A water resources study for Sark

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Version 4.54

Introduction

This study was commissioned in the spring of 2024 with the aim of making a rapid assessment of the available water resources of Sark. The work was of short duration – a 3 day visit to Sark, followed by 4 days of data analysis, water balance calculations and report writing.

The purpose of the report is to set the scene for how much water is available on the island and whether the proposed new housing and increased resident population would exceed the available water. The issue of possible climatic change is also explored.

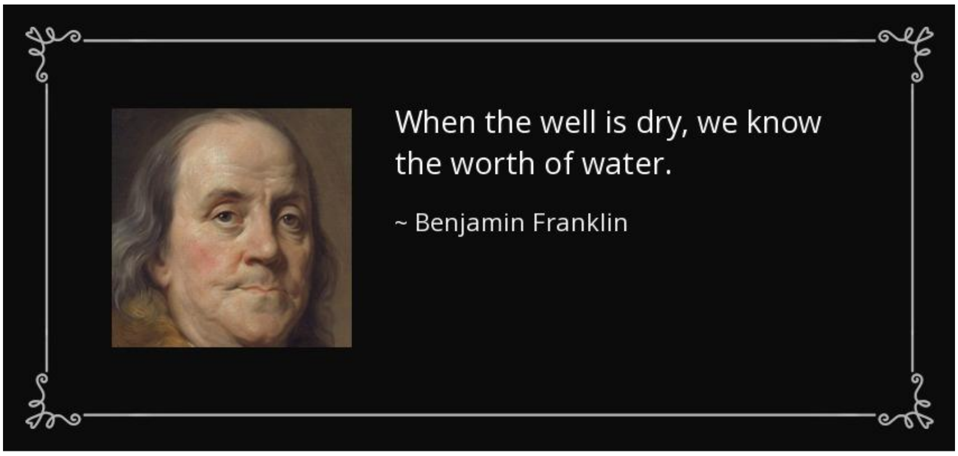
A series of Key Findings are presented, together with Recommendations for action.

Acknowledgements

We would like to thank the residents of Sark who were happy to assist in supplying information and background knowledge. Also, thanks to Peter Cole who helped to commission this report. Thanks must go to members of La Société Sercquaise who have collected climate data over many years and have provided mapping and population datasets.

A preliminary thought :-

As the vast majority of water resources on the island of Sark is from groundwater, we would like to remind readers of a well known quotation attributed to Benjamin Franklin :



https://www.azquotes.com/quote/358055

Executive Summary

We summarise the outcome of the water resources assessment for Sark as a set of Key Findings. Details of how the findings were obtained are in the report and Appendix A.

Key Finding 1 : Average annual rainfall is 825mm and it supplies 134mm/year to groundwater recharge at present.

Key Finding 2 : In densely populated parts of the island, groundwater extraction is estimated to be 64 mm/year.

Key Finding 3: Over the last 50 years, water extraction could be greater than groundwater recharge once every 5 years.

Key Finding 4: In the last 50 years, there have not yet been any "back to back" years of below average recharge (i.e. several years in a row of relative drought). As a result the groundwater has usually been replenished in the winter following a dry summer.

Key Finding 5: If the population rose to 700 people, the increased demands for water combined with the impacts of climate change may place impossible demands on the available groundwater. In the short term (10-15 years), drought frequency is likely to rise from 1 in 5 years to 1 in 3 years. By 2100 water extraction could exceed groundwater recharge every year.

This rapid assessment could not determine how quickly the groundwater recovers after a drought summer. There is an opportunity to gain a better understanding of the impact of dry years by re-instating the groundwater monitoring system and to gain additional "inside information" on how Sark coped with the severe drought of 1976.

Recommendation 1 : It is recommended that local knowledge is used to determine how the Island coped with specific severe drought years such as 1976.

Recommendation 2 : It is strongly recommended that the Island re-introduces a coordinated system to make regular measurements of ground water levels in observation wells and boreholes.

Recommendation 3 : An assessment should be made of the most productive boreholes, using local knowledge and drilling companies.

If new housing developments are to take place, they should incorporate water saving technologies and contribute a Water Development Fee to fund the groundwater monitoring programme

Recommendation 4 : Require that all new builds and major housing renovations incorporate water saving technologies to reduce water consumption.

Recommendation 5 : Introduce a "Water Development Fee" for all new builds and major housing renovations.

The groundwater of Sark is potentially at risk from a series of contamination sources. To reduce these risks, the general public and companies should be made aware of these risks.

Recommendation 6 : Make the greater population more aware of possible water contamination risks. It will hopefully help to identify contamination problems before they become an emergency.

Recommendation 7 : Create a coordinated storage system for all water quality test reports. This will provide information on the overall health of the water quality and help to identify any developing problems.

Background to water resources on Sark

Sark is an island of 5.45 sq km with most of its land surface being an undulating plateau about 90m above sea level. The soils on the plateau are thin, and the geology consists of dense volcanic rocks mainly gniess and igneous types. There is limited surface run off from small ephemeral streams. The bulk of available water used on the island is from groundwater. There are no major aquifers (i.e. porous rock systems such as sandstone) and water is held in cracks and fissures in the volcanic rocks.

Groundwater is recharged by rainfall only. There is no connection between the groundwater systems on Sark to any other island or the mainland of France.

The permanent resident population of Sark is 562 (2022 census). Water supply is via privately operated boreholes. These are typically less than 40m deep but there are a few examples of deeper wells (40-60m) and a small number are more than 90m deep, which places the base of the borehole close to sea level.

Additionally, some properties capture rainfall from roof surfaces and store this water in tanks on their property. A small number of shallow wells also exist.

However there are now concerns that

a) additional housing development may place an additional strain on the existing water supplies. The proposition by the Seigneur and Sven Lorenz is for the resident population of Sark to rise from 562 to between 800 and 1000 (an increase of 40% - 80%).

b) the onset of climate change may affect the amount of water getting into the groundwater system of Sark. Future climate scenarios by the UK Climate Projections / Met Office suggest higher temperatures which may cause more evapotranspiration loss, whilst projections of rainfall are less certain.

Assessing the available water resources of Sark

The usual approach to assessing available water resources is to carry out a water balance calculation. This is achieved using a spreadsheet model.

Once the water balance has been calculated, we have a measure of how much water gets into the groundwater system of Sark each year. The water balance calculation should be carried out over a relatively long time period so that it includes known problem years such as very wet or very dry years.

The average water balance can then be compared against how much water is extracted from wells and boreholes - currently and under different future scenarios. As there are no formal records of how much water is pumped, the volume of extracted water will have to be estimated based on typical water consumption patterns.

The water balance calculation involves making some assumptions but as long as these assumptions are clearly spelled out, it is possible to use gain an understanding of how much water may be available under differing scenarios (see Appendix A for detailed calculations). Ideally, the model could be compared with the measured changes in water levels in observation boreholes (wells or boreholes that are not being pumped) to see if any trends are evident and if problems are already developing.

Note that this assessment will not include an analysis of the quality of the groundwater extracted. Current water quality testing is carried out in the hospitality industry once-a-year, testing for bacteria. For domestic residents it appears that it is a matter of choice if they test their water or not. This report will discuss the issue of contamination of groundwater by sea water and other water pollution risks such as contamination of water by fuel oils, waste products and agro-industrial chemicals. It is known that there are possible contamination issues due to heavy metals in the geology, but this analysis is beyond the scope of this brief report. We include some brief recommendations on how water quality tests should be recorded centrally to help identify developing problems.

The Water Balance Model

This model is based in part on these earlier publications, but with significant updates. It is recommended that these should be used as background reading as they include useful descriptions.

1. Cheney, C (2006) “A preliminary hydrogeological study of the Island of Sark”. Groundwater Systems and Water Quality Programme Internal Report CR/04/237C British Geological Society. (PDF supplied by La Société Sercquaise)

2. Robins N S, Griffiths K J, Merrin P D and Darling W G (2000) “Reconnaissance Hydrogeological Survey of Guernsey” British Geological Survey Report WD/00/07 https://nora.nerc.ac.uk/id/eprint/12706/1/WD00007.pdf

3. Robins N S & Smedley P L (1998). “The Jersey groundwater study.” British Geological Survey Research Report RR/98/5. https://nora.nerc.ac.uk/id/eprint/3650/1/RR98005.pdf

4. Davis A.C. (1998) “Water Budget Analysis – Sark”. Postgraduate Dissertation, Oxford Brookes University. (Scanned copy made available by La Société Sercquaise) *Note: the water balance calculation results in Davis contain a number of errors and although the overall approach is logical, the detailed methodology contains a number of flaws that make the numerical results questionable.*

Method Used

The water balance equation compares what water goes into the system and where it goes out, leaving a water balance, which is the water that can be pumped out for our use. This is much like a current bank account where you have incoming deposits and outgoing payments, leaving the bank balance, which is money available to be used.

Because water exists in various forms (rain, streamflow, groundwater flow, evaporation, soil moisture, water pumped), it is necessary to convert these volumes of water into the same units for consistent accounting. In this case the units of water will be in mm depth of water, the same units as rainfall.

The basic equation used, and the different components of the water system (numbered 1 to 9) are shown below :

WATER INPUTS	minus	WATER OUTPUTS	leaves	WATER BALANCE
1 rainfall 2 imported water		3 evaporation 4 plant transpiration 5 stream and surface flow to the sea 6 groundwater flow into the sea 7 water pumped from boreholes 8 water taken from wells		9 groundwater stored (seen as changes in levels in observation boreholes)

We have been able to construct a working water balance model between 1969 and 2023. We were missing some key climate data before 1969 which meant that accurate evapotranspiration calculations could not be done. Details of the calculations used and the assumptions made are shown in Appendix A.

