WATER MANAGER SYSTEM, SALDANHA BAY
OVERVIEW AND TECHNICAL GUIDANCE

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CONTENTS

1. Introduction

Surface water has traditionally been the primary resource for water supply in South Africa. While relatively easy to assess and utilise, the surface water resource is vulnerable to climatic conditions, where prolonged periods of drought can lead to an overexploitation and eventually water shortness and supply failure. Following the drought in 2018, more focus has been given to the groundwater resource to supplement the water supply in South Africa.

In the Saldanha Bay municipality the water supply is based on a combination of surface water and groundwater, with plans to supplement this with desalination and managed aquifer recharge (MAR) in the future. For an efficient and sustainable utilisation of the different water resources, a Water Supply Management System (WSMS) has been developed that can be used to manage water mix from multiple sources. The system builds on top of a flexible WaterManager system developed for operation of complex water supply infrastructures, which in the current study has been extended to compare actual groundwater levels to expected groundwater levels estimated by the flow modelling.

As part of the current project, a geological model for the area has been developed, which has provided a basis for the development of a flow model/groundwater model. A brief technical description of the geological model development is provided in /1/, while the flow modelling is described in /2/. The flow model has been used to run model scenarios, which are imported to the WaterManager system. With future detailing of the modelling in the area, and/or the need to revise the current model scenarios, new model results can be uploaded to the WaterManager system. The current brief technical documentation provides an overview of the overall approach in the project, a brief description of the WaterManager system and how future model results can uploaded into the WaterManager system.

The project has been carried out in collaboration between Danish: Ramboll Denmark and Krüger Veolia and South African partners: GEOSS, Zutari, University of the Free State as part of the Strategic Sector Cooperation programme for water between Denmark and South Africa, funded by the Ministry of Foreign Affairs in Denmark.

2. Overall approach

The goal of the water supply management system on the long term is to enable the simultaneous management of multiple sources of water. In this project only groundwater has been targeted. Critical to the introduction of groundwater in the water mix, has been to assure that the groundwater abstraction do not result in an unacceptable impact on the groundwater system itself or associated systems dependable on groundwater. To ensure this, a system has been developed that enables the users to combine information on the current state of the groundwater levels with expected long-term development, from which a potential risk for over abstraction can be identified and mitigation measures can be defined.

A schematic of the management system is illustrated in Figure 1. The core of the WSMS is the WaterManager programme and the associated design criteria and predictions on expected development in groundwater heads. The design criteria are formulated as control points at which the groundwater level cannot be lowered below a user specified threshold. A flow model (groundwater model) is run for the area for a long period using historical climatic data from which a mean expected seasonal variation in groundwater head is simulated; i.e., the model results for each day are averaged across years in the simulation, providing a mean, or expected, groundwater level based on the historical climate data used as input. At each control point the expected groundwater level is compared to the actual groundwater level and using this data the expected seasonal groundwater head is predicted and can be compared to the thresholds defined. See more details in sections below.

