A climate change report card for water

Working Technical Paper

8. The possible impacts of climate change on public water supply availability over the 21st century

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Summary

Water availability is directly affected by climate. While public water supplies have proven to be reasonably resilient to variations in climate, shortages of water and environmental problems have been experienced in parts of the UK following major historic droughts. Water supplies can also be affected by flooding of infrastructure, leakage rates and changes in water quality.

Climate change could present both threats and opportunities to water resources. Any changes to river flows and groundwater recharge are likely to alter the amounts of water available for abstraction for public water supply, as well as for other users such as agriculture and industry. While parts of the UK may shift towards relatively arid conditions due to warmer conditions and reductions in average summer rainfall potentially affecting soil moisture, groundwater recharge, river flows and reservoir yields, increases in winter rainfall could provide opportunities in the form of increased storage. Climate change may also alter drought frequency and duration; there is, however, a need for further research to improve understanding of potential impacts on drought. Other ways in which climate change could affect the availability of water for public supply include the increased frequency of flooding potentially affecting water industry infrastructure and supply availability, and saline intrusion due to sea-level rise which may threaten abstraction points.

There is considerable evidence on the potential impacts of climate change on public water supply availability. For more than a decade, UK water companies have taken climate change into account within their water resources plans. In the latest available plans, water company estimates of the impacts of climate change on Deployable Output by water resource zone indicate that impacts vary widely. UK-wide projections suggest that there could be decreases in water available for public supply due to climate change in the near term (2020s), which become greater in the longer term (2050s and 2080s). Overall however, there has been little work looking at the potential impacts of climate change on public water supply availability beyond the 25 year planning period of the water company water resources plans.

Reductions in supply, together with potential increases in the demand for water, could lead to supply-demand deficits. It is, however, important to consider how drivers such as population growth, consumer attitudes, technological advancements and land use changes as well as regulatory changes might influence the situation too. There could also be further pressures on supplies should environmental requirements for water change due to the impacts of climate change.

Introduction

The public water supply system in the UK has developed over the last 100 years to meet the needs of a growing population, higher drinking water quality standards and, more recently, improved environmental standards and commitments to reduce greenhouse gas emissions. Water supplies are sourced from groundwater (natural springs as well as deeper boreholes) and surface water sources, with the former typically providing the highest quality water and hence low treatment costs. The drive in the early 20th century to supply water to growing industrial and urban centres involved the construction of large reservoirs to store excess winter rainfall to maintain supplies during the summer months. Although public water supplies have proven to be reasonably resilient to variations in climate, shortages of water and environmental problems have been experienced in parts of the UK following major historic droughts, such as those which occurred in 1921/22, 1975/76, 1990/92, 1995/97 and 2004/06 (Marsh, 2004; Marsh *et al.,* 2007; Watts *et al.*, 2012). As a result of the frequency of occurrence of water resources droughts over the past two decades, concerns regarding changes in climate have increased (Fowler *et al.*, 2007).

There is no single definition of drought, but several associated concepts. Deficits of effective rainfall significantly below long term averages, i.e. precipitation minus actual evapotranspiration, lead to meteorological droughts (also known as rainfall droughts). Such droughts can then develop into agricultural drought, where crops are affected by persistently high soil moisture deficits; hydrological drought, where there are reductions in groundwater recharge and river flows; environmental drought, impacting on habitats or species; or water resources drought, where both drought conditions and human activities lead to a shortage of available water to meet normal demands (Environment Agency, 2009). An original description of drought definitions is provided in Willhite and Glantz (1985).

The nature and impacts of drought vary with location and the sectors affected. Those areas which rely mainly on surface water sources can be affected by both short-term droughts as well as longer duration droughts, potentially having a severe effect on the availability of water resources. Those areas which abstract the majority of their water supplies from groundwater sources, or have large surface water stores, are more resilient to short-term droughts but remain likely to be affected by droughts of a longer duration (Marsh *et al.*, 2007). The majority of groundwater storage in the UK is in the chalk aquifers of southern England. Generally in the UK, supply systems are resilient to droughts of short-duration (for example of six to nine months), with difficulties arising when there are longer drought events lasting more than a year, as dry winters affect the refill of reservoirs and recharge of groundwater (Watts *et al.*, 2012). Past events in which there was a succession of dry winters have presented particular problems, such as the 2004-06 drought which resulted in the introduction of measures such as hosepipe bans in south-east England.

