St Helena
Cloud Forest Project

Year 3 Climate and Water Resource Addendum Report

October 2024

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Glossary

ANRD	Agriculture and Natural Resource Division
AWS	Automatic Weather Station
CABI	Centre for Agriculture and Bioscience International
UK CEH	UK Centre for Ecology and Hydrology
Connect	Connect Saint Helena Ltd
CSSF	Conflict, Stability and Security Fund
DEM	Digital Elevation Model
ERT	Electrical Resistivity Tomography
FCDO	Foreign, Commonwealth and Development Office
IPCC	Intergovernmental Panel on Climate Change
NEVC	North East Volcanic Centre

MAMSL	Metres Above Mean Sea Level
PEt	Potential Evapotranspiration
RSPB	Royal Society for the Protection of Birds
SHG	Saint Helena Government
SWVC	South Western Volcanic Center
TAG	Technical Advisory Group
UKOT	United Kingdom Overseas Territories
WRMP	Water Resource Management Plan
WTW	Water Treatment Works

1 Introduction

This report has been written as an addendum to the joint Cloud Forest Project and Darwin Plus DPLUS103 project (St Helena Climate Change and Drought Warning Network) report which was published as 2 volumes in July 2023. Data collected between April 2023 and March 2024 has been funded by the UK Government's Foreign, Commonwealth and Development Office (FCDO) through the Conflict, Stability and Security Fund (CSSF), as part of the 4 year Cloud Forest Restoration Project on St Helena which is managed by the Royal Society for the Protection of Birds (RSPB).

1.1 St Helena

The project is based on St Helena, a British Overseas Territory located in the South Atlantic Ocean. The island is formed from an extinct volcanic sea mount, has a sub-tropical climate and lies 4,000km east of Brazil and 1,950km west of Namibia. The island covers an area of 122km^2 (47sq miles) and is similar in size to the island of Jersey. Due to its volcanic origins, the island rises steeply from sea level to a central ridge of peaks that form a rugged and highly eroded volcanic terrain. Habitat zones include semi desert at sea level through to cloud forest at a maximum height of 823m above sea level.

1.2 Acknowledgements

We would like to thank Lawrence Muranganwa at Connect Saint Helena for his guidance and being a champion of the project, Janet Lawrence (Connect Saint Helena CEO) for her encouragement and Darren Duncan (Portfolio Director – Environment Natural Resource and Planning (ENRP)) for all his support in SHG.

We would also like to thank the FCDO and Sarah Havery, Kirstie Ellis, Shayla Ellick, Stuart Jennings from the RSPB for their continued Cloud Forest Project support.

1.3 Year 3 Objectives

The provision of water on St Helena is intimately linked to the distribution of habitats and in particular the cloud forest area above 650m. Previous work (DPLUS051[1], CEH 1990's[2] work) has demonstrated that native habitats function more effectively as hydrological units than introduced systems. These native habitats are the last refuges of St Helena's rich endemic flora and fauna but they are threatened by multiple drivers of extinction, e.g. invasive species habitat loss, genetic erosion and climate change.

For Years 3 and 4 of the Cloud Forest Project, the following water resource objectives were agreed between project partners and the FCDO, which build on the work reported in the joint report published in 2023:

1. Continuous water resource and climate monitoring data in Year 3 and updated in Year 4.

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[1] Sansom, B. Gray, A et al (2018). DPLUS051 Water Security and Sustainable Cloud Forest Restoration on St Helena.

[2] Gunston, H. and Rosier, P. (2002) Saint Helena Catching Mist and Clearing Flax CEH 2002

    a. Stream level and stream flow data collection from monitoring network.
    b. Groundwater level data collection from monitoring network.
    c. Climate data collection from monitoring network.
    d. Charts and spreadsheets shown as evidence.

2. Island water balance - Year 3 and update balance in Year 4.
    a. Developed using new climate and water resource data sets collected from Cloud Forest project monitoring activities.
    b. Output used to support water resource management decisions.

3. Climate change assessment – Year 3 and updated in Year 4.
    a. Climate change scenario assessment of water balance.
    b. Climate change scenario assessment of monitoring data.
    c. Output used to assess impact of climate change on the water balance and expected change in stream flows and groundwater levels.
    d. Output used to support water resource management decisions.

4. Annual water resource and climate report - Year 4.
    a. Summarise changes in island data sets based on previous 3 years data.
    b. Output used to communicate the status of the islands water resources and climate (see attached EA water and climate report – we could follow the same format but write it as an annual report and in a shorter format).

This document comprises a report on the Year 3 objectives.

1.4 New Tree Diseases in St Helena

A plant pathogen study[3] was undertaken across the island in October 2022 (as part of DPLUS104) by a team from the Centre for Agriculture and Bioscience International (CABI). The CABI team identified a *Phytophthora* infection in a number of trees which were dying in the Peaks tree nursery, George Benjamin arboretum and in the Scotland tree nursery. The disease was found in Whitewoods, Dogwoods, She Cabbage, Bastard Gumwood and Redwood trees.

Based on the findings of the study SHG formed a multi-agency Task Group to develop an action plan for controlling the plant disease. In November 2022 the Task Group restricted access to the Peaks where several of the DPLUS103 mist and rain dataloggers, automatic weather stations and water level monitoring sites are located. The Cloud Forest Project team have worked with the Task Group and their Technical Advisory Group (TAG) to arrange limited, controlled access to the Peaks so that project data can be collected.

Protocols implemented by the TAG have resulted in significantly less frequent data downloads since November 2022. The impact on Year 3 project work has been to limit the interpreted data set to data collected until the end of December 2023. Data has been collected in the first quarter of 2024 but is not available for interpretation due to time constraints. This data will be

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[3] Crozier, J. and Taylor, P (October 2022). New Tree Diseases in St Helena. Presentation at St Helena Museum.

interpreted during Year 4 of the project (2024/25 financial year). Activities associated with geophysics surveys and soil surveys have also been limited in extent as the key Peaks study area has been out of bounds for these technical research areas.

The water resource project team are continuing to collect data in impacted parts of the island, as and when permitted, and are working with SHG and the TAG to ensure post project monitoring can continue.

Harpers Reservoirs

2 Climate Monitoring

2.1 AWS Data

The project surface climate monitoring network has continued to be monitored in Year 3 of the Cloud Forest Project. A detailed description of the monitoring network can be found in the joint Darwin Plus and Cloud Forest project reports published in July 2023[4].

A new AWS was installed at The Depot in July 2024, along the Peaks ridge, south west of High Peak in the west of the island. The AWS had hardware problems soon after installation, which resulted in no data being collected in 2023 whilst spare parts were sourced and shipped from Europe.

Data from the Peaks AWS (Cabbage Tree Road) should be used with caution as there are several data gaps throughout the year for the months of May, August, September, November and December due to technical issues. Data from the Flagstaff AWS should also be used with caution as data missing from October to December 2023 due to technical issues with AWS.

An equipment log is presented in Appendix 3 summarising all AWS equipment issues.

AWS data is presented in Appendix 1 and comprises a table summarising 2023 climate data for Bottom Woods MET Station, plus climographs for each AWS and a map of the island showing wind rose data.

For Bottom Woods MET station total rainfall for 2023 was 2% less than the 20-year average, with the sunshine hours 6% under the average. The highest rainfall was in June (72.8mm), 22% over the monthly average but less that the highest recorded rainfall for that month (108.6mm). There were no months without any rainfall days. February had the fewest days rainfall (12 days) whilst June had the most rainfall days (24 days), giving an average of 18 rain days per month for 2023.

The highest temperature recorded in 2023 was 25.8°C in March, 1.9°C higher than the previous highest temperature for that month. The overall average max daily temperature for 2023 was 1% below the 20-year average. The lowest temperature recorded was 12.3°C in August, 1.5°C warmer than the lowest recoded temperature for that month. The overall average minimum daily temperature was 1% above that of the 20-year average.

A summary of key climate data is provided in Table 2-1.

2.2 Mist and Rainfall Data

2.2.1 Daily Mist and Rain

A summary of monthly mist and rainfall data collected between August 2021 and December 2023 from pairs of hobo rain gauges measuring mist and direct rainfall is presented in Figure

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[4] Saint Helena Government (2023). DPLUS103 St Helena Climate Change and Drought Warning Network. Volume 1 – Climate, Volume 2 – Water Resources. Sansom B, George R, Mullings-Smith E, Groen M, Palmer S, Henry M, Walmsley B, Gray A, Muranganwa L.

2-1 and Figure 2-2. Monthly rainfall data shows St Helena seasonal rainfall with wet months between March and August and drier months between September and February.

Table 2-1: Key Climate Data 2023

Monitoring Location	Average Temp (°C)	Max Temp (°C)	Min Temp (°C)	Average Station Pressure (Hpa)	Max Gusts (knots)	Average Wind Speeds (knots)	Total Rainfall (mm)
Boxwood Hill AWS	18.30	25.60	13.10	968.68	46.10	9.50	225.20
South West Point AWS	17.00	24.30	12.20	951.10	58.20	7.90	298.00
Sisters Walk AWS	22.80	31.10	16.50	1016.22	24.30	2.10	167.00
Horse Pasture AWS	15.20	23.60	10.30	952.82	59.10	13.90	510.80
High Peak AWS	15.50	24.00	11.00	932.33	37.00	5.00	922.60
Flagstaff AWS*	16.80	24.80	11.60	947.67	46.10	11.30	316.60
The Peaks AWS**	17.00	23.60	11.30	933.95	20.00	2.80	224.60
Bottom Woods Met Station	18.60	25.80	12.30	-	-	13.50	489.20
Stitches Ridge Rain Gauge	-	-	-	-	-	-	1041.20
Casons Rain Gauge	-	-	-	-	-	-	470.00
Diana's Peak Rain Gauge	-	-	-	-	-	-	1063.80

A figure showing the 2023 rainfall isohyets is presented in Appendix 1.

A new mist monitoring location was installed at the Depot on the western end of the Peaks ridge. The limited mist data from this site (July 2023 to December 2023) is significantly higher than at other sites. A longer data set is needed to see if this location is different from the other monitoring locations. The data set indicates that during the drier rainfall months, recorded mist is higher than rainfall (Figure 2-3), indicating that mist has the potential to contribute to the island water balance during the summer months.

Total mist averaged 3,184mm for 2023. Monthly mist ranged between 125mm and 534mm (excluding The Depot). Studies of cloud forest mist capture across the world have reported mist contribution between 20mm/a and 1,990mm/a, with mist contributing between 5% and 75% of total catchment runoff[5].

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[5] Ellison, D. *et al.* (2017) 'Trees, forests and water: Cool insights for a hot world', *Global Environmental Change*, 43, pp. 51–61. Available at: https://doi.org/10.1016/J.GLOENVCHA.2017.01.002

Figure 2-1: Monthly Rainfall

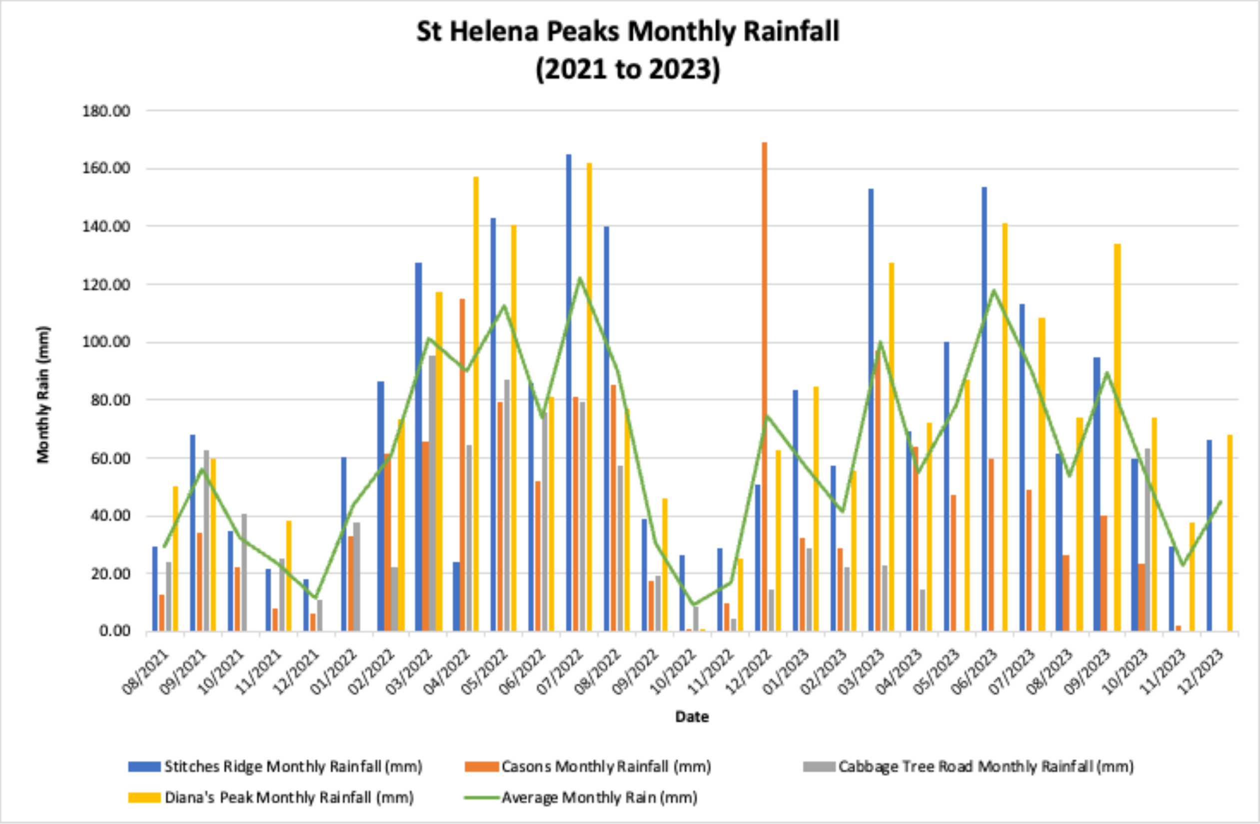


Figure 2-2: Monthly Mist

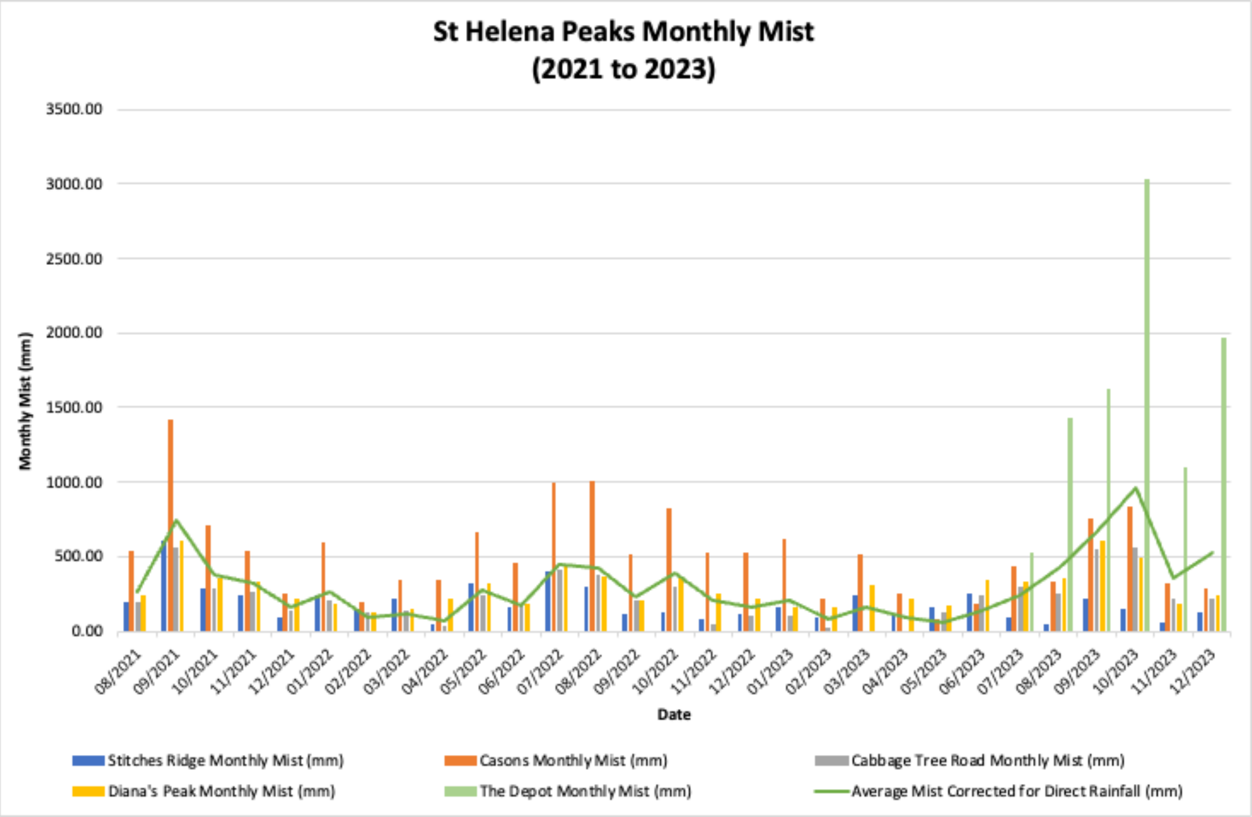
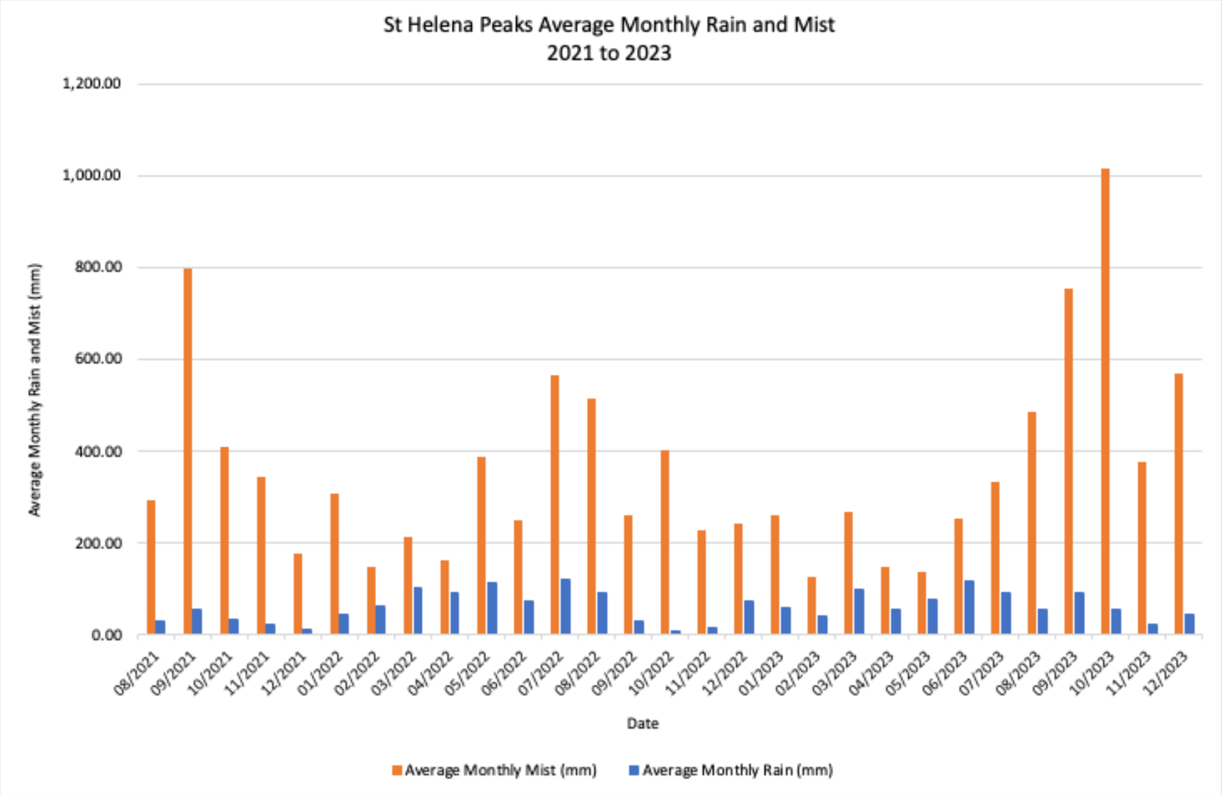


Figure 2-3: Average Monthly Rain and Mist



2.2.2 Rain and Mist Days

Table 2-2 and Figure 2-4 summarise the number of days per year where rain and mist were recorded or not recorded. Dry days are days where rain and mist are not recorded. Note: the Cabbage Tree Road AWS was not working between May 2023 and December 2023, so the rainfall data for 2023 at this location is not representative of rainfall recorded at the other monitoring locations (salmon shaded cells). The data set for 2021 started in August, so is not representative of a full calendar year. This data set will improve in time as monitoring of climate variables continues across the island.

Table 2-2: Mist and Rainfall Days 2021 to 2023

Location	Recorded Rain (Days/Year)		
	2021	2022	2023
Cabbage Tree Road	25	185	70
Diana's Peak	36	211	294
Stitches Ridge	81	213	251
Casons	84	215	223
Location	No Recorded Rain (Days/Year)		
	2021	2022	2023
Cabbage Tree Road	30	173	79
Diana's Peak	16	105	71

Stitches Ridge	57	125	114
Casons	54	125	114
Location	Recorded Mist (Days/Year)		
	2021	2022	2023
Cabbage Tree Road	132	249	227
Diana's Peak	137	339	345
Stitches Ridge	116	247	236
Casons	128	303	314
Location	No Recorded Mist (Days/Year)		
	2021	2022	2023
Cabbage Tree Road	6	51	112
Diana's Peak	1	19	19
Stitches Ridge	22	90	107
Casons	10	32	51
Location	Dry Days (Days/Year)		
	2021	2022	2023
Cabbage Tree Road	1	44	49
Diana's Peak	1	13	18
Stitches Ridge	21	84	92
Casons	9	31	35

For data collected in 2022 and 2023, the number of days of recorded rainfall for Diana’s Peak, Stitches Ridge and Casons are similar. Likewise, the number of recorded mist days are similar for each monitoring location, including Cabbage Tree Road. Days where no mist was recorded show a significant variation at Cabbage Tree Road (50 days in 2022 and 112 days in 2023). The remainder of the monitoring locations show a similar pattern between years. A longer data set will support a more detailed assessment of mist and rain across the Peaks.

For Diana’s Peak, Stitches Ridge and Casons the number of dry days (no recorded mist or rainfall) were similar between 2022 and 2023. As a proportion of recorded data for each monitoring location, 2023 had more dry days than 2022. Rainfall data across the monitoring network confirmed 2023 as a drier year, with an average of 825mm rainfall recorded in 2022 and an average rainfall of 806mm recorded in 2023.

2.3 Mist Contribution to Recharge

For the purposes of the catchment water balances (Section 4), it has been assumed that 1000mm of the 2023 average mist is available for recharge, with the remaining mist evaporated from the cloud forest canopy (2,184mm). Based on this assumption, mist is estimated to contribute between 51% and 75% of recharge in 2023 (average 57%) in water balance Zone 1 (land above 690m contour).

Further data collection between April 2024 and March 2025 will enable a more accurate estimate of mist contribution to recharge and potential evapotranspiration.

Figure 2-4: Mist and Rainfall Days 2021 to 2023

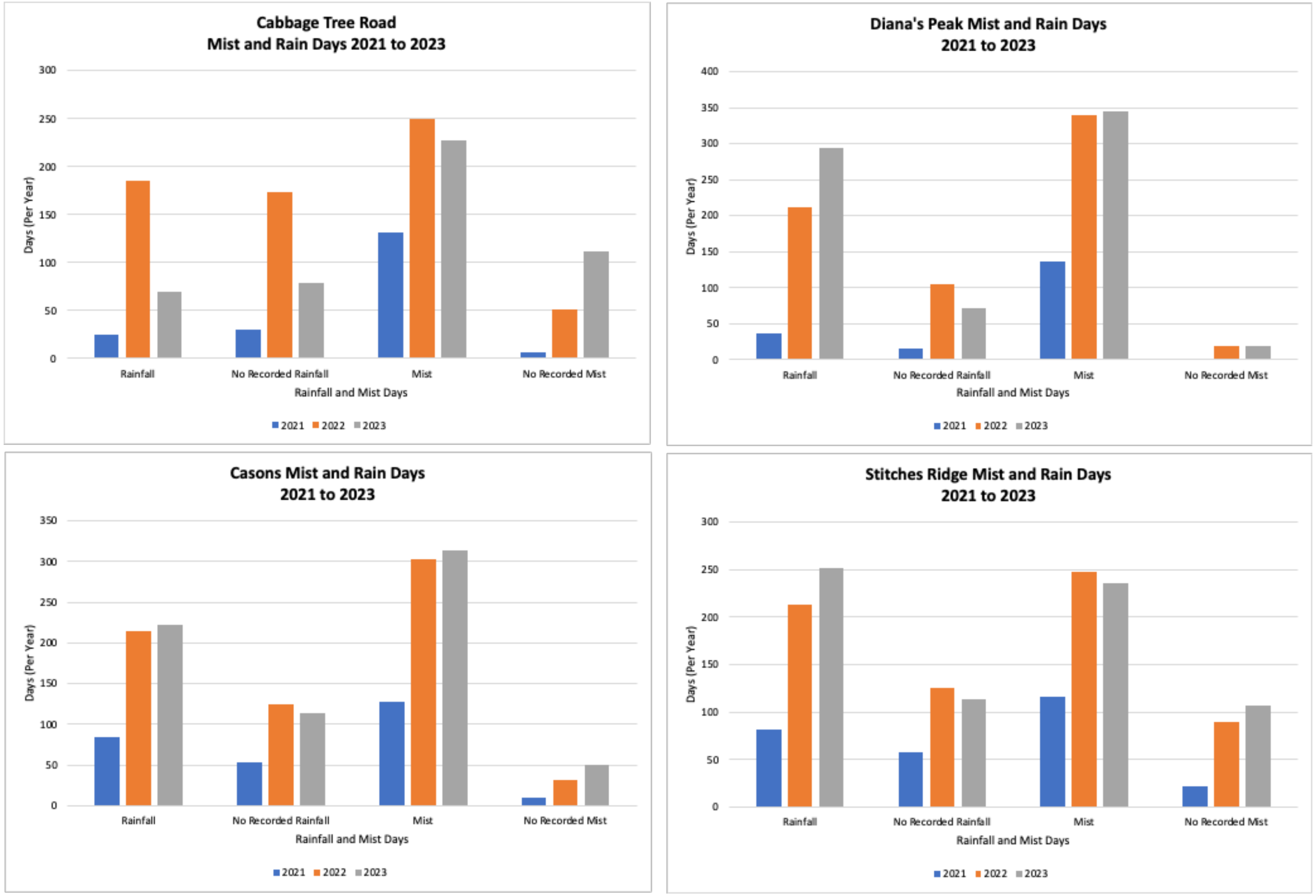
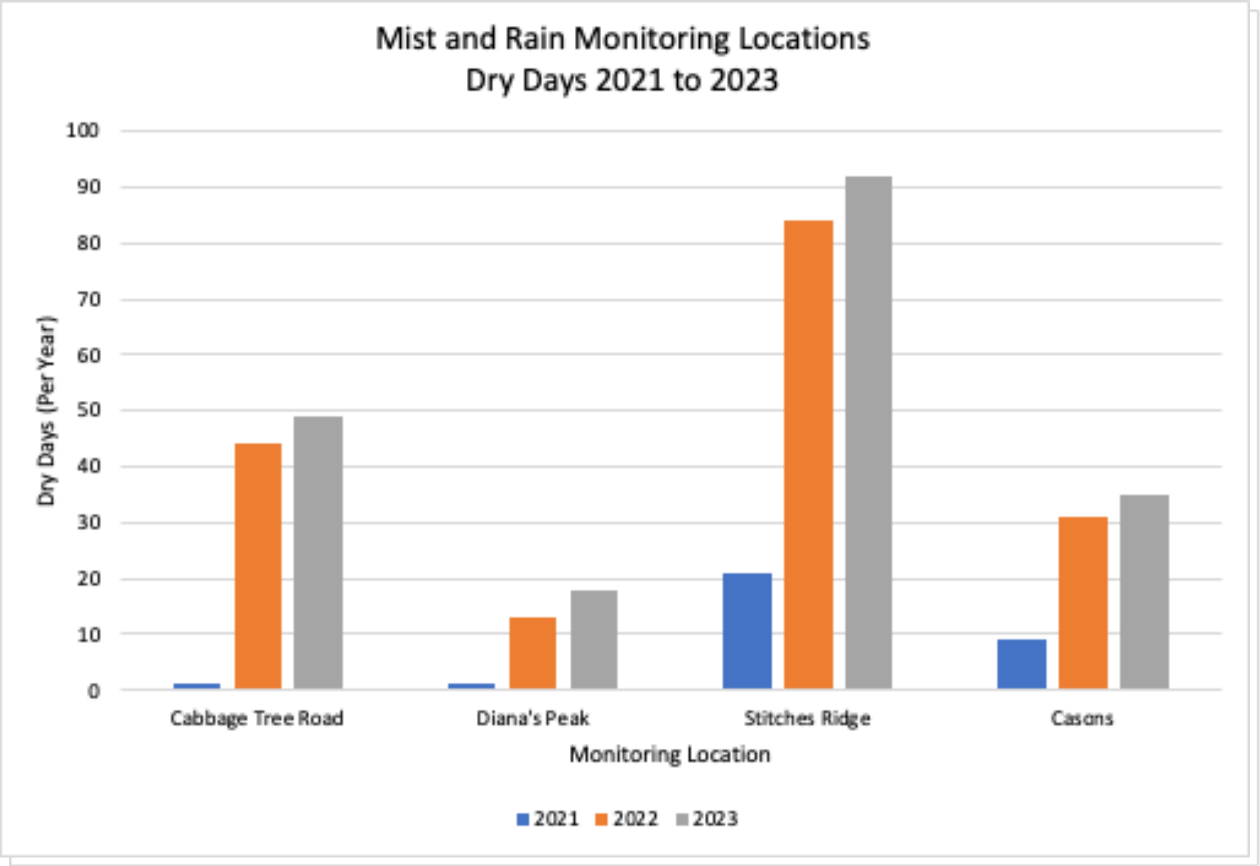


Figure 2-5: Dry Days Per Year



Black Bridge Data Collection

3 Water Resource Monitoring

3.1 Data Collection

The project surface water and groundwater monitoring network has continued to be monitored in Year 3 of the Cloud Forest Project. A detailed description of the monitoring network can be found in the joint Darwin Plus and Cloud Forest project reports published in July 2023[6].

Data has been collected on a monthly basis. However, due to the continued access restrictions in the Peaks, data collection has at times been more sporadic at some monitoring locations.

3.2 Data Collection Log

During the past 12 months, gaps in the data sets have occurred. Common reasons for data gaps are:

- Equipment failure. No data collection between equipment failure and equipment repair.
- Infrastructure maintenance. In the case of SW02WG, the catchpit used at the start of the project was completely rebuilt in 2022. This resulted in a 7-month data gap whilst construction activities were completed between August 2021 and February 2022.
- Flooding. Some of the v-notch weirs were inundated by heavy rains, so stream level and flow data could not be calculated as the "v" was flooded. This is mainly down to the structures being too small to accommodate the stream flows.
- Vandalism. During 2023 it was discovered the Diver data logger at LGSW01 was missing, with the cord cut close to where it was secured to the structure. Was searched for inside the structure and surrounding area with no result. Loss of data from August 2023.

A log of problems encountered when collecting data at the monitoring locations is presented in Appendix 3.

3.3 Surface Water

The most complete record of island stream flows is provided in Appendix 2 of the 1990-2010 Water Plan[7]. The data set reported was for 19 catchments across the island, with daily flows recorded between 1975 and 1989. Nine of the catchments were reported to have limited data due to sporadic data collection. Where relevant, these historic flows have been used as a reference point for flows recorded between 2021 and 2023.

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[6] Saint Helena Government (2023). DPLUS103 St Helena Climate Change and Drought Warning Network. Volume 1 – Climate, Volume 2 – Water Resources. Sansom B, George R, Mullings-Smith E, Groen M, Palmer S, Henry M, Walmsley B, Gray A, Muranganwa L.

[7] WS Atkins (1990). St Helena Water Plan 1990-2010. Public Works and Services Department, Saint Helena Government

3.3.1 Fishers Valley – the Peaks

Stream flow data collection started in May 2019 as part of an earlier funded monitoring project associated with the drafting of the Peaks Management Plan. Monitoring locations were integrated into the DPLUS103 monitoring network from April 2020. A summary of stream flows is presented in Table 3-1.

Table 3-1: Fishers Valley Stream Flows in The Peaks

Monitoring Location	Year	Average Stream Flow (m^3/d)	Maximum Stream Flow** (m^3/d)	No flow days	Flow Per Annum (m^3/a)	St Helena Water Plan 1990 to 2010 (m^3/d)
SW01WG	2019*	48	58	58	9,736	64.7 avge 10.2 min
	2020	98	130	22	32,393	
	2021	60	130	25	21,767	
	2022	109	130	0	39,683	
	2023***	98	130	130	23,095	
SW02WG	2019*	27	138	278	5,492	No data
	2020	77	202	115	27,639	
	2021~	51	177	133	12,006	
	2022~	144	204	0	47,382	
	2023	127	204	27	46,370	
SW03WG	2019*	121	230	20	No data	111 avge 42.6 min
	2020	98	389	8	34,820	
	2021	90	238	5	32,494	
	2022	56	191	0	20,498	
	2023	45	186	0	16,329	
SW01BG	2019*	3	4	26	552	46.8 avge 9.6 min
	2020	3	4	1	1,040	
	2021	3	4	1	943	
	2022	3	4	0	1,166	
	2023	3	4	130&	773	
Leggs Gut	2022	886	3,399	0	290,451	70 avge 10.4 min
	2023	216	1,575	151^	46,408	

*Note: 2019 is a partial year as data collection started in May 2019.

**Maximum flow in SW01GW, SW02WG and SW01BG is controlled by catchpit design and diameter of discharge pipe.

***No data collected at SW01WG between 6th January and 15th May 2023 due to equipment issues.

~The catchpit at SW02WG was reconstructed between August 2021 and February 2022, hence the number of no flow days.

`Water levels all below the bottom of the "V" in the weir except for a few days in July 2019.

&No data collected at Byrons Gut between 1st January and 15th May 2023 due to equipment issues.

^No data collected at Leggs gut between 11th August and 31st December 2023 due to equipment issues.

Data for the Wells Gut monitoring locations report flows similar to those recorded in the mid-1970's and 1980's, notwithstanding changes in climatic conditions when data was collected. Byrons Gut data differs from data recorded in the mid-1970's and 1980's and is thought to be related to the catchpit location used to calculate flows for DPLUS103, where flows are restricted to the diameter of the outflow pipe. Most flows in Byrons Gut are piped to Hutts

Gate Water Treatment Works (WTW) from higher in the catchment in an unmetered transfer pipe.

Flow data from Leggs Gut (highlighted in red) requires further review during Year 4 of the Cloud Forest Restoration Project, as it is remarkably different from the Wells Gut and Byrons Gut monitoring data and historic flows reported between 1986 to 1990. Until additional data is collected, it is recommended that historic average flows in Leggs Gut are used for any water balance as they are more representative of flows collected elsewhere in the catchment.

A Year 3 Cloud Forest project budget underspend has allowed the Water Pillar team to order new water level monitoring infrastructure for all the v-notch weirs in James Valley, Leggs Gut and Wells Gut. Infrastructure and equipment comprise new weir plates, stilling wells, gauge boards and a data logger telemetry system, so that stream flow and levels can be more reliably recorded.

3.3.2 James Valley

A summary of stream flows for monitoring locations in James Valley is presented in Table 3-2.

Table 3-2: James Valley Stream Flows

Monitoring Location	**Year**	**Average Stream Flow (m^3/d)**	**Maximum Stream Flow (m^3/d)**	**No flow days**	**Flow Per Annum (m^3/a)**	**St Helena Water Plan 1990 to 2010 (m^3/d)**
Black Bridge	2021*	320	852	0	81,047	282 avge 95.1 min
	2022	424	968	0	154,887	
	2023	316	675	4	114,225	
Drummonds Point	2021*	234	575	150	24,342	206 avge
	2022	380	992	162	63,080	
	2023***	1	239	125	133	
Harpers	2021*	126	234	156	8,161**	- avge - min
	2022	279	657	39	90,837	
	2023	231	1,293	0	84,153	
Lower Gents Bath	2021*	315	451	0	79,603	Gents Bath Spring 23 avge 6.7 min
	2022	325	598	0	118,677	
	2023	161	449	21	58,584	
Upper Gents Bath	2021*	109	334	1	27,358	
	2022	124	338	0	40,675	
	2023^	107	259	60	30,670	
Osbornes 1	2021*	117	352	70	21,277	Osbornes Spring 65 avge 16.5 min
	2022	257	579	190	44,983	
	2023	129	467	160	26,507	
Osbornes 2	2021*	211	1,455	3	52,695	
	2022	60	267	0	21,798	
	2023	24	49	0	8,700	

* Note: 2021 is a partial year as data collection started in April 2021.

**Harpers dataloggers vandalised. No data collection between July 2021 and February 2022.

*** No data between 12th and 22nd June and between 20th August and 12th December at Drummonds Point due to equipment issues.

^ No data between 1st January and 1st March 2023 at Upper Gents Bath due to equipment issues.

The Black Bridge monitoring location is a reliable long term indicator of stream flows into the bottom section of James Valley. The table shows that annual stream flows reduced by over 25% between 2022 and 2023. Rainfall data across the monitoring network confirmed 2023 as a drier year, with an average of 825mm rainfall recorded in 2022 and an average rainfall of 806mm recorded in 2023.

The Drummonds Point data set for 2023 is not complete due to a long period of problems with the data logger. Similar technical issues were encountered at the Upper Gents Bath weir.

Observations made whilst collecting water level data at the Osbornes 1, Osbornes 2, Upper Gents Bath and Lower Gents Bath V-notch weirs show that the structures silt up very quickly, which could have an adverse impact on the data collected to calculate stream flows. It is recommended that all the islands' weirs are maintained on a more regular basis by Connect to des-silt the structures and ensure water flow is unobstructed.

3.3.3 Stream Hydrographs

The water flow hydrographs for Fishers Valley monitoring locations within the Peaks indicate a variety of responses to rainfall events as shown in Figure 3-1. Precipitation has been used to describe the total recorded rainfall and mist (see Section 2 for more detail). Water levels for the catchpit at the top of Wells Gut (SW01WG) which has its source at Cabbage Spring, shows a relatively flat response. SW02 flows are controlled by the catch pit. Its continued monitoring is being reviewed as part of the Year 4 monitoring programme. Due to the pipe flow monitored at SW02, the project team will be moving to measuring a representative flow at SW03WG (the v-notch weir) for Wells Gut. The weir will have a new weir plate fitted, with a new stilling well, gauge board and data logger which will telemeter data to Connect Saint Helena for daily review.

The water flow hydrographs for the James Valley monitoring locations are presented in Figure 6-3.

Data collected between April 2021 and December 2023 show that Osbornes 1 and Drummonds Point respond quickly to rainfall events, whilst Black Bridge, Upper Gents Bath and Lower Gents Bath have a more consistent seasonal flow indicating a greater influence from groundwater (spring flows). It is worth noting differences between the rainfall response at Osbornes 1 and Osbornes 2 V-notch weirs which are located at a similar elevation and only 120m apart. Osbornes 2 appears to be more influenced by groundwater, hence the flatter response to rainfall events.

Figure 3-1: The Peaks Monthly Average Stream Flow and Rainfall

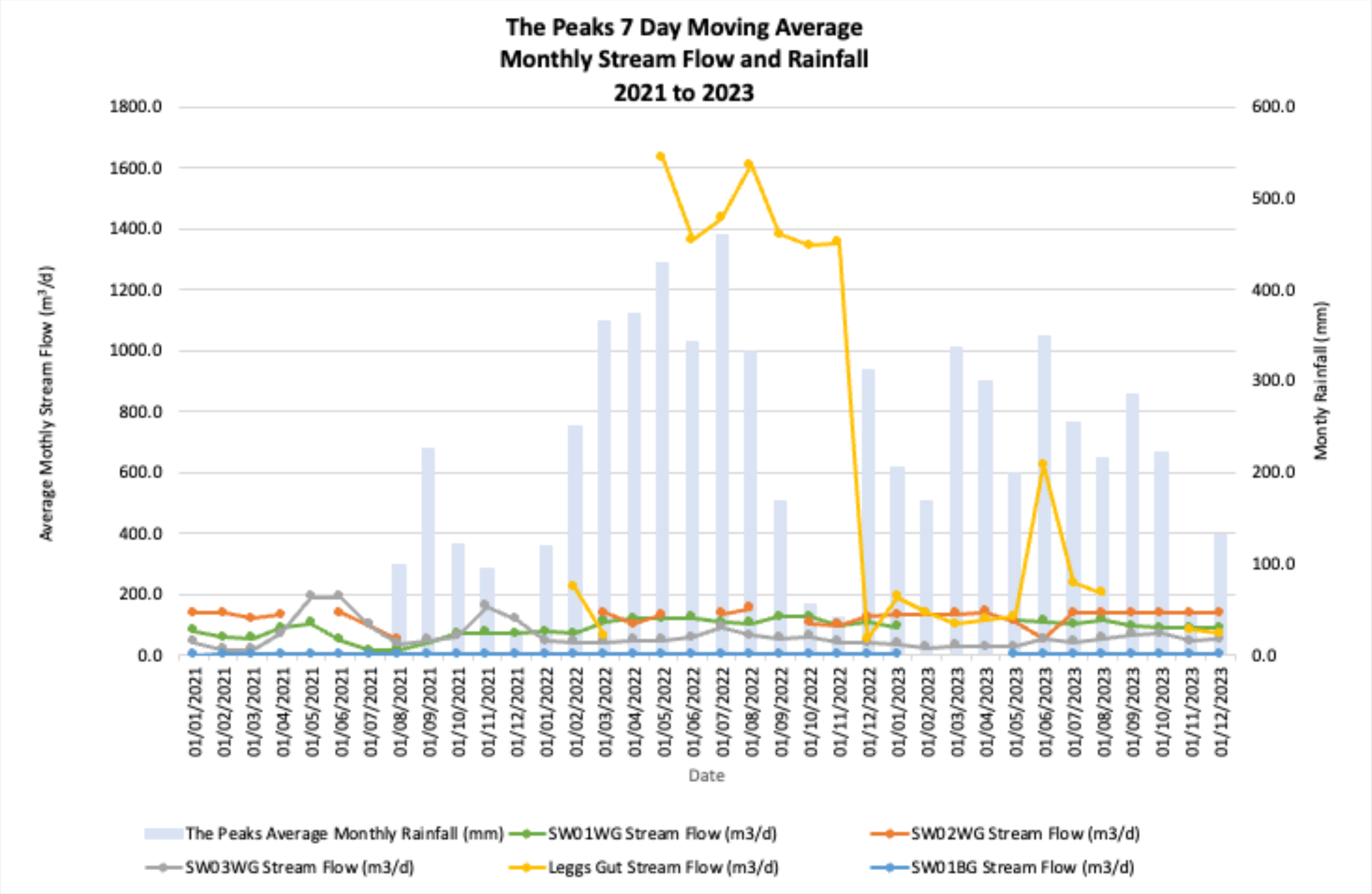
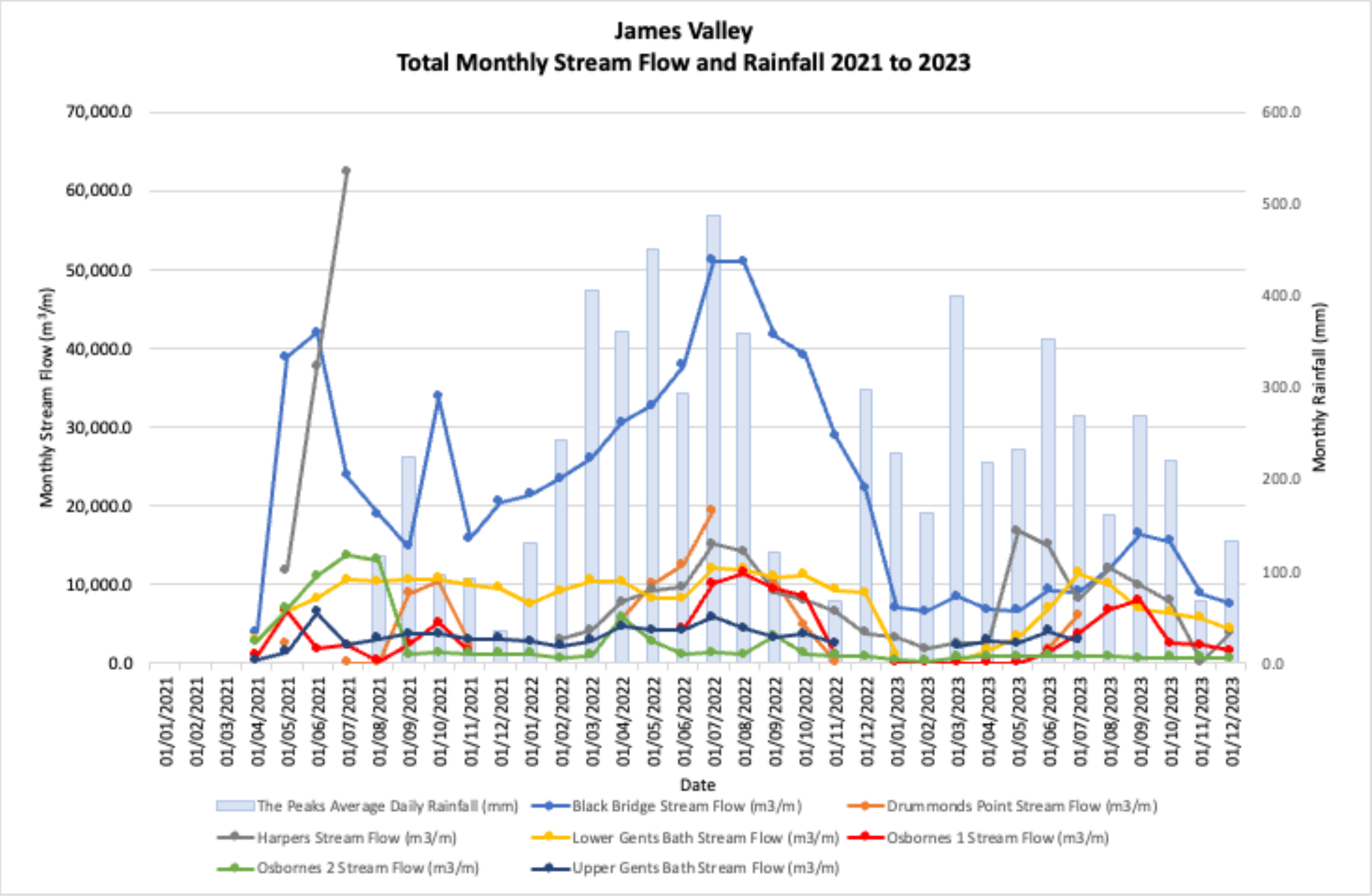


Figure 3-2: James Valley Monthly Average Stream Flow and Rainfall



3.3.4 Stream Response Times

Stream flow hydrographs for two tributaries in James Valley recorded at Black Bridge and Upper and Lower Gents Bath and a tributary of Fishers Valley (Wells Gut) have been reviewed to assess stream response times to rainfall and mist.

A series of three peak rainfall events were assessed between 21st July and 31st October 2023. They were selected as data from Connect indicated that the James Valley streams were not being abstracted for public water supply during that period. Surface water for SW03WG (also known as Lower Wells) was abstracted for public water supply all year round. A summary of the response times for all three streams are presented in Table 3-3. Hydrographs for the streams are presented in Appendix 2.

Table 3-3: Stream Flow Response

Stream	Response Times (Days)					
	Rainfall			Mist		
	3rd August	8th September	11th October	3rd August	8th September	11th October
Upper Gents Bath	2	3	9	3	6	8
Lower Gents Bath	0	1	4	1	4	4
Black Bridge	0	6	6	2	9	6
SW03WG Wells Gut	5	6	2	6	9	2

The review of rainfall response times across James Valley indicates that monitoring locations at higher and lower elevations show mixed response times. Data from the 11th October peak rainfall event cannot be assessed with any accuracy as the change in flow rate does not correlate with the rainfall record. The cause of this lack of correlation is still being investigated at the time of writing. Likewise, the quick responses at Black Bridge and Lower Gents Bath on August cannot be explained from the data collected to-date. A longer rainfall record and stream flow record will enable a more accurate assessment of stream response times to understand the mechanism for the varied stream responses to rainfall events at higher and lower elevations. It is hoped that upgrades to the v-notch weir monitoring infrastructure and flow telemetry system will improve the accuracy of data collection and help identify stream flow response times and trends.

3.4 Groundwater

A number of wellfields were developed after recommendations made by Lawrence[8], in particular Frenches Gut and Iron Pot which are located at the top of the Lemon Valley catchment. The DPLUS103 project team installed monitoring equipment in 3 boreholes located up and downstream of the Frenches Gut valley borehole and upstream of the Iron Pot pumping borehole to see if rainfall recharge could be seen in groundwater level responses. Groundwater was also monitoring in the WPS deep borehole at Molly's Gut (MGTBH01) and a shallow observation borehole in Fishers Valley.

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[8] Lawrence, A. (1983). The Groundwater Resources of St Helena, WD_OS_83_12. Overseas Development Authority.

3.4.1 Frenches Gut Well Field

Groundwater levels recorded in Frenches Gut boreholes between February 2022 and December 2023 are presented in Appendix 2. The borehole upslope of the pumping borehole named FGBH01 showed a slow change in groundwater levels when compared with rainfall events. Borehole FGBH03 is located 98m downslope of the pumping borehole showed a very minor change in groundwater levels when compared to rainfall events, however it is influenced by rainfall recharge more directly than the other boreholes. Deeper groundwater in borehole FGBH04 located 278m downslope of the pumping borehole showed almost no response to rainfall events.

3.4.2 Iron Pot Well Field

Groundwater levels recorded in two Iron Pot boreholes between February 2022 and December 2023 are presented in Appendix 2.

Both of the Iron Pot boreholes monitored showed a response to rainfall events. Borehole IPBH01(LM11) upstream of the pumping borehole showed a longer response to rainfall events, whilst the shallower borehole IPBH02 (LM7) which was located 10m from the pumping borehole showed a similar response but also recorded more frequent short-term fluctuations which are attributed to the operation of the water supply borehole pump. More data analysis is required to determine the influence of the pumping borehole on observation borehole groundwater levels.

3.4.3 Molly's Gut Wellfield

Borehole MGTBH01 monitored at Molly's Gut, was drilled by WSP as part of a deep borehole drilling project.[9] which was completed in 2017. A majority of the deep boreholes have been found to puncture upper and lower aquifer systems which have resulted in shallow groundwater draining into the lower aquifer, including MGTBH01. Borehole logs showed that MGTBH01 was drilled to 74m below ground level, however, a borehole camera survey completed in October 2022 showed that the borehole had been backfilled and installed with a case and screen to approximately 29.7m below ground level. The survey showed that the borehole had a groundwater column of 1.5m depth.

In Volume 2 of the 2023 DPLUS103 report, groundwater levels for monitoring borehole MGTBH01 were reported. During 2023 the borehole case was lifted in preparation for rehabilitation of the borehole and restore the wellfield, which has prevented the use of the borehole for continued groundwater monitoring. Connect aims to drill through the collapsed debris a further 10m to reach a total depth of approximately 40m below ground level, and then seal up to the depth of the first water strike that occurred at 30m during the deep hole drilling project. This is aimed to be completed in 2024/2025. As a consequence, another observation borehole in the Molly's Gut wellfield has been monitored, which was located approximately 10m from MGTBH01 within the wellfield compound.

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[9] WSP, 2017. Deep Aquifer Exploration Drilling Feasibility Study, St Helena Island.

Groundwater levels recorded in MGTBH02 between January and December are presented in Appendix 2. The data indicate that there is a mixed response to rainfall, but the relationship between rainfall recharge and a longer term groundwater recharge response cannot be made from the short data set.

3.4.4 Fishers Valley

Connect Saint Helena operate a borehole for public water supply in Fishers Valley in the middle of the wetland. The borehole is used during times of water stress and has a standby borehole (located 146m northwest) and observation borehole (located 194m northwest). A data logger was installed in the 5m deep observation borehole. Groundwater levels are presented in Appendix 2 and show that the shallow groundwater levels respond quickly to rainfall events. A review of the Fishers Valley Wetland indicates that groundwater levels in the observation borehole are consistent with surface water levels in the wetland, indicating they are in hydraulic continuity. This relationship is also confirmed by the groundwater response to rainfall recorded from August 2021.

3.5 Groundwater Abstractions

Connect Saint Helena groundwater abstractions for 2022 to 2023 are summarised in Table 3-4. Data for January 2023 is missing for most of the boreholes, it should be noted that for Frenches Gut and Iron Pot boreholes pumping volumes are calculated from weekly meter readings. As a consequence, it is difficult to assess the impact of groundwater abstraction on groundwater levels and rainfall recharge events.

Groundwater is primarily abstracted from the shallow boreholes in Lemon Valley and from boreholes in Fishers Valley. The Lemon Valley boreholes are located close to the top of the High Peak Ridge at elevations above 600masl and are fed by a shallow aquifer recharged by rainfall. The Fishers Valley boreholes are located at lower elevations, with Willowbank borehole at approximately 500masl and Fishers Valley borehole at 350masl. Geophysics surveys completed in 2022 indicate that the Fishers Valley borehole is located within a deeper aquifer, with the wetland located within an unconfined aquifer. The Willowbank borehole aquifer is thought to be near surface, however there is no data to corroborate this.

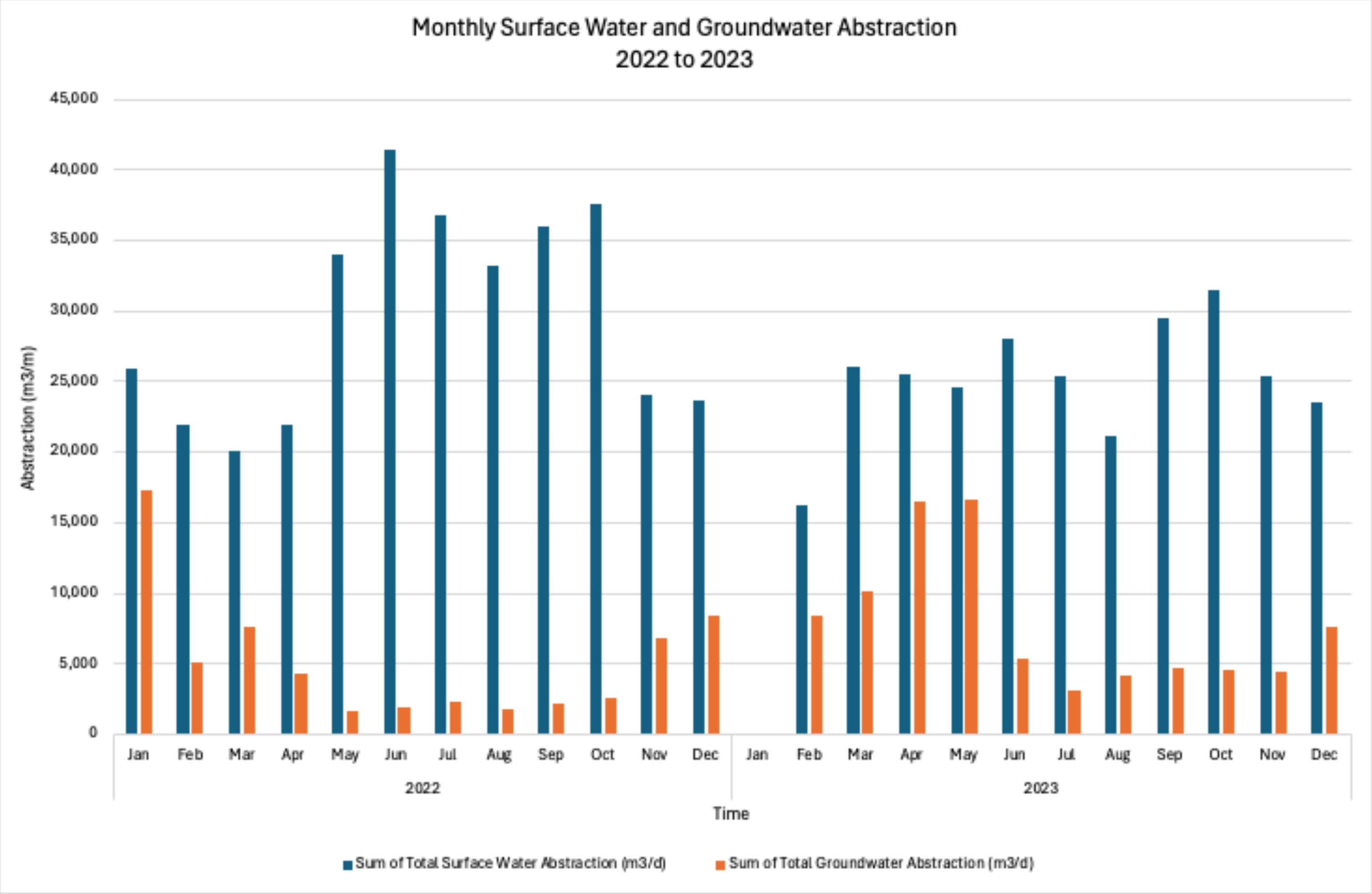
Table 3-4: Groundwater Abstraction 2022 to 2023

Date	Lemon Valley		Fishers Valley		Sharks Valley	Dry Gut
	Frenches Gut Pump House 1 (m^3/m)	Iron Pot Wellfield (m^3/m)	Willowbank Borehole (m^3/m)	Fishers Valley Borehole (m^3/m)	Warrens Gut Borehole (m^3/m)	Borehole 5 (m^3/m)
Jan-22	1,259	1,616	7,033	7,229	674	0
Feb-22	1,174	0	3,916	0	0	0
Mar-22	1,385	837	5,340	0	0	0
Apr-22	1,243	2,126	924	0	0	0
May-22	1,101	525	0	0	0	0
Jun-22	1,139	779	0	0	0	0
Jul-22	1,143	1,209	0	0	0	0
Aug-22	1,165	616	0	0	0	0
Sep-22	1,188	952	0	0	0	0
Oct-22	1,382	1,141	0	0	0	0
Nov-22	1,612	1,890	3,266	0	0	0
Dec-22	1,274	2,240	4,874	0	0	0
Jan-23						
Feb-23	1,214	3,430	3,827	0	0	0
Mar-23	1,391	3,948	4,809	0	0	0
Apr-23	1,429	10,626	4,433	0	0	0
May-23	1,406	10,962	4,269	0	0	0
Jun-23	1,250	2,534	1,549	0	0	0
Jul-23	1,329	1,827	0	0	0	0
Aug-23	1,195	2,968	0	0	0	0
Sep-23	1,204	3,534	0	0	0	0
Oct-23	1,326	3,297	0	0	0	0
Nov-23	1,707	2,751	0	0	0	0
Dec-23	1,435	2,485	3,679	0	0	0

Total 2022	15,065	13,931	25,353	7,229	674	0
Total 2023	14,885	48,362	22,566	0	0	0

A summary of monthly total abstraction for surface water and groundwater sources is presented in Figure 3-3.

Figure 3-3: Monthly Surface Water and Groundwater Abstractions



The total monthly groundwater and surface water abstractions indicate that groundwater is mainly pumped during the summer months to augment reduced stream flows. Groundwater is primarily abstracted from Frenches Gut and Iron Pot to support local water supplies to the west of the island where there are limited surface water courses and springs. Willowbank borehole is used to supplement water supplies at the Hutts Gate treatment works during the summer months, with the Fishers Valley borehole used as a standby supply during more acute water shortages. The deep aquifer exploited by Borehole 5 in Dry Gut is being tested by Connect with the aim to introduce deeper groundwater into the islands water supply during periods of water stress.

Based on water supply data provided by Connect, surface water abstractions accounted for 83% of total raw water abstracted in 2022 and 69% of total raw water abstracted in 2023.

