performance. • Warm dry summers and cold winters can cause soil movement which can lead to increased raw water aqueduct and main failure frequency
Water treatment	• Risk of pluvial and fluvial flooding
Treated water distribution	• Warm dry summers and cold winters can cause soil movement which can lead to increased water main and communication pipe burst leaks.
Sewerage	• Pipe failure rates because of changes in soil conditions and in particular soil moisture content.

	• Infiltration to ground water into sewerage system • Flooding of sewers.
Sewerage treatment	• No specific strategies required
Sludge treatment	• No specific strategies required
Sludge disposal	• No specific strategies required

For some of the climate change dependencies, Anglian Water has already taken action in reducing the impact of climate change on their assets. For example their flood resilience schemes (Anglian Water, 2011) which have already been implemented have significantly reduced the risk of their coastal assets due to flooding. Nonetheless plans are needed for the majority of the climate change strategies of each of their asset groups. Failure rate trends at specified time intervals need to be established for certain assets as a result of climate change so that a quantitative risk can be assigned to use for their investment decisions.

4.2.1.3 Risk & Opportunity Value, (R & OV)

The R&OV process supports decision making for Anglian Water, enabling the business to effectively optimise its capital delivery programmes and better manage on going risks to the business. Risk management underpins the principle behind the R&OV process. The R&OV process is utilised when capital delivery is needed for any of the 'Asset Group Strategies.' The R&OV is based on a systematic approach, with several intervention stages that intervenes at different stages of the Anglian Water capital delivery programme, as illustrated in Figure 6. The process covers all stages of capital delivery; commencing with the initial identification of operation needs and asset risks, through solution development, delivery and post project appraisal.

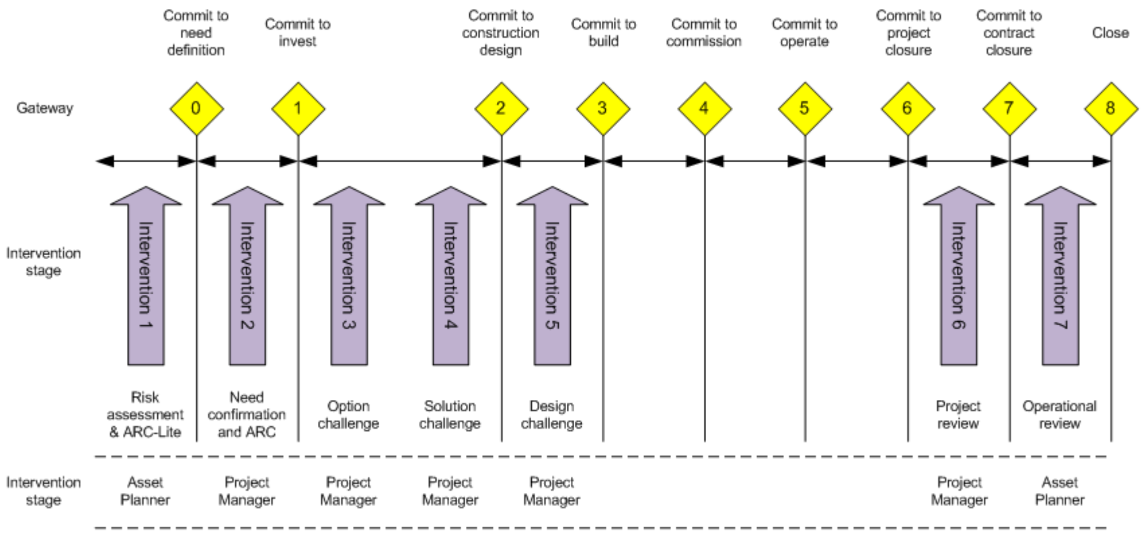


Figure 6: Intervention Stages

The main points of each stage are highlighted below.

Intervention 1 & 2:

The initial stage, Intervention 1, focuses on understanding and defining the problem and a provision of high level recording and planning. A preliminary baseline risk is also assessed and a risk index is generated to inform the level of the R&OV challenge for the following stages of the process.

Intervention 2 involves a more comprehensive 'root-cause' analysis. The baseline business risk is reviewed and an indicative solution is identified for target costing.

The initial stages are heavily reliant on data to find out the root cause and to provide the risk baseline. Such data includes rainfall trends, asset performance data, process diagrams, costs, pollution records, water quality trends, supply/interruptions records, and asset failure records.

Intervention 3, 4 & 5:

Interventions 3, 4 and 5 concentrates on finding possible solutions to the problem, narrowing down to a particular solution and providing a more detailed assessment of the implications of that chosen solution and finally evaluating opportunities of the chosen solution. Interventions 3-5, mainly consist of costing and risk management. The baseline risks are continually reviewed and updated accordingly and residual risk are also evaluated. Capital, operational costs and whole life costing are estimated and further refined. Intervention 4 accounts for the embodied and operational carbon footprint of the chosen solution.

Robust costing and risk data are essential for these stages. The accuracy of the costing figures generated for capital, operational and whole life costing is based on the quality of the provided data.

The risks in these stages are quantified into a financial cost using Anglian Water's BIM, *Business Impact Matrix*, which provides an economic evaluation of regulatory, environmental and customer service impacts. There is no formal procedure for the BIM to quantify the risk into a cost – the BIM is generally a multi-phased process through which the risks are quantified by the analysis and evaluation of the impacts to different business operations. A basic assumption behind BIM is that every business operation of AW is reliant upon the continued functioning of every other operation, but that some are more crucial than others and require a greater allocation of funds for a capital delivery project.

Again, the accuracy of the quantification of the risks are dependent on how well the impacts are analysed and evaluated by AW and also how regularly the risk registers are updated to ongoing changes in business operations.

Intervention 6 & 7:

The final stages review the project and operational performance of the new asset. Action plans outlining what has been learnt and what can be improved in future are developed. These stages are not so data reliant compared to stages 1-5.

In the context of climate change, it is apparent that the integration of climate change data will mainly be in intervention stages that are heavily reliant on data. Hence climate change data will be used more so in the intervention stages 1-5, rather than 6-7. Climate risks are derived through the identification of climate impacts. Only when climate data trends and patterns are correlated with asset performance can the climate risk be calculated. Consequently, the risks cannot be converted into a monetary value if the BIM does not include any climate change specific failure modes. Table 8 below shows some of the relevant failure modes of the existing BIM that could be a result of the climate change parameters.

Table 9: Current BIM failure modes and data sources

BIM failure mode	**Climate Change parameter**	**Data source**
Water quality: physical-chemical	Temperature and rainfall	• Log of failure records through entire system kept by WQ, *Water Quality*, Performance team.

		• Strategy & Risk Team of Regional Quality keep separate failure record. • Alarm levels and shutdown kept by Operational Management team.
Water quality: microbiological	Temperature and rainfall	• Log of failure records through entire system kept by WQ, *Water Quality*, Performance team.
Water quality: aesthetic	Rainfall	• Water quality event database controlled and managed by the WQ Performance team.
Interruption to supply	Low risk to Anglian Water till 2035. Climate extremities	• Properties affected by supply interruptions recorded • Unplanned/planned interruptions that has no affect recorded
Sustained low pressure	Rainfall and temperature	• Risk register owned by asset planning
Pollution	Rainfall	• WQ Performance team manages pollution incident database which contains historic records of all Anglian Water pollution incidents
Discharge	Rainfall	• Water Resource team and Environment Agency has data
Flooding	Rainfall	• Risk register contains data on all properties risk of flooding.

		• Existing system to monitor frequency of actual flooding events

As it stands, the current Anglian Water BIM lacks specific climate change risks that prevent the conversion to cost values that can be used for decision making. Where there is an apparent gap is that Anglian Water has not integrated climate change specific risk into their business. Anglian Water produced their own version of semi-quantified risk assessment of climate change impacts on their business in 2010 called the CCRA, *Climate Change Risk Assessment* (Anglian Water, 2011[1]). The identified climate change impacts and frequency used for the CCRA is questionable because of the complexity involved in determining the probability of that climate change impact occurring due to the lack of historical climate change data. Some of the failure modes in the BIM, such as pollution, use forecasted data as the measure of frequency; however in relation to climate change, simulating future scenarios is purely probabilistic therefore any of these data used for the CCRA is probabilistic. Consequently any financial figure created using the BIM carries an uncertainty that can potentially have adverse consequences on Anglian Water's decision making. In addition the CCRA was created using United Kingdom Climate Projections 2009 (UKCP09) data, a now dated modelling tool, producing future probabilistic climate values, further increasing the uncertainty.

Another gap that the BIM does not account for when measuring the frequency of the failure modes is possible trends and patterns of the climate change impact. Measuring the frequency at which a climate change impact occurs is challenging because:

1. The lack of collated historical climate change data in the Anglian Water region
2. The frequency of extreme climatic events is increasing and is a recent phenomenon in terms of time scales. Only in the past decade have we started to witness more extremities. Hence determining a trend or pattern over such a short period of time, especially when the impacts and extremities of climate change have only started to percolate in the past decade or so, is nearly impossible.

