

Modelling the Long-term Salinization of the Cape Flats Aquifer in the Philippi Horticultural Area



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Abstract

For decades, the City of Cape Town relied heavily on groundwater as its primary source of supply for agricultural activity in the Phillipi Horticultural Area (PHA). Groundwater is extracted from boreholes, held in holding ponds, and then used for crop irrigation. The IPCC expects that semi-arid regions in the Southern Hemisphere will be the most affected by rising surface temperatures, decreased rainfall, and increased evaporation. This increase will put tremendous pressure on the quality and quantity of groundwater resources. This study hypothesizes that if groundwater and irrigation holding ponds are subjected to climate variability forces, groundwater and irrigation water salinity will increase. This study aims to develop a three-dimensional steady state model to estimate the extent to which irrigation-induced salinity affected groundwater in the past and present. Moreover, another aim is to assess how future climate change scenarios and increased groundwater abstraction may affect the salinity of Cape Flats Aquifer (CFA).

Groundwater levels and chloride concentrations were used to calibrate the groundwater flow and transport model for the past state and validate the model for the present state using MODFLOW and MT3D codes respectively. Then, a variable density model (SEAWAT) was used to delineate the freshwater-saltwater interface for past and present states. Thereafter, the validated model has been used to simulate the impacts of three projected Global Climate Models under Socioeconomic Pathways 245 and 585 (i.e. an average of long-term rainfall, predicted rainfall 2050-2060 and 2090 -2100) on groundwater recharge and groundwater solute concentrations. From the existing Global Climate models (HadGEM3-GC31-LL, AWI-CM-1-1-MR, BBC-CSM2-MR) under Shared Socioeconomic Pathway 245 and 585, one climate model, HadGEM3-GC31-LL, was selected to perform sensitivity analysis of abstraction scenarios.

The results of this study found that depth to water decreased from 18 to 16m from winter to summer in regions of the aquifer with clay lenses. Moreover, the chloride concentration is greater in the summer season compared to the winter season (e.g. Borehole EM-08) for most boreholes for both past and present state. As a result of summer irrigation more saline water has a higher chance of being recharged compared to winter where rainfall may act to dilute the aquifer. The HadGEM3-GC31-LL was selected as it is widely used in climate studies for weather generation for the future state. The results showed that the SSP245 (2050-2060) scenario had a slightly lower salinity (less than 10%) when compared with the SSP585 (2050-2060). Lower rainfall during SSP585 has led to a slight increase in salinity when compared to SSP245, probing the need to abstract more water and overall increasing irrigation return flow. Moreover, the seawater freshwater interface has encroached much further inland in the SSP585 scenario in comparison with the SSP245 scenario. This study is important to inform farmers to improve water management, especially if abstraction rates should be significantly higher in the future, on which crops to plant currently as most of the plants are sensitive to

moderately sensitive to salt. The farmers are advised to improve irrigation techniques and plant salt-resistant crops in future, especially under increased abstraction scenarios. The municipality is advised to monitor the water quality of the Cape Flats Aquifer as the municipality plans to augment the domestic water supply during time of low rainfall.

1. Introduction and Project Aims

The Philippi Horticultural Area (PHA) has been farmed for more than a century, and crops rely significantly on groundwater from the Cape Flats Aquifer (CFA) for irrigation, particularly during the summer. Boreholes were drilled, and water was pumped from the aquifer into unlined storage ponds where it is exposed to atmospheric conditions and evaporation, which increases the concentration of chemical elements present in the ponds. Irrigation return flows leads to increased salinity of groundwater recharge. The unlined dams in the PHA are a potential source of groundwater recharge to the CFA, which may increase salinity. Groundwater salinization occurs as a result of this positive feedback process, where pumped saline groundwater stored in unlined holding ponds, is the source of groundwater recharge.

Forecasted climate variability (increased temperature and decreased rainfall) could accelerate the salinization process by reducing the much-needed rainfall recharge, which serves to dilute dissolved solutes in groundwater during winter precipitation. Furthermore, growing water demand in the PHA due to increased population may apply pressure on groundwater resources due to increased demand for municipal supply. To ensure that the aquifer serves as a sustainable source of freshwater for Cape Town, predictive numerical modeling is required to simulate the effects of climate change, groundwater abstraction and irrigation.

The research questions for the study are:

1. To what extent does climate variability impact groundwater level for the CFA?
2. To which extent will increased abstraction rates, efficient irrigation practices and seawater intrusion affect future salt concentrations in the CFA in the PHA?

The hypothesis of the research is that if persistent crop irrigation increases, coupled with climate change and unsustainable groundwater abstraction, then the likelihood of groundwater salinization is higher.

The objectives of the study are the following:

1. To characterize the aquifer and develop a conceptual model of the groundwater flow using GIS techniques.
2. To calibrate a groundwater flow and mass transport model to estimate the water and salt balance for PHA using MODFLOW-2005 and MT3D.
3. To analyse the impact of projected climate change scenarios and increased abstraction on groundwater level and salt concentration using MODFLOW-2005 and MT3D.
4. To analyse the risk of seawater movement in the groundwater system of PHA, by evaluating seawater intrusion modelling results.

2. Methodological Approach

Among the saturated flow and transport models available in the literature, MODFLOW-2005 was deemed appropriate for use in this study. MODFLOW-2005 is a three-dimensional groundwater flow model (McDonald & Harbaugh, 1988). It simulates groundwater flow inside a user-defined domain (Figure 1). It is a fully distributed model that calculates groundwater flow using aquifer properties. It solves the three-dimensional groundwater flow problem with finite-difference approximations. The finite-difference approach needs the aquifer to be partitioned into cells, with the assumption that aquifer parameters are uniform within each cell. MODFLOW-2005 is intended to mimic aquifer systems in which saturated flow conditions prevail and Darcy's Law applies.

Mass transport was simulated using MT3D. MT3D is a model code for groundwater contaminant and solute transport that simulates advection, dispersion, dual-domain mass transfer, and chemical interactions of dissolved constituents (Zheng and Wang, 1999; Zheng et al., 2001). The mathematical model SEAWAT for 3-D variable density flow was used to simulate seawater intrusion (Langevin et al., 2003). This integrated package, which combines MODFLOW, MT3D, and SEAWAT, was used with the common graphical user interface Model Muse (Winston, 2009), enabling for the creation of complicated geographic models and visual control of input and output data. The methodological approach for developing the model is shown in Figure 2.

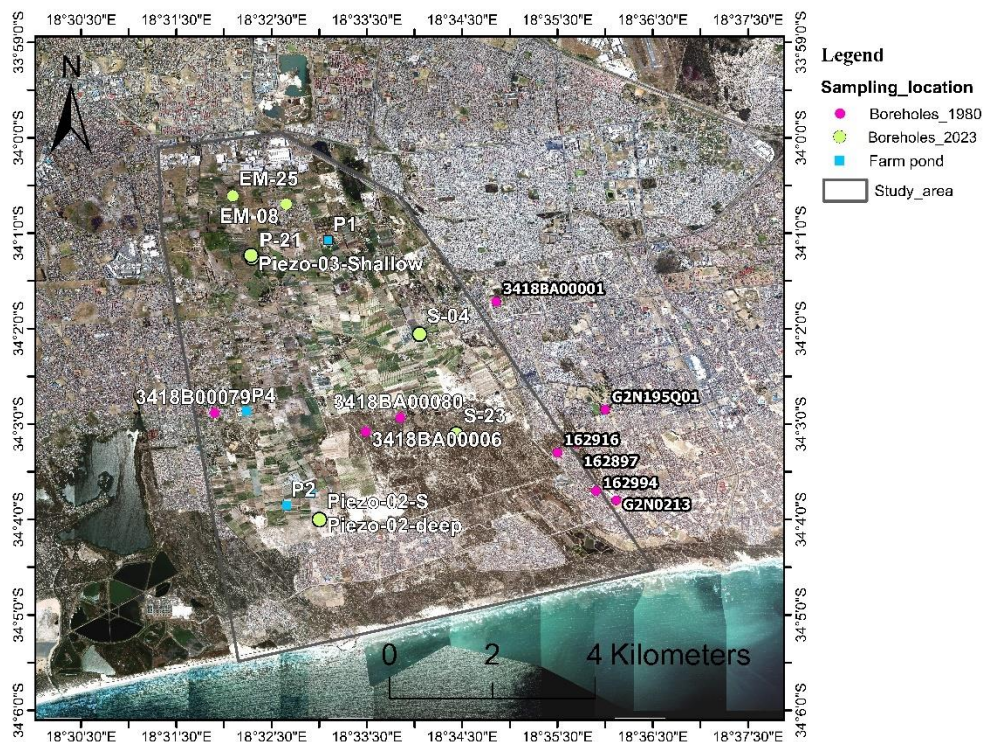


Figure 1: Map of the study area with the model domain outlined. Historic monitoring boreholes and location of groundwater sampling boreholes and surface water sampling points in the Philippi Horticultural Area.