From these calculations we have obtained the long term average values (1969-2023), for variables 1-8, which are shown in **red** text.

1 **Rainfall : 825mm/year**. We have good annual, monthly and daily measurements form the sites at Point Robert and Far Horizons.

2 **Imported Water** : **0 mm/year**. This is assumed to be zero as the cost of transporting water is high.

3 and 4 - Evaporation and transpiration, usually combined into “Evapotranspiration” and calculated using formula such as the Penman or Penman Monteith equation. **Actual Evapotranspiration : 429 mm/year**

5 **Stream and surface flow into the sea** : **255mm/year.** There are no direct measurements of flow so this was estimated.

6 **Groundwater flow out to sea : less than 50mm/year.** This was estimated using assumed values of the hydraulic conductivity of the rocks and estimates of flow from springs around the coastline.

7 and 8 - **Water from boreholes and wells : between 12 and 64 mm/year** (depending on well location). There are no direct measurements but human water demands can be estimated from typical consumption rates, population size and the density of borehole groupings on the island.

8 **Groundwater stored** - Changes in storage are demonstrated by the changes in water levels in the observation wells and boreholes which will be obtained by measuring water levels in key boreholes.

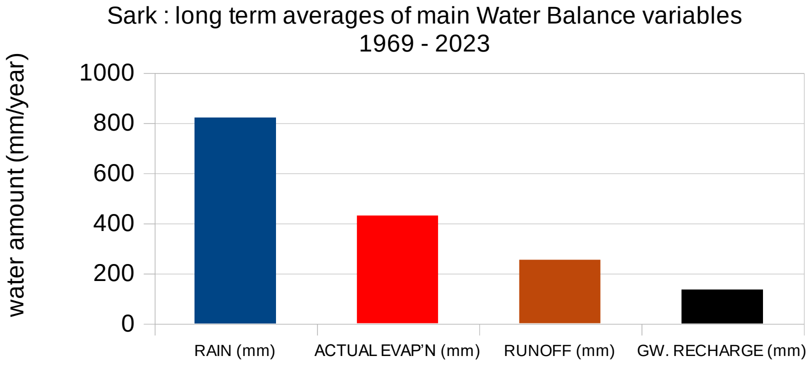
Placing these numbers into the water balance equation, we get

	825 + 0	=	429 + 255 + 50 + 64	(years 1969-2023)
or	825mm/year inputs	=	798 mm/year outputs	

The balance is not perfect but the calculated outflows are within 3% of the rainfall inputs. Considering that several of the output variables had to be estimated, the agreement between inputs and outputs is very close. We can use this water balance to calculate how much rainfall gets into the groundwater system each year and then compare it against how much is pumped out and used by us.

In an average year between 1969 and 2023, of the 825mm/year of rainfall, we lose 429mm from actual evapotranspiration and 255mm from surface runoff. The remaining 141mm seeps in to the soil and groundwater system.

We estimate that deep groundwater flow through the rocks into the sea is very small (5-10mm/year, say 7mm), so we effectively receive 141-7 = 134mm/year recharge into the groundwater system that is available for use. If no water were pumped out, the water table would rise and increase horizontal flow through the surface rocks and soils towards the coast. This would in turn increase the spring flows around the coastline. A medium level of pumping would lower the water levels in the groundwater and reduce the spring flows. A high level of groundwater pumping would deplete the groundwater store, further reducing the spring and stream flows and dewatering the cracks and fissures that hold the groundwater until no more water can be easily extracted.



Groundwater Recharge – average year

Key Finding 1 : Average annual rainfall is 825mm and it supplies 134mm/year to groundwater recharge at present.

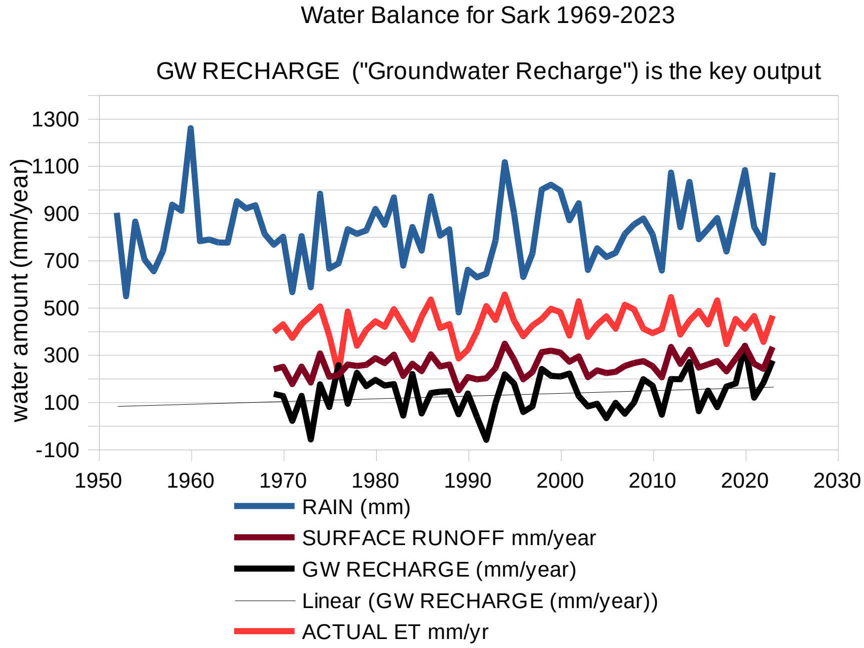
Of this 134mm/year, some of this water is pumped up from boreholes and wells (the amount varies in differing parts of the island). The rest drains laterally out of the rocks and into the sea.

In a similar study for the water resources of Guernsey by the British Geological Survey (Robins et. al., 2000), their estimate of ground water recharge was 128mm/year. This is very close to the value we obtained in this study.

Changes in the water balance over time

We repeated the water balance calculations for each year 1969-2023 to detect if there are any year to year variation or long term changes in groundwater recharge. The plot below shows that there is a slight trend towards increased groundwater recharge, probably due to the recent series of very wet winters.

However it must be noted that there are two years when groundwater recharge was below zero (in the 1970's and in the 1990's).



Estimates of water consumption

There are no formal records of how much water is extracted by individual households, hotels and businesses. Therefore water consumption must be estimated. In the UK the typical domestic consumption is around 150 litres per person per day. It is likely that water conscious residents on Sark consume less than this but there is no data to back this up.

In her 1998 thesis, Anita Davis assumed a consumption of 110-157 litres per person per day and she went to to make a detailed assessment of water consumption for hotels, guest houses, farm animals etc., together with likely water use by day trippers and campers. The overall consumption estimate was 64020933 litres per year.

When converted to the same units of rainfall (by spreading this volume over the land area of Sark), the water consumption is 12mm/year, which is much lower than the average annual ground water recharge of 134mm/year. However this does not take into account the varying density of housing (and their boreholes) and it refers to an average year.

If the boreholes used to extract water were evenly spread over the island (and the geology was uniform), then the extraction rate is 12mm/year (in units of rainfall). However, if the boreholes are grouped in the central 1 square kilometre of the island, the extraction rate is significantly higher (64mm/year) – see Appendix A. This would mean that extraction could exceed groundwater recharge in many more years, especially in areas where boreholes are close together.

Key Finding 2 : In densely populated parts of the island, groundwater extraction is estimated to be 64 mm/year.

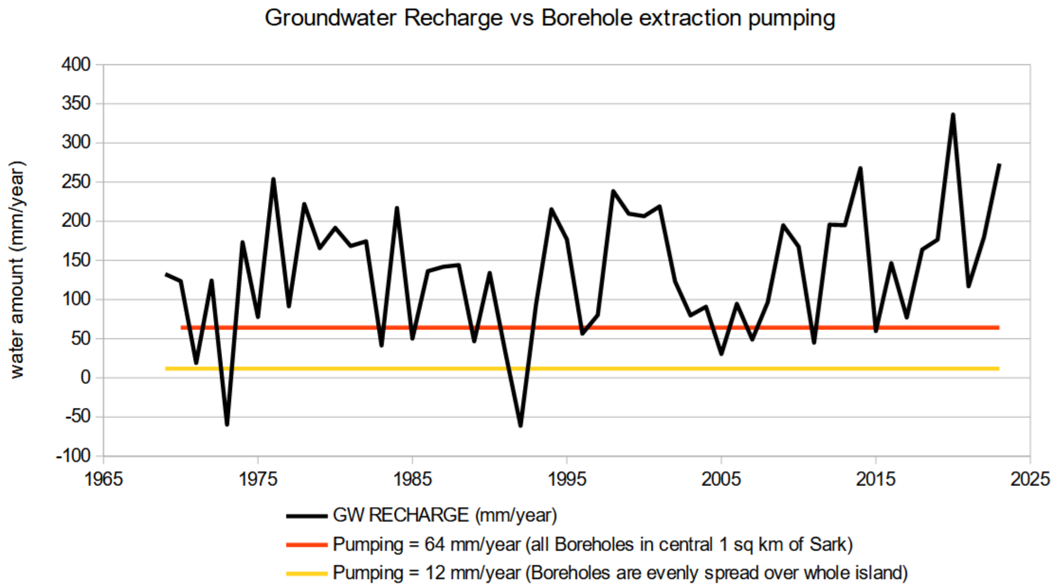
Dry years and pumping intensity

We know that there were notable drought events in 1974-6 and in the early 1990's. In 1976, the water levels in typical boreholes fell by around 5m as a result of consecutive years of below average recharge. It is entirely possible that these kinds of events could happen again, although recent years (2020-2024) have had relatively high rainfall.