Water availability for public supply can be affected by climate in other ways too. For example, an increase in long-term average rainfall or intense rainfall events can lead to the flooding of critical water distribution and treatment infrastructure, and the potential loss of water supplies. Recently this occurred in summer 2007, where the Mythe Water Treatment Works in Gloucestershire was flooded and drinking water supplies were cut-off for 17 days for thousands of people (Ofwat, 2008, cited in McBain *et al.,* 2010). Similarly, significant water quality problems, such as *Cryptosporidium* events following heavy rainfall or high nutrient concentrations and eutrophication following drier weather conditions can affect supplies (Whitehead *et al.*, 2009).

Potential impacts of climate change

There is good understanding in the water industry of the potential risks of climate change. For more than a decade, UK water companies have included consideration of the potential impacts of climate change within their water resources plans (Arnell, 2011). Water Resources Management Plans (WRMPs) are produced by all water companies in the UK, and look ahead 25 years to show how the water company intends to ensure a sustainable balance between the supply and demand for water. These plans are prepared within a policy framework set by Government and consider a wide range of factors in developing measures for managing demand and developing new supplies, including changes in demand, population growth, environmental legislation as well as climate change. WRMPs need to consider potential reductions in water availability coupled with the possibility of increased demands as well as the requirement to maintain 'good ecological status'[1] in rivers and lakes. Water companies have also presented their assessment of climate change impacts and how they plan to adapt in Adaptation Reporting Power (ARP) reports. Water companies in England are 'reporting authorities' and are required to prepare these reports under the Climate Change Act (2008), detailing the assessments they have undertaken on their assets of current and future climate risks, as well as potential adaptation options. Water companies in Wales have prepared these reports voluntarily.

Due to these assessments and other research studies there is considerable evidence available on the potential impacts of climate change on public water supply (New *et al.*, 2007; New *et al.*, 2009). The analysis of water availability and the effects on water resources and quality tends to be extremely site-specific, and most research studies look at particular catchments. The effects of climate change on water availability and the impacts that has in turn for public water supply management can vary widely, depending on the system being considered. For example, in situations where there are already pressures on the availability of water supplies, a small change in climate could lead to a significant impact (Arnell, 1998).

Climate change could present both threats and opportunities to water resources. Perhaps the most obvious group of impacts relate to how changing seasonal rainfall patterns and increasing temperatures may influence water availability. Climate change projections for the UK indicate that during the 21st century there could potentially be significant decreases in average summer rainfall and increases in winter rainfall (Murphy *et al.*, 2009). However, wetter summers are also a possibility

[1] The EU Water Framework Directive (2000/60/EC) requires that Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015, and prevent deterioration in these water bodies.

and cannot be ruled out (Met Office, 2012). It is estimated that evapotranspiration will increase with increases in temperature (Arnell, 2004; Bates et *al.,* 2008; Watts, 2010; Vidal *et al.,* 2011). Yet there is still considerable uncertainty with respect to the response of plants to elevated carbon dioxide levels and what the net effects of actual evapotranspiration may be at the basin scale (Betts *et al.,* 2007). Warmer conditions together with reductions in annual precipitation and changes in seasonal precipitation (Murphy *et al.,* 2009) may mean that parts of the UK shift towards relatively arid conditions, which would affect soil moisture content, groundwater recharge, river flows and reservoir yields.

Any changes to river flows and groundwater recharge are likely to vary the amount of water available for abstraction for public water supply, as well as for other users (e.g. agriculture and industry). The potential impacts of climate change on river flows in the UK have been studied in some detail over the last two decades (CCIRG, 1996; Arnell, 2004; UKWIR, 2007; Watts, 2010; Vidal *et al.*, 2011). These studies generally indicate a more intense hydrological cycle characterised by higher winter flows and lower summer flows. With the development of more climate models and downscaling approaches, river flows and groundwater recharge studies have built up an improved understanding of the uncertainties associated with the choice of climate model, the downscaling approaches used and the hydrological modelling methods implemented (Lopez *et al.*, 2009). It is clear from this research that changes in seasonal precipitation and evapotranspiration are important factors to consider (Watts, 2010), as are river basin characteristics, for example the river flow derived from baseflows or groundwater sources (UKWIR, 2007).