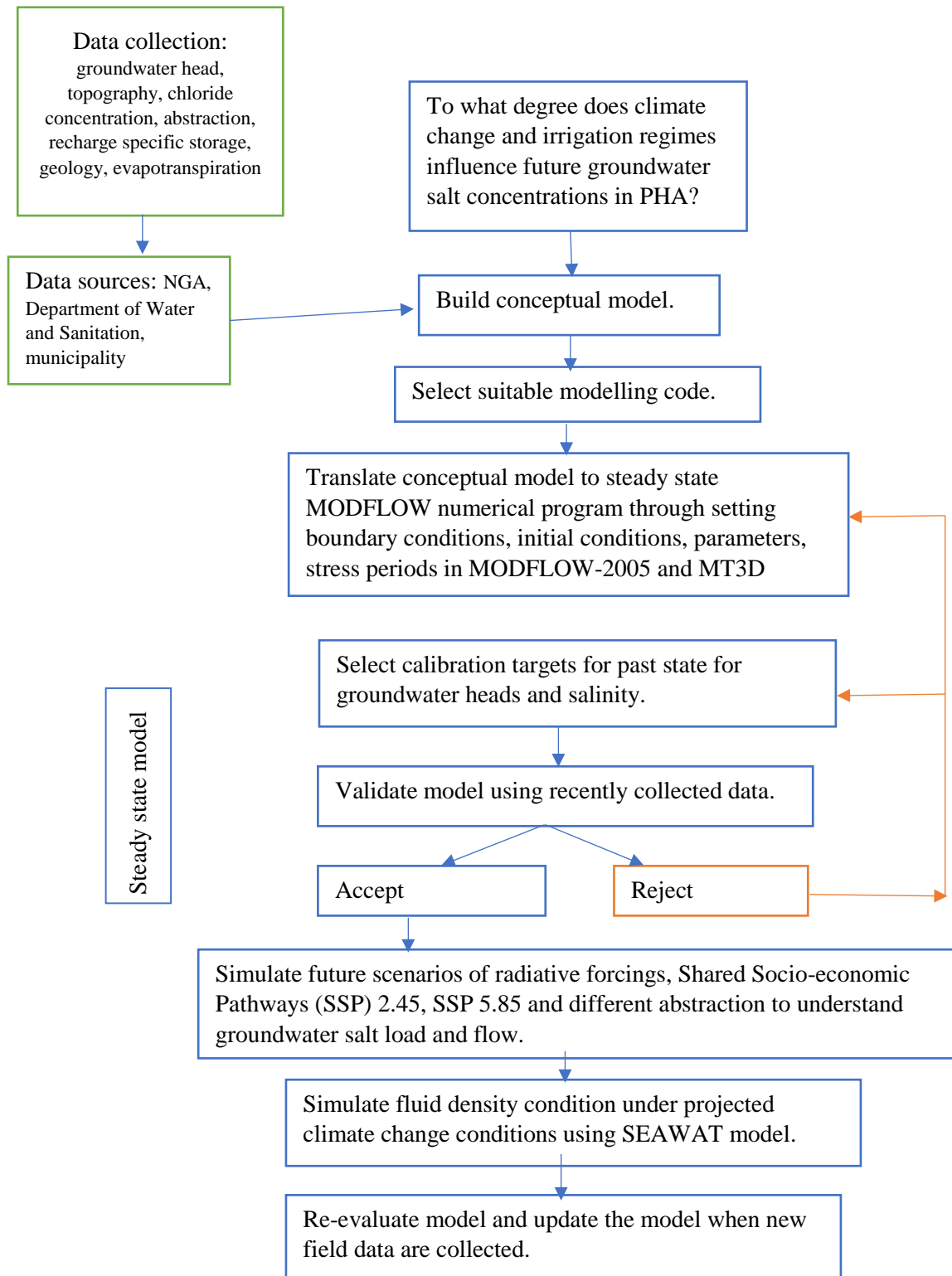


Figure 2: Flow diagram for the methodological approach, used to calibrate the numerical groundwater model.

3. Results and Discussion

Hydrochemical Characterization

Figure 3 illustrates the spatial distribution of chloride (a and b) and TDS (c and d) for the PHA for the past state. In the north-eastern region of the study area, the average chloride concentration is above 400 mg/l and exceeds drinking limits (SANS 241, 2011) and crops area at risk of chloride accumulation in soils (DWAF, 1996). The results show that the southern portion of the study area has low measured chloride and TDS concentrations which suggests recently recharged groundwater. In comparison, areas with low recharge that are located in the northern regions of the aquifer, where clay lenses may be found, leading to the dissolution of minerals present in the impermeable layers, providing longer residence times and the addition of chemical elements. Hence, it can be seen in Figure 3 that areas with high chloride also have high TDS. Therefore, areas experiencing high recharge are less susceptible to contamination. Measured groundwater aluminium and iron concentrations exceeded the maximum allowed limits at borehole Piezo-2-shallow. The aluminium concentration was reported to be 13.092 mg/l and the SANS limit is 5 mg/l. The aluminium concentration was the highest at Piezo-2-shallow due to the acidic nature of the measured groundwater (pH = 4.9), which enhances the mobilization of aluminium. Elevated concentrations of groundwater iron are a major threat to irrigation equipment and crop health. The other parameters that were analysed meet drinking and irrigation guidelines (SANS 241, 2011; DWAF, 1996).

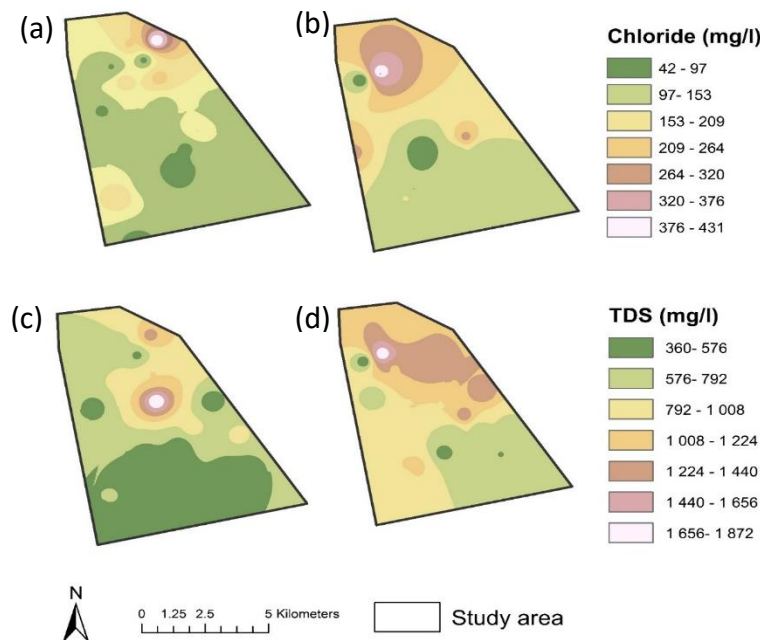


Figure 3: Water chemistry distribution of chloride for (a) winter, (b) summer and total dissolved solids (TDS) for (c) winter and (d) summer. Data were obtained from DWS (2008) for the past state.

The tri-linear piper diagram (Figure 4) shows that most of the ponds and groundwater samples collected during August 2023-April 2024 fall within mixed calcium-sulphate and sodium-chloride type water. Pond 1, Piezo-3-shallow and EM08 are predominantly Na-Cl water type and have a slightly higher salinity compared to the rest of the site. Comparing the different time periods shows that the dominant anions and cations have diversified within the study area. The groundwater and surface water samples demonstrated 2 distinct groups of water types namely NaHCO_3 type and Na-Cl type. Sampling also suggests that samples S-04 and Piezo-2-Shallow demonstrate sulphate enrichment at the site and ion exchange processes between Ca and Na. Furthermore, cation exchange and carbonate dissolution may have caused water to evolve to Ca^{2+} - Cl^- type waters. The Ca^{2+} - Cl^- type waters may have originated from the dissolution of calcite, dolomite, gypsum or halite. Furthermore, hard water that are characterized by Ca^{2+} and Cl^- ions may be due to infiltration of concentrated saline surface waters resulting from evaporation. As seen in Figure 4, some boreholes had a Ca^{2+} - Na^{2+} - HCO_3^- - Cl^- type water and graded towards Ca- SO_4 which indicates the dissolution of evaporitic soil or rocks that originate from salts or gypsum.