A common theme that seems to repeatedly emerge throughout interventions 1-5, is the continual reviewing of the baseline risk. The baseline risk is produced through identified impacts to the business and their frequency of occurring. With respect to climate change, the current R&OV does not utilise a database that explicitly contains climate change impacts and its frequency. The baseline risk is core to the R&OV process and if the baseline risk is does not consider climate change risks the outputs from the R&OV become less relevant.

Currently the R&OV process only considers climate change mitigation; in that it takes into account the carbon footprint of the asset. Climate change adaptation however, is currently not an integral part of the R&V process because there are currently no climate change specific risks that are used in Anglian Water's decision processes. The question of why Anglian Water's quantified CCRA isn't integrated in Anglian Water's decision making arises. A lack of incentive, company culture and the lack a climate change baseline data set are the main reasons for not adapting the CCRA into the Anglian Water's R&OV, BIM's and risk methodology.

4.2.1.4 Capital Maintenance Models, (CMM)

The purpose of the CMM system is to provide asset failure rates at some point in the future. The failure rate is calculated through asset deterioration models. The deterioration models consider future failure rates of up to 25 years ahead into the future using Monte Carlo over a set duration of time to calculate the likelihood of asset failure rates.

The deterioration models take into account certain factors that can affect the failure rate of the asset. The influencing factors that can affect the performance of the asset that is currently included in CMM are whether the asset is over/underground, the material of the asset and the local environment that the asset is located. Regarding climate change impacts, both, a gradual progressive increase in the climate change parameters and climate extremities; these are currently not taken into consideration by the deterioration models. External factors that can affect asset performance such as precipitation and temperature needs to be considered, if the failure rates are to yield reliable values. Secondary impacts, for example, how temperature affects asset material or how precipitation can affect the local pollution or corrosiveness of the local asset environment, which in turn can accelerate the wear on the asset material.

Gaps in CMM

There is a gap in integrating rainfall data and temperature data in CMM. This data can be produced by climate modelling such as the UKCP09 tool, but there is an inherent uncertainty in the raw data produced by this tool. Furthermore even if reliable raw data is produced, there is a gap in translating this data into information that shows trends and patterns.

Impacts of temperature and rainfall on existing factors that are already accounted for in the CMM deterioration models such as material has not been studied. CMM needs to completely assimilate climate change into its processes. It requires the data, information and interpretation of climate change impacts on assets.

A Monte Carlo simulation is a mathematical phenomenon. It generates probabilistic values that are dependent on the following information:

1. A mathematical formula that represents how inputs turn into an output.
2. A reasonable estimation of the variation of each input.
3. An idea of what output performance is acceptable.

A problem appears if climate change data is used in the existing CMM Monte Carlo method. Using probabilistic data in a model that randomly selects that probabilistic data over an amount of iterations will augment the level of uncertainty in the final output. There is an apparent knowledge gap of how this climate data can be integrated effectively into the CMM.

4.2.1.5 Operational Management Centre, (OMC)

The OMC is the core of all operational business and operational management and activity in Anglian Water. It monitors more than half a million assets through Anglian Water's telemetry system and plan and schedule customer and asset related operational jobs as well as managing field technicians. The OMC's purpose is to deliver excellence in risk and work management through the provision of business resilience and supporting the delivery of their business key outcomes, particularly in the areas of service, serviceability, efficiency and health and safety. The OMC encapsulates numerous teams within Anglian Water and is split into the following.

1. **Asset Maintenance Performance**: Their purpose is to enhance and prolong asset life through better maintenance and reduce operational cost.
2. **Business Resilience**: Cover all areas and activities within Anglian Water ensuring resilience to hazards, risks and challenge.
3. **Integrated Operational Management**: Ensures that operational ground staff maintains the assets when required and manages them across various Anglian Water sites.

4. **Operational Change**: Collectively manage and deliver operational change projects. To manage this they must understand both day-to-day activities and long term strategic direction of the business.

5. **Asset delivery**: Liaises with operational ground staff to deliver assets effectively and as efficiently possible.

6. **Customer Delivery**: Responsible for planning and scheduling jobs based around customers.

7. **Tactical Operations Management**: Investigates patterns in alarms it see what can be done in the short term. For issues that develop over the longer term, the Tactical Operations Management team strategizes on how to solve these issues such as burst mains, flooding, pollutions and problems caused by bad weather.

Table 9 below shows how each of the teams as listed above are relevant to climate change impacts.

Table 10: How climate change is relevant to OMC teams

OMC team	Climate change relevance
Asset Maintenance Performance	Asset data on thresholds at which it fails to operate due to extreme weather events.
Business Resilience	Climate change impacts and its importance must be percolated through either top-down or bottom-up so that everyone in the Anglian Water business understands its importance. A collaborative approach through all divisions in Anglian Water could potentially help to change company and incentive the business to do more.
Integrated Operational Management	The availability of more information on how climate change is impacting assets from an operational standpoint.

Operational Change	The availability of more information on how climate change is impacting assets from an operational standpoint .
Asset delivery	Negligible affect
Customer delivery	Negligible affect
Tactical Operations Management	Climate change data monitoring and pick up trends or patterns of impacts of assets as a result of climate change. Real time control of monitoring pollution or turbidity where physical, chemical and biological reactions occur in very short spaces of time. Data management and ability of analysing and interrupting the data.

4.2.1.6 Data Management

Table 9, shows that the team with the most influence on integrating climate change impacts to Anglian Water's business processes are the Tactical Operations Management team. This is because so much of the challenge of integration is based around climate change data. Without the data there cannot be an effective climate change risk management system. Data acquisition challenges and the challenge of data management, especially relating to climate change, remain huge within the water industry. The full and complete integration of asset data systems is currently a vast challenge.

Gathering data volume in bulk is just one part of the process of an effective data management system, but analysing and interpreting the collected data is another, as explained in section 1.1. Significant work has been done in Anglian Water in their telemetry systems to gather data however there remains a knowledge gap on how to analyse and interpret the large volume of data effectively.

Table A.1 in the Appendix section, summaries the data, information and knowledge gaps in Anglian Water's business decisions with respect to climate change. Before information or knowledge can be created, it needs to be derived from good quality data. This calls the need to monitor or measure assets in order to produce data which can be later interpreted and analysed to close some of the knowledge gaps found.

4.2.1.7 Summary of Anglian Water's knowledge Gaps

While elements of climate change are somewhat indirectly included in Anglian Water's business decisions, there is a pressing need to explicitly include climate change in their business decisions. Much of the gaps in Anglian Water's business processes based on climate change data and their assets revolve around the absence or in some cases, inconsistency of climate change data. Without this, the yielded cost values, or outputs of Anglian Water business units, become more uncertain. Data is needed to create the probabilities of climate change impacts occurring so that climate change risks can be assigned to their assets and integrated into the business processes.

Identifying the knowledge gaps in Anglian Water's business decisions is a somewhat linear process that requires the identification of climate change impacts and its associated data. In order to translate the climate change impacts, as discussed in chapter 1, into climate change risks, its associated data must be interpreted to find trends and patterns, and so the probability of that impact occurring. Only once these parameters are met, can the risk be calculated.

However, even if the impacts, data, frequency and consequently risks are developed, there still remains a gap. A method of prioritising the climate change impacts for Anglian Water has yet to be established. Prioritising would become more transparent once the impacts have been translated into risks though it is dependent on the level of accuracy in the risks and how financial cost is assigned to the impact.

A common shortfall amongst all Anglian Water's business units is that it currently does not treat the impacts of climate change on their assets in isolation. At present Anglian Water's business units indirectly or even coincidently contain data and information that is relevant to climate change impacts. Climate change occurs in two ways, one being a gradual change in rainfall and temperature, progressively having an effect on Anglian Water assets and the other is extreme events. Whether climate change impacts and data should be merged and mixed into the current business units or partially treated as a standalone information piece in parallel to the existing information and data in each of the business units remains unclear. Further questions arise in the two ways that climate change occurs, for example a gradual increase in temperature and extreme, prolonged droughts. Both scenarios should have their own associated risk registers used for decision making.

Before any such relevant climate change specific data can be produced, the correct assets that needs to be monitored needs to be identified. To date, no such official risk methodology or framework exists, that can allow a water utility company to rank their assets that reflects the level of risk they are exposed to due to climate change.

The case study in Section 4.4.1, presents a need on why it is absolutely essential for Anglian Water and possibly other water utility companies to incorporate climate change impacts and their frequency in their business decisions in order to sustain a successful organisation in the face of future climate change challenges. Section 4.6 goes on the next natural step, which is the first step of developing a risk model.

4.3 Review Risk Approaches

Once the review of the business decision making processes of a water utility company has been completed I order to establish the need for monitoring assets, a detailed literature review of existing risk management practices needs to be undertaken as described in Chapter 2.

Chapter 2 evaluates past studied of risk based approaches, including qualitative, quantitative and semi-quantitative risk studies. Previous risk studies applied to different industries as well as the topic of climate change were targeted to understand how different risk approaches were implemented for a complex subject area such as climate change. Given that climate change is a multifaceted global challenge and complex phenomena, a semi-quantitative risk approach, in particular in form of a risk matrix, was chosen due to its widely applicable use. Such an approach can be applied to scenarios that are complex in nature or where there lies much uncertainty. Therefore complex phenomena such as climate change become an ideal candidate for a semi-quantitative risk-matrix based approach and for this reason this risk based approach was chosen.