Climate change may alter drought frequency and duration in the UK (Vidal and Wade, 2008a), although this is an area in which there are conflicting views and further research is needed to improve understanding. For instance, while some research shows that there could be an increase in meteorological droughts (Vidal and Wade, 2009) other studies conclude that it is not yet possible to robustly project changes in these droughts (Burke *et al.*, 2010), particularly in modelling the persistence of long droughts (Watts *et al.*, 2012). An increase in the severity and frequency of drought would have substantial implications for water resources management.

Other potential ways in which climate change could affect the availability of water for public supply include the increased frequency of flooding, potentially affecting water industry infrastructure and supply availability, as well as saline intrusion due to sea-level rise which may threaten abstraction points for groundwater sources. Changes in precipitation and temperature patterns may also increase soil movement, affecting underground assets such as pipes and potentially leading to increased pipe bursts and leakage, and therefore loss of water for supply. There may also be opportunities too, for example an increase in winter rainfall could allow for more water to be stored. Table 1 summarises the main possible impacts of climate change and consequences with respect to public water supply availability.

Table 1 Possible climate change impacts and consequences

Climate effect	Impact	Consequence
Periods of extremely low rainfall	Major drought	Change in available water
Decrease in summer rainfall	Low flows	
Long periods (multi-season) of lower than average rainfall	Changed recharge and low groundwater levels	
Increased summer temperatures	Increased evaporation from open water (e.g. reservoirs)	
Long periods (multi-season) of lower than average rainfall	Change in reservoir yields for public water supply	
Increased summer temperatures	Increased demand for water	Increased competition for water
Sea-level rise	Saline intrusion and incursion	Freshwater supplies potentially affected
Changes in temperature and rainfall	Increased soil movement	Water supply pipe bursts/leakage
Increased rainfall (either long-term average or intense rainfall)	Flooding of critical infrastructure	Water supplies affected
Changes in rainfall	Erosion and sedimentation	Reduction in water storage and yield

Source: Rance *et al.* (2012)

Assessing and managing climate change impacts on water availability

All water service providers in the UK use research evidence from UKWIR and Environment Agency funded research that has been translated into practical methods for including climate change in water resources planning (Arnell, 2003; UKWIR, 2006; Arnell and Reynard, 2007). These studies have made use of available climate change projections or General Circulation Models (GCMs), downscaled to UK catchments (Hulme and Jenkins, 1998; Hulme *et al.*, 2002; Murphy *et al.*, 2009; UKWIR, 2007; Vidal and Wade, 2008a; 2008b). They provide projected changes in monthly river flows and annual average recharge for catchments in the UK, together with practical methods for the inclusion of these changes in water resources planning. The most recent WRMPs submitted in autumn 2009 for the last Periodic Review (PR09) were based on the national-scale assessment from 2008 (Vidal and Wade, 2008b). In these plans, calculations were generally made using the UKWIR06 climate change scenarios: ‘wet’, ‘mid’ and ‘dry’ according to Environment Agency guidance (Environment Agency, 2008). The ‘mid’ scenario is the average of six downscaled GCMs, and is in effect equivalent to the UKCIP02[2] medium high emissions scenario (Hulme *et al.*, 2002), while the 'wet' and 'dry' scenarios are the 'mid' plus and minus one standard deviation respectively (UKWIR, 2007). The Environment Agency's Supplementary Guidance (Arnell and Reynard, 2007) outlines how the impacts of climate change on water availability can be included in water resources planning. Impacts for the 2020s[3] period are first calculated for river flows and/or groundwater recharge levels under the three scenarios, before Deployable Output (DO)[4] from that zone is calculated. These figures are then scaled between 2010 and 2035 using a standard methodology (Environment Agency, 2008). The final stage in the process is to calculate headroom allowance, a component which allows for uncertainty in the supply-demand balance.