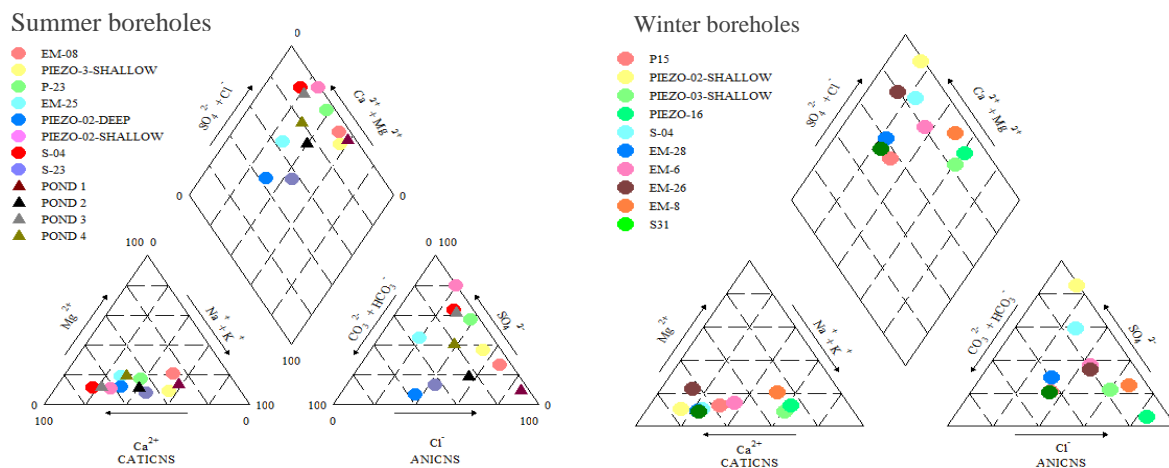


Figure 4: Piper diagram of water quality facies for samples collected in Philippi for the dry season (February 2024) and wet season (August 2023).

Groundwater modelling - past and present state

A groundwater flow model and solute transport model was developed in MODFLOW-2005 to simulate the movement of groundwater in the Philippi region of the Cape Flats Aquifer. The past groundwater data were used to calibrate the model, the present data were used to validate the model and then climate change scenarios were used to model the impact of future climate change on groundwater. The model was used to determine the movement of water and chloride in the aquifer. It was run in steady-state mode with two stress periods (winter and summer) to account for seasonality. Different abstraction rates were used to assess the sensitivity of the model.

The groundwater flow model indicates that groundwater flows from the higher head in the north toward the lower head in the south (the ocean) (Figure 5). In the past simulation (1983), a greater head occurred in the south as greater groundwater volumes were being discharged compared to the present state; this is because there was less abstraction in the past compared to the present state.

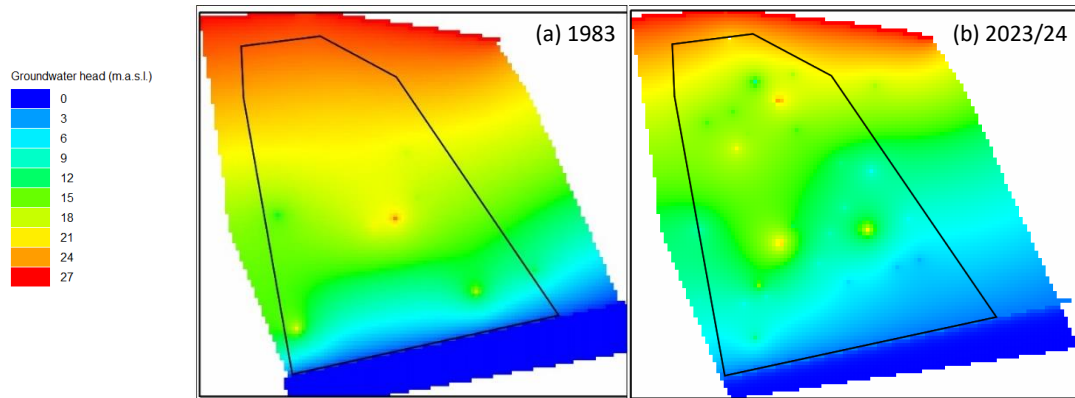


Figure 5: Groundwater heads for (a) past state 1983 and (b) present state 2023.

Chloride concentrations were used as a proxy for salinity, due to its conservative and non-reactive nature, and because Na-Cl is the dominant salt in the study area. The simulation of groundwater chloride movement has shown that the chloride concentrations in the past are less than the chloride concentrations in the present state. The limitation of the chloride concentrations is that limited data was available for the past. The chloride concentrations for the present state (Figure 6 e-i) show that with an increase in groundwater abstraction there is greater advection (transport of chloride by groundwater flow) with increased abstraction. Most regions of Philippi were simulated to have acceptable chloride concentrations, that fall within water quality guidelines for drinking water of 300 mg/l (SANS241). However, in the northern region of the study area, concentrations greater than 300 mg/l are present due to the clay lenses beneath the surface. These clay lenses slow down the movement of water and salts, which tends to accumulate salts in the soil. The assumption in the model was that, when abstracted groundwater gets stored in ponds, which further concentrates the water and is then used to irrigate adjacent crops, groundwater is recharged with more saline water. Furthermore, during winter there is less opportunity for salts that are stored in the regions of clay to be diluted. Hence, lower recharge occurs in the northern regions of the study area (where clay lenses are present) and higher chloride concentrations are found. Different abstraction scenarios were performed to see how different abstraction rates impact chloride concentrations in the MT3D for the past and present and results are presented in Figure 6. The higher the abstraction rate the greater the diffusion of salts when comparing visualisation of chloride in Figure 6.e. and Figure 6.i. Chloride moves from regions with high chloride to regions with low chloride within the groundwater system.

The groundwater discharge from inland regions to the ocean has decreased with more groundwater being abstracted. The Philippi area is a coastal zone and the net water (inflow water - outflow water) of the model has shown that it is in a deficit. Meaning water flowing out of the Cape Flats Aquifer in Philippi is greater than the water flowing into the aquifer system. Hence, with increase in abstraction, the hydraulic pressure of the freshwater that discharges into the ocean becomes less. This can cause seawater intrusion. As seen in Figure 7, seawater-freshwater interface is illustrated, with the freshwater to the north and the saline water indicated to the south. Figure 7 shows that, with increased abstraction rates, there is less energy exerted by the freshwater volumes to the seawater volume and seawater intrusion occurs. This is because groundwater flows through a porous subsurface and groundwater ensures that enough hydraulic energy is exerted to allow seawater not to intrude. However, when abstraction exceeds the recharge to the groundwater, the groundwater levels drop, groundwater storage becomes less and then less hydraulic energy is exerted to prevent seawater intrusion. However, as indicated by the side view of past (Figure 7) and present abstraction rates (Figure 8), there is seawater interface moving inland. The freshwater-saltwater interface will progress at certain distances into the aquifer, due to salt water density being greater than freshwater density. Therefore, abstraction rate of 45% above present, without any additional recharge (i.e. managed aquifer recharge), was simulated to cause seawater intrusion beyond the coast and into the Cape Flats Aquifer (Figure 7.d. and Figure 8.d.).

