WORKING PAPER 1. NEXUS FUTURES Project

An overview on work in progress on modelling water use for Luxembourg with reference to the three NEXUS FUTURES Scenarios for engagement with water and land in 2045

The modelling approach and specific assumptions are still subject to change and refinement but are provided to inform structured discussions on plausible alternative futures with respect to water use and management decisions. The paper is circulated more broadly now for the purpose of extended peer review. Please send any feedback or comments that you might have to improve the working paper to alex.cornelissen@rtc4water.com

An expert contribution to the NEXUS FUTURES scenario project, a working paper as basis for a publication, please sight as "manuscript in peer review".

Project : 2019-158 Uni.lu Luxembourg NEXUS FUTURES

Original date: 02.09.2019
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Version: 19
This update: 27.8.2020

Preface: The project is funded by the Ministry for the Environment and Sustainable Development and the University of Luxembourg. The remit and modelling assumptions for three scenarios for water use for this expert study was developed in close collaboration with Dr Ariane König as part of a participatory scenario process based on over 60 interviews and four workshops in the period from 2017-2020.

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Executive summary

This report concludes that Luxembourg probably has security of supply until 2028-2029 if the new SEBES installations are completed on schedule. In 2020 and 2021 there is real reason for concern, but severe disruptions are unlikely from a solely water distribution perspective. It is imperative that action is taken soon to initiate water saving measures and a (re-) evaluation of any available sources and storage volumes available for peak shaving is recommended. Generally, expanding the knowledge of the actual and future situation would be advantageous (data availability, modelling).

After 2028-2029, at current growth rates, without water saving, it is likely that water availability will be a limiting factor for population growth. With an increase of 12500 people/year an extra 2500 m3/year on average and 3750 m3/year at peak demand must then be found. Finally, the limited analysis done in this report clearly shows that there is a real potential that climate change could destabilise Luxembourg's water supply during peak demand times.

However, it is also clear that the state of the Luxembourg water supply is not a dire as often predicted and that maintaining a functional water supply for the next 25 years will be challenging but not impossible even with a population of 1,250,000 in 2045. Early planning, proper funding, consumer participation and legislation will be the key ingredients for success.

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1. Introduction, objective and scope of this report

The NEXUS FUTURES project is a transdisciplinary research project with practitioners, policy makers and experts in the natural and social sciences, as well as volunteers to explore sustainability challenges associated with our current and possible future ways to engage with water and land. These resources are under increasing pressure from economic and population growth, as is particularly evident in small and fast-growing countries such as Luxembourg. There is a clear need for new approaches to decision-making in policy making and practice amongst all water users that can deal with the complexity of today's tightly interconnected environmental, economic, social and technological challenges. The NEXUS-FUTURES project serves to co-design and implement participatory processes to transform current ways of engaging with natural resources and with each other, resulting, hopefully, in more sustainability and resilience.

The objective of this report is to systematically explore the question: How might Luxembourg's water supply system develop in the face of accelerating demographic and climate change over the next 25 years? Is the current infrastructure adequate to cope with the predicted increase in population and, if this is not the case, how can water shortages be avoided? In order to address this question a simplified model is developed that nevertheless takes into consideration a range of factors that emerged as important from the scenario process in affecting water use and supply in Luxembourg.

The scope of this report includes the existing water supply and the evolution of demand or more accurately, water use and projected water use by households and industry in Luxembourg. Although the current raw[3] water availability will be considered, future raw water availability, i.e. water from sources yet to enter the water distribution network, is not within the scope of this report.

In consultation with climatologist Dr Andrew Ferrone from ASTA, the report is based on the assumption that the average annual rainfall in Luxembourg and the greater region, which is one of the main determinants of surface water and ground water availability, will not change significantly with climate change. The seasonal distribution of the rainfall and temperatures affecting the duration of hydrological winters however is likely to change. The potential impact of these changes are discussed after the modelling in the discussion. Impacts on diverse ecosystems from such changes and their altered behaviour with respect to water retention and trans-evaporation are however beyond the scope of this study.

This report consists of the following sections:

- A detailed description of the assumptions and information used to develop the predicted drinking water consumption rates for the years 2020-2025. Given that the first section of the report deals with the immediate future, it is probably the most realistic and scientifically accurate section of this report. For this same reason, it was decided by the NEXUS team to utilize only one, jointly used scenario in terms of water demand for this period. At first, a simplified model for the water consumption in Luxembourg was created and then this model was run at a 15 minute resolution period to examine the relationship of water demand versus water supply using the adjusted water demand patterns for the period of 2015-2019. In other words, there was a first attempt made to answer the question: "Is there enough water for the next five years?" or, to use the correct terminology, "does Luxembourg have security of supply until 2025?"
- Modelling water demand and supply 2020-2025

[3] Raw water is water found in the environment that has not been treated and does not have any of its minerals, ions, particles, bacteria, or parasites removed. (https://en.wikipedia.org/wiki/Raw_water)

- Method for describing and modelling the water consumption rates and predictions made for the years 2025 until 2045. In this section the three scenarios deviate based on demographics, the public's attitudes towards water, politics and many other factors which are described in the NEXUS Futures scenarios. Here, similar modelling efforts were made but focused more on answering the question: Is this scenario realistic in terms of water demand/supply.
- A discussion of the results for the modelling (2026-2045)
- A short conclusion
- A discussion of the effects of climate change
- Appendices with some of the data gathered

2. Background knowledge on the three scenarios and modelling assumptions for the purpose of this report

2.1. The NEXUS FUTURES Scenarios: Three different futures of water supply and use

The NEXUS FUTURES project, of which this report is one contribution, has generated three scenarios which will give interested parties an insight into the possible changes in our water and land use systems in the year 2045 compared to today.[4] The NEXUS FUTURES scenario approach explicitly seeks to explore the possibility of less foreseeable disruptive changes, and not solely consider futures in which a small set of quantifiable variables has been tampered with to bend a trend, the more open scenario approach has served to develop three very different snapshots of possible futures, each of which is deemed plausible, within itself coherent, but also challenging to the imagination of the reader, such that the three scenarios can be used as a set to explore the future as open in deliberative processes in diverse groups. The current report then has taken these three very different scenarios as a source of modelling assumptions and key factors to determine possible evolutions in Luxembourg's water supply and demand in three such very different future settings. The scenarios, in brief, are:

A. SCENARIO A - "Smart Sustainability"

General - Innovation in global business models and alignment of global and European economic, political and environmental interests fosters the emergence of a highly interconnected, circular economy based on third industrial revolution policies. Industry is highly regulated and on-line transaction taxation is now more important than income and corporate taxes combined. Artificial intelligence has slowly creeped into every aspect of society, the economy and personal decision-making; most members of society have become comfortably numb. Recycling design expertise and related industries dominate the global market. Energy is made accessible for for human use stems largely from renewable sources. Water is a precious resource that is measured and controlled microscopically. Some have a faint inkling that collapse might be near.

[4] For more information on the project and the scenarios please see https://sustainabilityscience.uni.lu/nexus-futures/

Changes in water supply and usage systems between 2020 and 2045 developed as modelling assumptions for this report: -

2020-2025: In this scenario there is a successful (without much dissent from the population) overcoming of water shortages in 2021 before the new SEBES[5] plant is finished on-time in early 2022. The additional 41000 m3/day volume this brings means that there are no water shortages before 2030. In this period, technological improvements for recycling of water in households (such as low water use showerheads 3% , grey water toilets 5%) and technology based water recycling (included in the 5%) in newly build housing estates means that it becomes feasible to implement regulations where to the growth of the resident population in Luxembourg is only permitted when it is being matched by water savings or extra water production. Industry's access to water initially remains largely unaffected in this scenario. Additional local sources also become available again (+5000 m3/day) because of the technological based removal of pesticides/herbicides/fungicides with Activated Carbon and/or Ozone. Although micropollutant levels in these waters are slowly reducing because of drinking water protection zones, the reality is that new compounds and their breakdown products (example: chlorothalonil in 2021) that are found still maintain the need for treatment of source water to remove micropollutants. The Farmers lobby subsequently argues for the reintroduction of certain pesticides because the water is "treated anyway". A similar demand is made by homeowner's associations, in this case to reintroduce biocides in façade treatments. A global maximum level of many pesticides in drinking water is maintained at 100 ng/l (in accordance with the revised drinking water directive) for single compounds while breakdown products are increasingly ignored.

2030 – 2045: Plans and implementations for sourcing extra water from the Ardennes in Belgium and Germany (these countries have declining population levels and have enough water) at a massive cost of laying large, long pipelines eventually fail because, in practice, it is found that the political implications of such a development are considerable and lead to significant regional tensions.

Overall, this means that the water use per inhabitant is continuously decreasing while the population is increasing in balance with a slowly rising overall water demand. This has a huge impact on the cost of water, which rises dramatically in 2030-2035, depressing demand a little further in the process. However, too many people in the Greater Luxembourg region, too much extraction of water for industrial purposes, in addition to a reduction in surface and groundwater availability due to shortening hydrological winters and a greater frequency of extreme weather events means Luxembourg is always on (or over) the edge of water shortages. In this period industry will eventually be forced to invest in alternatives to water cooling, resulting in a much-needed decrease of peak demand in long, hot, and dry summers due to climate change. The installation of costly water savings devices such as recycling showers becomes cost effective and depresses demand further allowing some additional immigration and growth for the country.

B. Scenario B "Web of Life"

General - As a consequence of consecutive years of summer droughts causing hardship and the collapse of the global food system, combined with fundamental changes in EU and Luxembourg policy making - giving primacy to environment and resilience - and a culture change in innovation and progress seeking largely nature based solutions to fulfil human needs, the regeneration of ecosystems for resilient water and food provision has gained primacy over all other human concerns, in government, the economy, and private lives. Serving nature's regeneration in recognition that diverse

[5] SEBES Syndicat des eaux du barrage d'Esch-sur-Sûre

life forms are interdependent, is the fundamental role of citizens. This replaces the consumer citizen at the service of economic growth. Over 70% of Luxembourg's land is a nature protection zone and is owned by the public. Development of buildings and other economic activities are confined to the 'settlement basin', an area around the Alzette basin that is surrounded by a local food garden area. Beyond lies the wilderness zone in which biodiversity regeneration has primacy. By 2045, individualism and the freedoms associated with property in a humanistic worldview linked to a liberal market economy are in dispute and starkly curtailed in every-day-life.

Changes in water supply and usage systems between 2020 and 2045 developed as modelling assumptions for this report: –

2020-2025: Here a massive water shortage in 2020 and 2021 has sensitised the community and politicians to the importance of water management. Many people, communes and companies become obsessed with managing with the minimum amount of water, this brings an extra 7,000 m3/day (regulator approved) production from existing sources in the space of 5 years and a reduction in demand of 10 %. Rainwater storage becomes the norm and companies are named and shamed in the press when they have a high-water demand. Some companies which are in Luxembourg only for the tax environment, will then relocate to areas where they can use more water without being penalized. Other, more locally rooted companies outsource server farms to Germany. Water consumption per person (including industry) rapidly drops from 202 l/p.p. to 125 l/p.p. from 2026 to 2035 (38%).

2030-2045 However, the changing focus on high-tech agriculture and the demand for local crops and the subsequent rise in urban farming and food subsistence cultivation activities that consume a lot of water during their production (lettuce, cucumbers, tomatoes etc.), as well as the drive to restore aquatic ecosystems ensuring a minimum water flow in rivers and bringing back rivers to their original state, increasingly put competing pressures on water resources. This results in another water crisis in 2032, after which many sources that have long been offline (>25 years) are rediscovered and taken into production for supplying drinking water again. The maximum level of micropollutants in water are set based on a toxicological assessment of the mother compound as well as its breakdown products- meaning that some pesticides - which are considered less harmful, are reintroduced (example: Glyphosate) while many are completely banned. In terms of consumption costs, there are three periods:

1. 2025 – above a certain threshold additional usage is priced higher, the price goes up proportional to usage levels owing to a nationwide smart metering system for water use on a per household-level.

2. 2030 – seasonally differentiated prices are implemented resulting in higher water costs during the summer. This hits industry in particular.

3. 2035 – the infrastructure allowing a circular economy differentiation between biological and technological water cycles is implemented in an urban corridor in which all further urban developments have been concentrated since 2025. Each of these water cycles has piping systems for two distinct qualities of water. The price of this water is dependent on the cycle and quality level of water used. Drinking water is now only used for drinking (at a huge additional cost of laying the needed additional distribution piping).

C. Scenario C. "Common Good"

General - The power of decision-making and the organisation of key infrastructures, including the water, information and electricity grids, have shifted from central and/or local government to regions and in Luxembourg this translates to five increasingly autonomous districts. Consecutive mergers of and improved collaboration between municipalities and regional currencies have helped to develop a sharing economy. The activities of various syndicates, most notably drinking water provision and wastewater treatment, were merged and expanded to collect funds. Layered pension plans with national public plans, private plans and regional plans are the norm and the importance of the regional pension provisions have increased over time with the turnover in regional currencies and markets. Hospitals and schools are also increasingly regionally organised, specifically the national health service experiencing a decline from dangerously bad to worse in the three decades after 2015.

Changes in water supply systems between 2020 and 2045 developed as modelling assumptions for this report: –

2020-2025: In this scenario moderate water shortages in 2020 and 2021 did have some political impact but mainly in the changing of attitudes and the loss of cohesion and increasing competition between the Luxembourg regions. These regions have taken over many responsibilities which were previously in communal hands, including the responsibility for water quality and security of supply, mean that there is an increasing focus on having "own" water supplies. Local sources, no matter their size, are lovingly restored and used, even without the necessary formal approvals, the lack of this water is resulting in a decrease of river water levels, creating tensions between farmers and environmentalist lobbies on the one side and home-owners on the other. However, this leads to the "rediscovery" and strict local/regional control of the 970 sources, 1020 drillings (of which 770 previous drinking water abstraction points) of which in 2019 only about 270 are still monitored/registered as active drinking water abstractions. Homemade, parallel (or "dual") water supplies for flushing toilets from local sources are springing up everywhere with the Luxembourg regulator powerless to stop these practices. Local water bottling initiatives in glass bottles means that piped drinking water is not often used for oral consumption anymore. Rainwater catchment and utilisation is widespread. As a result, there are some pollution events where "drinking" water is contaminated with faecal bacteria but the overall effect on the population is trivial. A decreased dependence on nationwide sources is observed and the SEBES is therefore forced to decrease its operations. SEBES water therefore becomes increasingly expensive and even less used.

2030-2045: The infrastructure is aging and without enough maintenance there is an incident in the summer of 2030 where a SEBES trunk main bursts and water supply cannot be restored for some time. This results in an even more widespread independence of SEBES water and some people even start to produce their own drinking water in the home (as much as 40%), both from rainwater and grey water, some being completely independent from the public water supply. Again, the regulator is powerless to stop these practices.

2.2. Water demand: Main assumptions and factors considered in the modelling

Starting from the scenarios developed in the participatory process over four years, a wide range of factors has been identified as critical to the development for a systematic exploration of future water use and supply. Looking at the main factors of the number of users and the rate of use in both households by residents and by industry some additional factors affecting these parameters are explored:

Demography: How many people will live in Luxembourg, how many non-Luxembourgish residents travel each day into Luxembourg for work and, to a lesser extent, what is the age distribution of these people.

Current population estimations for inhabitants in the year 2045 vary between 750,000 to 1,250,000; up from 614,000 on the 1st January 2019. The three scenarios cover this range.

Water use, per person, per day. People use more or less water depending on the time of year, the day of the week, the temperature, their lifestyle, their age, level of wealth and many other factors. Currently, 202 litres per day (l/day) per person is a yearly average amount used for estimation purposes and includes the amount of consumption used by industry. When separated, these amounts become 135 l/person per day and 67 l/day/person for the rest industry, foreign worker etc.

The rate of total average water use expressed as litres/person/day is affected by the following factors:

- **Incentives to reduce consumption and water saving devices**. Although several methods for saving water exist, most people need an incentive or external pressure to use them. These pressures may include fines, social pressure, financial incentives and an increase in environmental awareness. Estimations vary but, in this project, we will assume that by 2035 it will be possible to reduce water consumption by an absolute maximum of 38 %, (24-28% is currently more realistic) which is in line with other estimations[6]. In this report the maximum was maintained because it is assumed that in 25 years technology will have progressed and 38% will be achievable.
- **Industry uses water for manufacturing, to supply offices and for cooling purposes**. The latter one is the most problematic when considering the security of the drinking water supply[7] because more industrial cooling is normally needed when the temperatures are high, and this demand directly competes with increased volumes of drinking water used by the population.
- **Highly visible, high-profile events** relating to water, such as shortages reported in the media are possibly one of the most interesting factors that determine water demand. From "What happens during a phase rouge event?" where certain water uses are prohibited during critical periods, to "what happens when it is necessary to implement water restrictions/outages?". Reactions by the public are extremely difficult to predict and can range from a general placidness to a large public outcry. What is certain is that, during periods of normal availability, most members of the public will express only a limited interest in their water supply. But once their supply is restricted, or the quality is threatened, their attitude will change dramatically. As a result, so do the opinions of their political representatives.
- **Water costs:** although not many members of the public are really concerned with the cost of water, an increase in these costs normally brings about at least a temporary reduction in water use.
- Changes in temperatures, and in particular heat waves are also a factor which affects water use. Water use is higher during periods with high temperatures and therefore an increase of 1-2 degrees in summer may mean a substantial increase in peak water demand, due to cooling needs, but also due to increased trans-evaporation in urban gardens and thirst and hygiene needs in humans and livestock as already mentioned above. Furthermore, changes in the distribution of precipitation patterns with the expectation of dryer summers and more rain in winters will result in an increased reliance on storage used for peak shaving. However, will this be the same in 2045? Probably, but not certainly.

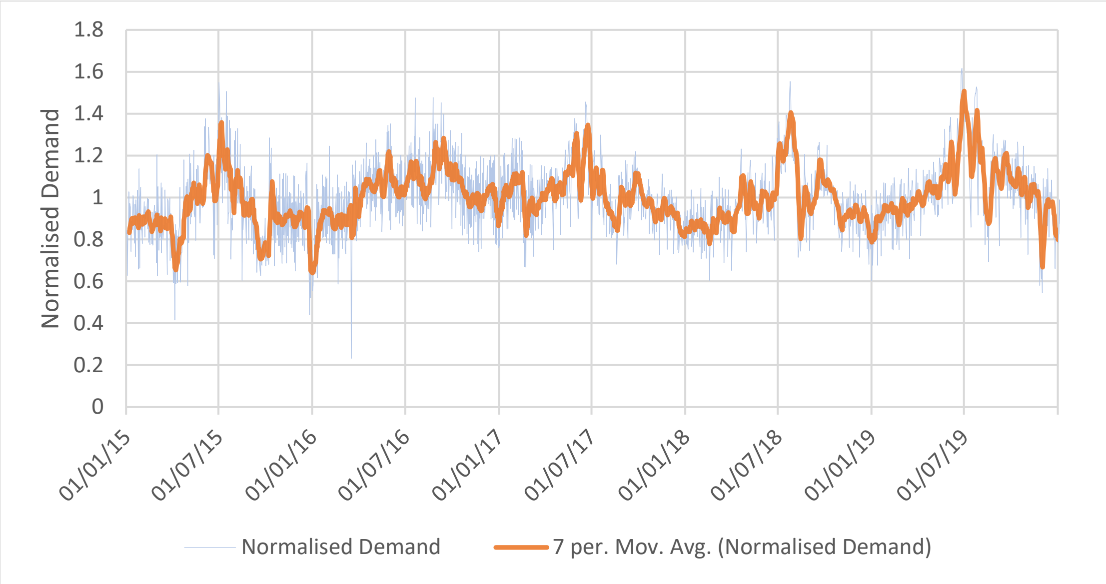
Average versus Peak Demand – If the water demand in Luxembourg only fluctuated slightly around the average then it would be highly unlikely there would ever be a water shortage. Unfortunately, this is not the case. In the winter months the demand is below the average and in the two weeks before the summer holidays the demand is above the average. During the summer holidays as well as the "conge collectief" the demand is usually considerably lower (due to people traveling out of Luxembourg) with another

[6] Presentation AGE at ALUSEAU meeting 28/02/2019 : Eau Potable Luxembourg: Feuille de route pour un approvisionnement durale

[7] The security of supply refers to a region's ability to provide a constant and renewable source of drinking water for its inhabitants.

period of high demand in September and sometimes October (see Graph 1). There are daily patterns, weekly patterns, and yearly patterns, and all of these have different typical values for the normalised data.