An analysis of 21 draft WRMPs in England, published in April and May 2008 for public consultation, is provided in Charlton and Arnell (2011). Water company estimates of the impacts of climate change by water resource zone indicate that impacts vary widely in terms of percentage of DO. The greatest impacts were shown to be in South East England, with all but one of the resource zones with climate change DO reductions greater than five percent over the planning period (less than 20 percent of the total number of resource zones) located in Southern England (Charlton and Arnell, 2011). Impact variability between zones could be attributed to a number of factors, including the size of the resource zone and source type. The greatest percentage changes in DO were found mostly within the smaller resource zones, while the impact on surface water and groundwater sources also varied between water companies. An aggregated national level figure (for England) totalled a loss of 523 Ml/d in DO in 2034/35, relative to 2006/07 figures. This equates to roughly three percent of DO, or the entire supply of one water company. While decreases in summer rainfall could present increasing challenges for water supply management, increases in winter rainfall could provide opportunities in the form of increased storage. Charlton and Arnell (2011) recognised that there are small climate change impacts in some water resource zones, because wetter winters mitigate the effect of drier summers.

Within the 2008 WRMPs, climate change is also considered in the uncertainty allowance. Arnell (1998) recognised that there are three main uncertainties to consider when looking at the potential impacts of climate change on water resources. Firstly, there is the uncertainty associated with climate change projections, which includes, for example, uncertainty relating to the future rate of greenhouse gas emissions and uncertainty relating to the climate modelling. Secondly there are uncertainties associated with translating these climate changes to an effect on a system like a catchment; this includes the uncertainty relating to the use of hydrological models. The third type of uncertainty considers the actions and responses of managers and other actors within the water environment, as this would affect the impact of climate change. The range of uncertainty considered within water company WRMP assessments could have significant implications for the planning process and in some water resource zones there is very large uncertainty due to climate change (Charlton and Arnell, 2011).

[2] The UKCIP02 climate change scenarios released in 2002.
[3] A 30-year time period centred on the 2020s
[4] Deployable Output (DO) is the amount of water that can be pumped from a water company's sources (surface and groundwater), constrained by licence, hydrology or hydrogeological factors and works capacity.

For the next release of WRMPs, most companies are expected to use the UK Climate Projections 2009 (UKCP09) to estimate the impact of climate change on DO. The UKCP09 projections are ‘probabilistic’ in that they reflect a range of changes in climate based on observations, a large number of models and expert judgement (Murphy *et al.*, 2009). While this can provide for more robust assessments of climate change, it does introduce considerable complexity and because of this, research has shown that it has been quite difficult to propagate this information into impact studies (Christierson *et al.*, 2012; New *et al.*, 2007; Stainforth *et al.*, 2007).

A recent project funded by UKWIR developed a practical method for using this probabilistic information in assessing the potential impacts of climate change on monthly river flows (Christierson *et al.*, 2009; Christierson *et al.*, 2012). The analysis focused specifically on the 2020s, Medium emissions (A1B) scenario and indicated that at a 50 percent probability level and based on averaging the results for between four and eight catchment models, there would be changes in flows ranging from an increase of roughly 15 percent in the winter to a decrease of 33 percent in the summer, compared to a baseline period of 1961 to 1990. For individual river catchments, however, changes could be significantly outside of this range. Other recent work with UKCP09 indicates that statistically significant changes in summer flow may occur well before increases in average winter flow (Vidal *et al.*, 2011).

One of the changes to the water resources planning guidelines in England and Wales has been the introduction of a climate vulnerability analysis, which provides the background information to justify decisions on climate change impact assessment methods (Environment Agency *et al.,* 2012). One approach is to base this vulnerability assessment on information from previous climate change impact assessments, and use a magnitude versus sensitivity plot as shown in Figure 1. The figure displays DO change data from draft and final WRMPs (PR09) for water resource zones across England and Wales. It plots the magnitude of change in DO for a ‘mid’ climate change scenario against the sensitivity of the results to the climate change scenario (uncertainty range), calculated as the difference between the ‘wet’ and ‘dry’ scenarios (Environment Agency, 2013).