From the plot below, in the 54 years of calculations, there were 11 years when the estimate of groundwater pumping (64mm/year) exceeded the groundwater recharge, so we can estimate the current state of the groundwater resource as :

Key Finding 3: Over the last 50 years, water extraction could be greater than groundwater recharge once every 5 years.

Key Finding 4: In the last 50 years, there have not yet been any "back to back" years of below average recharge (i.e. several years in a row of relative drought). As a result the groundwater has usually been replenished in the winter following a dry summer.

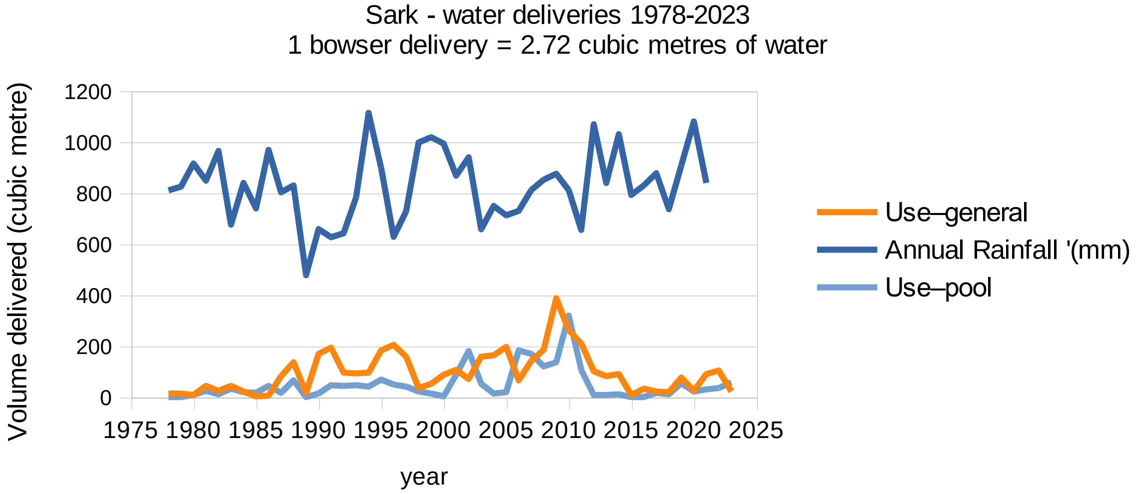


Responses to water shortages

Known drought years were recorded in 1976, 1989/91 and 1996. These prompted drilling additional boreholes. Dry years (with annual rainfall less than 670mm) have also been recorded in 2003 and 2011.

There is a system of delivering bowser loads of fresh water (2.7m^3/load) from a productive borehole in the centre of the island. This supplies water to properties when required for roof water collection tanks to be filled if they run dry, or for other purposes such as construction or filling a swimming pool (Kevin Adams, pers. comm. 2024).

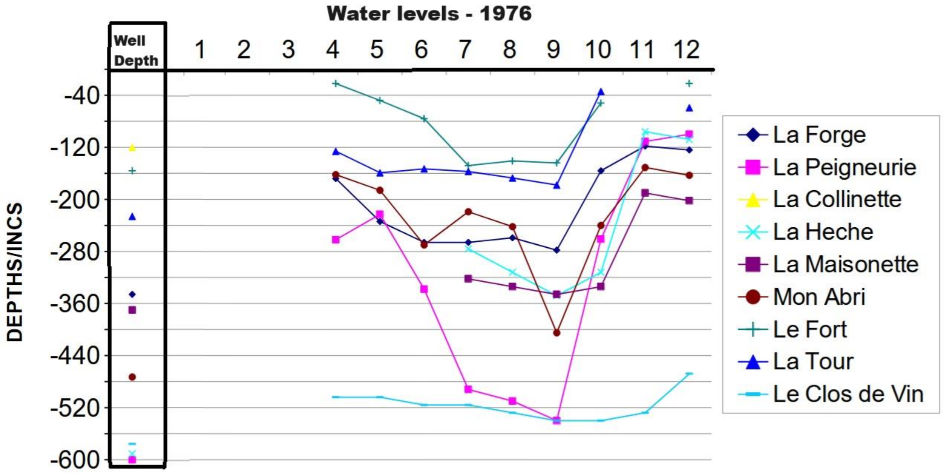
In discussions with staff delivering the bowsers of water, there have been no true water crisis years to their knowledge in the past 40 years. It is known that problems did develop on Little Sark in 1976, when water for cattle was delivered twice a day from La Moinerie Farm.



Records of deliveries between 1978 and 2023 suggest that the average annual water bowser delivery volume is 145m^3 and the highest year was 2011 with 580m^3 delivered. However there is no direct correlation with the pattern of annual rainfall evident. There is a possible increase in bowser deliveries 2005-2010 when rainfall was slightly below average, but this is not a confirmed cause and effect relationship.

Recommendation 1 : It is recommended that local knowledge is used to determine how the island coped with specific severe drought years such as 1976.

Because boreholes are owned and operated by individuals, there is no simple way of knowing how much water is abstracted from the groundwater. Nor is there a control on sinking new boreholes. Groundwater level measurements have been taken in a series of wells between 1994 and 2003 (Cheney). These suggest that there was no clear long term trend in groundwater levels but as this is a short record, longer term changes and severe drought periods may not have been detected. A check of the 1976 water levels showed that typical water levels fell by 200 inches (5m) and some boreholes were effectively dry.



Adapted from a spreadsheet supplied by La Société Sercquaise

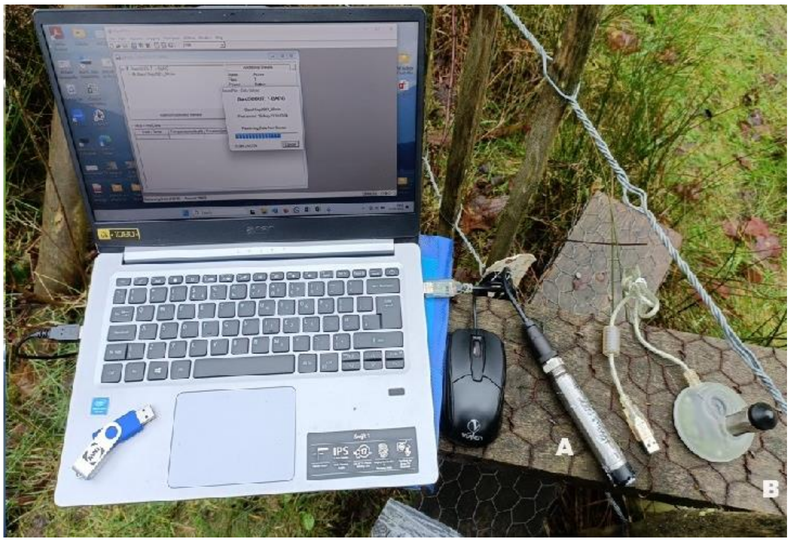
It is understood that that regular monitoring of groundwater levels ended sometime after 2003.

Recommendation 2. It is strongly recommended that the Island re-introduces a coordinated system to make regular measurements of ground water levels in observation wells and boreholes.

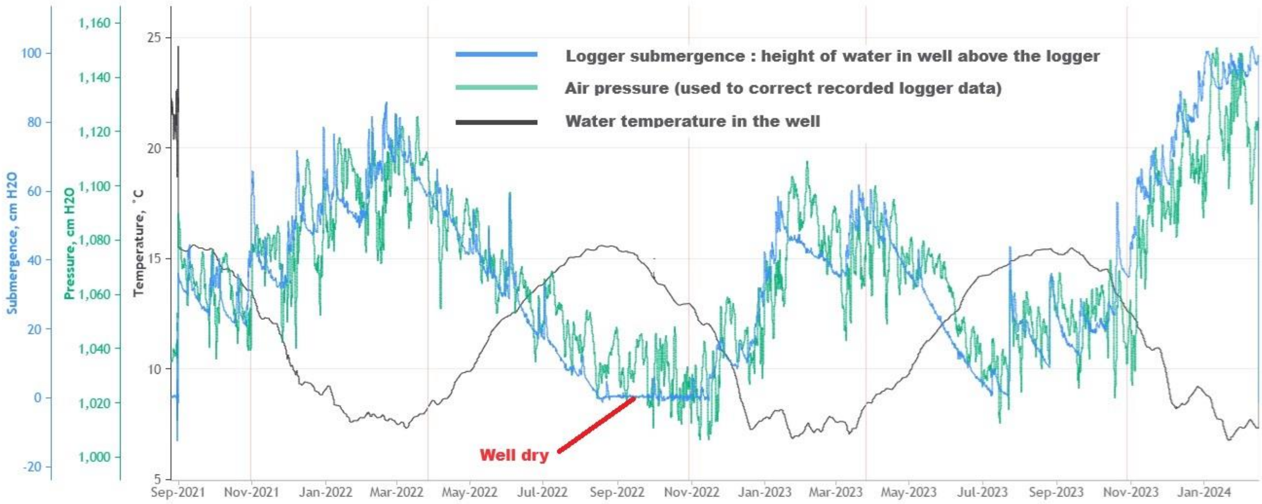
These observation sites should be in wells and boreholes that are never pumped for water supply. In the first instance, there should be a manual water level reading made on the first day of each month at 5-10 representative sites. This could be coordinated by La Société Sercquaise. By involving a network of interested individuals, this will create a "Citizen Science" project (possibly involving local school children/ teachers). The monthly measurements should be posted on a web page alongside monthly rainfall to inform the wider population of the current state of the available groundwater resource.