3.6 Water Chemistry

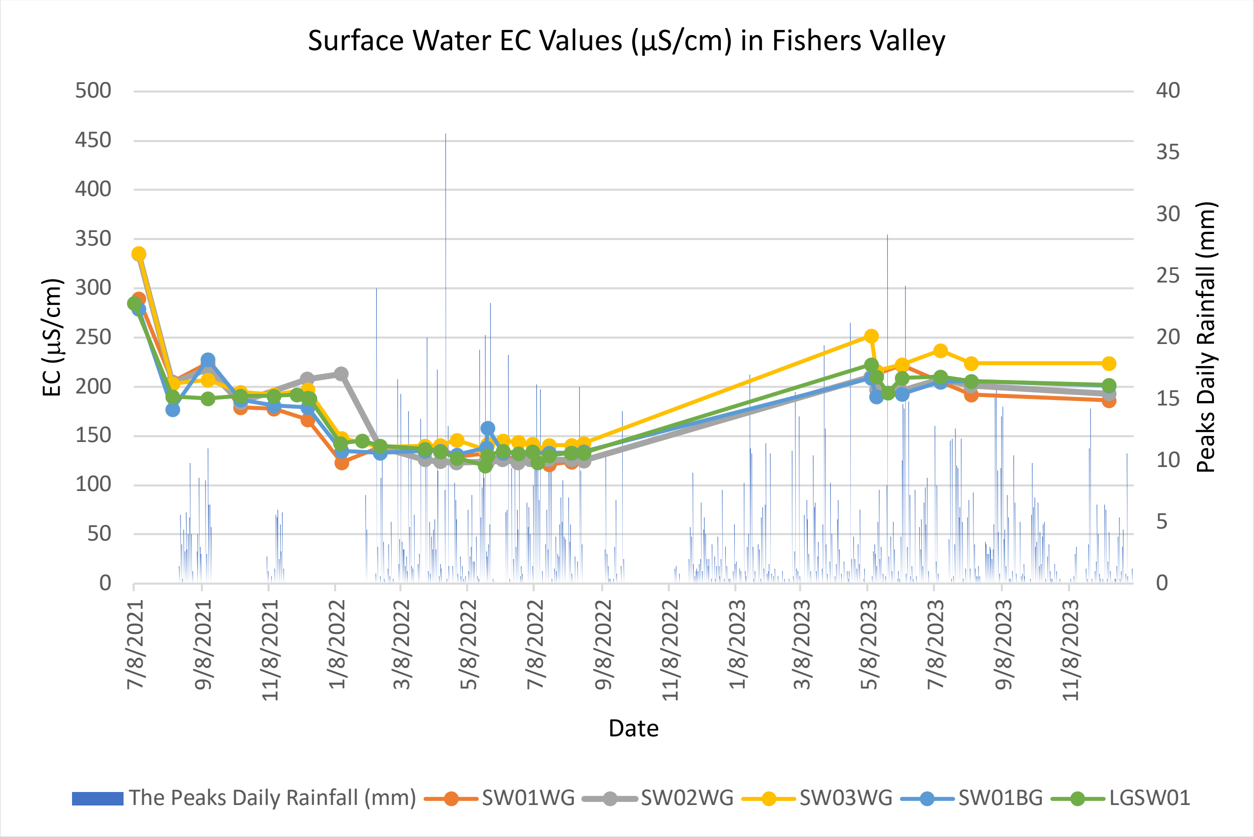
Water chemistry data has been collected from surface water sources within the monitoring network, to provide additional data and information to support the understanding of the relationship between surface water and geology within the catchments.

Manual water chemistry data of surface water was collected during site visits to the monitoring network for surface water levels and flow data downloads and maintenance visits. This was measured using a handheld Hanna Instruments multiprobe that was loaned to Connect from EMD. A handheld Hanna Instruments multiprobe was purchased later in Year 3 for Connect to use, which has the capability to measure samples with a much higher EC value, and can also measure an additional parameter of Dissolved Oxygen.

Manual water chemistry readings have been collected for the following parameters: Temperature, Electrical Conductivity, pH and Total Dissolved Solids between July 2021 and September 2022. Manual readings re-started from March 2023 when the new multiprobe was obtained and have added Dissolved Oxygen to the data sets.

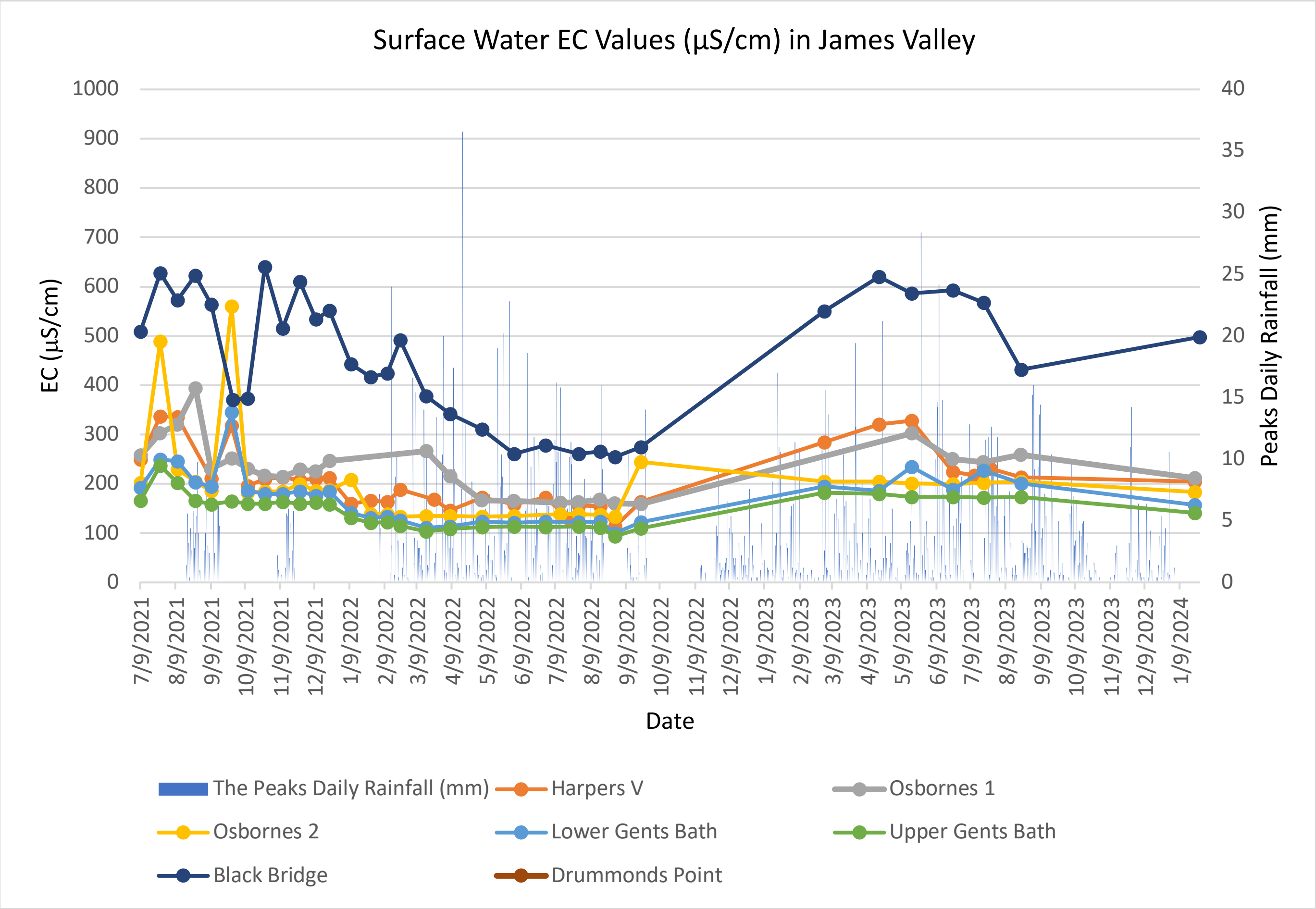
Electrical Conductivity (EC) readings taken at surface water monitoring locations in Fishers Valley and James Valley are presented in Figure 3-4 and Figure 3-5.

Figure 3-4: Fishers Valley Surface Water EC Readings



Due to issues with the water chemistry multi-probe, the water quality data set between July 2021 and January 2024 is missing. The monitoring locations in the upper reaches of Fishers Valley (Leggs Gut, Wells Gut and Byrons Gut) show similar EC values. The information collected to-date does not show a clear trend between rainfall and salinity due to the missing data.

Figure 3-5: James Valley Surface Water EC Readings



Due to issues with the water chemistry multi-probe, the water quality data set between July 2021 and January 2024 is missing. The salinity of surface water measured at Drummonds Point and Black Bridge is up to three times higher than monitoring locations in the upper parts of the James Valley catchments. The Black Bridge monitoring location receives water from the higher parts of Briars Gut, with Drummonds Point comprising spring flow and surface water from the base of the Heart Shaped Waterfall. The remainder of the monitoring locations are at higher elevations above the Heart Shaped Waterfall and Harpers.

The information collected to-date does not show a clear trend between rainfall and salinity.

Leggs Gut V-Notch Weir
Photography by Capricorn Studios
www.capricorn-studios.com

4 Amended Water Balance

4.1 Methodology

The Year 3 water balance using data collected during 2023 has been refined by the development of a spreadsheet catchment water balance. Each catchment has been subdivided into three zones by elevation:

- **Zone 1**. Land above the 690m contour (where previous studies have indicated mist interception in the cloud forest occurs alongside rainfall recharge).
- **Zone 2**. Land between the 500m and 690m contours (where rainfall recharge is believed to occur; and
- **Zone 3**. Land below the 500m contour (where PE is believed to be greater than rainfall e.g. no rainfall recharge occurs).

A table showing each catchment within each zone and its area is provided in Appendix 4.

A review of previous water balances has highlighted how important the calculation of Potential Evapotranspiration (PE) is for an accurate balance. As a detailed assessment of PE has not been possible due to the short length of the recent monitoring record, however PE values from several literature sources and global PE modelling studies[10] have been used to develop four water balance scenarios:

A. Water Balance A – using PE for land above the 500m contour and below the 500m contour (derived by Ian Mathieson from Hutts Gate and Jamestown climate data[11]).
B. Water Balance B – a single value for PE derived by Mathieson from data collected at Hutts Gate.
C. Water Balance C – Global modelled values of PE for each zone.
D. Water Balance D – using PE values for each water catchment and zone using AWS data.

The following climate data scenarios were selected for 5 model runs of each water balance:

1. Average island rainfall for each zone. Zone 1 is assumed to have 100% mist contribution to total precipitation (rainfall + mist).
2. Zone rainfall for each catchment calculated from the climate monitoring network. Zone 1 is assumed to have 100% mist contribution to total precipitation (rainfall + mist).
3. Zone rainfall for each catchment calculated from the climate monitoring network. Zone 1 is assumed to have 10% mist contribution to total precipitation (rainfall + mist).
4. Zone rainfall for each catchment calculated from the climate monitoring network. Zone 1 is assumed to have 1000mm[12] mist contribution to total precipitation (rainfall + mist).

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[10] Elnashar, A., Wang, L., Wu, B., Zhu, W., and Zeng, H.: Synthesis of global actual evapotranspiration from 1982 to 2019, Earth Syst. Sci. Data, 13, 447–480, https://doi.org/10.5194/essd-13-447-2021, 2021. Following values of PE estimated for each Zone from global model data: Zone 1 = 1000mm. Zone 2 = 500mm. Zone 3 = 1500mm.

[11] Atkins (1990) St Helena Water Plan (Final) 1990 – 2010. Public Works and Services Department, Saint Helena Government

[12] Ellison, D. *et al.* (2017) 'Trees, forests and water: Cool insights for a hot world', *Global Environmental Change*, 43, pp. 51–61. Available at: https://doi.org/10.1016/J.GLOENVCHA.2017.01.002

5. Zone rainfall for each catchment calculated from the climate monitoring network. It is assumed that there is no contribution from mist to total precipitation.

Mist data has been reported in Section 2.2. For the purposes of the water balances, it has been assumed that 1000mm of the 2023 average mist is available for recharge, with the remaining mist evaporated from the cloud forest canopy (2,184mm).

4.2 Connect Saint Helena Water Abstraction

Combined groundwater and surface water abstraction data collected between 2009 and 2021 are presented in Figure 4-1. Data is recorded as an inflow into each of the islands four Water Treatment Works (WTW) and is summarised in Table 4-1.

Figure 4-1: Connect Water Abstraction 2009 to 2021

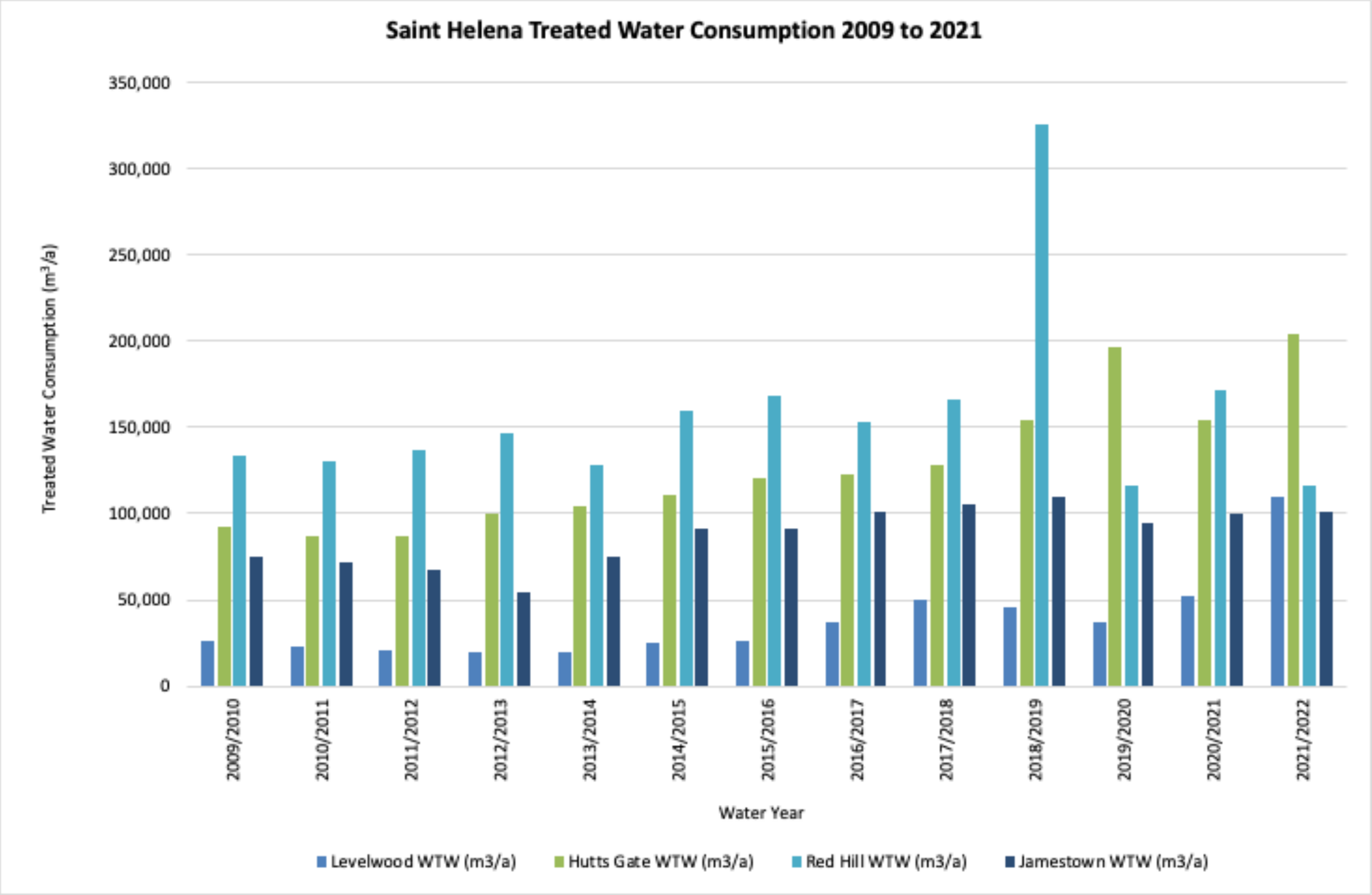

Table 4-1: Annual Water Abstraction 2009 to 2021

Year	Levelwood WTW (m^3/a)	Hutts Gate WTW (m^3/a)	Red Hill WTW (m^3/a)	Chubb Spring WTW (m^3/a)	Annual Total (m^3/a)
2009	26,154	92,577	133,903	75,007	327,641
2010	23,219	87,157	130,400	71,582	312,358
2011	21,120	86,504	137,099	67,220	311,943
2012	19,899	100,421	146,973	54,243	321,536
2013	19,599	103,968	127,957	74,732	326,256
2014	24,919	110,399	159,343	91,271	385,932
2015	25,982	120,490	167,896	91,205	405,573
2016	36,553	122,722	152,688	100,917	412,880
2017	50,340	128,144	166,065	105,571	450,120
2018	45,628	154,410	325,553	109,867	635,458
2019	36,865	196,467	116,373	94,094	443,799
2020	52,690	154,565	171,022	100,124	478,401
2021	109,865	203,754	116,260	101,379	531,258
Annual Average (m^3)	**37,910**	**127,814**	**157,810**	**87,478**	**411,012**
Monthly Ave (m^3)	**3,159**	**10,651**	**13,151**	**7,290**	**34,251**
Daily Ave. (m^3)	**104**	**350**	**432**	**240**	**1,126**

Table 4-2 below summarises annual average inflows into each WTW. Over the 12-year record, the Red Hill and Hutts Gate WTW provide on average 69% of the islands water supply.

Table 4-2: Summary of WTW Inflows

WTW	Annual Average WTW Inflow (m^3)	Proportion of Annual Inflows (m^3)
Red H-ill	157,810	38%
Hutts Gate	127,814	31%
Levelwood	37,910	9%
Chubb Spring	87,478	21%
Total	**411,012**	

Between 2018 and 2021, the Hutts Gate WTW has principally been supplied by surface water abstractions from Leggs Gut and Wells Gut (47%) and groundwater from Willowbank and Fishers Valley boreholes (40%). Some additional surface water is piped from Grapevine Gut and Levelwood reservoir (13%).

Between 2018 and 2021 the Redhill WTW was principally supplied by surface water abstracted from sources in James Valley (68%), Oakbank Well – a surface water source (11%) and water transfers from Chubbs Spring and Hutts Gate (21%).

During the same period Levelwood WTW received 69% of water from the two Deep Valley stream sources and 27% from groundwater abstracted from Warrens Gut. During February 2023, operational challenges caused the Warrens Gut borehole to come out of service. The borehole is now operational and is ready for use.

Jamestown WTW received abstracted surface water from Black Bridge (11%). Spring sources at Drummonds Point, Chubbs Spring, Tom Peters Spring and Hambess spring supplied 84% of the treatment works water supply.

4.3 Previous Water Balances

Water balances published in archive reports are summarised in Table 4-3.

Table 4-3: Earlier Water Balances for St Helena

Publication	Water Balance Year	Island Discharge (Million m^3 per annum)
Halcrow, 1969[13]	1969	3.8
Lawrence, 1983[14]	1979 to 1990	1.5 to 2.5
Atkins, 1990[15]	Used 10 years of water resource monitoring data	4.5

The Halcrow water balance was based on stream flow data collected over a 3-week period during the summer months and is very much an approximation. The hydrogeology report and conceptual model published by A.R. Lawrence in 1983 assessed groundwater recharge in the area above the 500mASL contour (approximately the area above the 600mm rainfall isohyet).

The Atkins Water Management Plan water balance reported that a discharge of 4.6million m^3 represented 10% of total rainfall (47million m^3 rainfall per annum). It supported the significance of the Peaks for the generation of stream flow. The area above 900mm rainfall isohyet is only 5.3% of the island area, but in an average year was calculated to generate 31% of rainfall percolation. At the time, the report did not include mist interception in the water balance calculation and recognised that a higher proportion of stream flow across the island could be supported by the Peaks if mist is included in future water balances. The Management Plan also indicated that the close balance between water supply and demand, a small increase in rainfall in the Peaks will mostly be contributing to stream discharges so that a 10% increase in rainfall could lead to a 30-40% increase in stream discharge.

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[13] Sir William Halcrow and Partners (1969) 'Report on the Water Resources of St Helena'.

[14] Lawrence, A. (1983). The Groundwater Resources of St Helena, WD_OS_83_12. Overseas Development Authority.

[15] WS Atkins (1990). St Helena Water Plan 1990-2010. Public Works and Services Department, Saint Helena Government

4.4 Catchment Area Water Balance 2023

The water balance for 2023 has been calculated on a catchment basis and compared against catchment balances reported by the Public Works and Services Department in 1990[16]. Table 4-4 summarises the island water balances for Water Balance D climate scenarios.

Table 4-4: Island Water Balances 2023

Water Balance Climate Scenario	Rainfall & Mist Recharge Above 690m (m^3/a)	Rainfall Recharge Between 500m and 690m (m^3/a)	Average Water Abstraction 2009-2022 (m^3 per annum)	Total Island Discharge (Million m^3 per annum)	St Helena Water Plan 1990 (Million m^3 per annum)
1 - Average Rainfall + Total Mist	6,023,586	1,751,174	411,012	6.95	4.50
2 - Zone Rainfall + Total Mist	6,025,290	1,706,503	411,012	6.91	
3 - Zone Rainfall & 10% Recorded Mist	945,482	1,706,503	411,012	0.53	
4 - Zone Rainfall & 1000mm Mist	2,153,745	1,706,503	411,012	3.04	
5 - Zone Rainfall and No Mist	381,059	1,706,503	411,012	1.27	

Note: No recharge below 500m

For the purposes of this report, the most representative developed in Year 3 was Water Balance D – Scenario 4 (highlighted in green in Table 4-4), using calculated PE values for 2023 climate data and assuming 1000mm mist is available for recharge.

Water balances for each catchment in each rainfall recharge zone are presented in Appendix 4. The key water resource catchments used by Connect Saint Helena are Deep Valley, Fishers Valley, James Valley and Lemon Valley. Table 4-5 summarises water balances for these key catchments using data for 2023.

Table 4-5: Key Water Supply Catchment Water Balances 2023

Catchment	Connect SW/GW Abstraction (m^3/a)	Proportion of Total Abstraction (%)	Recharge (m^3/a)	Stream Flow (m^3/a)	Surplus/ Deficit (m^3/a)	Surplus/ Deficit (%)
Deep Valley	40,950	12%	280,243	40,950	239,293	85%
Fishers Valley	109,604	33%	244,173	92,074	134,569	55%
James Valley	114,509	35%	378,993	90,054	264,484	70%
Lemon Valley	63,247	19%	165,331	0	102,084	62%

Total Abstraction	328,310.0	100%		**Total Surplus**	740,430

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[16] Atkins (1990) St Helena Water Plan (Final) 1990 – 2010. Public Works and Services Department, Saint Helena Government

The catchment water balances indicate that during 2023, each catchment had a surplus of over 55% available recharge. Much of the surplus recharge is groundwater recharge. Section 6 describes a revised Water Resource Areas Conceptual Model for the island water and indicates why much of the surplus recharge in each catchment is currently more difficult to exploit by Connect Saint Helena.

The top 5 recharge sub-catchments in Zone 1 and Zone 2 for Water Balance D, Scenario 4 are presented in Figure 4-2 and Table 4-6.

Table 4-6: Top 5 Recharge Sub-Catchments

	Zone 1	**Zone 2**
Recharge Sub-Catchments	James Valley	James Valley
	Sandy Bay Gut	Sandy Bay Gut
	Lemon Valley	Lemon Valley
	Fishers Valley	Fishers Valley
	Swanley Valley	Sharks Valley

In the majority of cases all sub-catchments conform to the 4 key water catchments used by Connect for the islands water supply, confirming their significance for a sustainable water supply. The only outlier is Swanley Valley (Zone 1) which has a higher recharge in Zone 1 than Deep Valley (the 6th highest recharge in Zone 1 for the model scenario).

Table *4-8* provides a comparison of the catchment recharge complete by Toens[17] in 2000 with the catchment water balances completed for 2023, using Water Balance D, Scenario 4. The table shows that the year 2000 calculated recharge is 65% of the 2023 recharge. The area of the island which supports recharge is only 28.6% of the islands total land mass, emphasising the importance of the green heartland and cloud forest for supporting the islands water supply.

The table also shows that differences between annual climate data and calculated PE are instrumental in variations of catchment recharge calculated between years and show the importance of implementing an accurate protocol for measuring PE for the island, which is representative of the islands vegetation. Whilst Zone 1 is important for the islands overall water supply, Lemon Valley in Zone 2 is also important for groundwater recharge.

4.5 Wet and Dry Year Comparison

A comparison of annual water balances between 2017 and 2023 for the Fishers Valley catchment is presented in Table 4-7.

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[17] Toens & Partners (2000). An Assessment of the Groundwater Resources of St Helena Island, T&P Report No. 2000241.

Table 4-7: Fishers Valley Water Balance - Wet and Dry Year

Catchment	**Zone 1 - Catchment Above 690m**							
	Catchment Area (m^2)	**Catchment Rainfall (m/a)**	**Catchment Mist (m/a)**	**PE (m/a)**	**Rainfall Recharge (m^3/a)**	**Streamflow (m^3/a)**	**Connect Abstraction (m^3/a)**	**Surplus/Deficit (m^3/a)**
Fishers Valley 2023	190,445	0.953	1.000	0.671	244,173	94,228	87,038	62,907
Fishers Valley 2017 - wet year	190,445	1.383	1.000	0.671	326,042	228,911	137,586	-40,455

The years were selected based on available monitoring data, with 2017 representing a wet year as February 2017 was the 6th wettest month on record and the third highest rainfall recorded during February. Despite this, the island was coming out of a drought, so additional groundwater was abstracted from the Fishers Valley borehole to augment water supply across the island.

The data illustrate that the water balance in the catchment can be significantly changed due to increases in groundwater abstraction and stream flow. The abstraction is not thought to have impacted the catchment surface water features, with groundwater storage exploited during the period the borehole was pumped. For the annual water balances, 2017 recorded 25% higher rainfall recharge than 2023. Streamflow in 2017 was 60% higher than 2023, which may be partly attributed to changes in water monitoring structures within Wells Gut and corresponding changes in the accuracy of recorded stream flow.

V-notch weirs across the island are being upgraded in the second half of 2024 and will improve the reliability and accuracy of surface water flow data collection. Coupled with a longer data set, it is expected that the interpretation of data between years will become more accurate and reliable.

Figure 4-2: Top 5 Recharge Sub-Catchments 2023

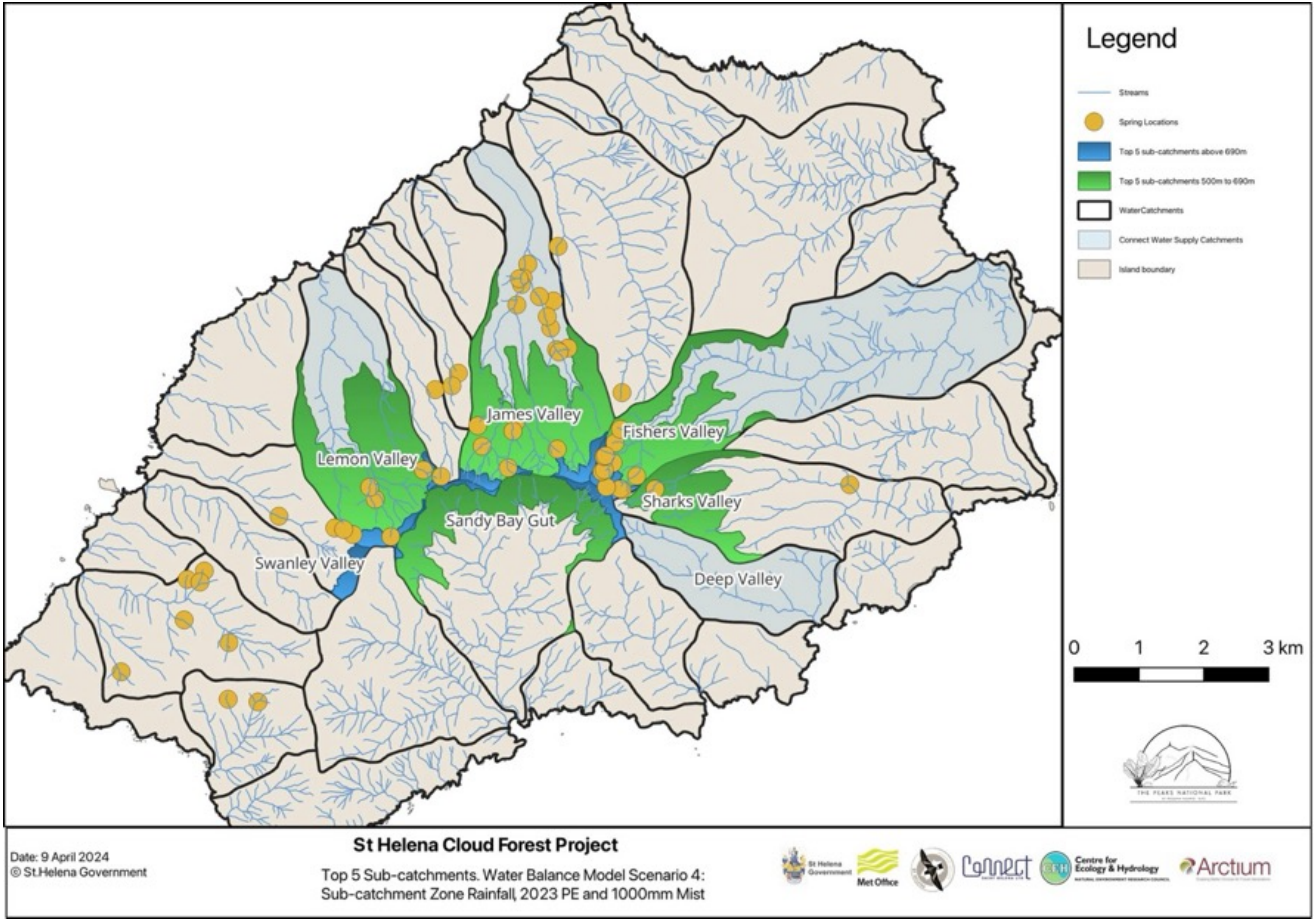


Table 4-8: 2023 Recharge Compared to Toens 2010

Catchment	**Zone 1 Catchment Area (m^2)**	**Zone 2 Catchment Area (m^2)**	**Zone 3 Catchment Area (m^2)**	**Catchment Area (km^2)**	**% Total Area (Zone 1 + Zone 2)**	**Mean Annual Precipitation 2023 (mm)***	**Annual Precipitation 2023 (mm) (Rainfall +1000mm mist)**	**2023 Annual Recharge Above 500m (m^3)****	**Recharge Rate (%)**	**Toens Annual Recharge Above 500m (m^3) *****	**Toens Recharge as % of 2023 Recharge**
St Helena Island				**123.37**	**100%**						
Area >500m				27.63							
Banks Valley	376	373,403	2,712,266	3.09	3.30%	562	1,685	177	16.85	0	
Breakneck Valley		226,872	1,629,583	1.86	5.44%	682	682	0		5,266	100%
Broad Gut	123,843	1,488,499	4,543,142	6.16	0.77%	807	2,421	110,070	24.21	39,841	36%
Deep Valley	152,865	801,558	2,373,088	3.33	1.29%	880	2,640	156,756	26.40	35,121	22%
Dry Gut	190,445	93,983	4,678,875	4.96	4.34%	690	690	0	6.90	1,398	
Fishers Valley	67,062	2,195,278	7,921,167	10.18	0.55%	914	2,741	207,798	27.41	81,489	39%
Friars Valley	291,702	985,272	1,228,596	2.51	0.97%	913	2,739	70,429	27.39	77,923	111%
James Valley	234,266	3,532,719	3,381,289	7.15	0.33%	951	2,835	323,065	28.35	259,793	80%
Lemon Valley		3,406,855	2,430,440	5.84	0.36%	875	2,626	235,498	26.26	208,094	88%
Manati Bay Stream		757,275	1,872,619	2.63	1.63%	553	553	0		13,193	
Old Woman Valley	35,739	1,295,499	1,877,866	3.21	0.93%	810	2,430	31,161	24.30	63,944	205%
Powells Valley	24,273	578,603	2,785,309	3.39	2.05%	892	2,677	24,770	26.77	21,795	88%
Ruperts Valley		1,065,785	7,115,929	8.18	1.16%	801	801	0		43,982	
Sandy Bay Gut	293,349	2,185,615	5,129,175	7.61	0.50%	940	2,820	382,854	28.20	145,648	38%
Sharks Valley	133,245	1,492,679	4,080,738	5.71	0.76%	898	2,695	139,881	26.95	44,559	32%
Swanley Valley	195,114	1,222,773	1,473,286	2.89	0.87%	829	2,488	179,632	24.88	69,462	39%
Thompsons Valley	27,085	2,090,548	3,196,984	5.31	0.58%	738	2,213	21,596	22.13	58,395	270%
Turks Cap Valley		1,419,514	7,316,127	8.74	0.87%	616	616	0		11,489	
Youngs Valley		647,122	1,011,922	1.66	1.91%	825	825	0		35,686	
Total					**28.58%**			**1,883,687**		**1,217,078**	**65%**

*Average of catchment zone rainfall and mist **Note: water balance for 1000mm mist contribution. *** Toens and Partners Report No.2000241, 2000

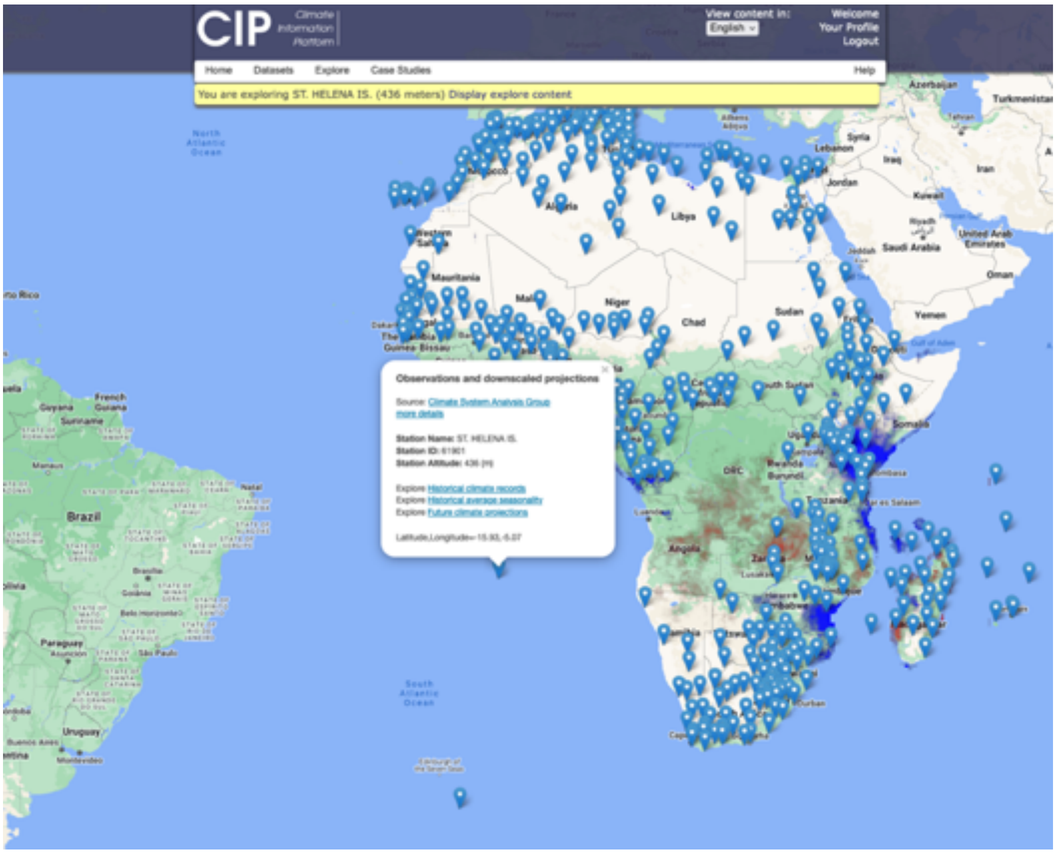
15 unnamed catchments which make up the remaining 23.5% (28.98km^2) of the island area have been excluded from this assessment in order for a direct comparison with the Toens water balance.

4.6 Climate Change

4.6.1 Local Scale Climate Model for St Helena

The University of Cape Town has developed local scale climate models based on the larger IPCC climate change model for Africa (including those for St Helena) and can be located through the climate web portal of the Climate Systems Analysis Group (CSAG[18]) (Figure 4-3).

Figure 4-3 University of Cape Town Climate Information Platform



You are exploring ST. HELENA IS. (436 meters) Display explore content

Observations and downscaled projections

Source: Climate System Analysis Group
more details

Station Name: ST. HELENA IS.
Station ID: 61901
Station Altitude: 436 (m)

Explore: Historical climate records
Explore: Historical average seasonality
Explore: Future climate projections

Latitude,Longitude=-15.93,-5.67

The downscaled models are based on the RCP4.5 and RCP8 greenhouse gas concentration model scenarios and include climate data collected by the UK Met Office at the Bottom Woods weather station on St Helena. The models output climate change scenarios for temperature and rainfall up to 2100. For the purpose of this assessment, we have principally looked at climate model results in the medium future for the period between 2040 to 2060. The models use climate data for the period 1980 to 2000. A full assessment of the climate model outputs was reported in the DPLUS103 reports published in 2023.

4.6.2 Local Scale Climate Model Rainfall Outputs

Figure 4-4, Figure 4-5 and Figure 4-6 show predicted changes in rainfall, maximum daily rainfall and the number of wet days on St Helena for the RCP4.5 model scenario. The climate model outputs do not agree as well for rainfall however they show that the months of May and June are expected to be far drier with a reduction of between 10 to 16mm rainfall (up to 25% drier

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[18] https://www.csag.uct.ac.za/ & https://www.csag.uct.ac.za/climate-services/cip/

in May and 30% drier in June, based on the monthly long-term average rainfall reported at Bottom Woods Met Station). January, September and November are predicted to be wetter months with an additional 4 to 5mm rainfall (between 14% and 26% higher than the monthly long-term average rainfall reported at Bottom Woods Met Station). The number of wet days increases by at least 0.5 day for January and February, with November expected to have an additional 2 wet days. For the RCP8 model scenario, the average change in is very similar.

Figure 4-4: St Helena Total Monthly Rainfall (RCP4.5 scenario)

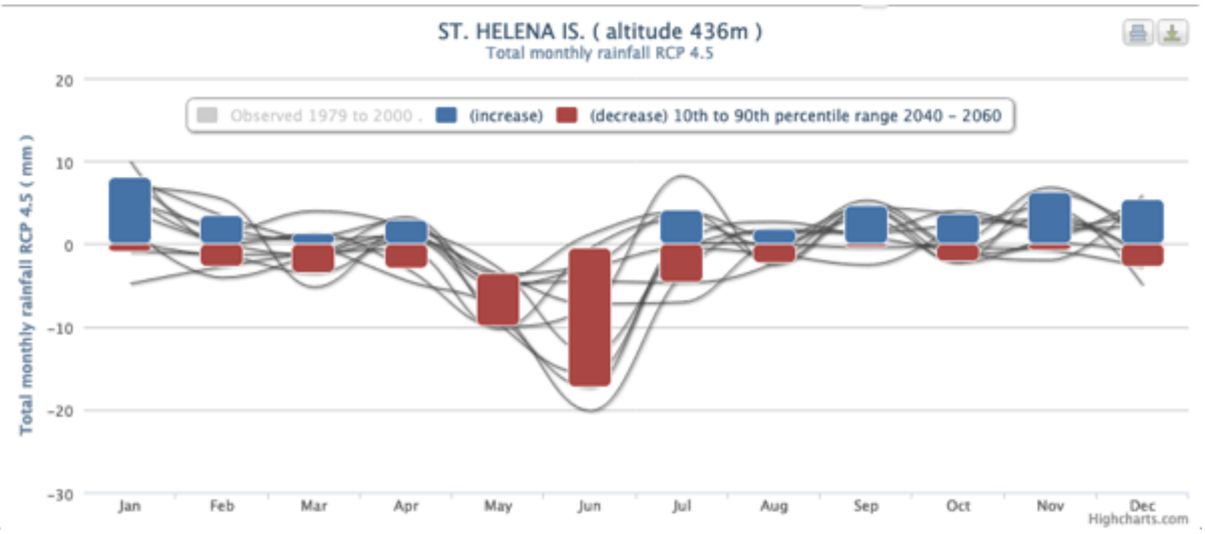


Figure 4-5: St Helena Maximum Daily Rainfall (RCP4.5 scenario)

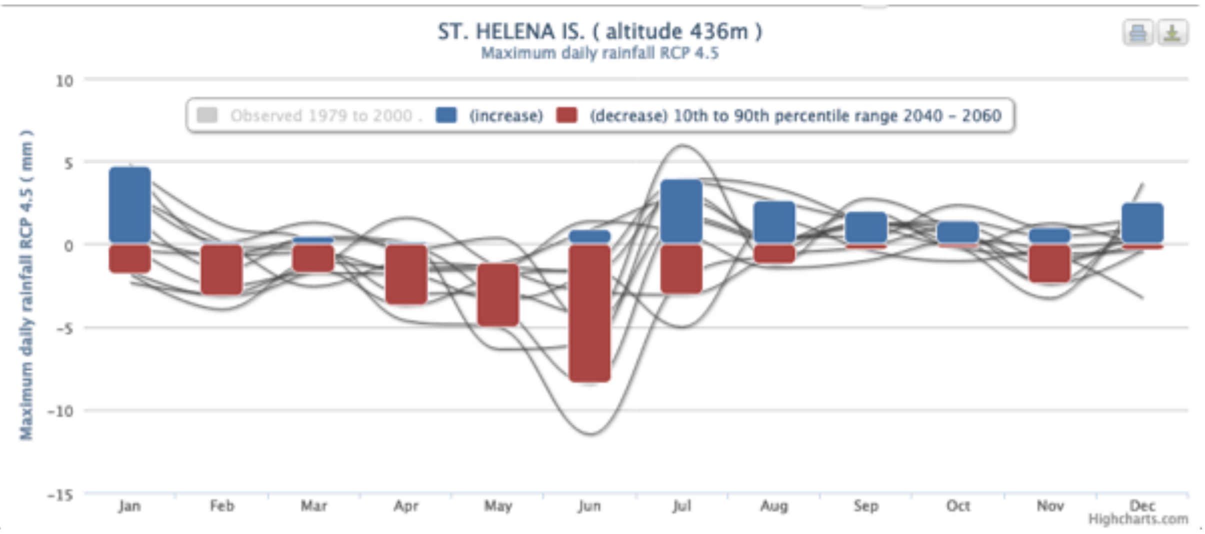
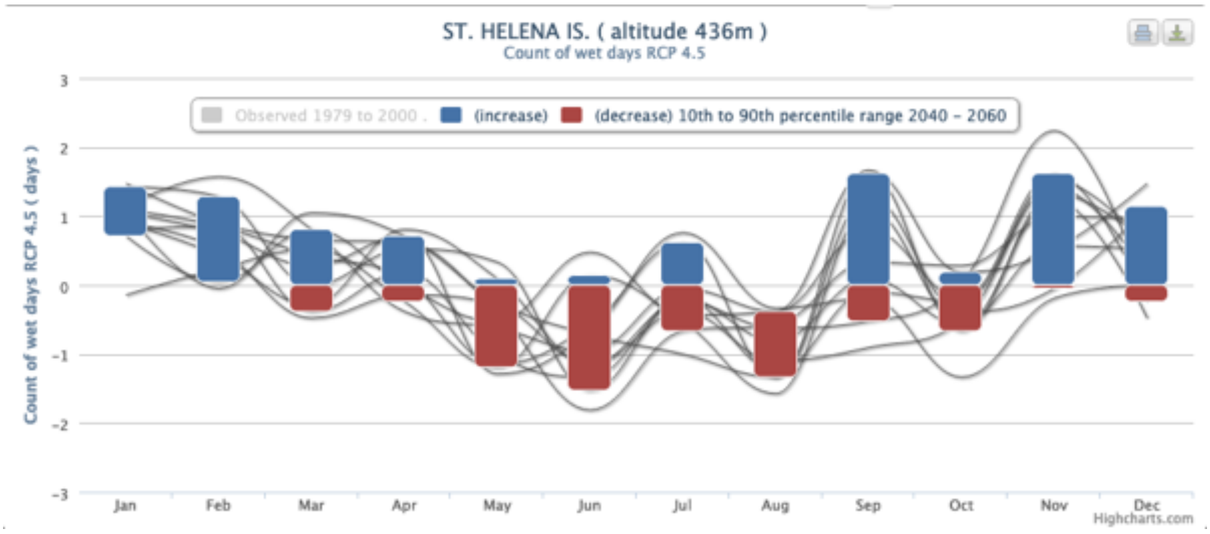


Figure 4-6: St Helena Number of Wet Days (RCP4.5 scenario)



4.6.3 Water Balance Climate Model

Using the outputs from the University of Cape Town local scale climate change model, a revised island water balance has been developed using Water Balance D – Scenario 4 outputs. Table 4-9 shows the best case and worst-case climate change water balances for the island compared with 2023 Water Balance D – Scenario 4. The climate change water balances were based on the 2023 island water balance and adjusted for monthly modelled changes in monthly rainfall (best case and worst case).

Table 4-9: Island Climate Change Water Balance

Water Balance Scenario	Rainfall & Mist Recharge Above 690m (m^3/a)	Rainfall Recharge Between 500m and 690m (m^3/a)	Rainfall Recharge Below 500m (m^3/a)	Average Water Abstraction 2009-2022 (m^3/a)	Total Island Discharge (Million m^3/a)
4 - Zone Rainfall & 1000mm Mist 2023	2,153,745	1,706,503	0	411,012	3.45
Climate Change Best Case +7%	2,304,507	1,825,958	0	411,012	3.72
Climate Change Worst Case -3%	2,002,983	1,587,047	0	411,012	3.18

Based on the RCP4.1 climate model data for St Helena, the worst-case climate change impact on the islands water balance is a 3% decrease in recharge.

A monthly water balance for Wells Gut and Harpers catchments above 500m elevation was calculated, as they have the most complete and reliable data sets and illustrate the monthly changes in recharge due to the impacts of climate change. The water balances for 2023 were compared revised water balances using RCP 4.1 climate change model best case and worst case predicted changes in monthly rainfall. A summary of the monthly water balances compared with climate change model outputs are provided in Table 4-10 and Table 4-11.

Table 4-10: Lower Wells Monthly Climate Change Water Balance

Month	Lower Wells Water Balance 2023 (m^3/d)	Lower Wells - RCP 4.1 Worst Case (m^3/d)	Lower Wells - RCP 4.1 Best Case (m^3/d)
Jan-23	8,284	8,039	10,245
Feb-23	-2,570	-2,834	-2,175
Mar-23	14,329	13,400	14,638
Apr-23	4,435	2,980	4,823
May-23	6,487	4,616	4,675
Jun-23	18,594	13,263	15,758
Jul-23	18,321	17,115	19,528
Aug-23	19,304	18,675	19,934
Sep-23	37,208	37,208	39,726
Oct-23	43,114	42,225	45,485
Nov-23	6,488	6,264	7,608
Dec-23	17,086	16,270	18,308

Table 4-11: Harpers Monthly Climate Change Water Balance

Month	Harpers Water Balance 2023 (m^3/d)	Harpers - RCP 4.1 Worst Case (m^3/d)	Harpers - RCP 4.1 Best Case (m^3/d)
Jan-23	217,606	213,060	253,973
Feb-23	5,162	270	12,499
Mar-23	328,852	311,627	334,594
Apr-23	139,233	112,235	146,433
May-23	167,437	132,744	133,830
Jun-23	402,978	304,075	350,357
Jul-23	400,730	378,349	423,110
Aug-23	423,919	412,248	435,590
Sep-23	766,789	766,789	813,510
Oct-23	884,677	868,187	928,650
Nov-23	188,217	184,059	209,006
Dec-23	387,723	372,588	410,385

For Lower Wells, the water balance is in deficit during February for all scenarios. The worst-case climate change scenario shows a deficit in all months when compared with the water balances for 2023. The best case scenario shows reduced recharge in May and June, with an increase in recharge for all other months compared to the 2023 water balance.

For Harpers catchment, the worst-case climate change scenario shows a reduction in recharge for all months except September which reports no change when compared to 2023. The best-case climate change scenario shows a reduction in recharge in May and June with an increase in recharge for all other months.

Based on the current monthly water balance data, St Helena should prepare for a 3% decrease in recharge between 2040 and 2060. The islands water network will need to plan for a climate change reduction in water supply for the months of February, May and June. Longer term water resource monitoring will support more accurate assessments of the climate change impacts on the islands water supply.

5 Geophysics Data Interpretation

A detailed description of geophysics techniques used to support the interpretation of catchment geology is provided in Section 5 of Volume 2 of the DPLUS103 project report[19]. The following sections comprise an update to Section 7 of Volume 2 of the 2023 DPLUS103 report. This update supersedes all interpretation from the 2023 report.

Understanding the complex geology and hydrogeology of St Helena is an ongoing process. Every type of information (old and new) such as borehole logs, groundwater and surface water monitoring data, meteorological and climatological data, data from pumping tests, water quality measurements, is important and should be stored properly and kept accessible for future investigations. This report section provides an update on our understanding of the geology of key water supply catchments, but due to the complex volcanic geology cannot be seen as a definitive answer, as gaps in our knowledge still remain to be answered through future phases of fieldwork.

In January 2022 a field reconnaissance and desk study were completed with the aim of investigating the application of geophysical resistivity imaging methods for groundwater prospecting for the DPLUS103 project. The ERT field measurements were collected in November 2022. A third and last visit was scheduled in October 2023 for additional measurements and final interpretation, combined with other data collected in the same project (geology, water balance, water chemistry, borehole camera). This last visit fits within the framework of the St Helena Cloud Forest Project which provided additional fieldwork budget and equipment, such as the new ABEM LS2 Terrameter geophysical instrument which is compatible with the cable reels and electrodes purchased through DPLUS103.

The geophysics data interpretation deals with the first results and a preliminary conceptual interpretation of the ERT measurements executed in November 2022 and October 2023.

5.1 Application of Electrical Resistivity Tomography (ERT) on St Helena

The instrumentation used in St Helena in the second and third period is an ABEM SAS4000 transmitter/receiver in combination with ES64 switch box and 4 reels of 100m, with 21 electrode connections each, resulting in a total of 84 different electrode positions and potentially much more than 1000 possible measurements. A fully stretched survey line with the reels in use, is in total 400m, with 84 possible electrode positions and 5m distance between the electrodes.

The equipment is shown in Figure 5-1 with the left image showing high resolution shallow measurement (small electrode distances), electrodes and connections. The right image shows mid-point of a 400 m profile in Fishers Valley. The bottom schematic in the Figure shows a set up with 4 reels.

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[19] Saint Helena Government (2023). DPLUS103 St Helena Climate Change and Drought Warning Network. Volume 2 – Water Resources. Sansom B, George R, Mullings-Smith E, Groen M, Walmsley B and Gray A.

Several protocols were experienced. The Schlumberger/Gradient protocol gave the best results in standard deviation and the amount of useful data points. At every ERT location 3 different positions of the instrument were applied in order to obtain the highest resolution. With this setup an exploration depth of 70 meter can be reached in the centre of the survey line and highest resolution laterally. The inversions were calculated with the RES2DINV software by Loke. Because of the severe change in topography along the profiles in relation to the exploration depth, the topography data of the DEM is incorporated in the inversion calculation.

Figure 5-1: ERT Setup

Vertical Electrical Sounding[20] (VES) was used to investigate the resistivity of the geological units and to see if this method of rock differentiation would be an appropriate geophysical parameter to help in determining subsurface geology and to provide additional physical information and context for water catchment of interest.

A Volterra 3 VES was supplied by the Practica Foundation and used in the second fieldwork period to test its suitability for fast, shallow and relatively simple measurements to acquire the resistivity of different (exposed) rock types and to investigate if it could be used for soil moisture monitoring applications. Figure 5-2 shows the collection of shallow Volterra Wenner measurements: left image - soils with different water content, (only 4 electrodes are in use); middle image - Volterra measurement on an andesitic dyke (at the top of Thomson Valley) and right image – measurements of in-situ weathered rock.

In the third period of fieldwork, the resistivity of different exposed rock types was measured at several locations using the Volterra.

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[20] VES were trialled using a Volterra 3 VES purchased through the Cloud Forest Restoration Project.

5.2 Combining Data Sets for Geophysics Interpretation

The interpretation of the ERT data is only possible in combination with existing information. The main sources of information are the existing reports, Geology (Baker, 1967[21]), Hydrogeology (Lawrence, 1983[22]), the digital elevation model (2019), Satellite image's (Google-earth and LANDSAT), various reports on boreholes and information made available by Connect. All this information is combined in a GIS project.

Figure 5-2: Volterra 3 VES

By using GIS, several sources of information and parameters can be compared. Figure 5-3 shows the relationship between altitude, geology and springs based on the DEM, the geology according to the map of Ian Baker and the location of springs using GIS data from Connect. From this Figure it can be seen that springs are concentrated into two groups between approximately 200m to 400mASL and between approximately 500m to 700mASL, which are related to the Upper Shield Western Volcanic activity and Main Shield Western Volcano.

The DEM is also used for the ERT profiles and to locate the measurements on the topography in relation to the geology. The difference in scale is obvious. The visual combination of information will lead to certain concepts and interpretations: see Figure 5-4 as an example for such interpretation.

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[21] Baker I. (1968). The Geology of St Helena Island, South Atlantic. PhD thesis, University College London.

[22] Lawrence, A. (1983). The Groundwater Resources of St Helena, WD_OS_83_12. Overseas Development Authority.

Figure 5-3: Spring Locations, Geology and Elevation

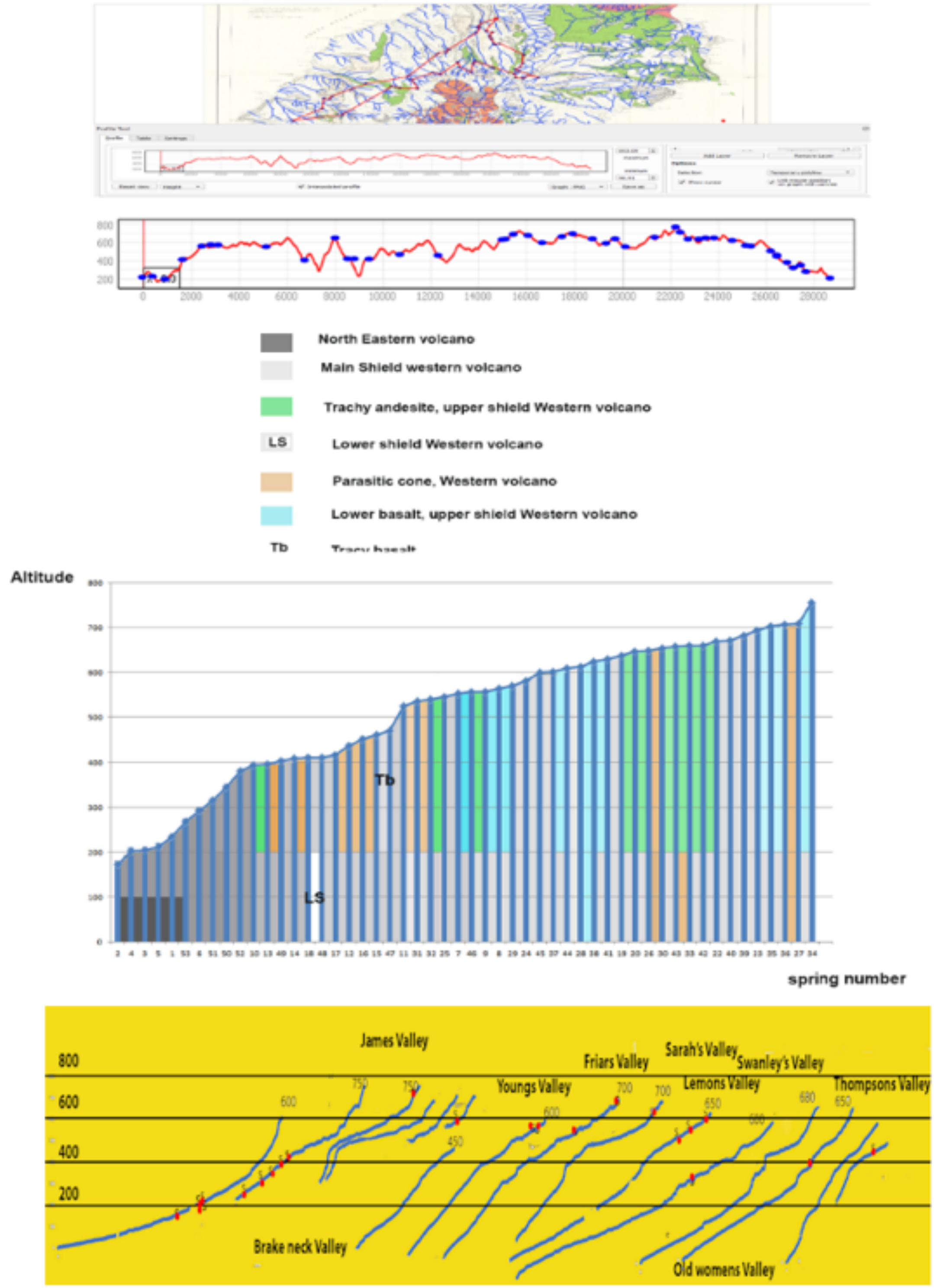
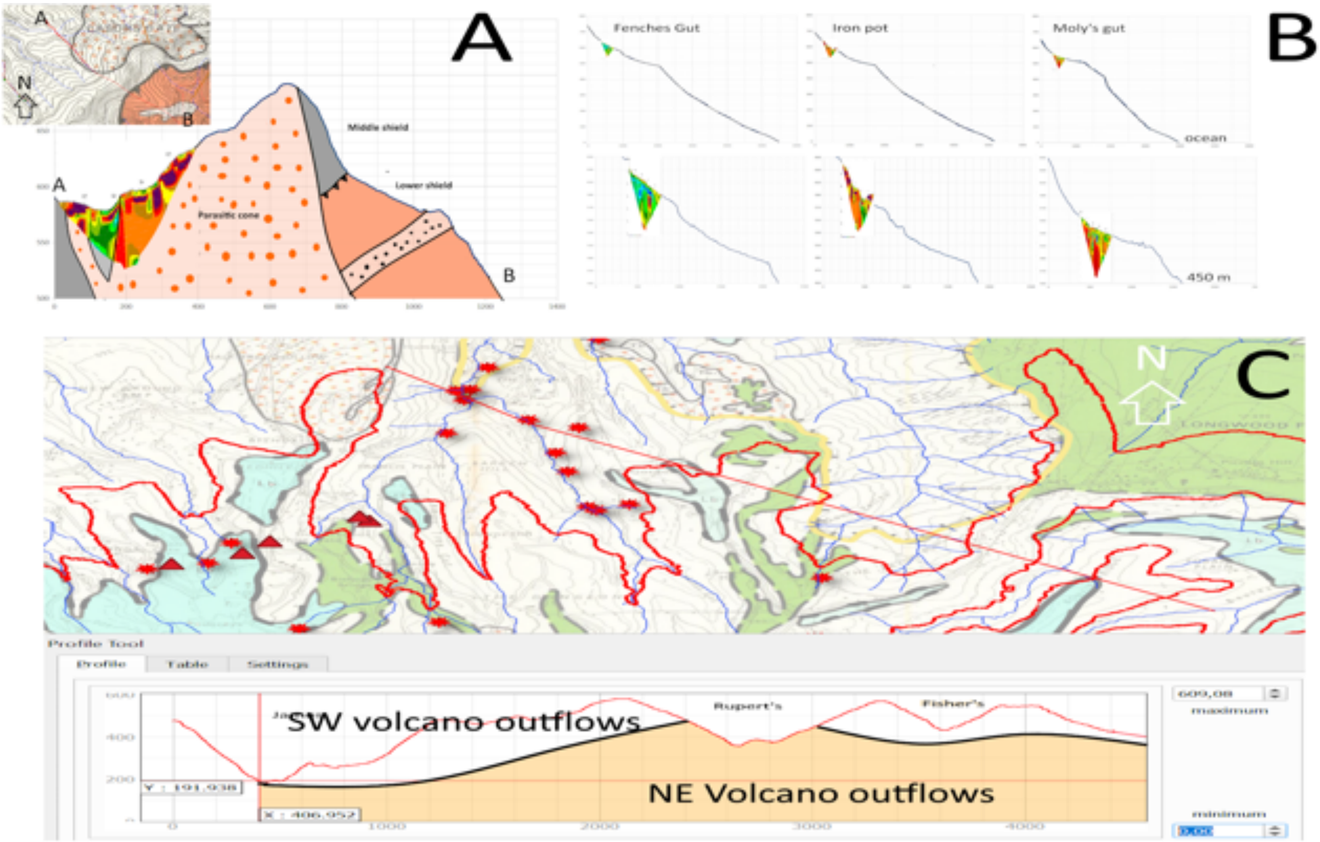
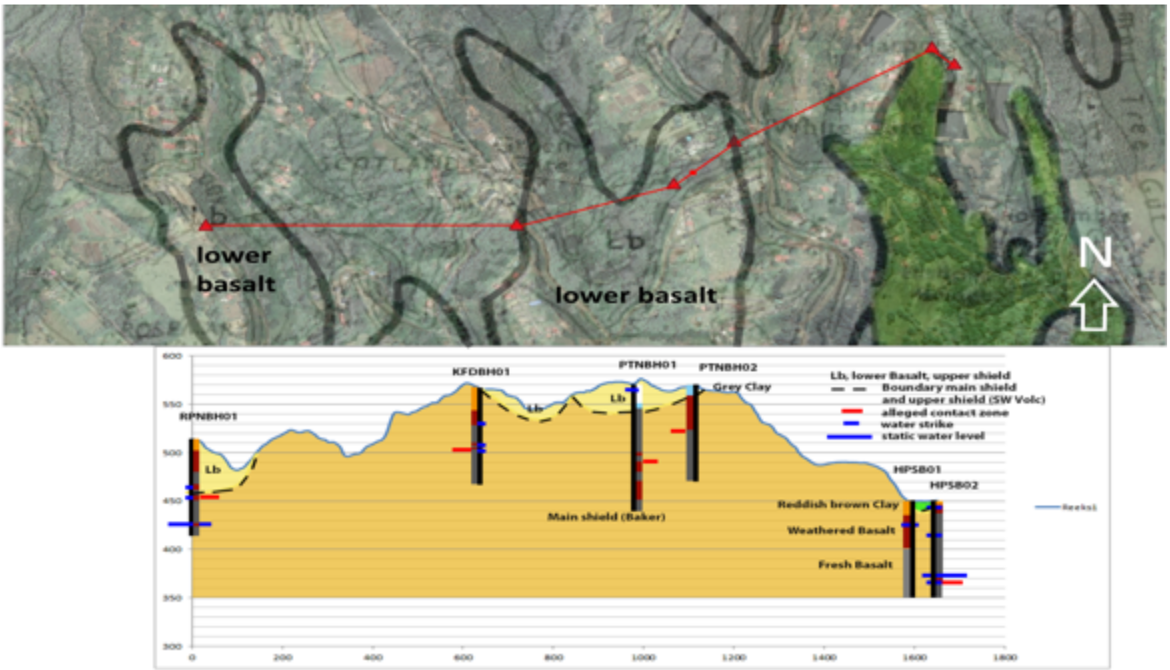


Figure 5-4: Combining DEM, ERT and GIS Data Sets



With the DEM, borehole information of existing boreholes can be compared in relation to the different levels of water strike and ground water. Figure 5-5 illustrates how the comparison of altitude, water strike, water level, geology of deep borehole locations can be achieved. From this figure the compartmentation of the aquifer systems can be observed.