Graph 1: Daily normalised demand for 2015-2019 with a 7-day moving average



2.3. Water supply: Main assumptions and factors affecting water supply considered in the modelling

It is assumed that the overall annual precipitation over Luxembourg and the greater region and sources of main rivers flowing through Luxembourg, some of the main determinants of surface water and ground water availability, will not change significantly with climate change. The seasonal distribution of the rainfall and temperatures affecting the duration of hydrological winters however is likely to change. Such changes are not considered in the modelling but discussed separately. Impacts on diverse ecosystems from such changes and their altered behaviour with respect to water retention and trans-evaporation are however beyond the scope of this study.

Drinking water provision to households is the responsibility of the municipalities. Most municipalities use a mixture of water from their own local sources and drinking water from a national centralised system coming from a rainwater fed artificial lake Esch-Sur-Sur supplying a drinking water treatment plant operated by SEBES, a public-private partnership. Over 70% of households in Luxembourg receive drinking water (completely or partly) supplied by SEBES.

The Water Supply Network - The layout and details of the water supply network in Luxembourg is not as well-defined as the reader may assume. As every Luxembourg commune is, in principle, responsible for supplying water to its citizens and has its own detailed view of their network. Many communes have their own water sources and wells. The Administration de la Gestion de l'Eau (AGE) has a good overview of the actual water supply situation but knowledge of wells and sources that are not currently in use, especially those that have not been used for many years, is not complete. To this end, a very significant effort was made by the AGE to contribute to this project by supplying accurate data about active sources and wells.

Without this data this project would not have been possible. In the annex to this report (Annex 1) a water source table is provided per commune containing the currently known sources.

Storage - Another critical factor is the amount of water stored in a discrete water distribution network. Precise management of stored drinking water can help overcome periods where the demand is higher than the average supply. This process is called "peak shaving"; the more storage in a network, the longer a system can operate without supply problems. However, use of large storage basins leads to long stand times and in principle this has a negative impact on the water quality. Therefore, a software tool like the GPC will balance the use of storage with the residence time[8] of the water in the system. A significant effort was made by the AGE to contribute to this project by supplying accurate data about the number and volume of available water basins on top of the existing knowledge RTC4Water has of these structures. Practically the most important factor used in this paper for assessing the condition of a drinking water network at any given time is the "remaining volume": The volume still available in the network for bridging any gaps between demand and supply. Often, in more industrial areas, the remaining volume recovers at the weekend while in residential areas the remaining volume often deteriorates during this time and may recover during weekdays.

The following additional facts and factors are considered relevant:

- Efforts to increase the water supply via the new SEBES Water Treatment Works (WTW) are underway and should be implemented in 2021. What effect this will have on the security of supply in Luxembourg in the longer term is debated.
- The countries raw water sources, in particular the Esch-sur-Sûre Stausee, will be close to its maximum supply capacity when the new SEBES WTW (2) becomes operational. After this there is limited room for further expansion. Or at least this is the general opinion amongst the Luxembourg water community.
- The quantity of water supplied by ground water resources have been on the decline for the last decade, however indications are good that the country may experience at least a partial rebound in early 2020 thereby introducing an uncertainty factor.

Necessary background for the reader:

Model Predictive Control (MPC) - A simulation of demand versus the possibilities of supply is difficult to accurately assess without the use of an artificial intelligence tool. This is due to the need to assess daily operational decisions made by a network operator which can greatly impact the overall stability of a water supply network. RTC4Water has developed a software called the Global Predictive Controller (or GPC) which takes the place of these human interactions. The technology behind this software is called Model Predictive Control and it is considered very mature. Without such an artificial intelligence tool, the planned analysis would not have been possible. As part of the development of its GPC software, RTC4Water also uses a drinking water network modelling tool called EPANET[9]. This tool allows RTC4Water to create a "digital twin" of the components and performance of a drinking water network under evaluation.

Water Abstraction and Water Availability – In this report the main concern is water consumption. However, the "raw" water which makes its way into the supply network first needs to be available, then needs to be abstracted, and then, if necessary, treated and finally delivered as "potable" water to the

[8] Residence time refers to the average length of time that water is stored in a basin

[9] EPANET an Application for Modeling Drinking Water Distribution Systems developed by the United States Environmental Protection Agency

supply network. Due to many factors, not all the water that can be abstracted will be abstracted, often because of quality issues or due to the necessity to maintain water levels in certain bodies of water, mostly rivers.

"Failure" of the Water Distribution System – Typically, a water distribution system fails when there are tanks or pipes that are empty. But is one empty tank a failure? What if this tank cannot be filled fast enough because of a local infrastructure limitation? There are multiple ways to address the issue of failure and multiple considerations that would need to be considered: local (communal level) failures vs a systemwide (national) failure, maintaining of fire[10] reserves, percentage of the community that has supply issues, etc. Finally, a system failure can be predicted with a certain level of confidence, and this confidence level increases the closer the system is to a failure point. It stands to reason that, if a potential failure is identified in the near future (in a few days or a week), measures would be taken to prevent the failure. In Luxembourg, a phase orange or a phase rouge water usage warning is declared if the security of supply approaches critical levels. The effect of this is likely to prevent a failure in the system (as opposed to a systemwide failure). Therefore, in this report the following terminology will be used:

	Local (communal) Level	System-wide (national) Level	Assumed Storage Volume (m3)
Phase Orange Local	Some chance of local failures	No issues	<175,000 =>150,000
Phase Rouge Local	Local failures likely	No Issues	<150,000 =>125,000
Phase Orange System	Significant number of local failures	Some chance of a system-wide failure	<125,000 =>100,000
Phase Rouge System	High number of local failures	Significant chance of a system-wide failure	<100,000

Table 1 Assumed Relationship between Phase Orange/Rouge, failures and storage levels

In essence, a local Phase Orange/Rouge could be compared to a warning of a potential future failure by a commune while a systemwide, or national, phase Orange/Rouge could be compared to a warning of a potential future failure by the SEBES. Again, a timely declaration of a Phase Orange/Rouge should have the effect of preventing such a failure in the security of supply.

Water Consumption, Water Demand and Water Use – The difference between water use and water consumption is that water that is consumed is not returned to its source, therefore power plants often have a high water use but a low water consumption (they return the water used to a river). Water demand is the total amount of water used by the customers in a water system or sub-system. For the purpose of this report the differences between the three terms are minimal although every effort is made to use the most appropriate wording.

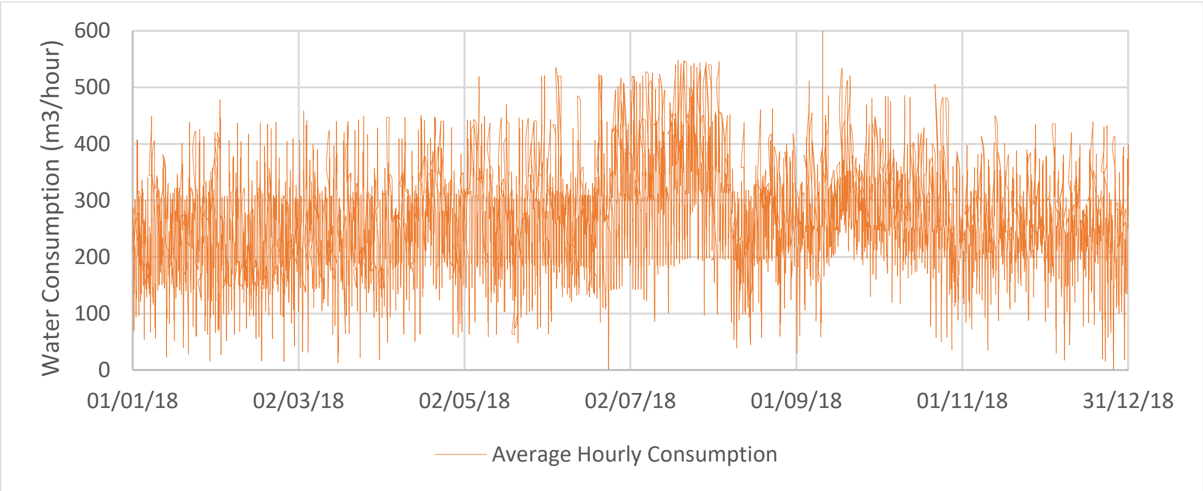
[10] The minimum volume of water that needs to be available to the local fire brigade to fight a fire

3. Methodology

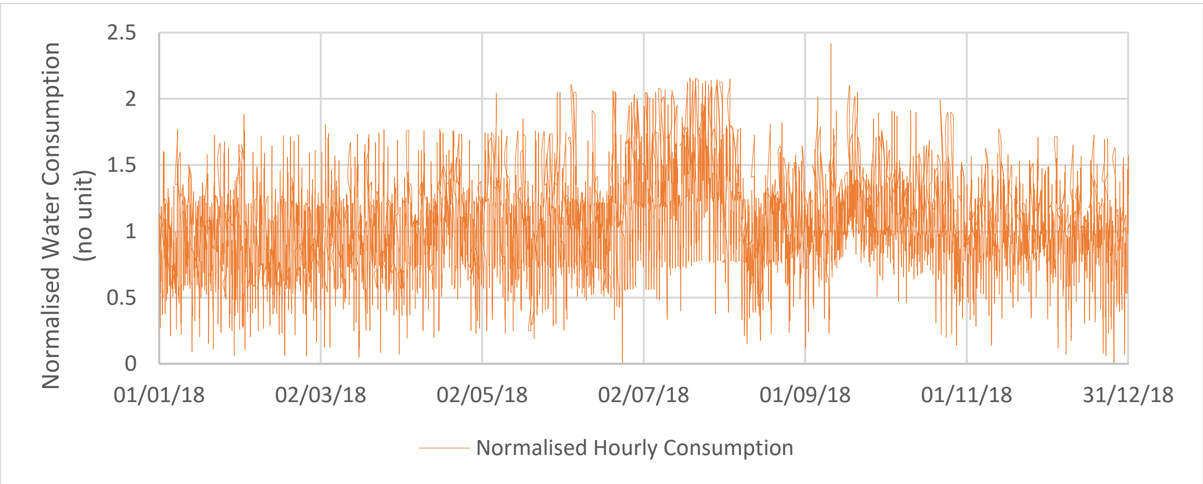
3.1. Modelling water consumption from 2020-2025

Drinking water consumption patterns (sampled at 1-hour intervals) for 2015-2019 for the total inflow of a Luxembourg Syndicate were collected (See Example: Graph 2 for 2018) and normalised (Example: Graph 3 for 2018).

Graph 2: Hourly water consumption of a Luxembourg Syndicate for 2018



Graph 3: Hourly normalized consumption of a Luxembourg Syndicate for 2018



Five normalised patterns were thus obtained - one of these being a leap year (2016). Then the average daily consumption per person was taken (202 l/p.p/day) and multiplied by the STATEC prediction for the number of people residing in Luxembourg for 2020-2025 (Table 2 and Example Graph 4 for 2021). The yearly normalised patterns were superimposed on these figures and, finally, the demand was split between the communes (85%) and the syndicates (15%, see example graph 5 for 2021).

Year	Population Prediction (STATEC)	Yearly Increase Population	Average Daily Consumption (m3/day)
2019	618'128	13'999	124'862
2020	632'048	13'920	127'674
2021	645'747	13'699	130'441
2022	659'596	13'849	133'238
2023	672'140	12'544	135'772
2024	684'554	12'414	138'280
2025	696'910	12'357	140'776

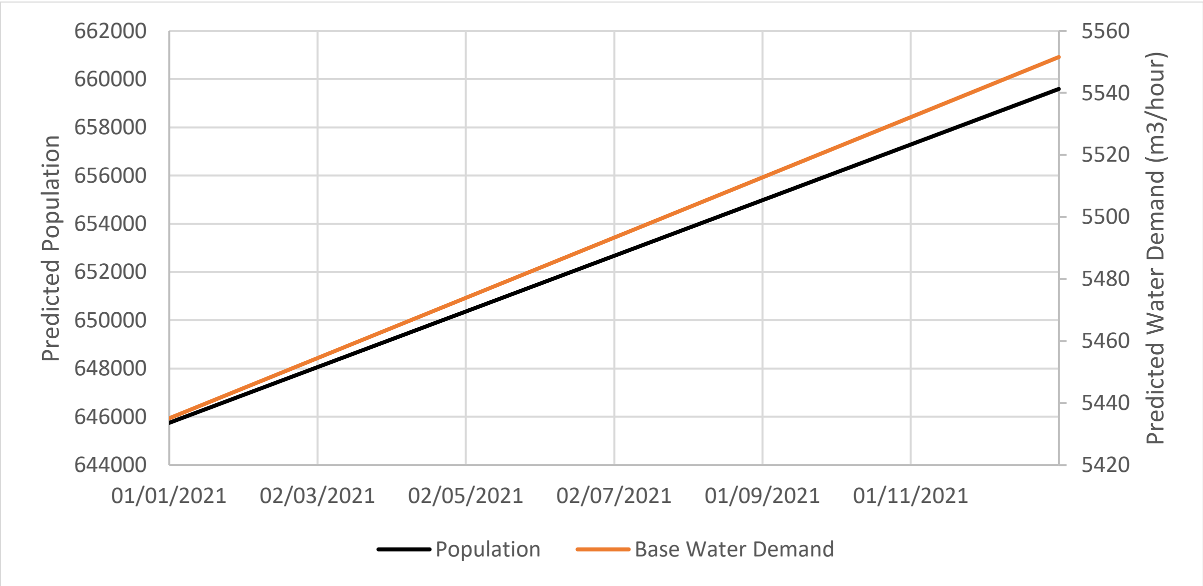
Table 2: Summary of the increase in population and the associated increase in consumption for drinking water

Assumptions:

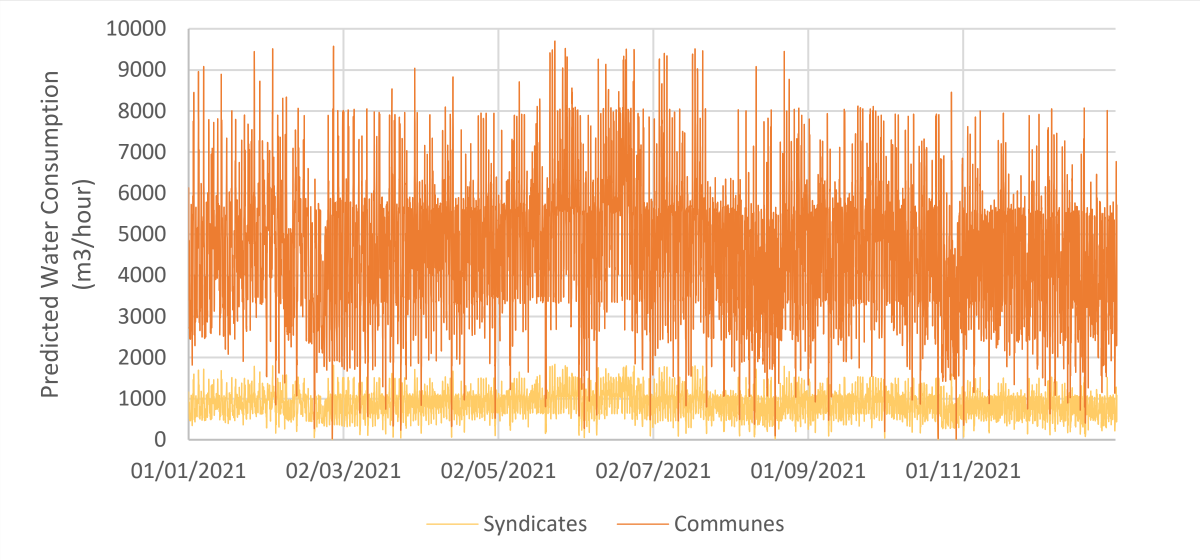
- The average daily consumption per person (202 l/day) is accurate and stays the same for the next 5 years. Current observations confirm that the 202 l/day/person is an astonishingly accurate figure and has been for the last 5 years.
- There are no water savings initiatives
- No improvements in leak management
- No changes in the ratio between industrial and household consumption.
- There are no alterations in demand due to climate change
- The STATEC predictions for population growth are reliable

It is argued here that although the above-mentioned assumptions cannot be sustained indefinitely, they can be assumed to be good approximations for a relatively short period of five years and the best figures available for the remaining prediction period.

Graph 4: The Increase in population associated with the predicted increase in water demand for 2021



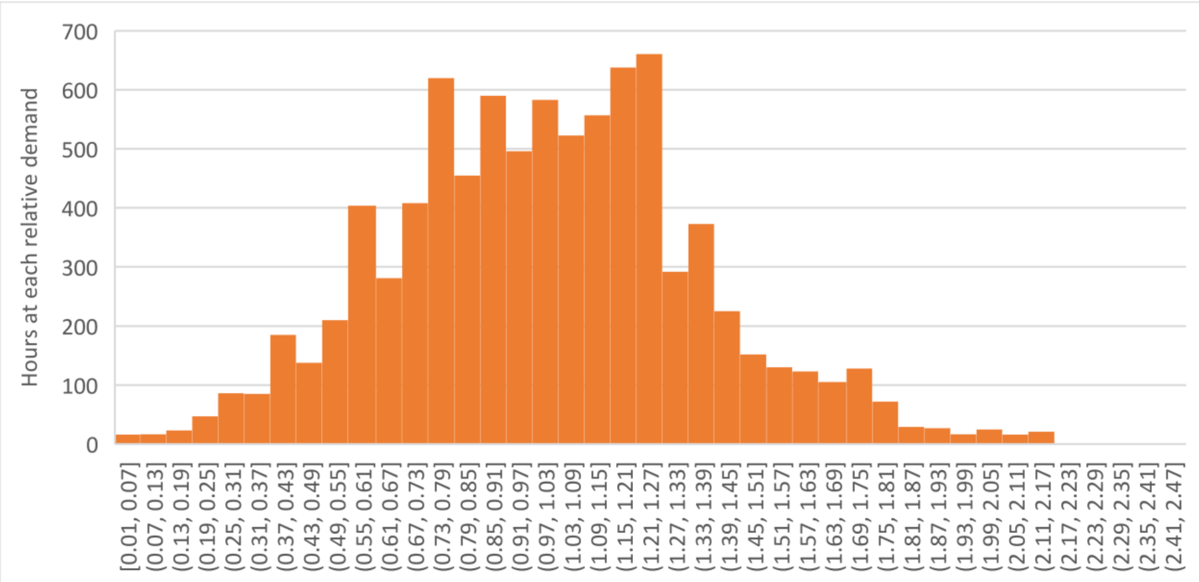
Graph 5: The predicted consumption for 2021 split by Communes and Syndicates



Checks made:

a. Average daily demand predictions. In the government reports[11], a slightly higher prediction for the average daily demand was made. Their values are about 7-11% higher. However, here local production from industry and agriculture were included (9589 m^3 and 1600 m^3). If a correction for these figures is included, the differences between the average daily demand in this report and that in ref 1,2 are minimal.

b. Relation between average and peak demand. In the above reports the relationship between the average and peak demand was around a factor 1.6. This is a reasonable factor when based on daily averages (Graph 1). Here however, hourly averages are often observed. Nevertheless, in the scenario for 2018 (Graph 6) a roughly similar behaviour can be observed albeit that more than 100 hours are within ratios of 1.69 to 1.75 with additional hours at a factor of 2.17. Note that the distribution around the average is close to, but not strictly Gaussian. **Graph 6: Distribution of the relative hourly demand of the 2018 scenario: The bars represent the number of hours at each normalised flow**



[11] Analyse des Wassereinsparpotentials für die Trinkwasserversorgung Luxemburgs, IWW, Mai 2018

3.2. Description of the model used for evaluation of the results 2020-2025 and 2026-2045

While RTC4Water has already developed EPANET models for the three largest water syndicates (DEA, SES, SIDERE, See Figure 1), they are currently too unproven to allow for a modelling effort for the entire country. For other parts of Luxembourg, RTC4Water has no models available, (parts of SEC, VdL, SESE and independent communes) although these may exist. Furthermore, the computational infrastructure for such an undertaking does not yet exist. Currently it would take from several weeks to upwards of a month to complete a single, detailed modelling run analysing over 25 years of data. It was therefore decided, for this first exercise, to use a highly simplified model to represent the behaviour of the national water infrastructure. This model would be developed specifically to answer the following questions:

- Is there enough drinking water for the next 5 years?
- Is there enough storage to be able to still supply drinking water even if, during short periods of stress, the demand exceeds the maximum supply (peak shaving capacity)?