Further reviews were conducted on past studied using a risk-matrix based approach to provide a better understanding of how it can be utilised and implemented effectively. The focus here was the scoring definitions and how risk can be classed assigned with different scores. Conventionally, the typical risk matrix such as the one depicted in Figure 5 uses a Likert-Scale from 1-5. A Likert-Scale use fixed choice response formats and are designed to measure attitudes or opinions (Bowling, 1997). Depending on the purpose of the questionnaire and the environment in which it is used in, the number of categories for scoring i.e. 1-5 or 1-7 can differ. Lozano et al. (2008) investigated the optimum number of response alternatives that maximises the fundamental psychometric properties of a Likert-scale; reliability and validity. The study found that the optimum number of alternatives is between 4 and 7. Therefore, the presented risk tool as shown in Chapter 5 uses a scale from -1 to 4 to assign the impacts scores for optimum extraction of information and ease of use. Only having three positive and negative scores would be easier for the participant, however, it would also mean that it would obtain less useful information from the participant. On the other hand, having a scale from -5 to 5 may cause further confusion to the participant, who may then simply select the middle number, 3 or -3, which would result in less reliable information.

4.4 Developing a Scoring Methodology

From the literature review presented in section 2.4, the relationship between the impacts of climate change to an asset (vulnerability) and the importance of an asset to the business decision of a water utility company (criticality) was established. There are three distinctive areas that were identified and are all linked with one another. These are climate change impacts, assets and their operational processes and the water utility firm's decision making processes. As discussed in section 2.4, these three areas relate to the hazard, vulnerability of assets and criticality to business decision.

- Climate change parameters are the ***hazard***
- How ***vulnerable*** the operational processes of the assets are to the different climate change parameters
- How ***critical*** the operational processes and climate change parameters are to the water utilities decision making processes

From here, the scoring method (model) to rank assets can be shaped. The two measures, vulnerability and criticality were combined to deduce the total risk.

Definitions of the different levels of vulnerability and criticality were defined along with its score, as shown in Table 11 and 12 respectively. From the literature review conducted earlier on the key climate change parameters, definitions were also provided for different key climate change parameters, shown in Table 10. Essentially, how vulnerable an asset is to each of the different climate change parameters is scored, as well as how critical an asset is to the business of the water utility company. Each of the vulnerability scores for an asset was totalled. The total risk is the multiple of the summed vulnerability score and the criticality score and is described in section 5.5. The risk methodology was developed in such a way that it is imperative that the term 'climate change,' is purposely not mentioned to the person who scores the assets in terms of its criticality and vulnerability to avoid any preconceived notions about climate change that can cause bias input of scores. This was found through the literature review on climate change that the phenomena can act as a barrier of acceptance to some people. Fischer et al., (2011) conducted 202 semi-structured interviews on citizens asking them their views on policies on energy use and climate change. Fischer et al. had overcome the citizens own attitudes and beliefs on climate change to gain accurate data. Therefore the presented scoring model in Chapter 5, purposely avoids the term 'climate change' to whoever uses the tool. The total risk score is the summed vulnerability score multiplied by the scaled criticality score. How the critical score is "scaled" is described in section 5.5. The main target group for this scoring methodology is someone who has experience and expertise in water industry assets, this could be a process expert, an operative, or an asset manager.

4.5 Presenting the Scores

The penultimate step of the method is to calculate the total risk scores and plot them in form of a Risk Matrix.

From the conducted literature review, the Risk Matrix is a widely used tool because it is simple to understand and provides a visual aid to the reader to easily interpret the risk. For these reasons the total risk score was presented in form of a Risk Matrix, as shown in Figure 10.

Section 5.1 provides guidance on how to use the risk tool. Section 5.5 defines the risk boundary lines and explains why the risk range of the matrix (Figure 10) is split into three equal portions.

4.6 Sensitivity Analysis

Testing the model is the final step, and allows the value of the outcome, the scoring method (or model) to be assessed. Reducing the model output uncertainty is imperative before releasing the model to the end user, and therefore a method of testing is required to ensure the uncertainty can be reduced as much as possible. Section 2.6 provides a review on sensitivity analysis and highlights some examples on how it was applied in past studied around climate change.
As described in section 1.2.1 the two key parameters are rainfall and temperature. Therefore these two parameters can be taken as the two key independent variables of the scoring tool and a sensitivity analysis, in form of a variance based method, can be applied to test the tools performance and outputs. The two independent variables are applied in two extreme scenarios; maximum and minimum values for both rainfall and temperature and its impacts on the assets. The literature review on the operational impacts of climate change as described in Section 1.2 is used as a guide when deciding the scores for the two extreme scenarios in the interest of sensitivity analysis.

5 Results and Evaluation

Figure 7 below, shows the conceptual framework of the semi-quantitative risk methodology and its systematic steps for ranking water industry assets in terms of its risk and subsequently, its need for monitoring. Each component of the developed methodology (Figure 7) is described in detail below.

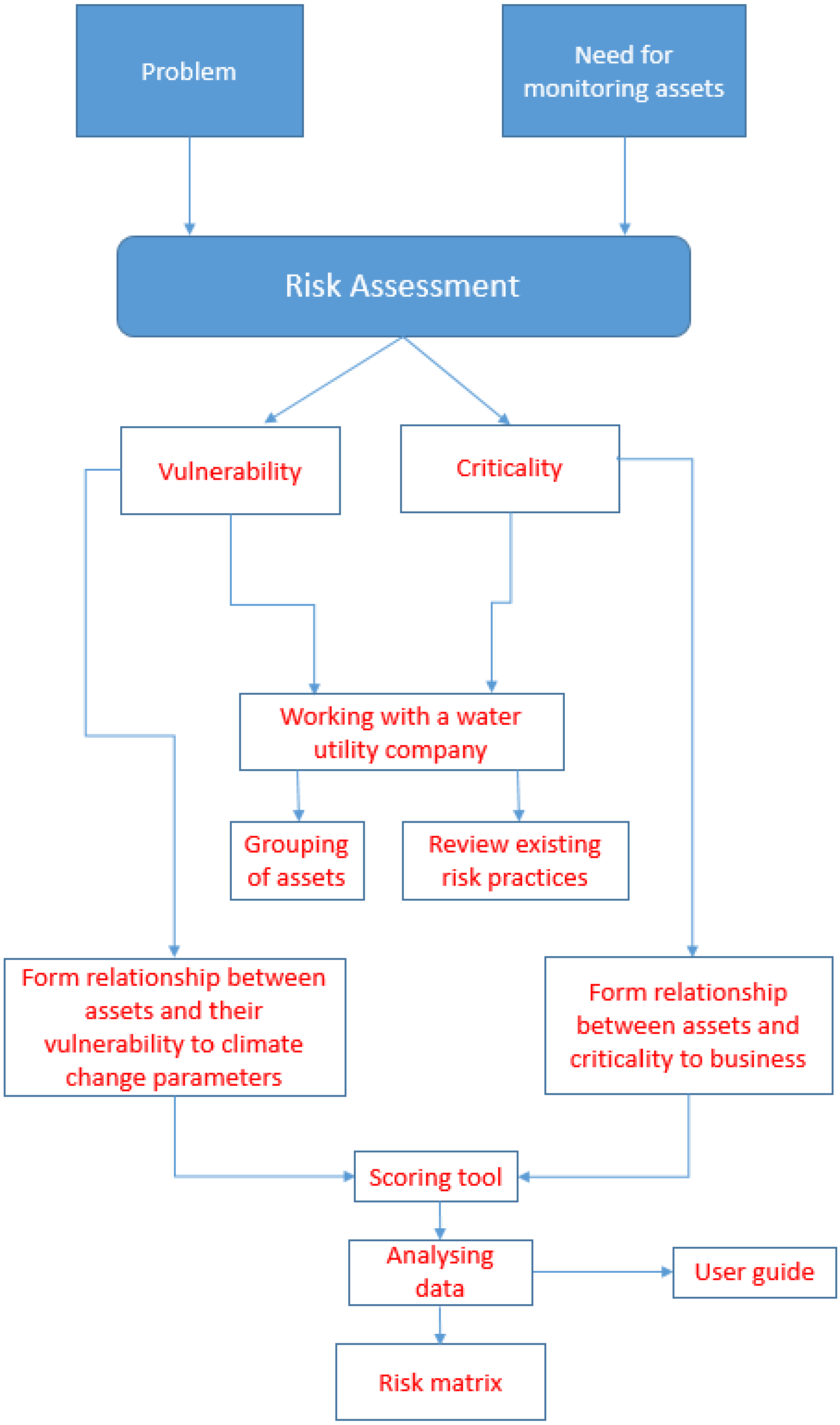


Figure 7: Conceptual framework to represent the proposed semi-quantitative risk methodology

“Problem” and the “Need for monitoring assets”

The first step of this methodology involved an in-depth study of the impacts and challenges faced by water utility companies as a result of climate change. It also involved an in-depth study of the different climate change parameter(s) which could affect a water utility asset.

The “*Problem*” is the source of the impacts caused by climate change to not only the water industry but also other industries, which are inter-dependent on each other, as described in Chapter 1 in the water-food-energy nexus. As for the water industry, in particular water utility companies, climate change has been realised as a future threat and the potential impacts have been widely documented.