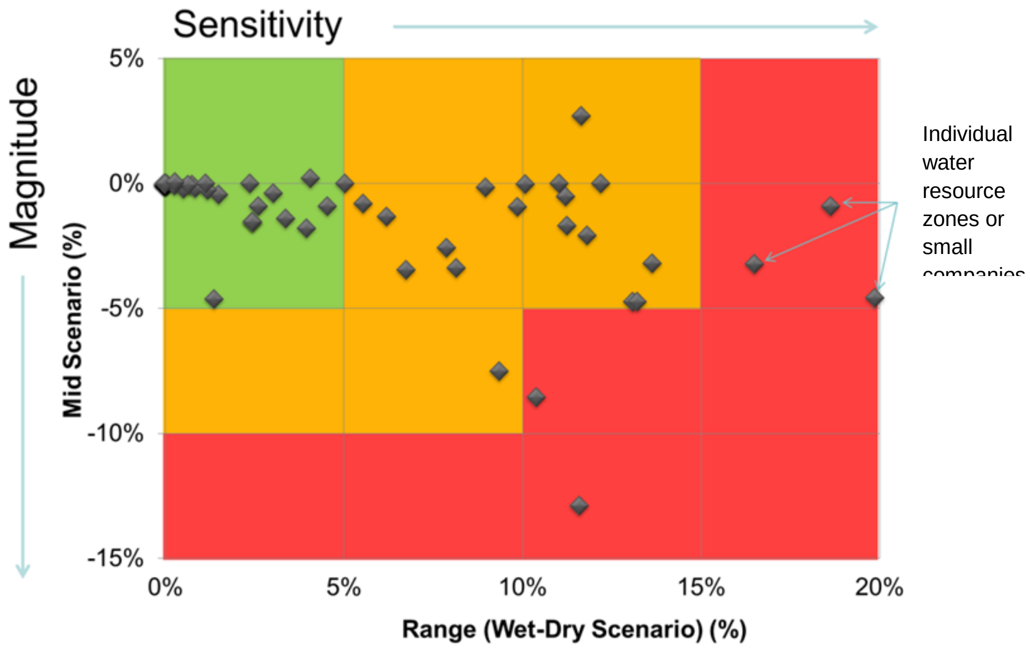

Figure 1 Magnitude of DO change (%) for the climate change mid scenario versus sensitivity for water resource zones in England and Wales based on WRMPs from 2009 (Source: Environment Agency, 2013)

Figure 1 shows that for the majority of zones, impacts vary from 'no change' to a decrease of five percent (for the 2020s, Medium emissions scenario). Generally the sensitivity, or range of changes in DO, i.e. from the 'wet' to the 'dry' scenario, is larger than the magnitude, i.e. the change in DO for the 'mid' scenario, illustrating the different sensitivities of the zones to future climate conditions (Environment Agency, 2013). The colours on the figure indicate whether a water resource zone is classed as 'low' (green), 'medium' (orange) or 'high' (red) vulnerability. Based on this approach it is anticipated that just under half of the water resource zones in England and Wales would require further detailed analysis into the impacts of climate change on DO.

There has been little work looking at the potential impacts of climate change beyond the 25 year planning period of the WRMPs (i.e. beyond 2034/35), and no water companies have considered changes out to the 2050s time period. One study which has looked beyond this period and up to the 2080s is the UK Climate Change Risk Assessment (CCRA), specifically the water sector analysis (CCRA, 2012; Rance *et al.*, 2012). The CCRA suggested that there may be substantial impacts from climate change on the water available for public supply. The analysis considered change in DO and made use of the impacts of climate change on DO reported in draft WRMPs and directly from water companies in the UK. The results were collated and expressed as the percentage change in DO from the baseline by UKCP09 river basin region. This informed the development of a response function to relate change in DO to change in relative aridity (a measure of how warm and dry the climate is compared to the 1961-90 baseline). It indicated that DO could continue to decline in more arid conditions, but was subject to a number of assumptions and caveats. The available evidence was then scaled using relative aridity to provide estimates of future risk under three different emissions scenarios (High, Medium and Low), three future 30-year time periods (centred on the 2020s, 2050s and 2080s) and for three probability levels (10, 50 and 90 percent) (CCRA, 2012).

Looking specifically at figures aggregated to a UK-level, there are projected reductions in DO of 3% (8 to -14%) by the 2020s, 17% (0 to -30%) by the 2050s, and 23% (-4 to -35%) by the 2080s[5]. The results for the 2020s are similar to those presented in water company plans with reductions in DO typically in the one to ten percent range for the 50 percent probability level (p50). However, the analysis considers changes in annual average climate only, and does not reflect seasonal changes.