It was felt that in order to answer such questions a simple model would be enough. This simple model is shown in Figure 4. The model consists of three drinking water supplies made up of:

a. A SEBES supply consisting of the existing Water Treatment Works (WTW) in Esch-sur-Sûre, the new WTW in Eschdorf and the emergency supplies located in Everlange, Troisponts and Scheidhof (close to Itzig). Currently the SEBES can supply a maximum of 112000 m^3/day.
b. A syndicate supply consisting of 132 distributed sources including a small amount of water supplied from Germany. For the sake of simplicity, these individual supplies have been grouped together as one source. (see Appendix 1)
c. A communal supply consisting of 134 smaller sources. Again, for the sake of simplicity, these individual supplies have also been grouped together as one source. (See Appendix 1)

Similarly, the same approach was taken concerning drinking water storage and the demand. Table 2 shows the capacities taken for sources and storage from January 2020 until December 2021 as well as from January 2022 onwards (Assuming the new SEBES WTW comes online on 1st January 2022.

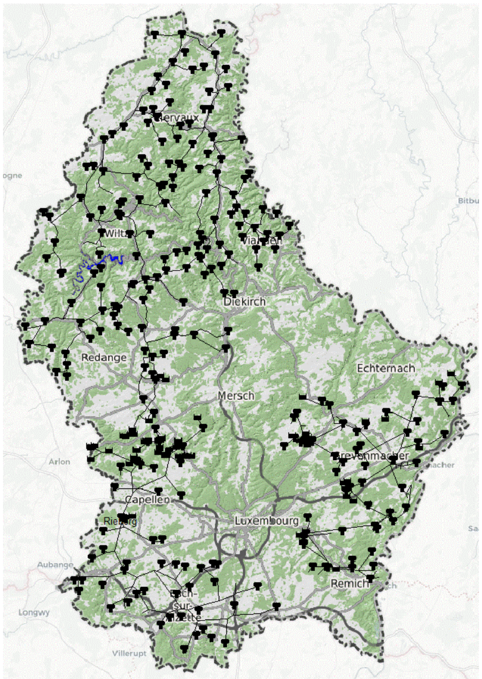


Figure 1: Schema of the networks for the syndicates DEA, SES, SIDERE on the Luxembourg map

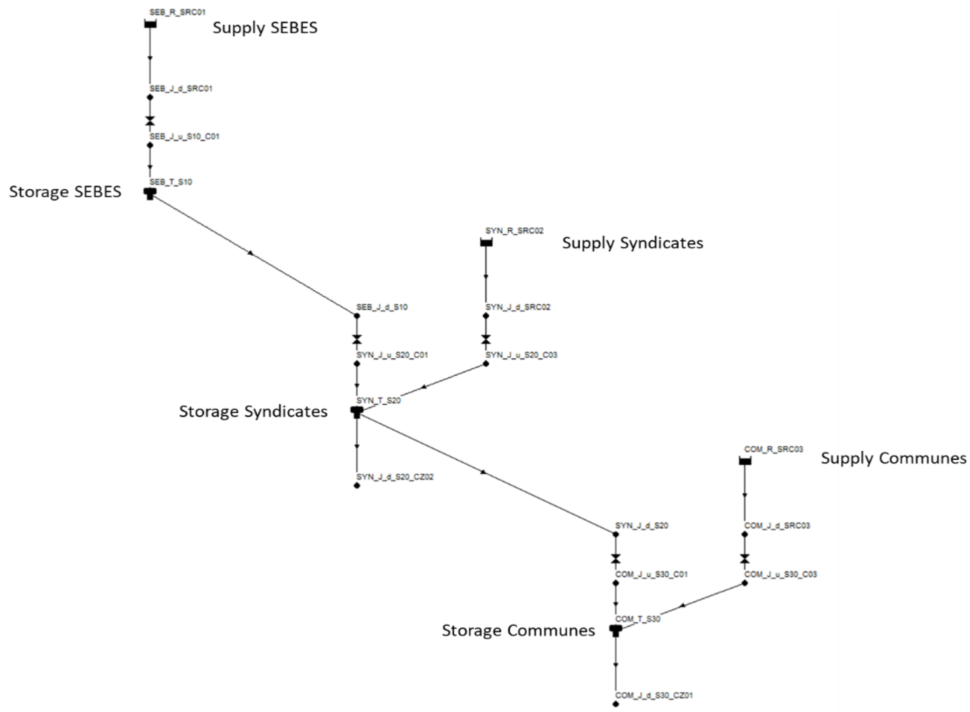


Figure 2: Schema of the simplified Luxembourg network, showing the locations of each tank and valve, the three-letter code represents either the SEBES, the Syndicates as a whole or the communes as a whole.

Table 2: Available daily drinking water production before and after the new SEBES WTW comes online.

SEBES	**Esch-sur-Sûre WTW**		**SEBES Sources**		**Total SEBES**	
Production up to 2021	74000	m3/day	38000	m3/day	112000	m3/day
Production after 2021	110000	m3/day	43000	m3/day	153000	m3/day

Other	**Volume**	**Unit**
Syndicates and communes (2014 data*)	61882	m3/day
Water from Abroad	4113	m3/day
Syndicates and communes (2019 preliminary data)	93224	m3/day

***Used in simulations**

In the second part of Table 2 there are two figures for syndicate / commune water production (2014 figures and 2019 figures). The 2014 figure comes from AGE reports and has been used extensively. The 2019 figure come from data (Appendix 1) that was gathered during the course of this project. However, this data is based on the production of individual sources and therefore it is water that is theoretically available, but may or may not be used for various reasons (examples: source fluctuations, contaminated water, source in the wrong physical location to allow its use). It was therefore decided to stick with the 2014 data to make this analysis more comparable. What is clear is that there is a "to be confirmed" potential of 31342 m3 of raw water that could potentially be used as potable water.

Table 3: Available Storage space before and after the new SEBES WTW comes online

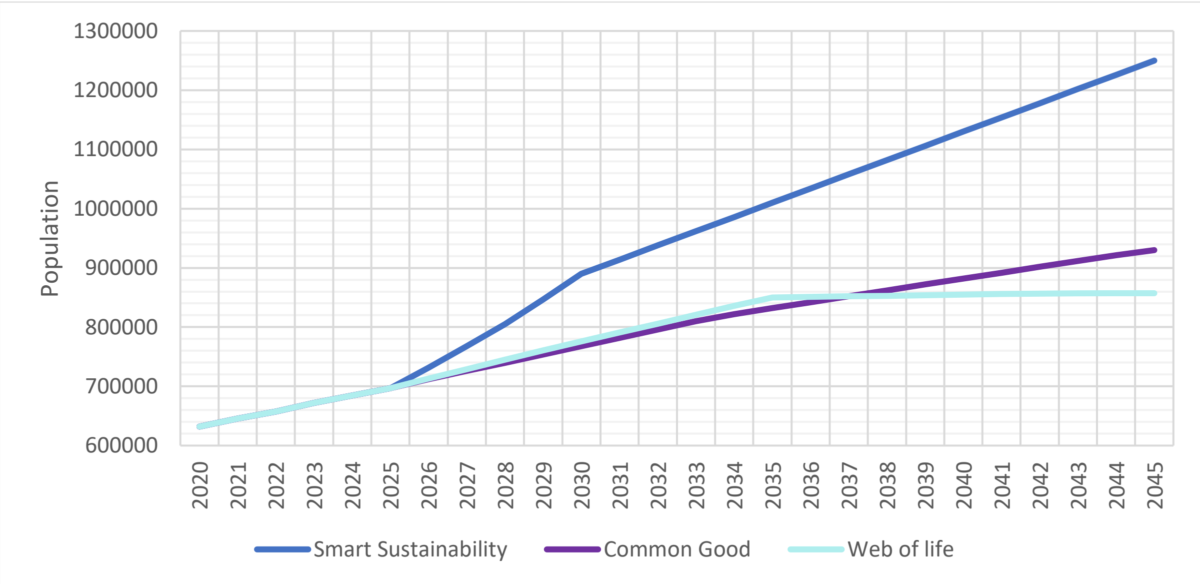
	SEBES Storage		Syndicate Storage		Commune Storage	
Storage up to 2021	35000	m3	70110	m3	145180	m3
Storage after 2021	65000	m3	70110	m3	145180	m3

The models in Figures 1&2 were created in EPANET, an extensively used modelling tool for water networks developed by the EPA in the US. Clearly using such a model to represent Luxembourg is an oversimplification, however, it is currently the best that can be done until current modelling efforts have progressed to a point where most water storage tanks in Luxembourg can be included in one global, Luxembourg wide, model.

3.3. Assumptions and approach for modelling water consumption for the three scenarios 2026-2045

With the help of the scenarios formulated jointly by a large group of people with wide ranging expertise, a resulting view of the water demand for the period 2026 until 2045 was developed for each NEXUS Futures scenario. It was decided to leave any increase in the water supply or the effects of global warming out of this model and instead consider the effects of global warming later in a discussion. With other words: The modelling done in this section reflects the situation of changing water demand with an unchanging water supply. The factors affecting the water demand are listed below.

Graph 14: The population increase for each scenario

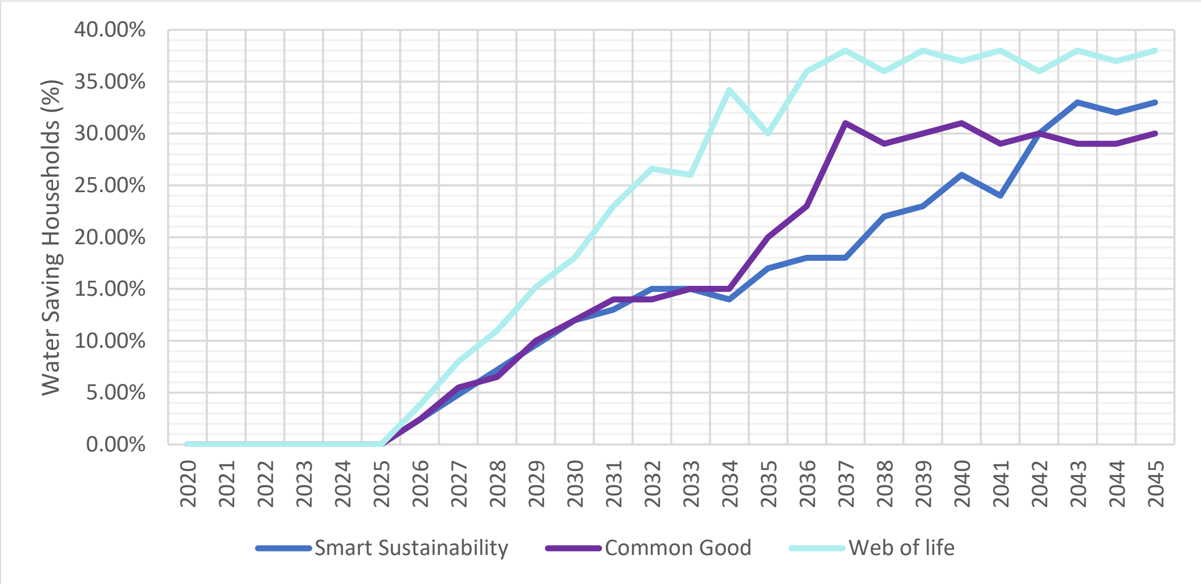


1. **Population**
   Population increases in Luxembourg until 2025 are relatively certain and, although some small deviations can be expected, a rough figure of around 700,000 residents can confidently be expected and were therefore modelled as just one scenario. After 2025 the situation for each scenario is expected to deviate. In the "Web of Life" scenario a relatively modest increase is projected which stabilises at around 850,000 in 2035 and then remains constant. In the "Common Good" scenario there is first a "business as usual" increase until around 2030 and then the increase in population

reduces and finally slowly rises to 930.000 in 2045. Finally, in the "Smart Sustainability" scenario, the increase in economic growth necessary to maintain our standard of living, means there is an associated increase in population until such a time that our natural resource limitations versus our increases in technology need to balance (starting in 2030), or limit, population increases to 1250 000.

2. Water Saving in Households

Graph 15: Water saving in households for each scenario

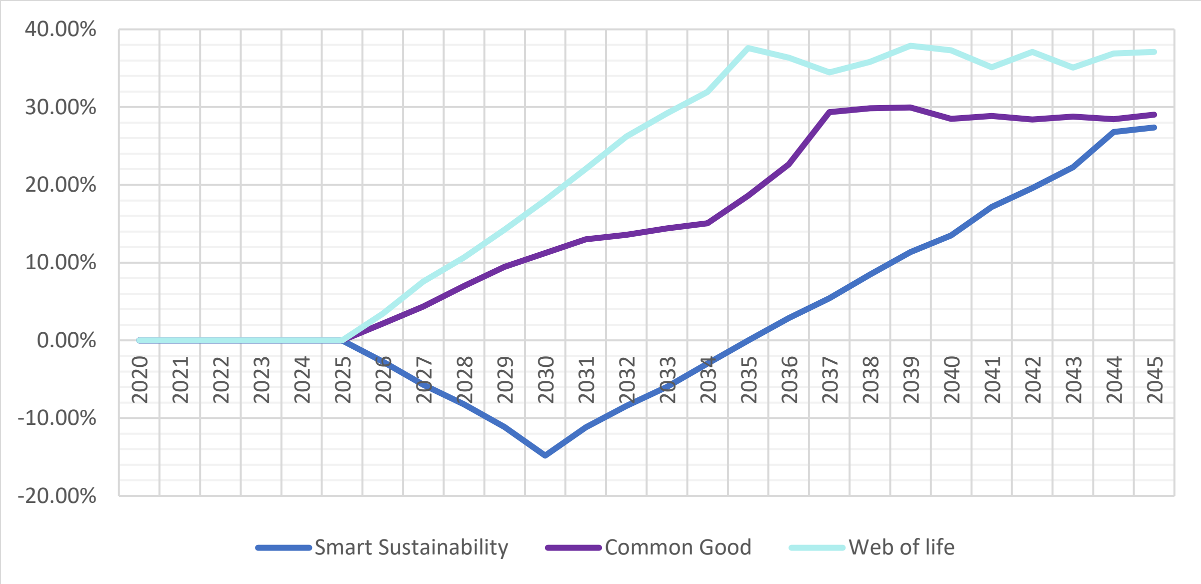


In the "Web of Life" scenario it is assumed that the population is the most eager to reduce water consumption from 2025. Initially this is a reduction in water that is relatively easy: reduction in water used for gardening and the use of smart shower heads and toilets, later more advanced water saving, and monitoring is implemented (example: water recycling showers). The "Web of Life" and the "Smart Sustainability" water savings initially fall behind with the "Web of Life" scenario making up considerable ground in 2035 and the "Smart Sustainability" scenario catching up a lot in 2040 because of necessity (frequent water shortages).

The potential for water saving has been described and researched in earlier publications of the AGE with a maximum achievable savings considered to be at approximately 38%. Note: A small noise element was added to the projections in Graph 12-15 to make the demand fluctuate a little and make the simulations more realistic.

3. Water Saving in Industry

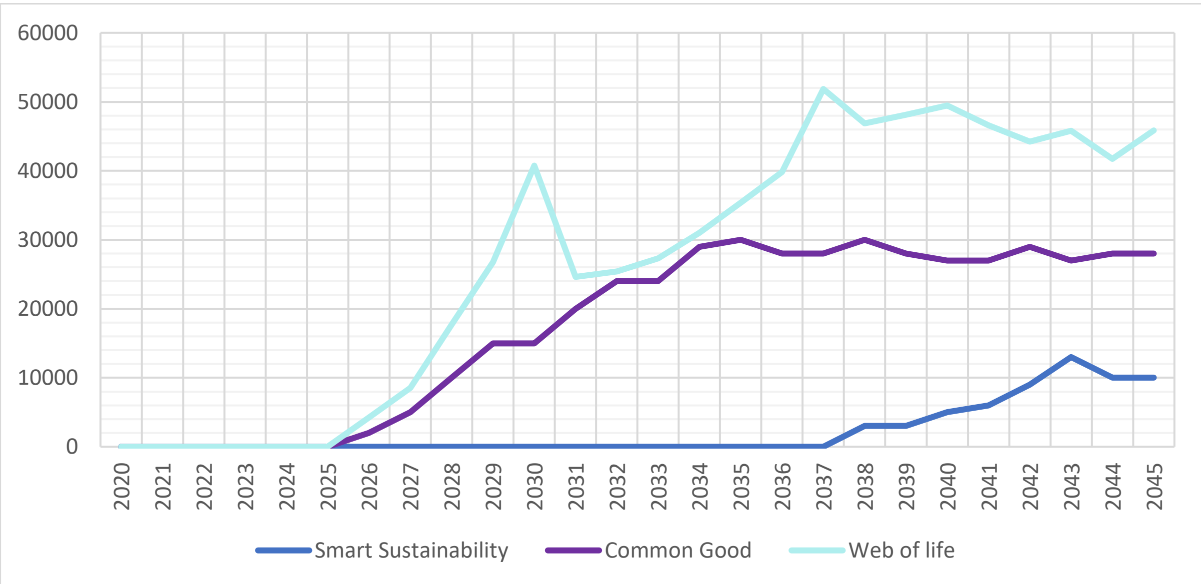
Graph 16: Water saving in Industry for each scenario



The "Web of Life" scenario again performs the best for water savings with the "Common Good" scenario trailing behind a little. In the "Smart Sustainability" scenario it is considered that there will be none, or very little, pressure on Industry to save water and as a result industry will actually increase its water consumption and use water for operations that currently are performed without water (example: passive cooling to active water cooling). Again, the reversal of this practice in 2030 will be because it will become imperative to save water and no longer be a "nice to have".