Figure 5-5: Boreholes, Water Levels and DEM

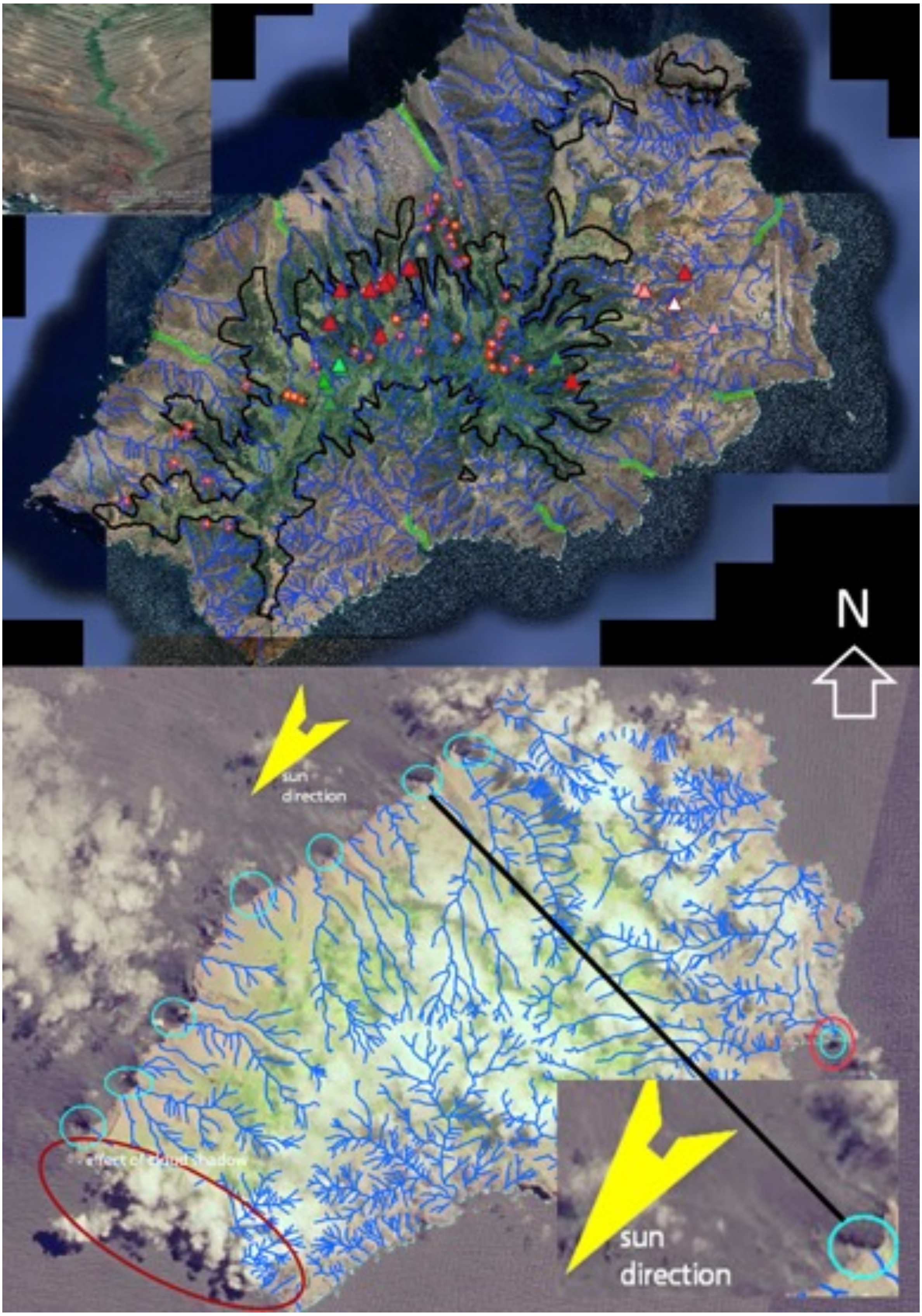


The DEM is also very useful to visualize outcrops and the superposition of the catchments (see Figure 5-6. The upper satellite image indicates vegetation below the 500m elevation where rainfall occurs. Triangles are visited boreholes (red triangles are inflow boreholes), springs (stars), streams (blue lines) and valleys with vegetation until the shoreline. The black line is the 500m rainfall isohyet, where recharge below this elevation is understood to be zero.

Satellite images can be used for monitoring vegetation in relation to the existence year-round surface and superficial groundwater. Thermal infra-red (TIR) images can be used to detect sub-surface groundwater flow into the ocean. The bottom image in Figure 5-6 shows a raw thermal infrared satellite image of seasonal temperature differences in the ocean around St Helena. Black spots could be due to the shadow of clouds and or cliffs or outflow of cooler water. Blue circles could indicate possible locations of surface water or subsurface ground water outflow. The spot at the end of Dry Gut (small red circle) is most probably due to the shadow of the cliff. The dark spot in the bay of James Valley, no visible clouds, at the opposite of the shadow side is intriguing.

Further research is needed to investigate the outflows of deep groundwater from the island using these data sets, linked with water quality sampling of the freshwater/saltwater interface in coastal caves which have been observed by the local dive community. This information would support the refinement of catchment and island-wide water balances and help understand where most of the recharge flows from the island into the Atlantic Ocean.

Figure 5-6: DEM and Superposition of Catchments



5.3 Measurement Locations

Based on the results of the first reconnaissance visit 7 ERT locations were proposed:

1. Lemon Valley – subsurface groundwater outflow into the ocean.
2. Iron Pot well field – located in a tributary of Lemon Valley (identify the relationship between deeper groundwater and superficial groundwater flow).
3. Frenches Gut well field – located in a tributary of Lemon Valley (identify the relationship between deeper groundwater and superficial groundwater flow).
4. Fishers Valley – located within the candidate RAMSAR wetland adjacent to the Connect water supply borehole (identify the relationship between the relative saline superficial groundwater and the deeper groundwater).
5. Wells Gut – located along the path leading to the Connect Saint Helena Spring source catch pits (identify the relationship between deeper groundwater and superficial groundwater flow).
6. Grapevine Gut – along the side of the above ground reservoir (identify the relationship between deeper groundwater and superficial groundwater flow).
7. Dry Gut – borehole 5 (BHDG5) used by St Helena Airport. This deep borehole has fresh water when pumped, but surrounding deep boreholes in the same valley are saline.

In the second period of field work 12 ERT measurements at 11 different locations were completed. The proposed location 6 (Grapevine Gut)was left out because of the limited length of the profile according to the desired exploration depth. Instead, ERT14 was executed along Harper's dam. ERT2, 3 and 12 were related to testing different instrument settings and were not interpreted. In the third fieldwork period (October 2024) 4 more ERT profiles were completed in:

1. Fishers Valley – extending existing measurements and connecting geophysics lines from fieldwork period 2.
2. Dry Gut, close to BHDG5 where the fieldwork period 2 geophysics line was extended.
3. Rosemary Plan – an extended ERT profile was completed close to a deep borehole drilled by WSP.

The location of ERT measurements is shown in Figure 5-7. An overview of ERT measurements is shown in Figure 5-8 and visited boreholes are shown in Figure 5-9.

Figure 5-7: ERT Measurement Locations

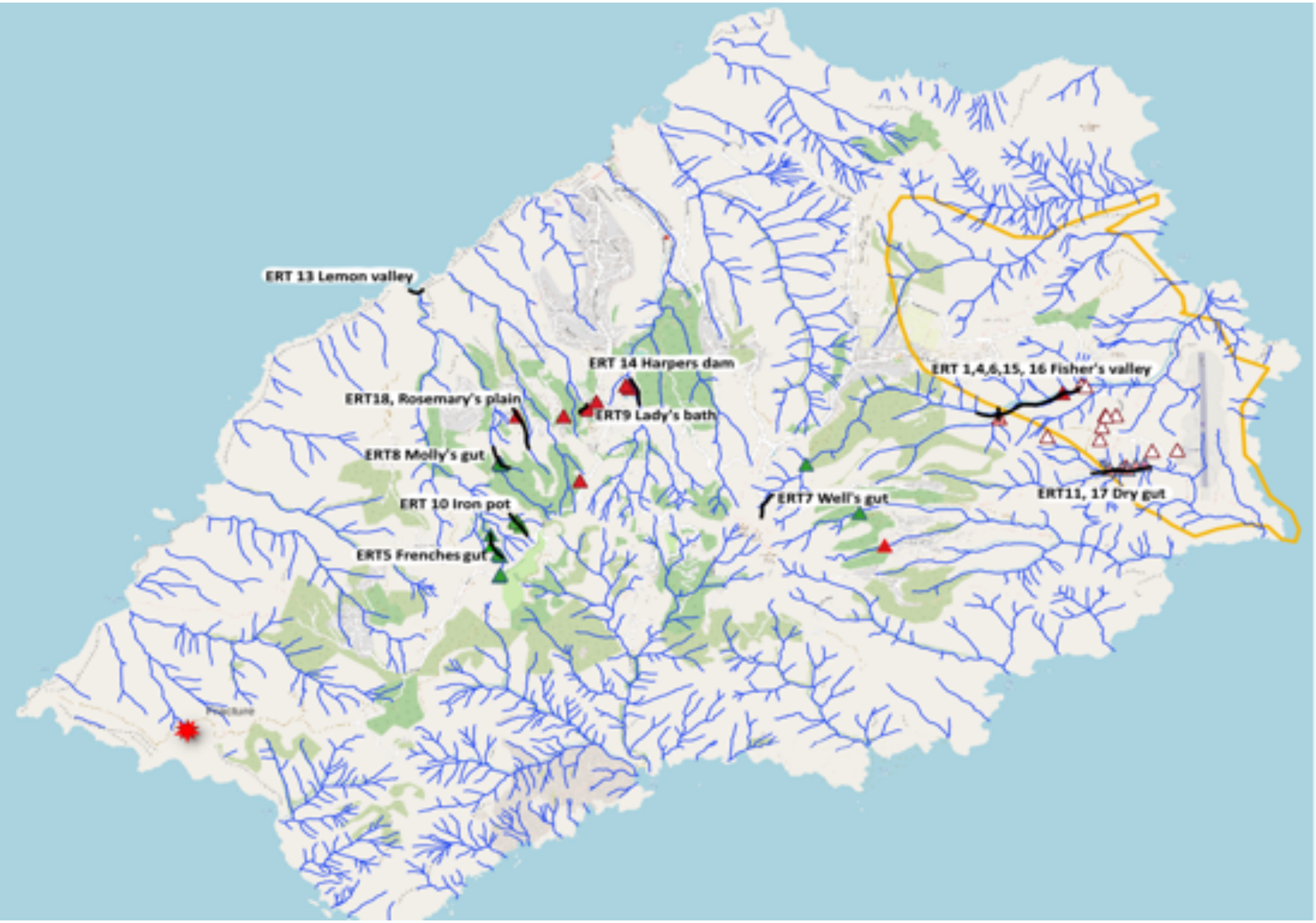
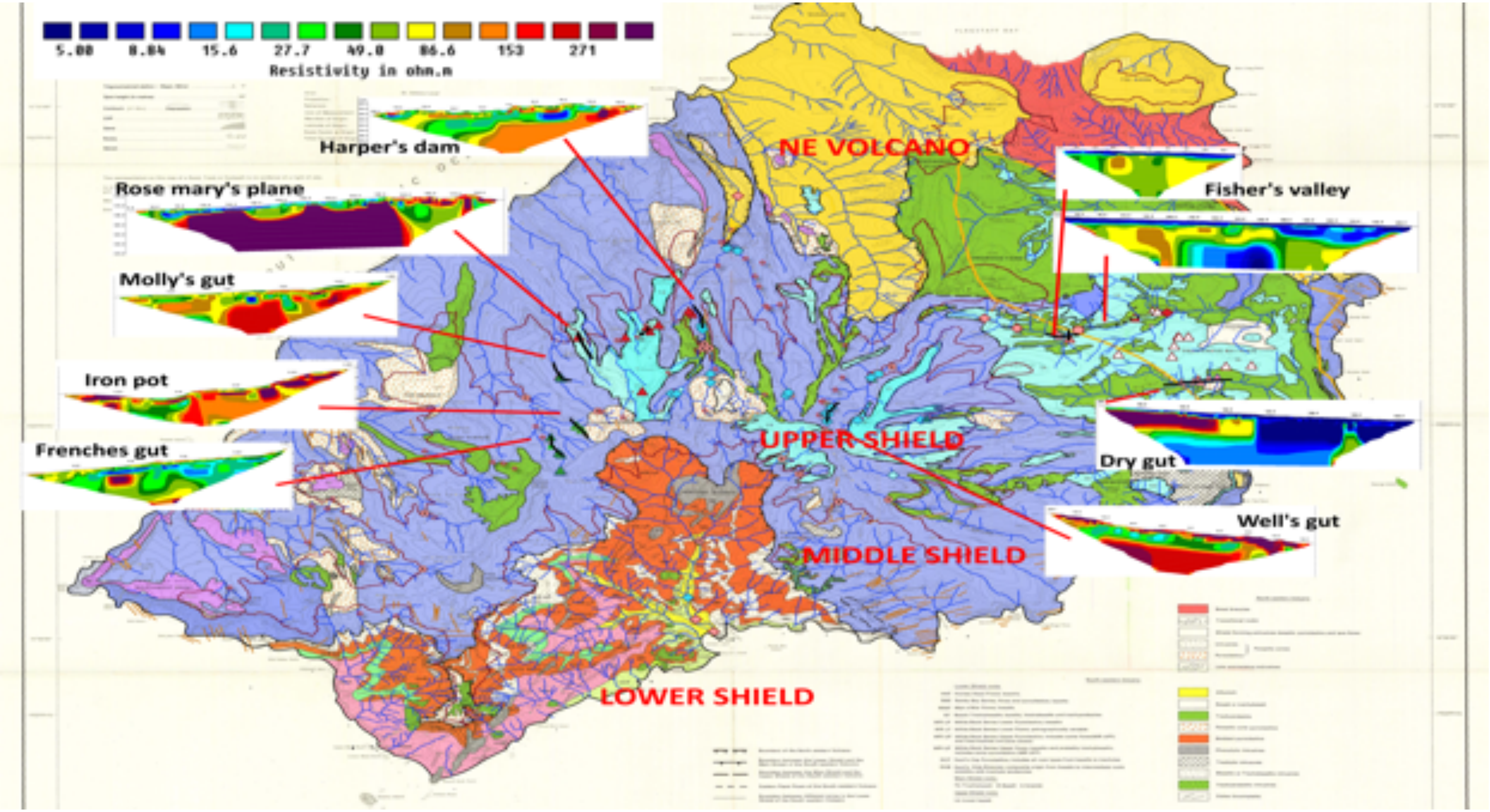
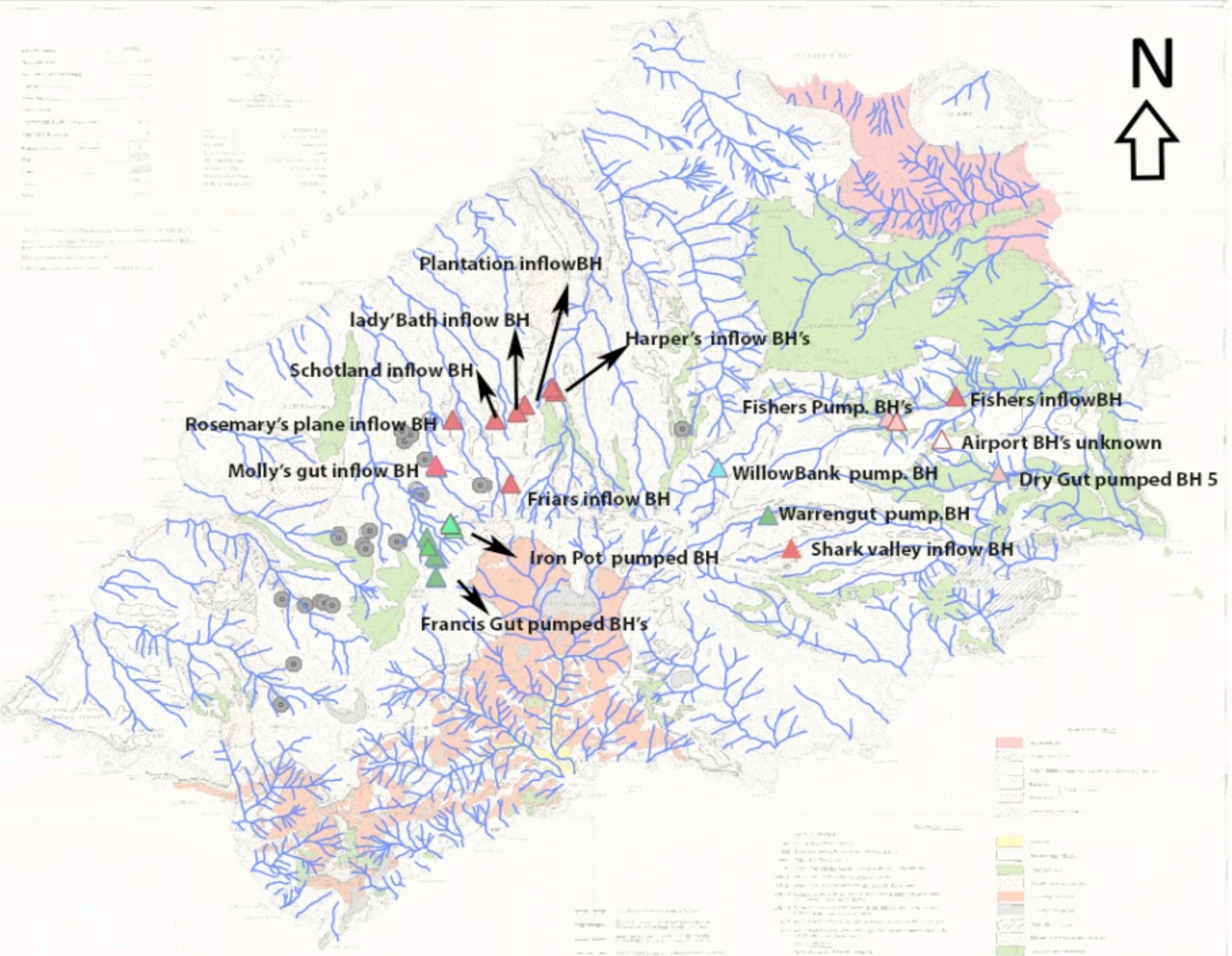


Figure 5-8: Overview of ERT Measurements



Note: Overview of most of the ERT measurements, projected on the geological map produced by Ian Baker. The Upper Shield outflow (light blue, lower basalt) seems to have a relative high resistivity. Main Shield = Middle Shield.

Figure 5-9: Overview of Visited Boreholes (red triangles)



Note: Red triangles are inflow BH; pink triangles are pumped BH with increased EC; green triangles are pumped BH; Grey dots are boreholes indicated by Connect. As the descriptions of these boreholes have not yet been identified these locations are approximate.

It is important that the ERT line or profile be as close to a straight line as possible. There were overriding field conditions at some key locations, such as accessibility and slope, where a considerable number of locations of interest had slopes of 18 - ~30 degrees, which limited the ability of the field team to adhere to this requirement.

The smaller the length of the electrode distances the more critical adherence to this requirement will be because the geometric factors will be incorrect and overestimated. This will result in a larger apparent resistivity than if the line was straight. This effect can be calculated and corrected, in cases where this effect was within the standard deviations of the measurements itself, this effect was neglected.

The colour scheme of the inversion results of the ERT can be adjusted to log or linear and the minimum and maximum of the scale can also be adjusted. For the lines competed for the project, a logarithmic scale was used to enable comparison of results for different lines.

To interpret the resistivity image into a hydro geological concept, it will be helpful to ask certain questions:

- What is the fit of the inversion?
- What further information is available to improve the interpretation (borehole log, groundwater table, water quality, geological map, topography etc.)
- What is the lithology of the different resistivities, and which geological unit does it belong?
- What will be the influence of the water quality?
- How does the image fit in the current understanding of the volcanic stratigraphy?
- Which layers could be permeable, semi permeable or impermeable?
- Which layers are saturated which layers are unsaturated or dry?
- Is there evidence for vertical structures (faults, dyke)?
- Does the 2D resistivity image show locations where the aquifer may be unconfined?
- Is the change in slope of the layers presented in the inversion directly related to the topography and does it have influence on recharge?
- What can be the continuation of the layers according to the down and upstream topography?
- How does the image compare with the other ERT profiles?
- Does the water balance of the catchment fit with the interpretation?

Although most of the questions will not be easy or even impossible to answer, asking these questions and combining it with other information and concepts will lead to a better understanding of the complex hydrogeology of St Helena. This is what has been done in this report.

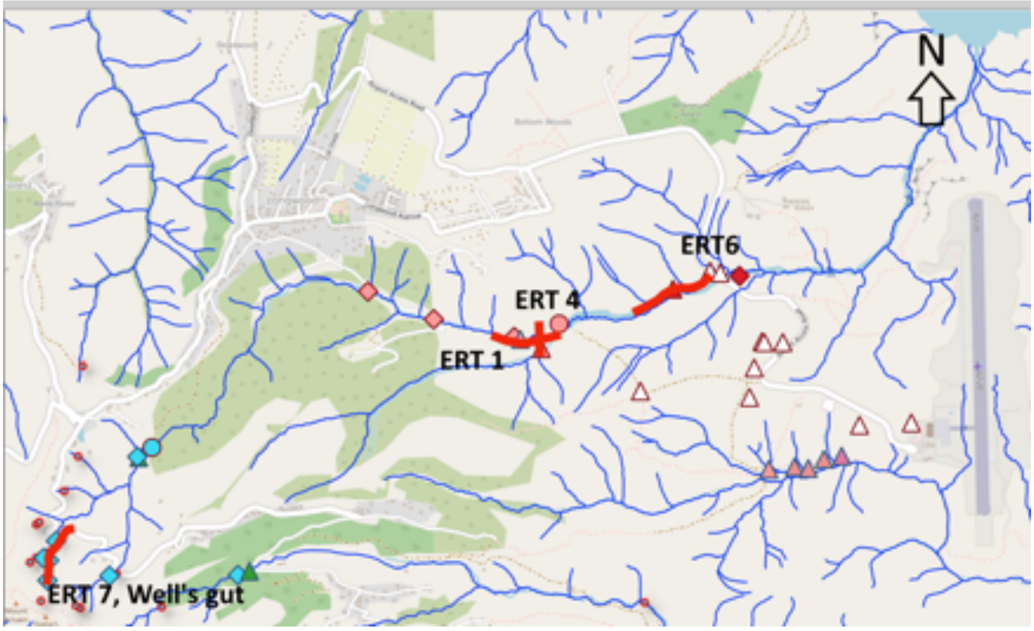
It will be become clear that most of the interpretations are highly conceptual due to the differences in resolution, exploration depth, scale and limited of information. Understanding ERT profiles is (especially on Saint Helena) an ongoing process, in which every bit of information is necessary. The ERT instruments used by Connect Saint Helena can be used to survey prospective borehole locations to assess suitability for water supply and also in preventing boreholes that lose water due to penetration of impermeable layers (inflow boreholes).

For the interpretation, negative boreholes and inflow boreholes are as important as high yielding boreholes. Geological logs, geophysical borehole logging, water strike, water table time series, water quality, pumping tests should be used and carefully executed. All of this data should be available and carefully and accessible stored also for future research and used in the interpretation of any type of (geophysical) prospecting.

5.4 Fishers Valley

In total 4 ERT profiles were executed in this catchment, ERT 7 up stream in Well's Gut, 2 ERT's downstream in the wetland area (1 and 4) and one even more downstream closer to the road to the airport near Cooks Bridge (ERT 6). The locations of the ERT are shown in Figure 5-10.

Figure 5-10: Fishers Valley ERT Locations (red lines)



5.4.1 ERT7 at Wells Gut: Fishers Valley Upstream

Upstream in Fishers Valley, ERT 7 is located parallel with the valley floor in Wells Gut from the upper catch pit towards the V-notch weir (SW03WG). The location of ERT7 is shown in Figure 5-11. Due to the local topography and safe access to the site, 70% of the geophysics line was located a few meters above the deepest part of the valley floor itself which might influence the resistivity of the top layer.

In Figure 5-12 and Figure 5-13 the results and the location of the geophysics profile are shown. Care must be taken with the interpretation at the edges of the measurement, due to missing apparent resistivity values at greater electrode distances (depth) which is inherent of the method. At the left side, the inversion does not "see" the increasing of the resistivity with depth. However, this dipping of the blue layer coincides with a groundwater seepage zone and a part of the picture could be real. At the right side there is evidence that the lateral change might be realistic. ERT7 is located within the Main Shield volcanic outflow.

Figure 5-11: Overview of ERT 7 Location

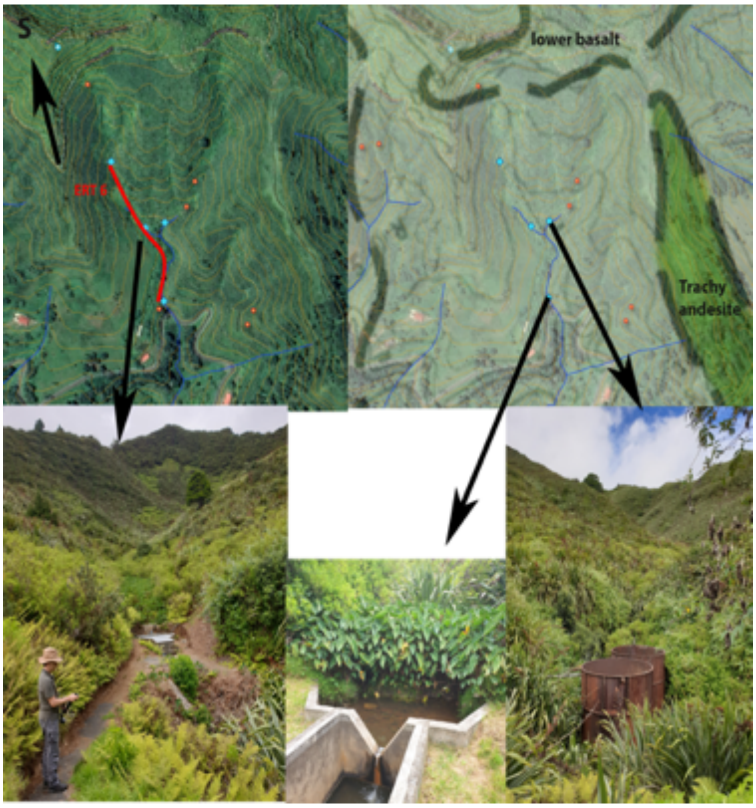


Figure 5-12: ERT 7 Inversion

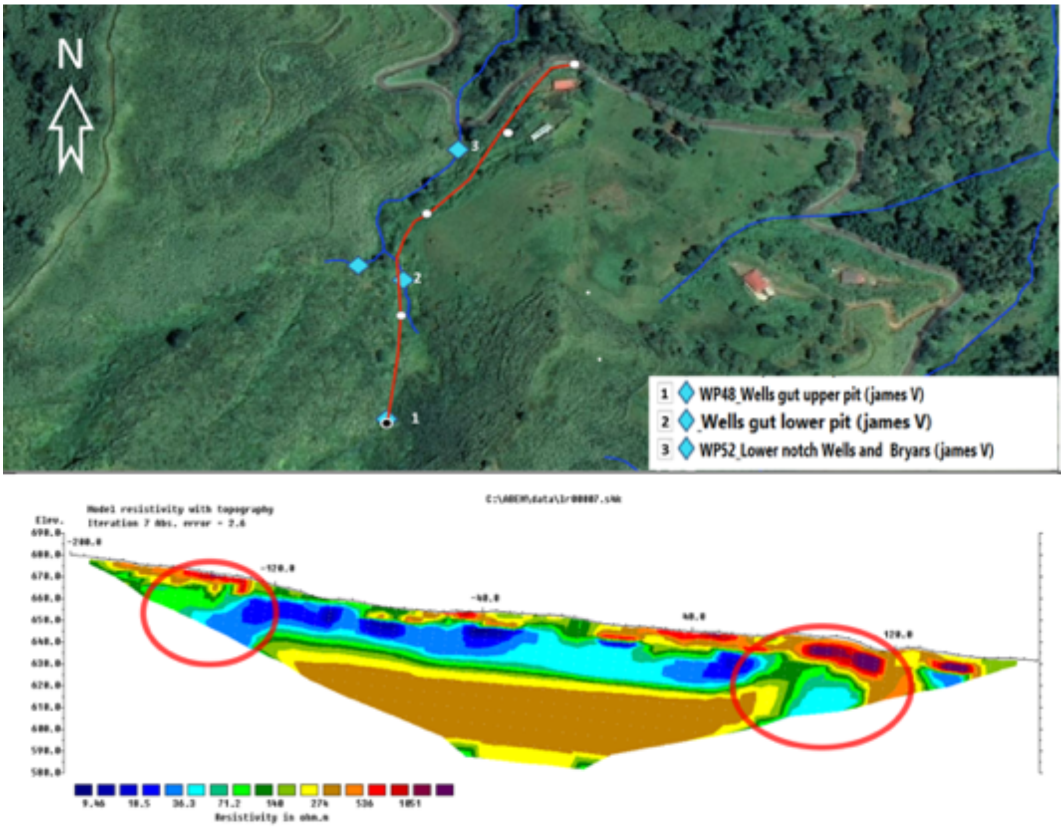
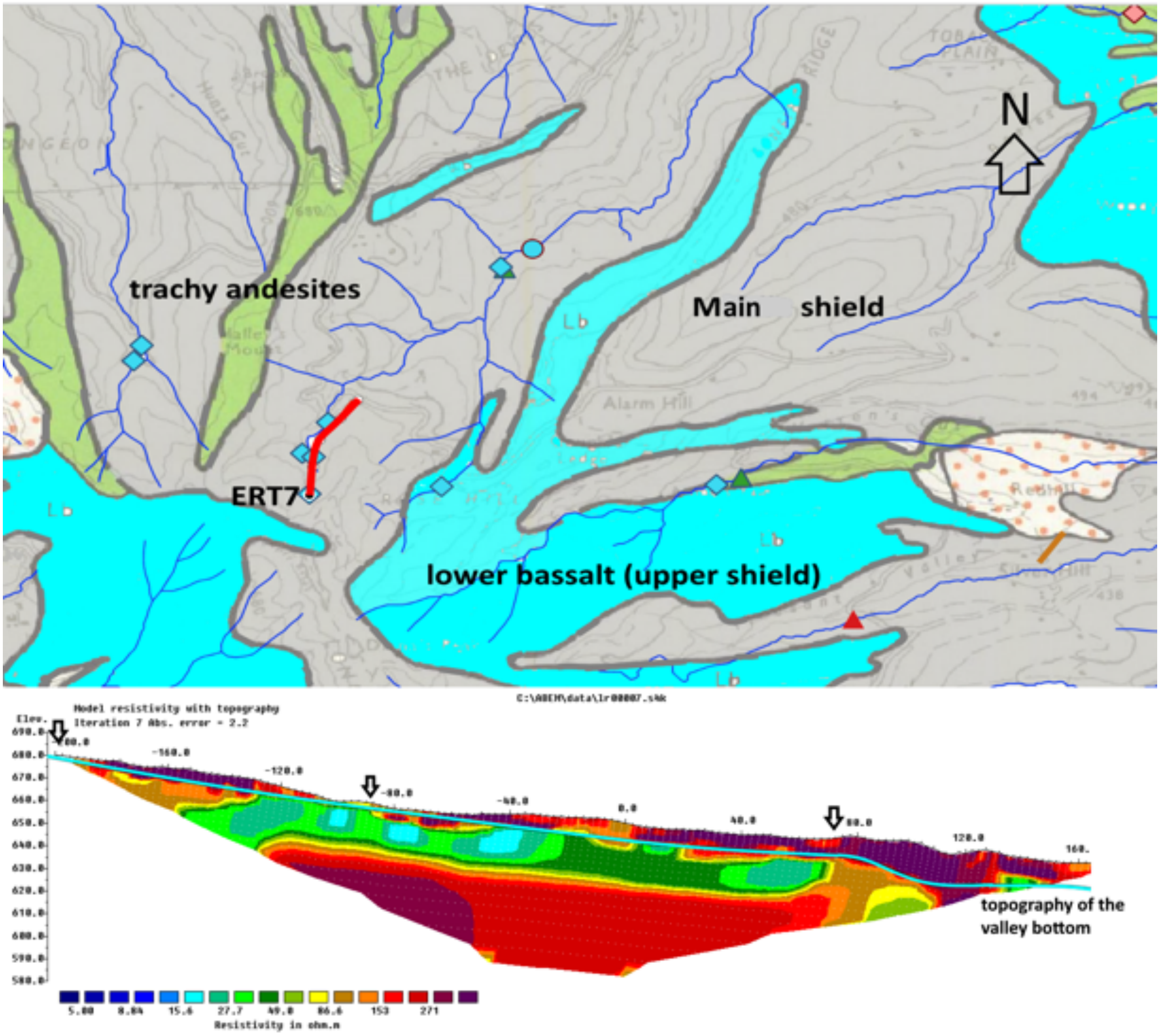


Figure 5-12 shows a close up of the location of ERT 7 in Wells Gut. The colour scheme of the inversion (bottom half of Figure) is based on the maximum and minimum resistivity. The left red circle might indicate edge effect of inversion because deeper information is missing, the right circle can be interpreted as a real phenomenon. However, at this side of the site where the line was placed, the elevation distance to the stream bed was increased due to accessible topography. At the left side it can be observed that the groundwater is nearer the surface as a seepage zone, which might indicate that the change into a relative high resistivity layer acts as a barrier forcing the water to come to the surface.

Figure 5-13 shows the location of ERT 7 on the geological map produced by Ian Baker (1971). According to this map, ERT 7 is located within the Main Shield stratigraphy of the NW volcano, (undifferentiated). Colours of the ERT are in the general format. The blue line represents the topography of the valley bottom. Part of the ERT line was above the bottom of the valley. The black arrows indicate the locations or the projection of the catch pits.

Figure 5-13: Location of ERT7 with Geology



EC measurements at Well's gut (surface water) show EC values around 250 μS/cm with water resistivity around 40 ohm. If this surface water is representative for the groundwater, depending on the matrix of the sediment or rock and considering that volcanic rocks are often conductive, the resistivity of the saturated layers will be of the same order or more likely somewhat higher.

In Figure 5-12, ERT 7 is shown with a dedicated colour scheme related to the maximum and minimum value. The saturated layer could be a superficial, relative thin aquifer, which might be a layer of river and slope sediments (this sediment was visible at the location of the catch pit) upon a more impermeable layer with a low resistivity of 15 – 40 ohm. This layer has a thickness of ca. 20m, consisting of weathered rock or it could be an ash layer.

Another possibility (less likely because of the relative low EC of the streamflow), is that the 20m thick greenish layer in Figure 5-12 is the aquifer which is completely saturated. The deepest layer of high resistivity (300 – 500 ohm) is expected to be impermeable or at least impermeable at the interface. This layer can then be dry and is most probably a layer of volcanic rock of Main Shield origin. Drilling into this layer might result in an inflow borehole.

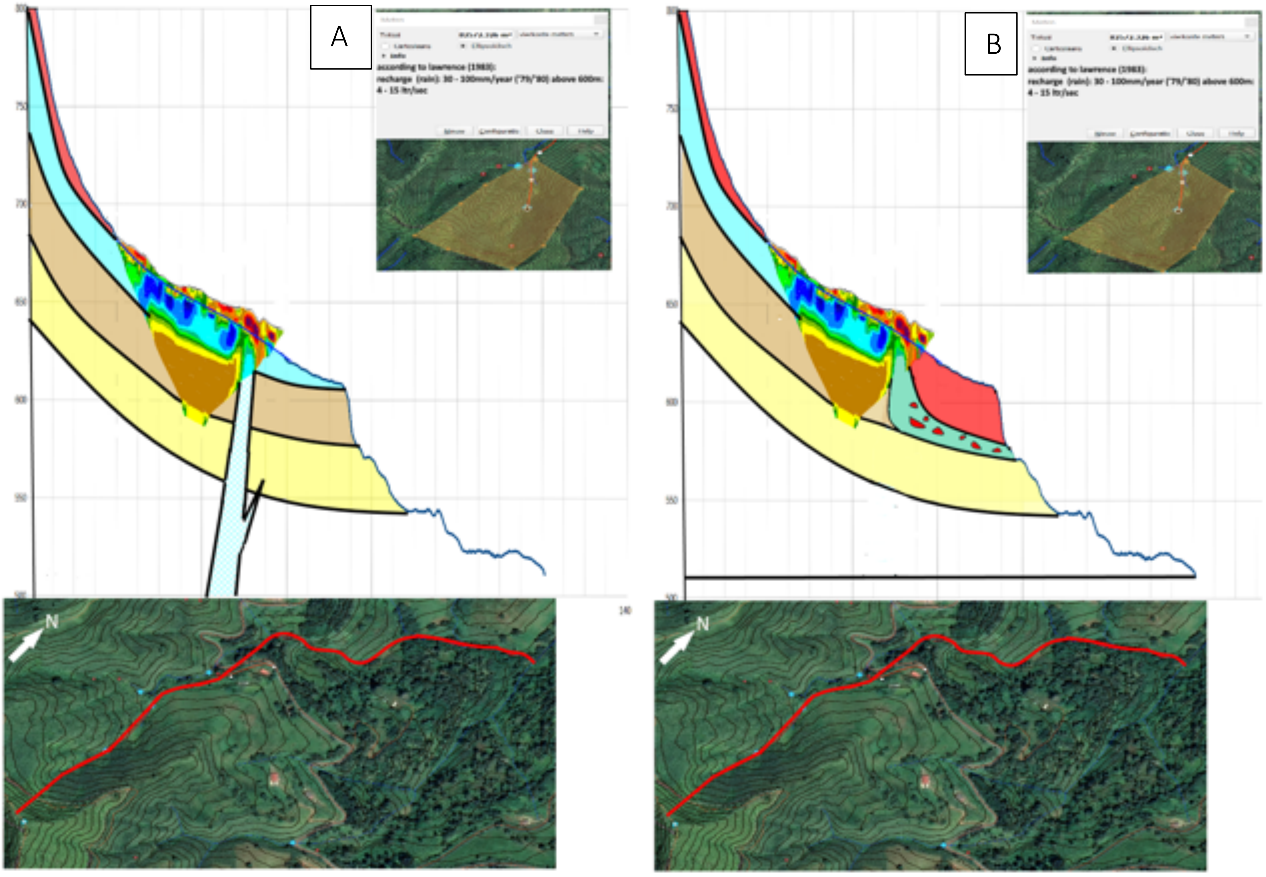
At locations where the river (or a borehole) cuts through the impermeable layer, both ground and surface water might infiltrate into the lower rock formations. At the right-hand side of the ERT profile, the distinct lateral change could be associated with a dyke-like feature or an abrupt change of a hidden paleo-relief. These dyke's can either block groundwater, especially at the interface, and/or leak ground water down within the dyke itself. On top, at the slopes of the valley, younger formations of a relative high resistivity, 500 – 1000 ohm are observed which could be dry rock or colluvium.

To illustrate some of the many possible interpretations, 2 conceptual models (among many others) based on the ERT resistivity assuming limited lateral change perpendicular to the ERT, are given in Figure 5-14. The topography of the valley floor is shown as a red line. The interpreted geological cross-section "A" shows the possible dyke-like feature intrusion which will control the flow of groundwater, with geological cross-section "B" showing impermeable Main Shield volcanic rock down gradient of the aquifer controlling the flow of groundwater.

According to the size of the catchment, a very rough calculation of the stream flow (if all the potential rainfall recharge according to Lawrence - 1983 would leave the catchment at the catch pit), would be 4 – 15 ltr/sec.

Figure 5-15 is based on the geology map of the island produced by Baker and also take into account the topography of Sandy Bay. In this interpretation, the ERT might show the different volcanic outflow layers within the Main Shield.

Figure 5-14: ERT 7 Conceptual Models



according to lawrence (1983):
recharge (rain): 30 - 100mm/year ('79/'80) above 600m:
4 - 15 ltr/sec

according to lawrence (1983):
recharge (rain): 30 - 100mm/year ('79/'80) above 600m:
4 - 15 ltr/sec

Figure 5-15: Wells Gut Simplified Cross-Section

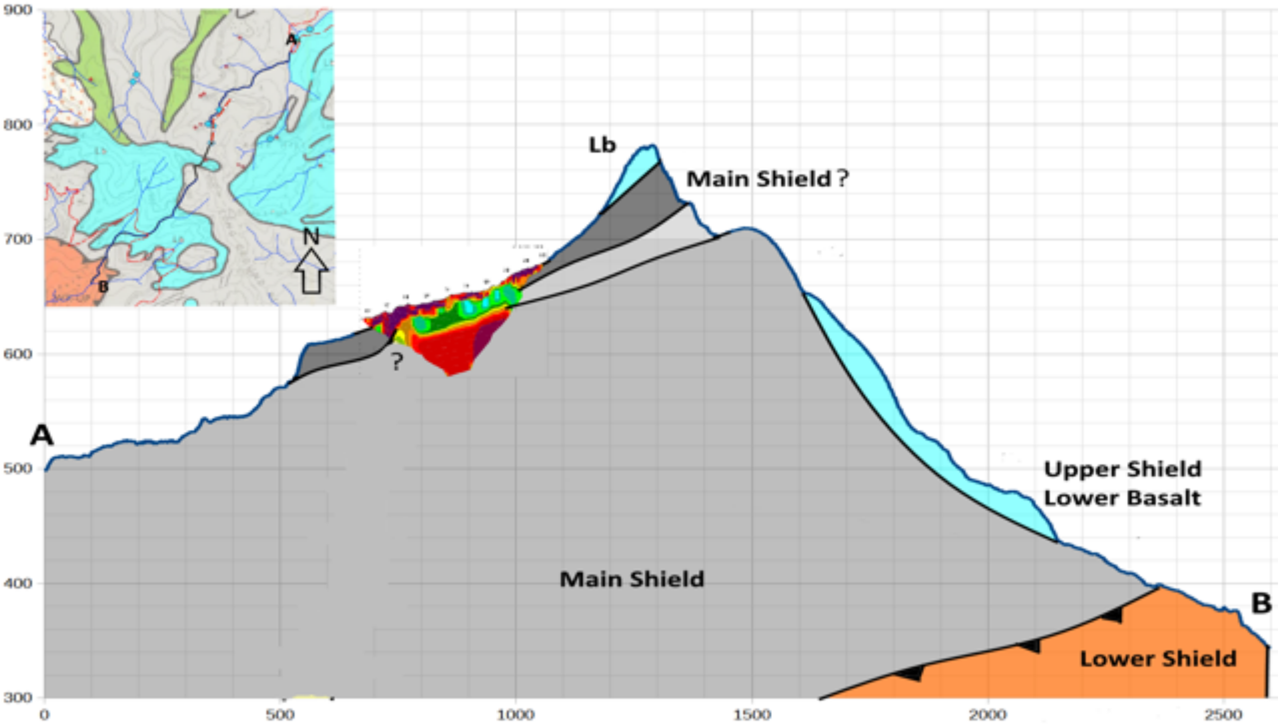
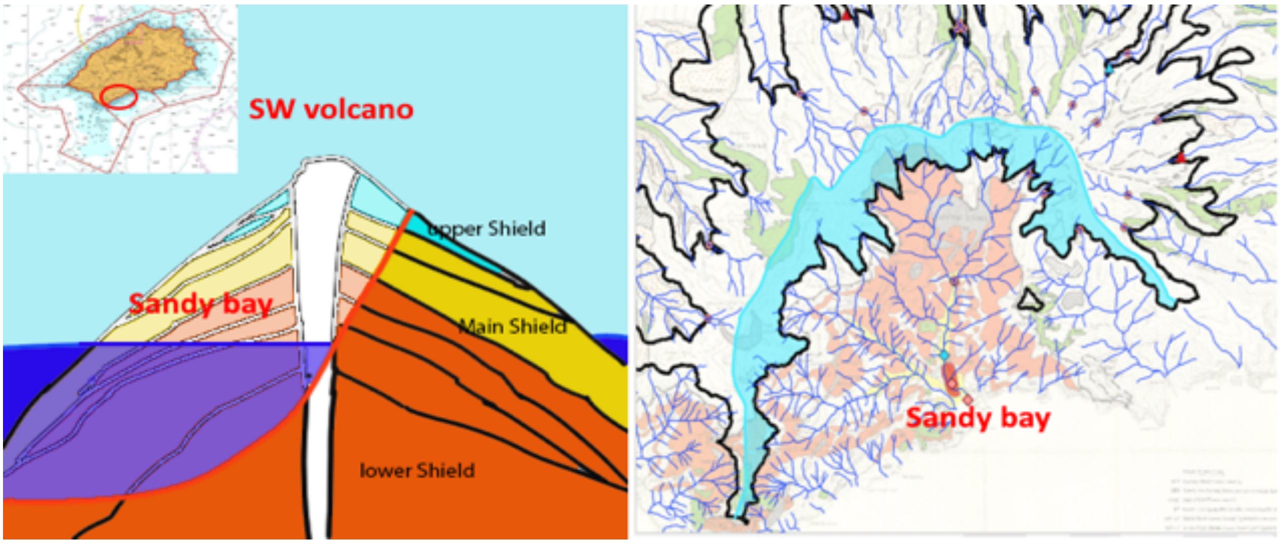


Figure 5-16 shows a schematic overview where, according to several authors, a huge landslide took place in Sandy Bay.

Figure 5-16: Schematic of Sandy Bay Area Landslide



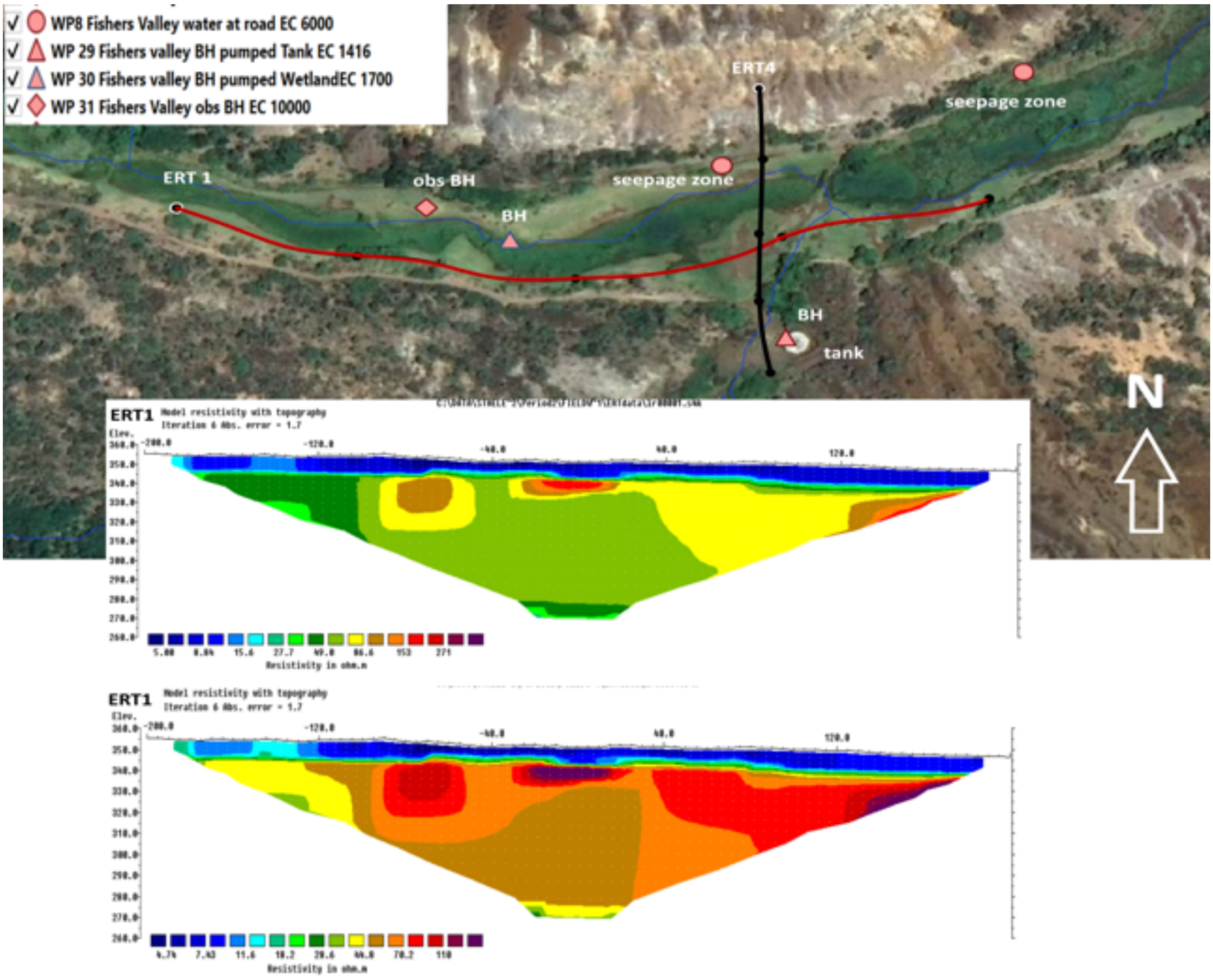
The left had side schematic in Figure 5-16 shows the effect of the landslide removing much of the southeast of the island land mass and illustrates why the Lower Shield geological layers outcrop in the Sandy Bay area (bathymetric map in upper left corner). This means that the centre of the outflow of the NE volcano is somewhere on the ocean floor to the southeast of Sandy Bay. It also means that part of the recharge area in the upper part of Sandy Bay is directed into the other side of the watershed (indicated by the blue area shown on the right-hand side schematic of Figure 5-16). The geological layers in the recharge area shown in blue slope downwards to the north, enabling rainfall and mist recharge in the cloud forest on the Sandy Bay side to flow northwards into the main water supply catchments such as James Valley and Lemon Valley.

5.4.2 ERT 1 and ERT 4: Fisher Valley Downstream.

Further downstream in Fishers Valley at an altitude of 300m is a location of the RAMSAR wetland. Connect Saint Helena operate 2 boreholes in the wetland area and were the location of the first ERT measurement during fieldwork period 2. At this location, different protocols and electrode distances (profile length) were experimented with. One profile was executed parallel with the valley and one as a cross-section. Both profiles were close to existing boreholes and an observation well.

Figure 5-17 shows the location of ERT1 parallel to the valley and two ERT interpretations. Results of the ERT are shown in two colour schemes (above: uniform scheme, below: colours related to max-min resistivity values). Indicated EC values are from February 2022. The high EC value in the observation borehole is due to contamination with cow manure inside the uncapped borehole.

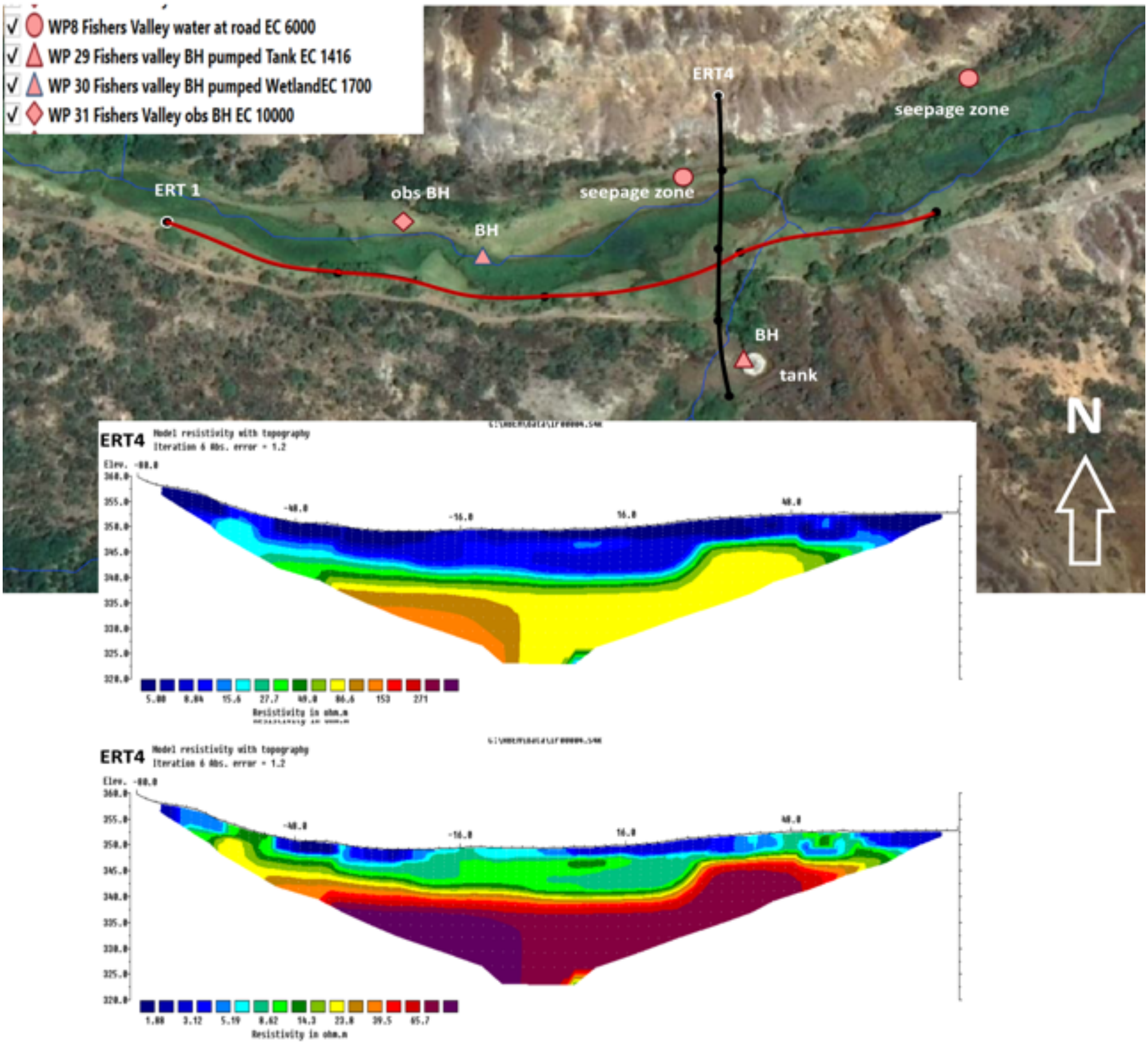
Figure 5-17: Overview of ERT1 Location



The EC values of the surface water and pumped groundwater are much higher than upstream in Wells Gut. This is most probably related to the latest Trachy-Andesitic outflows and the rock weathering process. The resistivity electrodes could be hammered into this surprisingly soft formation which looks like hard rock. The groundwater becomes more saline due to the solution of secondary minerals as Halite (NaCl) and Gypsum CaSo4) in the exposed weathered rock formations. The combination of the conductive clays and the high salinity of the groundwater leads to a very low resistivity (<5 ohms).

It is assumed that mixing of different groundwater types occurs in the boreholes due to the semi-confined leaky aquifer situation. The deeper groundwater is the fresher part of the pumped water and is mixed with the more saline and less permeable top layer. According to information from Connect, after a period of no pumping the groundwater in the borehole becomes more saline which decreases after a period of pumping. In ERT 1 the resistivity is increasing downstream.

Figure 5-18: ERT4 Fishers Valley Cross-Section Inversion



Note: The ERT 4 cross-section location is shown as a black line in Figure 5-18.

The EC of the stream flow at “Longwood Hangings” is 750 µS/cm (13 ohm), in some small pools it measured in between 3800(2,6 ohm) up to 6000 µS/cm (1.6 ohm) in the wetlands more downstream. The artesian borehole in the centre of the wetland or swamp was 1700 µS/cm (5,8 ohm) the borehole at the tank 1400 µS/cm (7 ohm), the monitoring borehole in the swamp was 7000 µS/cm (1.4 ohm). These low resistivities based on water quality match with the first layer in the ERT (<<10 ohm) in Figure 5-18. The boreholes are equipped with filter’s that reach into the layer with relative higher resistivity of between 50 ohm (200 µS/cm) and 80ohm (125 µS/cm).

Low EC values of the pumped groundwater are measured in the borehole close to the water storage tank which correspond with 7 ohm. These value’s do not match with the ERT resistivity’s of the deeper layers (around 100 - 200 ohm). This can be for several reasons, one of which could be due to the effect of a matrix with a high resistivity (which is unlikely in this area). More likely is that less saline water is present and mixed with the very high EC values of the upper layer. As an example, to reach a value of 1400 µS/cm with say 6000 µS/cm and 250 µS/cm (EC value of streamflow in the upper catchment) you need, say at least 4- 5 times more of the fresh water for dilution.