Therefore a strategy must be put into place help control the level of risk posed by climate change on water utility companies. This strategy is the “*Need of monitoring assets*” and is created in section Chapter 1 and section 4.2.1. Chapter 1 explains the challenges faced by water utility companies from different angles, for example technological challenges, the consequences of climate change and its impacts to the water utility company and section 4.2.1 goes on to explain the importance for a water utility company to integrate climate change risks in their business units in order to monitor assets.

Risk Assessment

The “Risk Assessment” is the core of the presented methodology. It is a semi-quantitative methodology, in which the 2 components of risk are the vulnerability of assets to climate change and the criticality of an asset to the business decisions of a water utility company.

Working with a Water Utility Company

This step of presented methodology involves working within a water utility company to collate all the relevant information surrounding their assets. Such information consists of how they categorise and group their entire nomenclature of assets. As example for one for Anglian Water is provided in Table A.2 and A.2 in the Appendices section. Additional information that needs to be collated from the water utility company is their existing business processes that focus on their assets. This would include the reviewing of their current risk management and practices and/or their risk tools for their assets. Section 2.1 provides a review on how Anglian Water manages their assets. This step of the methodology does not feed directly into the “*Risk Assessment*” but provides an idea on the existing gaps in a water utility companies risk practices regarding the incorporation of the impacts of climate change on their assets. This knowledge could be useful for any future refinements of the risk assessment or understanding how this methodology can add value to the water utility company. It can also help the forming of criticality definitions as described in the section below.

Vulnerability

These parts of the methodology are imperative to the level of quality of resultant risk data. Using the in-depth study or literature review, from the preceding steps, “*Problem*” and “*The need for monitoring*” of Figure 7, a relationship can be formed between the parameters of climate change and the assets. This step involves the defining of the different climate change parameters and the definition of vulnerability scoring in the range of from 1 to 4 and -1 and 4. It is important to note that this methodology is such that an asset can be affected either by one or a combination of the different climate change parameters. Also, the presented methodology specifically states that the term “climate change” should not be used to for the user to avoid any biased answers; instead the vulnerability definitions are called “weather change parameters”.

Criticality

The step of collating information from a water utility company and reviewing their current asset management practices should provide a better understanding on how the performance reduction or failure of an asset as a result of climate change parameter(s) can affect the business of the utility company. This stage involves the creation of forming a link between the asset the business of the water utility company. Definitions of the different severities of how critical an asset is created and assigned a suitable score, from range 1-4.

Scoring Tool & Analysing Data

The "*Scoring Tool*" component of the methodology enables the tallying of the total vulnerability and criticality scores. Table B.1 in the Appendix section provides an example. This part of the methodology also identifies the performance asset(s) of assets that are improved by the different climate change parameters in order to seek if there is an opportunity in future to further improve or adapt these assets.

Once the scores have been totalled they need to be analysed which comes into the "*Analysing Data*" step of the methodology. Ultimately, the methodology proposes that the total risk of the asset is the multiply of the total vulnerability score and the total criticality score. These scores are depicted in the next and final step, "*Risk Matrix".*

The methodology includes a *"User guide*" so that other can use the methodology properly once it has been created. B.2 of the Appendix provides an example.

Risk Matrix

The final step of the methodology is creating a visual illustration of how the data can be presented in a meaningful format. The risk matrix, as shown in Figure 11 as an example illustrates all the total risk scores. The methodology allows the ranges of what constitutes as low, medium or high risk to be changed, therefore changing the colour shading of the risk matrix.

5.1 How to use the Risk Tools

This chapter demonstrates how to use the final output – the Risk Scoring Table B.1 and the Risk Matrix Diagram B.3, as found in the Appendix chapter. These tools are a core part of the presented methodology and it is essential the user understands how to effectively use the tools to gain meaningful results.

5.2 Asset Groupings

Tables A.2 and A.3 in the Appendices section illustrates an example of how water utilities assets are categorised. Assets are split between two tables, 'Wastewater,' and 'Clean water.' Column heading 'Level 1,' defines whether the asset is grouped under the term infrastructure or non-infrastructure, 'Level 2' defines which sector the asset belongs in, 'Level 3' defines the process that the function is within and finally 'Level 4' states the asset name.

5.3 Assessing Vulnerability of Assets

This section focuses on how vulnerable an asset is to a particular weather event. Participants for this stage are required to be of a managerial position with a working knowledge of the assets as a whole or on assets that are within their sector, for example waste water.

There are six parameters in Table 10 and all six of the parameters include the potential consequences (at high level) of climate change. They are defined as follows.

Table 11: Climate Change Parameters

Parameter	Definition
Temperature Rise	Higher peak and average temperatures, increased evaporation and evapotranspiration, this includes gradual and extreme increase of temperature, i.e. heat wave
Freezing Temperatures	Winter temperatures that falls below 0 degrees Celsius
Drought	Lower levels of rainfall over prolonged periods, reduced levels of groundwater and soil moisture, lower levels of infiltration
Rainfall (frequency)	Decreased average summer and increased winter rainfall, increased average, prolonged rainfall, increased level of erratic rainfall patterns. Higher groundwater levels and increased soil moisture due to saturation. Does not include intense rainfall that can lead to flooding

Rainfall (severity)	Greater storm rainfall intensities, flash floods and fluvial flooding in a short space of time, compared to the parameter above
Sea Level Rise/Coastal Storm Surge	Includes the effects of global sea level rise, coastal erosion, coastal flooding and storm surges. Only relevant for assets that are subject to coastal floods, in a 1:50, 1:100, 1:200 or 1:1000 flood zone

Under each parameter, the participant should provide a score from -4 to 4. Scoring definitions of vulnerability are defined below, in Table 11. The score is based on the participant's opinion, which is appropriate at a screening level.

For clarity and ease of use, Table B.1 (the Risk Scoring Table B.1 as found in Appendices) has drop down list for the different definitions of vulnerability. This should save time for the participant, who would otherwise have to look back at the scoring table to remind themselves of the definitions. Consequently, this feature helps with objectivity and should help improve the participants scoring consistency.

Table 11, below, defines each score.

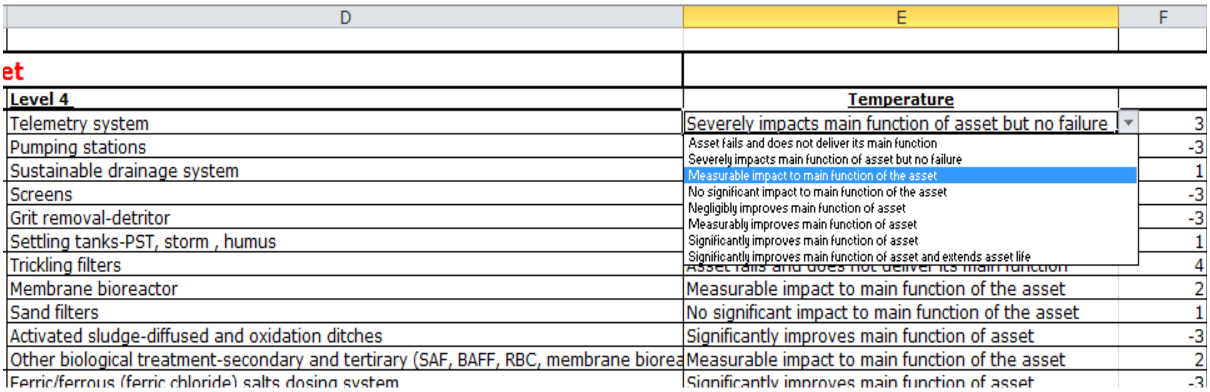
Table 12: Scoring vulnerability

Score	Definition
1	No significant impact on the main function of the asset
2	Measurable impact to the main function of the asset but no failure
3	Severely impacts the main function of the asset but no failure
4	Asset fails and does not deliver its main function
-1	Negligibly improves main function of asset
-2	Improves main function of asset
-3	Improves main function of asset and subsequent assets

-4	Significantly improves main function of asset and subsequent assets

The main function of the asset encapsulates both the operational process in which the asset is performing under and the ability of the asset to contain the operational process to acceptable levels. For example, a chemical spray asset to treat odour maybe working at its optimum rate of performance, however a weather parameter may drive the level of odour beyond the assets capacity. This means that the main function of that asset is impacted, in spite of the asset performing at its desired level. In the worse (score 4), both the operational process is severely impacted and the asset itself fails to operate.

Figure 8, below, shows the scoring method for vulnerability.



D	E	F
et		
Level 4	**Temperature**	
Telemetry system	Severely impacts main function of asset but no failure	3
Pumping stations		-3
Sustainable drainage system		1
Screens		-3
Grit removal-detritor		-3
Settling tanks-PST, storm , humus		1
Trickling filters	Asset fails and does not deliver its main function	4
Membrane bioreactor	Measurable impact to main function of the asset	2
Sand filters	No significant impact to main function of the asset	1
Activated sludge-diffused and oxidation ditches	Significantly improves main function of asset	-3
Other biological treatment-secondary and tertirary (SAF, BAFF, RBC, membrane biorea	Measurable impact to main function of the asset	2
Ferric/ferrous (ferric chloride) salts dosing system	Significantly improves main function of asset	-3

Drop down list:
- Asset fails and does not deliver its main function
- Severely impacts main function of asset but no failure
- Measurable impact to main function of the asset
- No significant impact to main function of the asset
- Negligibly improves main function of asset
- Measurably improves main function of asset
- Significantly improves main function of asset
- Significantly improves main function of asset and extends asset life

Figure 8: Drop down list for asset vulnerability

The user selects which definition he/she believes is most suitable for a particular asset using the drop down list as seen on Figure 8, under column 'E.' The numerical score automatically displays once the user has selected the vulnerability definition for that asset, as seen below column 'F' in Figure 78.