Ideally a system of 5 automatic water level recorders should be installed using data loggers (such as a "LevelScout" pressure recorder, together with a barometric compensation "BaroScout" https://www.vanwalt.com/water-level/ or Mini Divers https://www.vanessen.com/images/PDFs/Mini-Diver_Card_EN_Metric.pdf).

A MiniDIVER being lowered into an observation well



*Data collection from a LevelSCOUT (**A**) and a MiniDIVER (**B**)*



Typical data readout from a data logger. The pressure recorded by the sensor has to be corrected for changes in atmospheric pressure. Here we see that the well dried out between September and November 2022.

An estimated one off cost for these types of data loggers would be £600 per logger, plus about £30/year for routine logger maintenance and servicing (eg battery replacement every 3-4 years).

Key water sources

The use of the water bowsers to deliver water to properties that are short of water indicates that the central source is more productive than other wells and boreholes on the island. This is probably due to the pattern of fissures and fractures in the geology at the pumping site. A more detailed study of the capacity of this well/borehole should be made.

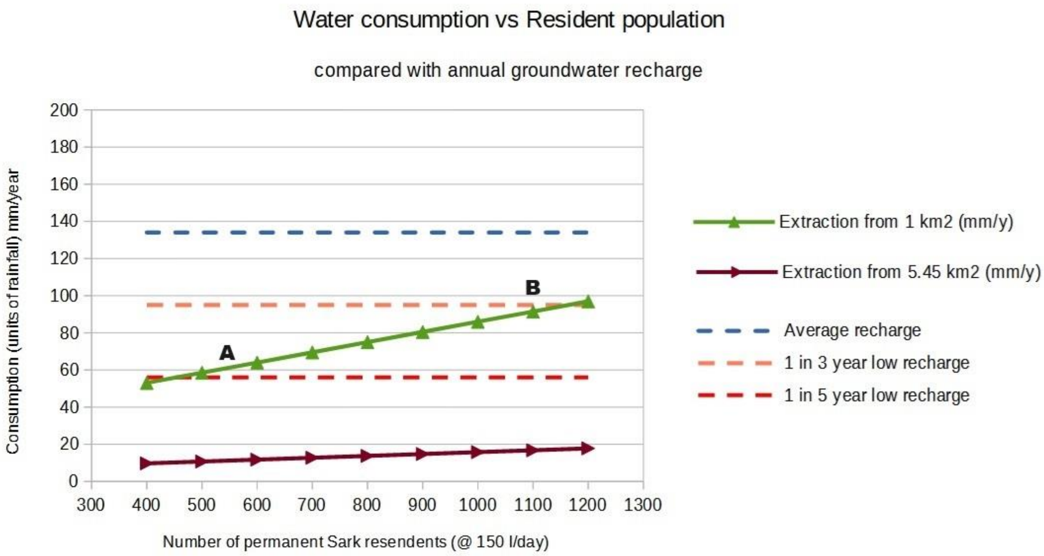
Recommendation 3 : An assessment should be made of the most productive boreholes, using local knowledge and drilling companies.

Future Changes 1: Increases in the resident population

If the permanent population of Sark were to increase, we need to estimate future demands for water. In the following scenarios, we assume that permanent residents consume 150 litres/person/day and all other water uses (tourists, animals, day trippers etc) remain the same as reported by Davis (1998).

SCENARIO 1 : In the graph below we are at point "**A**" with a resident population of about 562 (2022 census). As described above, the water consumption can be assumed to be extracted from either the whole island (brown line labelled "Extraction from 5.45km^2") or more realistically from a concentrated group of boreholes in the central 1 square kilometre of the island (green line labelled "Extraction from 1km^2").

Considering the 1 square kilometre case, the present day extraction of 64mm/year is about half of the average groundwater recharge of 134mm/year. However it is close to the 1 in 5 year low groundwater recharge (56mm/year). In other words, we can expect groundwater pumping to exceed groundwater recharge about once every 5 years or so (the exact timings are uncertain and they will not be evenly spaced apart). Note that this ignores climate change and population increases and that it assumes that all pumping is taken from the central part of the island - i.e. ignoring more distant properties and Little Sark.



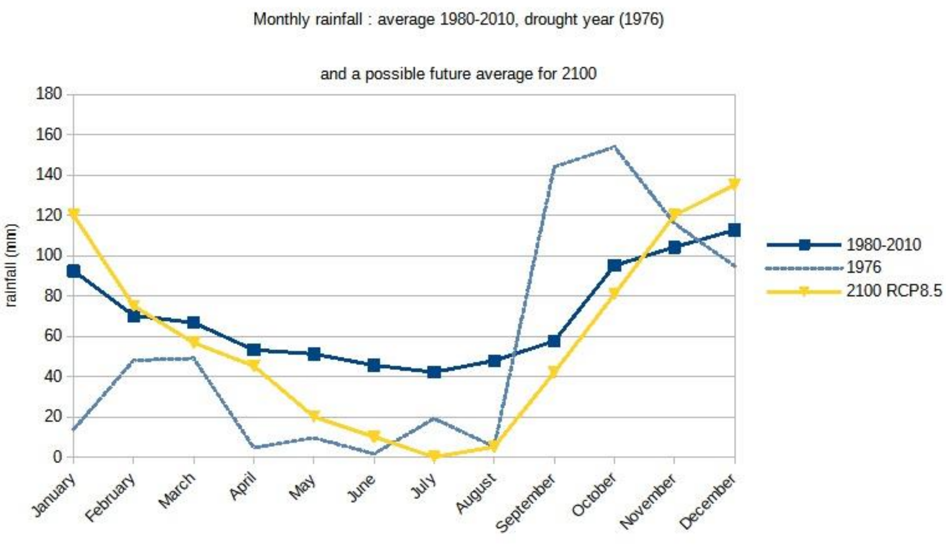
In a more extreme scenario, where the population of the island were to double to 1100 (and again most groundwater extraction is in the central 1 square kilometre), then demands would exceed groundwater recharge on average once every 3 years (point "**B**"). At this stage there is a much stronger possibility of sequences of "back to back" drought, meaning that there may not be enough groundwater recharge in winter for the groundwater levels in boreholes to recover.

Future Changes 2: Climate Change projections

Projections of climate change for the UK and north west Europe are for longer, hotter and drier summers, combined with wetter winters. It is not known if the increased winter rainfall will balance out the dry summers, but extended hot dry periods at times of high tourism is likely to put additional pressures on the available water resources when they are least available.

The UK Climate Impact Programme (https://www.ukcip.org.uk/) suggests that under a high carbon dioxide emissions scenario (RCP8.5) by the year 2100 the Channel Islands annual rainfall will remain much the same, but with an uncertainty of plus or minus 15%.

The graph below shows current average month rainfall and a low rainfall future climate scenario for 2100, together with the rain pattern that occurred in the great drought of 1976. In this admittedly pessimistic (but entirely possible) scenario, the *average* summer in 2100 could resemble the extreme drought year of 1976.



1980-2010 : https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gby1hzr7h
1976 : La Société Sercquaise
2100 : generated RCP8.5 scenario with low rainfall outcome (-15%).

Uncertainties in future climate projections

The projections of future rainfall are not certain. However there is a distinct possibility of wetter winters and drier summers, and under this scenario it is possible that groundwater demand will increase while the groundwater recharge may well decrease. This is because :

a) groundwater will be depleted by the additional water demands of a hotter, drier summer

b) the winter rainfall will be more intense and a higher proportion of the annual rainfall will flow off the island in the streams. This will reduce the opportunity for groundwater recharge to occur.

Whilst these projections contain a high degree of uncertainty, there is a definite *possibility* that Sark may experience extended hot dry summers which might place unmanageable stresses on the groundwater resource. A responsible approach to take is to be be prepared for this possible outcome.

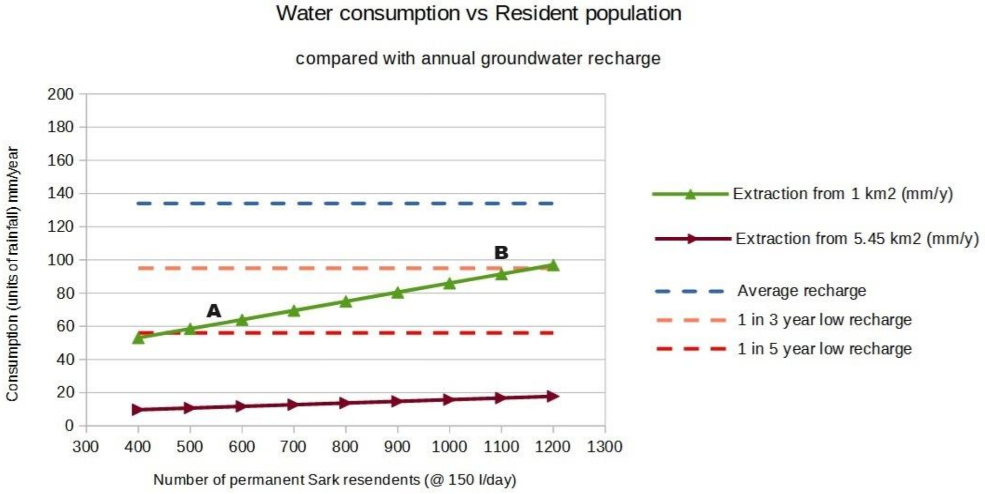
Possible future Scenarios

One way to do this is to look at cases where the climate has shifted and the groundwater recharge is reduced. Below are "Scenarios" where we compare the present day with future worlds in which annual groundwater recharge is reduced first by 25% then by 50%.