Figure 5-19: ERT4 Cross-Section Inversion Looking Up-Stream

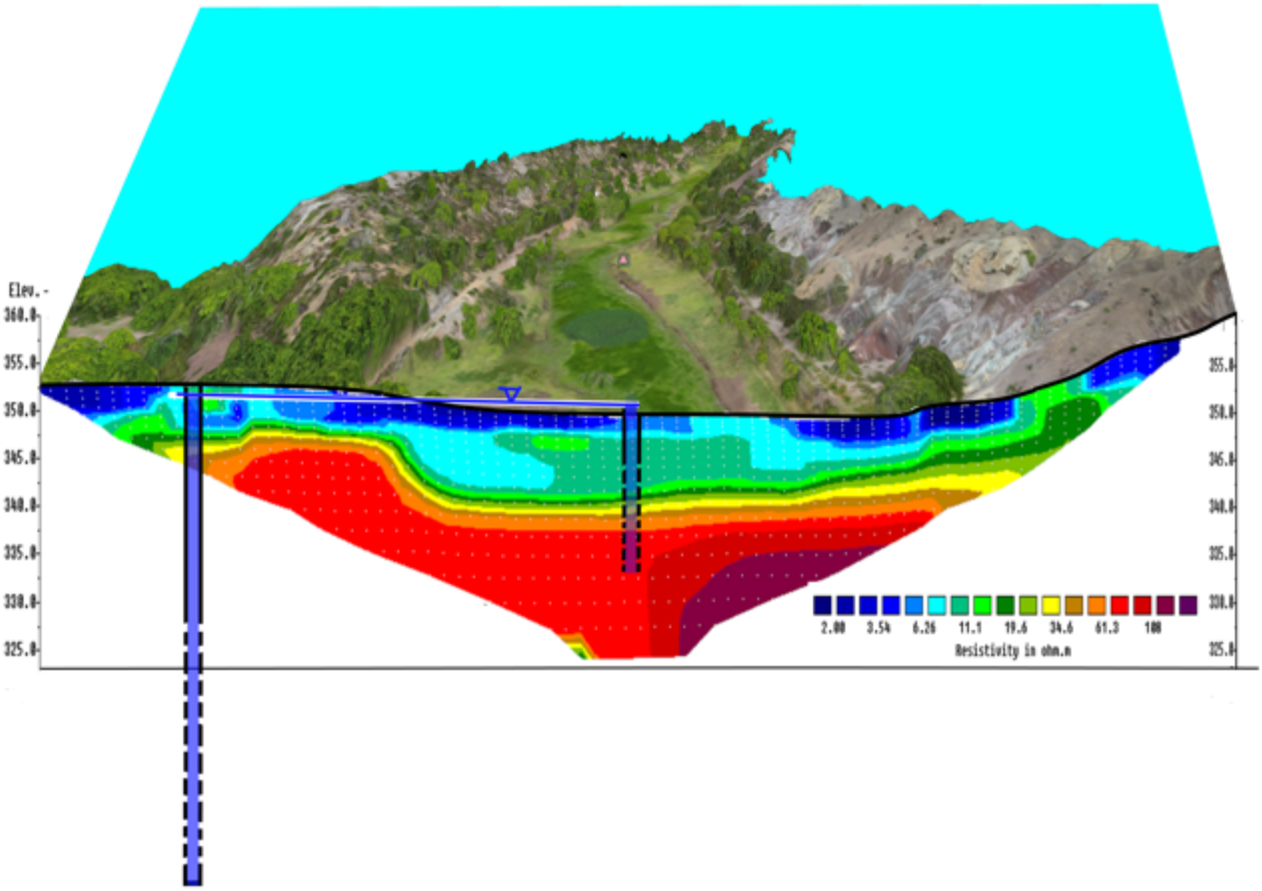
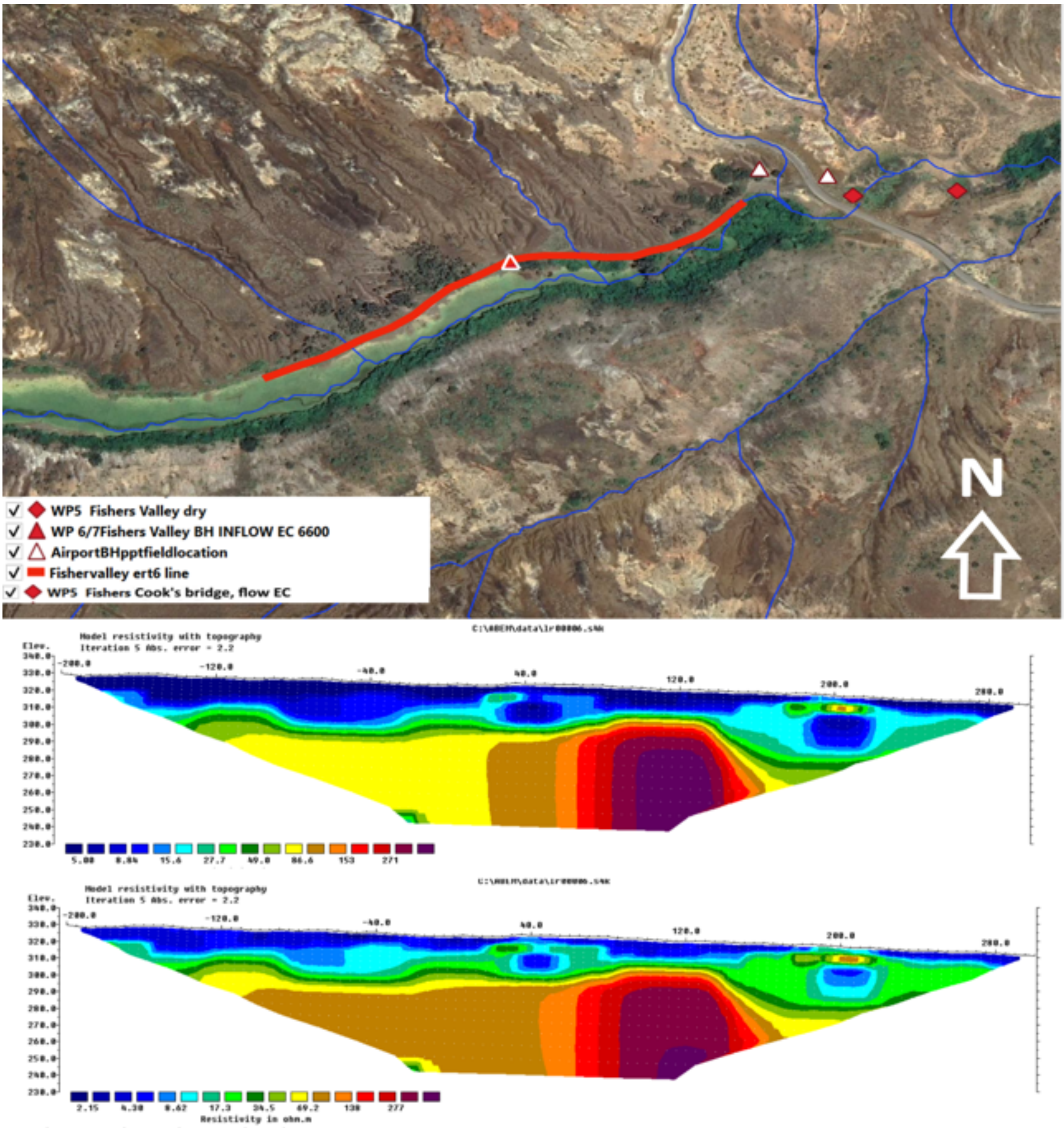


Figure 5-19 shows ERT4 again in cross-section, looking in the up-stream direction of Fishers Valley with the cross-section showing the location of the Connect boreholes. The static groundwater level is indicated as a white blue line. According to borehole information and the groundwater levels in wetland, the aquifer (or 2 aquifers) is (are) artesian. The deepest borehole close to the tank has an EC of 1400 (specific conductivity) µS S/cm (WL -1m BGL) and was measured (2 November 2022) after 1hr pumping. The borehole in the middle of the wetland measured (specific conductivity): 2100 µS S/cm (WL+0,8m AGL) at the same date. The resistivity of the in-situ weathered rock is the same as the valley sediment.

5.4.3 ERT 6 Fishers Valley

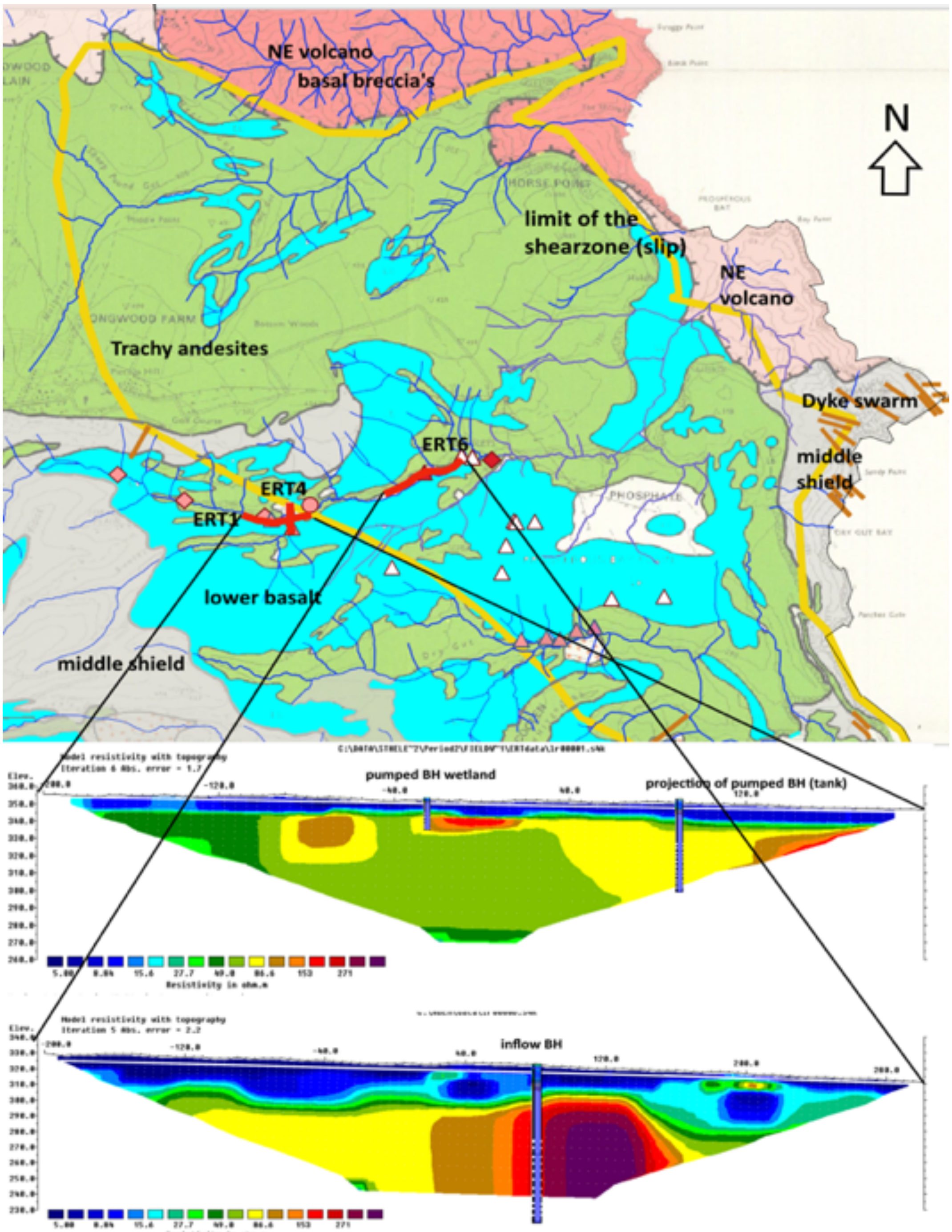
Figure 5-20 shows the inversion results and location of Fishers Valley ERT 6, downstream from ERT1, ERT4 and close to an inflow borehole (in the middle of the ERT, red triangle).

Figure 5-20: Fishers Valley ERT 6 Inversion



ERT 6 in Fishers Valley was located further downstream near a so called "inflow" borehole (red triangle with white contour lines) located in the "middle" of the ERT. In this borehole groundwater flows downwards, due to the penetration of an impermeable layer and because no bentonite or cement sealing in combination with a casing has been applied (which is the case in most of the WSP deep boreholes). At this borehole location, ERT 6 shows a relative high resistivity anomaly (>300 Ohm) which might be associated with dry and probably permeable rock formation like a vertical dyke. No static water table could be observed. According to recent observation of Baker (2012), this borehole is close to a slip fault. The EC of the groundwater in this borehole was around 6600 mS/cm (1.5 Ohm.) this fits to the upper layer visible in the ERT. At this location the deep fresher groundwater as in the 2 boreholes up stream is not reached and may be not present. Figure 5-21 shows ERT 1 and ERT 6 with the island geology map.

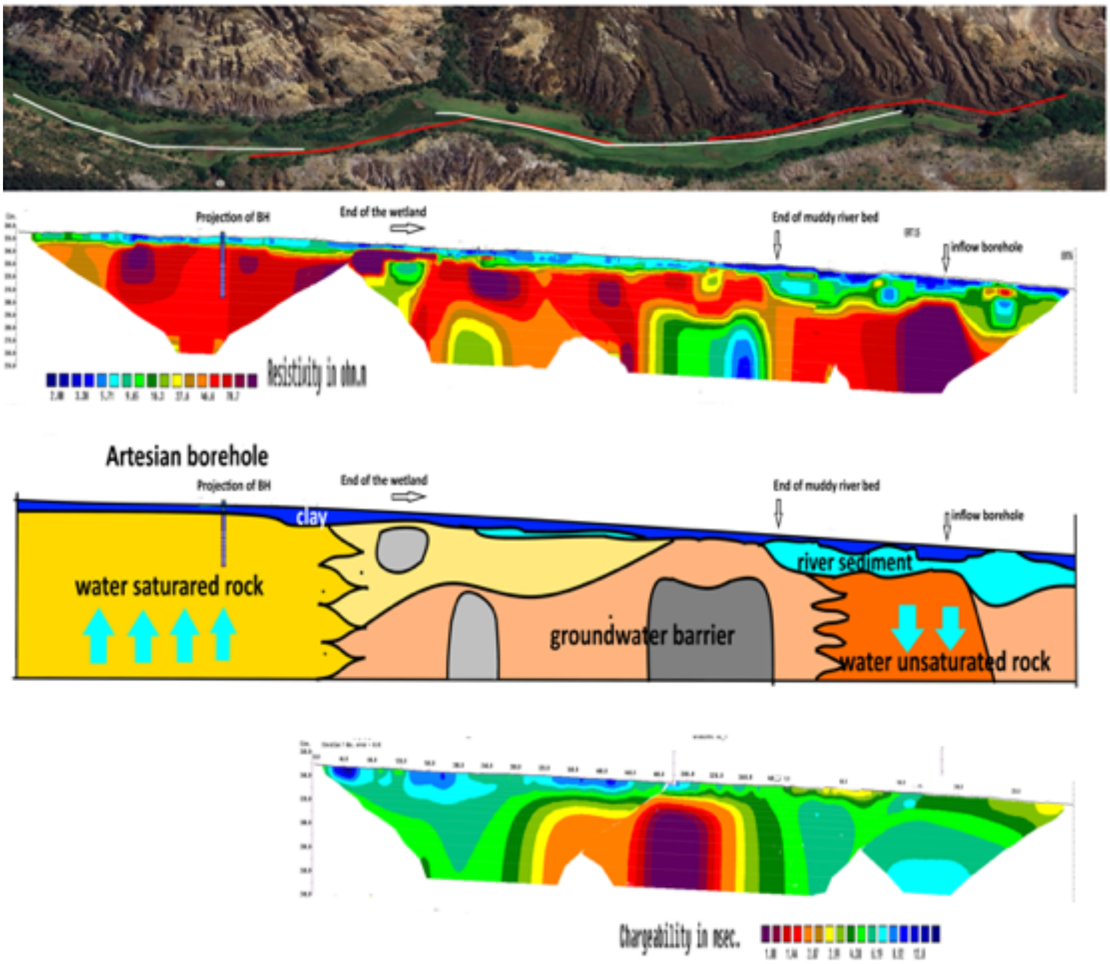
Figure 5-21: ERT 1 and ERT 6 with Island Geology



The white line shown on both of the inversion results is the “true” valley bottom. The yellow line on the map marks the border of a big landslide in the east of the island (Baker 2010[23]) which lies between the locations of ERT 4 and ERT 6. This unconformity is supposed to have a great influence on the groundwater flow and occurrence of springs.

During October 2023 the earlier profiles (ERT 1, ERT 4, ERT 15 and ERT 16) were extended and interconnected, A possible, highly conceptual and schematic interpretation of the resistivity's is given in Figure 5-22. At least one vertical structure with a different (lower) resistivity is visible in the ERT.

Figure 5-22: Combined ERT Profiles in Fishers Valley



The chargeability or IP is also measured in this profile, and this shows that the vertical structure with low resistivity in the profile has an unexpectedly low IP effect. It could be concluded that this phenomenon, which according to the boreholes, act as groundwater barrier could be interpreted as a heavy weathered dike. However, the weathering does not seem to increase the chargeability. This information can be of help in the interpretation of the ERT’s. The

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[23] Baker, I (2010). The Saint Helena Volcanoes: A Guide to the Geology for Visitors and Walkers. Southern Cross Publishers, Cape Town.

Volterra 3 measurements on outcrops of an Andesitic dike on island confirm this combination of heavy weathering, low permeability and low resistivity. The resistivity measured with the Volterra on an Andesitic dyke in the area upstream of Thompsons Valley was 9 ohm, which is in the same range as the vertical structure visible in the ERT. It could be possible that the slip fault, as indicated by Baker is also associated with this dyke. In this respect it may be of help to measure the chargeability of this dike with the ABEM LS2 in the same configuration (Wenner) with an electrode distance as was applied with the Volterra.

Figure 5-23 shows a conceptual schematic section of Fishers Valley based on the topography of the DEM, from Wells Gut to the coast illustrating the complexity and the scale of the geology in respect to the ERT measurements. The insert schematic shows the concept of a cross-section of a big paleo valley with a complex alternation of volcanic infill and erosion. The suggested dyke is highly conceptual.

Figure 5-23: Conceptual Schematic Section of Fishers Valley based on the DEM

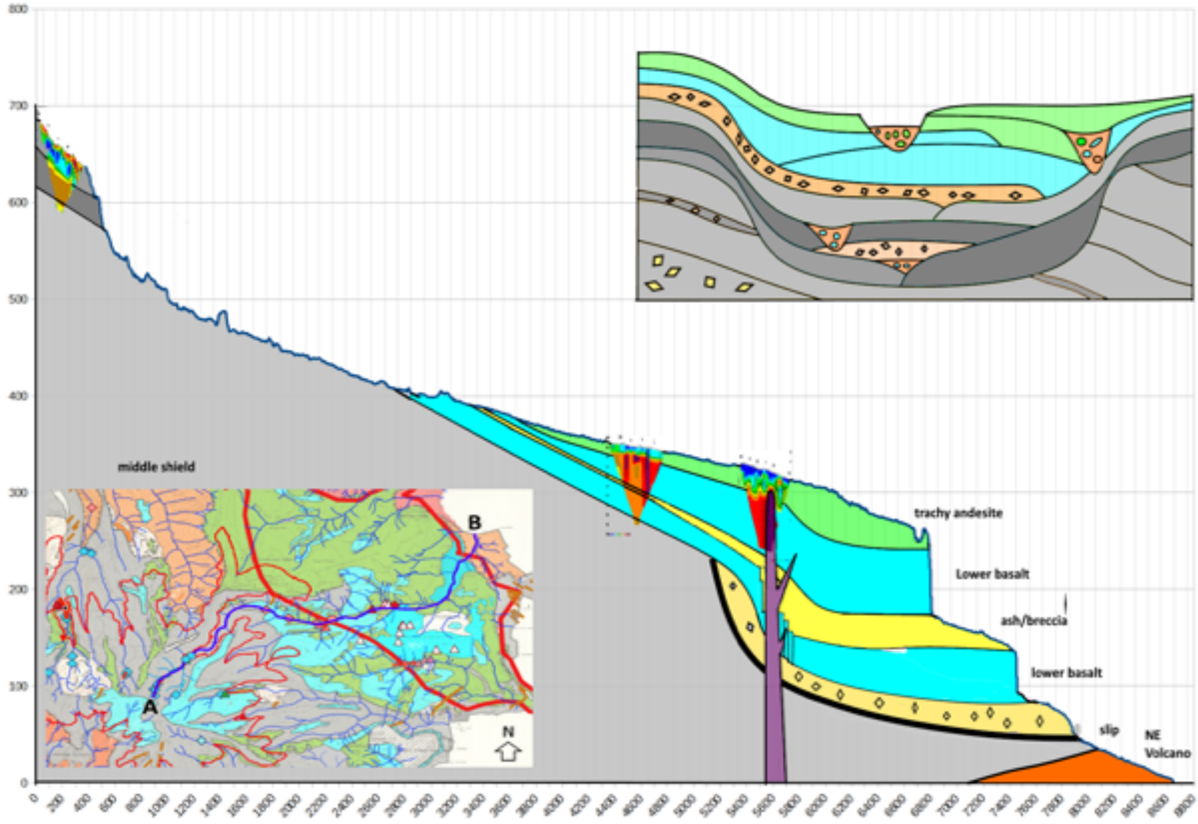


Figure 5-24 takes a closer look at the location of the structural slip identified by Ian Baker (2010) after the landslip event. The depression was filled with Upper Shield volcanic material, mainly Lower Basalt and Trachy-Andesites.

Figure 5-24: Location of the Structural Slip

It is clear that a simple and complete hydrogeological explanation of the complex situation of Fisher Valley and catchment is not easy. However, combining all the information and continuing to monitor water levels and Electrical Conductivity in water can give at least a better insight.

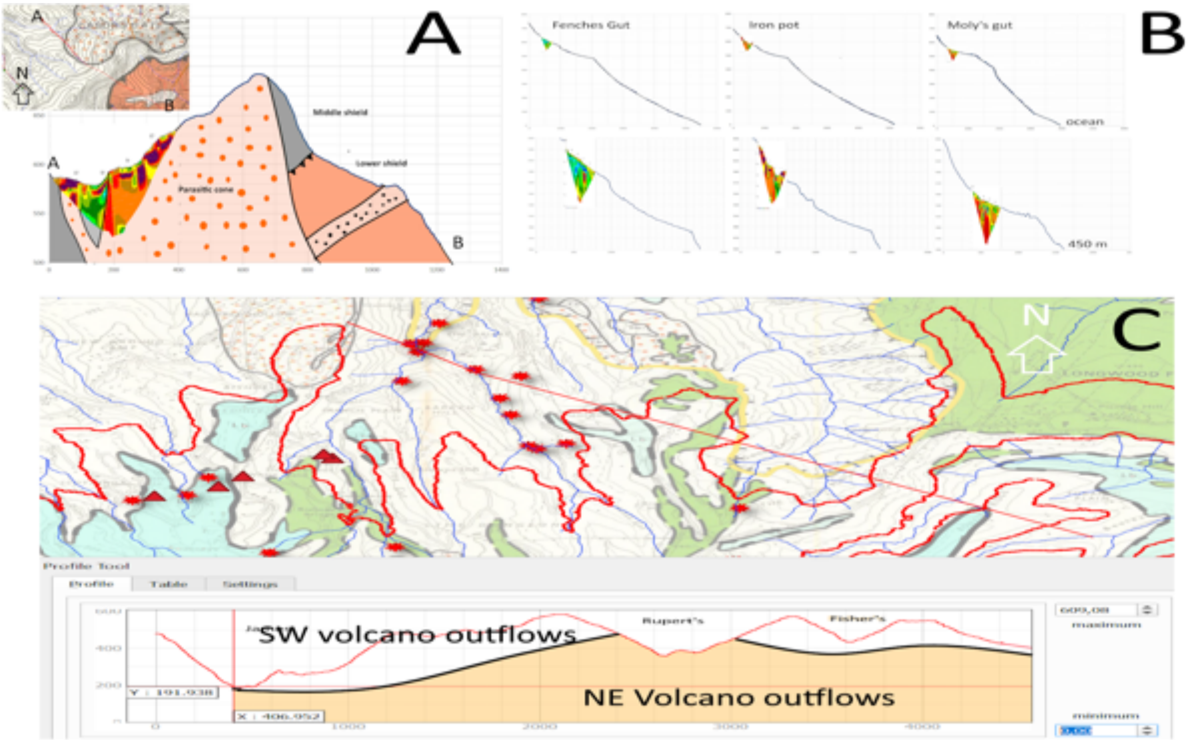
A final conceptual model cross-section showing the NE Volcano outcrops (light brown) is shown in Figure 5-25. The location of the interface is conceptual in-between the location where it is exposed at the surface.

5.4.4 Key Findings and Observations

The geological map indicates a combination of Main Shield and Lower Basalt and Trachy-Andesite of the Upper Shield volcanic rocks. An alternation of permeable and impermeable geological layers as well as saturated and unsaturated (sealed) layers are observed.

The geophysics data indicate that the existence of dyke's and dyke swarms can influence groundwater flow as impermeable barriers. The interface of a dyke with older volcanic rocks could be impermeable however the dyke itself can be either permeable due to fractures and cleavage or impermeable due to weathering (Andesitic dykes).

Figure 5-25: NE Volcano Outcrops



The very low resistivity of the in-situ weathered rock seems related to the Trachyandesite outflows. The vertical structures with a low resistivity are associated with weathered Andesitic dykes which might act as a barrier for groundwater flow.

The inflow borehole (close to Cook's bridge) is associated with a distinct increase in resistivity which is probably associated with dry volcanic rock.

Relative high resistivity (>250 ohm) could be associated with dry rock formations. Intermediate resistivity (50 – 150 ohm) could be associated with water bearing sediment or rock. Low resistivity (< 30 ohm) could be associated with clay and very low resistivity (<5 ohm) is related to groundwater with high EC values.

On top of high resistive rock formations impermeable ash layers could be present, however these are not visible in the ERT profiles due to lack of contrast. Penetrating these layers by drilling deep boreholes can lead to inflow boreholes (where shallow groundwater leaks into a deeper aquifer system).

According to Baker (2010), a big landslide has taken place in the past, at the end of the main shield period, due to tectonic movement and instability due to dykes. The slip fault line might be in-between the ERT 1 and ERT 6 measurements. The valley formed due to the slip is filled with later outflows (Trachy-Andesite, Lower Basalt) and alternated with periods of erosion. The slip interface can be impermeable alongside the Andesitic cover.

There is no visible groundwater outflow from the coastal cliffs (based on satellite image) which implicates that groundwater is lost at or below sea level. This might be because groundwater flow is concentrated in the (paleo) valleys, where rivers have been cutting through the impermeable ash layers and were permeable volcanic rock have steep dips.

The boreholes in the wetland area are artesian boreholes and downstream close to the slip front inflow borehole(s). Artesian boreholes indicate lower permeability layers on top of the aquifer and related to the expected dip of the water bearing layers also a phenomenon that is blocking the groundwater flow in the aquifer more downstream.

The 2 artesian Boreholes in and close to the wetland could be hydraulically connected. The water quality of the boreholes, especially from the one in the middle of the wetlands, seems to be related to the EC values of the surface water and seepage zones at the edges of the wet land area. These EC levels are high compared to upper catchments and higher than the borehole in the tributary (close to the tanks).

EC levels of the pumped groundwater decrease during pumping in the borehole in the tributary close to the tanks. There was no sign of decrease of the EC within a time frame of an hour when the boreholes were sampled.

The 2 main boreholes could penetrate the same (most likely) or different aquifers, however there are no water levels measurements available during pumping tests or long periods of pumping to compare borehole water level responses.

Seepage zones with high EC values are observed at several locations.

Crystals of Gypsum are observed in outcrops of the in situ weathered Trachy-Andesites, the rapid solution of these crystals causes the high EC levels.

Upstream in Wells Gut there appears to be a shallow aquifer mainly in river and slope sediments and at certain locations stream flow might infiltrate into deeper rock layers. A dedicated water balance, where base flow measurements at different levels of the streamflow are incorporated might give more information.

The Fishers Valley wetland area seems to be a leaky semi-confined aquifer system, the upper layer of low resistivity seems semi-confined.

Further downstream a complex geology dominates the groundwater flow and borehole(s) become “inflow” borehole(s) losing water down into the Main Shield volcanic series. Inflow boreholes are boreholes where impermeable layers are penetrated and ground water from upper layers flow downwards and disappear into dry permeable layers.

In between ERT1 and ERT6 an unconformity like a dyke or fault seems to be present, which might obstruct the groundwater flow because of the artesian behaviour of the 2 production boreholes. Further downstream the borehole drilled into the zone with high resistivity (ERT6) “looses” all its water. Another explanation can be that most of the less saline groundwater originates from the catchment of the tributary were the Connect Saint Helena water storage tank and boreholes are located.

The fast weathering process of exposed volcanic material is “sealing” the underlaying aquifers and decreases the groundwater recharge. This process is ongoing and also took place in-between the periods of the volcanic outflows. Lava flows in existing valleys could be reused by rivers as a preferential flow path after a period of volcanic activity. River erosion could cut through the most recent lava flows, reaching the older sediment filled paleo-valley. Surface water could then be infiltrated into deeper layers in these valleys. These buried infilled channels could be the origins of some deep groundwater aquifers beneath the island.

It is important to know what the gradient of the shallow and deep groundwater table is downstream into the valley.

The RAMSAR wetland has 2 sources of water, the first is surface streamflow from higher altitudes in Fishers Valley (Wells Gut, Leggs Gut), and the second is upwards percolating groundwater due to the (semi) confined aquifer. However, the origin of this deeper groundwater is still unclear.

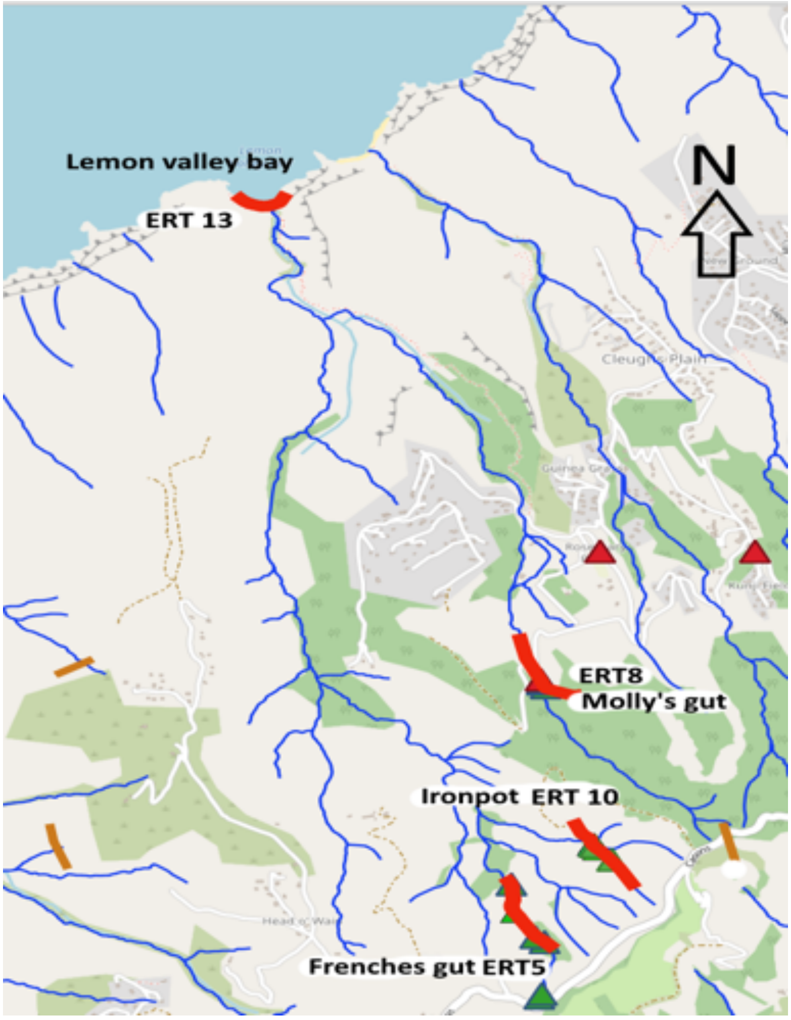
ERT can help to identify locations of potential inflow boreholes, groundwater barriers and conduits as well as an indication of water quality.

5.5 Lemon Valley

The geophysical investigations at Lemon Valley catchment and sub catchments were designed to examine stream water losses and the possibility of groundwater outflow into the ocean. 4 ERT profiles were executed with 3 located in the upper sub- catchments of Frenches Gut, Iron Pot, and Molly's Gut and one profile located on the coast at the outlet of Lemon Valley itself. According to the geology map of Baker[24], the rocks exposed in Lemon Valley are mainly formed from the main shield volcanic period. The two catchments close to the parasitic cones (Iron Pot and Molly's Gut) do not show surface water and the measured resistivity is higher.

The location of Lemon Valley ERT profiles are shown in . In all the upper catchment's above 500m, multiple shallow boreholes have been drilled over several decades. The field investigations completed as part of the combined DPLUS103 and Cloud Forest Project fieldwork have shown that in several cases, deep boreholes have penetrated impermeable layers and ground water from upper layers flow downwards and disappear into dry permeable layers which are referred to as inflow boreholes. In, green triangles denote pumped, abandoned or observation boreholes.

Figure 5-26: Lemon Valley ERT Locations



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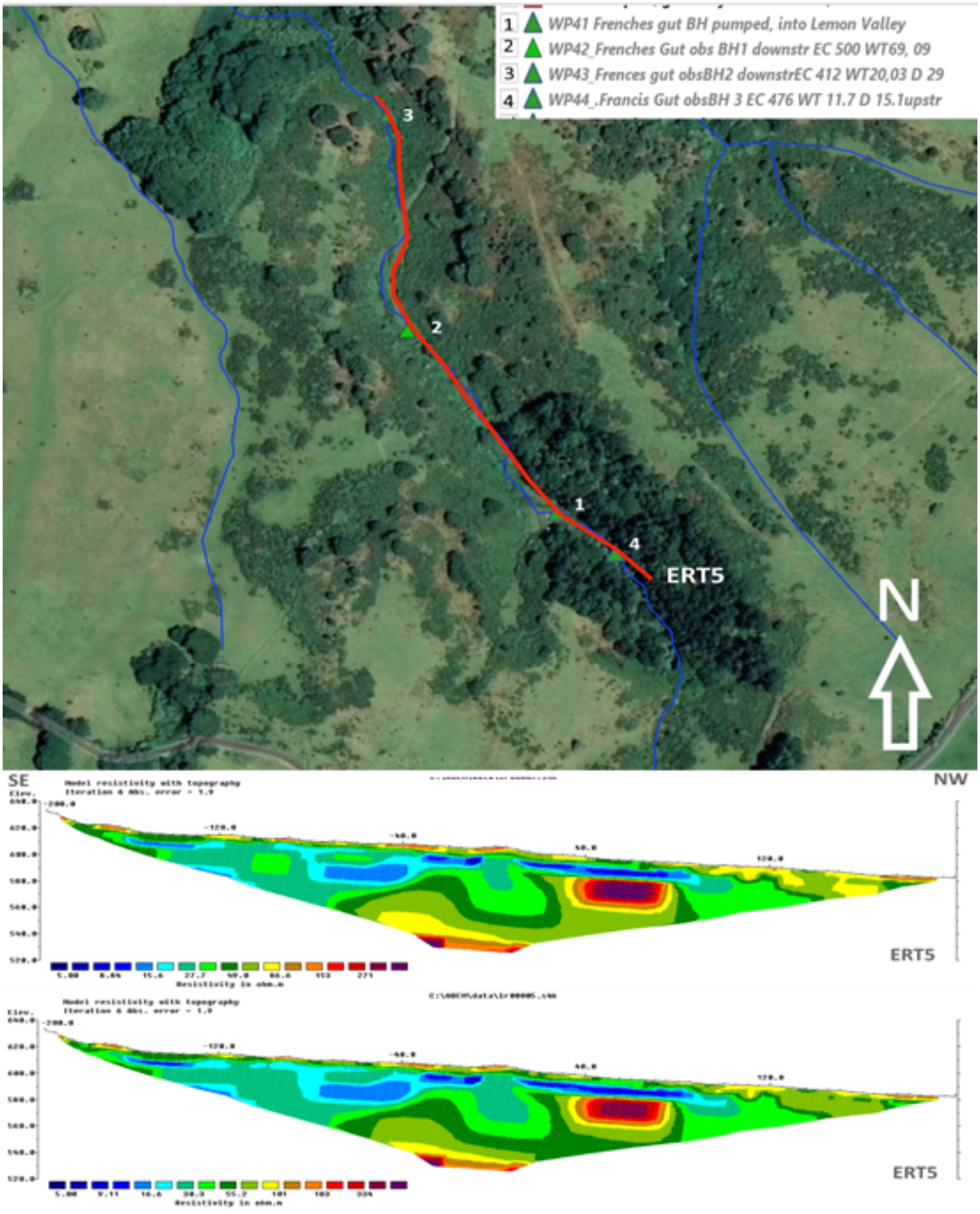
[24] Baker I. (1968). The Geology of St Helena Island, South Atlantic. PhD thesis, University College London.

5.5.1 ERT5: Frenches Gut

Frenches Gut is a sub-catchment of Lemon Valley and is used as a shallow groundwater source by Connect Saint Helena. The ERT inversion and location are shown in Figure 5-27. Groundwater EC values range from 300 µS/cm (30 ohm.), most upstream not in the ERT, up to 500 µS /cm downstream (20 ohm, depending on the matrix resistivity of the saturated formation will be higher).

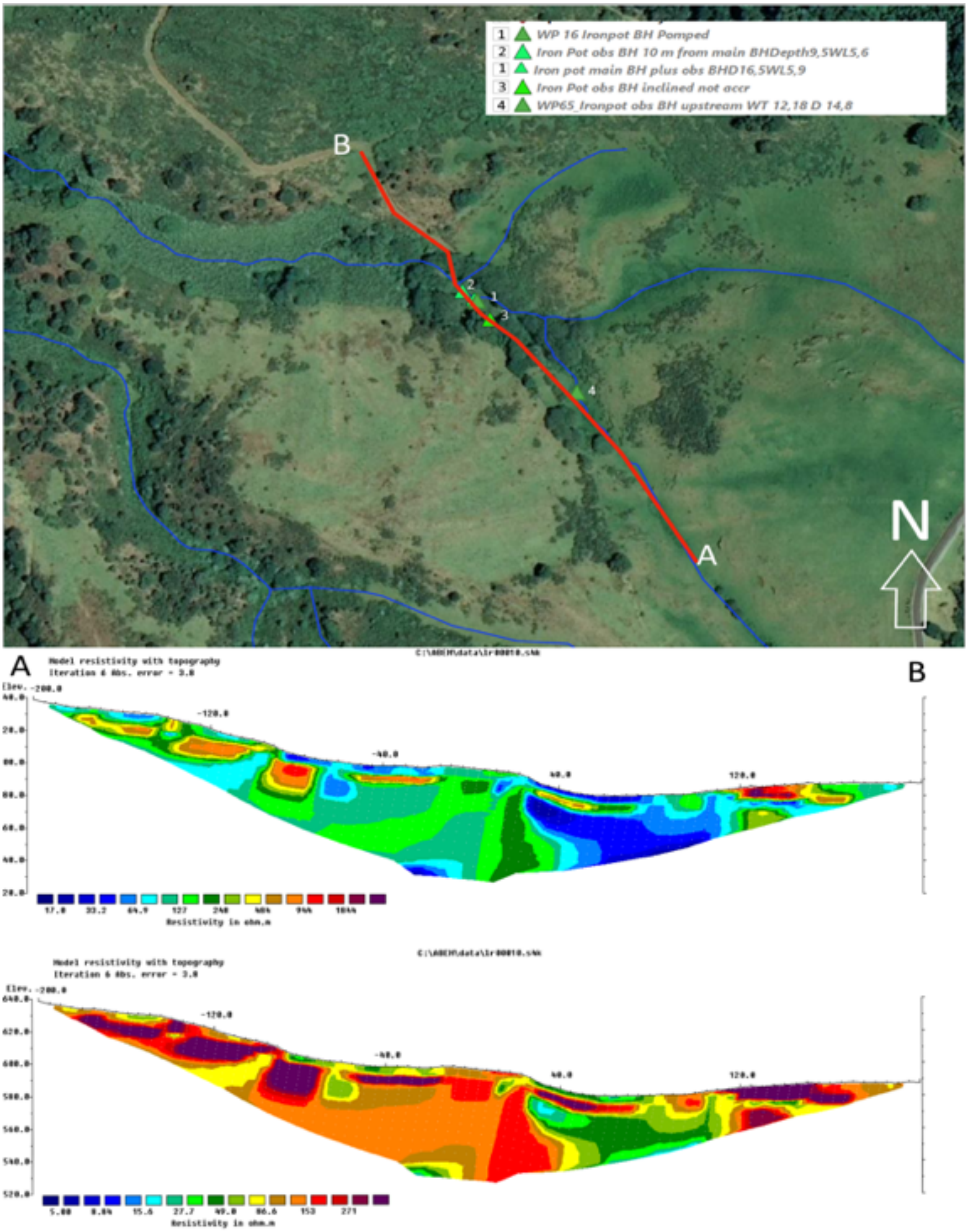
Figure 5-27:ERT 5 at Frenches Gut



5.5.2 ERT 10: Iron Pot

Iron Pot is a sub-catchment of Lemon Valley and is used as a shallow groundwater source by Connect Saint Helena. EC value of the pumped borehole 280 µS/cm (35 ohm, depending on the matrix the formation, resistivity will be higher). The lowest point of the ERT coincides with the crossing of a stream bed.

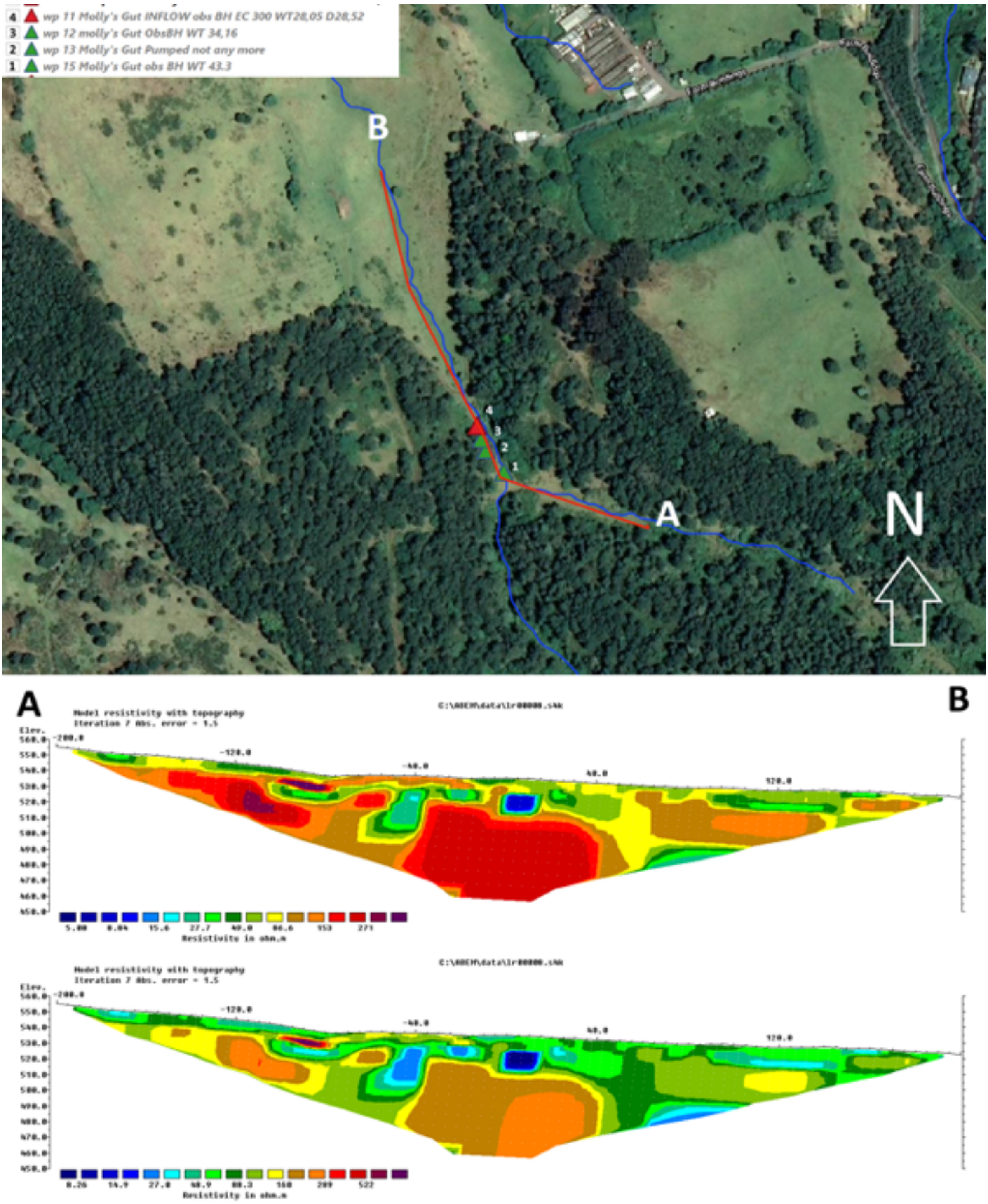
Figure 5-28: ERT 10 at Iron Pot



5.5.3 ERT 8: Molly's Gut

Molly's Gut is a sub-catchment of Lemon Valley and was formerly used as a shallow groundwater source by Connect Saint Helena until a borehole was drilled and penetrated a deeper dry aquifer system, draining the shallow aquifer which had been used for public water supply. EC values of the groundwater 300 μS/cm (30 ohm).

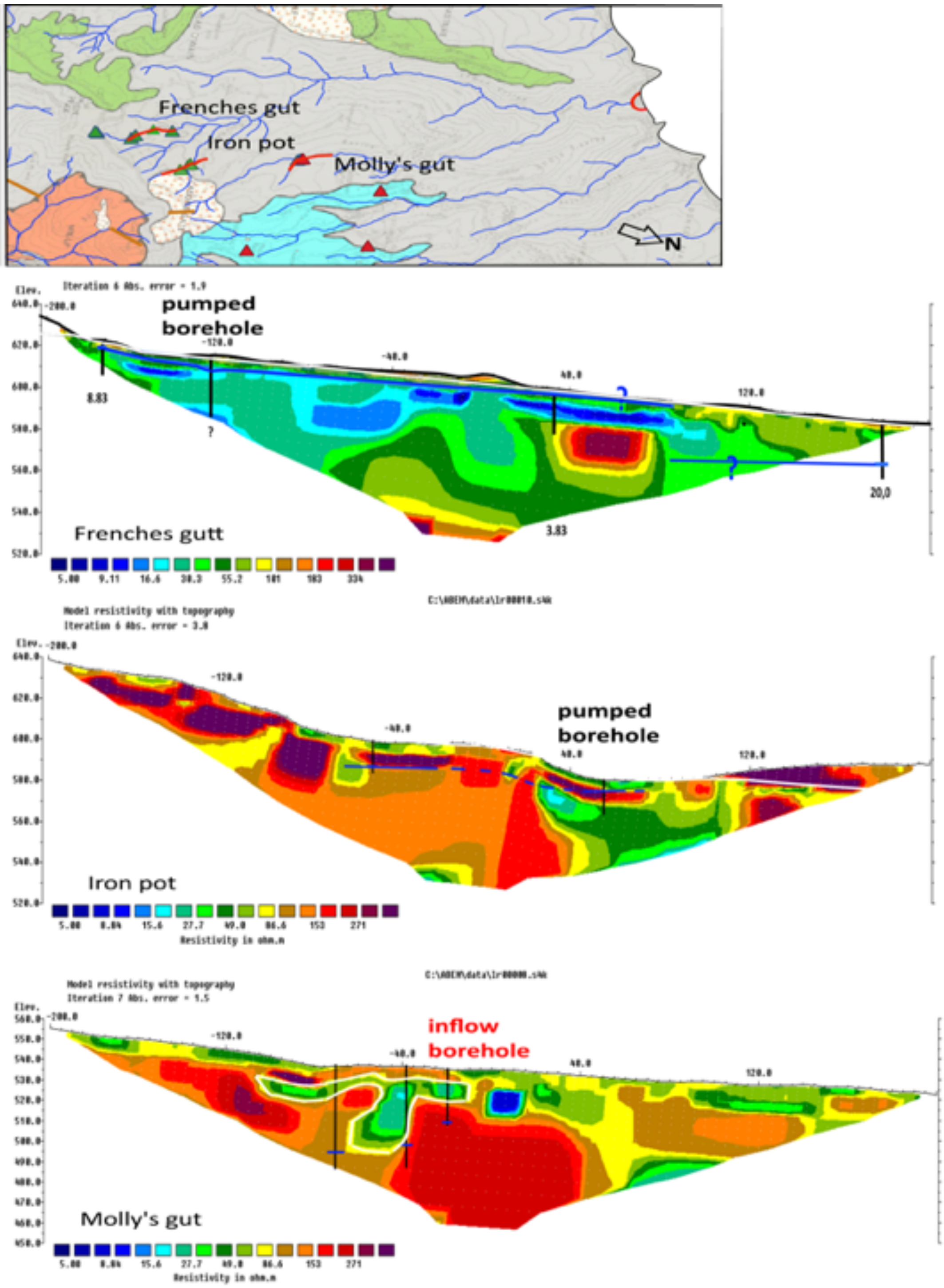
Figure 5-29: ERT 8 at Molly's Gut



5.5.4 Comparison of ERT 5, ERT 10 and ERT 8

Figure 5-30 shows the 3 upstream Lemon Valley ERT. Borehole locations and static water tables are indicated in the Figure. The thin white lines indicate the valley bottom. In Molly's Gut, the inflow borehole drained the other boreholes. Note the difference in resistivity between Frenches Gut and the other 2 profiles for Iron Pot and Molly's Gut.

Figure 5-30: Upstream Lemon Valley ERT



The EC values of the groundwater range from 300 – 500 μS /cm (ca. 30 – 20 Ohm.) The lowest values are measured more upstream in Iron Pot and Molly's Gut. This coincides with the difference in the formation resistivities between Frenches Gut and Iron Pot and Molly's Gut. Both Molly's gut and Iron P are located in dry valleys without any visible stream flow. Water resistivities seem somewhat lower than the formation resistivity, meaning low porosity in combination with a higher matrix resistivity.

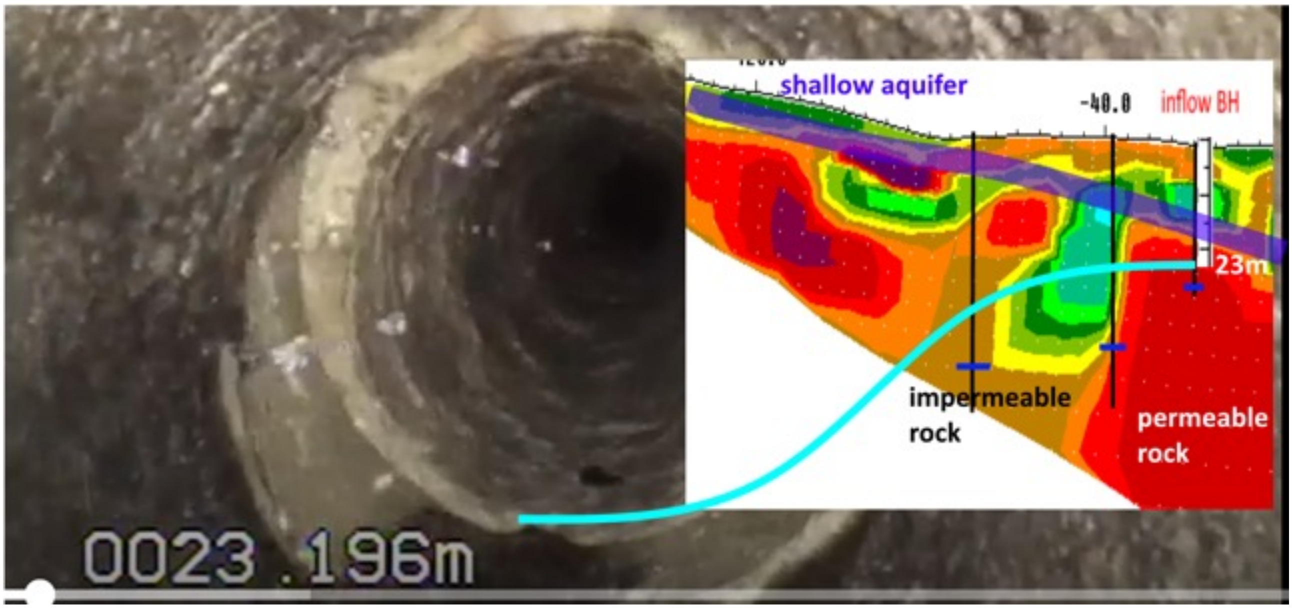
The groundwater table in Frenches Gut makes a jump in the most downstream borehole, this seems also to be expressed in the resistivity profile. The groundwater table itself is not visible in the ERT profiles because of the lack of contrast.

Molly's gut is of special interest because one of the boreholes is a so-called inflow borehole. This borehole was drilled sometime after the other boreholes were completed resulting in a severe decrease in yield of the older upstream boreholes as the newer borehole lowered the shallow water table. The level of the original water table of these upstream boreholes is unfortunately unknown. An explanation can be that an impermeable layer might be penetrated at the location of inflow borehole.

The high resistivity layer which the inflow borehole penetrates is probably (partly) unsaturated and seems very permeable. The upstream boreholes received water from the shallow upper part. Under natural or normal circumstances groundwater is expected to flow into the valley as long as the impermeable layer is intact. The fact that the existing production boreholes lost their yields after drilling the new borehole indicates that the aquifer is shallow and relatively small. Drilling in this kind of formation and within shallow aquifers should be done with care. Penetration depth should be carefully considered, and a technique should be used to seal the drilled borehole from the shallow aquifer to prevent inflows.

Figure 5-31 shows the location of the inflow at 23.5mbgl. A thin impermeable layer (probably ash) is visible in the borehole camera image would not be detected with the ERT; however, an ash layer is in general the start of a new series of eruption and can act as a marker for a change in rock type or the end of a period of erosion. At this depth the ERT shows a clear change in resistivity (see insert schematic). The permeable layer (with secondary or primary permeability) in which the water is lost is visible in the ERT as a layer of relative high resistivity. It is not possible to determine a new location for a production borehole until a parallel ERT profile is completed in combination with the extension of the ERT existing profile downhill. In general, based on what we learned until now the borehole should avoid penetration into the relative shallow high resistive areas. Drilling is preferable at locations where these layers of high resistivity are not too close to the surface, with a thick extensive layer of intermediate resistivity and preferably at the uphill side of low resistive vertical structures where groundwater could be blocked would be favourable.

Figure 5-31: Molly's Gut Inflow Borehole Camera Survey and Schematic



The Frenches gut pumped borehole seems to suffer from decreasing yields. In January 2022 during the first project site visit (DPLUS103) the pump was switched on and off within a few seconds. In the second period the pumped completely stopped, this indicates a shallow, thin superficial aquifer is being exploited with water skimmed at regular intervals. At greater depth a second layer with groundwater is not likely to exist because of the depth and location of the pumped borehole. The assumed permeable high resistive rock is not present in the Frenches Gut ERT.

Figure 5-32 shows an overview of the 3 ERT in respect to the scale and topography of Lemon Valley. The Figure illustrates clearly that a single ERT profile is not representative for a more regional geological setting. A remarkable feature is the distinct change in topography more or less at the same altitude in all the cross sections. This topographical change might coincide with a location were groundwater infiltrates and is lost into the ocean.

Figure 5-32: Topographical Cross-Section and ERT Comparison in Upstream Lemon Valley

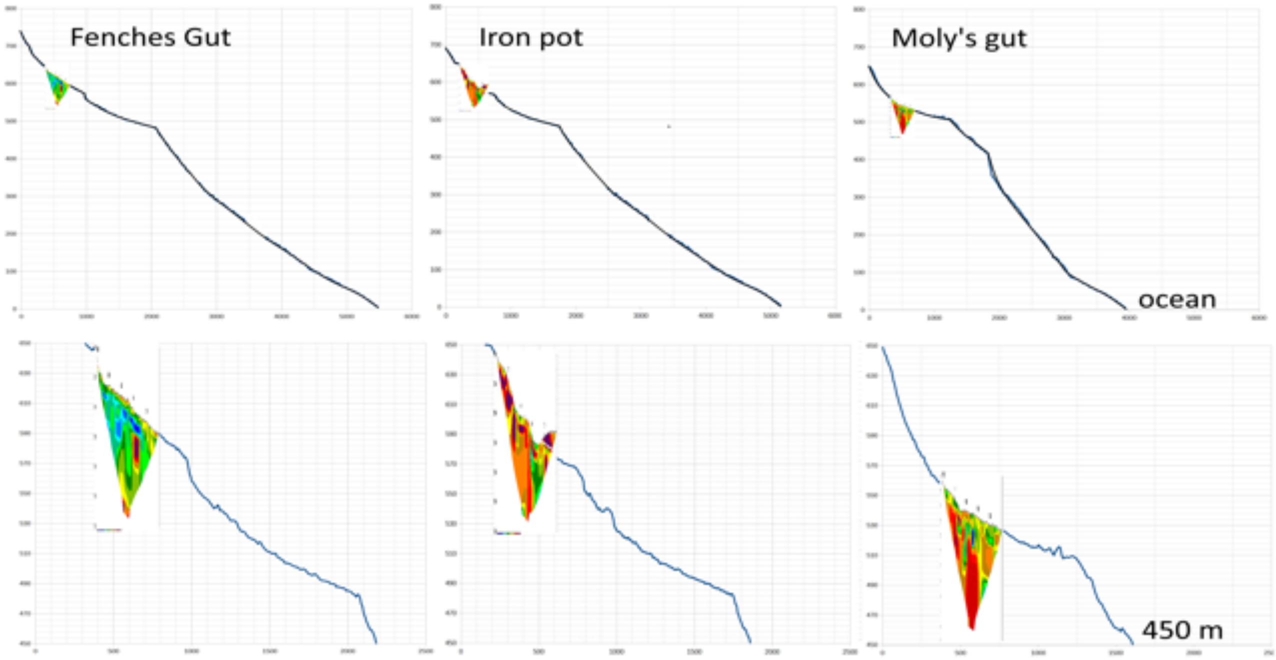
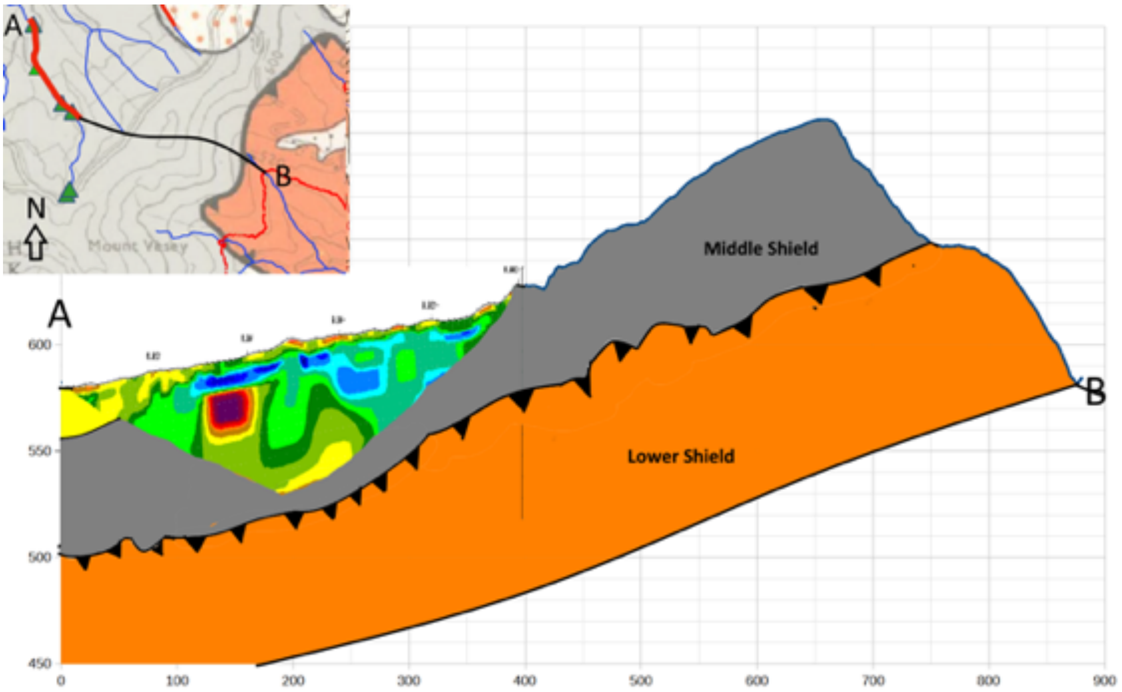


Figure 5-33 shows one of the many possible concepts of ERT 5 in Frenches gut, projected in a topographical cross section partly cutting into Sandy Bay. This contact zone seems to be less permeable than the younger Main Shield rocks.

Figure 5-33: ERT 5 Frenches Gut Conceptual Model Partially Cutting Sandy Bay



The situation in Iron Pot and Molly's Gut (Figure 5-34 and Figure 5-35) is complicated. The geological map indicates the location of a parasitic cone with pyroclastics and the Unconformity between the Main Shield and Lower Shield being located beneath the sites. This might also be reflected in the somewhat chaotic ERT profiles.

Figure 5-34: ERT 10 Iron Pot Conceptual Model Partially Cutting Sandy Bay

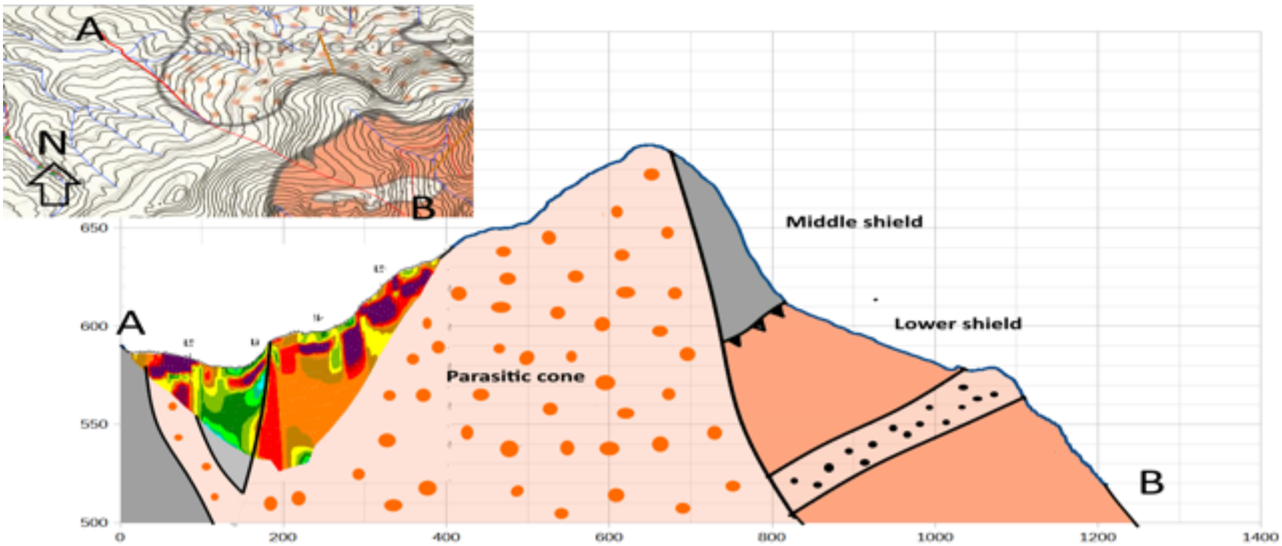
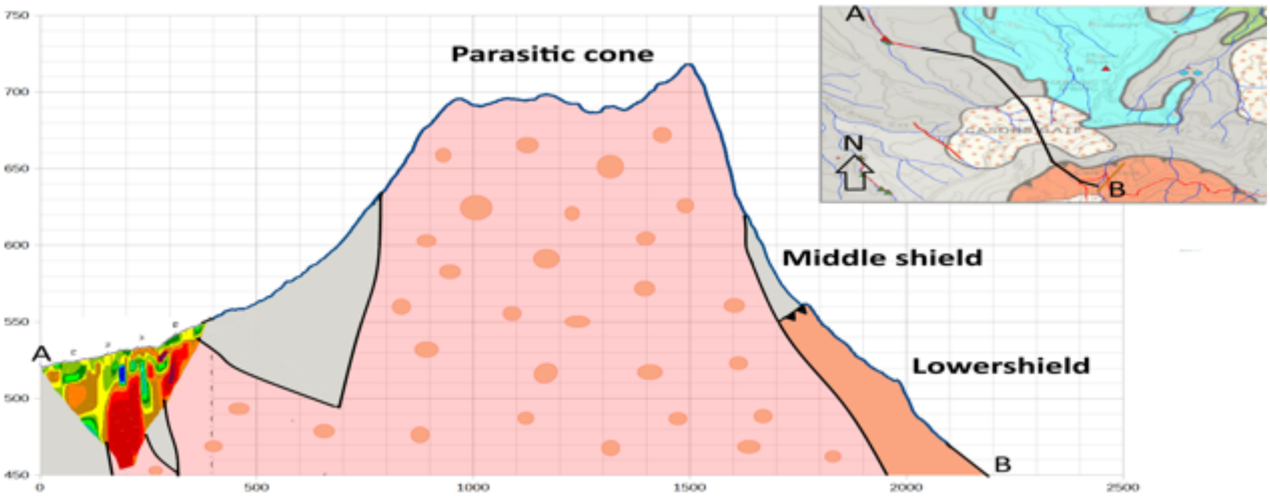


Figure 5-35: ERT 8 Molly's Gut Conceptual Model Partially Cutting Sandy Bay

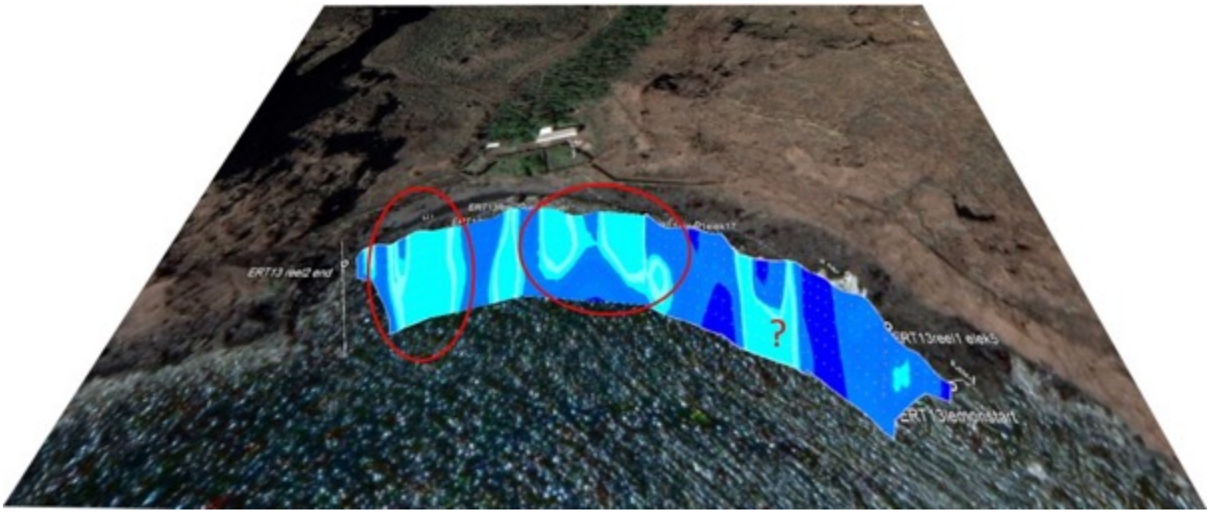


5.5.5 Lemon Valley Bay

An ERT lineation was planned for the bay of Lemon Valley with the aim to find evidence for fresh groundwater outflow into the ocean or saline ocean water intrusion into the bay. This ERT investigation was vastly different in field approach to the other terrestrial based ERT. For the coastal investigation, 2 ERT lines were required; one ERT parallel to the coast and a second ERT parallel to the stream bed. Because of the bulky equipment and the difficulty accessing the proposed site by land, the investigation team travelled by boat to the target site. At the measurement location at the bay, it became clear that a ERT parallel to the riverbed was not possible due to poor accessibility and the steep topography which made it uncertain that ocean level could be reached with the maximum expected exploration depth of the ERT.