5.4 Assessing Criticality of Assets

The same participants who scored the vulnerability for the assets are also required to score the criticality of assets.

In this context, criticality refers to how much importance an asset carries to the water utilities business. For example an asset could be of a low financial value with a low sensitivity to a weather parameter, but it could have significant ramifications if it did fail. In this case it could have a high criticality rating within the decision making processes.

Ultimately, the criticality of an asset captures the level of potential costs to the business. The cost is largely associated with failing Ofwat's serviceability indicators (Ofwat, 2009) which also include compliance failures that may occur in the treatment process. Additional substantial costs can be incurred through fines, court costs and compensation payments.

Table 12, below, provides the definition for each of the criticality scores.

Table 13: Criticality scoring

Score	Definition
1	No importance/dependency to business decisions
2	Carries small importance/dependency to business decisions
3	Important to business decisions and potential to cause repercussions
4	Carries significant ramifications to business decisions

In the event that the function of an asset is impacted to the point where it also affects the function of subsequent assets, this scenario is already accounted for in the scoring of criticality of that asset. In this event, it is clear that it is critical to the business because more than one process and asset are affected.

Figure 9, below, illustrates the drop down feature for the user to select the criticality score for each asset.

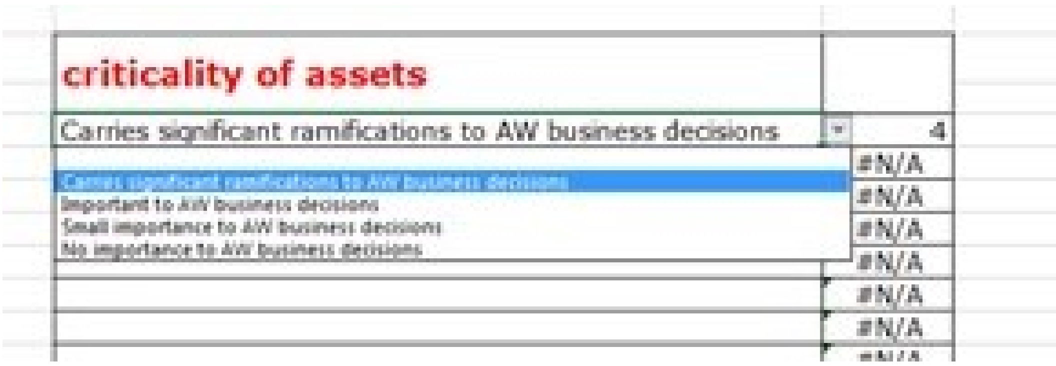


Figure 9: Drop down list for asset criticality

5.5 Analysing and Interpreting Data

Once Table B.1 has been completed with both vulnerability and criticality scores, quantifying and normalising the scores will provide a ranking of assets that are most at risk to climate change, and therefore in more need of monitoring. The total score for each asset is the combination of the vulnerability score and criticality score.

The method to analyse the results is as follows:

- First, add a separate column to display the total the score for the vulnerability impacts to weather change parameters. For accuracy of data and to have any meaningful results on the total vulnerability score, Table B.1 only adds the positive numbers. Hence, the lowest and highest possible vulnerability score for each asset is 6 and 24;
- Add a separate column to display the total criticality score. The lowest and highest possible score for each asset is 1 and 4;
- In order to scale the scores, so that both vulnerability and criticality scores have the same applied weighting, multiply the total criticality score by 6. This enables both scores to have the same scale range;
- The total risk score for each asset is the multiple of the total vulnerability score and the total criticality score.

The total score indicates the risk value. This can be plotted on a risk-matrix diagram as shown in Figure 10, below. The risk values are calculated from all the vulnerability and criticality scores.

Asset Risk Matrix

Vulnerability

24	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480	504	528	552	576
23	138	161	184	207	230	253	276	299	322	345	368	391	414	437	460	483	506	529	552
22	132	154	176	198	220	242	264	286	308	330	352	374	396	418	440	462	484	506	528
21	126	147	168	189	210	231	252	273	294	315	336	357	378	399	420	441	462	483	504
20	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480
19	114	133	152	171	190	209	228	247	266	285	304	323	342	361	380	399	418	437	456
18	108	126	144	162	180	198	216	234	252	270	288	306	324	342	360	378	396	414	432
17	102	119	136	153	170	187	204	221	238	255	272	289	306	323	340	357	374	391	408
16	96	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
15	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
14	84	98	112	126	140	154	168	182	196	210	224	238	252	266	280	294	308	322	336
13	78	91	104	117	130	143	156	169	182	195	208	221	234	247	260	273	286	299	312
12	72	84	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288
11	66	77	88	99	110	121	132	143	154	165	176	187	198	209	220	231	242	253	264
10	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
9	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216
8	48	56	64	72	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192
7	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	161	168
6	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Criticality

Figure 10: Risk matrix diagram

<u>Legend</u>

Green: Low risk

Orange: Medium risk

Red: High risk

The positive scale for both vulnerability and criticality has a range from 6 to 24. Hence, applying equivalent weights for low, medium and high risks respectively means that each of the components of total risk, e.g. vulnerability and criticality has a range of 6. This technique ensures fair weighting is applied for different levels of risk and calculates numerical values that can be assigned for each level of risk.

The risk value ranges are defined as below:

Green, LOW risk: -576≤144

Orange, MEDIUM risk: 145≤324

Red, HIGH risk: 325≤576

The ranges where calculated by simply splitting the x-axis and y-axis scale on the risk matrix (6-24) into three equal portions. Therefore the values that lie in the boundary of the three portions are 12, 18 and 24. Squaring these numbers (i.e. multiplying the x and y axis) gives the maximum value (total risk score) as 144, 324 and 576. These three values are the maximum scores for each portion and defines the boundary lines as the low, medium and high areas. The reason why the boundary were split equally on the risk matrix is because defining the boundary lines is, to an extent, arbitrary and inevitably affected by the subjective view, therefore although the risk matrix attempts to objectify the risk through splitting it into three equal portions, there is always an element of subjectivity. The boundary lines can be more clearly defined amongst a review with experts with a large set of data points, who will be able to define the risk ranges more clearly.

Add another column next to the 'Total vulnerability score,' that records the maximum value the given score of an asset. The provision of a maximum recorded value enables further clarity of how overall dependent as asset. For example an asset may have a total score of 12 that is added from scores of'2's' but another asset may have a total of 8 from the added scores of two '4's.' The asset with a total score of 8 carries more significance, therefore through recording the maximum value a distribution of scores can be tabulated to graphically see how the results are skewed.

If the total risk value for an asset is negative, it is automatically in the green region and therefore a low monitoring requirement.

The total, risk score for each asset that lies within the green region of the matrix is a low risk to the water utility and therefore has a low monitoring requirement. No monitoring action is required for assets that lie in this region. Assets that have a risk score in the orange region have a medium risk to the utility and therefore have a medium monitoring requirement. For these assets, monitoring is required but no action for adaptation is required. Assets that have a risk score in the red region have a high risk to the utility and therefore have a high monitoring requirement. For these assets, monitoring and action to adapt is urgently required.

Issues of assets that have a score lying between the boundaries of green/orange and orange/red and what constituents these assets to a certain level of risk may arise. It is therefore recommended that these assets are reviewed by experts within the water utility company once the scoring of assets has been completed, so that they are able to deliver the final verdict of the assigned level of risk to these assets. A water utility organisation is primarily concerned with cost and in order to avoid additional costs they need to ensure that the cost of taking action is less to that of the cost of damage, if nothing is being done. Hence, the boundaries lines between the low/medium and medium/high risk can move in accordance to the analysis of the cost effectiveness.

The focal points are assets that have a risk score that lies within between 325 and 576, i.e. the red region of the matrix. Only these assets are of attention for the proceeding step, which involves expert elicitation from process scientists/technicians, who'll be able to provide further insight into these particular assets. Assets that have a score located near the boundaries of green/orange and orange/red in the risk matrix diagram can also be further discussed between the managers and process scientists/experts in order to decide they are of important or not.

5.6 Features of Design of Risk Scoring Table

This section aims to evaluate the design features of Table B.1. Firstly before user looks at Table B.1, it is important for them to gain an understanding of the purpose of the risk method, the meanings of terms used such as climate change parameters, vulnerability of assets and criticality of assets. For clarity of the reader and to avoid inputting misconstrued scores, a user guide has been produced as found in the Appendences, 'User Guide for Table B.1'.

There is an additional feature of Table B.1, which records the total score for opportunity with respect to climate change parameters that positively helps the main function of the asset. For example temperature increase can in theory improve sludge thickening or biological activity occurring in aeration lanes. Totalling the 'opportunity' score for each asset provides an indication whether it is worth exploring any future potential opportunities in improving the performance of that asset.