Additional Water for Urban Farming

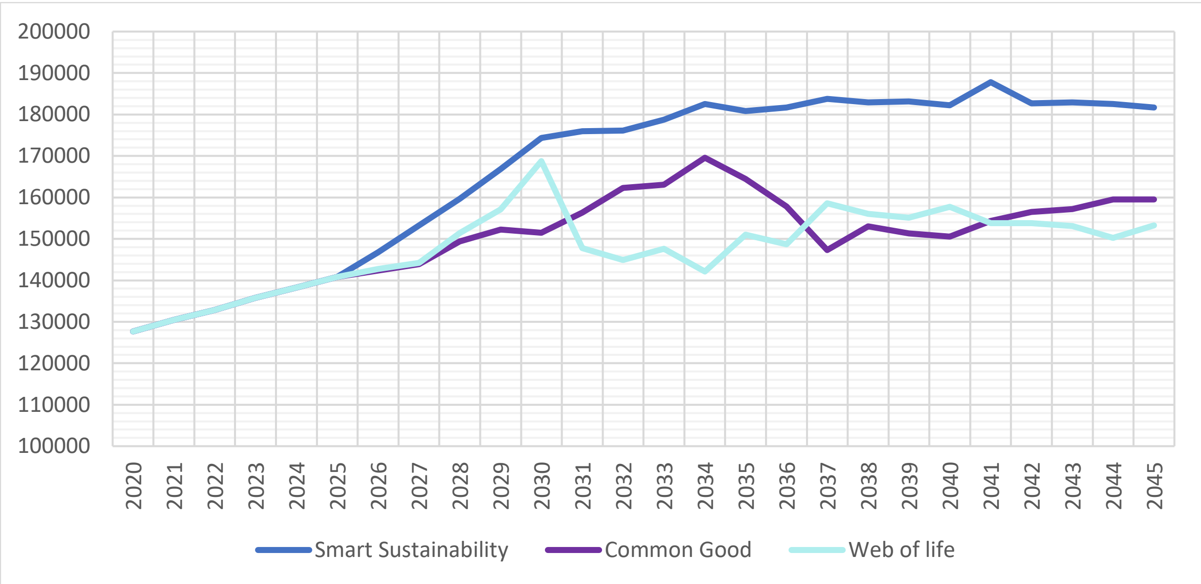
Graph 17: Additional Water for Agriculture for each scenario



With the realisation that transporting food around the world is not an optimal solution it will become necessary to introduce a new focus on local agriculture. This is often referred to as urban farming[12] However, regardless of the exact terminology used, foods containing a lot of water such as tomatoes, lettuce and cucumbers will increasingly be produced locally using high-tech practices in some form of distributed greenhouses. This will probably require additional, high quality water (although rain-water and grey water may also be used) and the "Web of Life" scenario is the first to realise this, closely followed by the "Common Good" Scenario. This change will come extremely late to the "Smart Sustainability" scenario (in the year 2037) because of the low availability of water and any water that is available is used to support the increased population - leading to a high dependency on foreign food sources. Note that the water used for urban farming must not be confused with the water used in agriculture. The drinking water demand for agriculture is negligible at around 1% of total potable water or approximately 1600 m3/day and is largely ignored for this project (although inherent in determining the 202 l/day/person estimate). A much larger volume for agriculture is possibly abstracted as raw water and used directly, but reliable figures for this volume were not available to the Author at the time of writing of this report.

4. Projected Water Demand

Graph 18: Projected water demand for each scenario

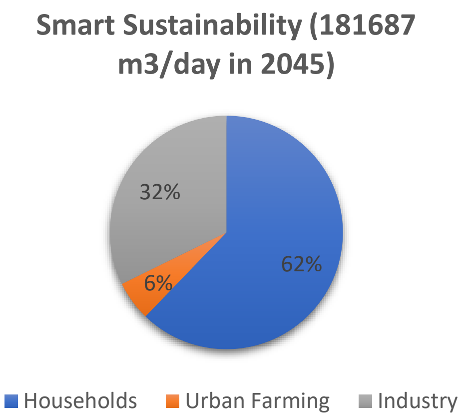


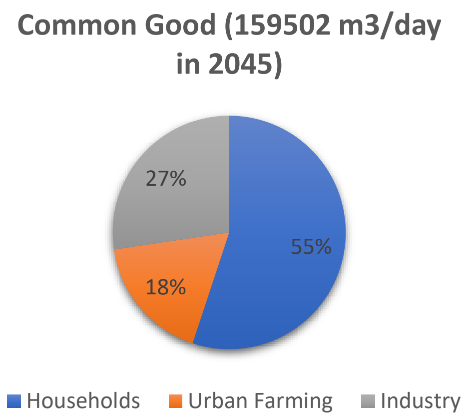
When all factors in 1-4 are added together a total projected water demand can be calculated for the period 2026-2045 (Graph 18). Here it can be observed that the water demand for the "Smart Sustainability" scenario reaches values of just over 180,000 m3/day. This is still well below the 220,000 m3/day that are available already in 2023. However, even without modelling it is already clear that a factor of 1.2 between daily total available water and daily summer water demand would be extremely challenging (see Graph 1).

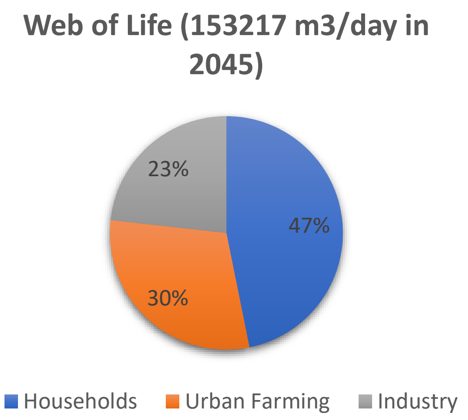
In Graph 19 the water distribution between Households, Industry and the water in use for Urban Farming are shown.

[12] https://www.urbanfarming.lu/la-strategie-nationale-urban-farming/

Graph 19: Pie charts with the projected water demand for each scenario in 2045 (with the different distributions for 750,000 people and 850,000 people in the Web of Life Scenario)





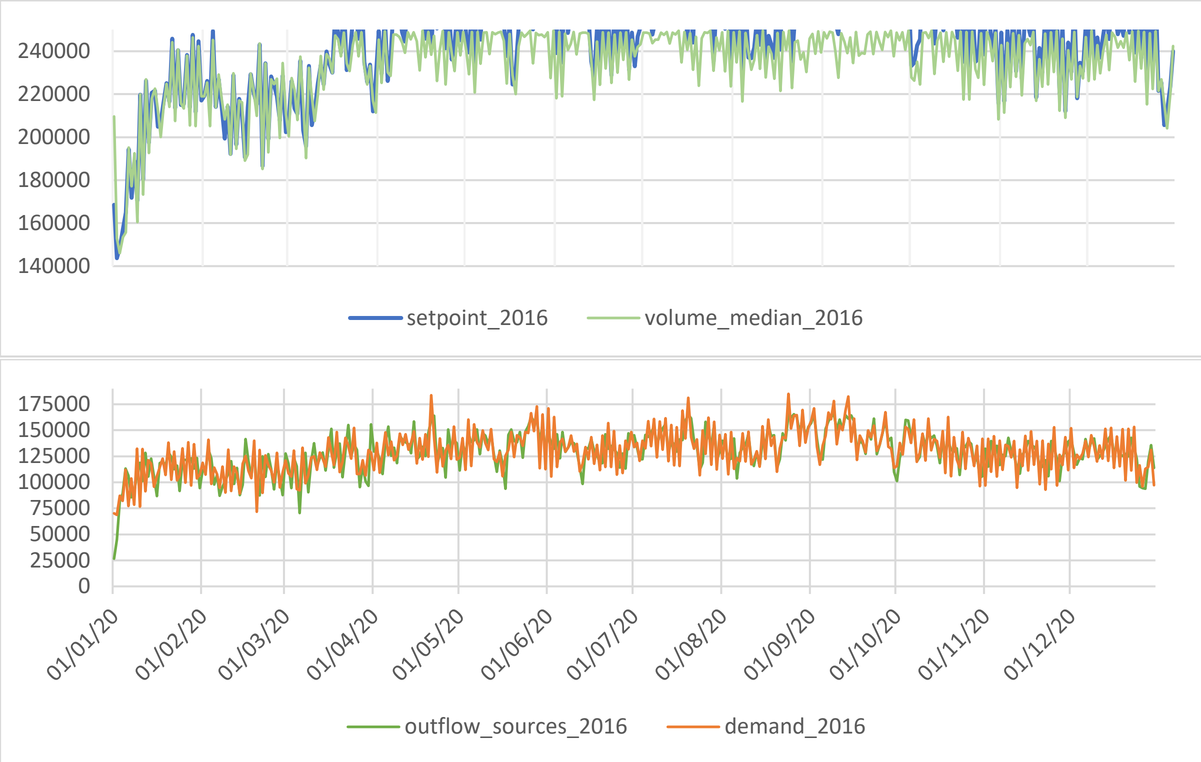


Note: Water for conventional Agriculture is mainly excluded from these graphs because: the majority is sourced from raw, non-potable sources and only 1% is from potable water which is included in the 202 l/day/person.

4. Results from modelling of water consumption from 2020 to 2025

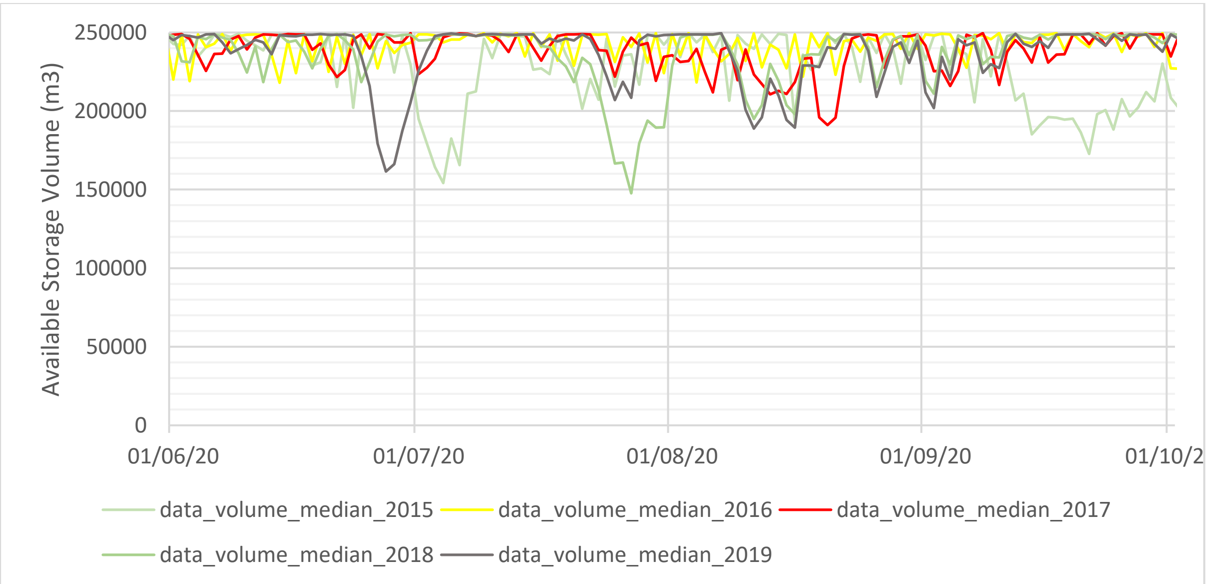
A RTC4Water GPC controller was constructed for this model to dynamically simulate flow and storage activity. Next, for 2020 a water demand scenario was created and then modelled. The results for 2020 are displayed in Graph 7. In this example the 2016 pattern was used. The top graph shows the total available storage volume (Green), and the setpoint (Blue) that the controller wants to achieve based on the predicted consumption demand, while the bottom graph shows the total demand (Daily Consumption, in orange) and the supplies from all the sources combined (Green). The complete year 2020 is displayed.

Graph 7: Results of the 2020 simulation using the 2016 pattern, the complete year (x-axes) is displayed). Top graph: available volume, bottom graph: demand and production



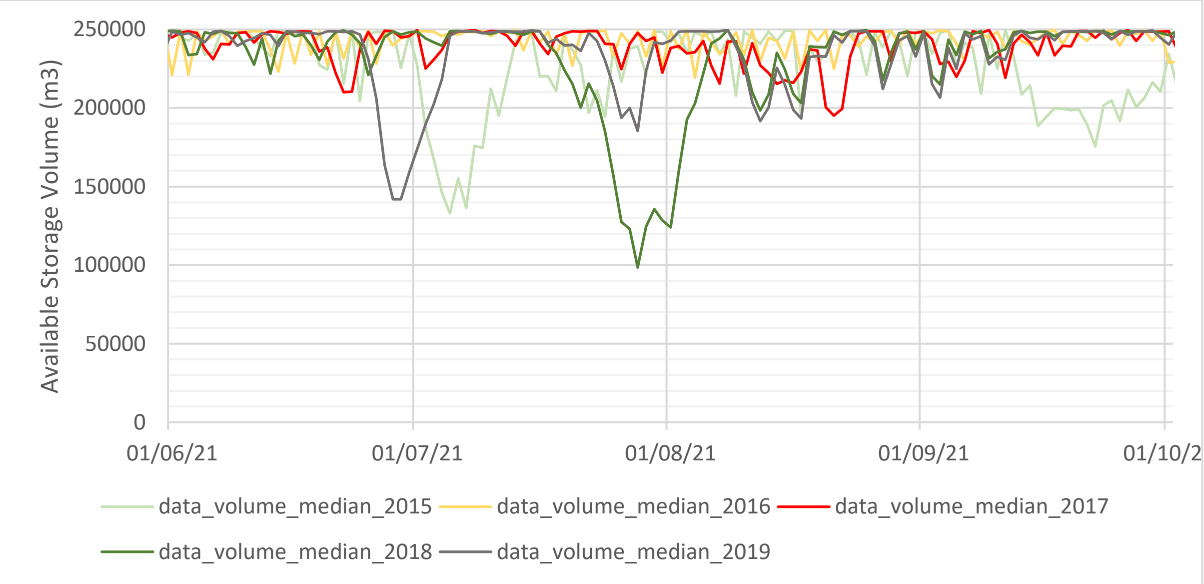
By observing the total available volume (and in the wintertime compare it with the setpoint) it is possible to get a good idea of the stress the system is under. If the actual storage volume follows the setpoint, the system has no stress and no stored volume is used for peak shaving. When examining this data in detail, it was concluded that in the 2020 scenario the demand experienced by the network had no real impact on the security of the water supply. The median daily available volume is displayed in subsequent graphs.

Graph 8: Results of the 2020 simulation: The available volume using the 2015-2019 patterns



However, when the same analysis is applied to other 2015-2019 patterns, it becomes obvious that the overall water supply system would experience some local phase rouge if the 2020 pattern is similar to the 2018 pattern and would experience a widespread phase orange if the 2020 pattern is similar to either the 2015 or 2019 patterns. Based on this data it would be fair to state that there is only a 40% chance (2 of the 5 scenarios) that 2020 would pass without some local water issues (2016 and 2017 patterns), this would only happen if longer periods of rain during the summer months are absent. Clearly the stated 40% is not a statistically relevant figure but it is the best that can be done with the available data. The results for 2021 show a slightly more serious loss of available volume due to the rising population.

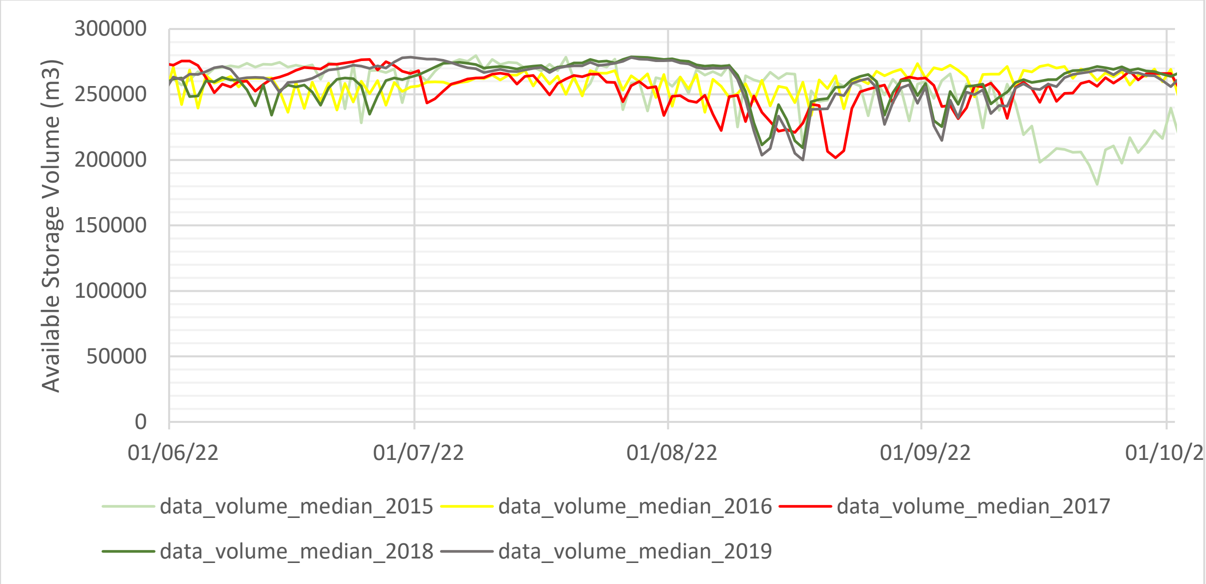
Graph 9: Results of the 2021 simulation: The available volume using the 2015-2019 patterns



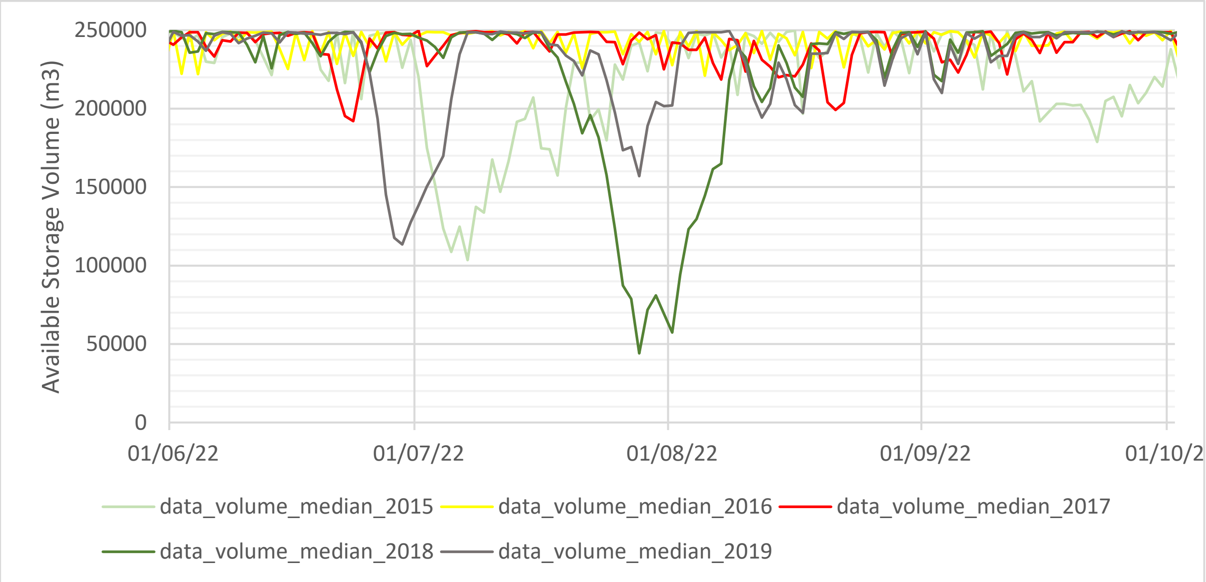
In Graph 9, it can be observed that a local (communal) phase rouge is likely (2018 pattern). When comparing Graphs 8 and 9, it is reasonable to conclude that although there is still only a 40% (2 of the 5 scenarios) chance that 2021 would pass without water issues, these issues would be much more acute than in 2020 because of population increases.

It is likely that with an available volume of around 100000 m3 the system would be under severe stress and there would be many local basins affected. The difference between 2020 and 2021 is a population increase of 13900 people, which translates to an additional demand of 13900 x 0.202 m3= 2808 m3/day. Although this does not seem like a lot, this volume quickly adds up during a period of drought. The difference in the drop in the 2018 available volume of stored water (or: available volume, for short) can be explained by factoring in a 17.8 day drought period where the demand exceeded the supply. In 2020 this exceedance is 5600 m3/day on average, in 2021 this figure has risen to 5600 plus 2808= 8424 m3/day or an additional 2808 x 17.8 = 50000 m3 loss of available storage (supply). Extrapolating to 2022 would provide a remaining available volume of 50,0000 m3 (for the simulation see Graph 11) resulting in a countrywide phase rouge.