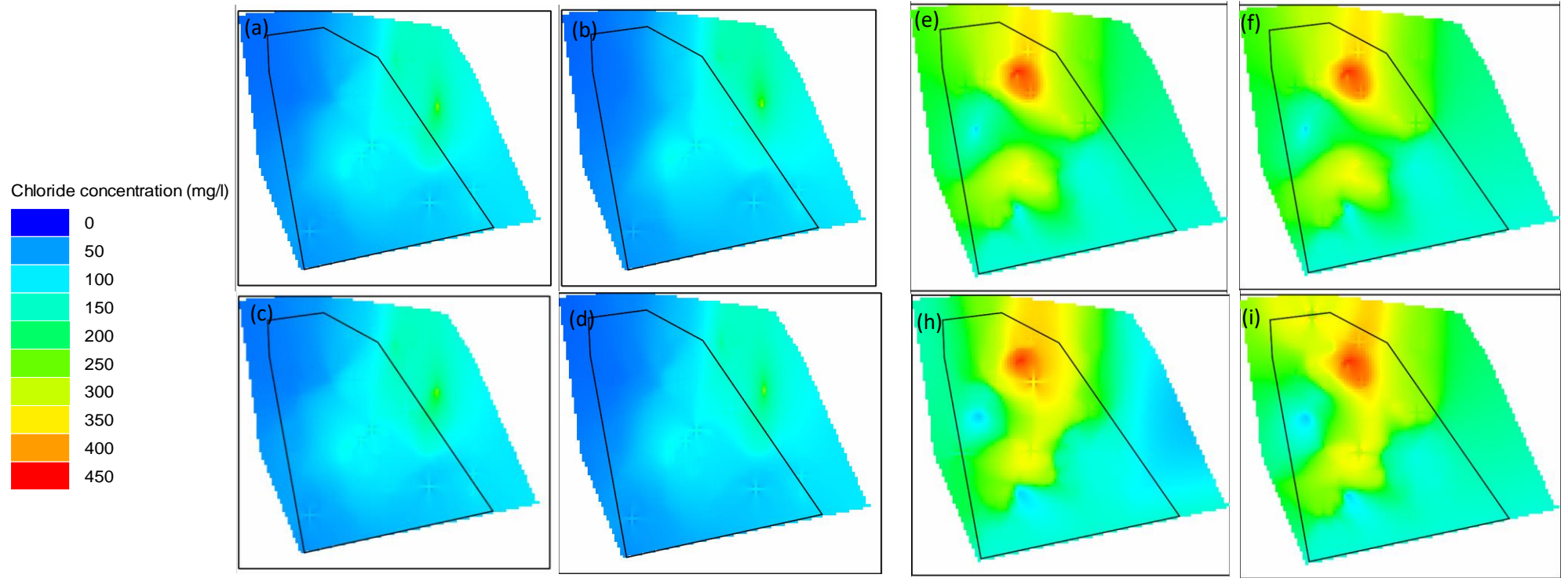


Figure 6: Visualisation of chloride concentrations for (a) past state baseline abstraction rate and an increase in abstraction by (b) 15%, (c) 30% and (d) 45%; (e) present state baseline scenario and increased in current abstraction by (f) 15%, (g) 30% and (h) 45%. High concentrations are presented in red and grades towards lower concentrations represented by blue.

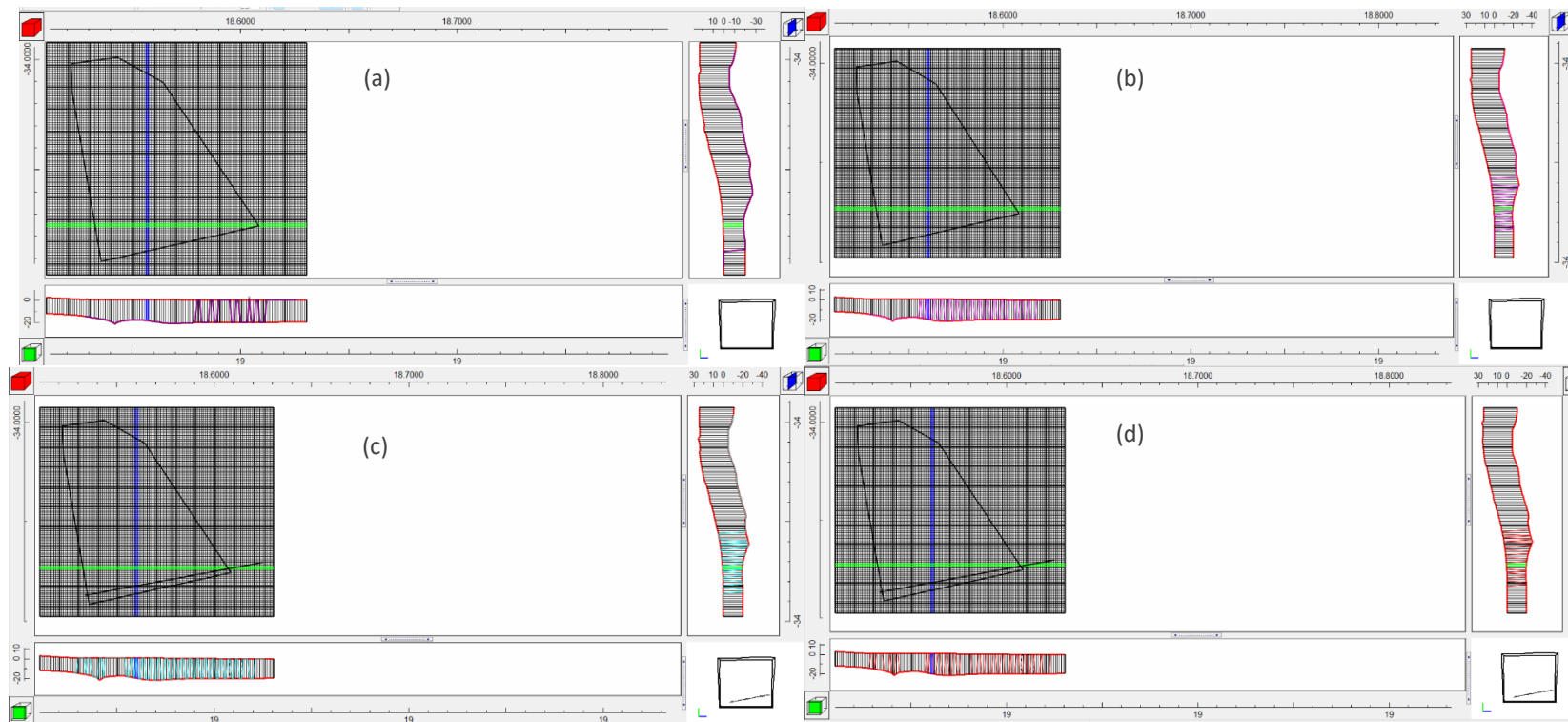


Figure 1: Display of SEAWAT simulation for the past state (1983), with model views from the top, side and front. The seawater results refer to data from 1983 and for the following groundwater abstraction scenarios: (a) baseline; (b) increased abstraction by 15%; (c) increased abstraction by 30%; and (d) increased abstraction by 45%. The front view represents the cross-section depicted with the green line in the top view. The side view represents the cross-section depicted with the blue line in the top view. The side view shows the distance of seawater intrusion from the coastline for the different abstraction scenarios.