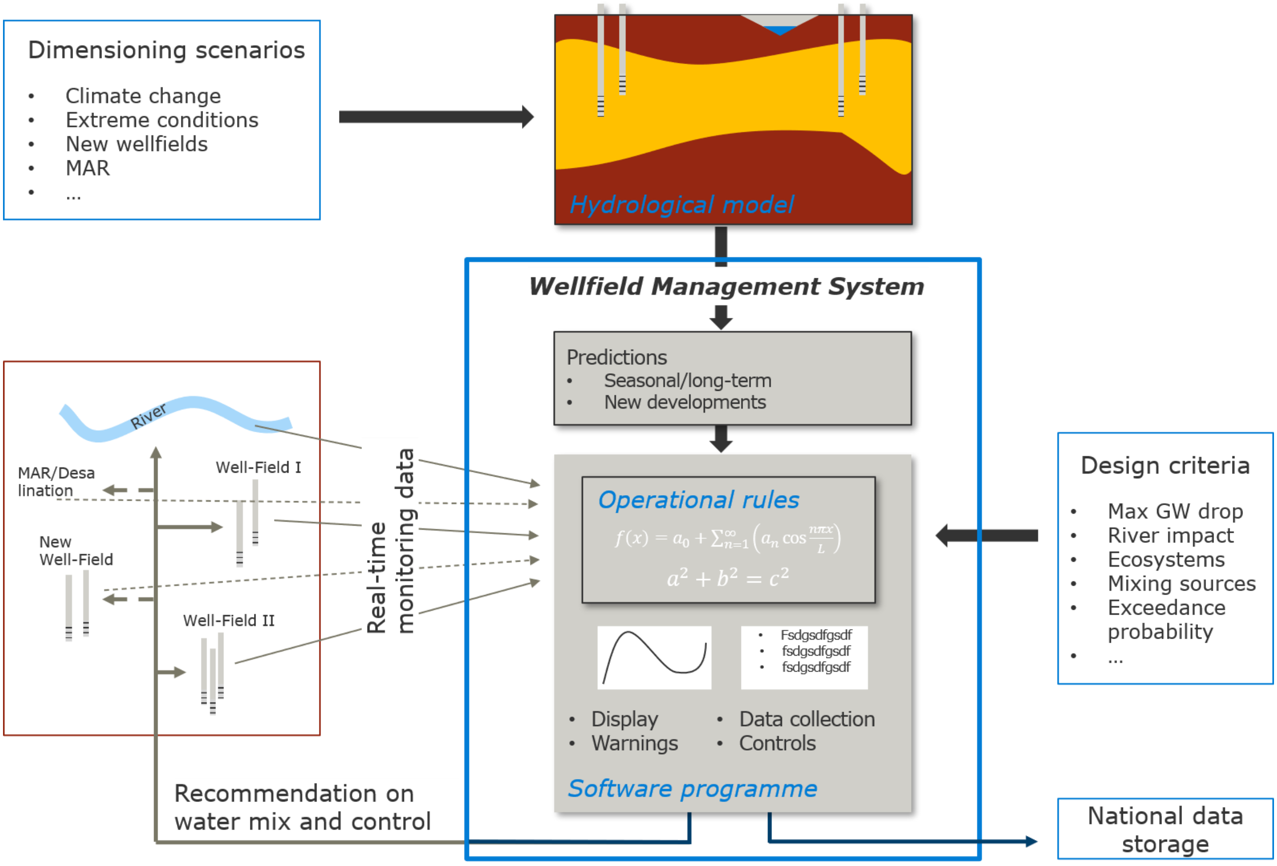


Figure 1. Schematic of the water supply management system and its interaction with data sources, dimensioning scenarios (hydrological modelling) and design criteria.

Two wellfields were developed by the Saldanha: Langebaan and Hopefield. While the Langebaan wellfield has been active and used during the drought situation in 2018, Hopefield has not been used regularly and a permit for the wellfield has not yet been issued. For the Saldanha Bay area, several locations have been identified as being potentially vulnerable to a lowering of the groundwater table, either due to quantitative or qualitative constraints. These includes:

1. Possible impact on Berg River
2. Possible reduction of the subsurface freshwater flow to the Langebaan Lagoon
3. A general lowering of the groundwater level that may impact other users in the area
4. Reduction of the groundwater level between the two wellfields Langebaan and Hopefield
5. Intrusion of saline groundwater

Based on an assessment of existing boreholes in the area, 15 wells have been identified as suitable for use as control points to monitor the possible effects from pumping. The monitoring wells are listed in Table 1 and their locations are shown in Figure 2.

Table 1. Boreholes defined at control points

BH NAME	LATITUDE	LONGITUDE	AQUIFER	DEPTH (mbgl)
G46092	-32.94473	18.08762	Upper	28
G46025	-33.01272	18.23847	Unkown	65
G33327	-32.96348	18.12761	Lower	83
G33326	-32.93397	18.27127	Upper	80
G46065	-32.91997	18.29422	Lower	34
BG00054	-32.96146	18.15705	Lower	45
BG00062	-33.04536	18.11176	Bedrock	27
G46031	-33.02411	18.17902	Upper	88
G46030	-33.03527	18.18360	Bedrock	119
G33313	-33.10663	18.12897	Upper	57
BH3	-33.18171	18.14594	Lower	60
BH1A	-33.18602	18.13195	Upper	44
G33501	-33.07463	18.30582	Upper	44
G33498	-33.07605	18.2511	Upper	73
G33246	-32.901	18.33653	Upper	25

Figure 2. Map of the Saldanha bay area with monitoring wells (green dots), Langebaan and Hopefield wellfields (red cirkels) and approx locations of saline water.

3. The WaterManager system in brief

The WaterManager system was originally developed to monitor the facilities of water supply and is used widely by Danish water utilities in groundwater management as well as management and surveillance of distribution networks.

The WaterManager system provides a common data platform for all relevant stakeholders such as managers, operators, consultants and authorities. It is a web-based digital platform - a cloud solution based on Amazon AWS. Data can be uploaded to the platform through a standardised web interface, csv upload (comma separated files) or customised API's enabling easy collection from a wide variety of data sources, Figure 3. WaterManager allows for data processing and easy overview through its 6 main visualisation modules. In addition, the system provides the opportunity to automatically distribute customised reports to relevant actors such managers/operators/consultants.