In the end only one ERT was executed parallel at the shore line at the ocean front and is shown in Figure 5-36 and Figure 5-37.

Figure 5-36: ERT 13 in Lemon Valley Bay



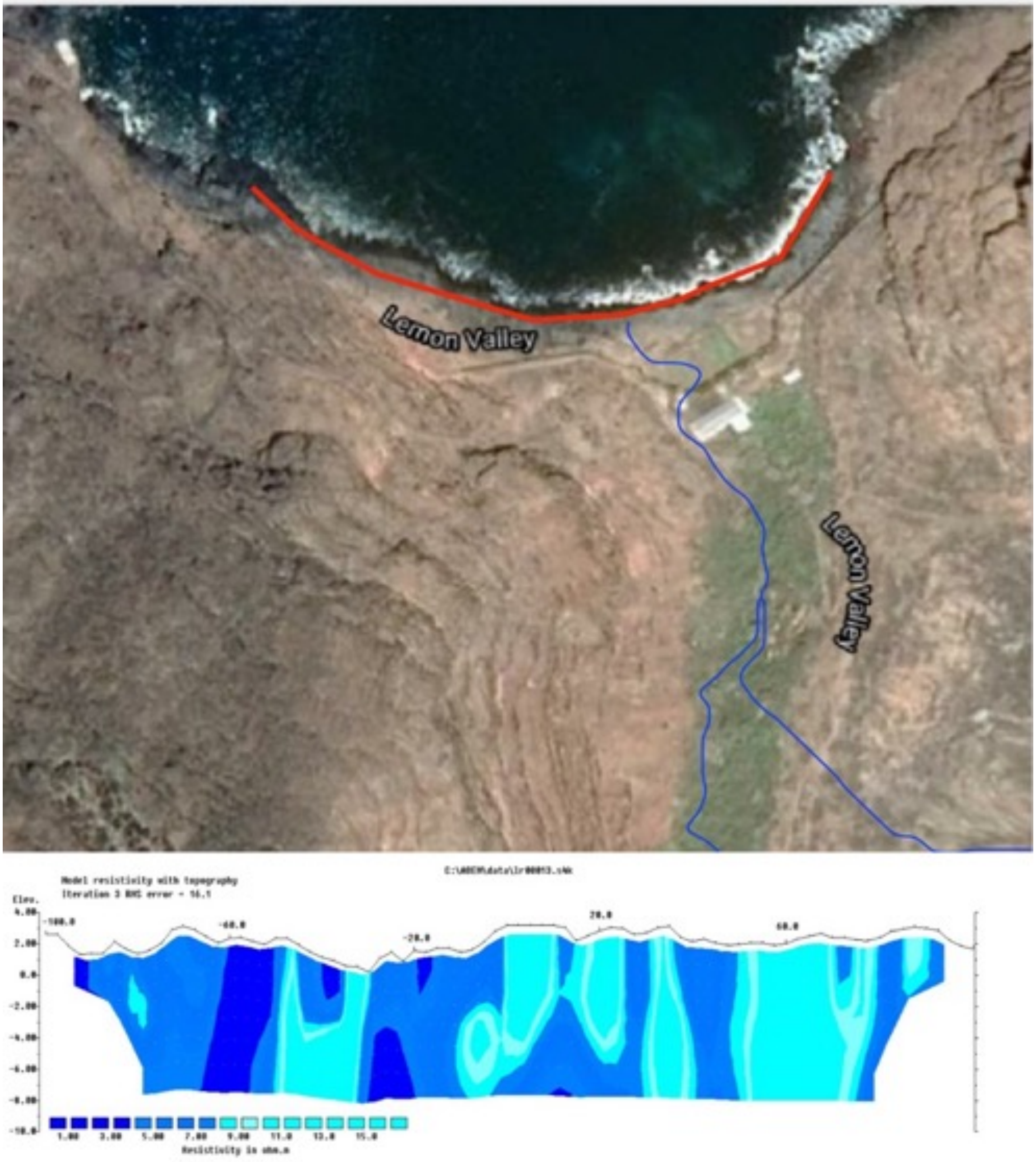
Note: the area indicated on the left of the ERT indicate spots were fresh groundwater is mixing with ocean water, the spot in the middle show the effect of the streamflow and streambed flow mixing with seawater, the right spot is unclear.

Almost all the electrodes were placed within the tidal zone. It was a difficult job to get the electrodes in place and stable, therefore only 2 reels were used (42 electrodes) in a Wenner configuration to reach reasonable values at the potential electrodes. This resulted in a much lower resolution than the other ERT measurements. The measurements were taken during a rising tide. The fit of the inversion is poor also compared to the other ERT measurements (4 reels, 82 electrodes). Considering the low resolution and the poor fit of the inversion, the reliability of this measurement is limited.

The resistivity of ocean water was approximately 0.5 ohm, with the formation resistivity (seawater and rock) was expected to be higher. In general, in very coarse sediment consisting of high resistivity rock pebbles the resistivity is expected to be around or less than 10 ohm. The inversion showed a resistivity varying between 1 and 15 ohm. At some locations these relative high values reached a depth of 12m.

Based on this, at the location of the outlet of the flowing river there might be evidence that fresh water was infiltrating and mixing with ocean water. However, caution should be applied to the interpretation of the results at this location as the ERT measurement may also only reflect the differences in rock matrix resistivity and not water quality.

Figure 5-37: ERT Lemon Valley Bay



5.5.6 *Key Findings and Observations*

Upstream shallow aquifers in the upper sub-catchments contain low groundwater yields, locating boreholes for water supply is difficult, especially in the areas with high resistivity close to the surface and with severe lateral change due to irregular weathering, dykes and parasitic cones.

In these areas compartmentalization due to difference in rock type and weathering processes seem to be the case resulting in low yields.

More information on actual yields, water strike, static water levels, detailed borehole logs of the boreholes would be of help to link the hydrogeology to the ERT resistivity profiles.
The differences in resistivity between Frenches gut (ERT5) and Iron Pot (ERT 10)/Molly's Gut (ERT8) seem to be related to the parasitic cone as indicated on the Baker (1970) geological map.

Drilling into these shallow aquifers should be done with care, ERT can help. The depth of the borehole should be limited, and the driller should be able to seal the borehole directly when inflow occurs to prevent shallow aquifers draining into underlying unsaturated layers.

Exploration boreholes in combination with ERT can help to find the best spot for drilling and will help to understand the aquifer systems. Where shallow ground water is encountered (water strike) a special strategy should be applied to protect these near surface aquifers if drilling to a deeper depth is desired.

High resistivity close to the surface seems to be coincident with an absence of stream flow and location where groundwater is infiltrating to a deeper layer. Drilling in these high resistivity areas might lead to inflow boreholes.

Information on the original water levels in Molly's Gut would be helpful for understanding the local geology. The question remains unsolved in which layer the oldest boreholes extracted their water, in which resistivity profile the groundwater is disappearing and in which lithology lies the impermeable layer (weathered rock, tuff, ash, sedimentary clay etc).

The clear differences in resistivity and the lateral continuity between the valley's cannot be explained with the geological map, however taking the topography of the DEM in Sandy Bay into account there seems to be a relation between topography, volcanic layering and resistivity.

It seems that both the parasitic cones and the geology within the Main Shield are very much influencing the direction of the groundwater flow (vertical or according to the slope).

The jump in the groundwater table in Frenches Gut is indirectly reflected in the ERT profile, however the groundwater table itself is not visible due to the lack of a sharp contrast. This is often the case in resistivity profiles.

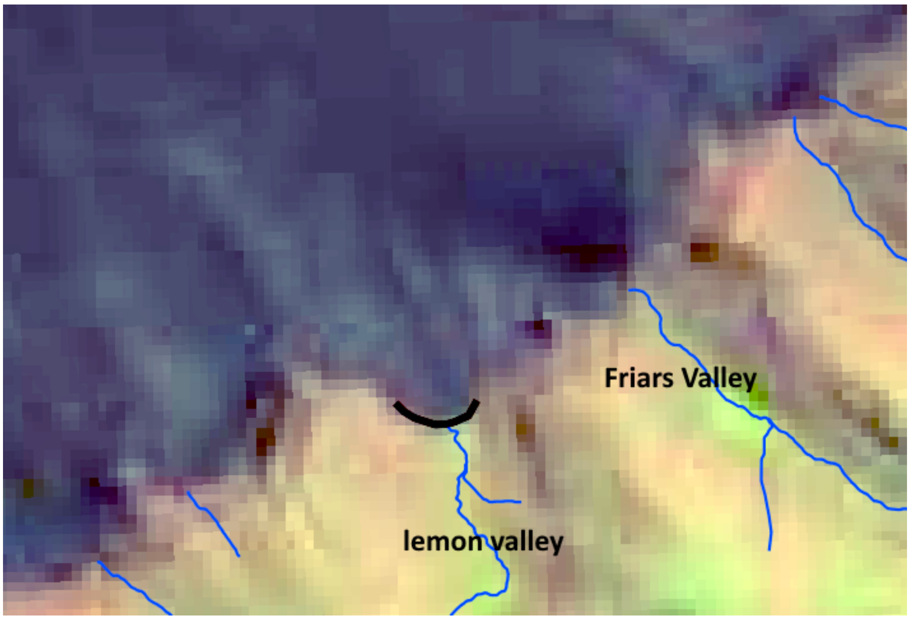
ERT 13 at Lemon Valley Bay, despite its low resolution and poor fit with other profiles, will be considered in the discussion on conceptual models to be had in Year 3 of the Cloud Forest Restoration Project.

The water balance of this catchment will be of interest. In the general conceptual model for the island, deeper aquifers are sealed on top by ash and the weathering process, are supposed to be dry. In the valley's, rivers may cut through these impermeable layers and water infiltrates into deeper layers ending as subsurface groundwater flow into the ocean.

This is also the case at location were boreholes penetrated the impermeable layers. The observation of the dry cliffs (no observations of running water from the cliffs) seems to support this concept.

A question to answer is at which location and altitude along the slope of the valley's towards the ocean does the water infiltrate into the deeper layers?
The TIR image in Figure 5-38does not show a clear dark spot, however the adjacent valley (Friars valley) does. It is also possible that fresh groundwater is flowing into the ocean at a depth were mixing diminish the temperature difference and makes it impossible to detect.

Figure 5-38: Thermal Infra-Red Image of Lemon Valley and Friars Valley



5.6 Harpers Earth Dam

5.6.1 ERT 14 at Harpers Earth Dam

ERT 14 is located upstream in James Valley, in a tributary adjacent to Francis Plain alongside of Harpers dam which is one of the main public water supply dams on St Helena. The ERT 14 location close to Harpers dam was selected instead of the original location in Grapevine Gut because of limitations in the accessibility and the limited profile length at Grapevine Gut. Because of the intention to drill a new groundwater exploration borehole at Francis Plain, close to the heart shaped waterfall escarpment, extra information could be of help to understand the situation in more detail.

The location of the ERT is shown on the island geology map in Figure 5-39 and Figure 5-40. The ERT is located within an area of a complex geology, parasitic cones, Lower Shield, Main Shield and Upper Shield formations as well as (further downstream) outcrops of the NE volcano. EC values of the stream flow at the input of the lake are around 200mS/cm (50 ohm) which might correspond with a formation resistivity in the ERT of 100 ohm (green colour in the lower figure). The question again is if this layer is permeable and acts as an aquifer with an impermeable clay layer on top, or is the groundwater restricted to a thin superficial layer? At this side of the valley no boreholes are present. At the other side of the valley two WSP deep boreholes are drilled, one borehole was dry when visited and the other one appears to be an inflow borehole (see DPLUS103 report). At the downhill side of the ERT, geological layers are dipping steeper than the topography and might indicate groundwater that infiltrates into deeper strata.

Figure 5-39: ERT 14 Location at Harpers Dam and Island Geology

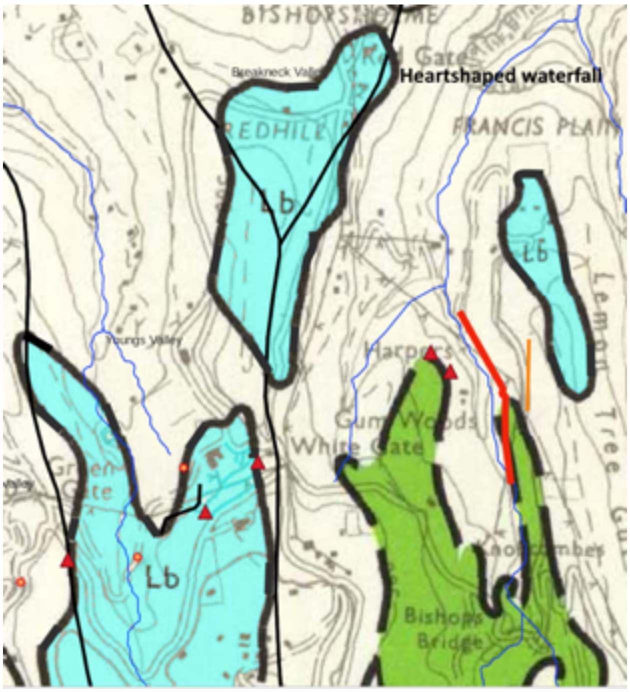


Figure 5-40: ERT 14 at Harpers Earth Dam

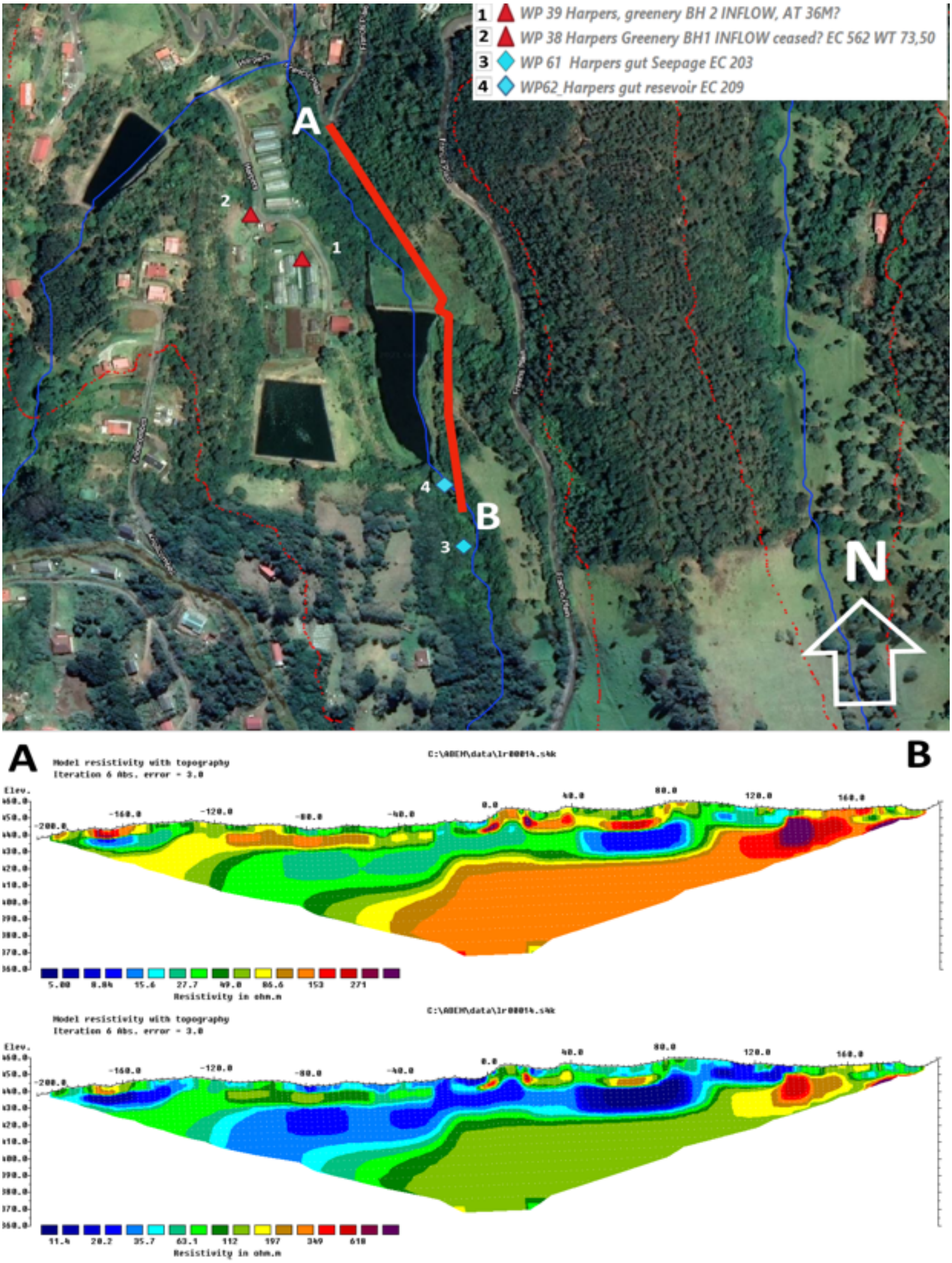


Figure 5-41 shows a schematic conceptual model of a cross-section between James Valley and Sandy Bay and based on the island geology map. It is possible that where the Lower Basalt formation ends, shallow groundwater is infiltrating straight into the Main Shield down to the more impermeable interfaces between the Main Shield and Lower Shield, resulting in a spring zone.

Figure 5-41: James Bay to Sandy Bay Conceptual Model with ERT 14

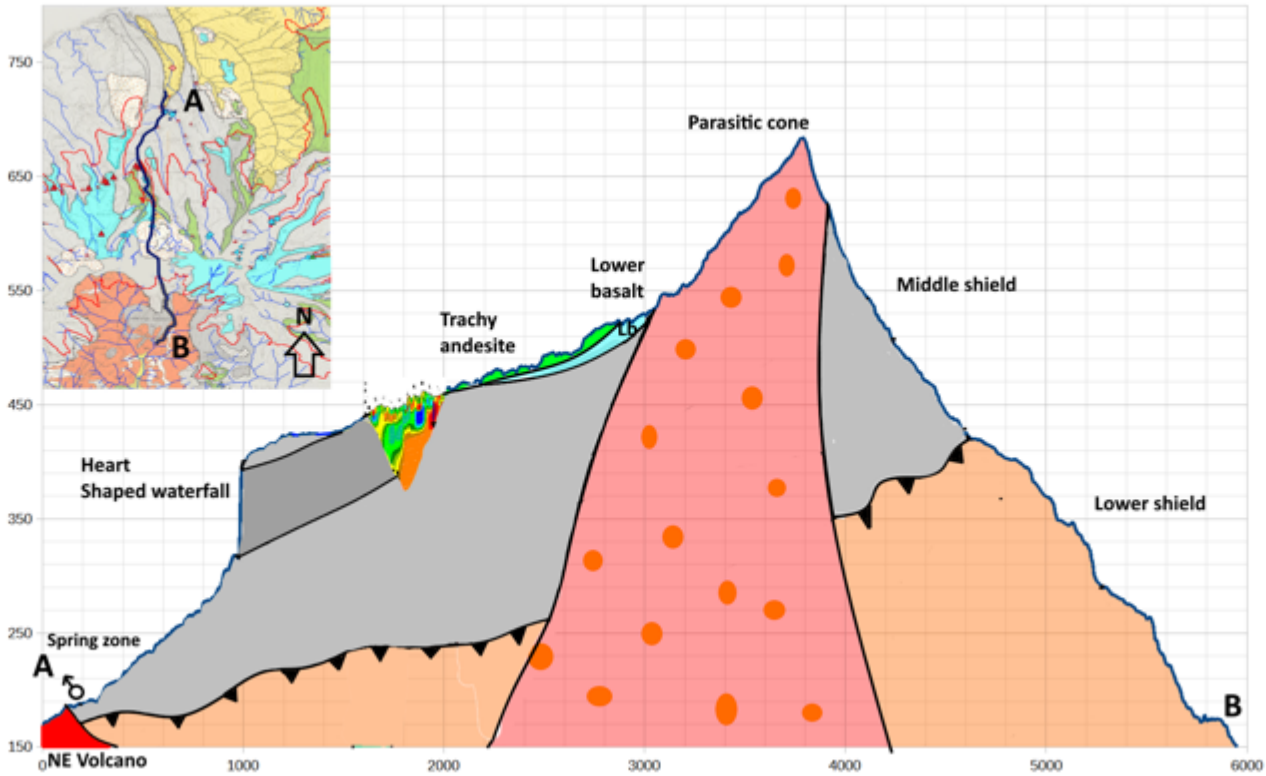
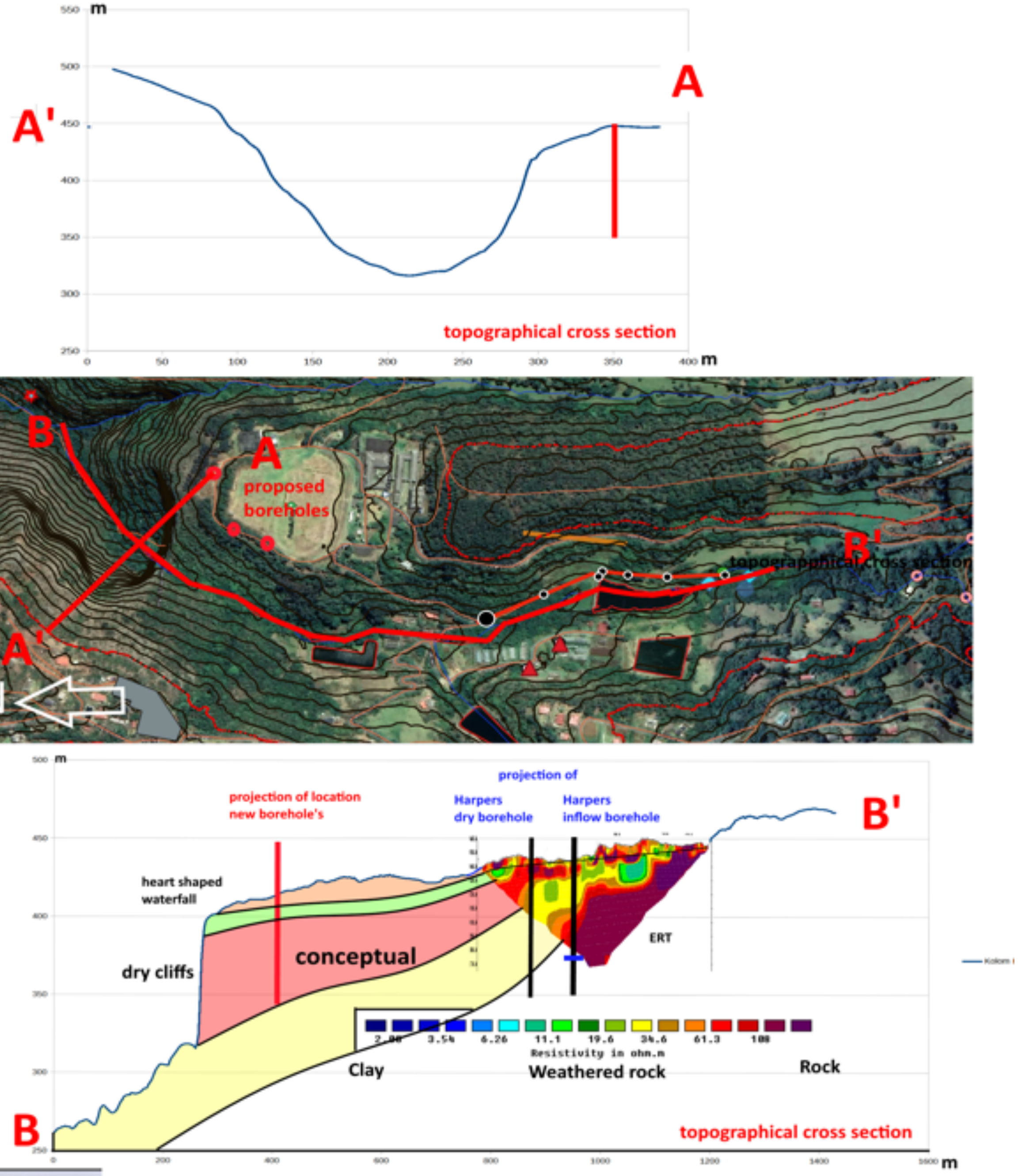


Figure 5-42 shows a topographical cross-section and long section schematic for ERT 14. The conceptual model uses geophysics survey data collected adjacent to Harpers earth dam in October 2022, deep borehole data from WSP boreholes HPSBH01, HPSBH02 and topography data from the island digital elevation model.

The rocks of heart shaped waterfall are according to Baker of Main Shield origin. It is possible that the resistivity of the rock unit of the Heart Shape Waterfall compares to the relative low resistivity given in ERT 14. The ending of the Lower Basalt may be related to infiltrating superficial groundwater into deeper strata (however dyke like structures might also be present). The cliff of the Heart Shaped Waterfall proves that these massive volcanic deposits are dry.

The location of the proposed boreholes is not far from the two abandoned WSP deep drilling boreholes on the other side of the dam. According to the topography and the fact that the cliffs of the Heart Shaped waterfall are dry, and the proposed borehole does not reach below the cliffs, it might be concluded that at this depth no groundwater can be expected.

Figure 5-42: Topographical Cross-Section and Long Section Schematic Conceptual Model



Heart shaped waterfall.

More analysis of the data is required, however further consideration of deep borehole locations should adopt a cautious approach as they have a high potential for failure based on past evidence

5.6.2 Key Findings and Observations

The origin of the spring zone in James valley might be related to this upper part of the catchment, according to the conceptual cross section. Recharge seems to be related to a more permeable Main Shield formation or distinct locations were groundwater infiltrates further down (like parasitic cones, eroded layers of ash, permeable dykes etc). The spring zone, downstream in James valley, is related to the assumed impermeable interface between the old and new volcano (paleo relief, layers of ash, weathered top layer, type of (sub marine) outflow etc.) .

Depending on the scale and resolution of available data, different hydrogeological concepts are possible. Groundwater losses to deeper aquifer systems seems to be related to the penetration of the contact zone between Upper Shield and Main (Middle) Shield outflows. It would be interesting if old records of the Heart shape waterfall could be linked to climate change, change in land use and upstream surface and groundwater abstraction.

The complex geological situation in combination with the ERT image indicate that drilling a new 100 m borehole close to Francis plain should be carefully considered. Some information on this project (Francis plain ring road boreholes) is given at the Saint Helena governmental website: https:/www/sainthelena.gov.sh/wp-content/uploads/2020/09/Harpers-Reservoir-One:

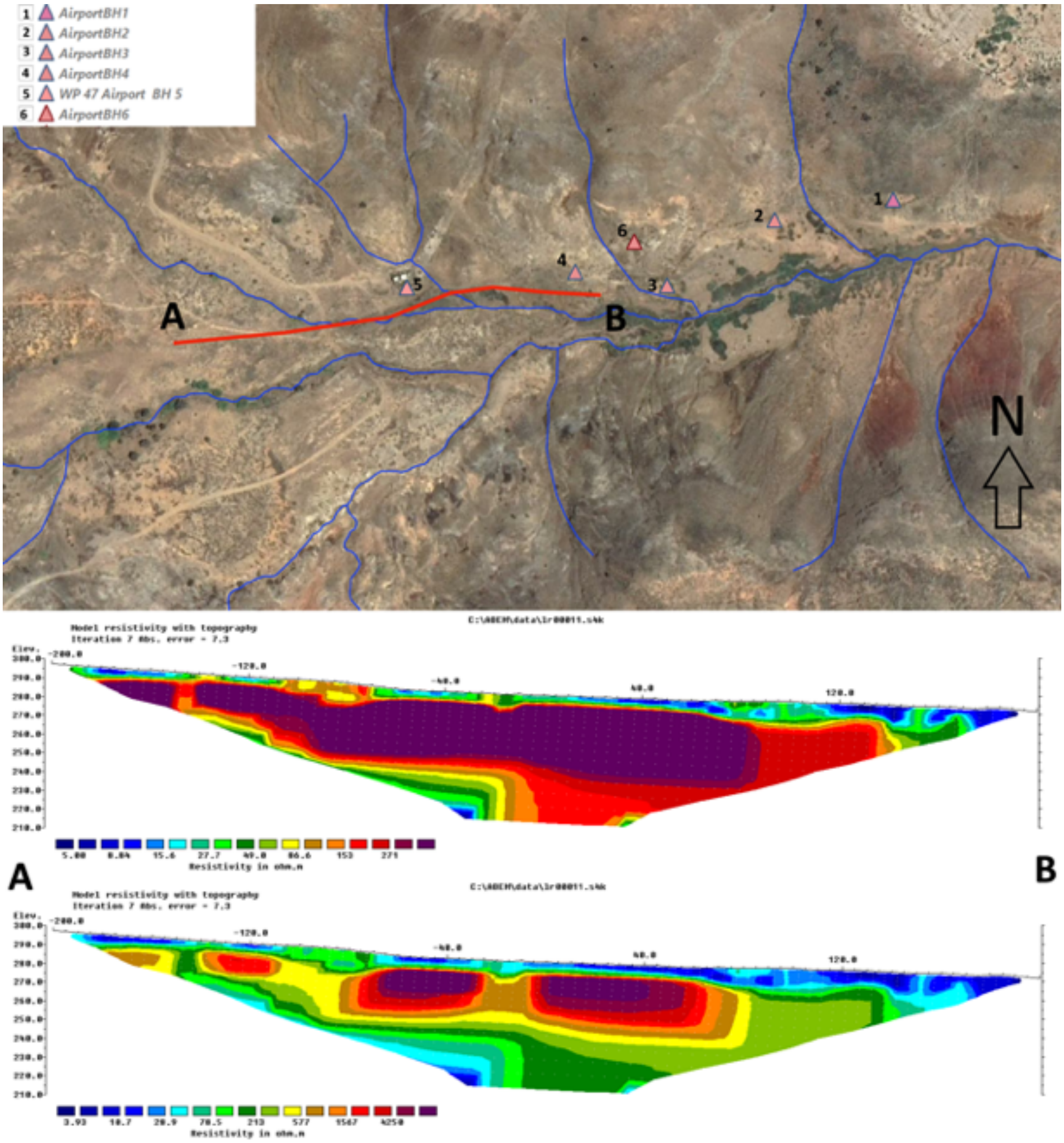
> *"Historical data, maps and walkover surveys were used to inform this Project and help identify potential water-bearing aquifers close to Scott's Mill on the Francis Plain Ring Road. Specific field data from the successful boreholes in Dry Gut (developed for the Airport Project) were also used to calibrate the water divining techniques utilised in this Project."*

5.7 Dry Gut

5.7.1 ERT 11 at Dry Gut

ERT 11 is located in Dry Gut, a valley in the northeastern part of the island close to the airport. Most part of the Dry Gut catchment is below the 500m contour (600mm rain isohyet) so no recharge is to be expected. In this dry valley at least 6 boreholes were drilled for the construction of the airport. More boreholes were drilled along the airport road outside the valley at higher altitudes. The exploration depth did not reach the water strike according to the logs, so the resistivity's in ERT 11 and ERT 18 do not represent water bearing formations (see Figure 5-43, Figure 5-44, Figure 5-45 and Figure 5-46.

Figure 5-43: ERT 11 and ERT 18 at Dry Gut



The poor water quality in most of the boreholes is probably related to the weathering of Trachy-Andesite, as in Fisher's Valley. These saline shallow aquifers drain into the deeper layers. The artesian aspect might be related to the fact that the groundwater is trapped and recharged from higher elevation. This might also explain the lowest EC values in BHDG5, and its behaviour (when pumped, the EC decreases after a time). During airport construction the pump was set at a lower level in BHDG5, however due to collapse of the borehole it had to be raised 50m. A pump test was completed at BHDG5 in 2022 and reported in DPLUS103. During the pump test the EC did not decrease as much as observed when the borehole pump was set at a lower level. Observations of the borehole behaviour indicate that the borehole does not seem to lose water into the high resistivity layer. It would be interesting to know if a better filter design could avoid the mixing of the saline and the fresh water. With borehole logging it might be possible to detect this zone.

The land slip does not seem to be the cause of the artesian situation because the slip interface is assumed to be above the aquifer (see Figure 5-44). The "young" Trachy-Andesitic infill is most probably responsible for the poor groundwater quality found at BHDG5. The geological map of the island indicates that a parasitic cone is close to boreholes BH1, BH2 and BH3 in Dry Gut.

There are no spring flows in the coastal cliffs below Dry Gut indicating that groundwater flow may be blocked by an impermeable barrier but does not explain the artesian behaviour observed at BHDG5 during airport construction drilling. Figure 5-45 shows static groundwater levels in the airport boreholes drilled in Dry Gut. The groundwater level data indicates that there is a significant change in water level between BH3 and BH2. A more detailed assessment of these water levels and the pump test at BHDG5 is provided in the DPLUS103 report. The ERT show a layer with a very high resistivity at this location which could be the Lower Basalt of the Upper Shield or a specific lava outflow within the Andesitic flow series or the layer originates within the Main Shield. More information might be obtained from a camera inspection at BHDG5 which will involve lifting the pump.

Figure 5-44: Schematic Conceptual Cross-Section from Sandy Bay to Dry Gut

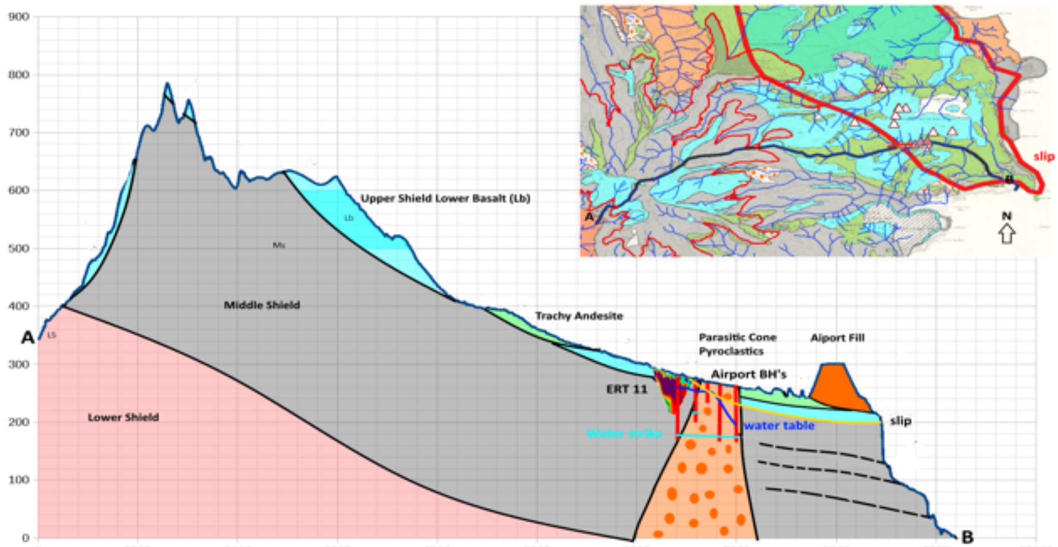
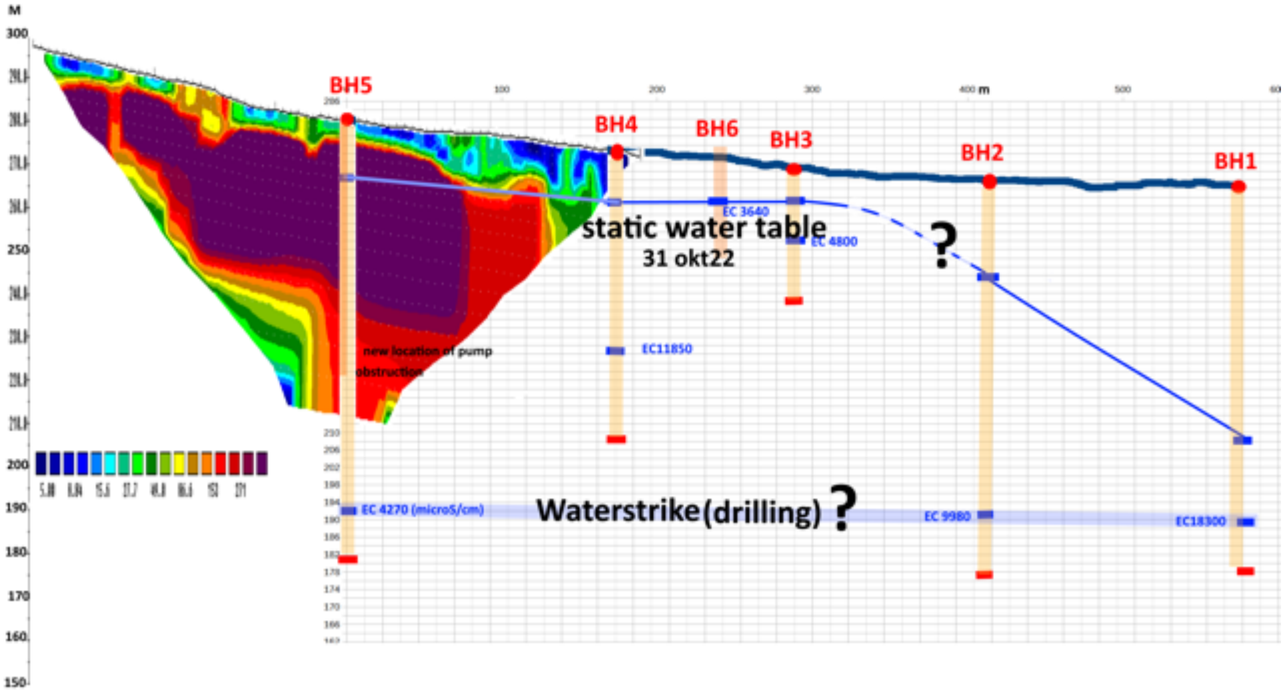


Figure 5-45: ERT11 and Recent Borehole Information



5.7.2 ERT 18 at Dry Gut

During 2023 ERT 11 in Dry Gut was extended with ERT 18. The inversion showed a strong lateral change in the downhill direction of the ocean (see Figure 5-46). The dark blue line in Figure 5-46 is the water strike and the light blue line is the static groundwater level. A cross-section of all airport borehole groundwater levels is provided in Figure 5-47 (EC values are shown in red, static groundwater levels shown in dark blue and water strike shown in light blue).

This lateral change could explain the behaviour of BHDG5 in respect to the other boreholes and the increase of the salt content in these other boreholes in the direction of the coastline. This increase in salinity is not related to the ocean itself because the boreholes are more than 250 m above the sea level and the drilled boreholes did not reach sea level. The high salinity is expected to be connected to the weathering process of the alkaline rocks producing soils rich in minerals like Gypsum and Halite as in Fishers Valley. Because there is no groundwater fed springs flowing out from the cliffs below Dry Gut and the fact that BHDG5 is artesian, it is assumed that groundwater flow is blocked, probably due to the interface with the NE volcano similar as the location of low altitude springs in James Valley.

BHDG5 has a high yield and produces relatively fresh water compared to the other boreholes which have a reduced water quality and yield. All these boreholes were artesian when drilled, and groundwater levels recorded during drilling and as part of this project show a decrease in groundwater level in the direction of the coast, which coincides with the Gypsum in the weathered Andesitic outflows and soils.

ERT 11 was completed close to BHDG5. The Dry Gut boreholes were continuously pumped for almost 2 years between 2013 and 2014 (especially BHDG5 and BHDG4) during the construction of the airport runway. An estimation of this enormous amount of pumped groundwater might be linked to the water balance and may give information of the size of borehole recharge area or support the assumption of the existence of paleo-water or inflow from other catchments. According to a memo from the airport Design Build and Operate contractor (Basil Reed) dated 25 February 2013, the water needed for runway construction was estimated at 1,950m^3 per day. According to the memo the most important boreholes pumped during this time were BHDG5 and BHDG4, both situated in Dry Gut.

Figure 5-46: ERT 18 as an Extension of ERT 11

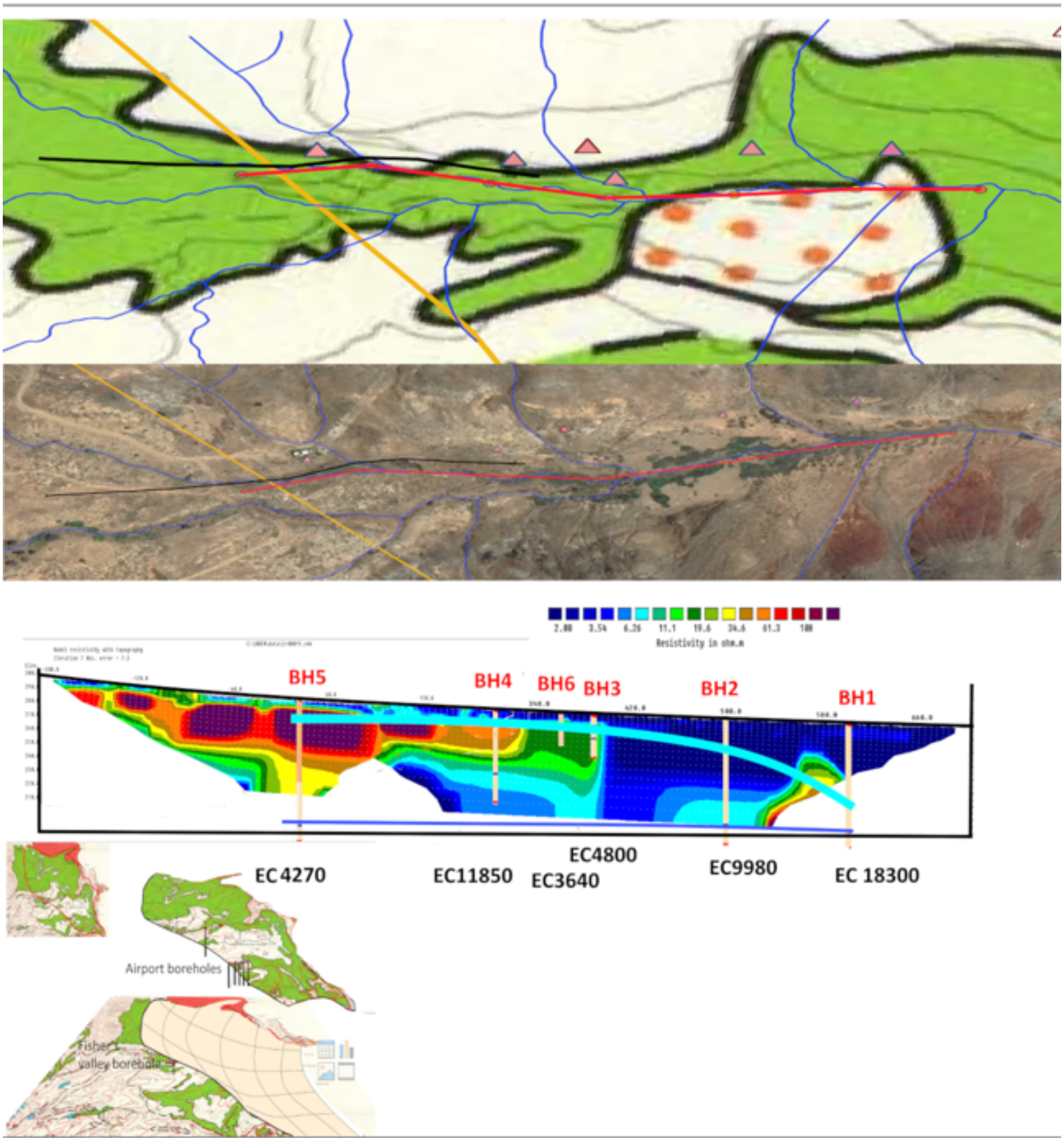
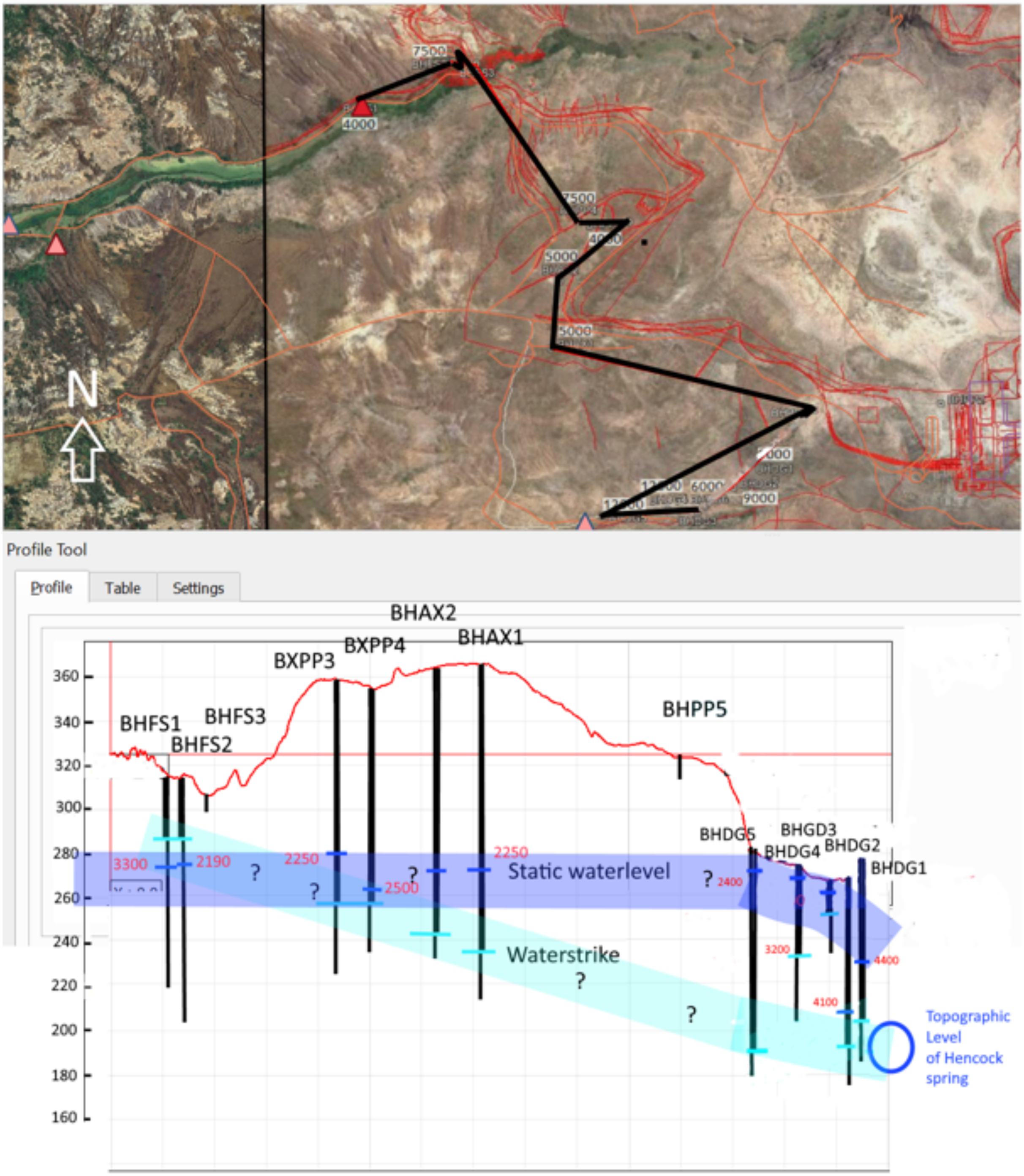


Figure 5-47: Cross-Section of Airport Borehole Groundwater Levels



The Dry Gut catchment does not receive any recharge according to the water balance (see Section 4). The recharge of Fishers Valley (rainfall and mist) is estimated at 290,000m^3/a, which is around 800m^3/d.

Based on the most recent water balance, the calculated recharge of Fishers Valley is not enough to support the groundwater volumes pumped in 2013 and 2014 to meet the water demand from the runway construction phase of the airport project. This could mean that that the recharge of Fishers Valley is underestimated, or there is another source of groundwater supplementing groundwater flows in Dry Gut. Shark's Valley is adjacent to the southern side of Dry Gut, which has a calculated recharge of 400,000 m^3/a, which is around 1,100 m^3/d.

Another possibility for the high groundwater volumes pumped during 2013 and 2014 is groundwater mining, where old/historic groundwater stored in a large aquifer is abstracted whilst rainfall and mist recharge in modern times are too small to replace the pumped groundwater. Comparing the static water levels at BHDG5 in 2013 and 2023 the difference is not significant (12.9 mbgl and 14.25 mbgl) making groundwater mining a less likely reason to explain the high pumped groundwater volumes in 2013 and 2014 at BHDG5.

It should be noted that airport groundwater abstraction volumes were an estimation and never measured or recorded at the pumped boreholes during airport construction. However, the comparison of estimated pumped volumes based on the water demand and the most recent water balance point to Dry Gut boreholes being supported by groundwater flow from both Fishers Valley and Sharks Valley.

Hancock spring might also be related to this system, and it would have been very useful to know if the two years of continuous pumping at BHDG5 would have affected this spring. No records were found in Connect Saint Helena or Saint Helena Government archives, however the EC measured in Hancock Hole in October 2023 was around 1,000 μS/cm and the EC of Fishers Valley borehole close to the water storage tank in the wetland area was also around 1,000 μS/cm during the same month. The EC of BHDG5 after a period of pumping in October 2023 was recorded around 4,000 μS/cm (2023) and a review of airport construction data the EC values at BHDG5 decreased even more. The reason for this higher EC more recently could be that the borehole pump at BHDG5 is now located at a higher level (50 m above the original pump depth) due to the collapse of the borehole when the pump was lifted for repair and lowered in the open borehole. It is believed that the salinity in BHDG5 is due to mixing with saline water from the late Andesitic outflows as in Fishers Valley.

A better borehole design could have avoided this resulting in an EC of around 1,000 μS/cm. From these observations it may be concluded that BHDG5 is a key borehole for the water resources of Saint Helena. A program of continuous water level, water quality and water abstraction monitoring is needed in order to understand Dry Gut and the performance of BHDG5. Due to the collapse of BHDG5 when the pump was lifted, it is essential that the borehole is rehabilitated to avoid further borehole collapses. A new borehole (or reamed existing borehole) in combination with a better well design (liner, filter, pump location of the pump etc) will lead to higher and more sustainable yield a more stable water quality and no danger for collapse.

5.7.3 Key Findings and Observations

The static groundwater levels and water strikes of all the airport boreholes seem connected and show water strike and artesian behaviour decrease towards the coast. On a smaller scale the artesian behaviour of the boreholes changes gradually along the profile line shown in Figure 5-47, from no overpressure (BHFS1) to a pressure difference at BHDG5 (ca 80m). The water strike was far below the exploration depth of the ERT, most probably within the Main Shield sequence.

Salinity increases in the direction of the coast. The altitude of the water strike in airport boreholes is more than 200m above sea level, so mixing with recent sea water is not the reason of this increase in salinity. Salinity decreases in BHDG5 when the borehole pump is located approximately 90mbgl and is likely to be a mixing of relative fresh groundwater with local superficial saline groundwater. This re-freshening effect is diminished after the “collapse” of the borehole when the pump had to be located at a higher level (50mbgl). A liner or blind filter could help to prevent further collapse of the borehole. BHDG5 is the most upstream, the most productive and least saline borehole drilled in Dry Gut.

No change in groundwater level is observed in BHDG1, BHDG2, BHDG3, BHDG4 and BHDG6 during the pumping test in 2023, which is unexpected given the confined aquifer response of the boreholes.

The relative high resistivity layer in the ERT indicate the presence of the Lower Basalt which is likely to be dry (partly sealed from above and receiving limited recharge from rainfall), however the artesian groundwater does not seem to infiltrate into this layer. The layer of high resistivity could be the Lower Basalt of the Upper Shield as no water seems to infiltrate from the artesian open wells.

It would be interesting to know if a better filter design could avoid the mixing of the saline and the fresh water (depending on where this mixing takes place). This might be visible in borehole camera recordings or could be detected with borehole logging (depending upon the type of borehole casing used).

During airport construction in the years 2013 and 2014, it is understood that all the boreholes were continuously in use. Two years of continuous pumping of these boreholes represents an enormous amount of abstracted groundwater, which supports the conceptual model that recharge from Fishers Valley and Sharks Valley support groundwater flows in Dry Gut.

Groundwater does not support springs along the coastal cliffs in this area. According to the extended ERT at BH 5 there is a strong lateral change in resistivity which supports the case for an impermeable barrier preventing the outflow of groundwater at the coast. This is probably due to the interface with the NE volcano, similar to the location of low altitude springs in James Valley. This is partly due to the slip fault and infill with Andesite outflow, Ash layers, dykes, parasitic cone or a combination of the volcanic geological features.

The water strike (main aquifer) is in the Middle/Lower Shield and recharged above 500m, possibly from another catchment and/ or paleo-groundwater. It might be possible to make a water balance based on the pumping of BHDG5 during airport construction as part of further studies.

Deeper TDEM soundings could be of help to get more insight in the hydrogeological setting in Dry Gut. Assuming it is supported by recharge from Fishers Valley and Sharks Valley, BHDG5 is a key borehole in groundwater exploitation at St Helena.

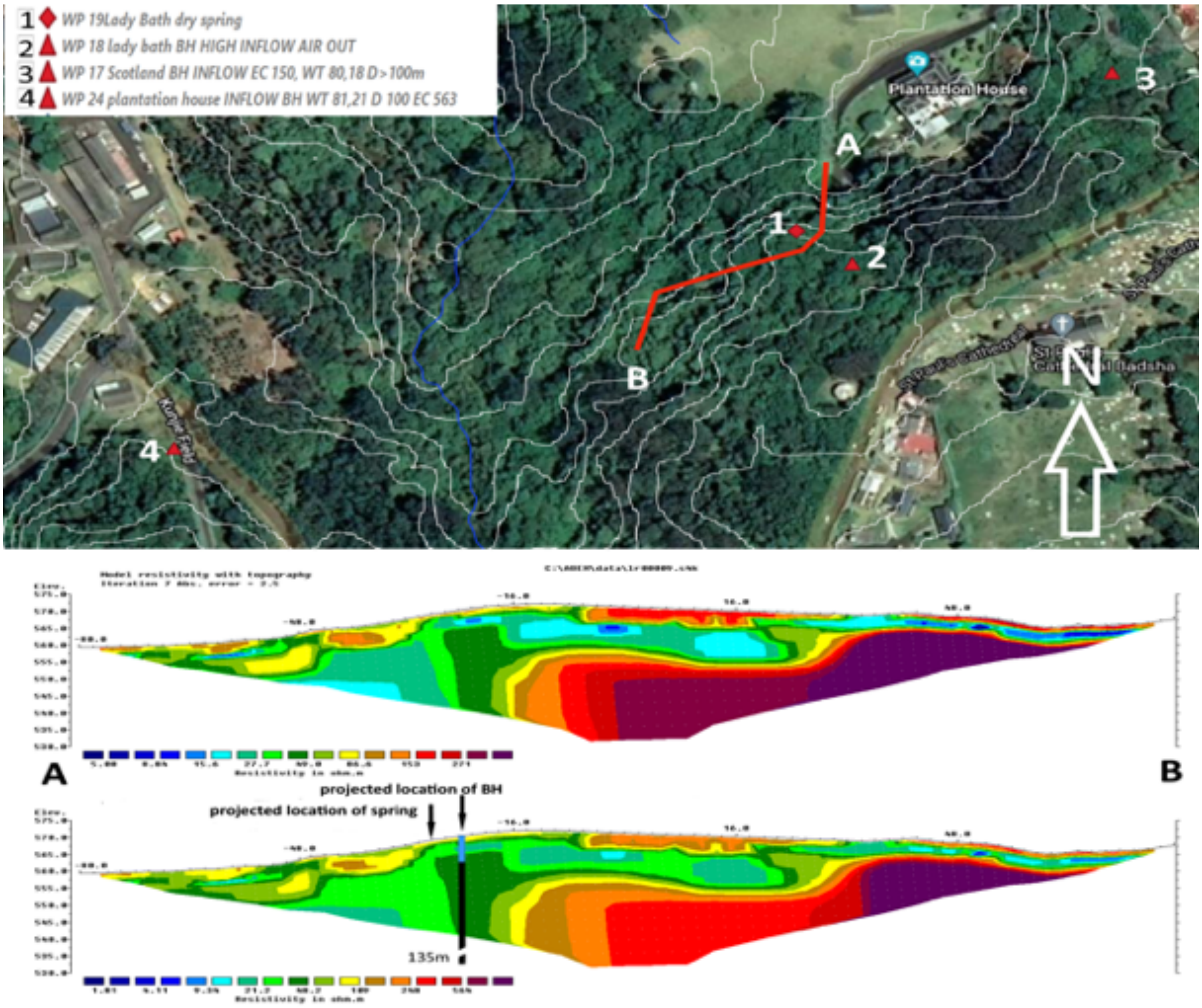
5.8 Ladies Bath

5.8.1 ERT 9 at Ladies Bath

Lady's Bath Spring is a historical spring located near Plantation House in Youngs Valley catchment. One of the boreholes drilled as part of the WSP deep borehole project (PTNBH01) was drilled within a few metres uphill from this spring. Unfortunately, the spring source stopped flowing following the drilling and development of this borehole.

The length of the ERT was limited (160m) because of the local circumstances as topography and vegetation but also because of the superficial character of the spring and inflow in the borehole. Exploration depth in the middle was 40m, which was less than the depth of the borehole (135m). The location of the borehole and ERT are shown in Figure 5-48. Note the 3 WSP deep inflow boreholes. Groundwater flow direction is from the SE to the NW.