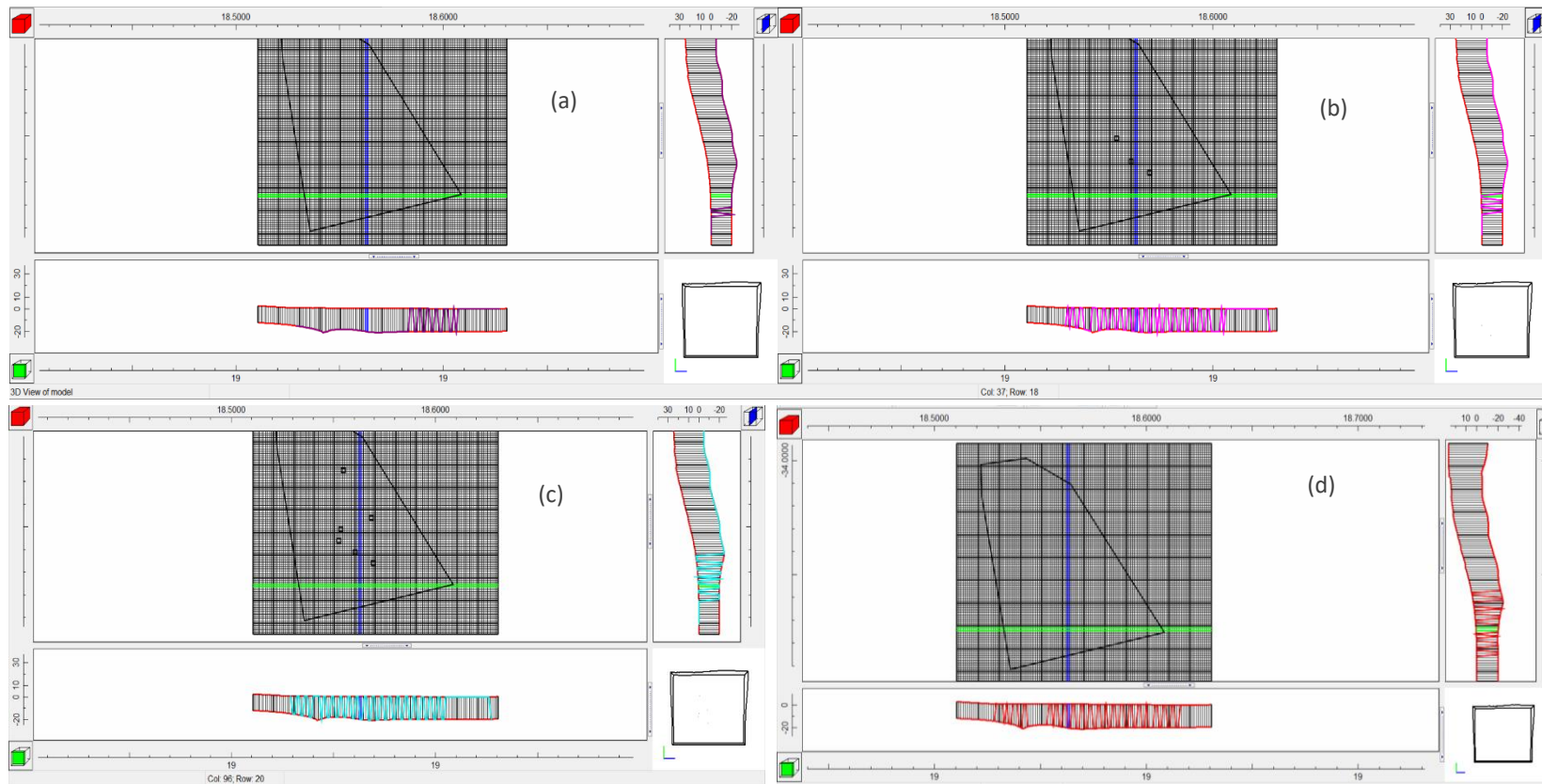


Figure 8: Display of SEAWAT simulation for the present state (2023/24), with model views from the top, side and front. The seawater results refer to data from 1983 and for the following groundwater abstraction scenarios: (a) baseline; (b) increased abstraction by 15%; (c) increased abstraction by 30%; and (d) increased abstraction by 45%. The front view represents the cross-section depicted with the green line in the top view. The side view represents the cross-section depicted with the blue line in the top view. The side view shows the distance of seawater intrusion from the coastline for the different abstraction scenarios.

Future state simulation results

To increase the reliability of simulating climate projections, 3 climate models under SSP245 and SSP585 were used to assess the impact of climate change on groundwater flow and solute transport. For each SSP scenario, 6 Global Climate Model projections were generated with HadGEM3-GC31-LL (for years 2050-2060 and 2090-2100) and they were applied to estimate groundwater recharge. Groundwater recharge was then used as input into the validated groundwater flow model for PHA. For each climate model condition, groundwater recharge was estimated for two stress periods (winter and summer). These scenarios were then simulated under steady-state conditions using MODFLOW-2005 and then MT3D code to produce concentrations for the salt balance, thereafter results of the saltwater-freshwater interface were created using SEAWAT.

The groundwater discharge from inland regions to the ocean decreased with more groundwater being abstracted. The Philippi area is a coastal zone and the net water (inflow water - outflow water) of the model has shown that it is in a deficit, meaning that water flowing out of the Cape Flats Aquifer in Philippi is greater than the water flowing into the aquifer system. Hence, with increase in abstraction, the hydraulic pressure of the freshwater that discharges into the ocean becomes less. This can cause seawater intrusion. Moreover, the aquifer hydraulic conductivity along the coast is high compared to inland areas, thanks to sand and shells in the geology, through which water travels easily. This allows for more freshwater to discharge and maintain that freshwater barrier. However, under future climate change conditions, SSP245 (best case scenario with decreased carbon emissions) and SSP585 (worst case scenario with increased carbon emissions) were simulated. The model results show that under SSP245 the hydraulic gradient will be maintained, and there is no increase in seawater intrusion under baseline (current) abstraction rates for the year 2050-2060. However, with increased abstraction, as seen in Figure 9, the salinity concentrations increase above that of the current state, especially in the northern region of the PHA where clay lenses are found. These clay lenses have low hydraulic conductivity and restrict the movement of salts, where groundwater that is abstracted will increase the salinity and chloride concentration and the crops may also have to endure increased salinity in the soil. The corresponding simulations with SEAWAT for seawater intrusion are shown in Figure 10.

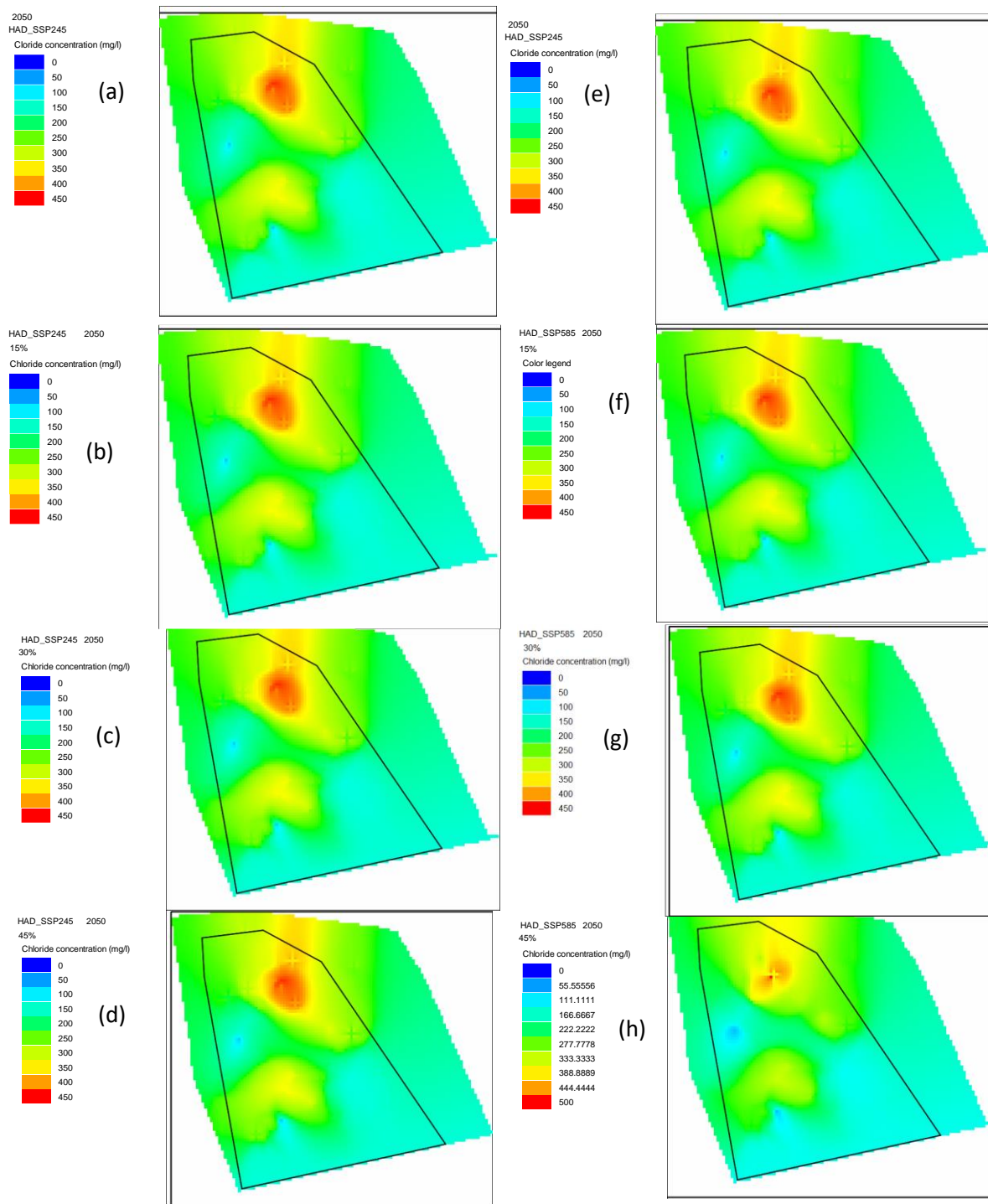


Figure 9: Solute concentrations in the sensitivity analysis for HAD-GEM3-GC31-LL model for the year 2050-2060, where a - d is the SSP245 scenario and e - h the SSP585 scenario. Furthermore, sensitivity analysis was conducted for (a) and (e) under the current abstraction scenario, (b-f) increase the current abstraction by 15%, (c-g) increase the current rate by 30% and (d-h) increase the current rate by 45%.