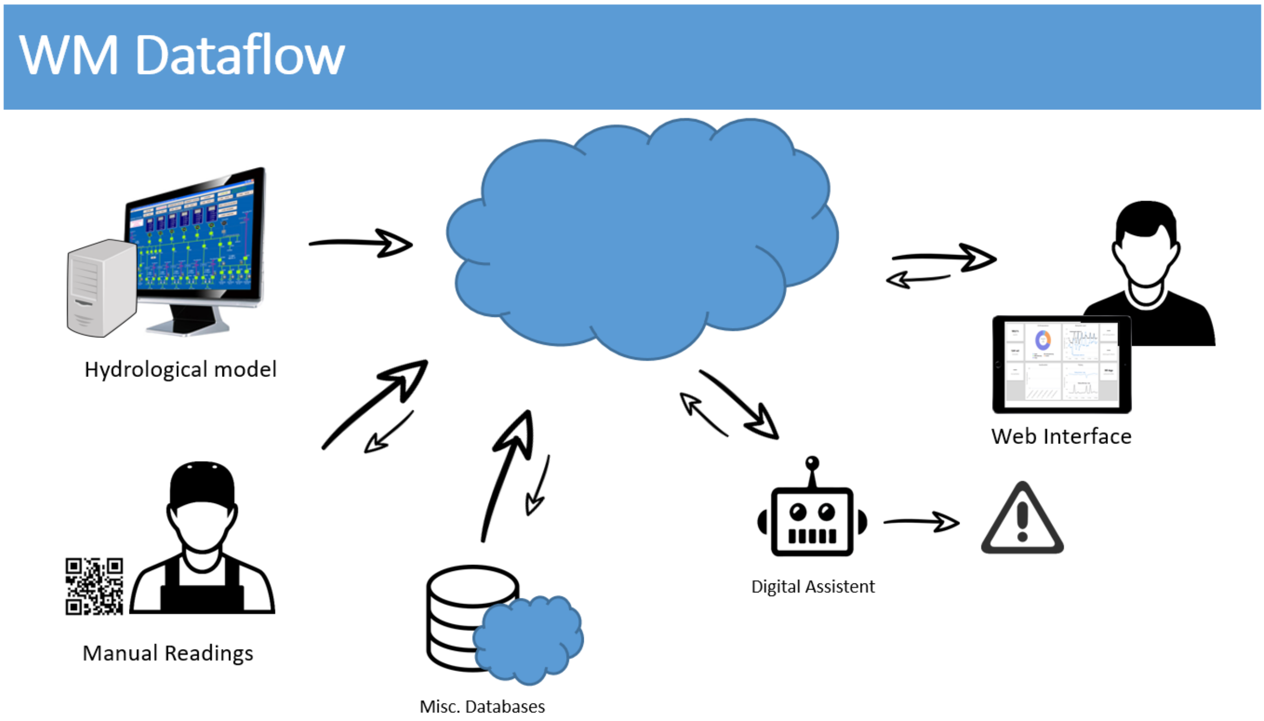


Figure 3. Schematic of the dataflow between WaterManager, water resources, complementary data and software users.

The six visualisation modules in WaterManager are:

1. **Geographic**. Wells, weirs and other data points can be visualised on a map. The map view provides an overview of the system and allows for easy navigation to present recent issues and highlights any issue that requires special attention from the operators.
2. **Key performance Indicators (KPI)**. The KPI view provides a dashboard of the current and historic system performance compared to pre-set performance goals and targets. The dashboard may be customised to present data using intuitive graphs and figures to support operational decisions and actions.
3. **Activities**. This module provides a list of recent operational activities ranging from inspections to operational interventions and process deviations. The list may be filtered to give specific insight.
4. **Calendar**. Here activities can be scheduled in a calendar, and operators can be notified when an activity is due.
5. **Report**: Customised reports on the operation of the water supply system can be set up for any period of time, e.g., daily/weekly/monthly etc. The system can further be set up to automatically distribute the reports to relevant actors such managers/operators/consultants.
6. **Graph**: Graphs can be generated from the operational and observation data collected by the system, Figure 4. The specific parameters to display can be selected by the user and preferred graphs can be stored.