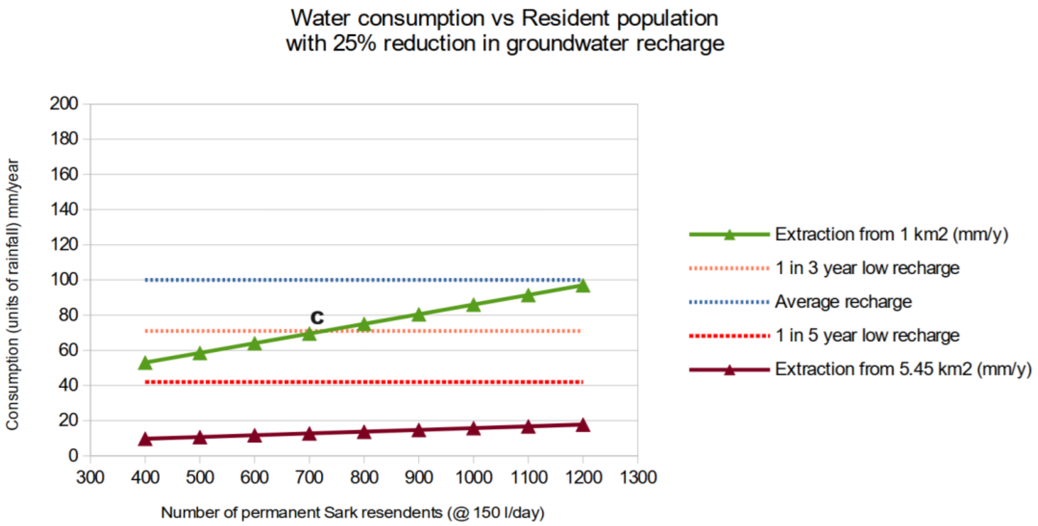
We begin with the current situation (SCENARIO 1) and present day climate.

Under current conditions, point "**A**" suggests that water recharge is close to the extraction on average once every 5 years. However if the climate remains the same and the population doubled to 1100 residents, then demands will be close to the present day 1 in 3 dry year (point "**B**").

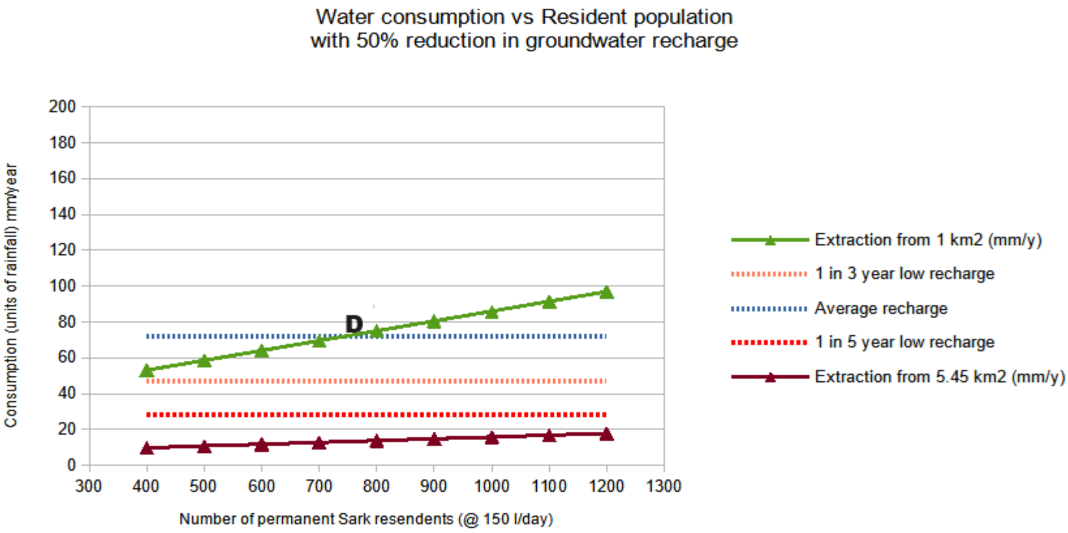
SCENARIO 1: Current groundwater recharge conditions.



SCENARIO 2: With a 25% reduction of recharge, and a population increase to 700 permanent residents, the extraction is approaching recharge once every 3 years (point "**C**") :



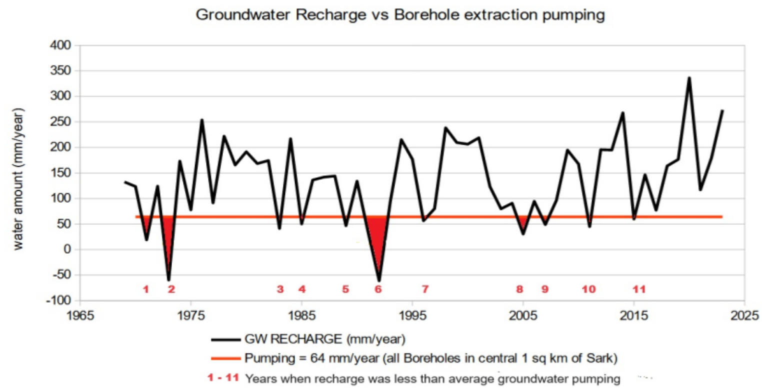
SCENARIO 3: With a 50% reduction in recharge and a slightly increased population. Groundwater extraction is close to the average annual recharge (point "**D**"). this means that in 50% of years, extraction will be greater than recharge.



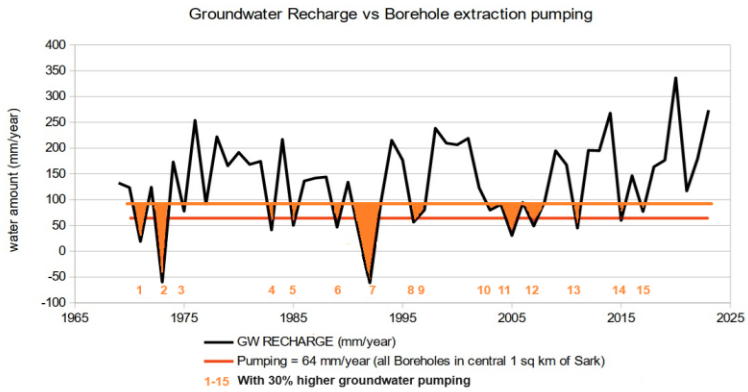
At point "**D**" any further water extraction will mean that the island is taking more water out than what is going in. This is known as "groundwater mining", and in this Scenario the water resources become unsustainable. It will result in continual lowering of groundwater levels until no more water can be extracted.

The three scenarios can also be shown as time series graphs – so how the number of drought years increases as demand increases and recharge decreases, and, more importantly how the occasional drought at the moment becomes almost the "norm".

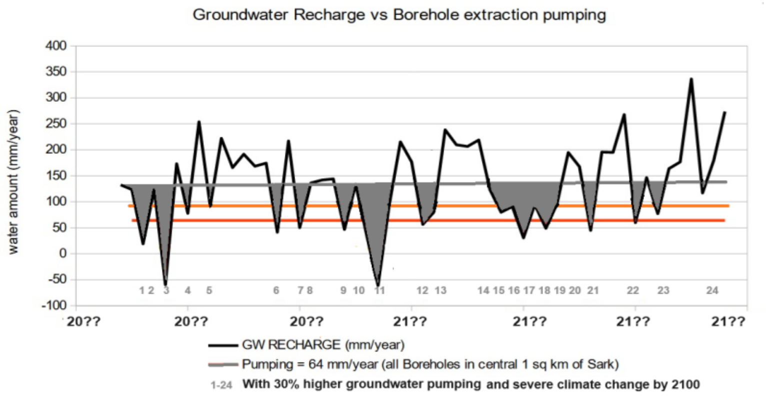
SCENARIO 1 (Present day, population 550). The red line is the estimated groundwater pumping rate. In 11 of the 54 years, pumping was greater than groundwater recharge, so we estimate that there is a nominal drought event on average once in every 5 years.



SCENARIO 2 (Present day, population increases to 700). If we increase the population on the island by (say) 50%, the groundwater pumping would probably increase by 30%. There will be more years when we extract more water than the groundwater recharge. Here the 15 drought events in 54 years means that there may be a water shortage 1 year in every 3 years. More seriously, there will be multiple years in a row when we pump more water than recharge. This means that the lowered groundwater levels may not recover ready for the



SCENARIO 3 (2100, population 700+). By 2100, with reduced groundwater recharge from rainfall combined with and longer hotter summers. There will be many more years when we extract more water than the groundwater recharge. Here the 24 drought events in 54 years means that there may be a water shortage 1 year in every 2 years. Very seriously, there will be many years in a row when we pump more water than is recharged in winter. This will cause groundwater levels to decline to an unsustainable situation.