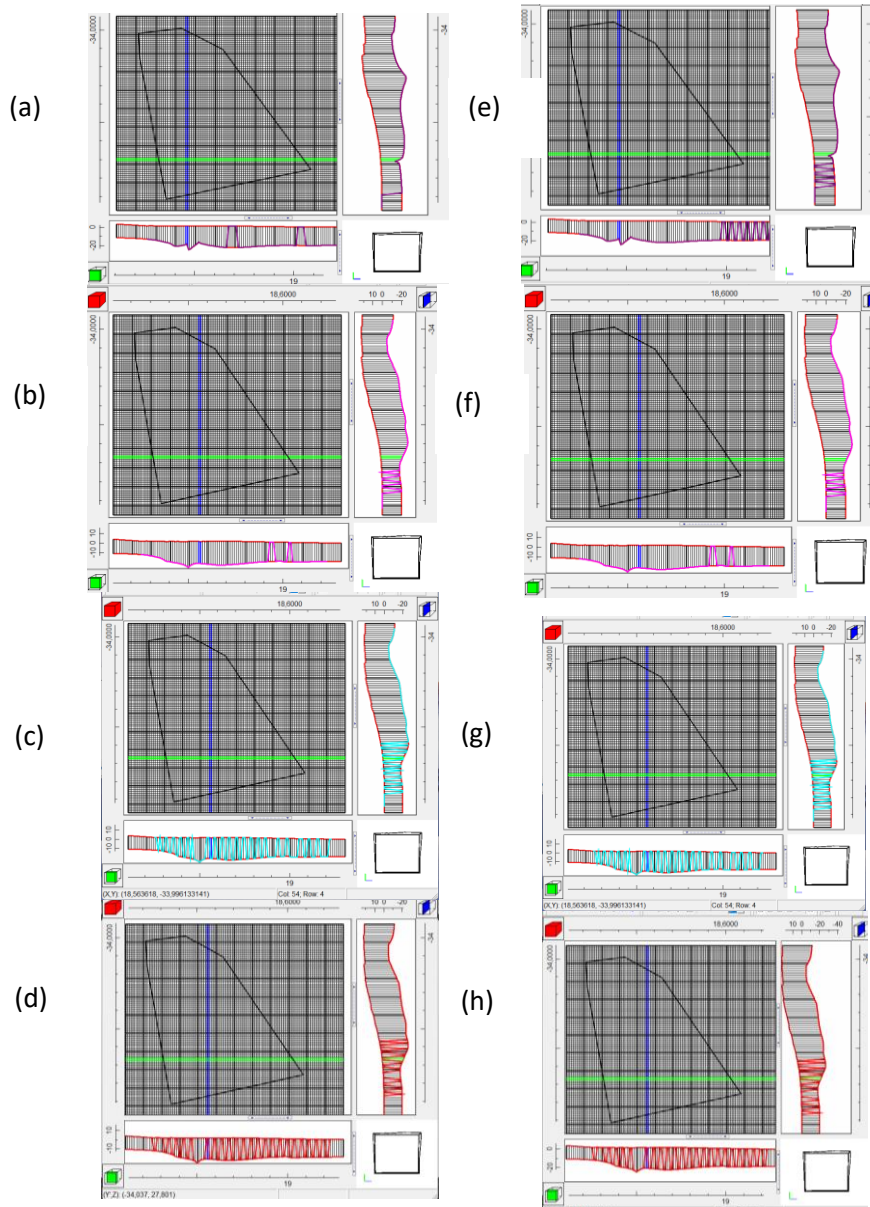


Figure 10: Change in freshwater-seawater interface for climate scenarios generated with the HadGEM3-GC31-LL model under SSP245: (a) baseline conditions, and increased abstraction by (b) 15%, (c) 30% and (d) 45%; climate scenarios generated with HadGEM3-GC31-LL under SSP585: (e) baseline conditions, increased abstraction by (f) 15%, (g) 30% and (h) 45%. The front view represents the cross-section depicted with the green line in the top view. The side view represents the cross-section depicted with the blue line in the top view. The side view shows the distance of seawater intrusion from the coastline for the different abstraction scenarios.

4. Conclusion and recommendations

In this study, the movement of groundwater and chloride movement in the agricultural region of PHA in CFA were investigated for the past, present and future state. Moreover, the seawater-freshwater interface was estimated to determine if seawater intrudes into the aquifer. Climate change scenarios were used to assess the response of water balance, salt balance and freshwater-seawater interface to the different recharge triggered by climate change.

Based on the results, there is an overall increase in groundwater salinity with an increase in abstraction. Due to the natural movement of water flow in the porous media, salts are transported by advection, which is the bulk movement of chloride salts by water. The regions in the north (where clay lenses are present) allow for the accumulation of salts, especially during the summer season, when there is less recharge from precipitation. Similarly, during winter, there is greater recharge, and this allows for dilution processes to decrease the chloride concentration. With increased abstraction, there is less water remaining in storage and less dilution. Moreover, with increased abstraction, there is less groundwater discharge to the ocean. Denser seawater will tend to intrude at lower elevations below the freshwater. From the future state simulations, under SSP585, where greater carbon emissions occur, there will be greater variability in rainfall and a slight increase in groundwater salinity, in northern regions of the PHA. Hence, under future drought conditions, there may be less recharge and more abstraction. The municipality should ensure to plan for excess abstraction and replenishment of groundwater for both municipal, farming and other sectors that rely on groundwater.

The results from this study can help to better identify regions, such as the northern region in the PHA, to adopt salt-tolerant crops. The utilization of salt-tolerant crops may also increase crop yields, food quality and overall sustainability should salinization occur in the future. The farming community may consider water management strategies such as precision and sustainable irrigation that are applied to crops based on their specific needs, to prevent poor irrigation-related salinization in regions with clay layers. High TDS and salinity in water may be remedied by distillation or chemical separation technologies, however the purification associated with these technologies is expensive, and uneconomical for irrigation use. The reason for this is that Philippi remains an important part of food security, employment and contributes to the local economy of the City of Cape Town. Hence, the groundwater use should be sustainably managed, not to excessively abstract it, and cause seawater to move into the aquifer.

Groundwater is a strategic source for water use and management especially for ensuring food security in the City of Cape Town in times of projected climate variability. Unregulated pumping may affect groundwater storage and cause drawdown and salinization of the Cape Flats Aquifer, as recharge will not be sufficient to replenish the aquifer. A transient model that will incorporate the recent implementation of managed aquifer recharge, in combination with climate change conditions, is needed to sustainably estimate the water and solute balance in the Cape Flats Aquifer for the future. Future studies should estimate the influence of sea level rise on groundwater intrusion in the Cape Flats Aquifer. This research supports the motivation

for managed aquifer recharge to supplement the recharge into the groundwater system and prevention of seawater intrusion. Hence, groundwater can be used as an alternative supply during times of drought, only when groundwater recharge is supplemented by managed aquifer recharge. The municipality has to ensure continuous monitoring of groundwater close to the coast to prevent the upwelling of seawater or inland movement of seawater into the Cape Flats Aquifer. Monitoring of groundwater quality ensures the sustainability of the aquifer and prevention of saltwater intrusion into the aquifer. Water resource managers could better plan for future demand exceeding supply by implementing more managed aquifer recharge schemes should groundwater levels decline below critical levels to halt seawater intrusion.

5. Budget

The budget was used to buy bottles, a cooler box, bailers and gloves for collecting samples, a total of R2488. This equipment was used together with equipment from the University of the Western Cape for sampling in Philippi Horticultural Area in August 2023, February 2024 and June 2024. The samples were sent for analysis at CAF-BIOGRIP laboratory for trace elements, major ion and cation analysis and together the water chemistry analysis costed R41,988.85. The report writing and stationary costed R 11,740.80. The research assistant cost of R10,000 has been used for doing research on salinity and modelling that have been used to create the model. The report writing budget has been used to prepare, edit documents and office expenses to assist in writing the reports (Table 1).