There is also another column for both clean water and waste water tables that records the maximum vulnerability score for each asset. For example, asset A may receive a score of 1,2,2,1,1,4 whereas asset B may receive a score of 2,2,2,2,2,2 for each of the 6 climate change parameters. Therefore asset B has a total vulnerability score of 11 compared to asset B which has a score of 12.

At face value, asset B has the higher vulnerability score; however, on further reflection the climate change parameter that had scored 4 for asset A may prove more paramount in contrast to all the other inputted scores. Hence, overall asset A may have an overall higher vulnerability due to that sole score of 4. Recording the maximum vulnerability score for each asset enables further clarity when analysing results.

Conversely there is a separate column that records the lowest score, i.e. the parameter that improves the main function of the asset. This could help the water utility company to identify and exploit any opportunities of the performance of assets and the treatment processes that are improved as a result of climate change.

5.7 Demonstration of Presented Risk Methodology using a Variance based Sensitivity Analysis

This section aims to provide a test of Table B.1 to demonstrate a working example on how the presented methodology operates and also to test the model performance of the tool, through a variance based sensitivity analysis, to identify any weak areas. Table B.1 shall be used to process inputted data and risk matrix in Figure 10 shall analyse and present the data.

As mentioned in section 4.6, the two key independent climate change variables are rainfall and temperature. The following scenarios (variances) shall be applied to the tool and therefore the tool shall be run twice:

1. Extremely high rainfall and extremely low temperature (Scenario 1);
2. Extremely High Temperature and extremely low rainfall (Scenario 2).

Extremely high temperatures is taken as the highest record UK temperature recorded by the Met Office as 38.5 degrees Celsius and lowest temperature in the UK recorded by the Metoffice as -27.2 degrees Celsius (Metoffice Extremes, 2016). Highest rainfall shall be taken over a three day consecutive period and is assumed at 456.4mm over this specified period. (Metoffice Extremes, 2016). The lowest rainfall is assumed to be 0mm over a three day consecutive period.

The literature review provided in Chapter 1 shall be used as a guidance to determine the suitable input scores in the tool with respect to Scenario 1 and Scenario 2.
The scoring of wastewater assets were chosen because overall, their treatment processes are more impacted by impacts of climate change than that of clean water, as described in literature review in Chapter 1. More specifically the assets categorised under 'Level 2: Sewage treatment works; Level 3: Physical-Clarification and Biological' in Table B.1 were selected to assign scores.

5.7.1 Scenario 1

Table 14, 15 and 16 below represent the scores for Scenario 1. Figure 11 provides the risk scores for Scenario 1.

Table 14: Vulnerability Score Results for Scenario 1

Asset	Climate Change Parameter						Total Vulnerability Score	Maximum Value Recorded
	Temperature Rise	Freezing Temperature	Drought	Rainfall-frequency	Rainfall-severity	Sea rise/Coastal storm surge		
Screens	1	2	1	3	4	4	15	4
Grit-removal detritor	1	1	1	3	4	4	14	4
Settling tanks: Storm, humus, primary settling tanks	1	1	1	3	3	3	12	3
Tricking filters	1	2	-1	1	2	2	8	2
Membrane bio-reactors	1	1	-1	2	2	2	8	2
Sand filters	1	2	2	1	2	4	12	4
Activated sludge-diffused and oxidation ditches	1	1	1	2	3	3	11	3
Other secondary and tertiary biological treatment-(Submerged Aeration Filter, Rotating Bio-contractor)	1	1	2	3	3	4	14	4

Table 15: Criticality Score Results for Scenario 1

Asset	Criticality Score	Scaled Criticality Score
Screens	4	24
Grit-removal detritor	2	12
Settling tanks: Storm, humus, primary settling tanks	3	18
Tricking filters	2	12
Membrane bio-reactors	1	6
Sand filters	1	6
Activated sludge-diffused and oxidation ditches	3	18
Other secondary and tertiary biological treatment- (Submerged Aeration Filter, Rotating Bio-contractor)	4	24

The total risk score for each asset is the total vulnerability score multiplied by the scaled criticality score as shown in Table 15 below:

Table 16: Total Risk Score for Scenario 1

Asset	Vulnerability Score	Scaled Criticality Score	Total Risk Score
Screens	15	24	360
Grit-removal detritor	14	12	168
Settling tanks: Storm, humus, primary settling tanks	12	18	216
Tricking filters	8	12	96
Membrane bio-reactors	8	6	48
Sand filters	12	6	72
Activated sludge-diffused and oxidation ditches	11	18	198
Other secondary and tertiary biological treatment- (Submerged Aeration Filter, Rotating Bio-contractor)	14	24	336

Asset Risk Matrix

Vulnerability

24	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480	504	528	552	576
23	138	161	184	207	230	253	276	299	322	345	368	391	414	437	460	483	506	529	552
22	132	154	176	198	220	242	264	286	308	330	352	374	396	418	440	462	484	506	528
21	126	147	168	189	210	231	252	273	294	315	336	357	378	399	420	441	462	483	504
20	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480
19	114	133	152	171	190	209	228	247	266	285	304	323	342	361	380	399	418	437	456
18	108	126	144	162	180	198	216	234	252	270	288	306	324	342	360	378	396	414	432
17	102	119	136	153	170	187	204	221	238	255	272	289	306	323	340	357	374	391	408
16	96	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
15	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
14	84	98	112	126	140	154	168	182	196	210	224	238	252	266	280	294	308	322	336
13	78	91	104	117	130	143	156	169	182	195	208	221	234	247	260	273	286	299	312
12	72	84	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288
11	66	77	88	99	110	121	132	143	154	165	176	187	198	209	220	231	242	253	264
10	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
9	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216
8	48	56	64	72	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192
7	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	161	168
6	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Criticality

Figure 11: Total Risk Scores plotted on Asset Risk Matrix for Scenario 1

The total risk score in Table 15 are plotted on the risk matrix diagram, as shown above in Figure 11. The scores are denoted on the diagram through a dotted cross.

Table 16, below, shows the assets and their associated risk classifications:

Table 17: Asset Risk Classifications for Scenario 1

Asset	**Risk Classification**
Screens	High
Grit-removal detritor	Medium
Settling tanks: Storm, humus, primary settling tanks	Medium
Tricking filters	Low
Membrane bio-reactors	Low
Sand filters	Low
Activated sludge-diffused and oxidation ditches	Medium
Other secondary and tertiary biological treatment-(Submerged Aeration Filter, Rotating Bio-contractor)	Medium

5.7.2 Scenario 2

Table 18, 19, 20 and 21 below represent the scores for Scenario 1. Figure 12 provides the risk scores for Scenario 2.

Table 18: Vulnerability Score Results for Scenario 2

Asset	Climate Change Parameter						Total Vulnerability Score	Maximum Value Recorded
	Temperature Rise	Freezing Temperature	Drought	Rainfall-frequency	Rainfall-severity	Sea rise/Coastal storm surge		
Screens	4	1	3	1	1	1	11	4
Grit-removal detritor	3	1	3	1	1	1	10	3
Settling tanks: Storm, humus, primary settling tanks	2	1	2	1	1	1	8	2
Tricking filters	-1	1	-1	1	1	1	4	1
Membrane bio-reactors	-1	1	-1	1	1	1	4	1
Sand filters	1	1	1	1	1	1	6	1
Activated sludge-diffused and oxidation ditches	-1	1	1	1	1	1	5	1
Other secondary and tertiary biological treatment-(Submerged Aeration Filter, Rotating Bio-contractor)	-1	1	1	1	1	1	5	-1

Table 19: Criticality Score Results for Scenario 2

Asset	Criticality Score	Scaled Criticality Score
Screens	4	24
Grit-removal detritor	2	12
Settling tanks: Storm, humus, primary settling tanks	3	18
Tricking filters	2	12
Membrane bio-reactors	1	6
Sand filters	1	6
Activated sludge-diffused and oxidation ditches	3	18
Other secondary and tertiary biological treatment- (Submerged Aeration Filter, Rotating Bio-contractor)	4	24

Table 20: Criticality Score Results for Scenario 2

Asset	Vulnerability Score	Scaled Criticality Score	Total Risk Score
Screens	11	24	264
Grit-removal detritor	10	12	120
Settling tanks: Storm, humus, primary settling tanks	8	18	144
Tricking filters	4	12	48
Membrane bio-reactors	4	6	24
Sand filters	6	6	36
Activated sludge-diffused and oxidation ditches	5	18	90
Other secondary and tertiary biological treatment- (Submerged Aeration Filter, Rotating Bio-contractor)	5	24	120

Asset Risk Matrix

Vulnerability \ Criticality	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
24	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480	504	528	552	576
23	138	161	184	207	230	253	276	299	322	345	368	391	414	437	460	483	506	529	552
22	132	154	176	198	220	242	264	286	308	330	352	374	396	418	440	462	484	506	528
21	126	147	168	189	210	231	252	273	294	315	336	357	378	399	420	441	462	483	504
20	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480
19	114	133	152	171	190	209	228	247	266	285	304	323	342	361	380	399	418	437	456
18	108	126	144	162	180	198	216	234	252	270	288	306	324	342	360	378	396	414	432
17	102	119	136	153	170	187	204	221	238	255	272	289	306	323	340	357	374	391	408
16	96	112	128	144	160	176	192	208	224	240	256	272	288	304	320	336	352	368	384
15	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
14	84	98	112	126	140	154	168	182	196	210	224	238	252	266	280	294	308	322	336
13	78	91	104	117	130	143	156	169	182	195	208	221	234	247	260	273	286	299	312
12	72	84	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288
11	66	77	88	99	110	121	132	143	154	165	176	187	198	209	220	231	242	253	264
10	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
9	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216
8	48	56	64	72	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192
7	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	161	168
6	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144

Criticality

Figure 12: Total Risk Scores plotted on Asset Risk Matrix for Scenario 1

Table 21: Asset Risk Classifications for Scenario 1

Asset	Risk Classification
Screens	Medium
Grit-removal detritor	Low
Settling tanks: Storm, humus, primary settling tanks	Low
Tricking filters	Low
Membrane bio-reactors	Low
Sand filters	Low
Activated sludge-diffused and oxidation ditches	Low
Other secondary and tertiary biological treatment-(Submerged Aeration Filter, Rotating Bio-contractor)	Low

5.8 Critique of Pilot Test

This section shall critique the presented semi-quantitative risk tool as well as the pilot test results produced.