Graph 10 Results of the 2022 simulation: available volume using the 2015-2019 patterns and incorporating supply from the new SEBES WTW

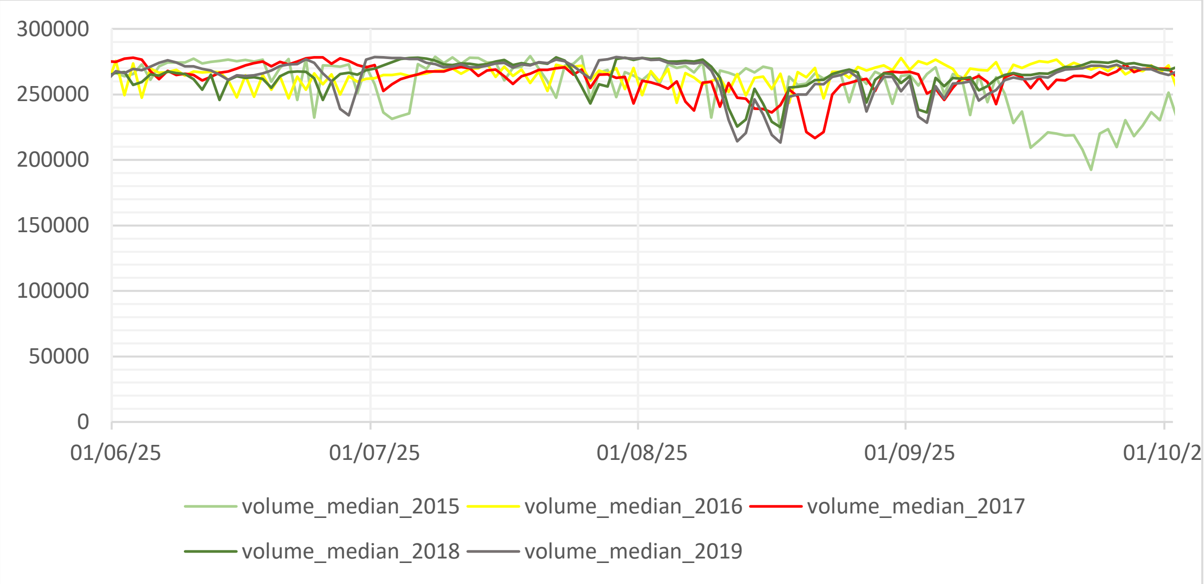


Graph 11: Results of the 2022 simulation: available volume using the 2015-2019 patterns without supply from the new SEBES WTW



With the SEBES WTW completed on time, the 2022 (Graph 10) simulation results are generally back to normal because of a large increase in available volume and the increased production capacity of the SEBES (Table 2). When the new SEBES resources are on-line there should be no real risk of water shortages until at least 2025 (Graph 12).

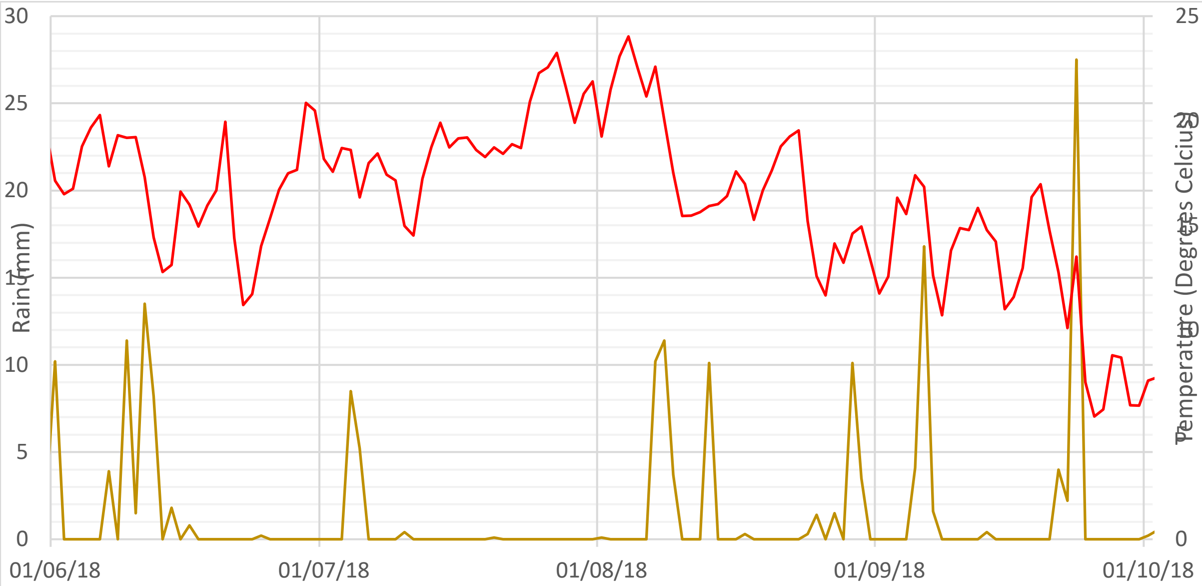
Graph 12: Results of the 2025 simulation: The available volume using the 2015-2019 patterns



Overall, it can be concluded that 2020 and 2021 will be crucial years for the water supply in Luxembourg. Several points should be mentioned here:

1. The availability of the new SEBES plant. It will be crucial that the new SEBES plant is online in 2023 and it would be advantageous if some way could be found to increase the supply for 2022 by some small amount (estimated 5000 m3) to reduce the risk of water shortages during a potential drought period in the summertime.
2. It may be possible to reinstate a few strategic sources in the communes and syndicates, either on a temporary or a permanent basis. A total extra supply of 5000 m3/day in 2021 would alleviate the situation dramatically and with a reasonably likelihood prevent water shortages altogether. The figure of 5000 m3 roughly equals a population increase over 2 years.
3. It is still (see point 4) unusual for periods of high demand to last longer than 2 weeks, therefore peak management using existing storage is a realistic option. However, to successfully do this the storage space must not only be available, it must also be well managed.
4. Although, still difficult to prove once and for all, it seems clear that we are seeing small but significant effects of climate change on the Luxembourg water supply: Extreme weather events are becoming more frequent and wet weather periods are moving to winter periods while dry spells are becoming longer and more frequent (example: dry spell from 22 March until 27 April 2020, spring 2020 was 1.1 Degrees Celsius higher than the reference period). If the drought experienced during the Spring of 2020 would have happened later in the year and been combined with higher temperatures, significant issues would have been experienced given the currently available supply volume.

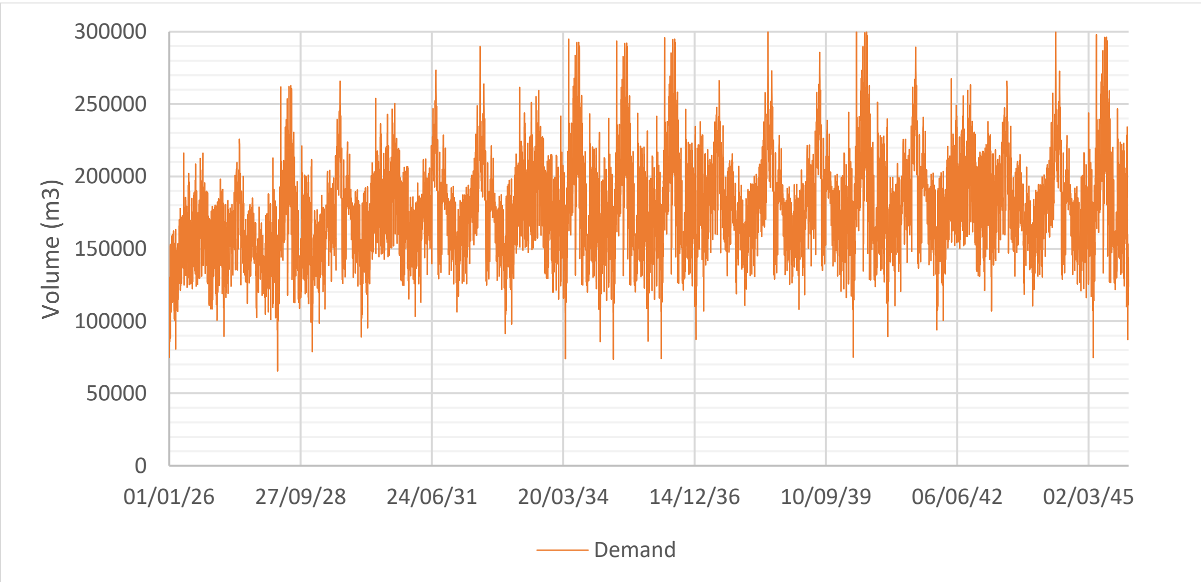
Graph 13: Rain and Temperature data for the summer of 2020 (Temperature is in Red, Rain is in Ochre)



5. Results of the modelling of the water consumption 2026-2045

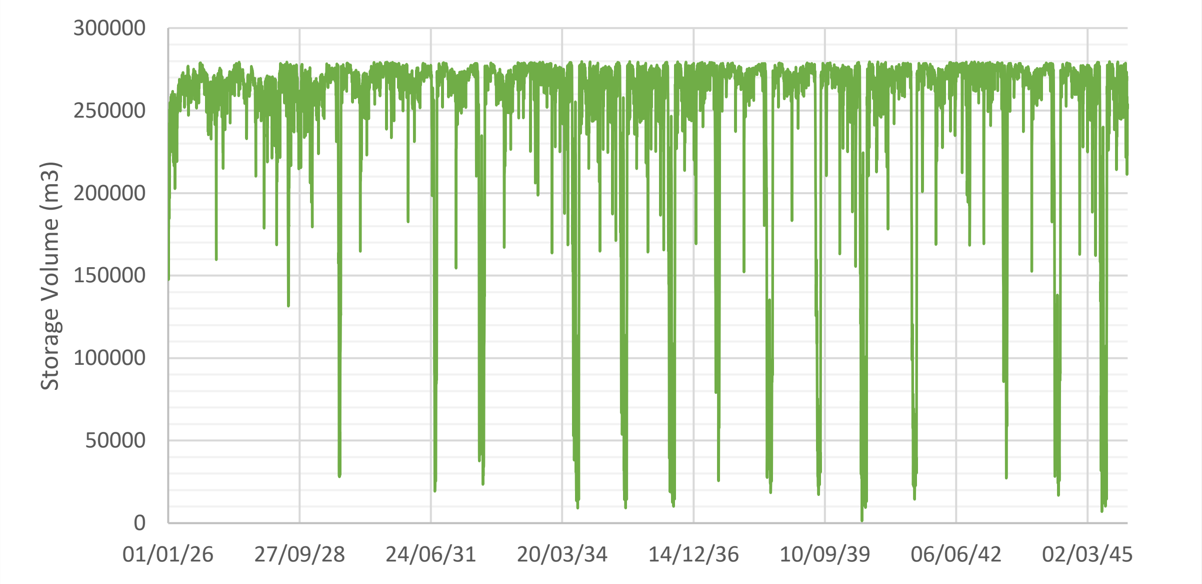
The yearly scenarios using the values in Graph 18 for the yearly demand were built and were modelled with a resolution of 15 min over 20 years. Significant advances in technology were made and methodologies were developed and validated. An Example: Initially a single modelling run for all scenarios took 3 servers approximately 10 days to run, however, eventually it was possible to run all simulations on a single server with a runtime of 2 days. These results can be used in many ways and can be further expanded to build more complex models. In the context of this report however, it was decided to show one graph where, from 2026 to 2045, one of the patterns (randomly selected) was chosen to illustrate a potential outcome over the course of several years. Graph 20 shows this graph for the "Smart Sustainability" Scenario.

Graph 20: Projected water demand for the Smart Sustainability scenario using randomly selected yearly outcomes from the 2015-2019 patterns



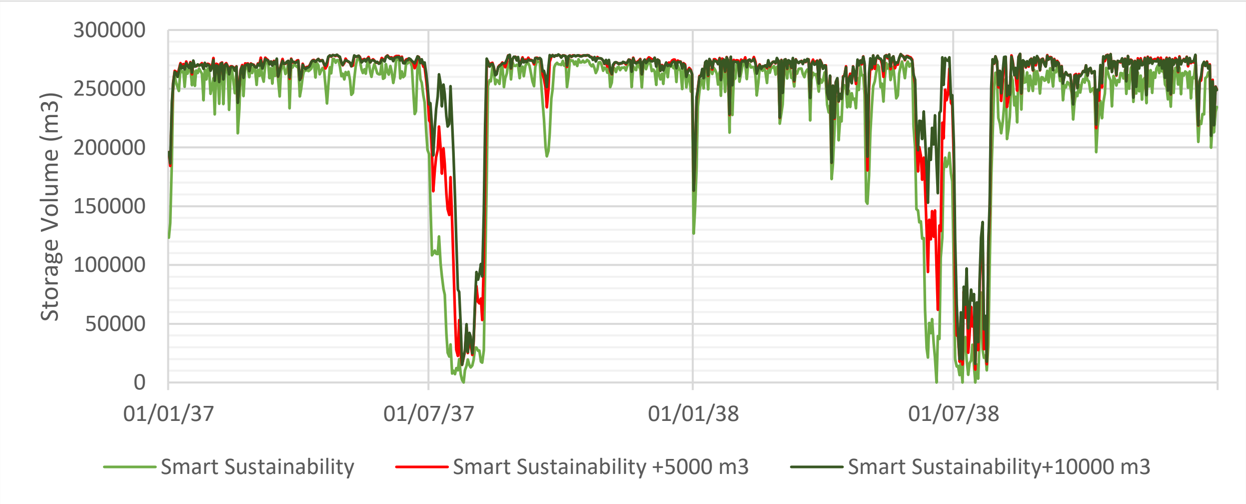
The resulting remaining water storage volume is given in Graph 21.

Graph 21: Projected storage volume for the Smart Sustainability scenario using randomly selected yearly outcomes from the 2015-2019 patterns



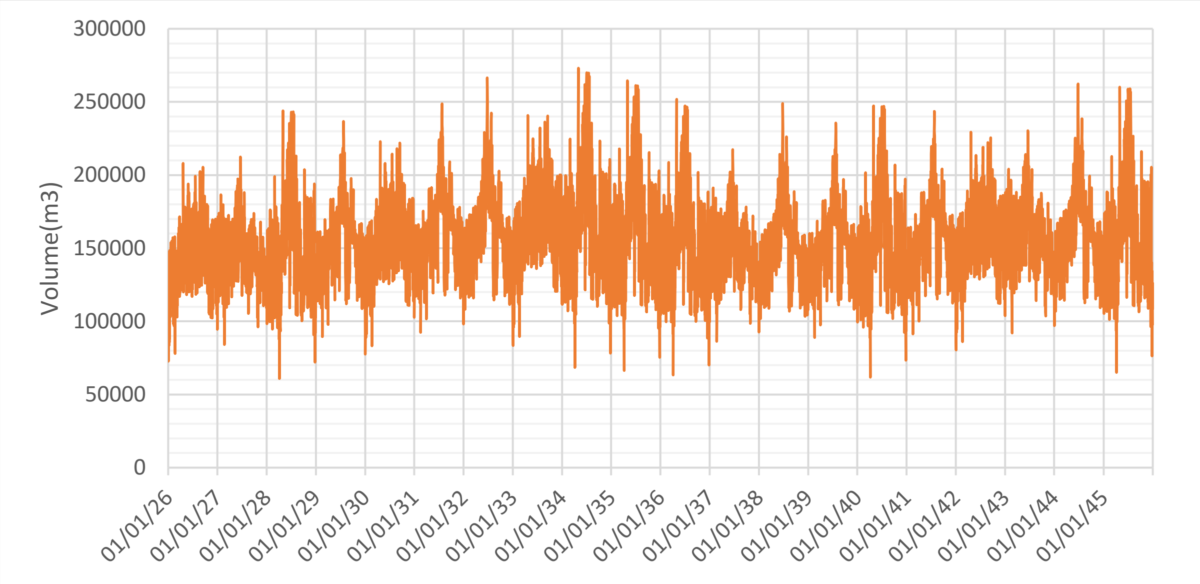
It can be observed from graph 21 that the "Smart Sustainability" Scenario suffers regular summertime water shortages from 2029 onwards, consistent with a population growth policy where water is the limiting factor. This high population directly results in frequent systemwide failures in water supply even after a maximum water saving of 38% has been achieved. It must be said that in this scenario the amount of available water has not increased from 2022 onwards and it may be possible to find the extra 50,000 m3/day to overcome some or most of the projected shortages. Another 5,000 or 10,000 m3 do improve the situation but not to the point where there are no more water shortages (see Graph 22). For this scenario it can be concluded that the policy where water savings can cancel out increasing population has failed.

Graph 22: Projected storage volume for the Smart Sustainability scenario with 5000 and 10000 m3 additional available water for the period 2037 and 2038



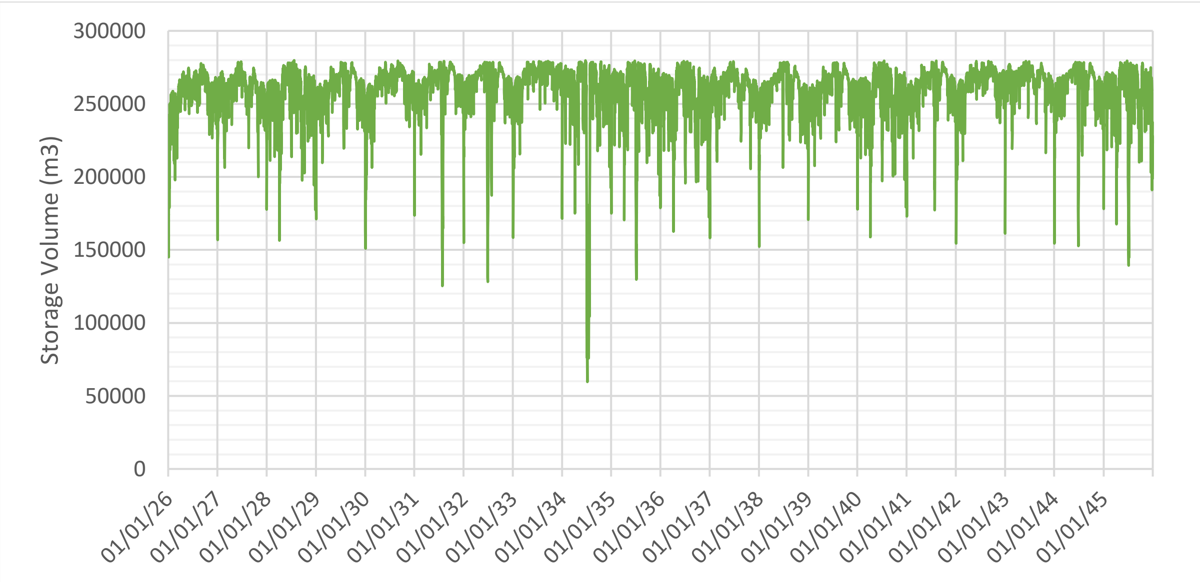
The same procedure for Scenario 2 "Common Good" result in Graph 23 and 24.

Graph 23: Projected water demand for the Common Good scenario using randomly selected yearly outcomes from the 2015-2019 patterns



The resulting storage volume is given in Graph 24.