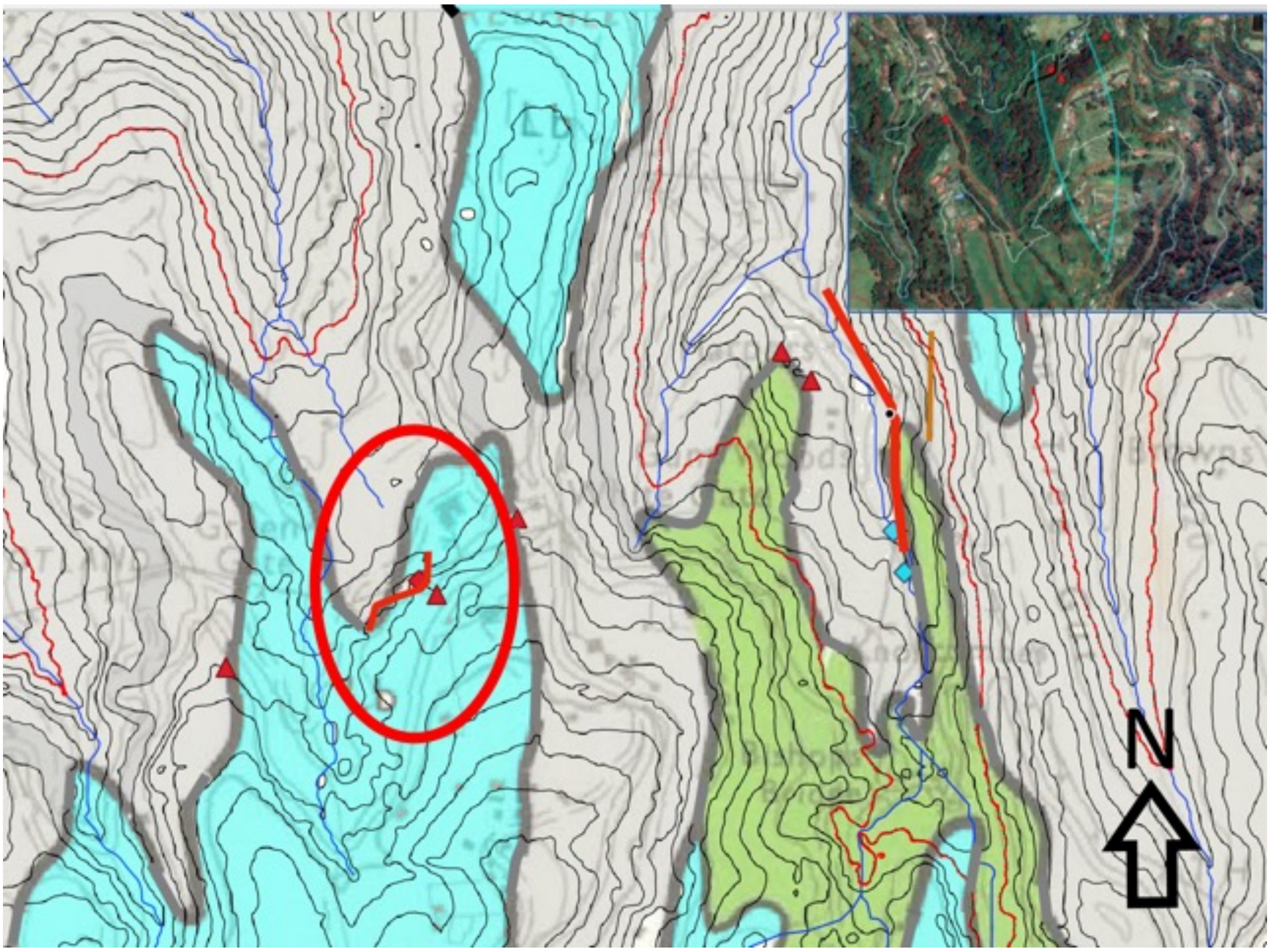
Figure 5-48: ERT 9 at Ladies Bath



The inflow from the borehole into the formation is close to the surface at approximately 7mbgl according to the borehole camera inspection. According to the WSP drilling report[25] the borehole collapsed during drilling . The camera inspection of the borehole showed a slotted casing up to 18m, with big slots made by hand with an angle grinder or welding torch.

A borehole packer was installed in the borehole on site in an attempt to create a seal between the upper and lower geological units and to artificially restore the impermeable layer. However, it was noted that slots also existed in the casing below the impermeable layer and as such, water is flowing between the casing and the rock. Because of this the packer could not stop the inflow because of the water leaking outside of the borehole filter. Restoring Ladies Bath Spring will require pulling out the complete filter and replacing the slotted and unslotted casing in the correct configuration. Based on the information gathered to date, grouting inside the borehole is unlikely to stop the leakage.

Figure 5-49: ERT 9 and Island Geology



The limited scale of the ERT9 made it difficult to match the different data sources. Because the ERT was located at some distance from the spring and borehole, the location of the borehole

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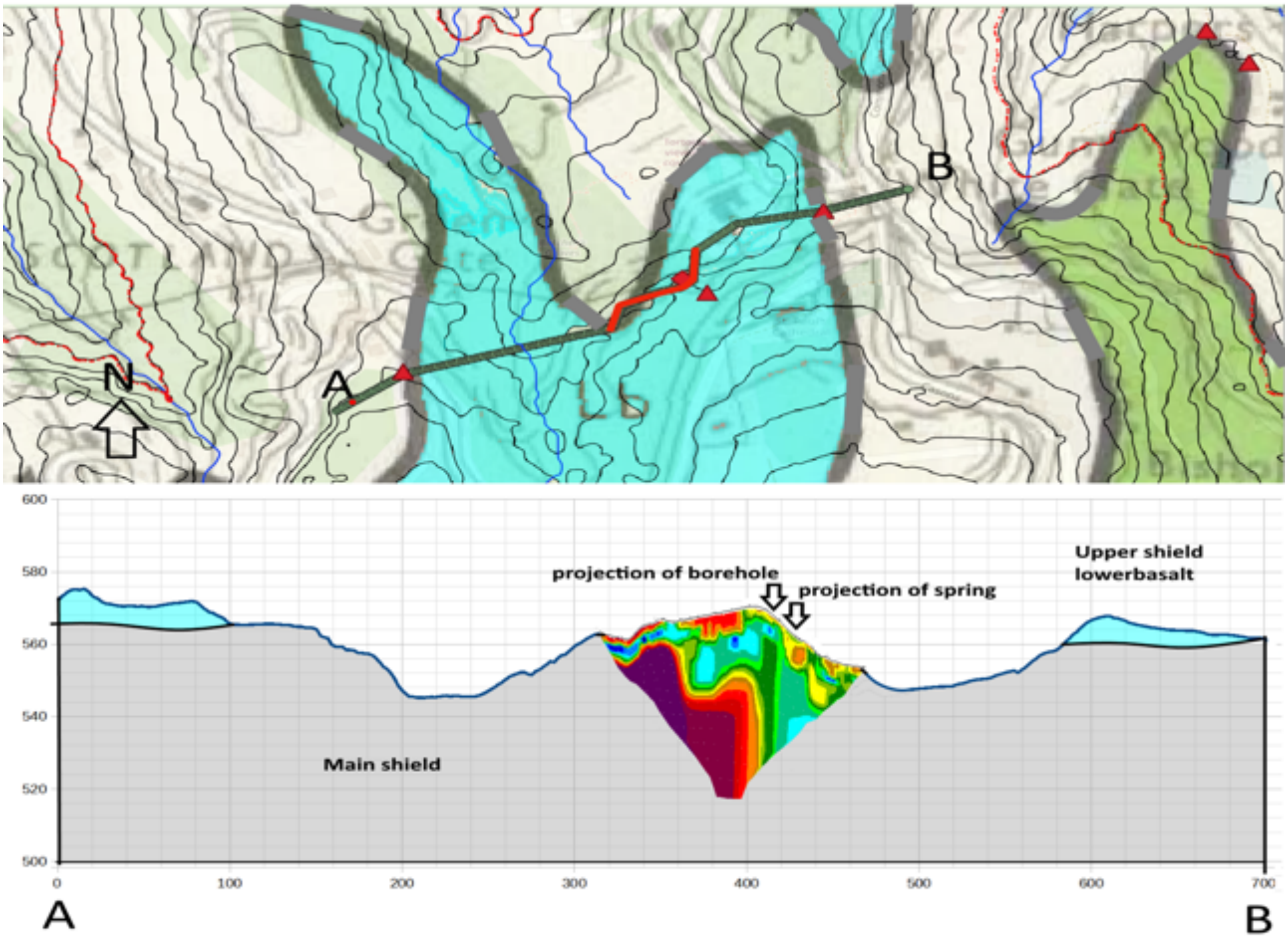
[25] WSP, 2017. Deep Aquifer Exploration Drilling Feasibility Study, St Helena Island.

and spring were both projected on to the ERT graph. As a consequence, they do not align completely with the ERT results.

The resolution of the island geological map is not sufficient at this scale and did not match with the DEM (see Figure 5-50). It seems reasonable that the high resistivity in the ERT is of Main Shield origin and not the Lower Basalt of the Upper Shield. According to Ian Baker, the Lower Basalt was eroded in the island valleys and is relative thin. There is clearly an unconformity visible in the ERT, most probably related to the inflow borehole.

Figure 5-50: Cross-Section of ERT 9



The step in the topography towards Plantation House coincides with the lateral change in resistivity. The potential recharge area of the spring according to the topography is limited, with part of the water flowing into the spring coming from the graveyard area of St Pauls Cathedral upslope of the spring. Groundwater from the graveyard area is known to have high levels of lead. The EC value of the inflowing water in the WSP borehole was 370 µS/cm (ca. 30 ohm) this matches with the intermediate resistivity (green colour in Figure 5-50). Although the ERT does not show this, because the borehole was projected, the borehole itself most probably penetrated the layer with the high resistivity which was also observed at other locations.

The key question again is which of the resistivity's visible in the ERT are representing the aquifer. It is likely the water bearing layer is at surface or partly within the green intermediate resistivity layer. Because the locations of both borehole and spring are projected on the ERT, it could be that the borehole penetrated the intermediate resistivity and went into the high resistive layer, in which it loses all its water. It is clear that the distinct lateral change in resistivity in the ERT close to the borehole and spring is responsible for the situation and the borehole most probably loses water into the high resistivity formation (most likely from the Main Shield volcanic rock.

5.8.2 Key Findings and Observations

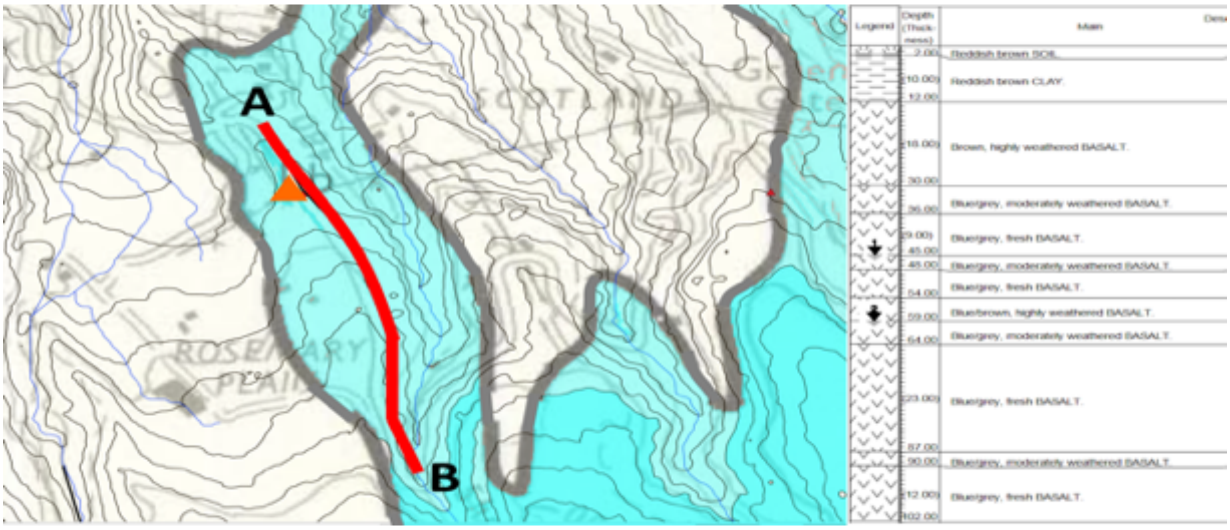
1. The ERT9 data for Ladies Bath shows a complex local geology with distinct lateral changes.
2. The recharge area is restricted in size by topography and supports a shallow aquifer.
3. Borehole PTNBH01 was drilled through an impermeable layer, as identified on the Resistivity graph for ERT9, which again demonstrates the need for care during drilling. Breaching an impermeable layer may lead to an inflow borehole, where shallow groundwater in a near surface aquifer is drained into a lower aquifer.
4. The slots in the filter (casing) are above and below this breached impermeable layer in PTNBH01 and water is leaking outside the filter.
5. Installing a packer and filling the filter with bentonite or cement to grout the filter will NOT restore the spring flow at Ladies Bath.
6. The filter should be completely removed from the borehole and the borehole wellscreen, case and filterpack re-installed.

5.9 Rosemary Plain

5.9.1 ERT 18 at Rosemary Plain

A 600m long ERT was conducted along the road parallel to a small valley upstream of Friars valley in 2023. The ERT was located close to WSP deep inflow borehole RPNBH01 on Rosemary Plain, which is located on the edge of the watershed between Friars Valley and Lemon Valley at an altitude of 500m. The location of the ERT is shown in Figure 5-51 alongside RPNBH01.

Figure 5-51: Location of ERT 18



WSP deep borehole RPNBH01 was drilled down to 102m with a water strike recorded at 45mbgl and 59mbgl. The static water table was measured in 2017 as 86mBGL and in January 2022 as 98mBGL. An iron casing was inserted down to 30m. When inspecting the borehole, groundwater was clearly running down, below the casing, into the open borehole. According to the projection of the borehole on the ERT (orange triangle - Figure 5-51), this location was more or less on top of a rock mass with a high resistivity (see Figure 5-52).

According to the island geological map the borehole is drilled into the Lower Basalt of the Upper Shield which overly the Main Shield formations. The drillers log for RPNBH01 mainly described Basalt in the borehole. The ERT inversion indicates that in this high resistive rock, some water is still flowing which is probably associated with weathering and the location of thin impermeable ash layers which are too thin to detect with the ERT. When the colour scheme is focussed on the high resistivity part of the inversion, some changes are visible which might be associated with these zones (see Figure 5-53). When the DEM and the Google satellite image are combined with the island geological map, it becomes clear that thick probably Main Shield lava flows are present at the location of ERT 18, undulating on a paleo-relief dipping towards the coast and overlain at higher altitude by the Lower Basalt of the Upper Shield.

Figure 5-52: ERT 18 Inversion

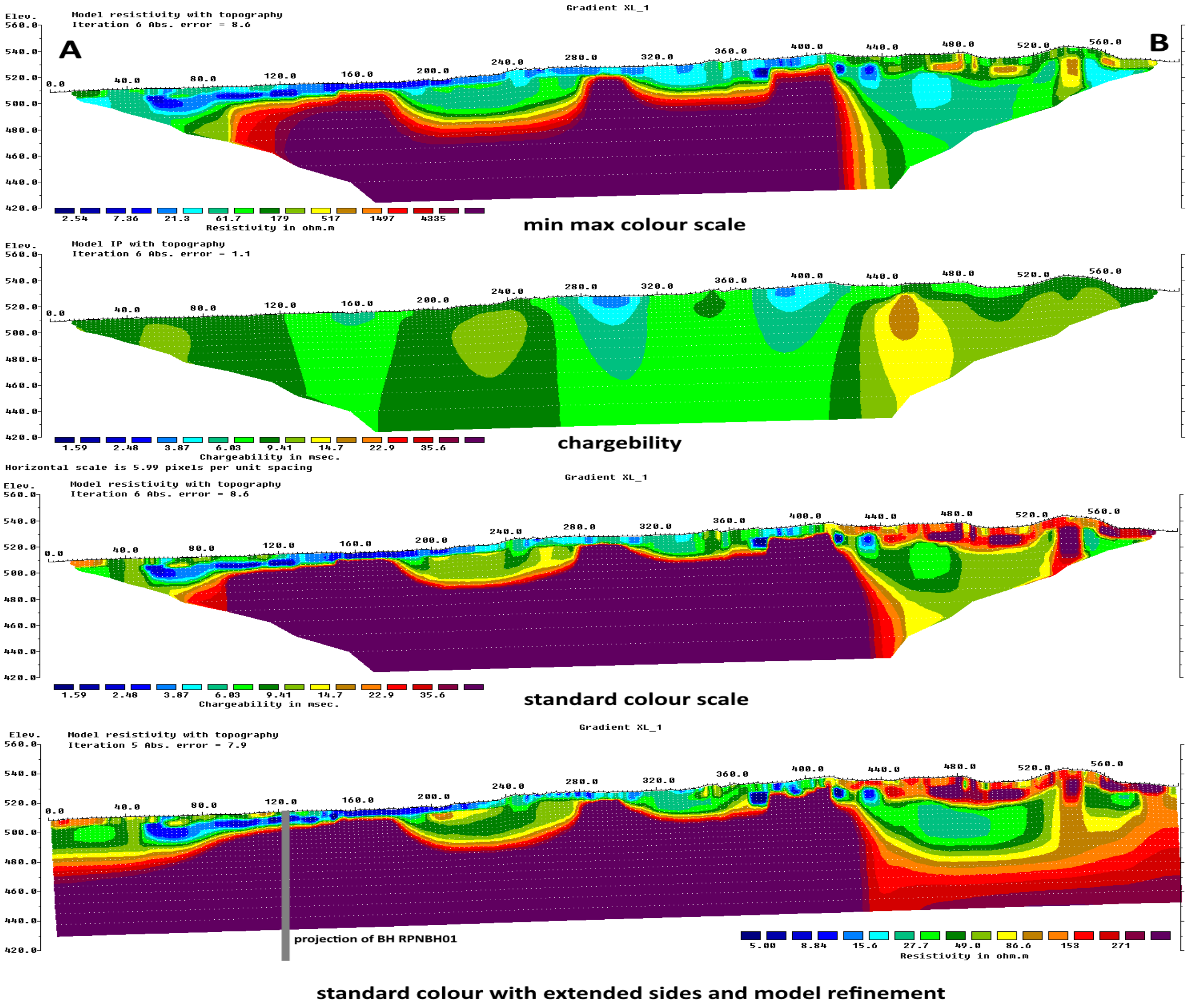
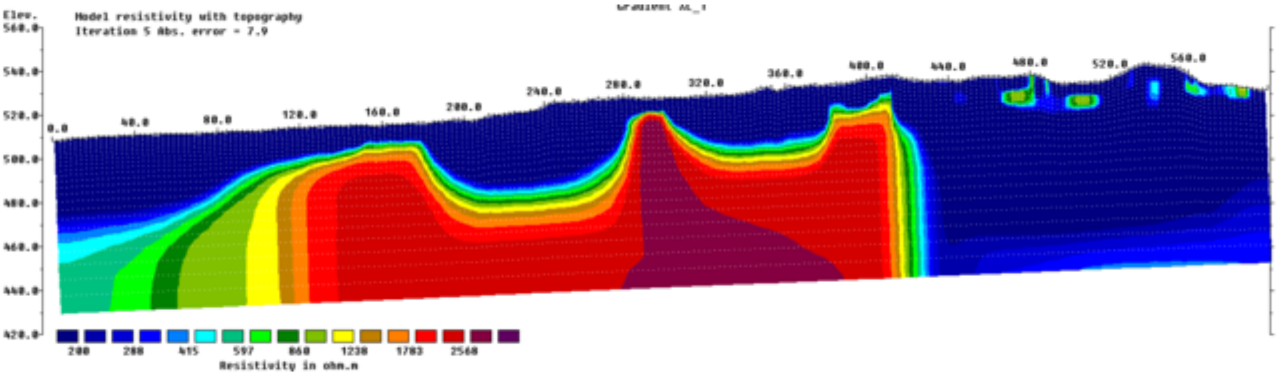


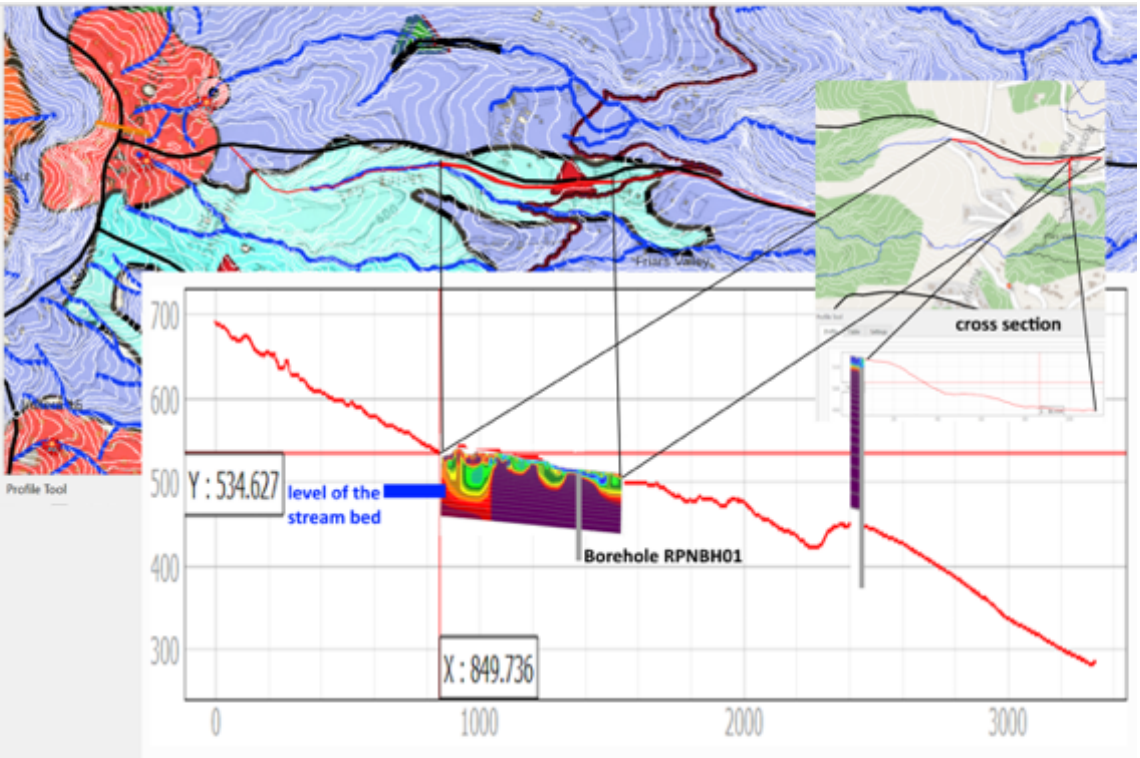
Figure 5-53: ERT 18 with Extended Inversion Looking at High Resistivity



The chargeability inversion in Figure 5-52 show a slightly increase in lateral change however it is unknown what causes this. It could be an infilled part of the valley filled with river, slope sediments and weathered rock or the underlying Main Shield outflow.

The high resistive part of the ERT seems to be the continuation of a ridge which is clearly visible on the DEM and Google Earth which is associated with a dip-slope forming part of the undulating Basalt lava. The ERT was conducted along the road and part of it followed the ridge line, where upstream the ridge changed abruptly with a small cliff into the valley fill. See Figure 5-54.

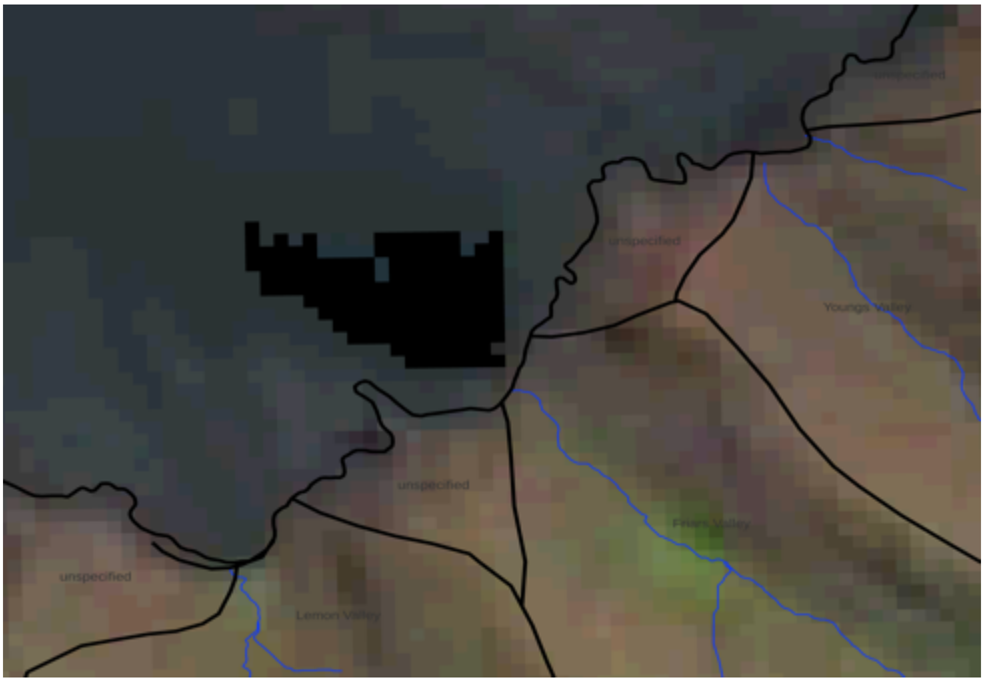
Figure 5-54: ERT 18 Topographical Cross-Section



When taking the TIR satellite image into account (Figure 5-55), a dark spot is visible at the outlet of Friars Valley indicating the possibility of sub-ocean groundwater discharge. Due to the relative steep dipping lava sheets most of the infiltrating water will flow along the dip downwards towards the coast. This may be representative of many valleys along the northern coast of St Helena which dip towards the coast.

Figure 5-56 is a composite image of all ERT’s completed in catchments on the northern half of St Helena which all topographically and geologically dip towards the coast. In Figure 5-56, red triangles denote the inflow boreholes, green triangles are shallow pumped boreholes, red lines are the ERT’s, red stars show the location of springs, the green line is the 500m isohyet and black lines are 10 metre interval topographical contours. The Main Shield is not coloured.

Figure 5-55: Thermal Infra-Red Image of Friars Valley Discharge



It is interesting to note that all of the deep WSP boreholes are located in areas where there is a strong decrease in topographical elevation and where the spring line in absent below 500m elevation. The abrupt change in topographical dip is representative of a change in the underlying geology and the absence of spring lines below 500m may be indicative that groundwater is lost at depth to the ocean. A schematic showing a possible mechanism for deep groundwater flow into the Atlantic Ocean is presented in Figure 5-57 where groundwater is lost through dipping permeable Main Shield lava layers. Further work is needed to confirm if the relationship between the change in geology, topography and spring lines are linked to deep groundwater outflows at the coast.

Figure 5-56: Overview of all Northern ERT's on St Helena

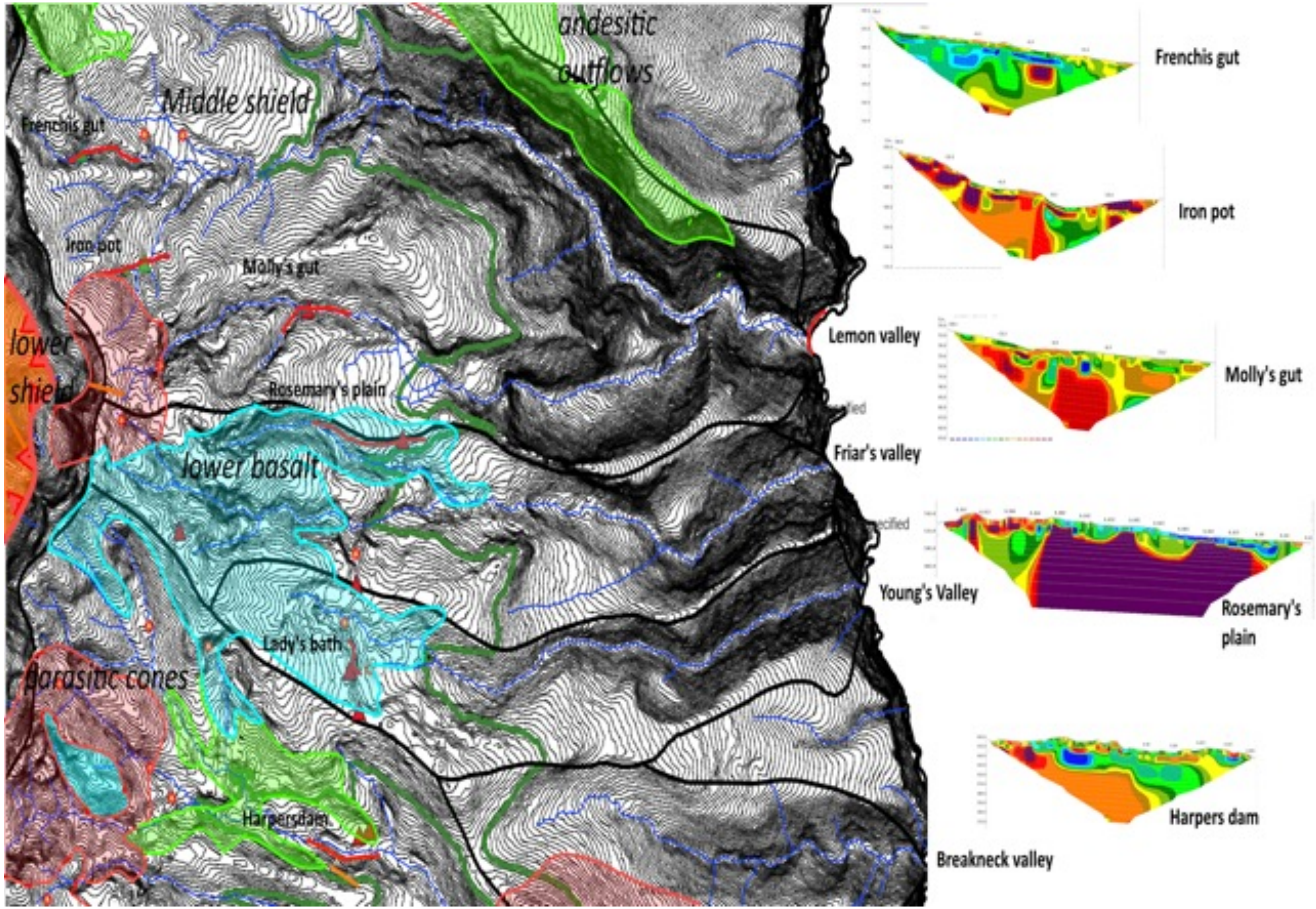
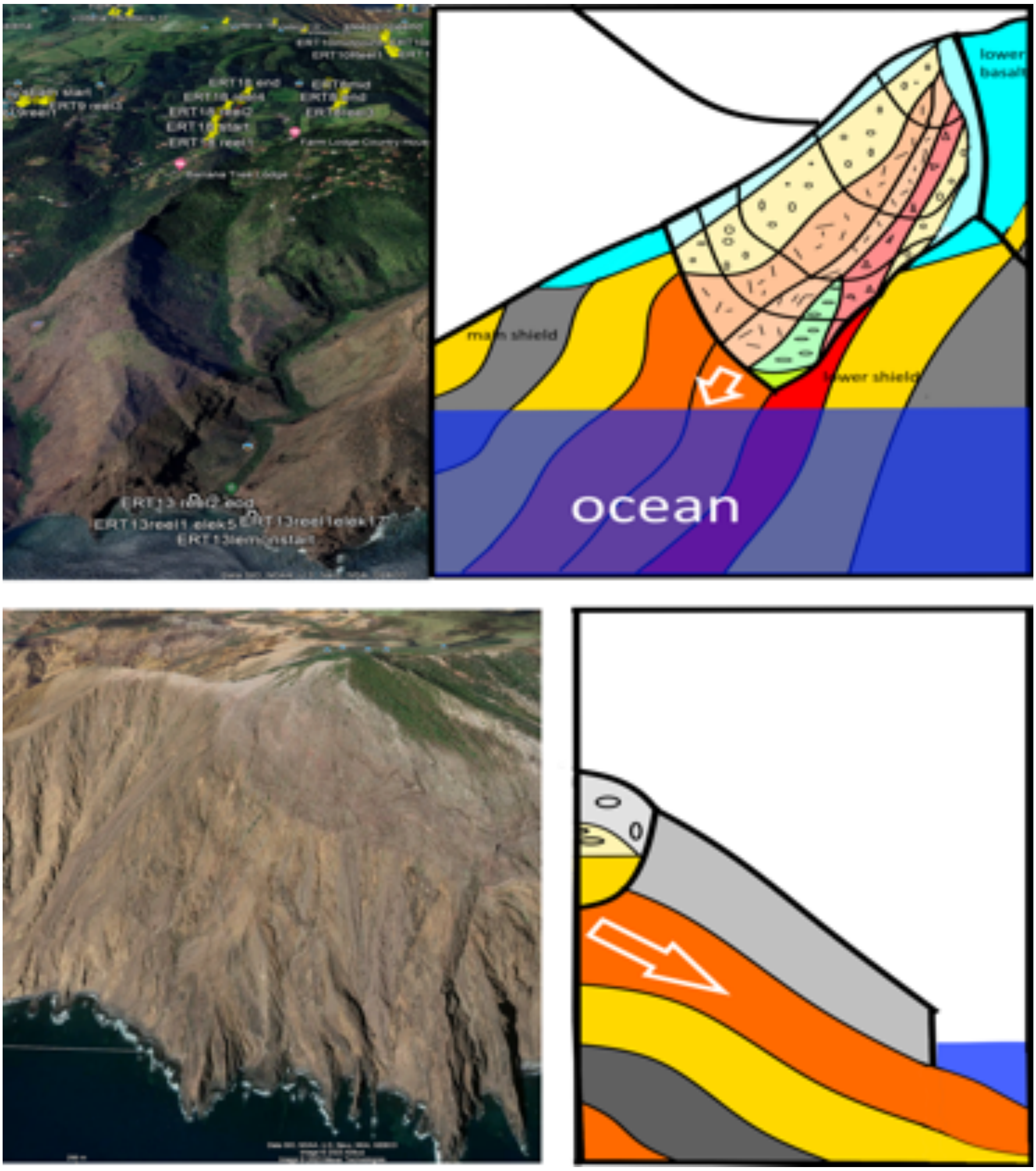


Figure 5-57: Schematic showing Deep Groundwater Outflow to the Atlantic Ocean



5.10 Volterra Rock Resistivity Measurements

The Volterra 3 is a small light weight instrument which can be used for shallow 1D resistivity measurements. The primary idea was to use this instrument in the first fieldwork trip in January 2022 to investigate the resistivity of the different volcanic rocks, the influence of weathering on the resistivity and difference between saturated and unsaturated sediments in Saint Helena. This information was to be used to evaluate the suitability of ERT as a geophysics method on St Helena. This resistivity information would also be of help with the hydrogeological interpretation of the ERT profiles. Unfortunately, the island shipping service was delayed, so the equipment did not arrive on time. This work was postponed until October

2023. The results of the Volterra 3 rock resistivity measurements are shown in Figure 5-58 and overlain on the island geology map.

The measurements confirm that in volcanic areas, the rock itself is conductive and this increases as the weathering process increases (decreasing resistivity). The resistivity of the saturated sediments is also influenced by the water quality such as that recorded in Broad Gut stream and the Sandy Bay stream). As an example, in Broad gut the EC of the stream flow at the confluence was around 4,000 μS/cm, which corresponds with a resistivity around 2.5ohm. The Volterra measurements of saturated river sediment from several locations were around 20 ohm. According to Archie's law, this implicates (in a very rough calculation) a formation factor of 20/2.5 = 8. The EC values of springs and streams at the higher altitudes range mostly between 200–400 μS/cm, which corresponds as 25-50 ohm. Using this formation factor shallow fresh groundwater in river sediment could have a resistivity of 200-400 ohm.

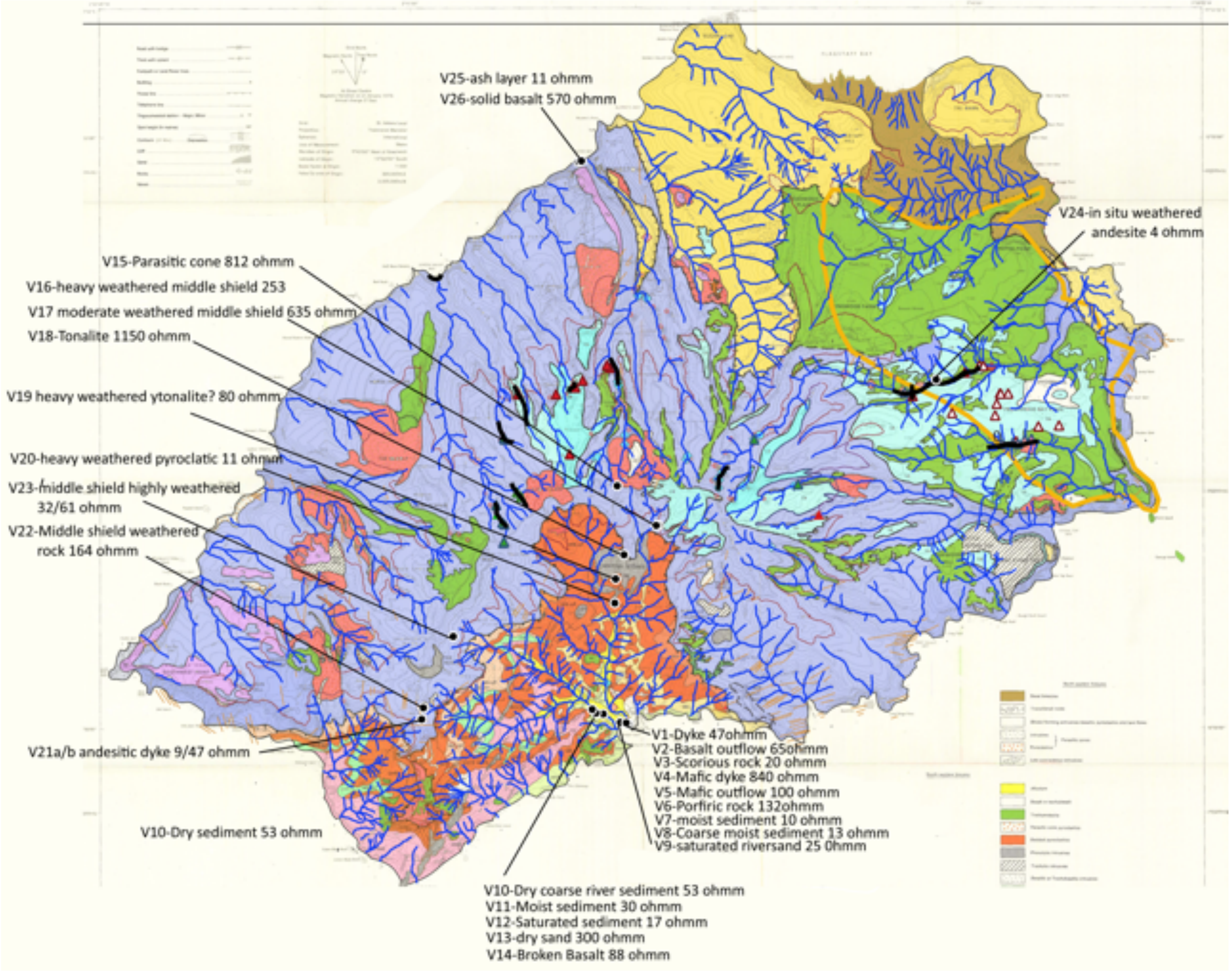
These resistivity's are found in some of the ERT in the superficial deposits where shallow aquifers are present. For the groundwater in the rock itself Arcie's law could not be applied because the rock itself is conductive and the permeability is principally due to secondary porosity. In this case a more structural approach should be applied.

In general:

- Andesitic dykes and the andesitic lava flows (even unweathered rock) have a very low resistivity (<10 ohm.).
- Ash layers seem to have low resistivity's (around 10).
- Scorious rocks and pyroclastics have low resistivity's (<50 ohm.).
- Most of the other volcanic rocks if not weathered, have a relative high resistivity (>100-1,000 ohm), however when weathered the resistivity decreases rapidly.
- Lower Basalt of the Upper Shield if not weathered seem to have the highest resistivity (around 1,000 and greater).

Because of the irregular continuous weathering process which decreases the formation resistivity, a clear distinction between rock types based on resistivity is not possible. Also, the change in resistivity due to water content is not visible in the resistivity due to the conductive matrix. The weathering of the rocks is measured and not the water content, which is the case in most of the volcanic areas. However some rock does weather fast, and some rocks have a very low resistivity. Indirectly water bearing and barrier potentials could be derived from the profiles. The most important application of ERT is to detect vertical and lateral change in resistivity's which is an indication of a change in the hydrogeological characteristics of the rock formations and therefore a very useful tool for locating new boreholes.

Figure 5-58: Volterra 3 Rock Resistivity Measurements



5.11 Conclusion

The geology and hydrogeology of St Helena is complex. Our understanding of the geology of key water supply catchments has been improved through the use of geophysics, but there still remain gaps in our knowledge. Filling in these gaps is an ongoing process and can be achieved through future phases of fieldwork.

In conclusion, the ERT methodology is very useful for understanding groundwater flow when interpreted with other data sets and pin-pointing favourable locations for groundwater exploration, especially in respect to lateral change. The measurements at Dry Gut, Rosemary's Plain and Molly's Gut have proven this. Because this is the first time that this method has been used on St Helena, groundwater exploration based on ERT is an ongoing learning process where both negative and positive boreholes give essential information. In some cases, it might be necessary to drill even at locations where low yields are expected based on the geophysics surveys in order to test the concept.

RBC Flume at Fishers Valley
Photography by Capricorn Stu
www.capricorn-studios.com

6 Updated Water Resources Areas Conceptual Model

6.1 Context of the Conceptual Water Resources Areas Model

Water resources planning is essential for ensuring a sustainable and secure supply of water. To be able to build a resilient water supply network, it is important to consider factors which have primary influence on the integrity and sustainability of water resources such as the complexity of geological events which shaped the island, as well as the challenges imposed by externalities such as climate change.

All the reviews, studies and field investigations undertaken have served to expand and further enhance knowledge, information and data regarding the island's water resources. This includes the genesis, and the natural dynamics related to the availability, accessibility and storage of surface water and groundwater resources within the key Connect water supply catchments and other catchments with notable good potential supply. This increase in understanding has established a need to contextualise the natural framework of the islands water resources. For this purpose, 5 Water Resources Areas have been defined as the main components of a hydrological model for the island, based on geo-hydrological characteristics shared across catchments. The Water Resource Areas Conceptual Model provides an important holistic perspective for the management and future development of the islands water resources. The water resource areas are presented in Figure 6-1 alongside a basic outline of the island geology map which shows the main phasis of volcanic activity.

The Water Resource Areas Conceptual Model attempts to frame the important characteristics of the water resources of St. Helena. It highlights possible reasons (as noted from field observation, measurements and monitoring data) for high yielding catchment areas and identifies opportunities to further enhance or rehabilitate water resources through potential development, rehabilitation or maintenance works.

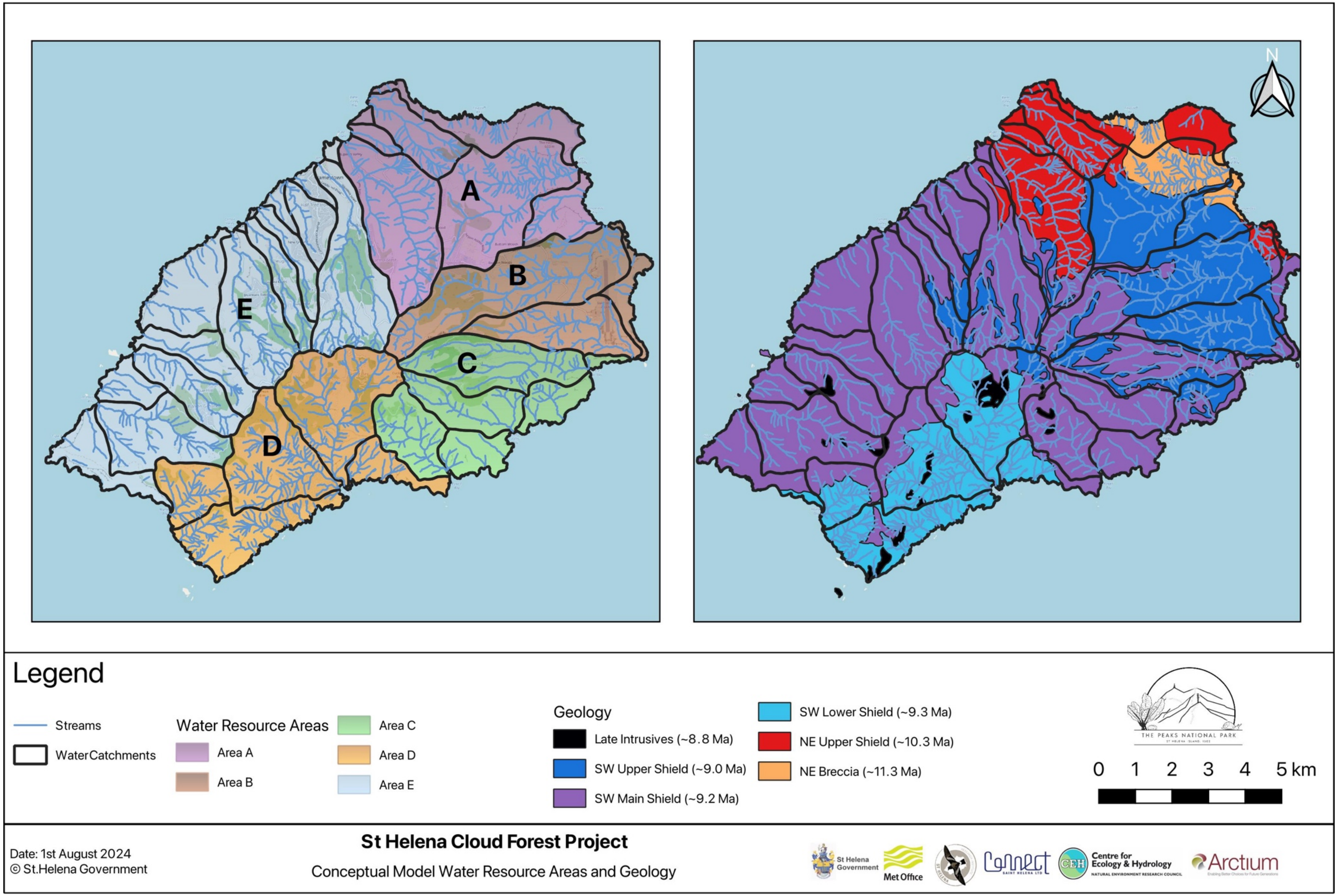
6.2 Framework of the Water Resource Areas Conceptual Model

Section 4 summarised the 2023 water balance for the island resource and identified the top 5 recharge sub-catchments in Zone 1 and Zone 2 for Water Balance Scenario D which aligns with the 4 key water catchments used by Connect for the islands residential and commercial water supply. The 2023 Water Balance demonstrates that these 4 key water supply catchments are significant and sustainable sources for island water supply. It also identified outliers for recharge such as Swanley Valley (Zone 1).

6.2.1 Geological Events

However, the movement, storage, availability and accessibility of the island water resources are governed by its underlying geology and the nature of the geological events that have given rise to the geological units of interest for water resources. Of the 2 known major volcanic centres for the island, it is the larger South Western Volcanic Centre (SWVC) which is of most interest regarding water resource availability and accessibility.

Figure 6-1 Water Resources Areas (l), alongside (r) general geology map (after Baker 1968)



The geological events that have influenced the islands water resources are not limited to the deposition of volcanic material through effusive lava flows, explosive pyroclastic deposits and flows and the development of fractures and faults. The intrusion of dykes, overextension and collapse of volcano flanks with mass landslide events such as with the NEVC to the east and SWVC to the south at Sandy Bay also have had a profound effect on the location, availability and accessibility of water resources across the island.

Regarding the accessibility of water resources, there are several oceanic island analogues which were reviewed and display similar complexities regarding volcanic units which enable or provide water resources through runoff, percolation or springs. Examples of these include the Canary Islands, Madeira, and the Hawaiian island of Kauai. Information regarding their water resources contributes to expand the understanding of the geological processes associated with oceanic islands that influence water resources.

In St Helena, the Main Shield of the SWVC is the most important volcanic aquifer on the island comprising over 800 m of predominantly lava flow with each flow event typically 1 m to 3 m thick, with its height generated from several scoria and cinder parasitic cones around the central Sandy Bay area. It is important to note that palaeoclimatology research on St Helena (Barker et al 1970)[26] indicates that the SE trade winds were established and had a strong influence on the orientation of ash deposition from cinder cone clusters located close to the current Peaks. These were oriented with a steeper profile to the southeast and gentler to the northwest.

The ash horizons form tuff layers which are often marked by their reddish colour from the alteration of iron in the deposit due to weathering, baking and dehydration from overlying flow. These layers have the potential to form effective aquicludes and create perched aquifers in the units above.

The paleoclimatic conditions during the hiatus in volcanic activity are also significant. Previous work by Baker (ibid.) on paleoclimatic events which influenced the island, it has been noted that there was a period of extensive weathering and erosion ~9.5Mya (late Miocene), with wetter conditions than found today from evidence of water erosion with deep fluvial channels along major radial fractures along the length of the active centres of the SWVC forming the primordial valleys (paleo valleys).

This extensive and extreme period of weathering and erosion and break in volcanic activity would have been the reason for the known unconformity between the Main Shield and the Upper Shield. The later lava and ash flow events associated with the Upper Shield flooded these primordial valleys of the SWVC predominantly to the northeast and east of central area of lava effusion, which was located around the current Peaks area and dyke intrusion. Later fluvial

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[26] Baker, I. 1970. II. – Geological history of Saint Helena and relation to its floral and faunal composition. pp. 23-36, pl. 20-21. *In*: Basilewsky, P. (Ed.). La faune terrestre de l'île de Sainte-Hélène. Première partie. *Annales du Musée Royal de l'Afrique Centrale*, *Serie in*-8°, *Sciences Zoologiques*. 181: 1-227, 31 pl.

activities would have continued along the preferential pathways or stream imprint in the paleo valleys.

Coastal studies around St Helena (Nunn 1984)[27] have revealed an elevated strandline and abandoned caves around the island and prominently on the northwest coast, known for its low energy environment but with no bays. Anecdotal information from the local dive community have confirmed the existence of a freshwater/saltwater interface in coastal caves, indicating freshwater discharge to sea at these points, which may help explain the losses noted for some catchments and the island water balance.

6.2.2 Influent and Effluent Streams

Streams can be classified into two types based on the geology they flow over: effluent and influent streams. Effluent stream receives water from an aquifer, such as through perched groundwater sources or springs within the channel or stream bed. Rainfall events may have minimum impact on such streams and during dry or low-flow periods, groundwater can be the sole source of water for the stream. With an influent stream, water seeps out through the stream bed, recharging the local aquifer. These are also known as disappearing streams. As such, these streams often dry up downstream, leading to arid conditions in those areas. Examples of both can be seen in St Helena and reflect the nature and location of volcanic aquifers and aquitards.

For example, Deep Valley, stream abstractions occur in Zone 1 in the upper catchment and represents 15% of the potential available water on St Helena as calculated from its recharge area. There is no noticeable flow in its lower catchment. The remaining 85% of this recharged water is lost to groundwater and is inaccessible due to the dip of the flow units. It is likely that most of this water is discharged to sea as the deeply incised valley cuts almost parallel to the strike of the Main Shield flows which may conduct water away from the streambed altogether.

6.2.3 Water Abstraction

Abstraction for island water supply is primarily from surface water resources, dominated by mist as its primary source and as such, may present some vulnerability regarding climate change events. The current monthly water balance data indicates that St Helena should prepare for a 3% decrease in recharge between 2040 and 2060 and plan for a climate change reduction in water supply for the months of February, May and June. Streams that are ephemeral may become increasingly challenged with flow retreating landwards during wet months; whilst it is believed that those which are influent, i.e. fed within the streambed by groundwater will be unaffected. As such, the groundwater resources in Lemon Valley and Fishers Valley which are currently used to augment surface water supply, will need to be supported and other potential high yield sources developed to contribute to water resources security for the island. Boreholes that have been poorly developed in terms of depth and location of screens, can be rehabilitated to provide resource augmentation. There are some groundwater resources that are located in areas which make abstraction and long-distance transmission difficult due to cost. There may be need to create opportunity to review these

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[27] Nunn, P. 1984 Evidence for late Quaternary sea level change around St Helena, south Atlantic CATENA, Vol 11 Issues 2-3

sources and the possible application of more cost-effective engineering methods to enable access and sustainable abstraction.

6.2.4 Vegetation

Vegetation plays an important part in recharge of streams. It is confirmed by previous work under the Darwin Plus project that the endemic vegetation increase flow in the peaks. Anecdotal evidence from farmers have pointed to the decrease in flow down gradient with the removal of flax. Not enough is known about the role flax plays in water resources management. There is very little available information on its root system, the soil physics associated with its root system with respect to the triggers for retention or release of water from the soils or root mass.

6.2.5 Surface Water Catchment Areas

The scientific investigations, field measurements and computations to date have served to provide robust underpinning for the islands water resources development and management by outlining important attributes of its source, movement, storage and challenges to support island water resources security. Infrastructure for water treatment and conveyancing is managed by water distribution zones and focused on the populated areas of the island (see Figure 6-2). The Water Treatment Works (WTW) are located at Chubbs Spring, Hutts Gate, Red Hill and Levelwood.

For water resources management, the island has been subdivided by the utilities company Connect, into surface 36 water catchment areas, of which 19 are uninhabited and located near the coast (see Figure 6-3).

Figure 6-2 Connect SH Water distribution zones

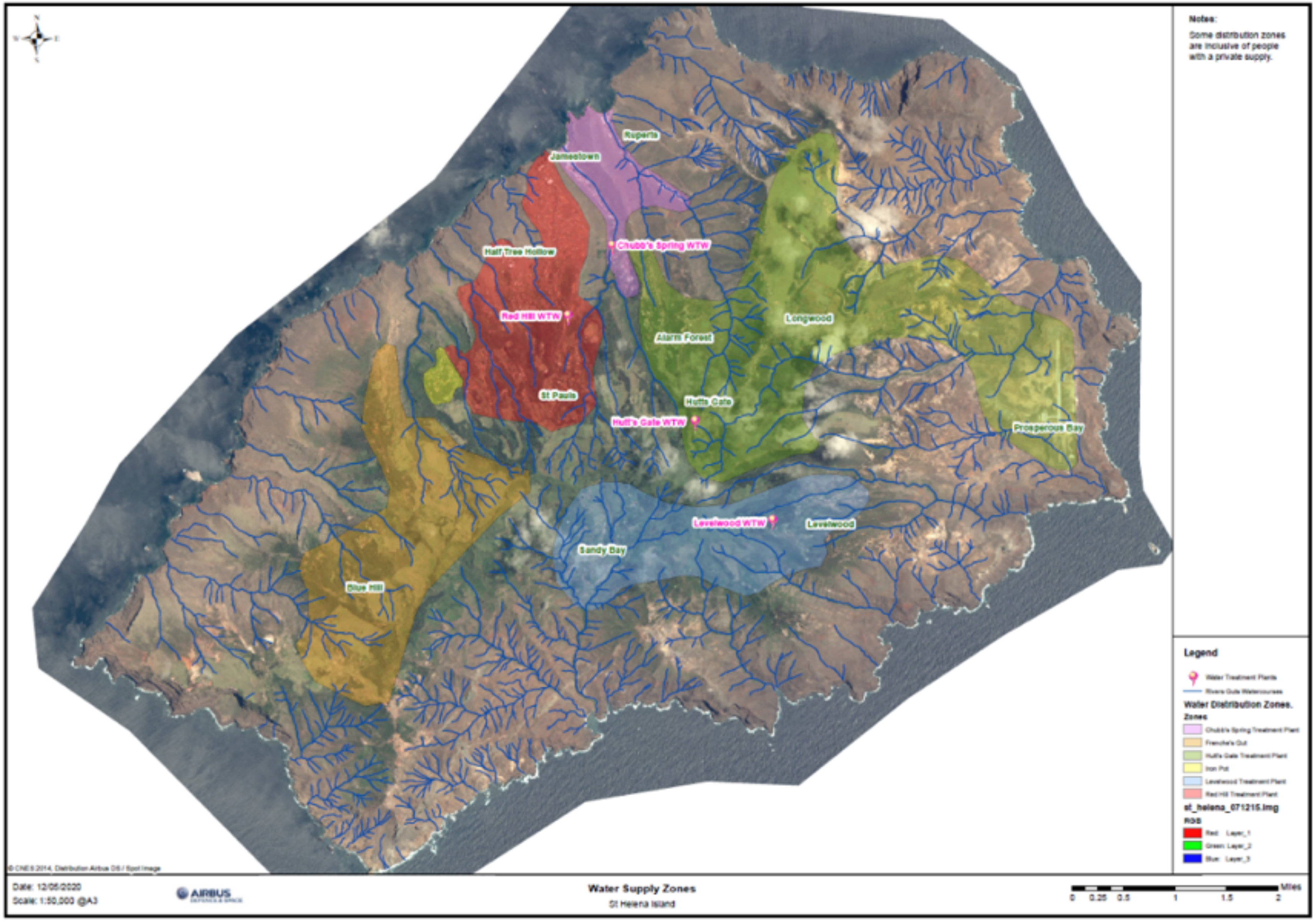
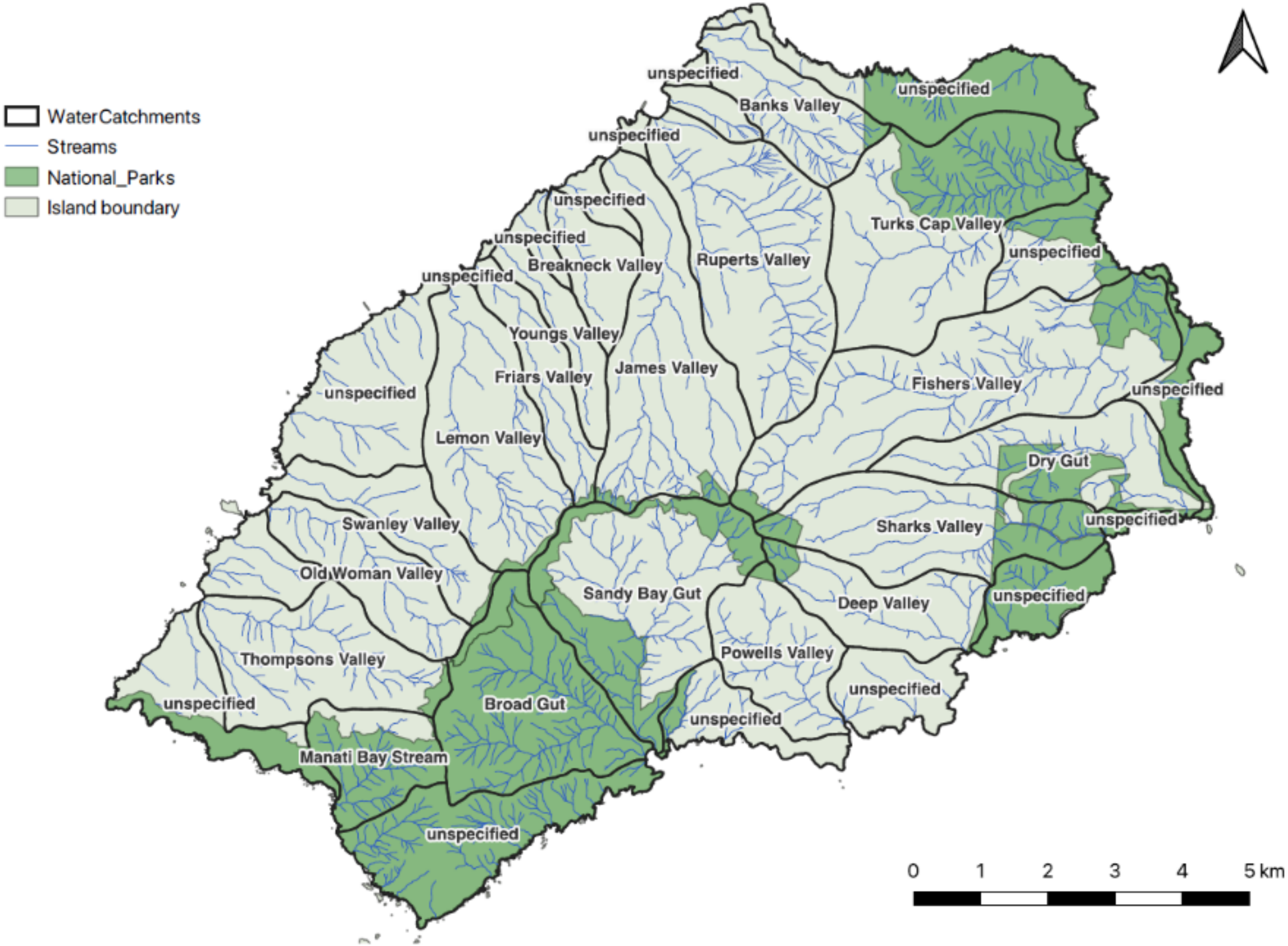


Figure 6-3 Connect SH designated catchment areas



6.3 Water Resources Areas (WRA) Conceptual Model

STH Water Resources Strategy 2020-2050 highlights the need for a focus on water scarcity and water sustainability which are addressed under Objective 1 and 4 respectively. This conceptual model aims to provide information to underpin the plans necessary to enable this water resources strategy. The model attempts to frame the important characteristics of the water resources of Saint Helena. It highlights possible reasons (as noted from field observation, measurements and monitoring data), for high yielding catchment areas and identifies opportunities to further enhance or rehabilitate water resources through potential development, rehabilitation or maintenance works.

The purpose of the Water Resources Areas are to improve the level of granularity regarding the understanding of the islands water resources and to provide a holistic compendium of the characteristics that influence and govern water resources including its genesis, flow, quality, storage and losses. It is hoped that it will serve as a supporting framework to current water resources management planning and catchment maintenance and to facilitate future decisions on water resources enhancement for greater climate change and water demand resilience.