Advantages

- Several values in the pilot test were negative. This signifies that the climate change parameter improved the performance of that asset(s). The user can look back at Table B.1 and further investigate assets that scored negatively to explore any potential future opportunities.
- The risk matrix, Figure 10 is a visual aid to represent the calculated risk data. The methodology splits the assets categorically enabling the identification of areas in terms of their levels (as defined Table A.2 and A.3) which are most at risk. For example it may be found that primary treatment in wastewater treatment is more impacted by climate change or is deemed more critical to the business than tertiary treatment. The assets are categorised and ranked in terms of low, medium and high risk and therefore the user is able to establish treatment areas, i.e. primary, secondary or tertiary treatment that are most at risk.
- The methodology is flexible since assets can either be added or removed from Table B.1. Moreover, as Table B.1 groups assets in their treatment stage and at different levels. This could help identify asset groups that are posing more risk.

- Table B.1 records the maximum vulnerability score in order to help differentiate between assets that may have the same a vulnerability score but with different cumulative combinations. For example membrane bio-reactors can have a vulnerability score of 12 with a maximum recorded value of 2 whereas activated sludge can have a vulnerability score of 13 but with a maximum recorded value of 14. Whilst their total vulnerability score is very similar, the added feature of recording the maximum vulnerability score enables the user to infer which assets are most impacted by climate change. Regarding Table 13 the climate change parameters "Drought" and "Rainfall-frequency" have the biggest impact on activated sludge assets – which could be deemed as more important to the user than membrane bio-reactors which have all scored 2's.

Disadvantages

- The extrapolating or normalisation of the criticality scale on the "X" axis in order to match the scale of the "Y" axis may distort or add further inaccuracies to the final risk value.
- Some of the risk scores for Scenario 2 in Figure 12 are is not represented. The risk matrix diagram vulnerability scale on the "Y" axis should ideally start from 0, to provide a better representation of assets that have a vulnerability score of less than 6. The presented methodology is designed so that the total risk score is a multiply of the scaled criticality score and vulnerability score and therefore should be visually presented on the risk matrix to denote these 2 components of their respective values, however, what is additionally identified with an asset with a vulnerability score of 5 is that it may be confusing for the user to match the total risk score on the risk matrix diagram because a total risk score of 60 could also have a criticality rating of 6 and a vulnerability score of 10. The user could mistakably mark the wrong cell in the risk matrix that does not accurately convey its vulnerability and criticality scores.
- The maximum recorded vulnerability score not visually presented on the final output, the risk matrix diagram, as it only shows the total vulnerability score. It is up to the user to look back at Table B.1 and analyse the maximum recorded values to aid interpretation of the data.
- The assets that scored negatives values in Table 13; this information is not represented in the final output, Figure 10. Although the purpose of the methodology is to rank assets that are exposed to risk as a result of climate change, the added feature of illustrating assets with for example a vulnerability score of -24 and a scaled criticality score of 24 to Figure 10 would have been an added benefit.

- The weather change parameters used in this methodology as defined in Table 11 signify a change of weather at any one time; it does not include information on the rate of weather change in the future. In addition, the geographical distribution of the high risk assets and the number of these assets in use has not been accounted for in the methodology. Both these pieces of information can be added to refine and potentially improve to the accuracy of the risk ranking. For example, an asset may have the highest risk score of 576 but if there are only 5 of these assets in use through water utility sites, it may not be as significant as an asset that are used in the thousands, with a 'high risk score of 400. This issue could be resolved through UKCP09, weather generator tool which can be utilised to assess which weather change parameters that are most exacerbated until the end of the 21st century. Further work can be done in future once a list of assets have been assigned risk scores, such as the semi-structured interview with process experts and the use of UKCP09 to fill some gaps regarding drawbacks with the presented semi-quantitative risk methodology.

5.9 Evaluation

The application variance based sensitivity analysis on the risk methodology tool revealed similar results to the literature review on the operational impacts of climate change on water industry assets as described in Chapter 1. The results showed that high rainfall and low temperature have much more of an impact to assets than low rainfall and high temperature.

The aim of this research report, as described in Chapter 3 was fore filled, however there are a number of implications that hinder the effectiveness of the presented semi-quantitative risk methodology. Additionally, new relationships and how they interrelate have been identified; which can be further investigated to refine and improve the presented risk methodology.

Key relationships and interdependencies between the impacts of climate change (climate change parameters), water industry assets and the business decisions of a water utility company were found. Each of these areas can be very complex and pervasive if dwelled into further, especially that of the nature of climate change and how it affects the treatment operations and assets of a water utility company. For example, it is difficult to accurately determine the frequency and intensity of a climate change parameter for the future and therefore, there is more uncertainty as to how it can affect an assets performance. Climatic changes in weather can come about in 2 ways; one being a gradual increase in rainfall or temperature and the other being extreme, prolonged weather events and both has their own unique risks and need to be managed differently. GCMs can be used to find how each climate change parameter may take form in future but there is an inherent uncertainty in these models to predict the future climate. Ultimately, because of the inherent uncertainty of climate prediction and that the presented risk methodology relies on the subjective input of the user, there will always naturally be uncertainty in the final data, which is the total risk value plotted on Figure 10, the Risk Matrix.

Through the development of the presented risk methodology many data, information and knowledge gaps were found, mainly around asset data and how this data is stored and managed. In order to produce a more accurate and comprehensive methodology that ranks assets in terms of their need of monitoring many of these data, information and knowledge gaps need to be closed. In spite of all these short comings the presented risk methodology was developed in such a way that it handles the complex subject areas by treating them in a broader sense and uses a simplified semi-quantitative risk approach to overcome many of the gaps.

The presented methodology as a whole, is a systematic approach because each step can be traced back to understand the antecedent and precedent steps by forming a link between climate change impacts, water industry assets and their respective treatment operations and the business decisions of a water utility company – which in turn provides the information to produce the risk tools to rank assets.

6 Discussion

To date, there is no literature that shows a methodology in which water utility companies can effectively rank their assets in terms of their need of monitoring and the output as illustrated in Figure 11 clearly presents a format through which users can easily mark and assign risk to assets. The presented semi-quantitative risk methodology demonstrates a risk methodology that combines the two risk components *vulnerability* of an asset to climate change and the *criticality* of the asset to the business in order to calculate the total risk. The presented methodology is transparent and systematic that describes the end to end process of how risk is calculated which helps the user to form a logical argument to drive investment in adaptation or mitigation efforts towards certain assets. The methodology includes qualitative and quantitative elements and uses a relatively easy mathematical approach without being too numerically complex. The methodology meets the aim to create a semi-quantitative risk based methodology that identifies and ranks water utility assets that are I need of monitoring; however, there are drawbacks as discussed in Chapter 7. The methodology is open to further improvement and serves as a tool to *produce* a preliminary guide to help water utility companies understand the risks of climate change to their business. Ultimately, the presented methodology of ranking assets in terms of their level of risk, meets the stated objectives in Chapter 4

– and these objectives has been discussed in Chapter 7, showing it they have been met. Going forward, the presented methodology once effectively used, can provide a water utility company with a baseline dataset in order to better manage asset risk practices and therefore better inform their business decisions.

7 Conclusion and Recommendations

The main quantitative results of this developed risk based methodology are found in Table 14 and 18. The framework methodology itself is found in Figure 7.

The framework methodology and the developed risk based tool can be transferred and optimised to other water utility companies around the world.

As a future recommendation, additional steps can be taken to further improve and refine the risk methodology. Once all assets are assigned a total score and ranked, only the assets that are within the red zone of Figure 101 (high risk) can be analysed deeper to understand what exactly needs monitoring. Expert elicitation through process experts (i.e. scientists and/or technicians) who specialise in a specific treatment process and operate particular assets within that process can be used to help determine particular monitoring requirements. A semi-structured interview with such experts can be undertaken to help further filter down the list of assets that need monitoring.