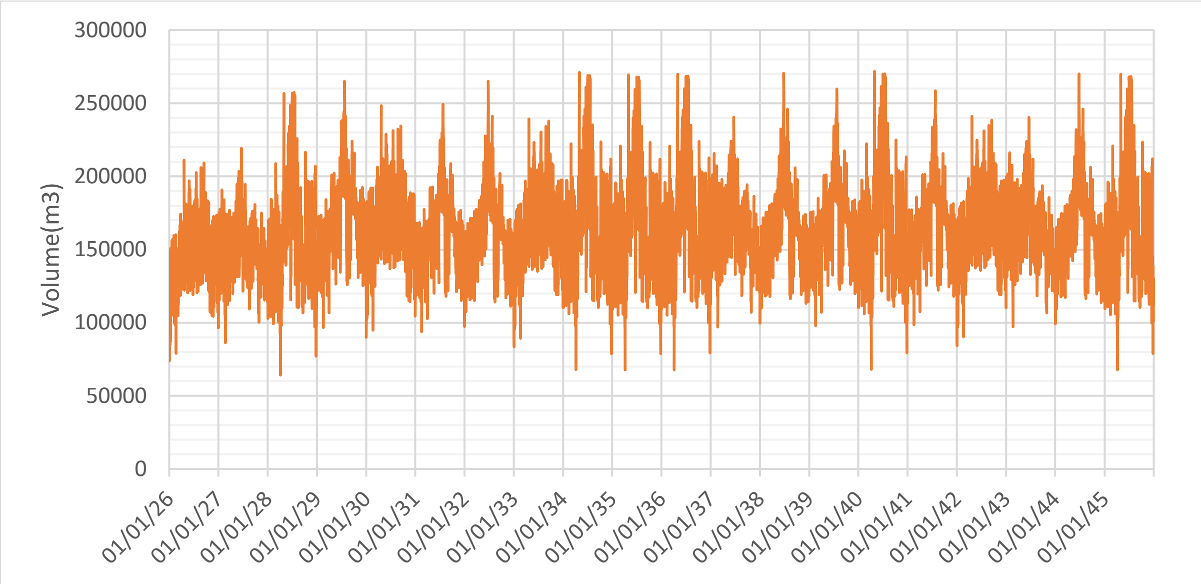
Graph 24: Projected storage volume for the Common Good scenario using randomly selected yearly outcomes from the 2015-2019 patterns



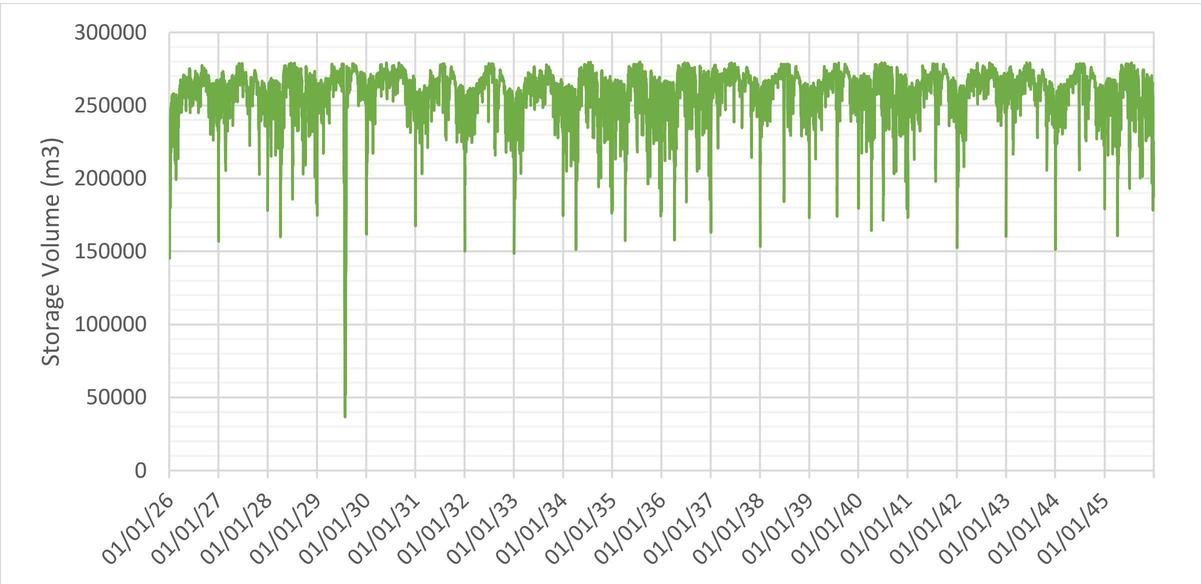
It can be observed in graph 23 and 24 that the demand is clearly lower than in Graph 20 and that the resulting available volume shows much lower dips in the summer. So much so that only one national (systemwide) failure (2034) occurs, although local failures are frequent. Clearly, in this scenario there is some resilience against climate change and short demand peaks of an additional 20,000-30,000 m3/day could be absorbed. If an extra 30,000 m3/day could be found, the situation would become very stable without any water supply issues.

In the third “Web of Life” scenario, the total water demand is similar on average to the “Common Good” scenario but higher demands occur earlier. This is demonstrated below in Graphs 25 and 26.

Graph 25: Projected water demand for the Web of Life scenario using randomly selected yearly outcomes from the 2015-2019 patterns



Graph 26: Projected storage volume for the Web of Life scenario using randomly selected yearly outcomes from the 2015-2019 patterns



For this Scenario it becomes apparent that there are one year in the fairly near future (2029) that the water supply system is severely challenged, but local failures are far less severe as in the Common Good scenario. It would be possible to stabilise this further with additional storage and an early increase in available supply.

6. Discussion and Conclusion

Is there enough water in the period 2020-2025?
In this report, the first research question that needed to be answered is: Is there enough water to have a security of supply for Luxembourg until 2025? The answer is a "Qualified Yes": in 2020 and 2021 there is reason for concern, and it is likely that some communes may need to establish a "phase orange" or even a "phase rouge" warning for water consumption. Also, it is unlikely that wide-spread water outages will occur Luxembourg. It is however imperative that the new SEBES WTW and the new SEBES water storage tank come online as soon as possible and certainly before the summer of 2022. Once the new supply is on-line, it is unlikely that there will be further difficulties for the next 5-7 year from a water treatment or water distribution point of view (note: in this report raw water volumes have not been considered and it has been assumed that there is enough raw water). This would give Luxembourg as a country a little time to decide which water policies to pursue. However, 8 years is not a lot considering the length of time it has taken to build the new SEBES facilities. In general, it could also be stated that the historic policy of water supply in Luxembourg to date has been the correct one though a small criticism could be that the process of building the new SEBES WTW has been "just in time" at best and "possibly a little late" at worst. However, such a process is always wrought with delays and difficulties - many of which are political or planning related.

The next research question that needed to be answered is: is there enough storage to be able to still supply drinking water even if the demand exceeds the maximum supply for short periods (peak shaving capacity) until 2025? The answer is a definitive yes with two small preconditions: a peak shaving volume of around 150,000 m3 must be available and the summer experienced should not be significantly "worse" than 2018 in terms of water demand or drought duration. It needs to be mentioned here that water storage amongst syndicates and communes is on the decline and it would be good if this trend is reversed.

Is there enough water for the period 2026-2045?
When the period between 2026 to 2045 is considered, it is clear from the simulations that a water saving approach is crucial to the continued functioning of Luxembourg's water supply infrastructure. An increasing population **must** go hand-in-hand with an increasing water saving initiatives otherwise water shortages are inevitable and will become dramatic. Achieving a water saving of 38% by 2035-2045 (graph 13) is currently not really possible and will be extremely challenging even with significant technological advances in 2045 but necessary goal if Luxembourg wants to stand a chance of maintaining a functioning water supply with a population of 900,000 people and no increases in available water. It is also clear that Luxembourg simply cannot support a population of 1.2 to 1.3 million people without increasing the water available and that with current resources a population of about 900,000 is the maximum (while also leaving some room for other uses of water in the agricultural sector). For a population of 1,250,000 people, a minimum additional supply of 50,000 m3/day is needed, while at the same time still needing to achieve a 33% water saving for this scenario. A currently more realistic figure of 26% means an extra 12,000 m3/day on top of this.

From these analyses it become evident that water availability will likely going be a limiting factor for population growth. If Luxembourg wants to avoid a situation where it will have to limit its population growth and the associated economic growth, then increased resources coupled with stimulation of water saving initiatives becomes imperative. The figure of 202 l per person, per day is again especially useful in this context. An increase of 12500 people per year essentially means an extra demand of 2500 m3 on average and 3750 m3 during peak demand.

Some recommendations can be given as to actions which would reduce the possibilities of water shortages:

- A better overview of the available water/available storage capacity with a higher temporal resolution. From the data collected there seems to be a discrepancy between the theoretical total output of the sources and the actual water availability. The theoretical difference in volume seems to be around 30,000 m3. Although the practical difference would certainly be much smaller and may even be zero, an on-line measurement of the debit from water sources would make a more dynamic management of Luxembourg's water supply feasible.
- Over the last decade many sources of water have been abandoned for a variety of reasons and given the indications given in this report that water may become a limiting factor to economic growth, it would be good to investigate these sources individually to examine if some of them could be taken back into use after a proper evaluation, source protection evaluation, well head rehabilitation and, if necessary, water treatment. It should also be considered if in some cases water syndicates should supply the know-how to maintain and operate such installations in preference to local councils who may lack the expertise.
- For some time there have been warnings by various actors that in the future Luxembourg will lack enough drinking water. A figure of 40,000 - 60,000 m3/day has been indicated as to the amount that is lacking. In some ways, this assumption has been born-out by this report; it is essentially the amount of water that is needed when a water saving strategy fails and a moderate increase in population (750,000-850,000) is assumed. Luxembourg will than have a set of colliding objectives and may need to decide that providing drinking water to its citizens is more important than maintaining a sufficient water level in its surface waters.

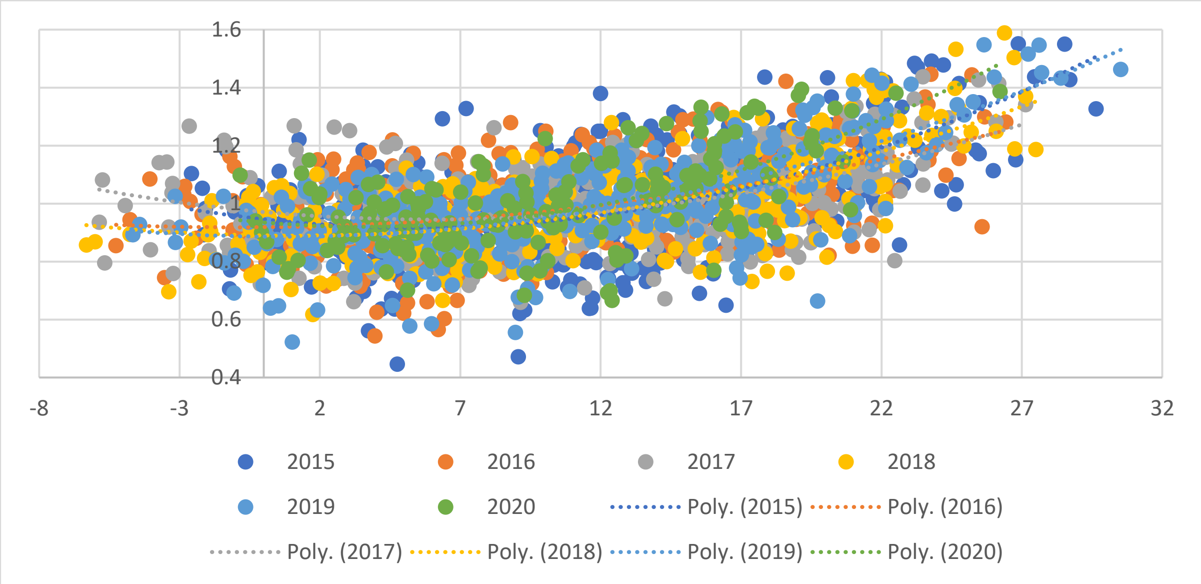
However, it is also clear that the state of the Luxembourg water supply is not a dire as often predicted and that maintaining a functional water supply for the next 25 years will be challenging but not impossible. Early planning, proper funding, consumer participation and legislation will be the key ingredients for success.

The close collaboration of many experts in varied fields of expertise during the NEXUS FUTURES project has illustrated that reaching a population of 1,250,000 people is <u>NOT</u> an impossibility as many have previously considered. It would be challenging, but it is possible to achieve the necessary infrastructure for so many people in Luxembourg without too many sacrifices.

Impact of Climate Change

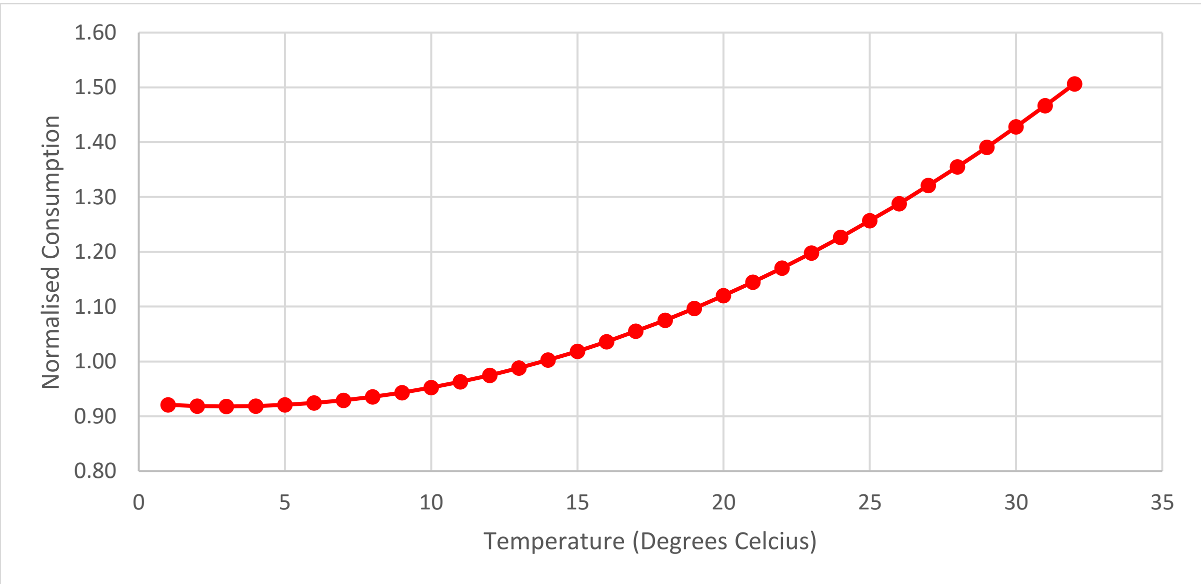
In closing, an attempt has been made to include the effects of climate change. From the results obtained from the meteorological department of the Administration of Technical Agricultural Services (ASTA), it is estimated that over the next 25 years the average temperature in our region will rise by 1 degree and the average rainfall during the summer months will decrease by 2-3%. These numbers may seem small, but upon closer examination the figures show that the temperature will rise between +0.34 and +2.74 degrees in July (reflecting a 95% confidence interval). While rainfall decreases in July by -24% and +16% (an increase, again reflecting a 95% confidence interval). Clearly a 2% decrease in rainfall in July would not change things considerably. However, a 25% decrease in rainfall in July would present Luxembourg with considerable difficulties. The increase in temperature is worth considering a little closer: when the dataset for 2015-2020 is considered and the average temperatures for these days are plotted against the normalised consumption, the following results become apparent:

Graph 27: Normalised demand as a function of temperature



From this plot it is clear that an increase in temperature means an increase in consumption. This is even more obvious when the "best fit" curve through these datapoints is applied.

Graph 28: Best fit line from the normalised consumption as a function of temperature



The above plot, although a gross simplification of what is in reality an extremely complex interaction of many variables, shows that a normalized consumption volume at 25 degrees Celsius is 26% above the average. However, if this curve is shifted by one degree then this is value becomes 29%. If a 3 degrees shift is applied, the value becomes 36% above the average. This translates to a 4-10% increase in demand. A 225000 m3/day to 247500 m3/day (10%) increase in demand is the difference between a stable water supply and a national (systemwide) phase rouge. When examining an increase from 29 to 32 degrees

Celsius, the difference becomes 12%; a conservative observation as these values are at the edge of our observations. If we add a "once in every 20 year" severe drought, for example a reduction of rainfall by 25%, the Luxembourgish water supply would experience a systemwide failure. It is therefore very clear: Climate Change has the potential to destabilise the Luxembourgish water supply.

Further work

Finally, the Authors would like to urge that, since digital performance models for the SES, the DEA and SIDERE are beginning to become available, some modest funding be made available to expand the current modelling capabilities so that over the next 2-3 years it becomes possible to model significant proportions of Luxembourg in more detail. This way it will be possible to evaluate, with greater certainty, both short term (days-weeks) as well as long term (years-decades) effects and identify bottlenecks and hotspots with greater accuracy. Furthermore, considering the discussions about new industries (e.g. Fage, Google), it would be interesting to estimate what additional quantities of water could be available for new industries, without affecting population growth for the 3 scenarios.

Last but not least, it would be interesting to develop some ways to consider changes in ecosystems capacity for water retention and changes in transevaporation rates, and changes in run-off patterns vs perculation of water through soil to form ground water after drought periods and during an increasing proportion of precipitation as extreme weather events – possibly in collaboration with LIST. AT least theoretically options for ecosystem engineering for a more water resilient Luxembourg may be considered if all these factors and interactions between them can be considered systemically.

Acknowledgements

The Authors wish to thank the Administration de la gestion de l'eau (AGE) for their cooperation. Especially, Mrs. Lambert and Mr. Michel, who have contributed significantly to this report by providing invaluable data and sharing their expert knowledge and advice.

-Also, many thanks to the Ministry of Agriculture, Viticulture and rural Development, specifically Dr. Andrew Ferrone for sharing his expert knowledge on climate change.

-Finally, many thanks to the NEXUS core team and the NEXUS extended team for the invaluable discussions without which such thought-provoking scenarios would have never been possible. Two persons stand out here: Dr Ariane König who developed the NEXUS FUTURES Project and led the scenario development process in close collaboration with Ciaran McGinley from the consultancy firm with long standing scenario expertise NormannPartners.

It should be noted that this report does not necessarily reflect the opinions of any specific institution, administration, organisation or company and that the opinions expressed in this report are those of the author and even then, on occasion, provided in a thought provoking or even provocative way.