The 5 Water Resource Areas are as follows:

WRA-A	Northern Catchment Units: Ruperts Valley to Turks Cap Valley
WRA-B	Eastern Catchment units: Fishers Valley and Dry Gut
WRA-C	Southeastern Catchment Units: Sharks, Deep and Powell Valleys
WRA-D	South Catchment Units: Sandy Bay and Broad Gut
WRA-E	Western Catchment units : Thompson Valley to James Valley

These WRA are defined using the following characteristics:

Catchments	Which catchments are included
Geology	Summary of key geological attributes pertinent to water resources management
Geomorphology	Summary of key geomorphological features pertinent to water resources management
Recharge	Outline of the recharge for the WRA
Surface Water	Surface water assets for the WRA
Groundwater	Groundwater assets for the WRA
Abstraction	Raw abstraction volumes (surface and groundwater) supplied per catchment
Water Supply	Transmission and treatment works
Water Quality	Water chemistry as a function of source waters

The following sections provide a summary of key characteristics for each of the identified Water Resource Areas.

6.3.1 WRA- A Northern Catchment Units: Ruperts Valley to Turks Cap Valley

Catchments	This WRA comprises 3 main catchments: Ruperts Valley, Banks Valley and Turks Cap Valley. None of these are Connect primary supply catchments.
Geology	These catchments are located within the NEVC and whilst of interest geologically, they do not contribute to the water resources of the island.
Geomorphology	Topographic variability related to its geological history of the NEVC erosion, landslip and infilling with thick andesitic tuff deposit.
Recharge	No recharge.
Surface Water	No contributory surface water resources regarding public water supply
Groundwater	No contributory surface water resources regarding public water supply
Abstraction	No abstractions for public water supply
Water Supply	Water supply provided by Hutts Gate WTW and Chubbs Spring WTW
Water Quality	Not part of monitoring programme
Opportunity	None identified.

6.3.2 WRA- B Eastern Catchment units: Fishers Valley and Dry Gut

Catchments

This WRA comprises 2 catchments: Fishers Valley, Dry Gut. **Fishers Valley** is a Connect primary water supply catchment.

Geology

In Fishers Valley the Upper Shield presents is the dominant unit and overlies the Main Shield. The valley comprises flows of the Upper Shield where eight thick basaltic flows are exposed; top 4 flows are trachyandesites, lower flows are basalts. These flows infilled a primordial (paleo) valley formed from the extensive subaerial weathering and erosion of the Main Shield during the late Miocene. The Upper Shield flows are near horizontal with individual flows averaging 15m thick with well-developed columnar and weak horizontal jointing, with scoriaceous bases, and tops, the latter usually obscured by volcanic pyroclastic detritus. Fine-grained reddened tuff horizons separate several of the flows. The flows are overlain with andesitic tuff (ash) from the last phase of volcanic activity and there are signs of hydrothermal alteration of the Upper Shield trachybasalts There is geological evidence of extensive weathering of the Upper Shield during its formation, strongly suggesting wetter conditions in the Pliocene than presently found (Baker 1968). Dry Gut has a small Main Shield outcrop but is predominantly comprised of weathered trachyandesite and andesitic tuff.

Geomorphology

Fishers Valley is Gently incised but comparatively wide with a gentler relatively flatter terrain at lower altitudes through the Upper Shield deposits with evidence of extensive fluvial activity and competent tributary rill development along valley lineation in both Fishers Valley and Dry Gut. Whilst Fishers Valley has a flowing perennial stream and is host to a RAMSAR designated wetland, Dry Gut has no current flow.

Dry Gut is predominantly gentle topography of incised Upper Shield deposits of trachyandesite and andesitic tuff.

Recharge

Zone 1 sub catchment of Fishers Valley significantly contributes to island recharge with the 3rd highest calculated recharge. Zones 2 and 3 have 4th highest recharge all in the Main Shield.

Surface Water

Fishers Valley: Surface water abstractions are primarily from zone 1 in the Peaks, from perennial effluent-type streams at Wells Gut, Byrons Gut and Leggs Gut which seem to have little response in flowrate to rainfall events. Water resources contribution in this WRA is primarily from surface water abstractions in zone 1 of Fishers Valley, with a total streamflow of 94.228 m^3/a of which 92% is abstracted by Connect leaving a small surplus of 330 m^3/a

Groundwater

It is believed that Fishers valley and Dry Gut are part of the same aquifer system with recharge upgradient into the Main Shield in Fishers valley as the main recharge area, with some of the water flowing southeast into Dry Gut and then into Sharks valley.

Fishers Valley: Fisher Valley is the second main source of groundwater for public water supply and is abstracted from during times of water stress.

Untapped aquifer: Upstream in Wells Gut there appears to be a shallow aquifer which may be supporting streamflow. However, there is need for baseflow measurements to confirm.

Willowbank BH: Located at approx. 500masl and thought to be very shallow, however there is no data to corroborate this.

Fishers Valley BH: Located at 350masl. 2022 Surveys indicate that this BH is within a deeper confined aquifer, located in the middle of the wetland. This is the main catchment groundwater source used during times of water stress and has a standby borehole (located 146m northwest) and a shallow observation borehole (located 194m northwest). Pumping of the deep BH does not affect the integrity of the wetland area.

Observation BH: This shallow Obs BH is in an unconfined aquifer and water levels in and in hydraulic continuity with the wetland. This relationship has been confirmed by groundwater response to rainfall recorded from August 2021.

FV1 (96m) and FV 2 (106m): These BH are artesian with water in the Main Shield and the confining layer (aquitard) comprised mainly of clays derived from weathered andesitic flows (ash/pyroclastics) similar to that found outcropping on the valley flanks. Pumping of these artesian wells will not affect the integrity of the wetland area.

Wetland area (RAMSAR) - this is sustained by surface water and an unconfined upper aquifer. Wetland inundation is sustained and not lost from percolation due to the competent confining layer below as confirmed from the geophysical surveys.

Dry Gut: This catchment is located below the 500m contour (600mm rain isohyet) and as such, no surface recharge is expected as it has only a small outcrop of the Main Shield. There is no surface water flow in Dry Gut, and it seems that any groundwater flow is being enabled/recharged from Fishers Valley. This groundwater eventually discharges to sea. 6 boreholes were developed as part of the airport construction programme of works to locate water for use in construction and operation of the airport. Looking downgradient, the boreholes are as follows: BHDG5, BHDG4, BHDG6, BHDG3, BHDG2, BHDG1.

BHDG5: Good yield and good water quality – abstracting from Main Shield

BHDG4,6,3,2,1: poor yield and higher EC values reflecting water quality of the shallow unconfined aquifer within the trachyandesite deposits.

The static groundwater levels and water strikes of all the airport boreholes seem connected and show water strike and artesian behaviour decrease towards the coast.

Abstraction

This WRA includes the 3rd most important catchment for the island which provides 33% of the islands current water demand with a calculated the capacity for greater yield.

Catchment	Connect SW/GW Abstraction (m^3/a)	Proportion of Total Abstraction (%)	Recharge (m^3/a)	Stream Flow (m^3/a)	Surplus/Deficit (m^3/a)	Surplus/Deficit (%)
Fishers Valley	109,604	33%	244,173	92,074	134,569	55

Water Supply

Hutts Gate WTW has principally been supplied by surface water abstractions from Leggs Gut and Wells Gut (47%) and groundwater from Willowbank and Fishers Valley boreholes (40%).

Water Quality

Seepage zones with high EC values are observed at several locations. This may reflect water impacted by enrichment from hydrothermal alteration deposits of halite, gypsum, zeolite and halloysite.

Fishers Valley: There is a change in surface water quality below 500m which seems to be affected by weathering and hydrothermal byproducts.

Dry Gut, BHDG5: The pump for BHDG5 was located at a deeper level to the other developed airport construction BH. When the pump was raised to 50m following lower BH collapse, a pump test was undertaken in 2022 (please see DPLUS103 report). During the pump test the EC did not decrease as much as observed when the borehole pump was set at a lower level, so the water quality seems to reflect mixing of mineralised waters from groundwater derived from the unconfined Upper Shield volcanic aquifer unit and the lower, fresher groundwater Main Shield volcanic aquifer, which is recharged at higher elevations in Fishers Valley. It was also noted that BHDG5 does not seem to lose water into the high resistivity layer noted from the geophysical survey.

The unconfined shallow groundwater has been penetrated by BHDG 1,2,3,4,6 which show similar high EC values and may be enriched with byproducts of weathering and hydrothermal alteration. The observed low sulphates in the water quality measurements may be due to the presence of halloysite. Crystals of gypsum were observed in outcrops of the in situ weathered trachyandesites, the rapid solution of these crystals can cause high EC levels.

The difference in water quality between BHDG5 and the other 5 BH i.e., BHDG1,2,3,4,6; may be due to the parasitic cone geometry, as noted from the geological map, which can block flow and hydraulic connectivity over a short distance.

Opportunity

There is an opportunity for further development of boreholes in Fishers Valley however, care must be applied when drilling any new boreholes in this area, as surface water (unconfined) can be lost to the lower aquifer if the confining layer is breached.

Dry Gut - BHDG5 could benefit from BH rehabilitation with better screening-off of the upper more mineralised water to produce a BH with better water quality and yield, which could probably augment water resources in times of water stress. This could be undertaken with detailed borehole EC logging to determine the interface. If the observation that BHDG5 may be supported by recharge from Fishers Valley and Sharks Valley, then BHDG5 is possibly a key borehole in groundwater exploitation at St Helena.

6.3.3 WRA- C Southeastern Catchment Units: Sharks, Deep and Powell Valleys

Catchments	This WRA comprises 3 main catchments: Sharks Valley, Deep Valley, Powells Valley. **Deep Valley** is a Connect primary supply catchment.
Geology	These catchments are located within the Main Shield and exhibit 3 key geological eruptive phases. Sharks Valley: Basaltic flows of Main Shield are unconformably overlain by thicker lower basalts of the Upper Shield series from the central peaks eruptive centre poured out thick sequences of basaltic and later intermediate lavas to flood highly eroded Main Shield. Later intrusive domes of Great Stone Top are composed of 4-5 thick horizontal flows over 100m thick and seen on in the flank of Sharks Valley. The distribution of the Bencoolen trachyandesites demonstrate that the development of the valley came later after the extrusion of these trachyandesites. Deep Valley: Trachyandesite second flow, petrographically comparable to Sharks Valley, is exposed at about 500m O.D. in the head of Deep Valley. The flow is 60m thick, and dips eastwards at about 6°. The flow is about 1km wide, and rests on a thick orange tuff horizon. Powell's Valley: The Main Shield dominates Powell's Valley with 50% of its flow thickness being scoriaceous and similar to sections to the northwest of Jamestown and north in Ruperts Valley and to the west in Thompsons Valley Dykes are exposed in both Deep Valley, and Powell's Valley where dykes are t 1km from the sea and dip north-westerly at 80°-85° and in the in the central area of the valley the dykes are more or less vertical.
Geomorphology	Sharks, Deep and Powell's valleys are deeply incised but with no streamflow below 500m
Recharge	Deep Valley is a key water resource catchments for connect, with the 6th highest recharge in Zone 1 sub catchment.
Surface Water	**Deep Valley 1 and 2:** For Deep Valley stream abstractions represent 15% of the potential available water as calculated from its recharge area. There is no noticeable flow in its lower catchment. **Hancock Spring:** It is postulated from field evidence that groundwater many be flowing from the Fishers Valley into Sharks Valley. EC measured in Hancock Spring, in Sharks Valley in October 2023 was around 1,000 mS/cm and the EC of Fishers Valley borehole close to the water storage tank in the wetland area was also around 1,000 mS/cm during the same month. There is no water resource monitoring information to determine if Hancock spring was affected by the two years of continuous pumping at BHDG5 during the construction of the airport to then confirm this postulation. Recent water balance calculations seem to support the thought that Dry Gut boreholes were being supported and sustained by

groundwater flow from both Fishers Valley and Sharks Valley during the airport construction programme.

Groundwater

Sharks Valley: Groundwater flow in Sharks Valley is believed to be hydraulically connected to Fishers valley and Dry Gut and are part of the same aquifer system with recharge upgradient into the Main Shield in Fishers valley as the main recharge area.
Deep Valley: The remaining 85% of recharged water is lost to groundwater and is inaccessible due to the dip of the flow units. It is more likely that most of this water is discharged to sea as the deeply incised valley cuts almost parallel to the strike of the Main Shield flows which may conduct water away from the streambed altogether.
Powells Valley: Not significant for exploitation.

Abstraction

For Deep Valley, stream abstractions occur in Zone 1 in the upper catchment and represents 15% of the potential available water as calculated from its recharge area. There is no noticeable flow in its lower catchment. The catchments provide 12% of the islands current water demand.

The remaining 85% of this recharged water is lost to groundwater and is inaccessible due to the dip of the flow units. It is more likely that most of this water is discharged to sea as the deeply incised valley cuts almost parallel to the strike of the Main Shield flows which may conduct water away from the streambed altogether.

Catchment	Connect SW/GW Abstraction (m^3/a)	Proportion of Total Abstraction (%)	Recharge (m^3/a)	Stream Flow (m^3/a)	Surplus/Deficit (m^3/a)	Surplus/Deficit (%)
Deep Valley	40,950	12%	280,243	40,950	239,293	85%

Water Supply

Levelwood WTW receives 69% of water from the two Deep Valley stream sources and 27% from groundwater abstracted from Warrens Gut. During February 2023, operational challenges caused the Warrens Gut borehole to come out of service and has since been repaired and is now back in service.

Water Quality

Not part of monitoring programme

Opportunity

Sharks Valley should be reinvestigated as a potential groundwater abstraction source. Whilst accessibility may be an issue, the availability of the groundwater resource and the potential to apply for renewable and efficient pumping systems may be economically attractive for the resource to be considered to augment current supply.

There is an opportunity to monitor Hancock Spring and complete an investigation to determine its viability as a resource for Connect, especially in the context of future water stresses associated with climate change.

6.3.4 WRA- D South Catchment Units: Sandy Bay and Broad Gut

Catchments	This WRA comprises 2 main catchments: Sandy Bay and Broad Gut. None of these are Connect primary water supply catchments.
Geology	The Lower Shield sequelae of events is exposed in the sandy bay and Broad Gut Catchments. Here, following an explosive rupture and mass rotational landslip which led to the loss of the southern flank of the SWVC to sea, the Main Shield volcanic units, known to be the most productive hydraulically for the island was lost. The remaining crest and flank of the SWVC with its flows to the west and northwest and southeast remained intact. The exposed Lower Shield and remnant Main Shield and intrusive feeder dykes of the Lower and Main Shields are inseparable, and the swarms in Sandy Bay must be considered in terms of feeding both of these units. The loss of the substantive mass of the Main Shield would have exposed the Lower Shield units to extensive subaerial weathering and erosion. Sandy Bay and Broad Gut are the only catchments on island with a well-developed alluvium plain with graded sediment banks, sediment and river profile indicate very strong fluvial forces.
Geomorphology	Both catchments coalesce but are represented by 2 distinct riverbeds.
Recharge	With the loss of the southern flank of the Main Shield, recharge is minimum with most of the recharge directed to the west in keeping with the dip of the Main Shield.
Surface Water	Local streams are Mr Haywards stream located in the lower catchment area of Sandy Bay. It is a perennial effluent stream with sustained baseflow.
Groundwater	No abstraction sources
Abstraction	No abstractions for public water supply
Water Supply	Water supply provided by Levelwood WTW Private water supply boreholes.
Water Quality	Not part of monitoring programme
Opportunity	Streamflow in Sandy Bay is high and is supported from surface runoff draining from the southern flanks of the Peaks (Mount Acteon, Diana's Peak and Cuckolds Point) flowing down steep valleys such as Perkins Gut and Jockeys Gut. The costs of moving water from Sandy Bay to the north of the island have been previously assessed as too expensive, however this potential source of water should be assessed in more detail as part of an options appraisal.

6.3.5 WRA- E Western Catchment units: Thompson Valley to James Valley

Catchments	The largest WRA comprising 13 catchments from Thompson Valley to James Valley and includes the Connect primary supply catchments of **Lemon Valley** and **James Valley.**
Geology	Dominated by the deeply eroded Main Shield lavas and is unconformably overlain by lavas of the Upper Shield around the central Peaks area, high on the flanks of the Main Shield. This area is replete with springs in the upper catchment areas which are used for water supply.
Geomorphology	Steep with deeply incised valleys with poorly developed or absent bays which may be due to subterranean discharge to sea and reason why there is no development of deposits on the coast. Thermal infra-red (TIR) images may provide information to confirm. Lemon Valley exhibits stream water losses despite having surplus water from calculated recharge.
Recharge	This WRA is calculated as having the highest recharge for the island (2023 Water Balance). In areas with no vegetation, precipitation percolates directly and may discharge to sea as valleys cut almost parallel to the strike of the units.
Surface Water	**James Valley**: Osbornes 1 and Drummonds Point respond quickly to rainfall events; Black Bridge, Upper Gents Bath and Lower Gents Bath have a more consistent seasonal flow indicating a greater influence from groundwater (spring flows). It is worth noting differences between the rainfall response at Osbornes1 and Osbornes2 V-notch weirs which are located at a similar elevation and only. Black Bridge monitoring location is a reliable long-term indicator of stream flows into the bottom section of James Valley. Annual stream flows reduced by over 25% between 2022 and 2023. Rainfall data across the monitoring network confirmed 2023 as a drier year, with an average of 825mm rainfall recorded in 2022 and an average rainfall of 806mm recorded in 2023. Black Bridge is an example of an effluent stream, which is sustained by groundwater flow into its channel thus normally sustaining it during seasonal dry periods. The measurements for 2022-2023 demonstrates that there was reduced groundwater recharge upgradient which reduced the level of groundwater in the volcanic aquifer, leading to a notable drop in the annual stream flow.
Groundwater	WRA-A provides the greatest area of potential groundwater recharge but is also an area of lowest groundwater availability with loss to depth in the lower catchment area due to the orientation of Main Shield lava flow layers and the absence of dykes in this area to act as “aquitards” for water retention – considerable water lost to sea, and the lack of Upper Shield outcrop to create an area for extensive recharge in the zone 1 and 2 sub catchment area (see section on Water Balance). Upstream shallow aquifers in the sub-catchments contain low groundwater yields, locating boreholes for water supply is difficult, especially in the areas with

high resistivity close to the surface and with severe lateral change due to irregular weathering, dykes and proximity to parasitic cones.
In these areas compartmentalization due to difference in rock type and weathering processes seem to be the case resulting in high resistivity and low yields.

Lemon Valley: Water resource and geology data has demonstrated the importance of the Iron Pot and Frenches Gut wellfields in the Lemon Valley Catchment. These boreholes are close to the top of the ridge near High Peak, and above the 690m contour, in sub-catchment zone 1.

Frenches Gut: Water levels in these boreholes do not respond to rainfall events.
Iron Pot: both observation wells showed a positive response to rainfall events.
In 2023 Frenches Gut supplied 24% and iron Pot 22% of total groundwater abstracted on island.

8 deep boreholes drilled by WPS created ‘inflow’ boreholes due to water from the shallow Upper Shield aquifer draining into the deeper unsaturated basalts in the Main Shield due to drilling though the aquitard, critical to the sustainability of the shallow aquifer - 6 of these inflow BH lie within this WRA.

Abstraction

This WRA is the most important for the island and includes the 2 largest catchments which provides 35% of the islands current water demand, with a calculated the capacity for greater yield.

Catchment	Connect SW/GW Abstraction (m^3/a)	Proportion of Total Abstraction (%)	Recharge (m^3/a)	Stream Flow (m^3/a)	Surplus/Deficit (m^3/a)	Surplus/Deficit (%)
James Valley	114,509	35%	378,993	90,054	264,484	70%
Lemon Valley	63,247	19%	165,331	0	102,084	62%

The total monthly groundwater and surface water abstractions indicate that groundwater is mainly pumped during the summer months to augment reduced stream flows. Groundwater is primarily abstracted from Frenches Gut and Iron Pot to support local water supplies to the west of the island where there are limited surface water courses and springs.

Water Supply

Chubbs Spring WTW and Redhill WTW supply almost 60% of the population on island. However, this accounts only for households and business connected to the mains and excludes private boreholes. So the actual water supply from water resources in WRA-A may be greater.

Between 2018 and 2021 Redhill WTW was principally supplied by surface water abstracted from sources in James Valley (68%), Oakbank Well – a surface water source (11%) and water transfers from Chubbs Spring and Hutts Gate (21%). Chubb Spring WTW received abstracted surface water from Black Bridge (11%). Spring sources at Drummonds Point, Chubbs Spring, Tom Peters Spring and Hambess spring supplied 84% of the treatment works water supply. Note: there is an unaccounted for 5% waster based on the data reviewed.

Water Quality

James Valley: Water quality from surface and groundwater sources are generally good. Salinity of surface water measured at Drummonds Point and Black Bridge is up to x3 higher than monitoring locations in the upper parts of the catchment. The Black Bridge monitoring location receives water from the higher parts of Briars Gut, with Drummonds Point comprising spring flow and surface water from the base of the Heart Shaped Waterfall.

Both may be intercepting gypsum and halite deposits from localised, secondary hydrothermal alteration as this high salinity does not occur upgradient in any spring or stream source waters. There is no clear trend between rainfall and salinity which demonstrates that this may be the point-source causing elevated salinity at both locations.

Opportunity

As noted from observations using the borehole camera system, borehole rehabilitation should be considered for the deep 'Inflow' boreholes in WRA-A to restore the contact zones between the Upper Shield and Main Shield by sealing it with bentonite clay. Molly's Gut BH is already in preparation for BH rehabilitation.

It is important that weirs are de-silted as part of an ongoing water resources infrastructure maintenance programme to ensure water flow is unobstructed.

7 Recommendations and Options for Water Supply

The DPLUS103 and FCDO funded Cloud Forest Restoration Project combined climate change and drought warning monitoring network has collected a baseline set of climate, water resource and geological data to support the development of conceptual models for key water resource catchments across the island.

The limited well development data has presented a challenge, but a better understanding of the current groundwater yield has been gained from reports, geological reconnaissance, geophysical investigations and pump tests. It is recommended that all drilling logs, geophysical borehole logging, water strike, water table levels, water quality and pumping test data and information should be carefully documented, safely stored and made accessible for future research and future geophysical and hydrogeological prospecting.

The geophysical instrumentation used in this fieldwork has been demonstrated to be helpful in future shallow groundwater prospecting and can be very useful in preventing boreholes from being drilled too deep that they lose water due to penetration of impermeable layers (inflow boreholes). Exploring the deeper aquifer system is essential in order to comprehensively understand the hydrogeology of St Helena.

In summary, the geology and hydrogeology of St Helena is complex. Our understanding of the geology of key water supply catchments has been improved through the use of geophysics, but there still remain gaps in our knowledge. Filling in these gaps is an ongoing process and can be achieved through future phases of fieldwork.

7.1 Further Research

A botanical and water resource research project is needed to understand the water resource function of flax. The cloud forest area is inundated by invasive flax and the impact the flax has on soil moisture, water retention and the cloud forest water balance (through evapotranspiration) is essential to completing our understanding of how the cloud forest provides water for the island. Anecdotal evidence from the past 40 years indicates that removal of large areas of flax has a negative impact on stream flows, however the reasons for these changes can only be inferred from other data sources. For example, these negative changes may only be short lived, as the soil moisture increases in areas that had previously dried out beneath the flax due to the flax leaves shading the ground and allowing water to runoff the slopes quickly.

Further research is needed to investigate the outflow of deep groundwater from the island using coastal thermal imaging satellite data sets, linked with water quality sampling of the freshwater/saltwater interface in coastal caves which have been observed by the local dive community. This information would support the refinement of catchment and island-wide water balances and help understand where most of the recharge flows from the island into the Atlantic Ocean.

Upstream in Wells Gut there appears to be a shallow aquifer mainly in river and slope sediments. It may support stream flow and at certain locations stream water may infiltrate into deeper rock layers. A dedicated water balance, where base flow measurements at different levels of the streamflow are incorporated might provide greater insight on this observation.

7.2 Water Resource Management Planning – Options Assessment

Based on the water resource research completed in the DPLUS103 project and the Cloud Forest Project the following water resource options should be considered as part of the Water Resource Management Plan being developed between 2024 and 2025.

1. Drilling deep boreholes can lead to inflow boreholes (where shallow groundwater leaks into a deeper aquifer system). They are a high-risk option and will require significant data collection to plan a drilling program and careful design of the well completion to avoid puncturing shallow aquifers which has happened in most of the deep boreholes on the island.

2. Connect should resume active management and maintenance of vegetation in stream beds which the company uses for public water supply. This work will ensure that streams are not choked with vegetation and silt up.

3. Connect should also support and encourage the restoration and management of endemic cloud forest in key water resource catchments used for public water supply in partnership with SHG and the islands NGO’s. Funding for such activities would need to be found through grants and philanthropic funding routes as it is recognised that Connect do not have the funds to do this from recurring budgets. A number of research studies and island water resource plans have identified mist capture as a significant contribution to the islands stream flows and groundwater recharge. The cloud forest should be seen as a water resource asset with a shared maintenance programme.

4. A regular water infrastructure maintenance program is funded by Connect and adhered to, in order to ensure that all V-Notch weirs are desilted. This will improve the quality of surface water level and flow data collected at the weirs and will improve the quality of WTW inflow water by reducing water turbidity and the concentration of suspended solids.

5. All public water supply boreholes should be inspected on an annual basis using Connects borehole camera system to identify defects and any obstructions in the slotted screen. The boreholes should also have a regular programme of aquifer testing (step tests and constant rate tests) to check borehole efficiency and identify other maintenance requirements.

6. WRA-A

The rehabilitation of the boreholes at Molly’s Gut would yield a proportion of the 500m^3/d needed by Connect to deliver a secure water supply for the island. It is recommended that all deep boreholes are backfilled with bentonite grout to restore a shallow groundwater table. This work should be planned carefully and replacement well screens and case installed in shallow aquifers. A borehole camera survey should be completed at each borehole where the old well screen and case is removed so that the surrounding geology can be properly understood and additional fracture flows identified.

7. WRA-B

Fishers valley: There is opportunity for further development of boreholes in Fishers Valley however, care must be applied when drilling any new boreholes in this area as surface (unconfined) water can be lost to the lower aquifer if the confining layer is breached. The resource is also located within a candidate RAMSAR wetland (the only wetland on St Helena), so any new groundwater development should be planned with a study to fully understand potential risks associated with groundwater abstraction on the wetland.

Dry Gut: The yields of BHDG5 in Dry Gut should be further assessed to support the islands water supply as it has previously supported large groundwater abstraction volumes during airport construction. It is essential that a better borehole design is used to avoid the borehole collapses in BHDG5 which have resulted in higher salinity groundwater (see DPLUS103 report for more detail). A program of continuous water level, water quality and water abstraction monitoring is needed in order to understand Dry Gut and the performance of BHDG5. Due to the collapse of BHDG5 when the pump was lifted, the borehole should be rehabilitated to avoid further borehole collapses. A new borehole (or reamed existing borehole) in combination with a better well design (liner, filter, pump location of the pump etc) will lead to higher and more sustainable yield a more stable water quality and no danger for collapse. A constant rate test and performance pump test are needed to assess groundwater yields, changes in water quality over time and potential impact on groundwater levels in observation boreholes surrounding BHDG5.

If the observation that BHDG5 may be supported by recharge from Fishers Valley and Sharks Valley, then BHDG5 is possibly a key borehole in groundwater exploitation at St Helena.

8. WRA-C

Sharks Valley should be reinvestigated as a potential groundwater abstraction source. Whilst accessibility may be an issue, the availability of the groundwater resource and the potential to apply for renewable and efficient pumping systems may be economically attractive for the resource to be considered to augment current supply.

There is an opportunity to monitor Hancock Spring and complete an investigation to determine its viability as a resource for Connect, especially in the context of future water stresses associated with climate change.

9. WRA-D

Streamflow in Sandy Bay is high and is supported from surface runoff draining from the southern flanks of the Peaks (Mount Acteon, Diana’s Peak and Cuckolds Point) flowing down steep valleys such as Perkins Gut and Jockeys Gut. The costs of moving water from Sandy Bay to the north of the island have been previously assessed as too expensive, however this potential source of water should be assessed in more detail as part of an options appraisal.

7.3 Cloud Forest Restoration Areas

Due to the impacts of the *Phytophthora* infection within endemic cloud forest vegetation, planned restoration of the cloud forest within the Peaks National Park has been paused. The review of water resource and geology data has demonstrated the importance of the Iron Pot and Frenches Gut wellfields in the Lemon Valley Catchment. These wellfields are close to the top of the ridge near High Peak, and above the 690m contour, which the DPLUS051 report had indicated was the bottom of the cloud base within the Peaks. It is recommended that Crown land located within the wellfield catchments above the 690m contour is considered for reforestation with endemic cloud forest, as the catchments are located at a distance from the main *Phytophthora* infection area.

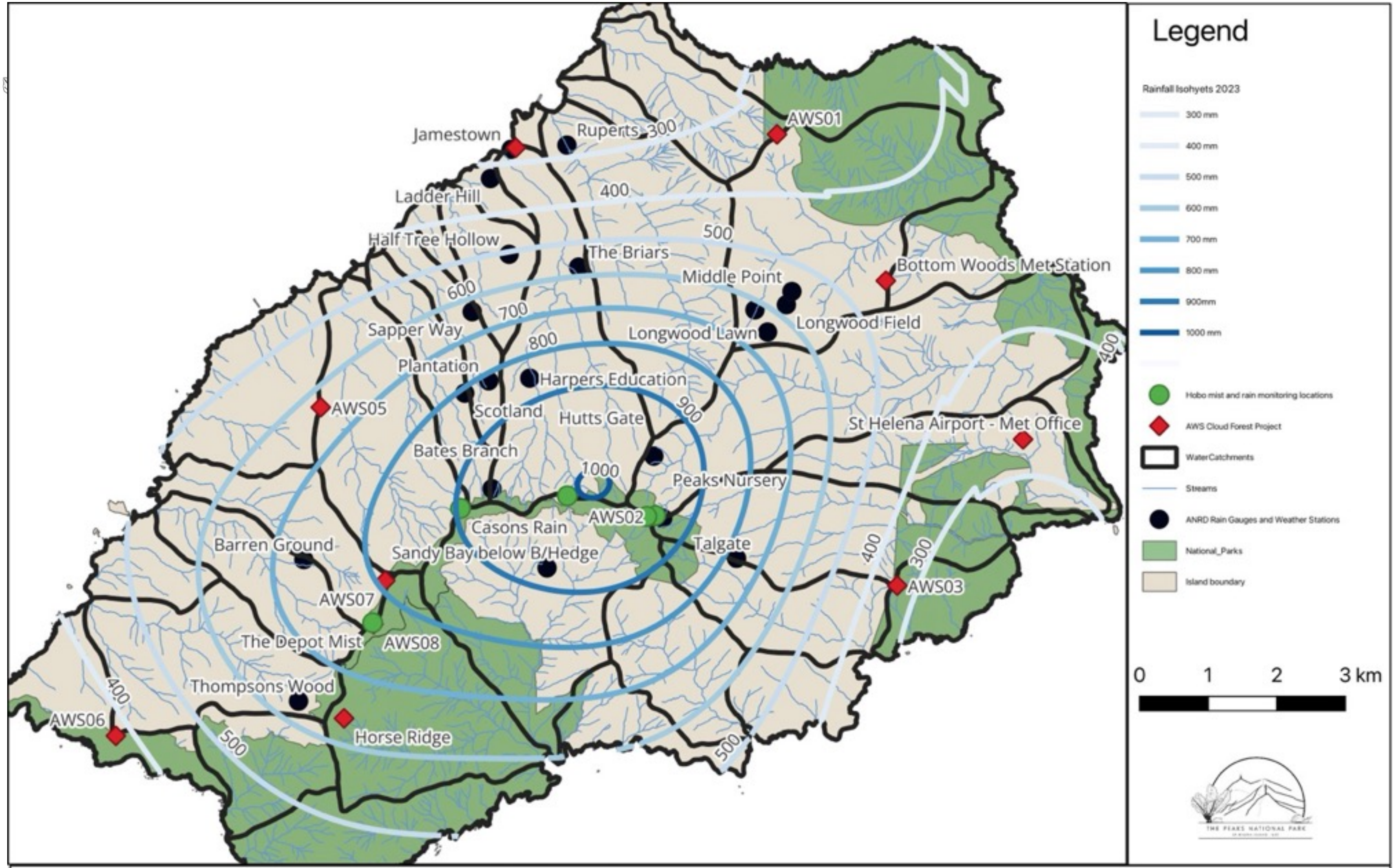
A larger scale Gumwood restoration below the cloud forest should also be considered with an ecological/hydrological gradation between the two including trees on grazing land.

Appendices

Appendix 1: Climate Monitoring Data

St Helena, Bottom Woods GCOS Station

	2023	2023	2023	Period 2002 - 2021	Period 2002 - 2021	Period 2002 - 2021	Period 2002 - 2021	Period 2002 - 2021	2023	Period 2002 - 2025	2023	2023	Period 2002 - 2021	Period 2002 - 2021	2023	2023	Period 2002 - 2021	Period 2002 - 2021
MONTH	MONTHY_ RAIN	MAX DAILY RAIN	RAIN DAYS	Avg MONTHY RAIN	Max MONTHY RAIN	Min MONTHY RAIN	MAX DAILY RAIN	Avg RAIN DAYS	SUN HOURS	Avg MONTHLY SUN	Avg DAILY MAX AIR TEMP	Max DAILY MAX AIR TEMP	Avg DAILY MAX AIR TEMP	Max DAILY MAX AIR TEMP	Avg DAILY MIN TEMP	Min DAILY MIN AIR TEMP	Avg DAILY MIN TEMP	Min DAILY MIN AIR TEMP
Jan	26.4	5	22	36.6	69.8	6.2	29.8	20	134.8	146.3	23.7	25.7	22.7	26.2	18.6	17.6	17.7	15.2
Feb	31.2	6.4	12	43.1	116.6	4	33.6	18	157.4	159.4	24	25.3	23.8	27.1	19.1	17.5	18.9	16.4
Mar	62.6	15.2	23	58.2	101.6	25	26.2	20	157.6	168	23.7	25.8	23.9	27.5	19	17.3	19.2	16.1
Apr	37.2	12	14	48.2	81.8	8.8	49	18	134.4	145.9	23.3	25.5	23	25.6	18.7	17.5	18.7	13.7
May	31.4	12.4	21	41	96.2	15.4	34.6	16	106	151.5	21.5	24.1	21.9	26.4	17.4	15.3	17.6	12.9
Jun	72.8	11	24	56.9	108.6	16.6	24	19	107.1	111.6	19.8	22	20.1	24.1	17	13.6	15.9	11.1
Jul	53	8.8	15	52.1	105.6	4.4	18.2	18	93.4	113.5	15.5	20.2	18.9	22.9	15	12.7	15	10.1
Aug	31.4	4.8	21	59.1	106	15.6	15.8	21	67.4	85.6	17.8	19.9	18	21.5	14.2	12.3	14.4	10.8
Sep	61.4	11.4	20	37.7	64.4	20.6	11.4	18	58.4	65.2	17.2	18.4	18	22.3	13.9	12.8	14.3	10.9
Oct	32	5.4	18	26.4	73.2	9.6	17.8	15	47.9	67.5	18	20.9	18.6	23.1	14.4	13.6	14.6	11.5
Nov	24.6	10.8	10	19.7	38.8	3.2	22.8	14	151	80.7	21	23	19.5	25.3	16.1	14.6	15.2	11.9
Dec	25.2	5.2	19	20.3	43.2	4	10.6	15	111.5	118.4	22.2	23.7	21.1	24.4	17.5	16.1	16.4	12.7
ANNUAL	489.2	15.2	219	499.3	116.6	3.2	49	212	1326.9	1413.6	20.6	25.8	20.8	27.5	16.7	12.3	16.5	10.1



Date: 26 February 2024
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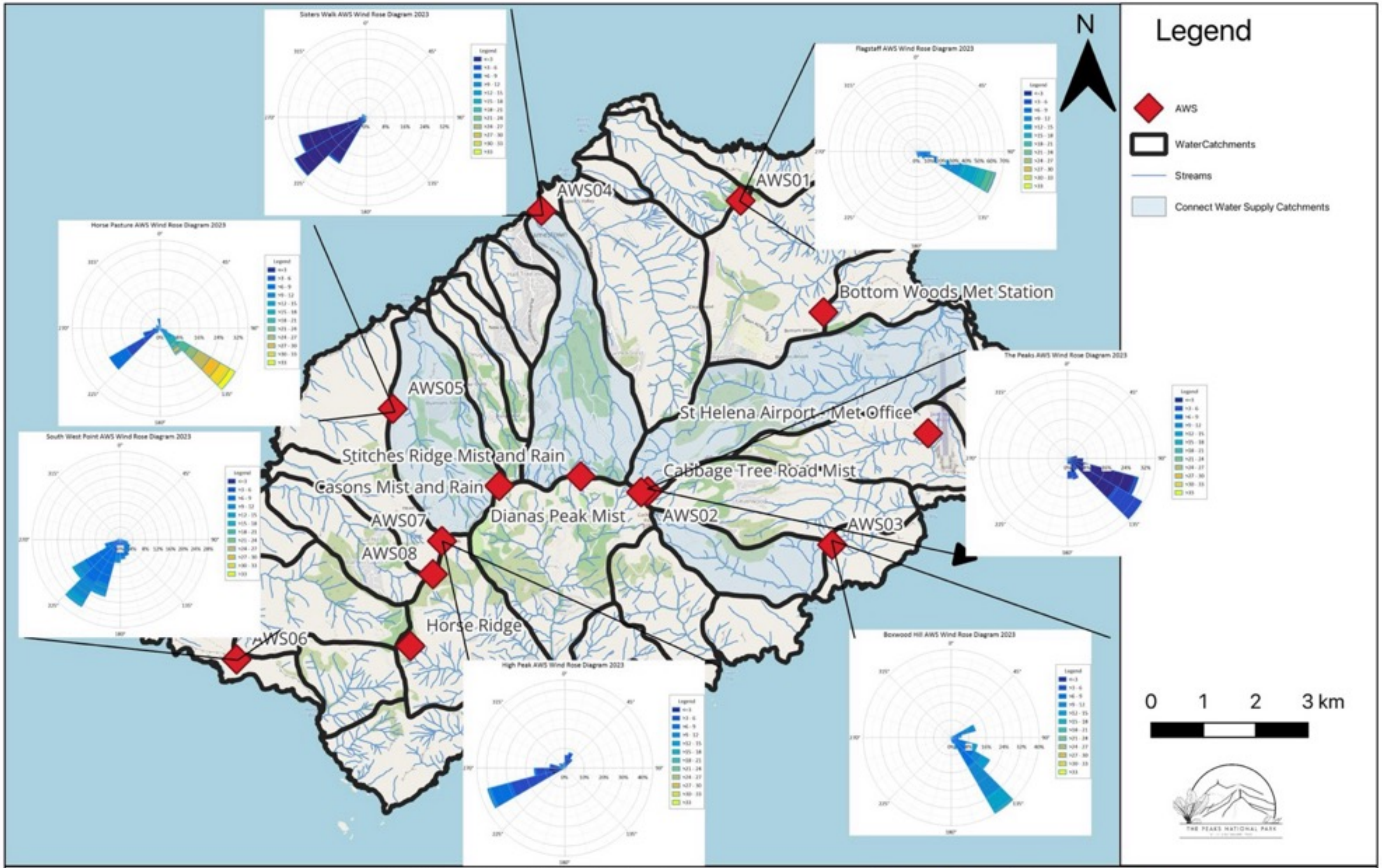
St Helena Cloud Forest Project

2023 Rainfall Isohyet Map



Date: 14 February 2024
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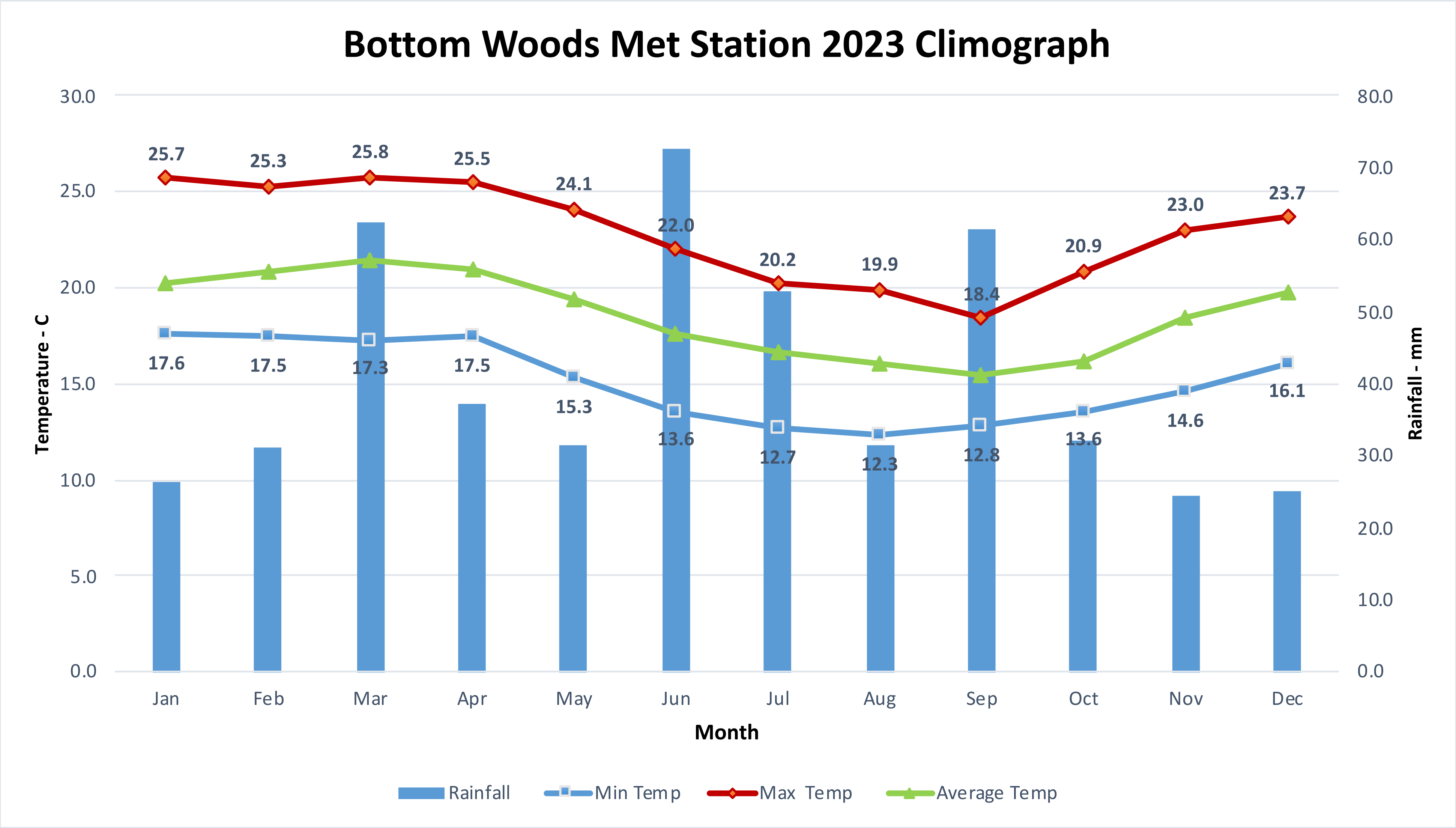
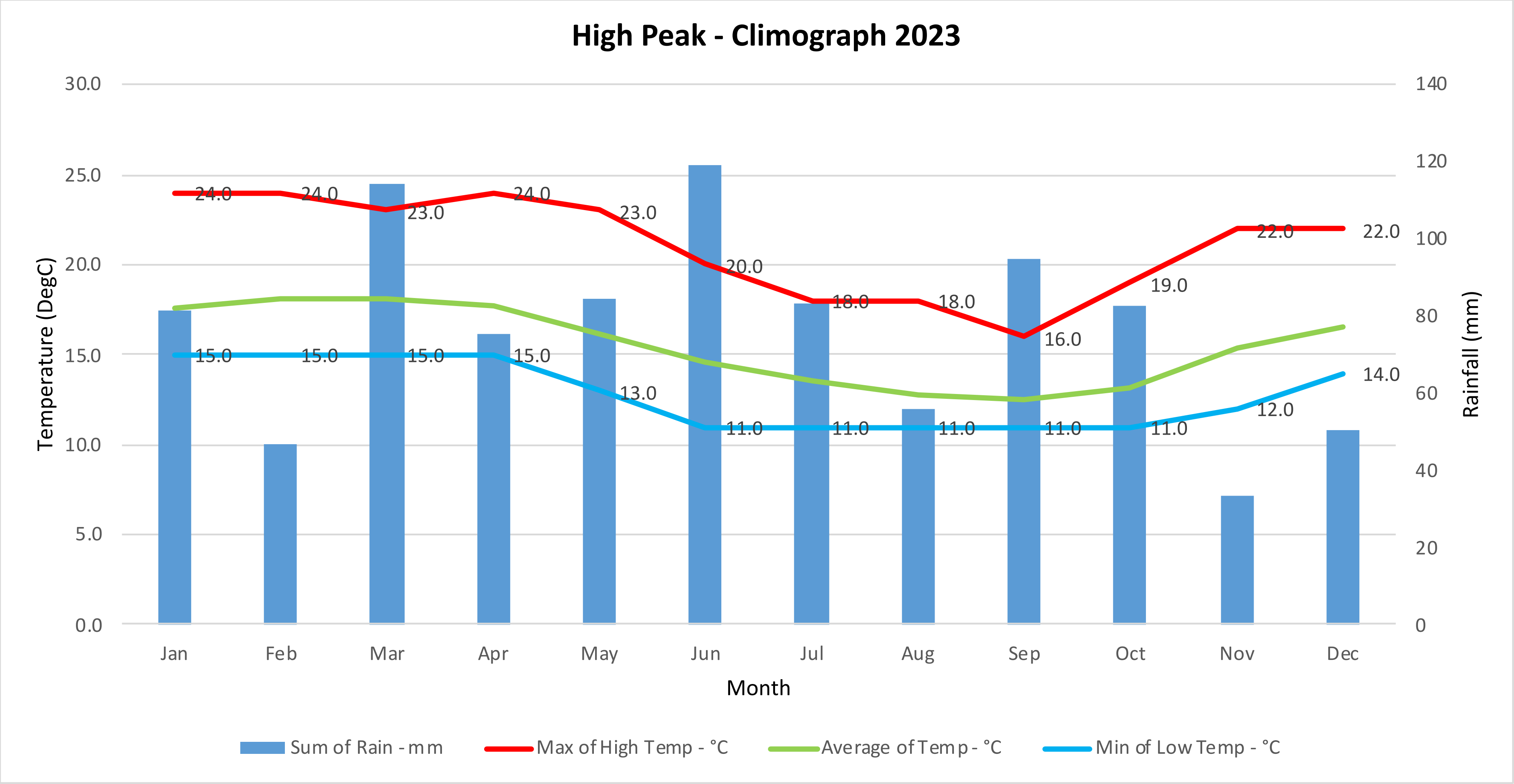
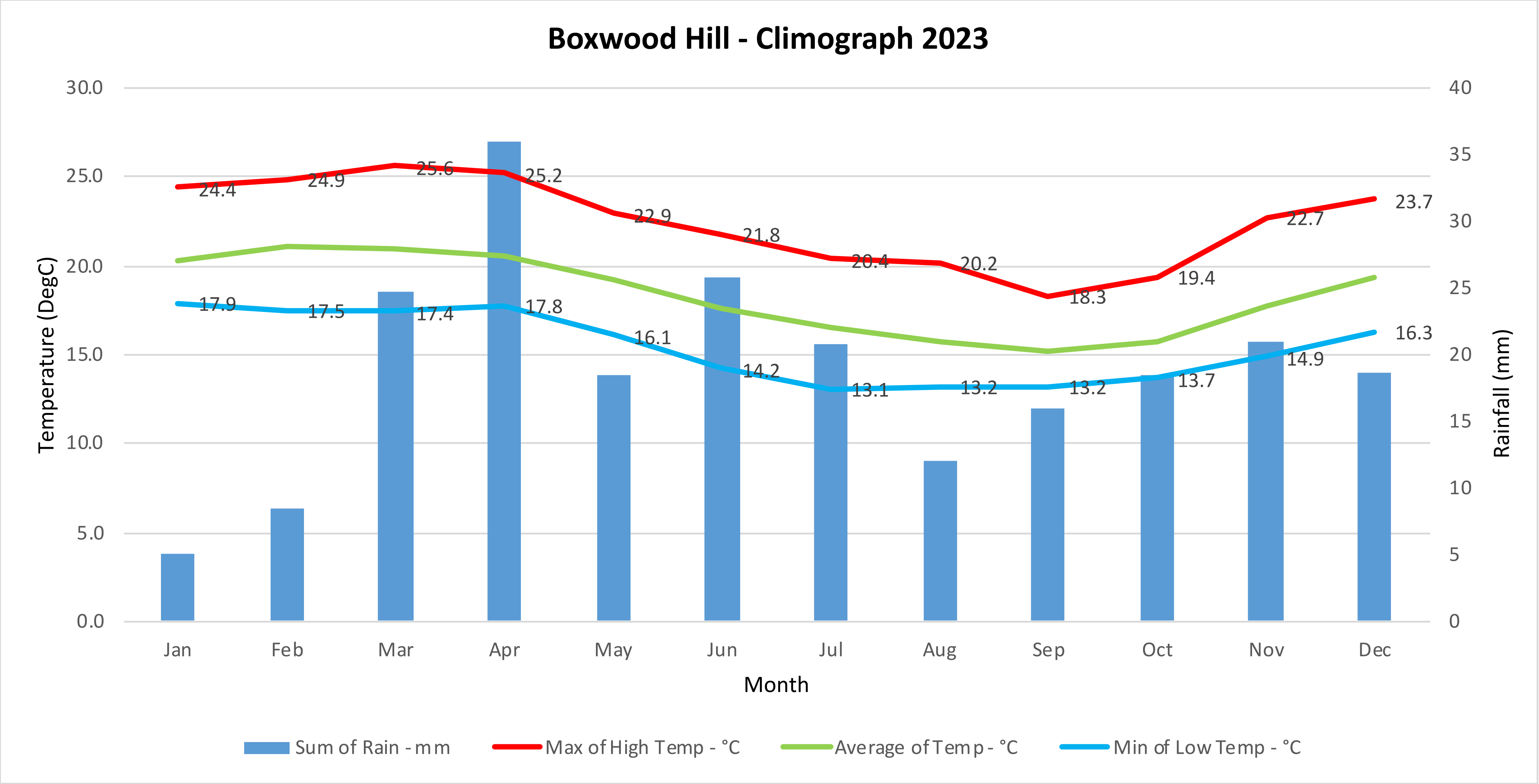
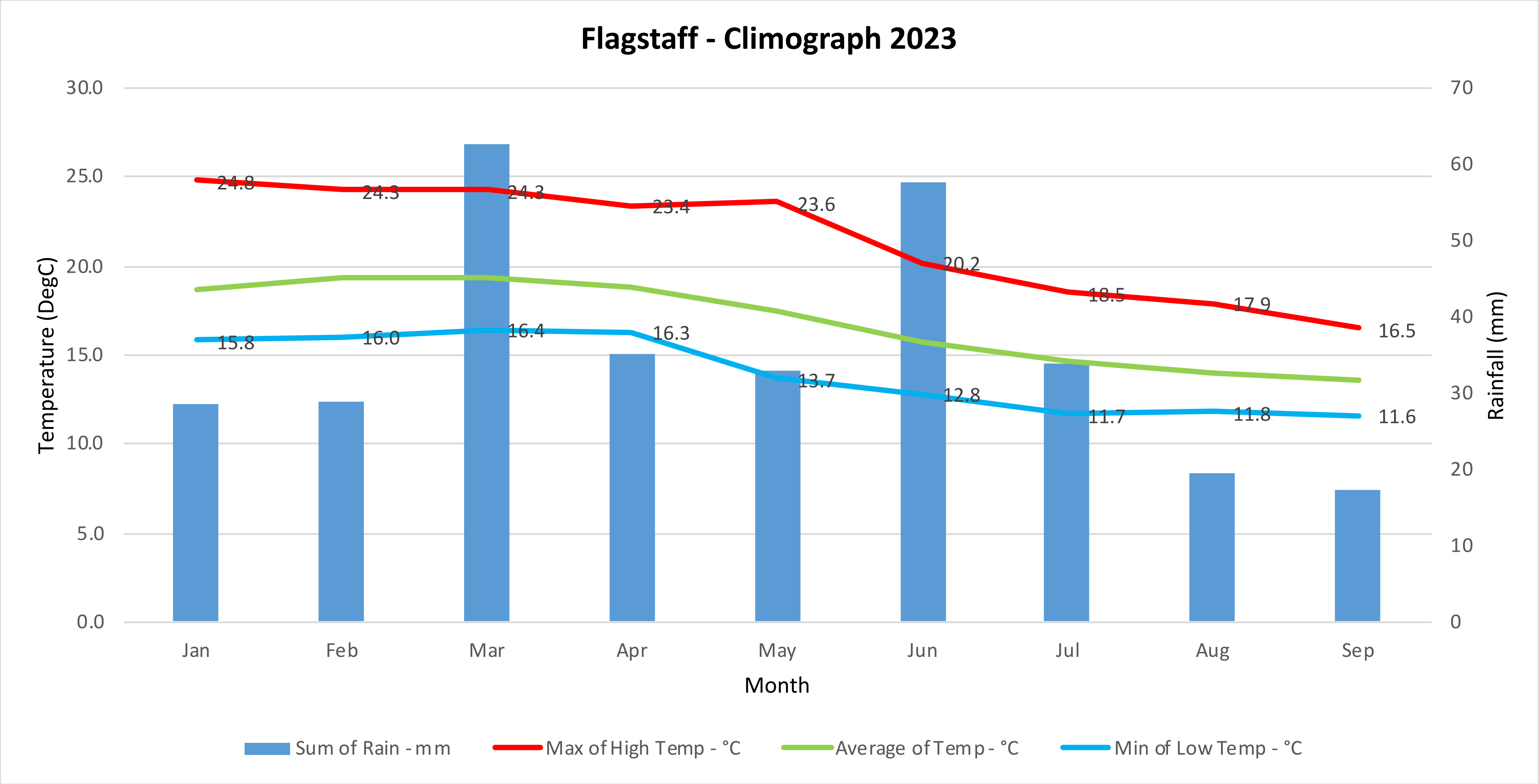
St Helena Cloud Forest Project
AWS Wind Rose Data 2023

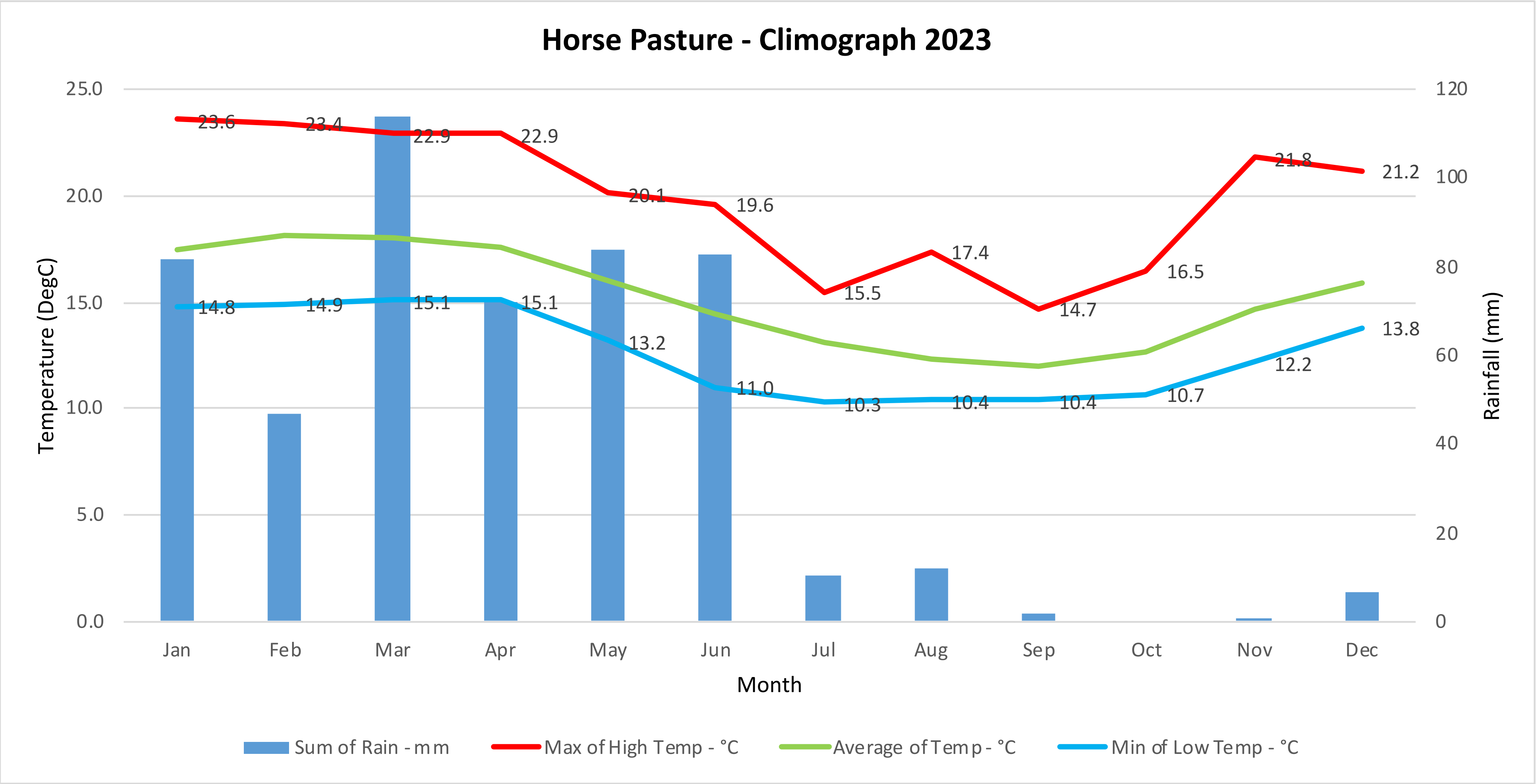
UK Government


Bottom Woods Met Station 2023 Climograph
Temperature - C
Rainfall - mm
Month
30.0
25.0
20.0
15.0
10.0
5.0
0.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
25.7
25.3
25.8
25.5
24.1
22.0
20.2
19.9
18.4
20.9
23.0
23.7
17.6
17.5
17.3
17.5
15.3
13.6
12.7
12.3
12.8
13.6
14.6
16.1
Rainfall
Min Temp
Max Temp
Average Temp

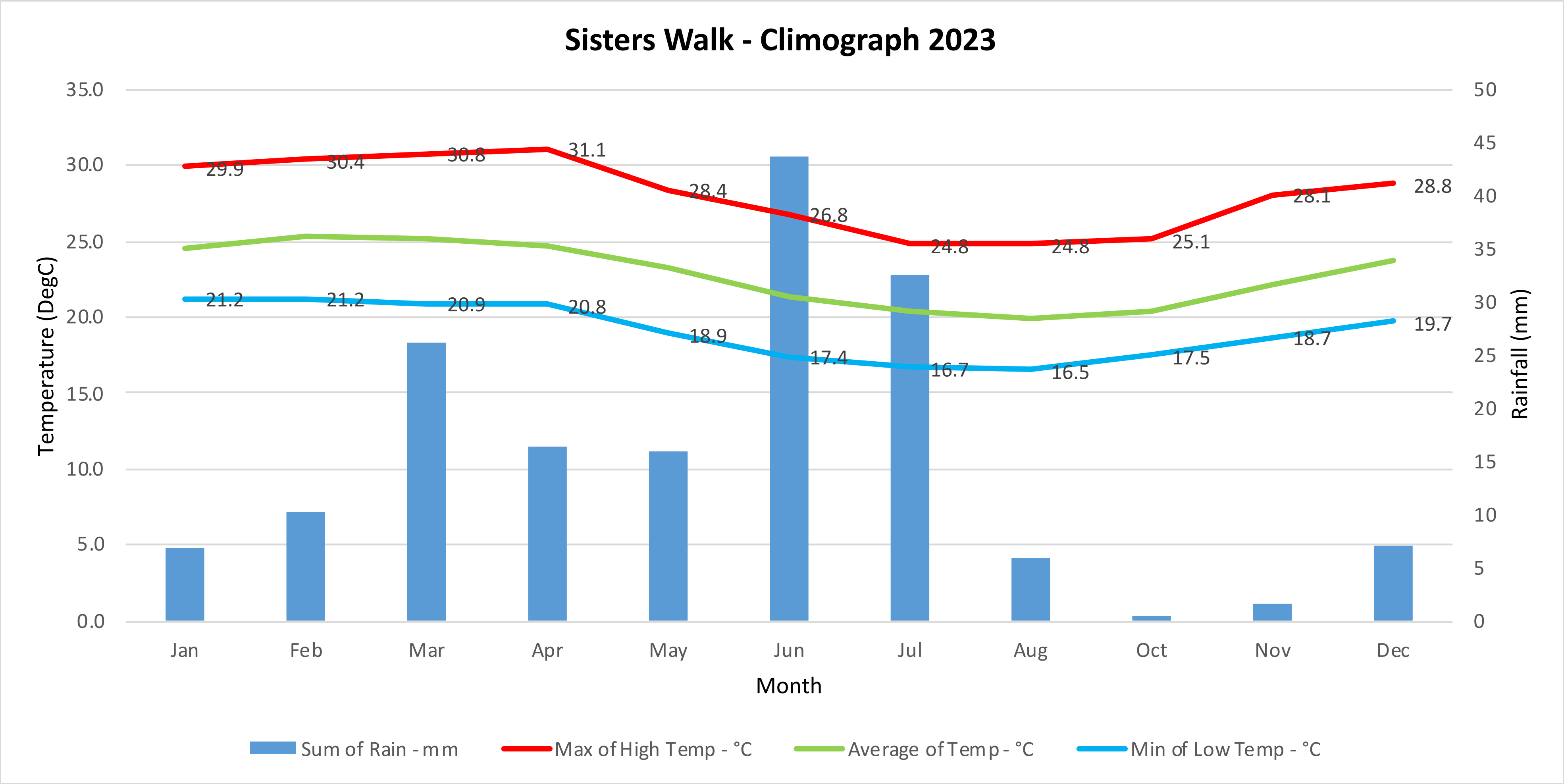

High Peak - Climograph 2023
Temperature (DegC)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Rainfall (mm)
140
120
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
24.0
24.0
23.0
24.0
23.0
20.0
18.0
18.0
16.0
19.0
22.0
22.0
15.0
15.0
15.0
15.0
13.0
11.0
11.0
11.0
11.0
11.0
12.0
14.0
Sum of Rain - mm
Max of High Temp - °C
Average of Temp - °C
Min of Low Temp - °C