Key Finding 5: If the population rose to 700 people, the increased demands for water combined with the impacts of climate change may place impossible demands on the available groundwater. In the short term (10-15 years), drought frequency is likely to rise from 1 in 5 years to 1 in 3 years. By 2100 water extraction could exceed groundwater recharge most years if the population goes above 700.

Once the groundwater recharge rate has been exceeded, constructing additional boreholes may not compensate for the lowered groundwater recharge. Indeed in many countries this has been the case – richer landowners drill deeper and deeper wells and install larger pumps, resulting in a "race to the bottom" of the groundwater resource. See for example https://eu.desertsun.com/story/news/environment/2015/12/10/how-unchecked-pumping-sucking-aquifers-dry-india/74634336/

Communicating this information : engaging with the local population

The only way to check on the impacts of climate change and increased pumping is to put in place a formal groundwater monitoring programme and have it running over several decades. (**Recommendation 5).** By engaging the local population in the monitoring this will encourage more responsible use of water.

It is not easy to communicate the exact impacts of future conditions to the general public, but we have found that asking questions such as these opens up useful thought processes :

- **What will our future weather and climate be like ?**
  (We don't know … but expectations are southern England in 2100 is likely to be more and more like the Bordeaux region of France today.)

- **How would we cope if every year was like 1976 ?**
  (Opening a dialogue with residents who experienced the drought in 1976 may give a better insight into the availability of water in dry years, noting that the winter in 1976-77 was exceptionally wet !)

- **What would we do if half of the wells and boreholes dried up?**
  (What water saving techniques and water saving technologies could be used?)

Reducing demands : adopting water saving technologies

The assessment of water demands carried out in this report assumed that the resident population consumes between 110 and 150 litres of water per person per day. These figures are based on typical UK consumption with an estimate of how a water conscious population (as on Sark) might lower their water use behaviour.

Existing properties

One way to reduce the impacts of future population and climate change on the demand for water is to encourage existing residents to modify their water use. A series of useful web links is listed below that could assist homeowners to reduce water use - either in a day to day behavioural change or by using new water saving technologies (when they may be renovating or upgrading their property).

A user can calculate their own water use and possible improvements https://watercalculator.uk/calculator/, together with a typical building specifications https://watercalculator.uk/example-specifications/

The UK Centre for Alternative Technology (CAT) provides a wide ranging advice service. It states "The average domestic use of water in the UK is 150 litres per person per day, but it is easy to reduce this to 70-80 litres per day". The CAT website provides information on improved domestic water management and sewage treatment. https://cat.org.uk/info-resources/free-information-service/. Grey water use (i.e. using rainwater and wastewater from taps and sinks) is a proven methodology to reduce overall water consumption. https://cat.org.uk/info-resources/free-information-service/water-and-sanitation/rain-and-grey-water/

There is a wealth of information on designing modern buildings with energy and water saving technology. Available at https://www.designingbuildings.co.uk/wiki/Greywater_recycling.
Also, see for example, https://www.tanks-direct.co.uk/water-tanks/rainwater-harvesting/c874

The European Union has created a "Unified Water Label" system, similar to the efficiency rating on electrical products https://uwla.eu/. It contains useful sections on domestic water saving devices https://uwla.eu/consumer/.

New builds and renovations

If the population of Sark were to increase by, say 50%, this might involve the construction of homes for 300 people. At an average occupancy rate of 2.2 persons/house (https://www.gov.uk/government/statistics/chapters-for-english-housing-survey-2022-to-2023-headline-report/chapter-1-profile-of-households-and-dwellings) this equates to about 130 homes.

We can expect there to be serious investment in renovating existing properties and the construction of new housing. This provides an opportunity for the Island of Sark to place some "soft touch regulations" on the owners and developers of these properties :

a) to ensure that all new homes are fitted with low water use devices (aerated taps, low flush toilets, water saving showers)
b) to connect grey water collection tanks for collecting water for toilet flushing or garden watering
c) to require the inclusion of rainfall harvesting systems eg https://www.tanks-direct.co.uk/water-tanks/rainwater-harvesting/c874

Recommendation 4 : Require that all new builds and major housing renovations incorporate water saving technologies to reduce water consumption.

Although regulations in Sark appear to be limited in many areas, there is also an opportunity to create a water management fund for the Island. This could be done by placing a (small) environmental levy on each new house/renovation by charging a one off "water development fee" of (say) £2500 per newly developed or renovated property. This sum is tiny in comparison with the overall costs of constructing a property.

If implemented, the Fees raised from the nominal 300 homes could create a fund of £0.75million. This fund could be used to pay for groundwater monitoring, water quality testing and to deal with any other water related emergencies.

Recommendation 5 : Suggest the introduction of a "Water Development Fee" for all new builds and major housing renovations.

Water Quality

This report was commissioned to assess the volume of water resources and the scope of the report will not cover water quality. However during the visit to the Island in June 2024, a number of issues relating to water quality monitoring and the risk of contamination were identified.

Water quality testing: this appears to be unregulated, except for businesses (hotels, bars, restaurants). It is up to the individual house occupier / owner to arrange testing of the quality of the water extracted from their own borehole. It is known that mineralisation and heavy metal contamination is a possibility due to the makeup of the geology of the island (Cheney 2006). Copies of typical water quality reports are included in Appendix B.

Advice on assessing water quality across the island could confirm the presence or absence of heavy metals, pharmaceuticals, pesticides, dog and cat flea treatments amongst others.

It would be very helpful if all water quality testing results from private dwellings and businesses were collated centrally by a Public Health Committee on Sark. Accurate water quality data would help recognise trends and areas with specific problems.

Saline intrusion risk : there have been no reports found that suggest that pumping groundwater from boreholes has caused ingress of sea water into the water supply of Sark. Most wells are no more than 60m deep and given that the land elevation is typically 90m, the base of these boreholes will be about 30m above sea level. However it must be noted that deeper boreholes, especially near to the coast, may connect with a fault or fissure that might permit the ingress of sea water.

Contamination risk of domestic boreholes : there appear to be no formal regulations in place to protect groundwater recharge zones – most householders own their own borehole and they may have a series of potential contamination risks in the vicinity of their borehole.

Such risks might include:

- A leaking septic tank releasing pathogens into the groundwater. This may be localised in nature due to the low permeability of the geology of Sark, but it reinforces the need for residents and businesses to carry out regular water quality tests (eg twice a year).

- Leaks from fuel oil storage – domestic fuel oil (a light Non Aqueous Phase Liquid or "LNAPL") is usually stored in tanks adjacent to the houses. An unnoticed slow leak, (or indeed a sudden catastrophic leak) would permeate through the soils into the groundwater and contaminate nearby boreholes. The same applies to fuel oils stored for agricultural use. LNAPL leaks are difficult to remediate once the contamination has occurred and it may result in one or several boreholes having to be abandoned as a source of water. (There is an example of this in the current 2024 news on the BBC website at https://www.bbc.co.uk/news/articles/czrrpw0702go - where the clean up from a petrol spill is disrupting domestic water supplies.)

- Commercial storage of herbicides, pesticides and other hazardous materials. We are not aware of any regulations relating to this.

- Waste disposal management - eg building waste (which may contain asbestos), paints, batteries, farm waste such as slurry and by products from processing meat and fish products.

- Human waste removed from septic tanks appears to be transported and stored for treatment at one coastal site. It is believed that in some circumstances, raw waste is discharged into the sea (unconfirmed). Although this is unlikely to have an impact on borehole water (which is extracted further inland), it raises the issue of who is responsible for dealing with a pollution incident should it occur.

Clearly, there are a number of potential risks to the existing groundwater which might compromise one or several water supply boreholes and thereby putting additional strain on other boreholes. Protecting the groundwater resource against contamination on Sark is difficult due to the apparent lack of formal regulations.

Recommendation 6 : Make the Island's population more aware of possible water contamination risks. This would be a first step in raising public awareness and hopefully will contribute to identifying a contamination problem before it becomes an emergency.

Recommendation 7 : Create a coordinated storage system for all water quality test reports. This will provide information on the overall health of the water quality and help to identify any developing problems.

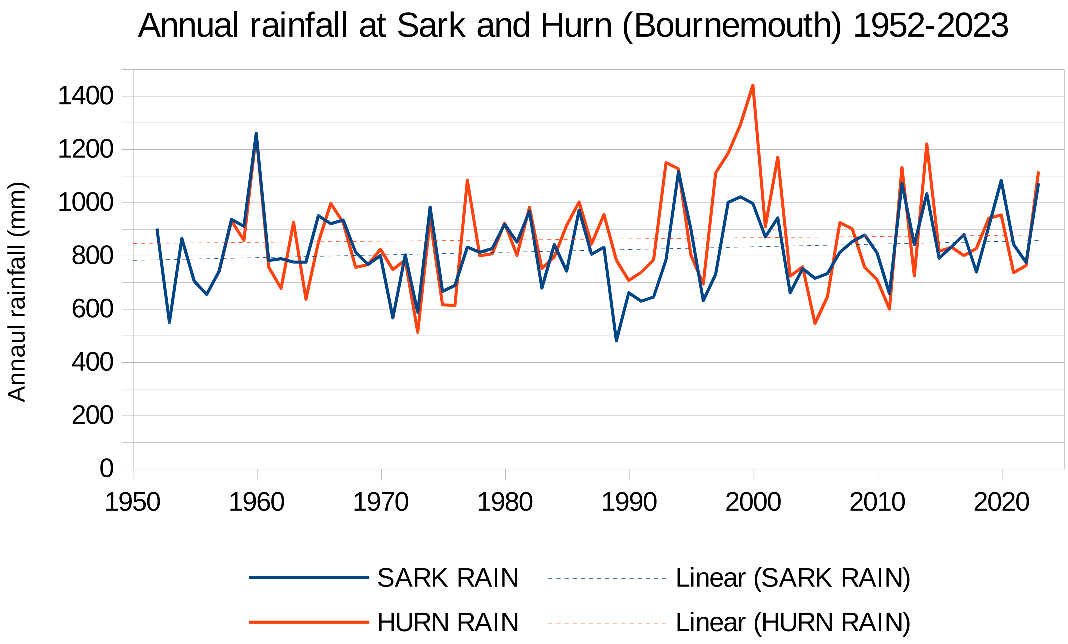
End of main report

APPENDIX A : DETAILED WATER BALANCE CALCULATIONS

Rainfall

All available fresh water on Sark comes from rainfall, but only a proportion of this gets into the rocks and becomes groundwater which can be extracted from wells and boreholes. The first action is to look at the trends of rainfall measured in Sark. Annual rainfall from 1952-2023 measured in Sark was provided by La Société Sercquaise.