Appendices

Appendix 1: Sources Luxembourg

Exploitant	Nom captage (code national)	Débit moyen (en m3/jour)
Beaufort	Cloosbierg 1 (SCC-111-11)	75
Beaufort	Cloosbierg 2 (SCC-111-21)	75
Beaufort	Cloosbierg 3 (SCC-111-33)	75
Beaufort	Dillingen (SCC-111-17)	39
Beaufort	Grundhof (SCC-111-18)	199
Bech	Alter Speicher (SCC-112-21)	44
Bech	Bech (Schlamfur) (SCC-112-01)	546
Bech	Rippig (Kellerbour) (SCC-112-03	111
Bech	Waldquelle (SCC-112-28)	64
Beckerich	Tunnel (SCC-802-04)	152
Berdorf	Meelerbuur 1 (SCC-113-01)	183
Berdorf	Meelerbuur 2 (SCC-113-04)	183
Berdorf	Weilerbach (SCC-113-03)	77
Betzdorf	Giedgendall 1 (SCC-121-01)	43
Betzdorf	Giedgendall 2 (SCC-121-02)	50
Betzdorf	Lampbour (SCC-121-05)	230
Bissen	Scheierbur (SCC-812-06)	483
Biwer	Brouch (SCC-112-51)	40
Consdorf	Wolper (FRE-114-04)	180
Contern	Millbech (SCC-402-01)	2151
Contern	Stuwwelsboesch (SCC-402-02)	1012
Dalheim	Klengelbour (SCC-132-05)	72
DEA	Béik S6 (SCS-810-01)	734
DEA	Fëschweier S2 (SCS-802-12)	147
DEA	Kaschbur S5 (SCS-810-04)	1131
DEA	Kazebur S4 (SCS-810-05)	80
DEA	Wäschbur S1 (SCS-802-07)	768
DEA	Wollefsbur S3 (SCS-810-08)	411
Diekirch	Dillingen 1 (SCC-111-38)	65
Diekirch	Dillingen 2 (SCC-111-39)	18
Diekirch	Dillingen 3 (SCC-111-40)	188
Diekirch	Dillingen 4 (SCC-111-04)	159
Diekirch	Dillingen 5 (SCC-111-37)	94
Diekirch	Dillingen 6 (SCC-111-03)	112
Diekirch	Dillingen 7 (SCC-111-01)	204
Diekirch	Dillingen 8 (SCC-111-10)	34
Echternach	Felsbuch 1 (SCC-115-05)	317
Echternach	Felsbuch 2 (SCC-115-06)	317
Echternach	Felsbuch 2b (SCC-115-06-b)	317

Echternach	Felsbuch 4 (SCC-115-70)	317
Echternach	Felsbuch 5 (SCC-115-71)	317
Echternach	Schankbour 1 (SCC-115-03)	333
Echternach	Schankbour 2 (SCC-115-04)	87
Echternach	Schankbour 3 (SCC-115-33)	33
Echternach	Schankbour 4 (SCC-115-34)	53
Echternach	Weissenberg 1 (SCC-115-43)	300
Echternach	Weissenberg 2 (SCC-115-44)	300
Echternach	Weissenberg 3 (SCC-115-45)	300
Echternach	Weissenberg 4 (SCC-115-46)	300
Ell	Bei Schroedeschweiher (SCC-805-02)	356
Ettelbruck	Dreibueren (SCC-509-18)	820
Flaxweiler	Buchholz-Niederdonven (SCC-123-17)	57
Flaxweiler	Lampicht (SCC-121-06)	189
Flaxweiler	Lavoir (SCC-123-05)	58
Flaxweiler	Setzen 1 (SCC-123-01)	52
Flaxweiler	Setzen 4 (SCC-123-04)	Schüttung nicht gemessen
Grevenmacher	Seitenquelle (SCC-112-11)	30
Grevenmacher	Waldquelle (SCC-112-08)	60
Grevenmacher	Widderquelle (SCC-112-10)	101
Grevenmacher	Wiesenquelle (SCC-112-12)	29
Grevenmacher	Willibrordusquelle (SCC-112-09)	250
Grosbous	Neiwiss (SCC-807-02)	166
Grosbous	Welterbaach (SCC-807-01)	133
Habscht	Laangegrond 1 (SCC-205-36)	21
Habscht	Laangegrond 3 (SCC-205-39)	21
Habscht	Laangegrond 4 (SCC-205-41)	21
Habscht	Laangegrond 5 (SCC-205-42)	21
Habscht	Tunnel 1 (Eichen) (SCC-205-15)	124
Habscht	Tunnel 2 (SCC-205-23)	124
Habscht	Uechtlach (SCC-205-12)	258
Helperknapp	Härebur (SCC-503-03)	430
Helperknapp	Hollenfels 1 (SCC-511-01)	934
Helperknapp	Hollenfels 2 (SCC-511-02)	701
Junglinster	Häertgen (SCC-125-03)	142
Junglinster	Hierber (SCC-125-04)	220
Junglinster	Kriepsweiher (SCC-125-02)	503
Kehlen	Direndall 1 (SCC-206-01)	227
Kehlen	Direndall 10 (SCC-206-17)	155
Kehlen	Direndall 11 (SCC-206-18)	155
Kehlen	Direndall 2 (SCC-206-02)	227
Kehlen	Direndall 3 (SCC-206-13)	227
Kehlen	Direndall 4 (SCC-206-04)	155
Kehlen	Direndall 5 (SCC-206-05)	155
Kehlen	Direndall 6 (SCC-206-14)	155
Kehlen	Direndall 7 (SCC-206-07)	155

Kehlen	Direndall 8 (SCC-206-15)	155
Kehlen	Direndall 9 (SCC-206-16)	155
Larochette	Am Deich (SCC-506-02)	468
Lintgen	Kasselt 1 (SCC-508-01)	470
Lintgen	Kasselt 2 (SCC-508-02)	421
Lorentzweiler	Grouft (SCC-508-04)	84
Lorentzweiler	Weissbaach (SCC-508-09)	462
Manternach	Vollwaasser (SCC-112-04)	275
Mersch	An der Baach 1 (SCC-509-28)	36
Mersch	An der Baach 2 (SCC-509-29)	36
Mersch	An der Baach 3 (SCC-509-30)	36
Mersch	An der Baach 4 (SCC-509-31)	36
Mersch	Boussert (SCC-509-16)	105
Mersch	Deiwelsfass 3 (SCC-509-40)	36
Mersch	Rouschtgronn 1 (SCC-509-22)	36
Mersch	Rouschtgronn 2 (SCC-509-23)	36
Mersch	Rouschtgronn 3 (SCC-509-24)	36
Mersch	Rouschtgronn 4 (SCC-509-76)	36
Mersch	Sulgen (SCC-509-13)	306
Mertzig	Maescheierchen 1 (SCC-807-03)	55
Mertzig	Maescheierchen 2 (SCC-807-04)	48
Mertzig	Schwaarzebur (SCC-711-01)	104
Niederanven	Rameldange (SCC-404-01)	395
Niederanven	Waasserwee 1 (SCC-404-09)	196
Niederanven	Waasserwee 2 (SCC-404-37)	196
Niederanven	Waasserwee 3 (SCC-404-38)	196
Niederanven	Waasserwee 4 (SCC-404-39)	196
Niederanven	Waasserwee 6 (SCC-404-41)	196
Nommern	Aeschelsbour (SCC-510-08)	70
Nommern	Brouchbour (SCC-510-04)	205
Nommern	Glabach (SCC-509-05)	177
Nommern	Schwaarzegronn (SCC-510-09)	150
Préizerdaul	Erdt (SCC-803-02)	154
Redange-sur-Attert	Kuelemeeschter (SCC-809-09)	724
Redange-sur-Attert	Weierchen (SCC-809-11)	273
Reisdorf	Goberhaff (SCC-712-07)	71
Reisdorf	Hanseschlaff (SCC-712-01)	85
Rosport-Mompach	Girst (SCC-117-01)	218
Rosport-Mompach	Herborn (SCC-112-33)	80
Schengen	Strombierg (SCC-135-02)	198
Schuttrange	Boumillen Ancienne (SCC-406-01)	389
SES	Koch (SCS-206-40)	471
SES	Stoltz (SCS-206-41)	471
SES	Ansembourg 1 (SCS-511-61)	415
SES	Ansembourg 2 (SCS-511-62)	410

SES	Brickler-Flammang (SCS-205-68)		848
SES	Buchholtzerbour (SCS-207-12)		1007
SES	Camping (SCS-210-31)		600
SES	CFL (SCS-205-09)		600
SES	Feyder 1 (SCS-210-51)		93
SES	Feyder 2 (SCS-210-52)		93
SES	Feyder 3 (SCS-210-53)		93
SES	Fielsbour 1 (SCS-509-35)		367
SES	Fielsbour 2 (SCS-509-36)		367
SES	Fielsbour 3 (SCS-509-37)		367
SES	Fischbour 1 (SCS-205-01)		750
SES	Fischbour 2 (SCS-205-02)		750
SES	Fischbour annexe 1 (SCC-205-65)		700
SES	Fischbour annexe 2 (SCC-205-66)		800
SES	François (SCS-511-63)		400
SES	Guirsch (SCS-206-47)		93
SES	Kehlen (SCS-206-42)		471
SES	Klingelbour 1 (SCS-206-38)		325
SES	Klingelbour 2 (SCS-206-39)		325
SES	Kluckenbach 1 (SCS-210-54)		89
SES	Kluckenbach 2 (SCS-210-55)		89
SES	Kluckenbach 3 (SCS-210-56)		89
SES	Kluckenbach 4 (SCS-210-57)		89
SES	Kluckenbach 5 (SCS-210-58)		89
SES	Kluckenbach 6 (SCS-205-59)		89
SES	Kremer (SCS-206-48)		93
SES	Lauterbour (SCS-207-15)		1300
SES	Lichtebirchen (SCS-210-20)		291
SES	Mandelbach 1 (SCS-511-33)		236
SES	Mandelbach 2 (SCS-511-34)		236
SES	Olmesbour (SCS-206-32)		600
SES	Peiffer (SCS-207-11)		2015
SES	Perdsbour (SCS-210-22)		291
SES	Ries (SCS-210-24)		900
SES	Schmit 1 (SCS-206-49)		93
SES	Schmit 2 (SCS-206-50)		93
SES	Schwind (SCS-210-19)		291
SES	Simmern (SCS-210-18)		291
SES	Simmerschmelz (COS-210-70)		600
SES	Theisen (SCS-210-25)		900
SES	Tro'n (SCS-210-60)		89
SES	Waeschbour (SCS-207-13)		1007
SES	Waeschbour (SCS-210-21)		291
SES	Waeschbour (SCS-210-26)		900
SES	Waeschbour annexe (SCS-210-62)		900
SES	Wagner (SCS-206-46)		471

SES	Weiher (annexe 2) (SCS-210-04)		900
SES	Wiersch 1 (SCS-206-43)		471
SES	Wiersch 2 (SCS-206-44)		471
SES	Wiersch 3 (SCS-206-45)		471
SES	Wölfragronn 1 (SCS-210-16)		115
SES	Wölfragronn 2 (SCS-210-17)		115
SES	Wölfragronn 3 annexe (SCS-210-61)		115
SES	Wyckersloth (SCS-207-14)		1007
SES	Zoller (SCS-210-23)		291
Steinsel	Heisdorf (SCC-407-05)		511
Strassen	Brameschbierg 1 (SCC-206-23)		182
Strassen	Brameschbierg 2 (SCC-408-01)		46
Strassen	Tennebierg (SCC-209-02)		402
Valléedel'Ernz	Bunten (SCC-710-12)		51
Valléedel'Ernz	Savelborn 1 (SCS-710-13)		1175
VDL	B1 (SCC-405-01)		121
VDL	B10 (SCC-404-19)		7200
VDL	B10a (SCC-404-35)		24
VDL	B11 (SCC-406-03)		98
VDL	B2 (SCC-404-13)		402
VDL	B3 (SCC-404-14)		557
VDL	B4 (SCC-405-06)		26
VDL	B5 (SCC-405-07)		12
VDL	B5a (SCC-405-09)		5
VDL	B6 (SCC-404-15)		152
VDL	B7 (SCC-404-16)		70
VDL	B8 (SCC-404-17)		0
VDL	B9 (SCC-404-18)		117
VDL	C1 (SCC-404-22)		321
VDL	C10 (SCC-1-10)		321
VDL	C2 (SCC-404-36)		321
VDL	C2a (SCC-404-24)		321
VDL	C2b (SCC-404-25)		321
VDL	C2c (SCC-404-26)		321
VDL	C2d (SCC-404-27)		321
VDL	C3 (SCC-404-28)		321
VDL	C4 (SCC-404-29)		321
VDL	C5 (SCC-404-30)		321
VDL	C6 (SCC-404-31)		321
VDL	C7 (SCC-404-32)		321
VDL	C8 (SCC-404-20)		321
VDL	C9 (SCC-404-21)		321
VDL	D1 (SCC-1-54)		400
VDL	K1 (SCC-208-01)		220
VDL	K10 (SCC-407-25)	Quelle verlaufen	
VDL	K11 (SCC-407-26)		42

VDL	K12 (SCC-407-27)	3
VDL	K13 (SCC-407-28)	176
VDL	K14 (SCC-407-29)	12
VDL	K15 (SCC-407-30)	4
VDL	K16 (SCC-407-31)	10
VDL	K17 (SCC-407-17)	114
VDL	K18 (SCC-407-18)	135
VDL	K19 (SCC-407-19)	117
VDL	K2 (SCC-208-02)	191
VDL	K20 (SCC-407-20)	147
VDL	K21 (SCC-407-21)	142
VDL	K21a (SCC-508-54)	142
VDL	K22 (SCC-208-22)	564
VDL	K23 (SCC-208-08)	15
VDL	K24 (SCC-208-09)	2335
VDL	K25 (SCC-208-10)	20
VDL	K26 (SCC-208-26)	214
VDL	K27 (SCC-208-27)	51
VDL	K28 (SCC-208-31)	282
VDL	K29 (SCC-208-29)	72
VDL	K3 (SCC-208-39)	87
VDL	K30 (SCC-208-03)	43
VDL	K31 (SCC-208-30)	217
VDL	K32 (SCC-208-32)	512
VDL	K4 (SCC-208-04)	34
VDL	K5 (SCC-208-05)	61
VDL	K6 (SCC-208-06)	4
VDL	K7 (SCC-407-07)	466
VDL	K8 (SCC-407-23)	48
VDL	K9 (SCC-407-24)	9
VDL	Katzebur (SCC-1-49)	800
VDL	Pulvermühlen (SCC-1-56)	133
VDL	Siweburen +Katzebur	5070
VDL	Siweburen 1 (SCC-1-66)	1423
VDL	Siweburen 2 (SCC-1-47)	1423
VDL	Siweburen 3 (SCC-1-48)	1423
Vianden	Bettel (SCC-101-02)	107
Vianden	Fouhren (SCC-101-01)	200
Waldbillig	Härebour 1 (SCC-118-08)	1175
Waldbillig	Schiessentümpel 1 (SCC-118-01)	1175
Waldbillig	Schiessentümpel 2 (SCC-118-02)	1175
Wincrange	Troine (SCC-601-01)	260
Wincrange	Hoffelt (SCC-601-07)	357
Wincrange	Klaus Hachiville (SCC-601-05)	221
	Total	93224

Appendix 2: Volume Tanks Syndicate SIDERE

ID_RTC4Water	Common Name Communal Tanks	Volume (m3)
BET_T_S10	Roodt-s-Syre	170
BET_T_S11	Olingen	180
BET_T_S12	Berg	500
BET_T_S13	Industrial Zone-Betzdorf	150
BET_T_S14	Lampecht	270
BET_T_S15	Giegendall	196
BET_T_S16	Ind.Zone Betzdorf Process Water	236
BIW_T_S10	Boudler	500
BIW_T_S11	Wecker	600
BIW_T_S12	Breinert	25
BOU_T_S10	Bous	603
BOU_T_S11	BousScheierbierg	100
CON_T_S10	(unknown)	236
CON_T_S11	(unknown)	236
DAL_T_S10	DalheimBuchholtz	1000
DAL_T_S11	DalheimWelfrengerheed	450
FLA_T_S10	REC Beyren, Laangwiss, Gostingen	236
GRE_T_S10	Gruewereck	236
GRE_T_S11	(unknown)	59
JUN_T_S10	Junglinster	438
JUN_T_S11	Zweckekopp	903
JUN_T_S13	Godbrange	243
JUN_T_S14	Altlinster	75
JUN_T_S15	Schoenert	94
JUN_T_S16	Biergebierg	859
JUN_T_S18	Imbringen	204
JUN_T_S19	Graulinster	59
JUN_T_S21	Rodenbourg	64
JUN_T_S22	Blumenthal	30
LEN_T_S10	Lenningen	2
LEN_T_S11	Houffeld	236
MAN_T_S10	Res_Berbourg	125
MAN_T_S11	Res_Manternach	62
MAN_T_S12	Res_Muenschecker	57
MAN_T_S13	Res_Lellig	55
MOM_T_S10	Herborn	236
MOM_T_S11	Boursdorf	59
MOM_T_S12	Moersdorf	59
MOM_T_S13	Born	59
MOM_T_S14	Mompach	59
REM_T_S10	Remich	250
SCH_T_S10	Wassertürm Schrassig	236

SIA_T_S10	SIAEG	236
STA_T_S10	Stadtbredimous	57
STA_T_S11	Greveldange	62
WOR_T_S10	480m3_Wuetelbierg	480
WOR_T_S11	1000m3_Um Puddel	1000
WOR_T_S12	120m3_Ahn	120
WOR_T_S13	390m3_Froumberg	390
	Syndicate Tanks	
SID_T_S14	Steipesbierg	236
SID_T_S12	Haed	499
SID_T_S10	Schaedchen	3000
SID_T_S13	Widdebierg	3500
SID_T_S18	Kaulen	5299
SID_T_S15	Kakeschboesch	2668
SID_T_S16	Randflaesch	499
SID_T_S19	Haertchen	499
SID_T_S20	Buchholtz (DMB)	236
	Total Volume	29226

Appendix 3: Volume Tanks Syndicate DEA

ID	Name	Volume
BUL_T_S10	REC-901-04_Surré	75
BUL_T_S11	REC-901-01_Baschleiden	75
BUL_T_S12	REC-901-03_Boulaide	75
BUR_T_S10	REC-703-04_Kehmen	50
BUR_T_S11	REC-703-03_Goebelsmuhle	30
BUR_T_S12	REC-703-07_Schlindermanderscheid	56
BUR_T_S13	REC-703-08_Welscheid	50
BUR_T_S14	REC-703-05_Lipperscheid	59
BUR_T_S15	REC-703-06_Michelau	51
BUR_T_S16	REC-703-01_Bourscheid	325
BUR_T_S17	BCC-703-26_Féischterhaff	10
BUR_T_S18	BCS-703-24_Goebelsmühle BC	5
BUR_T_S19	BCS-703-12_Fléibur-Michelau BC	2
CLE_T_S10	REC-608-03_Munshausen	62
CLE_T_S11	REC-603-07_Mecher-lez-Clervaux	25
CLE_T_S12	REC-603-03_Reuler	58
CLE_T_S14	REC-606-07_Kalborn	60
CLE_T_S15	REC-606-06_Hupperdange	228
CLE_T_S16	REC-606-04_Grindhausen	75
CLE_T_S17	REC-608-02_Drauffelt	91
CLE_T_S18	REC-608-04_Siebenaler	52
CLE_T_S19	REC-603-09_Weicherdange	55
CLE_T_S20	REC-606-08_Lieler	227
CLE_T_S23	REC-603-06_Clervaux	342

CLE_T_S24	REC_606_14_Fischbach new	211
COB_T_S11	REC-501-10_Colmar Kräizfeld	542
DEA_T_S10	RES-811-20_Useldange	991
DEA_T_S11	RES-906-01_Alebesch	4502
DEA_T_S12	RES-812-11_Michelbouch	999
DEA_T_S13	RES-102-16_Wahlhausen	3259
DEA_T_S14	RES-608-05_Schwaarzenhiwwel bas	572
DEA_T_S16	RES-810-02_Ditzebierg	627
DEA_T_S17	RES-806-15_Napoléonsgaart1000	958
DEA_T_S18	RES-806-16_Rambrouch	592
DEA_T_S19	RES-609-04_Buergplaz	598
DEA_T_S20	RES-911-05_Roullingen	358
DEA_T_S21	RES-601-15_Derenbach	1257
DEA_T_S24	BCS-501-03_Biischtert	151
DEA_T_S25	RES-909-07_Bichelchen	329
DEA_T_S26	RES-608-08_Schwaarzenhiwwel tour	2197
DEA_T_S28	BCS-703-09_Bourscheid-Bürden BC	3
DEA_T_S29	REC-706-13_Burden	226
DEA_T_S30	BCS-703-13_Flebour	3
DEA_T_S31	RES-101-18_Ronnebësch	110
DEA_T_S33	RES-101-06_Niklosbierg	986
DEA_T_S35	RES-907-14_Kiemel	291
DEA_T_S36	REC-907-06_Pintsch	52
DEA_T_S37	RES-911-05_Roullingen2000	2139
DEA_T_S38	RES-911-07_Wiltz Z.I.	469
DEA_T_S39	REC-905-11_Nothum	400
DEA_T_S41	RES-905-07_Tarchamps Pillen	628
DEA_T_S42	BCS-608-09_Meisbësch BC	2
DEA_T_S43	REC-601-41_Lentzweiler	75
DEA_T_S44	RES-609-06_Troisvierges station	701
DEA_T_S45	BCS-805-09_Roodt	55
DEA_T_S46	RES-806-15_Napoléonsgaart2000	1999
ELL_T_S10	REC-805-07_Petit-Nobressart	53
ELL_T_S11	REC-805-14_Colpach-Ell	526
ELL_T_S12	REC-805-08_Roodt	45
ERP_T_S10	REC-706-12_Erpeldange-sur-Sûre	268
ERP_T_S12	BCS-706-16_Erpeldange BC	4
ESS_T_S10	REC-906-05_Merscheid	51
ESS_T_S11	REC-906-04_Heiderscheid	62
ESS_T_S12	REC-906-03_Heiderscheid CE	49
ESS_T_S13	REC-906-08_Tadler	47
ESS_T_S14	REC-906-07_Ringel	60
ESS_T_S15	REC-703-02_Dirbach	46
ESS_T_S16	REC-902-02_Esch-sur-Sûre	75
ESS_T_S17	REC-906-12_Eschdorf	51
ESS_T_S19	REC-909-04_Neunhausen	50