Boxwood Hill - Climograph 2023
Temperature (DegC)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Rainfall (mm)
40
35
30
25
20
15
10
5
0
24.4
24.9
25.6
25.2
22.9
21.8
20.4
20.2
18.3
19.4
22.7
23.7
17.9
17.5
17.4
17.8
16.1
14.2
13.1
13.2
13.2
13.7
14.9
16.3
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Sum of Rain - mm
Max of High Temp - °C
Average of Temp - °C
Min of Low Temp - °C

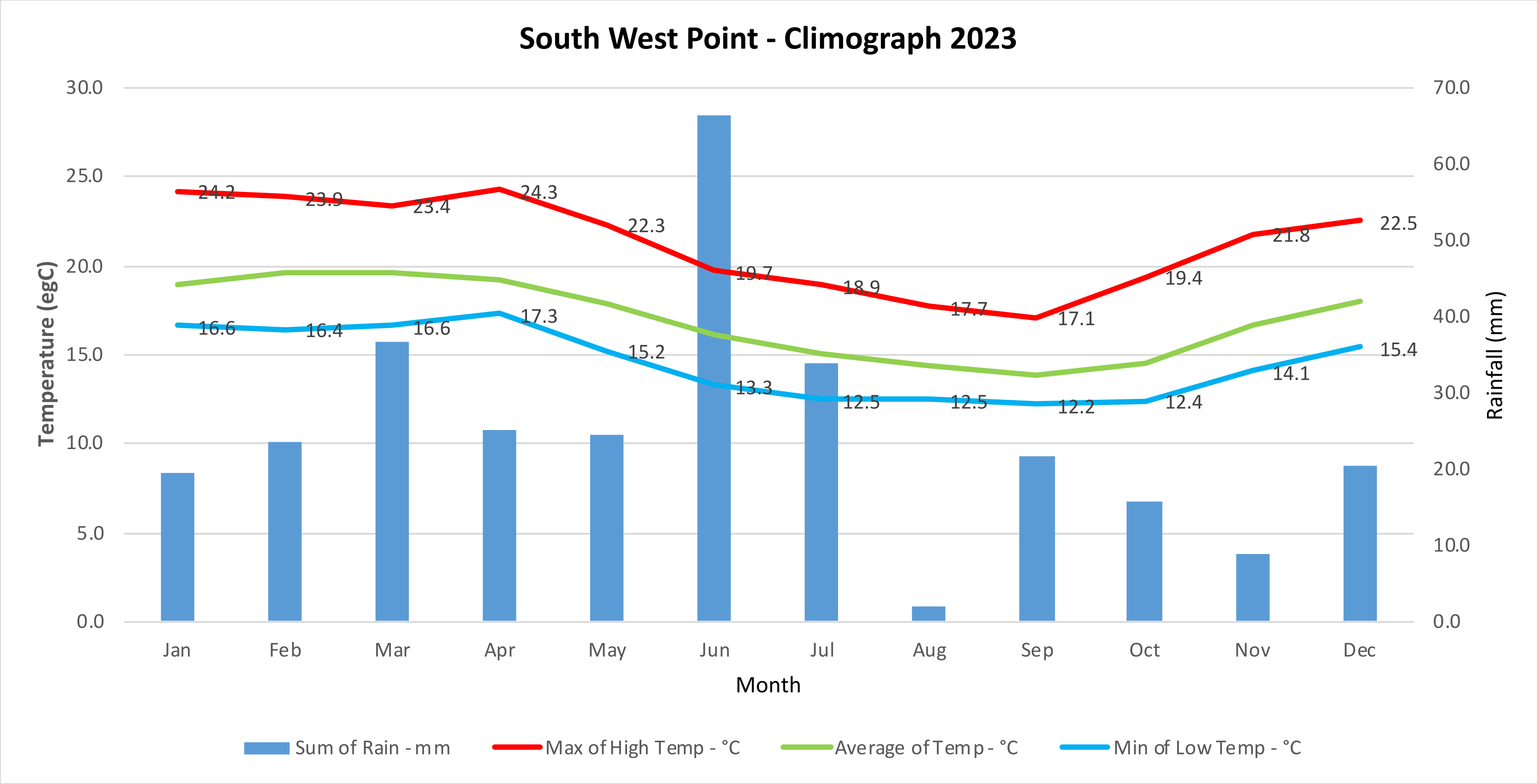

Flagstaff - Climograph 2023
Temperature (DegC)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Rainfall (mm)
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Month
24.8
24.3
24.3
23.4
23.6
20.2
18.5
17.9
16.5
15.8
16.0
16.4
16.3
13.7
12.8
11.7
11.8
11.6
Sum of Rain - mm
Max of High Temp - °C
Average of Temp - °C
Min of Low Temp - °C

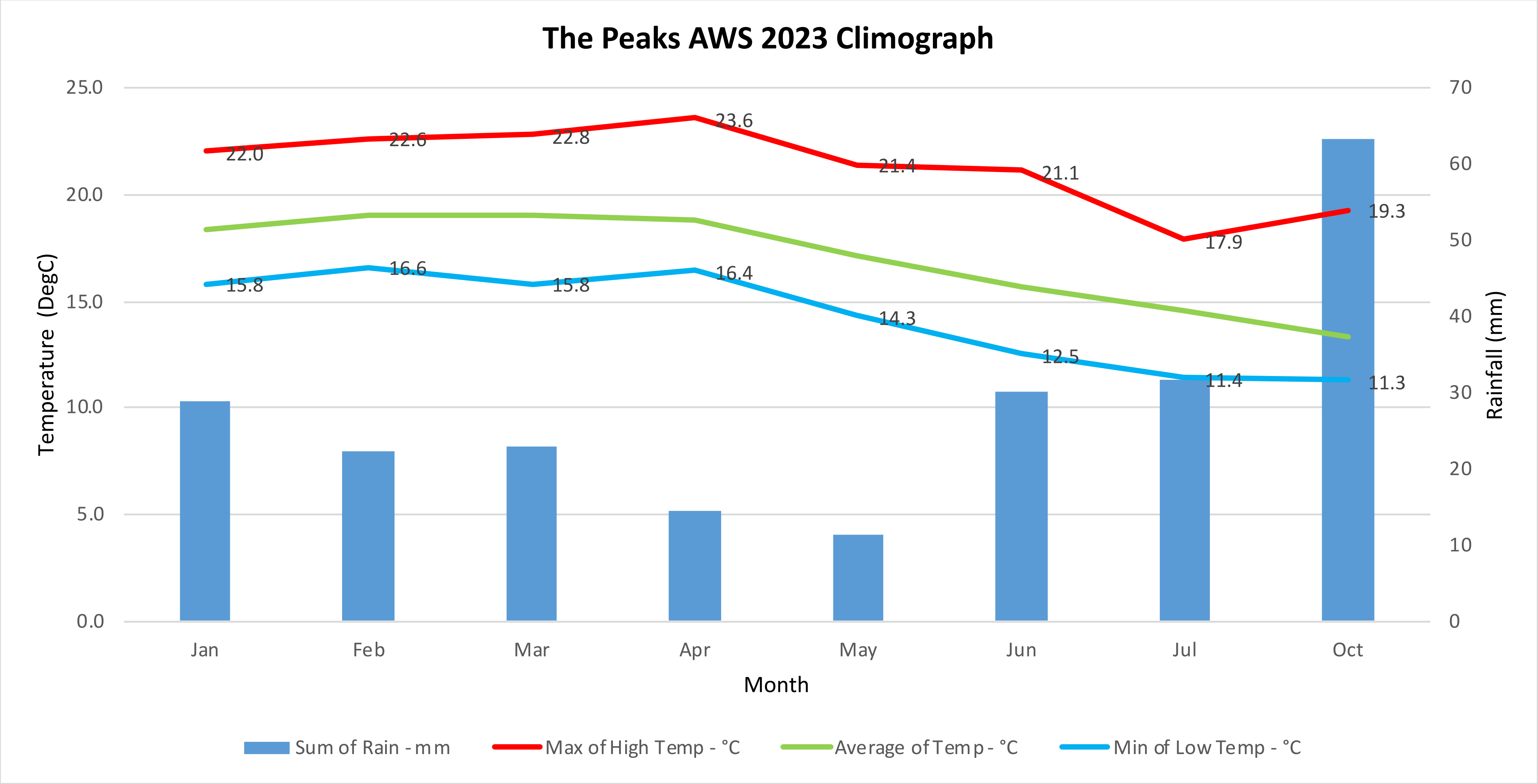


Horse Pasture - Climograph 2023

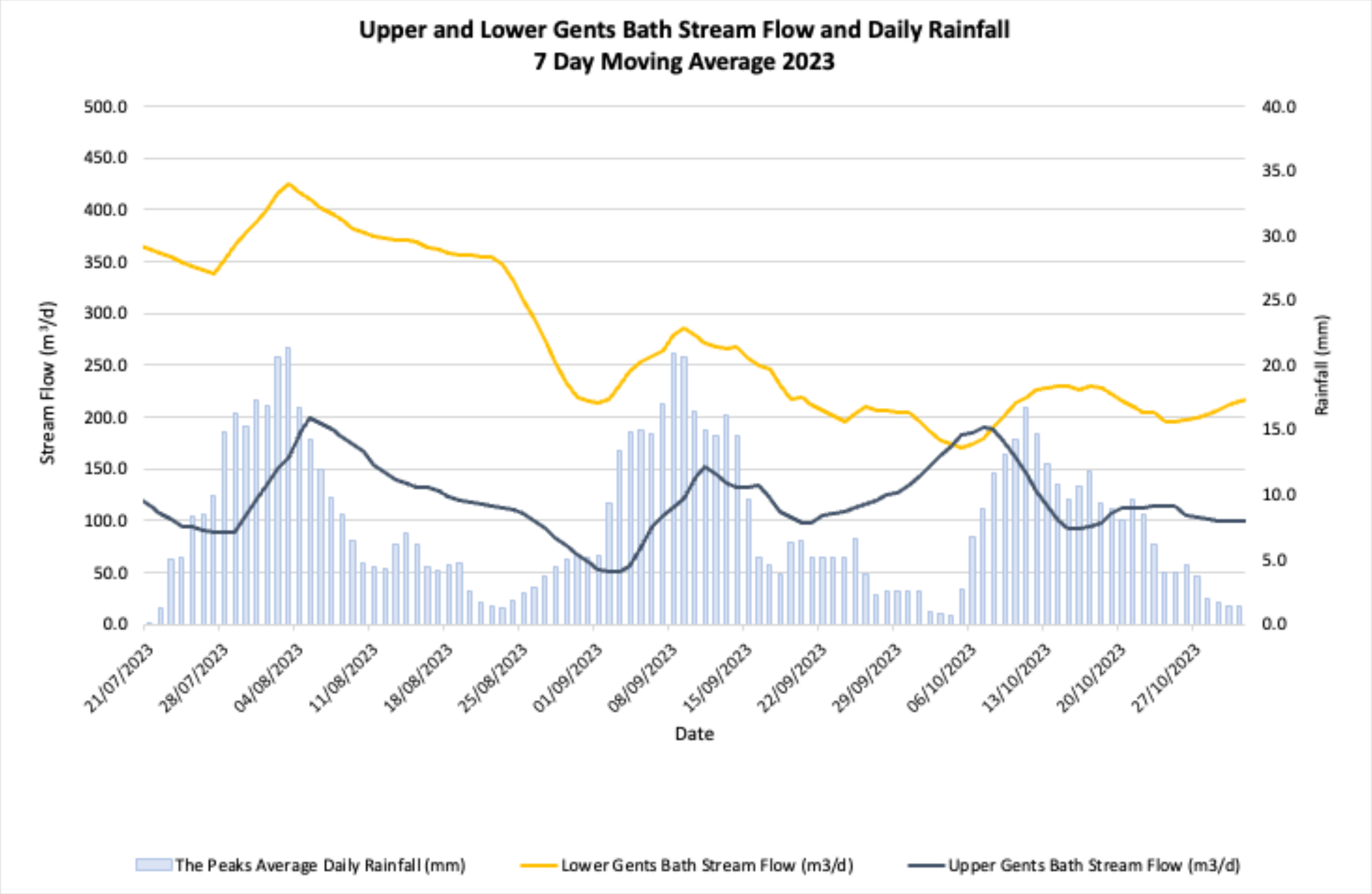


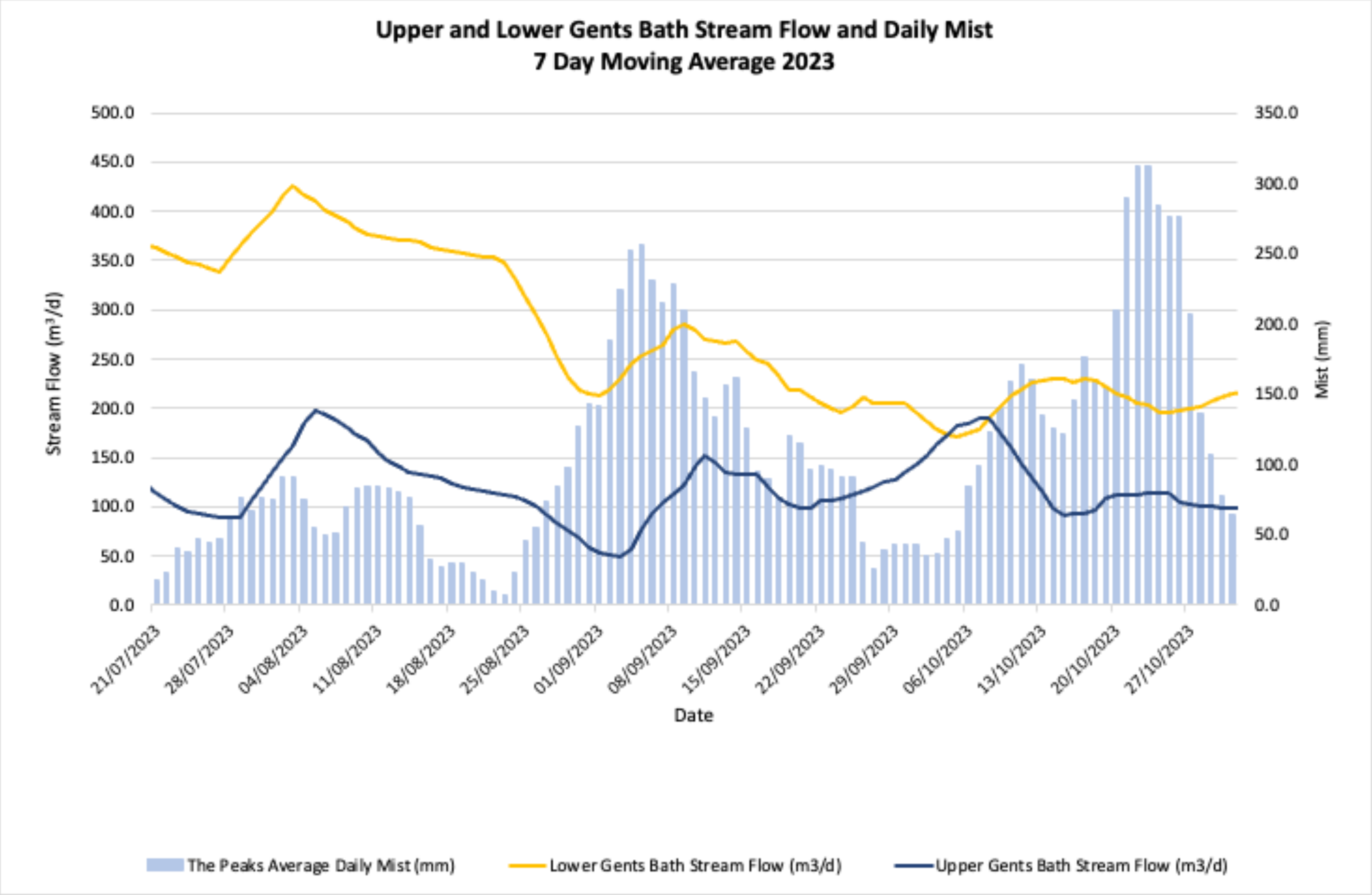
Sisters Walk - Climograph 2023

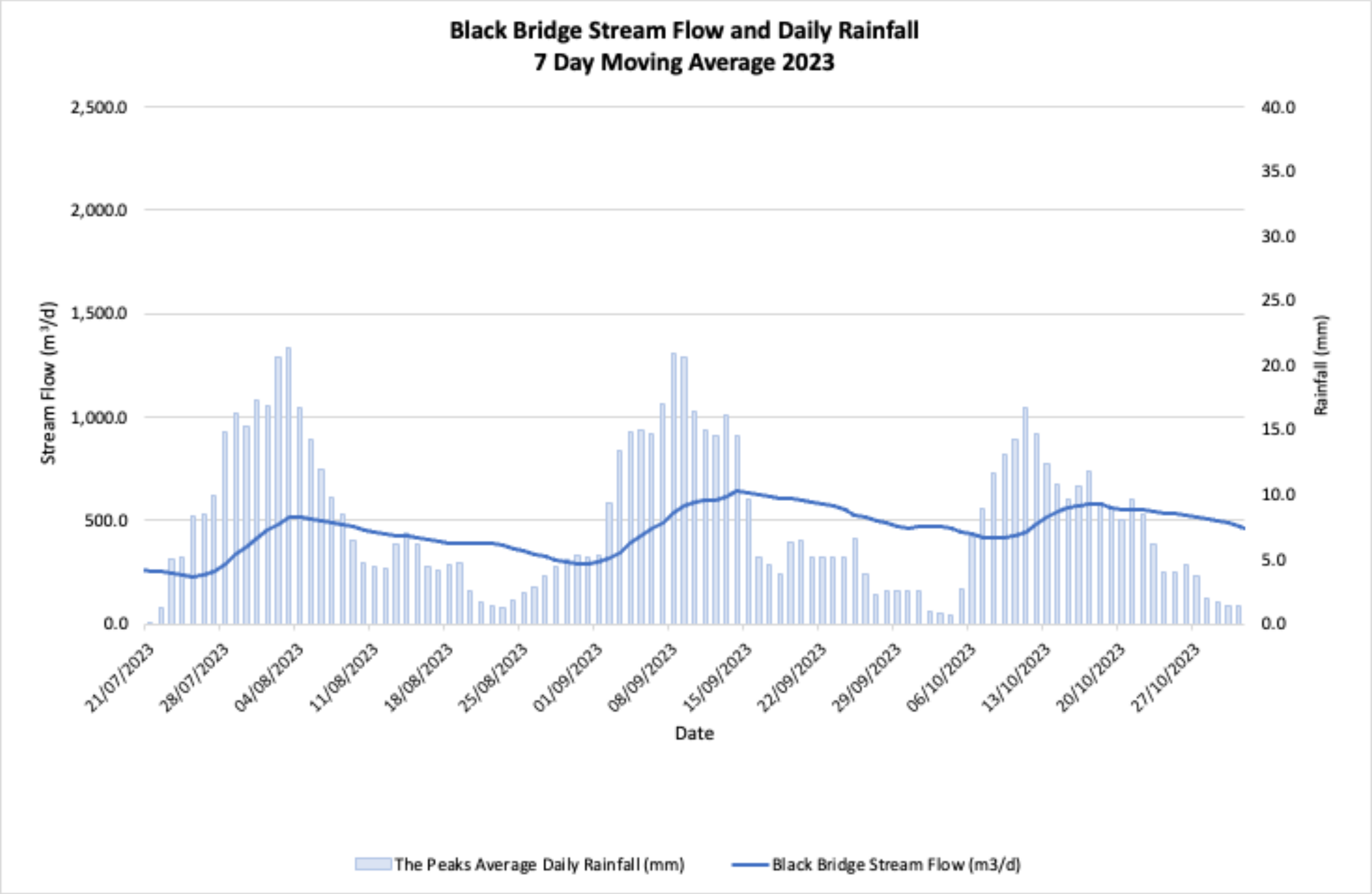

South West Point - Climograph 2023
Temperature (egC)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Rainfall (mm)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
24.2
23.9
23.4
24.3
22.3
19.7
18.9
17.7
17.1
19.4
21.8
22.5
16.6
16.4
16.6
17.3
15.2
13.3
12.5
12.5
12.2
12.4
14.1
15.4
Sum of Rain - mm
Max of High Temp - °C
Average of Temp - °C
Min of Low Temp - °C

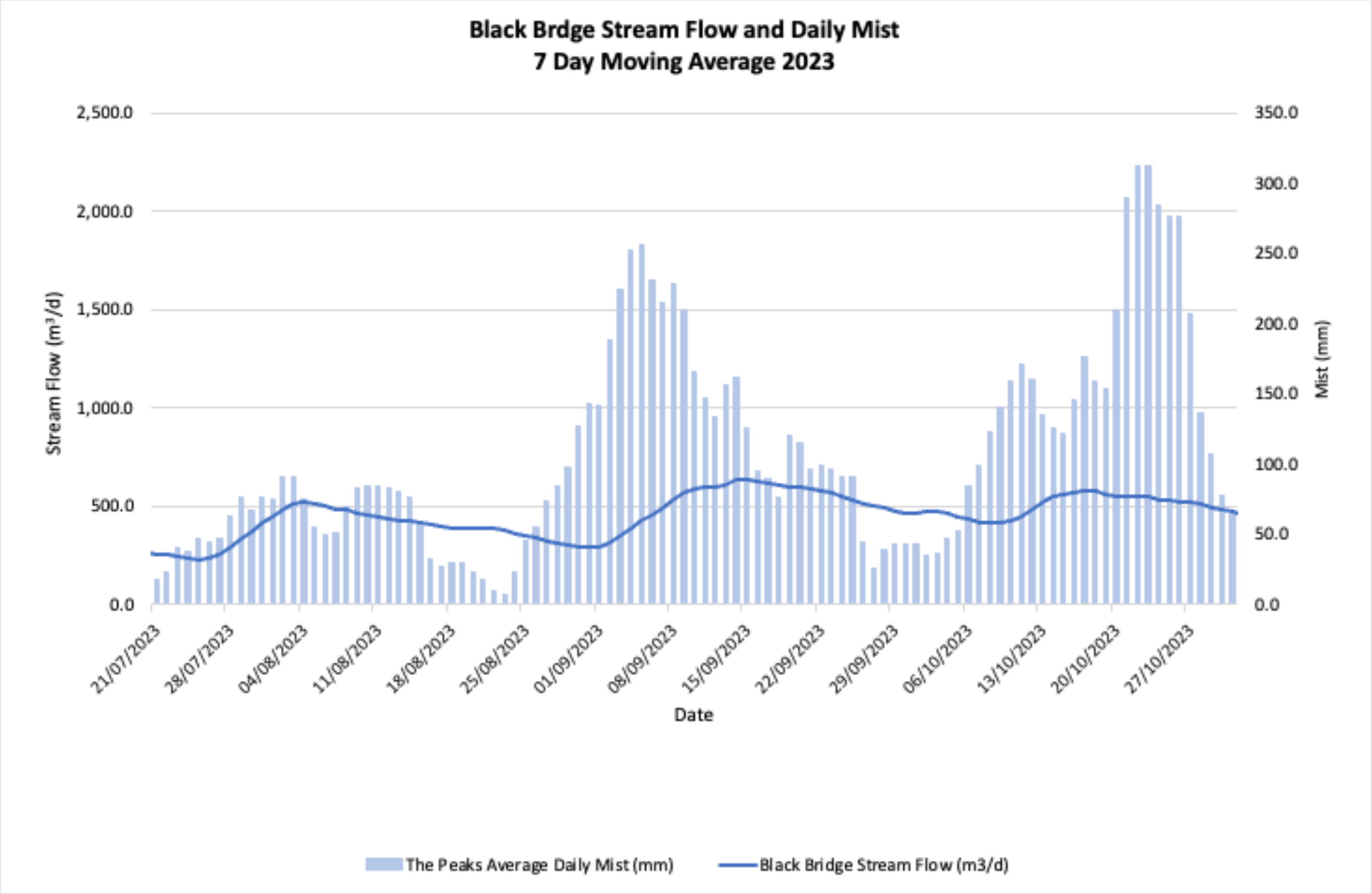

The Peaks AWS 2023 Climograph
Temperature (DegC)
Rainfall (mm)
Month
25.0
20.0
15.0
10.0
5.0
0.0
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Oct
22.0
22.6
22.8
23.6
21.4
21.1
17.9
19.3
15.8
16.6
15.8
16.4
14.3
12.5
11.4
11.3
Sum of Rain - mm
Max of High Temp - °C
Average of Temp - °C
Min of Low Temp - °C

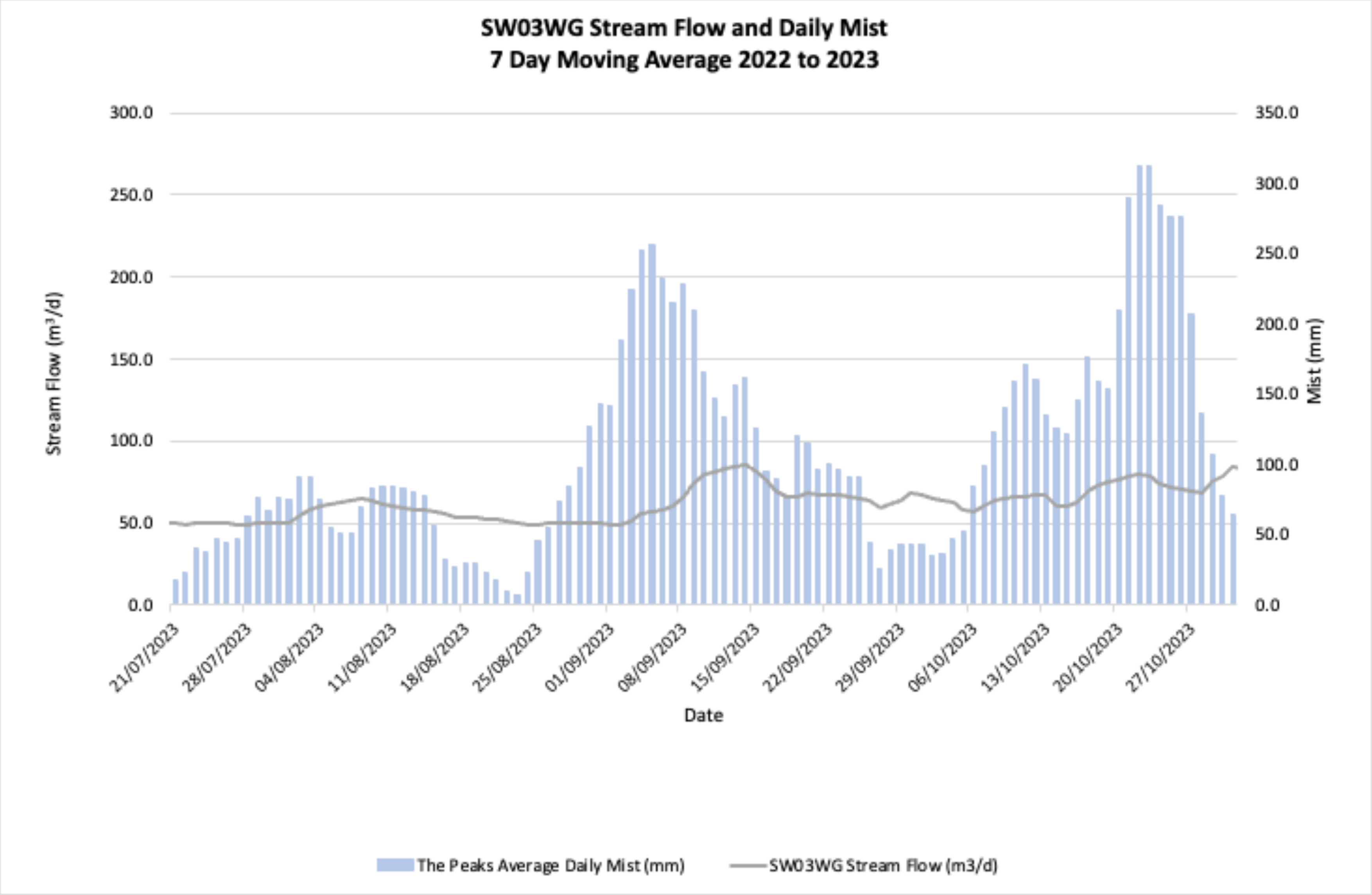
Appendix 2: Surface Water and Groundwater Data

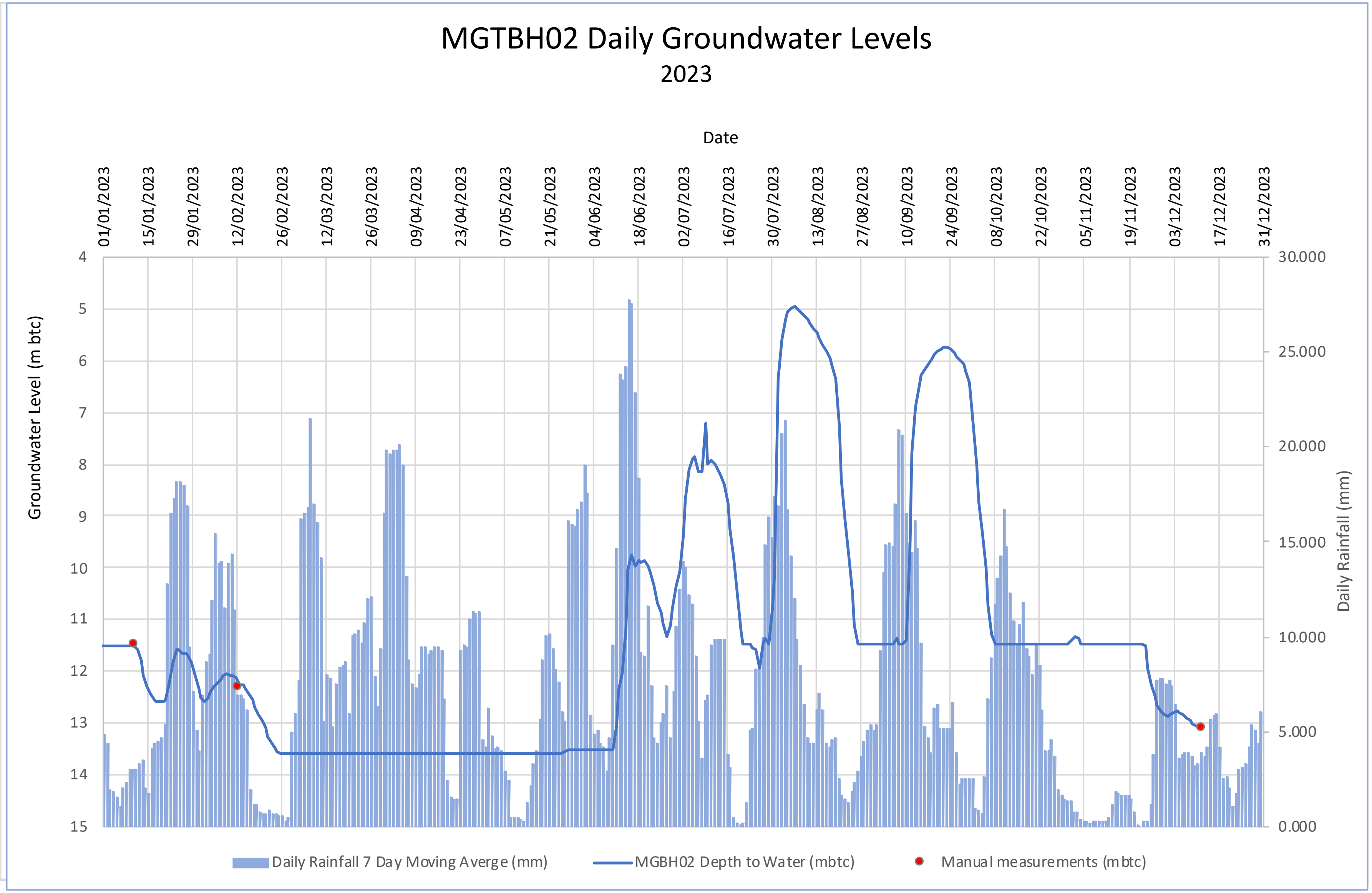

Upper and Lower Gents Bath Stream Flow and Daily Rainfall
7 Day Moving Average 2023
Stream Flow (m³/d)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Rainfall (mm)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
21/07/2023
28/07/2023
04/08/2023
11/08/2023
18/08/2023
25/08/2023
01/09/2023
08/09/2023
15/09/2023
22/09/2023
29/09/2023
06/10/2023
13/10/2023
20/10/2023
27/10/2023
Date
The Peaks Average Daily Rainfall (mm)
Lower Gents Bath Stream Flow (m3/d)
Upper Gents Bath Stream Flow (m3/d)


Upper and Lower Gents Bath Stream Flow and Daily Mist
7 Day Moving Average 2023
Stream Flow (m³/d)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Mist (mm)
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
21/07/2023
28/07/2023
04/08/2023
11/08/2023
18/08/2023
25/08/2023
01/09/2023
08/09/2023
15/09/2023
22/09/2023
29/09/2023
06/10/2023
13/10/2023
20/10/2023
27/10/2023
Date
The Peaks Average Daily Mist (mm)
Lower Gents Bath Stream Flow (m3/d)
Upper Gents Bath Stream Flow (m3/d)


Black Bridge Stream Flow and Daily Rainfall
7 Day Moving Average 2023
Stream Flow (m³/d)
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
Rainfall (mm)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
21/07/2023
28/07/2023
04/08/2023
11/08/2023
18/08/2023
25/08/2023
01/09/2023
08/09/2023
15/09/2023
22/09/2023
29/09/2023
06/10/2023
13/10/2023
20/10/2023
27/10/2023
Date
The Peaks Average Daily Rainfall (mm)
Black Bridge Stream Flow (m3/d)


Black Brdge Stream Flow and Daily Mist
7 Day Moving Average 2023
Stream Flow (m³/d)
Mist (mm)
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
21/07/2023
28/07/2023
04/08/2023
11/08/2023
18/08/2023
25/08/2023
01/09/2023
08/09/2023
15/09/2023
22/09/2023
29/09/2023
06/10/2023
13/10/2023
20/10/2023
27/10/2023
Date
The Peaks Average Daily Mist (mm)
Black Bridge Stream Flow (m3/d)


SW03WG Stream Flow and Daily Mist
7 Day Moving Average 2022 to 2023
Stream Flow (m³/d)
Mist (mm)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
21/07/2023
28/07/2023
04/08/2023
11/08/2023
18/08/2023
25/08/2023
01/09/2023
08/09/2023
15/09/2023
22/09/2023
29/09/2023
06/10/2023
13/10/2023
20/10/2023
27/10/2023
Date
The Peaks Average Daily Mist (mm)
SW03WG Stream Flow (m3/d)


MGTBH02 Daily Groundwater Levels
2023
Date
01/01/2023
15/01/2023
29/01/2023
12/02/2023
26/02/2023
12/03/2023
26/03/2023
09/04/2023
23/04/2023
07/05/2023
21/05/2023
04/06/2023
18/06/2023
02/07/2023
16/07/2023
30/07/2023
13/08/2023
27/08/2023
10/09/2023
24/09/2023
08/10/2023
22/10/2023
05/11/2023
19/11/2023
03/12/2023
17/12/2023
31/12/2023
Groundwater Level (m btc)
4
5
6
7
8
9
10
11
12
13
14
15
Daily Rainfall (mm)
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Daily Rainfall 7 Day Moving Averge (mm)
MGBH02 Depth to Water (mbtc)
Manual measurements (mbtc)

Appendix 3: Data Collection Log

Surface Water Monitoring Sites

Date	Time	Site	Discrepancy	Repair
10-Aug-2021	09:36	Harpers V	Vandalism - BaroScout datalogger removed from its deployed location and found in v-notch weir without cap on	Datalogger damaged beyond repair, replaced with new datalogger
10-Aug-2021	09:36	Harpers V	Vandalism - LevelScout datalogger missing	Data logger wasn't found, replaced with new datalogger 07-Feb-2022
13-Jan-2022	10:34	FVMBH01	Diver data logger clock not functioning; unable to recover data	Data logger taken out of service and replaced
24-Apr-2022	15:40	SBFL01	RBC Flume washed away from position due to heavy rainfall and increased streamflow (informed by Mr. Hayward Benjamin)	27-Apr-2022 – reinstalled flume
11-May-2022	10:55	FVSW01	MicroSiren logged data for 5 days only, 11-Mar-2022 – 15-Mar-2022	Relaunched Logger, monitored status for 2 weeks on weekly basis. No further issues found
14-Jun-2022	12:24	SBFL01	During site visit observed earth surrounding flume eroded away, only partial amount streamflow passing through flume	Reinstalled flume with waterproof membrane to prevent erosion
14-Jul-2022	11:37	SBFL01	RBC Flume submerged by about 80mm	Monitored situation over several weeks, flume was continually submerged. Decision made to relocate equipment to Fishers Valley where streamflow was suitable and allowed accurate monitoring.
30-Aug-2022	10:43	Drummonds Point	V-notch weir overflowing, LevelScout data logger found damaged possibly due to heavy streamflow as	Data logger damaged beyond repair; new data logger deployed

Date	Time	Site	Discrepancy	Repair
			data logger found with signs of wear and tear	
24-Nov-2022	11:10	All Sites	Hanna Multiprobe not functioning	Probe replaced 30-Jan-2023
05-Jan-2023	13:49	FVFL01	Data Logger in RBC Flume logging negative pressure readings	Consulted Suppliers, troubleshooting ongoing
12-Jan-2023	13:52	Upper Gents Bath	Unable to connect to LevelScout data logger	Returned back to attempt connection with a different laptop and different communication devices, but no success. New data logger deployed and original data logger sent to Van Walt for repairs
10-Feb-2023	11:32	Harpers V	BaroScout data logger did not log data for the duration it was scheduled to do	Use Frenches Gut BaroScout data for barometric compensation. Changed BaroScout data loggers at Harpers
19-Apr-2023	14:33	Lower Gents Bath	Unable to connect to LevelScout data logger	24-Apr-2023 replaced data logger.
11-May-2023	11:15	FVMBH01	Found Diver data logger out of monitoring borehole (still attached to cable)	Placed back in borehole after data downloaded
11-May-2023	13:50	SW01WG	Diver data Logger not connecting, stating communication error	Data logger removed from service and sent to supplier in UK for data retrieval. New Diver data logger deployed 16-May-2023
11-May-2023	14:12	SW01BG	Diver data Logger not connecting, stating communication error	Data logger removed from service and sent to supplier in UK for data retrieval. New Diver data logger deployed 16-May-2023
18-May-2023	14:06	Lower Gents Bath	Structure receiving water supply piped that bypass v-notch and directly into abstraction chamber	Supply pipe used as structure requires maintenance
25-May-2023	12:00	SBSF01	MicroSiren data logger not connecting, likely due to depleted batteries	16-Jun-2023 MicroSiren data logger repaired and deployed.

Date	Time	Site	Discrepancy	Repair
23-Jun-2023	10:46	Drummonds Point	Found LevelScout data logger outside of structure	Placed logger back in structure after data download. Data suggested there was a high flow that caused data logger to be displaced
23-Jun-2023	15:26	Harpers V	Found LevelScout data logger outside of structure	Placed logger back in structure after data download. Data suggested there was a high flow that caused data logger to be displaced
10-Aug-2023	10:31	FVMBH01	Diver data logger not connecting, stating diver clock not functioning therefore no data will be recorded	Data logger removed, no spare data loggers available at time.
13-Dec-2023	11:08	Drummonds Point	LevelScout data logger recorded only 11 measurements, was scheduled to record up to 10,000	Launched again and will be monitored. Battery was changed as part of network maintenance
13-Dec-2023	14:25	Harpers V	LevelScout data logger recorded only 1,611 measurements, was scheduled to record up to 10,000	Launched again and will be monitored. Battery was changed as part of network maintenance
14-Dec-2023	13:29	LGSW01	Diver data logger missing, cord cut near tie-off point	Searched for data logger inside structure and surrounding area but was unsuccessful. 09-Feb-2024 deployed a repaired LevelScout to monitor location, and BaroScout deployed at SW01BG

Mist and Rainfall Monitoring Sites

Date	Time	Site	Discrepancy	Repair
20-Apr-2022	11:15	RFStitchesRidge	Data gap due to full memory as logging for temperature was previously set to 1 min intervals. Last event logged 29-Mar-2022 08:20	Changed temperature logging to 1 hour interval
20-Apr-2022	11:24	MCStitchesRidge	Data gap due full memory as logging for temperature was previously set to 1 min intervals. Last event logged 30-Mar-2022 11:24	Changed temperature logging to 1 hour interval
20-Apr-2022	12:02	MCCasons	Data gap due full memory as logging for temperature was previously set to 1 min intervals. Last event logged 09-Apr-2022 16:48	Changed temperature logging to 1 hour interval
20-Apr-2022	12:06	RFCasons	Data gap due full memory as logging for temperature was previously set to 1 min intervals. Last event logged 13-Apr-2022 03:30	Changed temperature logging to 1 hour interval
21-Apr-2022	12:54	RF01DP	Logger head corrupted. 1 day data gap due to troubleshooting	Reset logger values. Temperature logging changed to 1 hour interval
21-Apr-2022	14:06	MCCTR	Data gap due full memory as logging for temperature was previously set to 1 min intervals. Last event logged 29-Mar-2022 22:18	Changed temperature logging to 1 hour interval
15-Dec-2022	10:20	MCCTR	Data gap due to battery fully depleted. Last event logged 08-Nov-2022 06:02. Plant pathogens at PNP delayed site visit resulting in late discovery of fault	Changed battery
24-Jan-2023	13:30	MCCTR	Data gap due to battery fully depleted. Last event logged 09-Jan-2022 14:17	Replaced battery, noted battery was recently changed. Monitor battery levels after 1 week

Date	Time	Site	Discrepancy	Repair
03-Feb-2023	11:05	MCCTR	Checked battery levels – indicated 6% battery remaining	Removed rain gauge from site for repairs. Opened logger to air dry overnight. Applied silicon lubricant to O-ring and reconditioned desiccant pack, changed battery and reassembled logger to monitor battery levels overnight. Logger status indicated 36%. 16-Feb-2024 Rain gauge replaced until original unit repaired. 01-Jun-2024 Logger replaced, monitored and showed no issues.
09-Aug-2023	13:52	MCStitchesRidge	Battery fully depleted	Changed battery and monitored battery consumption after a few days. 18-Aug-2023 battery fully depleted again, rain gauge replaced.
05-Oct-2023	13:50	MCDepot	Equipment mounting post leaning due to equipment due to strong winds at location, rain gauge not logging all mist	13-Oct-2023 installed stays to stabilize against windy conditions
06-Dec-2023	11:34	MC01DP	Mist capture stringed harp assembly dismantling	Removed from site and re-strung with more durable line, placed back at site 08-Dec-2023
07-Dec-2023	10:54	MCDepot	Data logger's memory full due to amount of data logged, full capacity reached 14-Nov-2023	Launched and continued monitoring

AWS Sites

Date	Time	Site	Discrepancy	Repair
27-Oct-2021	01:30	The Peaks	MiFi router batteries fully depleted due to poor weather conditions	None. AWS back in service 04-Oct-2021
10-Nov-2021	00:00	Flagstaff	Fault with charging board in MiFi router	Installed replacement MiFi router, back in service 01-Jul-2022
20-Feb-2022	06:30	Boxwood Hill	MiFi router batteries fully depleted due to poor weather conditions	None. AWS back in service 05-Mar-2022
24-Jul-2022	23:00	The Peaks	Intermitting data outages from AWS up to end of Apr-2023. Complete loss of data from May-2023 due to fault with AWS ISS transmitter board	Replaced ISS Transmitter board, back in service 03-Oct-2023
31-Oct-2022	02:00	Horse Pasture	MiFi router batteries fully depleted due to poor weather conditions	None. AWS back in service 04-Nov-2022
25-Aug-2023	02:30	Sisters Walk	No data being transmitted from AWS, WiFi logger issue	Replaced WiFi logger, back in service 11-Oct-2023
11-Aug-2023	07:00	South West Point	No data being transmitted, MiFi router solar panel damaged due to strong winds	Replaced MiFi router solar panel, back in service 21-Aug-2023
02-Oct-2023	12:30	Flagstaff	No data being transmitted from AWS, WiFi logger issue	AWS has been removed from site due to damage from cattle in area
08-Nov-2023	20:00	The Peaks	No data being transmitted from AWS, WiFi logger issue	Need to arrange site visit to make repairs
11-Feb-2024	19:00	South West Point	No data being transmitted from AWS, WiFi logger issue	Replaced WiFi logger, back in service 26-Feb-2024
21-Feb-2024	08:30	Boxwood Hill	No data being transmitted from AWS, MiFi router issue	Need to arrange site visit to make repairs
23-Mar-2024	17:26	South West Point	No data being transmitted from AWS, WiFi logger issue	Need to arrange site visit to make repairs

Appendix 4: Water Balance

St Helena Water Catchment Areas

Sources: Connect Catchment GIS Shapefile
Saint Helena Government 50m contour Shapefile

Note: 1. Each catchment has been split into 3 sections: Above 690m, between 500m and 690m and below 500m elevation.
2. The catchment sub-divisions have been selected as mist + rain are expected to contribute to the water balance above 690m elevation.
3. Rainfall is expected to contribute to the water balance between 500m and 690m elevation based on literature review.
4. Rainfall below 500m is not expected to contribute to the water balance as the lilterature review has reported earlier studies showing evaporation exceeding recharge below 500m elevation.

Above 690m Elevation				**Between 500m and 690m Elevation**				**Below 500m Elevation**			
Catchment No.	**Catchment Name**	**Catchment Area (m^2)**	**Catchment Area (Km^2)**	**Catchment No.**	**Catchment Name**	**Catchment Area (m^2)**	**Catchment Area (Km^2)**	**Catchment No.**	**Catchment Name**	**Catchment Area (m^2)**	**Catchment Area (Km^2)**
20	Banks Valley	375.1	0.00	20	Banks Valley	372,939.5	0.37	20	Banks Valley	2,708,851.9	2.71
13a	Broad Gut	123,679.0	0.12	5	Breakneck Valley	226,578.4	0.23	5	Breakneck Valley	1,627,466.2	1.63
15	Deep Valley	152,672.7	0.15	13a	Broad Gut	1,486,528.9	1.49	13a	Broad Gut	4,537,192.0	4.54
17	Fishers Valley	190,204.1	0.19	15	Deep Valley	800,556.5	0.80	15	Deep Valley	2,370,166.2	2.37
7	Friars Valley	66,974.4	0.07	16a	Dry Gut	93,867.0	0.09	16a	Dry Gut	4,673,263.2	4.67
24	James Valley	291,328.3	0.29	17	Fishers Valley	2,192,532.4	2.19	17	Fishers Valley	7,911,585.6	7.91
8	Lemon Valley	233,958.2	0.23	7	Friars Valley	983,987.3	0.98	7	Friars Valley	1,226,981.7	1.23
12	Manati Bay Stream	5.5	0.00	24	James Valley	3,528,191.5	3.53	01-Apr	James Valley	3,376,946.6	3.38
10	Old Woman Valley	35,692.0	0.04	8	Lemon Valley	3,402,362.3	3.40	8	Lemon Valley	2,427,219.7	2.43
14	Powells Valley	24,242.1	0.02	12	Manati Bay Stream	756,257.4	0.76	12	Manati Bay Stream	1,870,097.4	1.87
13	Sandy Bay Gut	292,974.8	0.29	10	Old Woman Valley	1,293,765.1	1.29	10	Old Woman Valley	1,875,327.0	1.88
16	Sharks Valley	133,104.9	0.13	14	Powells Valley	577,873.7	0.58	14	Powells Valley	2,781,802.6	2.78
9	Swanley Valley	194,856.4	0.19	18	Ruperts Valley	1,064,442.5	1.06	18	Ruperts Valley	7,106,926.8	7.11
11	Thompsons Valley	27,048.8	0.03	13	Sandy Bay Gut	2,182,797.6	2.18	13	Sandy Bay Gut	5,122,567.5	5.12
Unspecified 15	Unspecified 15	785.7	0.00	16	Sharks Valley	1,490,817.6	1.49	16	Sharks Valley	4,075,764.1	4.08
Unspecified 7	Unspecified 7	2,520.2	0.00	9	Swanley Valley	1,221,145.1	1.22	9	Swanley Valley	1,471,298.6	1.47
				11	Thompsons Valley	2,087,721.8	2.09	11	Thompsons Valley	3,192,623.0	3.19
				19	Turks Cap Valley	1,417,761.3	1.42	19	Turks Cap Valley	7,307,172.3	7.31
				Unspecified 15	Unspecified 15	579,053.2	0.58	Unspecified 1	Unspecified 1	1,766,040.2	1.77
				Unspecified 18	Unspecified 18	556,087.8	0.56	Unspecified 10	Unspecified 10	526,821.1	0.53
				Unspecified 3	Unspecified 3	65,141.2	0.07	Unspecified 11	Unspecified 11	576,125.4	0.58
				Unspecified 5	Unspecified 5	290,422.7	0.29	Unspecified 12	Unspecified 12	227,962.3	0.23
				Unspecified 6	Unspecified 6	285,515.2	0.29	Unspecified 13	Unspecified 13	671,201.0	0.67
				Unspecified 7	Unspecified 7	157,821.50	0.16	Unspecified 14	Unspecified 14	193,361.6	0.19
				6	Youngs Valley	646,281.1	0.65	Unspecified 15	Unspecified 15	3,123,226.4	3.12
								Unspecified 16	Unspecified 16	2,332,823.5	2.33
								Unspecified 17	Unspecified 17	1,350,132.0	1.35
								Unspecified 18	Unspecified 18	3,758,141.8	3.76
								Unspecified 2	Unspecified 2	298,786.5	0.30
								Unspecified 3	Unspecified 3	1,952,966.3	1.95
								Unspecified 4	Unspecified 4	1,838,693.3	1.84
								Unspecified 5	Unspecified 5	4,368,054.1	4.37
								Unspecified 6	Unspecified 6	2,551,404.8	2.55
								Unspecified 7	Unspecified 7	1,370,593.5	1.37
								Unspecified 8	Unspecified 8	53,608.7	0.05
								Unspecified 9	Unspecified 9	47,647.1	0.05
								6	Youngs Valley	1,010,597.6	1.01

Water Balance D, Scenario 4 – Zone 1 Catchment Water Balance 2023

Catchment	Catchment Area (m^2)	Catchment Rainfall (m/a)	Catchment Mist (m/a)	PE (m)	Rainfall Recharge (m^3/a)	Recharge (mm/a)	Streamflow (m^3/a)	Connect Abstraction (m^3/a)	Surplus/Deficit (m^3/a)	Surplus/Deficit (mm/a)	Mist + Rain (m/a)	Catchment Mist as Proportion of Recharge (%)
James Valley	291,701.70	0.970	1.000	0.671	378,780.49	1,298.52			378,780.49	1,299	1.97	51%
Sandy Bay Gut	293,349.40	0.926	1.000	0.671	368,047.89	1,254.64			368,047.89	1,255	1.93	52%
Lemon Valley	234,265.70	0.867	1.000	0.671	280,242.69	1,196.26			280,242.69	1,196	1.87	54%
Fishers Valley	190,445.00	0.953	1.000	0.671	244,173.34	1,282.12	94,228.0	87,038.0	62,907.34	330	1.95	51%
Swanley Valley	195,114.40	0.783	1.000	0.671	216,898.92	1,111.65			216,898.92	1,112	1.78	56%
Deep Valley	152,865.20	0.887	1.000	0.671	185,952.87	1,216.45			185,952.87	1,216	1.89	53%
Sharks Valley	133,245.40	0.912	1.000	0.671	165,330.89	1,240.80			165,330.89	1,241	1.91	52%
Broad Gut	123,842.50	0.751	1.000	0.671	133,723.89	1,079.79			133,723.89	1,080	1.75	57%
Friars Valley	67,061.60	0.912	1.000	0.671	83,238.20	1,241.22			83,238.20	1,241	1.91	52%
Old Woman Valley	35,739.40	0.734	1.000	0.671	37,987.05	1,062.89			37,987.05	1,063	1.73	58%
Powells Valley	24,272.70	0.882	1.000	0.671	29,405.89	1,211.48			29,405.89	1,211	1.88	53%
Thompsons Valley	27,084.80	0.659	1.000	0.671	26,768.72	988.33			26,768.72	988	1.66	60%
Unspecified 7	2,535.60	0.627	1.000	0.671	2,422.77	955.50			2,422.77	956	1.63	61%
Unspecified 15	786.70	0.335	1.000	0.671	521.98	663.50			521.98	664	1.33	75%
Banks Valley	375.50	0.335	1.000	0.671	249.14	663.50			249.14	664	1.33	75%
					2,153,744.74			**Total Surplus/Deficit**	**1,972,478.74**		**Average**	**0.57**

Water Balance D, Scenario 4 – Zone 2 Catchment Water Balance 2023

Catchment	Catchment Area (m^2)	Catchment Rainfall (m/a)	Catchment Mist (m/a)	PE (m)	Rainfall Recharge (m^3/a)	Recharge (mm/a)	Streamflow (m^3/a)	Connect Abstraction (m^3/a)	Surplus/Defecit (m^3/a)	Surplus/Defecit (mm/a)
James Valley	3,532,719.00	0.884		0.671	751,656.62	212.77	90,054.0	65,593.0	596,009.62	169
Sandy Bay Gut	2,185,614.90	0.894		0.671	488,288.22	223.41			488,288.22	223
Lemon Valley	3,406,854.90	0.759		0.671	300,518.67	88.21		63,247.0	237,271.67	70
Fishers Valley	2,195,277.50	0.788		0.671	255,969.36	116.60	5,036.0	22,566.0	228,367.36	104
Sharks Valley	1,492,678.60	0.783		0.671	166,866.54	111.79			166,866.54	112
Friars Valley	985,272.00	0.826		0.671	153,081.71	155.37			153,081.71	155
Ruperts Valley	1,065,784.50	0.801		0.671	138,530.67	129.98			138,530.67	130
Youngs Valley	647,121.50	0.825		0.671	99,572.59	153.87			99,572.59	154
Powells Valley	578,603.00	0.795		0.671	71,677.34	123.88			71,677.34	124
Deep Valley	801,557.90	0.752		0.671	65,182.69	81.32	40,950.0	40,950.0	-16,717.31	-21
Swanley Valley	1,222,773.00	0.705		0.671	41,549.83	33.98			41,549.83	34
Old Woman Valley	1,295,499.10	0.696		0.671	32,633.62	25.19			32,633.62	25
Breakneck Valley	226,871.90	0.682		0.671	2,538.70	11.19			2,538.70	11
Dry Gut	93,983.00	0.690		0.671	1,811.05	19.27			1,811.05	19
Unspecified 4	15,354.30	0.755		0.671	1,295.44	84.37			1,295.44	84
Broad Gut	1,488,498.60	0.670		0.671	-833.56	-0.56			-833.56	-1
Unspecified 3	65,222.30	0.587		0.671	-5,466.28	-83.81			-5,466.28	-84
Unspecified 7	142,680.60	0.600		0.671	-10,146.02	-71.11			-10,146.02	-71
Unspecified 18	556,833.20	0.632		0.671	-21,666.38	-38.91			-21,666.38	-39
Unspecified 5	290,809.70	0.512		0.671	-46,157.32	-158.72			-46,157.32	-159
Unspecified 6	285,907.20	0.429		0.671	-69,203.84	-242.05			-69,203.84	-242
Turks Cap Valley	1,419,514.10	0.616		0.671	-77,477.08	-54.58			-77,477.08	-55
Manati Bay Stream	757,274.70	0.553		0.671	-89,131.23	-117.70			-89,131.23	-118
Banks Valley	373,403.40	0.350		0.671	-119,724.33	-320.63			-119,724.33	-321
Unspecified 15	579,758.40	0.363		0.671	-178,681.54	-308.20			-178,681.54	-308
Thompsons Valley	2,090,547.70	0.553		0.671	-246,182.90	-117.76			-246,182.90	-118
					1,706,502.58			**Total Surplus/Defecit**	**1,624,289.47**	

Water Balance D, Scenario 4 – Zone 3 Catchment Water Balance 2023

Catchment	Catchment Area (m^2)	Catchment Rainfall (m/a)	Catchment Mist (m/a)	PE (m)	Rainfall Recharge (m^3/a)	Recharge (mm/a)	Streamflow (m^3/a)	Connect Abstraction (m^3/a)	Surplus/Deficit (m^3/a)	Surplus/Deficit (mm/a)
Unspecified 9	47,710.10	0.418		0.976	-26,622.24	-558.00			-26,622.24	-558
Unspecified 8	53,679.90	0.455		0.976	-27,967.23	-521.00			-27,967.23	-521
Unspecified 14	193,608.80	0.225		0.976	-145,400.21	-751.00			-145,400.21	-751
Unspecified 12	228,256.60	0.267		0.976	-161,833.93	-709.00			-161,833.93	-709
Unspecified 2	299,140.90	0.274		0.976	-209,996.91	-702.00			-209,996.91	-702
Unspecified 10	527,512.20	0.445		0.976	-280,108.98	-531.00			-280,108.98	-531
Unspecified 11	576,873.80	0.377		0.976	-345,547.41	-599.00			-345,547.41	-599
Unspecified 13	672,056.30	0.263		0.976	-479,176.14	-713.00			-479,176.14	-713
Youngs Valley	1,011,921.80	0.589		0.976	-391,613.74	-387.00			-391,613.74	-387
Friars Valley	1,228,595.90	0.630		0.976	-425,094.18	-346.00			-425,094.18	-346
Unspecified 17	1,351,720.50	0.367		0.976	-823,197.78	-609.00			-823,197.78	-609
Unspecified 7	1,372,476.00	0.526		0.976	-617,614.20	-450.00			-617,614.20	-450
Swanley Valley	1,473,286.40	0.623		0.976	-520,070.10	-353.00			-520,070.10	-353
Breakneck Valley	1,629,582.50	0.531		0.976	-725,164.21	-445.00			-725,164.21	-445
Unspecified 1	1,768,169.20	0.302		0.976	-1,191,746.04	-674.00			-1,191,746.04	-674
Unspecified 4	1,841,027.90	0.609		0.976	-675,657.24	-367.00			-675,657.24	-367
Manati Bay Stream	1,872,619.20	0.512		0.976	-868,895.31	-464.00			-868,895.31	-464
Old Woman Valley	1,877,865.90	0.613		0.976	-681,665.32	-363.00			-681,665.32	-363
Unspecified 3	1,955,379.50	0.488		0.976	-954,225.20	-488.00			-954,225.20	-488
Unspecified 16	2,335,628.20	0.441		0.976	-1,249,561.09	-535.00			-1,249,561.09	-535
Deep Valley	2,373,087.70	0.540		0.976	-1,034,666.24	-436.00			-1,034,666.24	-436
Lemon Valley	2,430,440.00	0.629		0.976	-843,362.68	-347.00			-843,362.68	-347
Unspecified 6	2,554,937.50	0.403		0.976	-1,463,979.19	-573.00			-1,463,979.19	-573
Banks Valley	2,712,265.50	0.322		0.976	-1,773,821.64	-654.00			-1,773,821.64	-654
Powells Valley	2,785,309.40	0.686		0.976	-807,739.73	-290.00			-807,739.73	-290
Unspecified 15	3,127,058.70	0.335		0.976	-2,004,444.63	-641.00			-2,004,444.63	-641
Thompsons Valley	3,196,983.50	0.532		0.976	-1,419,460.67	-444.00			-1,419,460.67	-444
James Valley	3,381,289.40	0.682		0.976	-994,099.08	-294.00		48,916.0	-1,043,015.08	-308
Unspecified 18	3,763,213.40	0.533		0.976	-1,667,103.54	-443.00			-1,667,103.54	-443
Sharks Valley	4,080,737.90	0.498		0.976	-1,950,592.72	-478.00			-1,950,592.72	-478
Unspecified 5	4,373,845.00	0.477		0.976	-2,182,548.66	-499.00			-2,182,548.66	-499
Broad Gut	4,543,142.10	0.688		0.976	-1,308,424.92	-288.00			-1,308,424.92	-288
Dry Gut	4,678,875.00	0.427		0.976	-2,568,702.38	-549.00			-2,568,702.38	-549
Sandy Bay Gut	5,129,175.20	0.843		0.976	-682,180.30	-133.00	27,468.0		-709,648.30	-138
Ruperts Valley	7,115,929.20	0.630		0.976	-2,462,111.50	-346.00			-2,462,111.50	-346
Turks Cap Valley	7,316,126.60	0.527		0.976	-3,284,940.84	-449.00			-3,284,940.84	-449
Fishers Valley	7,921,167.00	0.654		0.976	-2,550,615.77	-322.00			-2,550,615.77	-322
							Total Surplus/Deficit	**-39,876,335.93**		