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9 Appendices

1 Failure Modes

Table 20 below shows the information, data and knowledge gaps for each of the Anglian Water business units. In this context, a failure mode is defined as either or a combination of data, information and knowledge. There are four types of failure modes that can occur in each of the Anglian Water business unit.

1. There is no monitoring or measurement system to produce the data and therefore the system cannot integrate this required data. This is a data failure.
2. The raw data is available but the system is unable to integrate the data. This is an example of information failure.
3. The system contains the data, but there is no analysis of the data. As a result, there is no format to present the data. This is again an example of information failure.
4. The system can integrate the data and the data has been analysed and recorded in the format of a presentable piece of information, but there is no interpretation of this refined data, no trends and patterns have been realised to make an informed business decision. This is an example of knowledge failure.

Table A1: Failure modes in Anglian Water business units

AW Business Unit	Data failure	Information failure	Knowledge failure
R&OV	• Data gaps for specific climate change impacts are present. • Lack of historical climate change data • Inherent uncertainty in	• No climate specific baseline risk registers. • BIM does not contain explicit climate change failure modes. • Records of both gradual climate change trends and trends in climate change extremities.	• Analysing and interpreting the climate data to make investment decision based on the trend or pattern of probability of the impact occurring. • Whether to consider the occurrence of climate change (gradual increase and extremities) separately or to merge them together

	tools to generate data, i.e. UKCP09. • Data on frequency of impact occurring		• How to monitor the climate impact? • Method of prioritising climate change risks
CMM	• Data on asset failures due to the impacts of climate change • Quality of raw data produced by tools, i.e. UKCP09.	• Identification of climate change impacts to assets • Identification of secondary impacts to the factors already considered in the C-MM, i.e. material. • Integration of climate change data in the deterioration models. • Analysing data on asset failure rate due to climate change data	• How to monitor the relevant climate change impact on assets data? • Interpreting the information on analysed data on asset failure rate due to climate change to make informed investment decision. • Integrating of climate change data into the Monte Carlo simulation.
OMC	• Gaps database for older assets	• Integration of climate change impacts and data into the risk registers. • Analysing data for prioritisation	• Data management and ability of analysing and interrupting the data produced by telemetry system. • Employee skills to interpret data and effectively manage climate change risk. • Method of prioritising climate change risks

Table A.2: Asset Categorisation Clean Water

Level of Asset			
Level 1	**Level 2**	**Level 3**	**Level 4**
Water: Non-Infrastructure	Water resources	Physical - Water abstraction (river, reservoir, ground)	Pumps
			Pipe work
		Raw storage	Impound reservoir
		Raw distribution	Pumps
			Telemetry sensors
			Pipe work
	Water treatment	Physical-clarification	Screens
			Settling tanks
			Dissolved Air Floatation
			Filters-sand, membrane, rapid gravity sand filters
		Chemical	Coagulant dosing (alum, iron chloride etc.)
			Ozone dosing
			Chlorine/Chloramine dosing unit
		Other	UV disinfection unit
		Groundwater treatment Physical	Pumps
			De-nitrification plant-osmosis
			Air sparging
			Vacuum extraction system
			Air stripper
			Filters
		Ground water treatment - biological	Biological- iron removal
			Biological-de-nitrification
		Ground water treatment - chemical	Ion exchange
			Chemical oxidation- chlorine
			Carbon absorption
		Treated water distribution	Pumping station
			Meters
			Sensors
			Telemetry system
			Water tower
			Storage reservoir
		Site wide services (for both infrastructure and non-infrastructure)	Electrical supply, generators, gas supplies, transport links, admin buildings, welfare services etc.
Water Infrastructure	Treated water distribution	Treated water distribution	Pipe work (all materials)
			In-pipe meters and telemetry sensors (turbidity/ chlorine/ pressure etc.)
			Water mains

Table A.3: Asset Categorisation Waste Water

Level of Asset			
Level 1	**Level 2**	**Level 3**	**Level 4**
Wastwater: Non-infrastructure	Sewerage network	Collection	Telemetry system
			Pumping stations
			Sustainable drainage system
	Sewage treatment works	Physical-Clarification	Screens
			Grit removal-detritor
			Settling tanks-PST, storm , humus
		Biological	Trickling filters
			Membrane bioreactor
			Sand filters
			Activated sludge-diffused and oxidation ditches
			Other biological treatment-secondary and tertiary i.e. membrane bioreactor etc.
		Chemical	Ferric/ferrous (ferric chloride) salts dosing system
		Site distribution	Channels and pipes
			Pumps
			Vehicles
		Control systems	Telemetry system
		Other	UV treatment
	Sludge treatment	Physical -Sludge thickening	Sludge thickening systems- pick fence, belt press, drum thickener
			Sludge mixer
		Physical-De-watering systems	Dewatering systems- sludge heating, centrifuge, filter press
		Storage	Gas storage tanks
			Sludge storage tanks
		Biological	Digester
			Thermal hydrolysis/thermal dryer
			Enzymic hydrolysis
		Chemical	Polymer unit
			Lime treatment
			Odour control treatment (spray systems)
			Ferrous salts dosing for odour treatment
		Other	Heat exchange system
	Sludge disposal	Transportation	Vehicles-tankering
	Site wide services	ALL- both infrastructure and non-infrastructure	Electrical supply, generators, gas supplies, transport links, admin buildings, welfare services etc.
Wastewater: Infrastructure	Sewerage network	Collection	Sewer pipework
			Combined sewers
			Combined sewer overflows
			Sustainable drainage systems
			Outfalls
		Monitoring	Flow meters
			In-pipe sensors

Table B.1: Risk Scoring Table

Please refer to electronic copy on CD.

B.2: User Guide for Table B.1

User Guide

Research aim: To prioritise assets in terms of their need of monitoring by assessing the risk. The risk is determined by their vulnerability to changes in weather patterns and extremes (i.e. floods and droughts) and the criticality of assets to the water utility's business decisions.
Through monitoring these assets a baseline dataset will be created to help understand risks of climate change in order to better manage asset risk and therefore better inform Anglian Water's business decisions.

Please complete the following tasks:

- Please open up the Excel table called, 'Risk scoring,' and you will see two worksheet tabs named, 'Clean water,' and 'Wastewater.' Please ignore the tab named 'Data settings.'
- Click on the tab that best describes the relevant area that concerns your role. You will see that your area of business is highlighted in yellow. Please focus on these highlighted cells only
- As you will see, the level of assets from level 1 to 4 groups the asset in their respective areas. Columns 'E' to 'O' represent the different whether change parameters that can potentially impact the assets. The definitions of these weather change parameters are provided on the second page of this user guide
- Looking across on the void cells to the right of each Level 4 asset and under each parameter, if you click on this empty cell, a drop down list will appear
- Select the description that you believe is most suitable on how that particular weather change parameter affects the asset
- Repeat the above step for all six weather change parameters
- Automatically, as soon as you select a description, a number between -4 and 4 should appear to the right of the cell you have just clicked. This is simply the score assigned for each of the descriptions. Please see table D below to familiarise yourself with the scoring definitions
- Now go to column 'U' called 'Criticality of assets.' The definition of criticality in this context is shown in Table E

- A drop down list should appear for each of the empty cells in column 'U.' Select the most suitable description for each asset. Please note that how critical an asset is. Is only relevant to your areas of business and not the entire Anglian Water business
- A number should automatically appear to the right of each of the criticality definitions. Please see Table 2 on the next page to help familiar yourself with the scoring definitions
- Ignore columns 'R, S, X, Y, AA.' Numbers will automatically populate in the cells under these columns. Please leave them how they are
- Once you have finished please save a copy and email it back to the relevant person

Weather change parameters:

• **Temperature Rise**: Higher peak and average temperatures, increased evaporation and evapotranspiration, this includes gradual and extreme increase of temperature, i.e. heat wave

• **Freezing temperatures**: Winter temperatures that falls below 0 degrees Celsius

• **Drought**: Lower levels of rainfall over prolonged periods, reduced levels of groundwater and soil moisture, lower levels of infiltration

• **Rainfall (frequency)**: Decreased average summer and increased winter rainfall, increased average, prolonged rainfall, increased level of erratic rainfall patterns. Higher groundwater levels and increased soil moisture due to saturation. Does not include intense rainfall that can lead to flooding.

• **Rainfall (severity)**: Greater storm rainfall intensities, flash floods and fluvial flooding in a short space of time, compared to the parameter above

• **Sea Level Rise/Coastal storm surge**: Includes the effects of global sea level rise, coastal erosion, coastal flooding and storm surges. Only relevant for assets that are subject to coastal floods, in a 1:50, 1:100, 1:200 or 1:1000 flood zone.

Criticality: The importance of assets with regards to its dependency to ***your*** business decisions.

Risk Matrix Diagram B.3

Table A.5: Vulnerability of assets

Score	Definition
1	No significant impact on the main function of the asset
2	Measurable impact to the main function of the asset but no failure
3	Severely impacts the main function of the asset but no failure
4	Asset fails and does not deliver its main function
-1 to -4	Parameter helps the main function of the asset using same scale as above, but with positive impacts

Table A.6: Criticality of assets

Score	Definition
0	No importance/dependency to business decisions
1	Carries small importance/dependency to business decisions
2	Important to business decisions and potential to cause repercussions
3	Carries significant ramifications to business decisions