The CCRA water sector analysis also looked at the supply-demand balance, considering changes in DO and the demand for water. It is important to consider demand-side as well as supply-side impacts when assessing the potential impacts of climate change, because impacts on water supply could become insignificant if increasing demand-side pressures are much greater (Charlton and Arnell, 2011). Water demands have shown to be affected by climate with clear links between temperature and the demand for water for domestic, agricultural and industrial use. Water demand has also been observed to increase following above average temperatures, which has been noted in a few water company ARPs. The CCRA analysis made use of data from the Climate Change and the Demand for Water (CCDeW) project (Downing *et al.*, 2003). In the latest round of WRMPs, most water companies used these values to factor climate change into their demand estimates (Charlton and Arnell, 2011). The CCDeW project estimated that by the 2050s, the additional impact of mean climate change (above the socio-economic scenarios considered) would be to increase domestic demand by 2 to 4%, industrial and commercial demand by 4 to 6% and agricultural demand by 26% (for England and Wales only). Scaling these estimates as part of the CCRA indicated that the domestic demand for water is projected to increase by 5% (3 to 8%) by the 2080s (Rance *et al.*, 2012).

The Environment Agency quantified pressures on water availability up to the 2050s, through consideration of freshwater availability, the demand for abstraction and environmental requirements in their work supporting the Water White Paper (Environment Agency, 2011; Defra, 2011). This work considers all types of abstraction, and not just those for public water supply. Different scenarios were considered, and it was found that there may be insufficient water available for abstraction and the environment due to increased demand and the effect of climate change on flows. These pressures varied by region in England and Wales, with some areas such as the Thames, Severn and Dee river basin districts experiencing greater challenges than others. At a catchment level, catchments in Wales, south west and northern England are projected to experience the largest reductions in flows due to climate change, while also experiencing the most unmet demand. This illustrates that issues associated with water availability may not be limited to the south and east of England.

[5] Figures are for the Medium emissions p50 scenario, with ranges in the brackets the Medium emissions p10 and p90 scenarios for the 2020s, and Low emissions p10 and High emissions p90 for the 2050s and 2080s.

Socio-economic drivers

While climate change was found to be the single largest component affecting water supply in the latest water company WRMPs (Arnell, 2011; Charlton and Arnell, 2011), it is important to consider how socio-economic drivers may influence the supply-demand balance. These drivers include population growth, as this affects the total demand for water; consumer attitudes and behaviour affecting water consumption and the uptake of water-saving devices; property occupancy, with lower rates shown to lead to greater water use per capita; land use change, as this may significantly affect future flow regimes; and technological advancement such as improved water efficiency measures.

The CCRA water sector analysis considered the change in demand due to change in population as well as changes in per capita consumption. The findings indicate that the supply-demand deficit could be heavily influenced by population growth, further adding to the deficit resulting from projected climate change (Rance *et al.*, 2012).

It is also important to consider regulatory changes. Water resources management in the UK is influenced by the EU Water Framework Directive (WFD) and Habitats Directive. There could be further pressures on the situation should environmental requirements for water change due to the impacts of climate change (Environment Agency, 2011). Potential changes in water availability, coupled with variations in demand as well as the requirement to maintain 'good ecological status' in rivers and lakes under the requirements of the WFD means that long-term water resources planning is needed to manage risks and adapt to climate change.

Confidence in the science

There is medium confidence with regard to the possible impacts of climate change on public water supply availability. Confidence may improve with use of UKCP09 in water supply planning. It could also be improved by including broader consideration of factors that influence the supply-demand balance, such as leakage and the influence of the potential withdrawal of abstraction licences due to environmental pressures.

Research gaps

The following are some key areas and ways in which the evidence base and planning could be improved:

1. Methods of incorporating climate change information such as UKCP09 into assessments of water availability could be further developed.
2. Understanding of the impacts of climate change on drought could be improved. This might include climate modelling of multi-season droughts.
3. The characteristics of changes in climate over time could be investigated, e.g. up to the 2080s, and what this means for water supply availability.
4. Tools and techniques could be developed so that local case studies can be upscaled to a national scale assessment.
5. Knowledge on environmental water requirements under current conditions as well as different scenarios of climate change could be improved.
6. Improve understanding as to how the implementation of different adaptation strategies (e.g. supply-side measures) could influence the situation.

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