The graph below shows the annual rain in Sark and for comparison rainfall at Hurn Airport, Bournemouth (a UK Met Office "Historic Climate" site - see https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data).



The Sark average rainfall is 825mm/year and at Hurn is 862mm/year. Comparable averages for Guernsey are 831mm/year and for Jersey are 877mm/year.

Overall the trend of annual totals is very slightly upwards. However the year to year variation is very large and Sark has experienced as little as 478mm (1989) and as high as 1247mm (1960).

Potential Evapotranspiration (PE) and Actual Evapotranspiration (AE)

Potential Evapotranspiration is the amount of water that would be evaporated from a field growing a short green crop (eg a playing field covered in grass) that was well watered. In this situation the evaporation is controlled by weather conditions only. However in summer the soil will dry out and reduce the evaporation rate to less than the "potential" rate. The Actual Evapotranspiration will therefore depend on both climatic conditions and the dryness of the soil.

We use a two step approach to calculating Actual Evapotranspiration :

i) For each month, calculate the Potential Evapotranspiration assuming the fields and soils are not short of water using the Penman Monteith equation,

ii) Calculate a running daily water budget for each year to determine when and for how long the soils dry out. Use this information to reduce PE to Actual Evapotranspiration.

The calculation of the PE using the Penman Monteith equation is complex, requiring monthly values of average temperature, humidity wind speed, sunshine hours and solar radiation intensity. (Much of these data is recorded on Sark but the short time scale of this report meant that there was insufficient time to process it.) As a starting point, we used the United nations FAO “CLIMWAT” climatic database together with the “CROPWAT8” programme to extract average climatic data for Guernsey and calculate monthly Potential Evapotranspiration using the international standard Penman Monteith equation :

Monthly ETo Penman-Monteith - C:\DEREK\CROPWAT8\CLIMWAT2\My_CLIMWAT_Files\Guer...

Country Guernsey Met Office | Station 1980-2010 average

Altitude 25 m. | Latitude 49.40 °N | Longitude °E

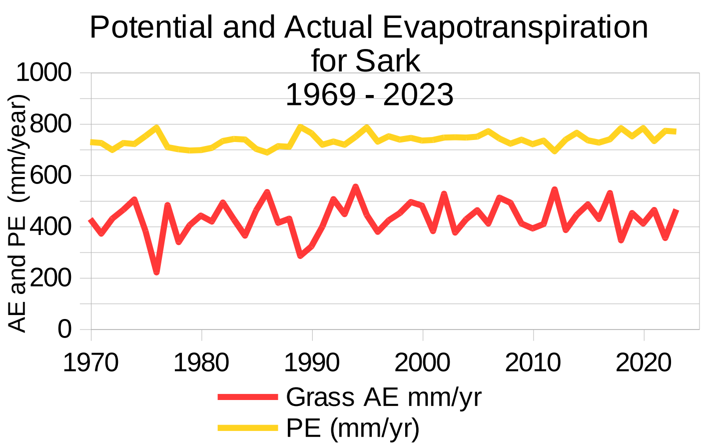
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	5.0	8.7	83	479	2.0	3.5	0.89
February	4.5	8.4	83	433	3.1	6.0	0.98
March	5.6	10.0	83	406	4.1	9.7	1.34
April	6.7	11.9	90	383	6.5	15.6	1.61
May	9.2	14.9	80	361	7.6	19.3	2.70
June	11.6	17.5	80	333	8.2	21.1	3.20
July	13.7	19.5	81	343	8.1	20.4	3.32
August	14.1	19.8	81	324	7.4	17.5	2.99
September	13.1	18.0	81	363	6.0	12.7	2.28
October	11.0	15.0	84	416	3.8	7.3	1.43
November	8.1	11.8	84	434	2.6	4.2	1.00
December	5.8	9.6	84	457	1.9	2.9	0.83
Average	**9.0**	**13.8**	**83**	**394**	**5.1**	**11.7**	**1.88**

https://www.fao.org/land-water/databases-and-software/cropwat/en/

PE is shown in the column labelled “**ETo**” (reference crop potential evapotranspiration). The annual average PE for Guernsey is 1.88mm/day or 686mm/year. By way of comparison, the BGS report in Jersey suggested 648-754 mm/year. Davis (1998) used the simpler Thornthwaite equation to estimate Potential Evapotranspiration and came up with a lower average of 613mm/year.

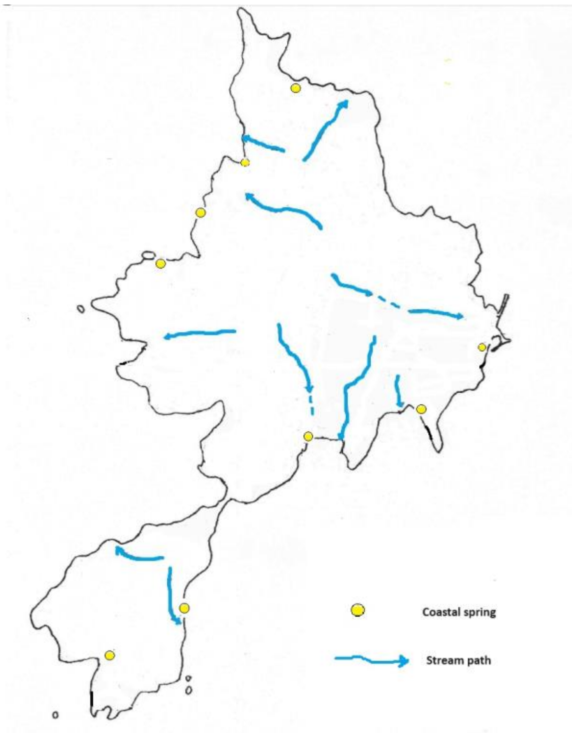
To create a time series of PE over several decades, we used data from the UK Met Office Historical climate station at Hurn Airport for the years 1969-2022. https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data . This was scaled for differences in wind speed and humidity between the two sites. The resulting average PE at Sark was 734mm/year which compares well with the BGS estimates for Jersey and is within 6% of the Guernsey ETo estimates.

Next, the effects of soil drying were simulated for each year using CROPWAT8. The provided the scaling factors that reduce Potential Evapotranspiration to Actual Evapotranspiration, primarily in the summer months. The average annual Actual Evapotranspiration (AE) for Sark was calculated as 429mm/year, approximately 58% of the potential rate. The graph below shows that PE and AE are increasing slightly over time, which is due to the gradual effects of climate change, particularly rising temperatures. The effects of soil drying on AE is visible in the drought summers of 1976 and 1989, when AE falls below 300mm/year.



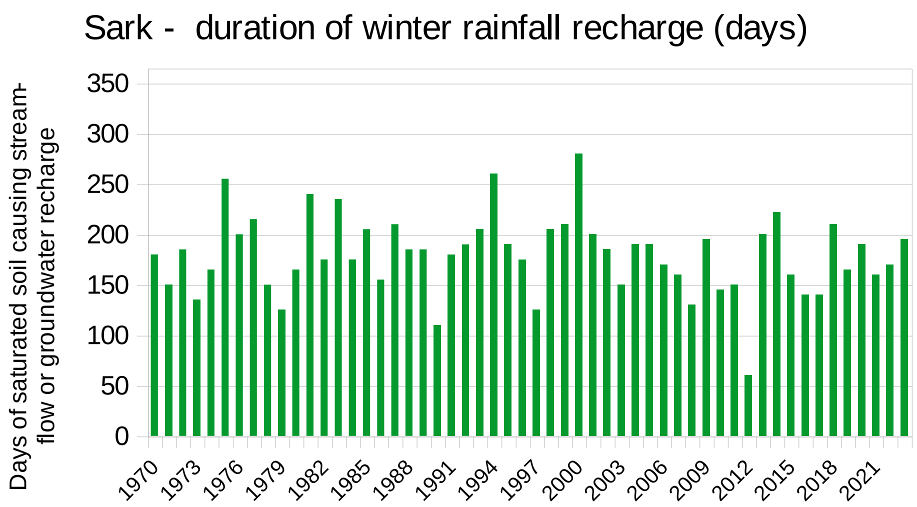
Stream Flow

Surface water is limited to a small number of minor streams (probably less than 10 – see map , which was adapted from Davis 1998). These flow mainly in winter, fed by excess rainfall and water draining from shallow saturated soils and groundwater (baseflow). No measurements of streamflow are available but it is estimated that each stream probably has an average flow of no more that 5 Litres/second when running.