Table 1: Budget for the project.

	Detailed description of budget line item	Amount	Expenditure
a.	Research assistants' fieldwork cost, including travel costs for sampling	R10 000	R10 000
R	Sampling (60 bottles, sample analysis, collection in winter and summer, vehicle, petrol)	R68 000	R41 988.85
c.	Interim Report preparation, editing, printing and office expenses	R6 000	R6 000
d.	Final Report preparation, editing, printing and office expenses	R6 000	R5 740.80
	TOTAL	R90 000	R26 720.35

6. References

- Anderson, M. P., Woessner, W. W., & Hunt, R. J. (2015). *Applied groundwater modeling: simulation of flow and advective transport*. Academic press.
- Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Irrigation.
- Department of Water Affairs and Forestry, South Africa. 2008. The Assessment of Water Availability in the Berg Catchment (WMA 19) by means of Water Resource Related Models : Groundwater Model Report Volume 5 – Cape Flats Aquifer Model. Prepared by Umvoto Africa (Pty) Ltd in association with Ninham Shand (Pty) Ltd on behalf of the Directorate : National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0408
- FAO. 2020. WaPOR database methodology: Version 2 release. 2020. Rome. Available from: <https://doi.org/10.4060/ca9894en>
- McDonald, M.G. and Harbaugh, A.W., 1988. *A modular three-dimensional finite-difference ground-water flow model*. US Geological Survey.
- SANS, South African National Standards 241–1 (2015) Drinking water. Part 1: microbiological, physical, aesthetic and chemical determinands. 2nd ed. Pretoria. SABS

Appendix 1: Water chemistry results for Philippi Horticultural Area. Values below detection level are indicated as not detected (n.d.).

Date	Borehole name	latitude	longitude	EC (µS/cm)	pH	TDS (ppm)	F (mg/l)	Cl (mg/L)	SO4 (mg/L)	PO4 (mg/L)	NO2 (mg/L)	Br (mg/L)	NO3 (mg/L)	Na (mg/L)	NH4 (mg/L)	K (mg/L)	Mg (mg/L)
2023/08/11	EM-08	-34.0116	18.5442	1297.0	6.025	648.5	n.d	313.482	144.899	n.d	n.d	1.037	4.184	138.919	0.797	27.128	28.919
2023/08/11	PIEZO-3 shallow	-34.0205	18.5381	1848.0	6.793	924.0	0.317	315.877	310.353	n.d	n.d	1.126	2.54	151.501	n.d.	47.481	27.512
2023/08/11	P-21	-34.021	18.5382	3806.0	6.587	1903.0	n.d	795.921	1013.576	n.d	n.d	2.478	n.d	436.754	2.747	19.107	94.91
2023/08/11	EM-25	-34.01	18.5348	659.8	6.517	329.9	n.d	80.768	50.511	n.d	n.d	0.345	1.877	62.557	0.05	2.046	6.968
2023/08/11	PIEZO-02-Deep	-34.0667	18.55	721.4	7.189	360.7	0.074	83.402	8.612	0.375	n.d	0.27	n.d	47.812	0.205	2.423	10.408
2023/08/11	PIEZO-02-Shallow	-34.0667	18.55	1217.0	7.049	608.5	0.101	145.89	172.834	n.d	n.d	0.83	n.d	76.13	0.903	7.347	21.918
2023/08/11	S-04	-34.0343	18.5676	2632.0	6.650	1316.0	n.d	318.189	899.485	n.d	0.697	1.463	30.968	144.322	n.d.	79.328	40.628
2023/08/11	S-23	-34.0517	18.574	1024.0	7.276	512.0	0.125	133.037	68.503	n.d	0.348	0.479	0.179	70.057	0.269	3.507	14.781
2023/08/11	Pond 1	-34.0131	18.5547	1805.0	6.557	902.5	n.d	443.887	138.661	1.852	0.564	1.292	35.998	208.31	2.86	32.079	32.468
2023/08/11	Pond 2	-34.0691	18.546	1702.0	7.186	851.0	n.d	265.859	319.317	0.695	n.d	1.658	n.d	132.466	2.267	23.271	32.995
2023/08/11	Pond 3	-34.0622	18.5486	1760.0	7.283	880.0	n.d	332.769	335.459	n.d	n.d	1.355	2.545	164.07	n.d.	20.256	38.193
2024/02/01	Pond 4	-34.0474	18.5376	1050.0	7.411	525.0	0.107	163.647	86.345	0.331	1.329	0.564	47.874	76.234	n.d.	21.081	17.559
2024/02/01	EM-08	-34.0116	18.5442	1542.0	5.73	771	n.d	389.423	203.251	n.d	n.d	1.383	n.d	158.516	2.847	30.643	36.32
2024/02/01	PIEZO-3 shallow	-34.0205	18.5381	1305.0	5.82	653	0.304	249.159	224.252	n.d	n.d	1.406	0.355	131.175	1.768	38.175	12.448
2024/02/01	P-23	-34.0222	18.5386	4252.0	6.26	2126	n.d	798.441	1576.63	n.d	n.d	2.484	n.d	435.081	3.105	36.88	106.348
2024/02/01	EM-25	-34.01	18.5348	864.8	6.77	432	0.067	58.97	176.414	n.d	n.d	0.397	7.58	40.321	0.128	7.232	21.21
2024/02/01	PIEZO-02-Deep	-34.0667	18.55	772.3	7.35	386	0.070	92.127	22.627	n.d	n.d	0.285		52.849	0.588	2.331	11.977
2024/02/01	PIEZO-02-Shallow	-34.0667	18.55	1471.0	4.42	736	0.099	140.588	747.388	n.d	n.d	0.549	9.457	72.051	3.346	7.693	15.419
2024/02/01	S-04	-34.0343	18.5676	3440.0	6.77	1720	n.d	473.118	1484.271	n.d	n.d	1.514	2.625	166.692	0.822	128.175	53.646
2024/02/01	S-23	-34.0517	18.574	1046.0	7.43	523	0.119	167.164	66.221	n.d	n.d	0.453	0.432	58.767	0.962	2.928	12.422
2024/02/01	PIEZO-16	-34.0156	18.5378	4871.0	7.39	2436	n.d	1861.2	137.021	n.d	n.d	4.218	1.707	702.825	n.d.	8.965	73.954
2024/02/01	EM-36	-34.0187	18.5372	2546.0	7.02	1273	n.d	474.016	580.061	n.d	n.d	1.572	0.387	280.84	n.d.	27.355	80.199
2024/02/01	Farm pond	34.01167	18.5433	2903.0	6.62	1452	n.d	1061.84	152.492	n.d	n.d	2.78	n.d	375.341	n.d.	24.412	48.624
2024/02/01	Farm pond	34.0175	18.5358	1625.0	8.07	813	0.109	350.578	155.314	n.d	n.d	0.911	0.327	147.224	n.d.	22.081	23.352
2024/02/01	Farm pond	-34.0343	18.567	3043.0	7.91	1522	n.d	436.262	1237.006	n.d	n.d	1.875	4.787	172.306	n.d.	86.66	50.398
2024/02/01	Farm pond	-34.0531	18.5465	1724.0	7.82	862	n.d	270.552	380.065	n.d	n.d	2.678	n.d	130.065	n.d.	11.795	45.416
2024/06/28	P15	-34.0703	18.5472	1181	7.79	591	n.d	155.84	126.51	n.d	n.d	0.60	n.d	90.212.	0.519	4.581	19.539
2024/06/28	PIEZO-02-shallow	-34.0667	18.5501	2409	4.96	1205	0.10	154.71	1238.61	n.d	0.23	0.54	27.00	87.075	2.247	34.791	38.167
2024/06/28	PIEZO-03-shallow	-34.0156	18.5378	1135	6.25	568	0.27	240.10	117.98	n.d	n.d	1.61		126.818	2.571	41.816	11.799
2024/06/28	PIEZO16	-34.0116	18.5421	5464	7.71	2732	n.d	1746.19	143.73	n.d	n.d	4.55	0.96	810.86	n.d.	7.61	86.00
2024/06/28	S04	-34.0205	18.5381	3284	7.27	1642	n.d	385.94	1124.80	n.d	n.d	1.45	1.60	161.96	n.d.	128.41	53.52
2024/06/28	EM28	-34.025	18.5549	1077	7.60	539	0.11	117.48	147.45	n.d	n.d	0.25	39.71	51.70	n.d.	19.25	13.36
2024/06/28	EM6	-34.0342	18.5676	1927	7.23	964	n.d	331.04	363.20	n.d	n.d	1.22	n.d	164.00	4.64	23.99	35.28
2024/06/28	EM26	-34.0561	18.5526	2793	7.24	1397	n.d	509.63	511.38	n.d	n.d	1.58	0.24	222.78	2.36	91.80	62.13
2024/06/28	EM8	-34.0178	18.5499	1573	6.17	787	n.d	380.42	186.46	n.d	n.d	1.48	n.d	167.17	1.56	30.39	38.68
2024/06/28	S31	-34.0263	18.5425	1268	7.58	634	n.d	168.81	132.85	n.d	n.d	1.79	0.43	67.76	0.58	4.33	13.13