ESS_T_S20	BCS-906-09_Tadler-Ringel BC	3
FEU_T_S10	REC-708-06_Feulen	306
GOE_T_S10	REC-904-01_Buderscheid	75
GOE_T_S11	REC-904-06_Dahl	75
GRO_T_S10	REC-807-10_Grosbous	75
GRO_T_S11	REC-807-05_Dellen	52
HOS_T_S10	REC-604-03_Holzthum	336
HOS_T_S11	REC-709-02_Hoscheid	82
HOS_T_S12	REC-607-05_Eisenbach	72
HOS_T_S13	REC-607-03_Hosingen	94
HOS_T_S14	REC-607-10_Rodershausen	66
HOS_T_S15	REC-607-04_Neidhausen	75
HOS_T_S16	REC-607-02_Bockholtz/Hosingen	56
HOS_T_S17	REC-607-12_Hosingen ZAER	194
HOS_T_S18	BCS-607-13_Eisenbach BC	4
KII_T_S12	KII_T_S12	75
KII_T_S13	REC-907-12_Wilwerwiltz	61
KII_T_S14	REC-907-13_Lellingen	52
LAC_T_S10	REC-905-54_Tarchamps	75
LAC_T_S11	REC-905-03_Harlange Ancien	75
LAC_T_S13	REC-905-05_Liefrange	75
MER_T_S10	REC-711-06_Mertzig Butzebierg	466
PRE_T_S10	REC-803-15_Reimberg	75
PUT_T_S10	REC-102-07_Nachtmanderscheid	62
PUT_T_S11	REC-102-13_Merscheid-Putscheid	68
PUT_T_S12	REC-102-08_Putscheid	62
PUT_T_S13	REC-102-06_Bivels	57
PUT_T_S14	REC-102-09_Stolzembourg	56
PUT_T_S15	REC-102-11_Weiler	56
RAM_T_S10	REC-806-04_Bigonville	154
RAM_T_S12	REC-806-22_Wolwelange	106
RAM_T_S13	REC-806-25_Perlé	211
RAM_T_S14	REC-806-33_Holtz	96
RAM_T_S15	REC-806-17_Holtz CE	63
RAM_T_S16	REC-806-06_Folschette	151
RAM_T_S17	REC-806-14_Eschette	22
RAM_T_S18	REC-806-18_Arsdorf	287
RIP_T_S10	REC-811-22_Rippweiler	52
ROM_T_S10	REC-806-32_Rombach Schock	250
SAE_T_S10	REC-810-07_Saeul	367
SIE_T_S10	REC-713-13_Schieren Kräizbierg	133
TAN_T_S10	REC-101-15_Landscheid	75
TAN_T_S12	REC-101-13_Bastendorf Tomm 1	49
TAN_T_S14	REC-101-05_Walsdorf	58
TAN_T_S15	REC-101-25_Fouhren Houwald	75
TAN_T_S16	BCS-101-16_Fringerhof BC	4

TRO_T_S10	REC-609-01_Biwisch	75
TRO_T_S11	REC-609-02_Bellain	105
TRO_T_S12	REC-609-05_Huldange	37
TRO_T_S13	REC-609-09_Wilwerdange	100
USD_T_S10	REC-811-21_Useldange Weidfeld	332
USD_T_S11	REC-811-24_Schandel	49
USD_T_S12	REC-811-17_Everlange	150
VIA_T_S10	REC-103-02_Vianden An der Spier	287
VIA_T_S11	REC-103-11_Vianden Sanatorium	380
VIC_T_S10	REC-812-10_Vichten	75
VIC_T_S11	REC-812-14_Michelbouch CE	75
WAH_T_S10	REC-813-02_Buschrodt	47
WAH_T_S11	REC-813-05_Wahl	50
WAH_T_S12	REC-813-03_Grevels	96
WAH_T_S13	REC-813-01_Brattert	52
WAH_T_S14	BCS-813-06_Buschrodt BC	2
WEI_T_S10	REC-610-06_Breidfeld	60
WEI_T_S12	REC-610-04_Beiler	75
WEI_T_S13	REC-610-07_Binsfeld	83
WEI_T_S14	REC-610-01_Weiswampach	75
WIC_T_S10	REC-601-25_Oberwampach	75
WIC_T_S11	REC-601-26_Niederwampach	75
WIC_T_S13	REC-601-30_Sassel	75
WIC_T_S14	REC-601-22_Asselborn	75
WIC_T_S15	REC-601-24_Boxhorn	75
WIC_T_S16	REC-601-20_Troine Route	75
WIC_T_S17	REC-601-28_Hamiville	75
WIC_T_S18	REC-601-62_Wincrange	801
WIC_T_S23	REC-601-17_Doennange Pulger	75
WIC_T_S24	REC-601-21_Rumlange	75
WIC_T_S25	REC-601-31_Stockem	75
WIL_T_S10	REC-911-11_Wiltz Roullingen	75
WIL_T_S11	REC-911-04_Wiltz Erpeldange	75
WIL_T_S12	REC-911-03_Wiltz Elsaass	75
WIL_T_S13	REC-911-02_Wiltz Baessent	75
WIL_T_S14	REC-911-15_Wilttz-Leiteschbaach	75
WIL_T_S17	REC-903-04_Eschweiler	75
WIL_T_S18	REC-903-03_Selscheid	142
WIL_T_S19	REC-903-06_Knaphoscheid	75
WIN_T_S10	REC-913-02_Winseler	75
WIN_T_S11	REC-913-01_Doncols	75
WIN_T_S12	REC-913-03_Berlé	75
WIN_T_S13	REC-913-07_Pommerloch	75
	Total	39570

Appendix 4: Volume Tanks Syndicate SES

ID	Name	Volume
GAR_T_S12	Reservoir Garnich	513
KAE_T_S13	Chateau d'eau Clemency	820
DIP_T_S14	Reservoir Bertrange	4099
KAE_T_S17	Reservoir Bascharage (Schack)	3075
PET_T_S18	Reservoir Petange Hierschtbierg	2051
LEU_T_S19	Chateau d'eau Leudelange II	1436
KAE_T_S20	Chateau d'eau Bascharage (Zaemer)	1016
REC_T_S21	Reservoir Limpach	102
REC_T_S22	Chateau d'eau Reckange-Mess	683
LEU_T_S23	Reservoir Kockelscheuer	513
REC_T_S24	Chateau d'eau Ehlange (HoÃ«n)	410
LEU_T_S25	Chateau d'eau Leudelange I (HueschterterbÃ«sch)	683
KAE_T_S26	Reservoir Sanem	328
PET_T_S27	Reservoir Lamadelaine	1539
PET_T_S28	Reservoir Rodange	2460
BTT_T_S29	Reservoir Abweiler (JongebÃ«sch)	3740
DIF_T_S30	Reservoir Niedercorn (GrÃ©itebierg)	5126
ROE_T_S31	Chateau d'eau Crauthem	683
MON_T_S32	Reservoir Pontpierre (enterrÃ©)	683
MON_T_S33	Chateau d'eau Pontpierre	1229
MON_T_S34	Chateau d'eau Mondercange	1025
DIF_T_S35	Reservoir Lasauvage	683
MON_T_S36	Chateau d'eau Foetz	820
SAN_T_S37	Reservoir Ehlerange (Denneboesch)	2051
SAN_T_S38	Reservoir Loetschet	4099
BTT_T_S39	Chateau d'eau Bettembourg I (Eidels)	683
FRI_T_S40	Chateau d'eau Frisange	870
DIF_T_S41	Reservoir Obercorn (Ratten)	3075
BTT_T_S42	Chateau d'eau Noertzange	770
SCI_T_S43	Reservoir Schifflange II (Weimeschkoeppchen)	1639
SCI_T_S44	Reservoir Schifflange I (Maertesbierg)	683
ESC_T_S45	Reservoir Esch / Alzette (Gaalgebierg)	683
DUD_T_S46	Reservoir Dudelange I (Gehaansbierg)	1539
KAY_T_S47	Reservoir Kayl (Kahlebierg)	1793
DUD_T_S48	Reservoir Dudelange II (Weich)	1025
DUD_T_S49	Reservoir Dudelange III (Roudebierg)	2561
RUM_T_S50	Reservoir Rumelange (Hutbierg)	1539
DIP_T_S51	Chateau d'eau Dippach	683
SES_T_S11	Reservoir Rebierg	30750
SES_T_S12	Rieberg Hogh	2051

	Total	90210

Appendix 5: Volume Tanks Syndicate SEC

ID	Name	Volume
REC-502-07	Réservoir Laaschert	unknown
REC-502-08	Réservoir Wobierg	unknown
REC-502-14	Réservoir Laaschtert (nv.)	unknown
REC-402-14	Réservoir Moutfort/Milbech	1000
REC-402-15	Réservoir Medingen	220
REC-402-16	Réservoir Contern (CE)	500
REC-402-17	Réservoir Z.I. Weiergewan (CE)	800
REC-403-14	Réservoir Espen (h.s.)	unknown
REC-403-16	Réservoir St. Hubert (h.s.)	140
REC-403-18	Réservoir Howald	1
REC-403-19	Réservoir Howald (CE)	unknown
REC-403-20	Réservoir Fentange (h.s.)	350
REC-403-36	Réservoir Espen	2500
REC-208-40	Réservoir Kopstal 1 (Lein)	unknown
REC-208-41	Réservoir Kopstal 2 (Buchenbusch)	1
REC-208-43	Réservoir Bridel 2 (Bridel Stuff)	500
REC-208-50	Réservoir Montée de Bridel	unknown
REC-408-11	Réservoir Bridel	unknown
REC-408-42	Réservoir Bridel (CE)	100
REC-408-43	Nouveau bassin Bridel	800
RES-408-11	Réservoir SEBES	800
REC-507-16	Réservoir Lintgen	1000
REC-507-18	Réservoir Prettingen (Im Bingel)	500
REC-507-30	Réservoir Beim Dorf (h.s.)	unknown
REC-507-36	Réservoir Schwunnendall	unknown
REC-508-11	Réservoir Kasselt	180
REC-508-21	Réservoir Blaschette	250
REC-508-33	Réservoir op der Hoehl (h.s.)	unknown
REC-508-34	Réservoir Bofferdange (Dauschkaul)	500
REC-508-35	Réservoir Hunsdorf (h.s.)	unknown
REC-508-38	Réservoir Belle vue	1000
REC-508-46	Réservoir Taellchen	80
REC-509-66	Réservoir Mierscherbierg (Z.I.)	2000
REC-509-67	Réservoir Krounebierg	150
REC-509-69	Réservoir Schoenfels	59
REC-509-81	Réservoir Beringen (Wenzel)	58
REC-509-86	Réservoir Rollingen (Boussert)	120
REC-404-07	Nouveau réservoir Senningerberg	1000
REC-404-48	Réservoir Ernster	200
REC-404-50	Réservoir Senningerberg (CE)	350
REC-404-54	Réservoir Niederanven	unknown
REC-404-55	Réservoir Hostert-Binnewee	380
REC-404-56	Réservoir Oberanven	175

REC-404-62	Réservoir Senningen	350
REC-404-64	Réservoir Binnewee (SPC)	100
REC-407-14	Réservoir Heisdorf 2	500
REC-407-16	Réservoir Heisdorf 1	25
REC-407-36	Réservoir Rellent	2000
REC-407-37	Réservoir Goergen	180
REC-408-02	Réservoir Stroosserbësch 2 (nouv.)	2
REC-408-03	Réservoir Stroosserbësch 1 (anc.)	450
REC-409-24	Réservoir Helmsange	1000
REC-409-25	Réservoir Bereldange	900
	Total	21321

Appendix 6: Volume Tanks Syndicate SESE

LuxRef	Name	Volume
REC-131-03	Réservoir Elvange (CE)	150
REC-131-04	Réservoir Emerange	25
REC-135-12	Réservoir Im Brouch (h.s.)	unknown
REC-135-15	Réservoir Strombierg (Schengen)	500
REC-135-17	Réservoir Remerschen	500
REC-139-02	Réservoir Bech-Kleinmacher	100
REC-139-03	Réservoir Wellenstein	400
REC-139-05	Réservoir Schwebsange	80
REC-139-08	Réservoir Schwebsange (nv.)	unknown
REC-131-05	Réservoir Ellange	unknown
REC-134-12	Réservoir Olbricht	200
REC-134-13	Réservoir Stengenerbësch	500
REC-134-14	Réservoir Wouerbësch	1000
REC-134-23	Réservoir Wouerbësch (HP)	unknown
REC-134-24	Réservoir Wouerbësch (BP)	unknown
	Total	3455

Appendix 7: Volume Tanks Communes not in a Syndicate

ID	Exploitant	Name	Volume
REC-111-22	AC BEAUFORT	Réservoir Fléibierg	Unknown
REC-111-23	AC BEAUFORT	Réservoir Supp (h.s.)	Unknown
REC-111-24	AC BEAUFORT	Réservoir Montée Hondsbierg	300
REC-111-28	AC BEAUFORT	Réservoir Op der Heed (anc.)	200
REC-111-30	AC BEAUFORT	Réservoir Chemin des sources	5
REC-111-31	AC BEAUFORT	Réservoir Grundhof	10
REC-111-32	AC BEAUFORT	Réservoir Virstadt	200
REC-111-35	AC BEAUFORT	Réservoir Op der Heed (nv.)	1200
REC-112-05	AC BECH	Réservoir Alter Speicher	Unknown

REC-112-07	AC BECH	Réservoir Graulinster	Unknown
REC-112-18	AC BECH	Réservoir Rippig	50
REC-112-19	AC BECH	Réservoir Altrier (CE)	42
REC-112-20	AC BECH	Réservoir Grassebierg	30
REC-112-24	AC BECH	Réservoir Leckebierg	50
REC-112-25	AC BECH	Réservoir Hemstal	250
REC-112-39	AC BECH	Réservoir Schanz (CE)	500
REC-112-44	AC BECH	Réservoir Geyershof	45
REC-125-14	AC BECH	Réservoir Graulinster (démoli)	100
REC-802-15	AC BECKERICH	Réservoir Mëllechbur 1	250
REC-802-16	AC BECKERICH	Réservoir Hovelange	500
REC-802-17	AC BECKERICH	Réservoir Raatzknapp	1
REC-802-19	AC BECKERICH	Réservoir Noerdange	Unknown
REC-802-20	AC BECKERICH	Réservoir Schweich 1	Unknown
REC-802-21	AC BECKERICH	Réservoir Schweich 2	Unknown
REC-802-23	AC BECKERICH	Réservoir Oberpallen	Unknown
REC-113-15	AC BERDORF	Réservoir Clocher (CE)	133
REC-113-16	AC BERDORF	Réservoir Huuscht	45
REC-113-19	AC BERDORF	Réservoir Aquatower (CE)	500
REC-113-21	AC BERDORF	Réservoir Bollendorf	80
REC-113-22	AC BERDORF	Réservoir Weilerbaach	25
REC-113-23	AC BERDORF	Réservoir Meelerbur	300
REC-113-24	AC BERDORF	Réservoir op der Knupp	Unknown
REC-702-10	AC BETTENDORF	Réservoir Gilsdorf	250
REC-702-11	AC BETTENDORF	Réservoir Broderbour	60
REC-702-12	AC BETTENDORF	Réservoir Bettendorf	500
REC-702-13	AC BETTENDORF	Réservoir Moestroff	120
REC-702-15	AC BETTENDORF	Réservoir Hirtzenhaff	30
REC-114-05	AC CONSDORF	Réservoir Wolper	2
REC-114-05-A	AC CONSDORF	Réservoir Wolper (venue A)	Unknown
REC-114-05-B	AC CONSDORF	Réservoir Wolper (venue B)	Unknown
REC-114-05-C	AC CONSDORF	Réservoir Wolper (venue C)	Unknown
REC-114-05-D	AC CONSDORF	Réservoir Wolper (venue D)	Unknown
REC-114-05-E	AC CONSDORF	Réservoir Wolper (venue E)	Unknown
REC-703-18	AC DIEKIRCH	Réservoir Krieschent	30
REC-704-35	AC DIEKIRCH	Réservoir Fridhaff	600
REC-704-38	AC DIEKIRCH	Réservoir Diekirch	2400
REC-115-38	AC ECHTERNACH	Réservoir Thoull 1	1450
REC-115-40	AC ECHTERNACH	Réservoir Felsbuch (h.s.)	Unknown
REC-115-58	AC ECHTERNACH	Réservoir Felsbuch (nv.)	1000
REC-707-12	AC ETTELBRUCK	Réservoir Kneppchen 1	900
REC-707-15	AC ETTELBRUCK	Réservoir Kneppchen 2	20

REC-707-17	AC ETTELBRUCK	Réservoir Lopert 1	500
REC-707-18	AC ETTELBRUCK	Réservoir Lopert 2	40
REC-707-20	AC ETTELBRUCK	Réservoir Haardt	1000
REC-707-24	AC ETTELBRUCK	Réservoir Camping	50
REC-707-29	AC ETTELBRUCK	Réservoir Kneppchen 3	500
REC-707-30	AC ETTELBRUCK	Réservoir Nuck	500
REC-504-05	AC FISCHBACH	Réservoir Fischbach	Unknown
REC-504-06	AC FISCHBACH	Réservoir Schoos	Unknown
REC-505-07	AC HEFFINGEN	Réservoir Heffingen (anc.)	Unknown
REC-505-10	AC HEFFINGEN	Réservoir Heffingen	Unknown
REC-505-12	AC HEFFINGEN	Réservoir Soup	70
REC-506-08	AC LAROCHETTE	Réservoir Delsebett	500
REC-506-09	AC LAROCHETTE	Réservoir rue de Mersch	120
REC-506-13	AC LAROCHETTE	Réservoir Montee Ernzen	500
REC-510-10	AC NOMMERN	Réservoir Glabach/Peffeschbierg	500
REC-510-11	AC NOMMERN	Réservoir Äechelbur	20
REC-510-15	AC NOMMERN	Réservoir Zäregrëndchen (h.s.)	Unknown
REC-809-15	AC REDANGE-SUR-ATTERT	Réservoir Krëschtebierg	1000
REC-809-16	AC REDANGE-SUR-ATTERT	Réservoir Redange	200
REC-809-17	AC REDANGE-SUR-ATTERT	Réservoir Niederpallen (Ditzebierg)	60
REC-809-18	AC REDANGE-SUR-ATTERT	Réservoir Lannenerbierg (abandonné)	50
REC-809-19	AC REDANGE-SUR-ATTERT	Réservoir Nagem	50
REC-809-20	AC REDANGE-SUR-ATTERT	Réservoir Reichlange	50
REC-809-26	AC REDANGE-SUR-ATTERT	Réservoir Lannenerbierg	250
REC-712-16	AC REISDORF	Réservoir Bigelbach	100
REC-712-17	AC REISDORF	Réservoir Reisdorf	500
REC-712-18	AC REISDORF	Réservoir Hoesdorf	100
REC-712-19	AC REISDORF	Réservoir Wallendorf	50
REC-118-22	AC WALDBILLIG	Réservoir Mullerthal	50
REC-118-23	AC WALDBILLIG	Réservoir Haller	300
REC-118-24	AC WALDBILLIG	Réservoir Waldbillig	50
REC-118-25	AC WALDBILLIG	Réservoir Härebur	50
REC-410-04	AC WEILER-LA-TOUR	Réservoir Syren	90
REC-410-05	AC WEILER-LA-TOUR	Réservoir Hassel	120
REC-410-08	AC WEILER-LA-TOUR	Réservoir Op der Haardt	800