Location of stream paths (based on Davis 1998) and coastal springs (La Société Sercquaise)

To estimate the volume of stream flow each year, we used the Actual Evapotranspiration soil drying calculation. The enabled us to determine when stream flow would stop in the summer months and restart later in the year. The average number of days a year that the soils ware saturated is 180 out of 365 (see graph).



By assuming that there are 10 streams flowing at an average rate of 5litres/second for 180 days of the year, the annual stream flow volume is 777,600m^3/year. To convert this to the units of depth of rain we divide by the area of Sark (5.45sq km) i.e. 777600/(5.45*1000*1000) = 0.142m or 142mm/year.

This stream flow represents approximately 17% of the annual rainfall on Sark. We still need to account for surface flow that seeps out of the soil in undefined small rivulets which is probably the same amount again. There is no simple way to measure this so in catchment hydrology we often use a “coefficient of runoff”, or “percentage runoff” which is a fraction of the rainfall that drains off the soil surface. The percentage runoff calculated using the UK Flood Studies report methodology is 31% and by way of comparison Davis (1998) used a coefficient of runoff of 0.29.

Surface runoff was therefore estimated to be 31% of the annual rainfall (825*0.31=255mm) which is made up from 142mm/year stream flow and 114mm/year surface flow in undefined rivulets.

Groundwater flow into the sea

This is difficult to assess and there is no direct way to measure it. We know that the geology of the island is of dense volcanic and metamorphic materials. The rocks are very unlikely to be able to permit water flow though the deep compressed rocks tens of meters below ground level. With a hydraulic conductivity of 3 x 10^{-4} m/day (Davis, quoted in Cheney, 2006) a simple Darcy calculation suggests that the groundwater outflow from the island is likely to be less than the equivalent to 10mm of rainfall/year. However the geology does contain fissures and cracks and it is entirely possible that some groundwater will discharge through small springs at the cliff faces overlooking the sea (see stream flow and coast spring map above).

For this reason we will assume that groundwater flow out of the system is no more than 50mm/year. The value is chosen as it is much smaller than the observed streamflow. If it were any larger, it would become obvious that a significant spring is flowing.

Water extracted from boreholes and wells

There are numerous cracks and fissures in the local geology that fill with water and it is these that are used for the water supplies of the island of Sark. In the 1970’s there were about 70 boreholes in operation. Cheney (2006) reported that there were approximately 250 deeper boreholes and 50 shallow wells being used for water extraction. It appears that there is no legislation that controls the construction of boreholes.

In general most properties have their own borehole but these are a few instances where several properties share a single borehole. Typical boreholes are less than 40m deep but there are a few examples of deeper wells (around 60m) and a small number are more than 90m deep (which places the base of the borehole close to sea level).

Additionally, some properties capture rainfall from roof surfaces and store this water in tanks on their property.

The majority of water extraction is for human use (homes, hotels etc). The resident population of Sark is relatively constant at around 550 people although this can double in the busy summer months with the arrival of tourists and day visitors.

There is no formal record keeping of water consumption on the island. A typical UK mainland person consumes 150 litres of water per day (drinking, bathing, washing). Davis (1998) suggested 155 litres of water per person per day, which is probably high for a water conscious island. She also added estimates of water consumption by tourists and in agriculture (animals). Her assumed water consumption rates were :

Residents	155 litres/person/day
Hotel visitors and guest houses	110 litres/person/day
Self catering guests	155 litres/person/day
Campers	60 litres/person/day
Day visitors	45 litres/person/day
Farm animals	50-150 litres/animal/day.

Other uses (eg industry, processing) are small. There is no formal use of water for irrigation of field crops on Sark (this can be an extremely large consumer of water). There may be some limited watering systems in a few domestic gardens.

For a typical year in the 1990’s Davis estimated a water consumption of 64020 cubic meters per year. Spread pro rata over the 550 permanent resident population, this is approximately 319 litres per permanent resident per day. This figure may be useful in planning water resources use for future development and population projections.

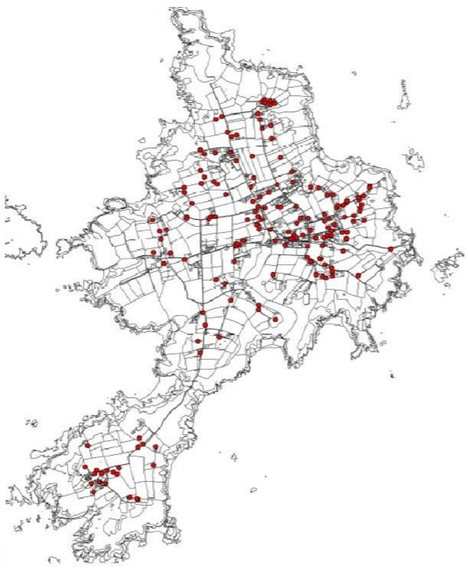
To place this water consumption into context and compare it with the annual rainfall of 825mm/year, we can convert the volume of 64020 cubic metres/year to an equivalent rainfall depth over the area of the whole island (5.45sq km) :

Volume of consumed water = 64020 m^3/year
Area of Island = 5.45 *1000*1000 m^2

Equivalent rainfall depth = Volume/Area
= 64020/ (5.45*1000*1000) m/year = 0.011747 m/year
= **11.7 mm/year** (units of rainfall used in the water balance equation)

Density of boreholes

We should note that the vast majority of water extracted is taken from the boreholes in central part of the island. Examining the distribution of boreholes provided on maps by La Société Sercquaise (image below), the concentration of water extraction boreholes is away from the coast. A rapid area assessment done using Google Earth suggests that the vast majority of these boreholes are within an area of 1 square kilometre :



Borehole locations

Central zone : 1 square km

Although this is an approximation (and ignores Little Sark), if we re-work the above water extraction calculation for the smaller area,

Equivalent rainfall depth = Volume/Area
= 64020/ (1.00*1000*1000) m/year = 0.06402 m/year
= **64.02**mm/year (units of rainfall used in the water balance equation)

We will use the extraction rate of 64mm/year as the best estimate of water extracted in the central populated area of Sark.

APPENDIX B : SAMPLE WATER QUALITY TEST DATA

Chemical Analysis of Groundwater in Sark

Laboratory number : S04-00584 **Date sampled : 23 June 2004**

Locality : Seigneurie Spring **Contact name : Mr M J Beaumont**

Grid Reference: 546243 5476524

Parameter	Data	Units
pH (lab)	7.03	
Conductivity	NR	µS/cm
Calcium (Ca)	18.8	mg/l
Magnesium (Mg)	10.7	mg/l
Sodium (Na)	74.4	mg/l
Potassium (K)	3.88	mg/l
Chloride (Cl)	103	mg/l
Sulphate (SO_4)	39.5	mg/l
Bicarbonate (HCO_3)	57	mg/l
Nitrate (NO_3)	7.2	mg N/l
Nitrite (NO_2)	0.0149	mg N/l
Ammonia (NH_4)	<0.03	mg N/l
Phosphorous (P)	0.21	mg/l

Parameter	Data	Units
Aluminium (Al)	<0.01	µg/l
Arsenic (As)	<0.05	µg/l
Barium (Ba)	0.0446	µg/l
Cadmium (Cd)	<0.001	µg/l
Chromium (Cr)	<0.002	µg/l
Copper (Cu)	<0.008	µg/l
Iron (Fe)	<0.005	µg/l
Manganese (Mn)	0.0047	µg/l
Nickel (Ni)	0.005	µg/l
Lead (Pb)	<0.01	µg/l
Zinc (Zn)	0.025	µg/l

Notes: **1.The "<" symbol refers to values which were less than the (stated) detection limit of the analytical technique used, and could not be resolved futher.**

2. In addition to the elements listed above, beryllium (Be), cadmium (Cd), cobalt (Co), lanthenum (La), molybdenum (Mo) vanadium (V), and yttrium (Y) were also analysed but in all cases values were below the detection limit of the analytical technique used.

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[redacted]

Laboratory number(s)	242616
Number of pages	1 of 1
Date sampled	14/05/2024
Time sampled	10.00
Submitted by	K Rang
Date received	14/05/2024
Time received	12.50
Date analysis started	14/05/2024
Reporter(s)	TG
Sample matrix	Borehole water
Condition of sample(s)	Satisfactory

Test Report

Sample site/ location	[redacted]

Method code	Test description	Result	Units	Limit
8	Colour *	**<5**	mg/l Pt/Co	<20
20	pH	**5.64**		6.5<pH<9.5
33	Turbidity	**0.76**	NTU	<4
9	Conductivity	**333**	µS/cm @ 20°C	<2500
3	Ammonium	**<0.01**	mg/l NH_4	<0.5
32	Total Oxidised Nitrogen	**7.3**	mg/l NO_3	<50
1	Alkalinity	**25**	mg/l HCO_3	
5	Calcium	**6**	mg/l Ca	
72	Iron*	**64**	µg/l Fe	<200
72	Copper*	**31**	µg/l Cu	<2000
#	Lead *	**8.92**	µg/l Pb	<10
72	Manganese	**<10**	µg/l Mn	<50
72	Zinc*	**<10**	µg/l Zn	
17	Nitrite	**<0.03**	mg/l NO_2	<0.5
47	Nitrate by calculation	**7.3**	mg/l NO_3	

Limits quoted on this report are those specified in The Private Water Supplies (England) Regulations 2016.

Comments:

UKAS TESTING 1749