Date	Borehole name	latitude	longitude	Ca (mg/L)	Colour (Hazen)	TOC (mg/L)	Al (ug/l)	Mn (ug/l)	Fe (ug/l)	Cu (ug/l)	Zn (ug/l)	As (ug/l)	Cd (ug/l)	Pb (ug/l)	U (ug/l)	Ba (ug/l)	HCO3 (mg/l)
2024/08/11	EM-08	-34.0116	18.5442	85.052	73.7	19.64	76.31	9.28	312.47	30.03	4.04	0.68	<LOQ				
2024/08/11	PIEZO-3 shallow	-34.0205	18.5381	218.542	191	31.90	31.41	32.44	108.86	3.46	3.66	1.88	<LOQ				
2024/08/11	P-21	-34.021	18.5382	389.607	151.4	23.34	<LOQ	186.59	17.18	<LOQ	4.78	0.31	<LOQ				
2024/08/11	EM-25	-34.01	18.5348	56.18	53.4	17.40	1.78	32.36	60.39	0.62	1.99	0.28	<LOQ				
2024/08/11	PIEZO-02-Deep	-34.0667	18.55	82.526	24.1	10.38	<LOQ	14.18	6.13	<LOQ	2.36	<LOQ	<LOQ				
2024/08/11	PIEZO-02-Shallow	-34.0667	18.55	177.675	54.7	13.30	5.48	6.63	1089.21	<LOQ	0.25	0.52	<LOQ				
2024/08/11	S-04	-34.0343	18.5676	444.365	10.1	12.58	<LOQ	48.53	5.77	1.21	7.05	0.29	0.11				
2024/08/11	S-23	-34.0517	18.574	152.406	12.8	11.20	<LOQ	5.84	10.07	0.14	6.00	<LOQ	<LOQ				
2024/08/11	Pond 1	-34.0131	18.5547	125.589	93.9	23.20	29.80	52.93	64.30	3.14	23.24	1.45	<LOQ				
2024/08/11	Pond 2	-34.0691	18.546	216.114	99.5	23.20	<LOQ	11.91	254.20	3.14	<LOQ	0.48	<LOQ				
2024/08/11	Pond 3	-34.0622	18.5486	187.214	22.4	13.71	<LOQ	0.40	3.59	3.14	7.54	<LOQ	<LOQ				
2024/02/01	Pond 4	-34.0474	18.5376	109.042	34.5	14.47	<LOQ	<LOQ	6.04	3.14	3.59	0.79	<LOQ				
2024/02/01	EM-08	-34.0116	18.5442	79.711	67.7	16.02	124.99	12.87	917.42	3.14	2.03	1.18	<LOQ	0.23	0.03	179.82	62.342
2024/02/01	PIEZO-3 shallow	-34.0205	18.5381	79.421	523.0	21.14	397.68	36.73	38487.00	3.14	3.53	3.65	<LOQ	0.57	0.09	22.27	86.62
2024/02/01	P-23	-34.0222	18.5386	458.294	40.9	16.28	1.54	172.23	44.73	3.14	8.68	0.67	<LOQ	0.11	0.07	230.66	189.466
2024/02/01	EM-25	-34.01	18.5348	100.022	35.0	11.18	10.15	13.77	32.10	3.14	2.29	0.54	<LOQ	0.16	0.29	47.60	220.332
2024/02/01	PIEZO-02-Deep	-34.0667	18.55	87.861	41.0	7.13	1.16	26.19	13.29	3.14	0.76	0.10	<LOQ	0.04	0.02	18.68	295.362
2024/02/01	PIEZO-02-Shallow	-34.0667	18.55	146.757	35.8	2.82	13092	22.73	101269.10	3.14	22.42	0.93	1.28	46.55	11.48	77.60	4
2024/02/01	S-04	-34.0343	18.5676	559.707	22.2	10.73	1.31	23.65	22.04	3.14	1.70	0.88	0.05	0.13	2.64	187.40	334.89
2024/02/01	S-23	-34.0517	18.574	119.352	9.1	6.91	1.70	3.38	17.38	3.14	10.24	0.19	<LOQ	0.26	0.07	33.70	357.094
2024/02/01	PIEZO-16	-34.0156	18.5378	275.542	44.1	14.74	7.34	47.10	28.56	3.14	6.24	8.04	<LOQ	9.43	0.30	178.46	346.48
2024/02/01	EM-36	-34.0187	18.5372	197.823	64.1	21.73	17.42	21.84	13.29	3.14	1.88	0.90	<LOQ	0.22	0.04	61.08	432.856
2024/02/01	Farm pond	34.01167	18.5433	159.228	74.2	14.24	11.97	109.52	214.33	3.14	3.09	0.42	<LOQ	0.12	0.01	200.41	104.676
2024/02/01	Farm pond	34.0175	18.5358	168.533	19.6	9.38	<LOQ	0.66	6.41	3.14	0.31	0.84	<LOQ	0.10	0.44	112.34	316.834
2024/02/01	Farm pond	-34.0343	18.567	479.154	17.5	11.07	5.43	12.74	6.37	3.14	2.03	0.84	0.02	0.13	1.68	186.69	297.68
2024/02/01	Farm pond	-34.0531	18.5465	194.924	44.3	16.71	3.51	12.31	22.62	3.14	0.77	0.37	<LOQ	0.05	0.02	76.70	298.9
2024/06/28	P15	-34.0703	18.5472	146.311	18.7	7.70	2.46	4.41	4.28	3.14	1.55	0.74	<LOQ	0.01	3.00	123.68	342.1
2024/06/28	Piezo2shallow	-34.0667	18.5501	461.433	<2	6.01	2.33	50.94	28.69	3.14	3.30	0.17	<LOQ	0.30	0.01	58.09	16.3
2024/06/28	Piezo3shallow	-34.0156	18.5378	64.487	483.3	34.06	4.03	0.45	11.01	3.14	6.94	6.52	<LOQ	0.44	0.27	180.85	116.0
2024/06/28	Piezo16	-34.0116	18.5421	291.32	40.1	16.77	1.83	7.71	4.90	3.14	3.07	0.35	<LOQ	<LOQ	0.13	51.75	351.5
2024/06/28	S04	-34.0205	18.5381	558.39	13.4	11.43	5.43	1.51	12.14	3.14	2.38	1.16	<LOQ	<LOQ	0.04	127.00	349.9
2024/06/28	EM28	-34.025	18.5549	158.67	28.7	9.75	136.93	12.84	839.39	3.14	35.12	0.74	<LOQ	0.09	0.11	189.00	257.3
2024/06/28	EM6	-34.0342	18.5676	205.19	34.1	16.67	9.28	20.72	23.99	3.14	5.88	0.81	<LOQ	<LOQ	0.10	325.22	240.8
2024/06/28	EM26	-34.0561	18.5526	295.74	54.7	23.60	5.35	2.55	7.38	3.14	0.69	3.13	<LOQ	<LOQ	1.50	29.22	393.2
2024/06/28	EM8	-34.0178	18.5499	86.98	52.9	23.27	2338.16	104.59	3345.56	3.14	53.02	1.27	1.44	14.31	3.53	47.01	77.0
2024/06/28	S31	-34.0263	18.5425	170.20	44.8	15.50	471.01	28.95	25283.34	3.14	7.81	5.51	<LOQ	0.31	0.17	14.65	371.5