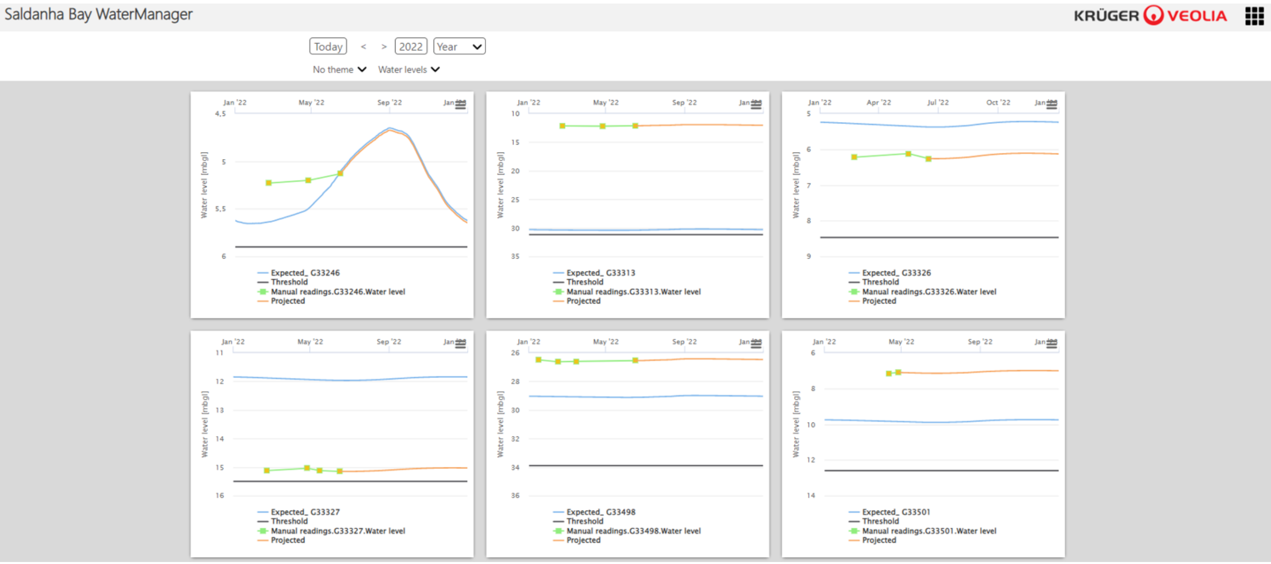


Figure 4 Example of a dashboard setup in the WaterManager programme.

4. Integration of data in WaterManager

The time frame of the graphs in WaterManager has been extended in the current project to visualise the expected future seasonal development in groundwater head, as simulated by the hydrological model, for each control point (CP) together with the actual observations and the threshold value for the minimum acceptable groundwater level at each control point, as illustrated in Figure 5. The graph also plots the projected groundwater level based on the current observed groundwater level, green line in Figure 5. Hence, based on the actual observed groundwater level, the expected seasonal development of the groundwater head is estimated, and from the graph it can be directly read if the projected groundwater head is expected to violate (cross) the design criteria (DC) for the control point. In case of violation, the pumping rate may be reduced and the effect of this can be calculated using a dedicated spreadsheet.

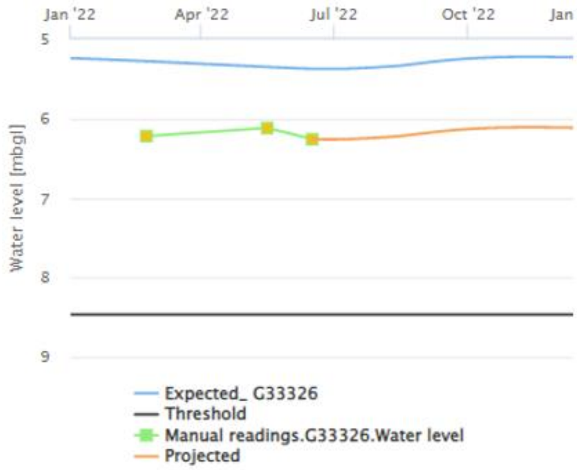


Figure 5. Expected seasonal variation in groundwater level at control point #1 (blue curve) together with monitoring data (yellow points), the design criteria (DC, oragne line) and the projected groundwater head (green curve).

Running detailed three-dimensional flow models are generally time-consuming and would require a complex setup if model runs should be executed directly via the WaterManager. Instead, model runs are carried out separately and data are pre-processed prior to their import into WaterManager (Figure 6). In the approach it has been utilised that the effect of pumping is linear in groundwater systems with a constant saturated thickness, i.e., twice the pumping rate has twice the impact with respect to a decrease in groundwater heads. The effect from different pumping rates can thus be scaled once a unit change impact, i.e., the impact caused by pumping of 1 cubic meter per day, has been established. With the scaling approach, the effect from different pumping rates can be estimated and imported in WaterManager. The linear behaviour builds on some assumptions and its precision will depend on the degree to which these assumptions may be violated. Most important for practical use is the assumption of a constant saturated thickness, which may be violated in shallow unconfined aquifers, but are rarely a problem for deeper aquifers. The validity of the assumption can be calculated by running the flow model and calculate the drawdown at the location of concern using different abstraction rates and test the linearity of the impact.

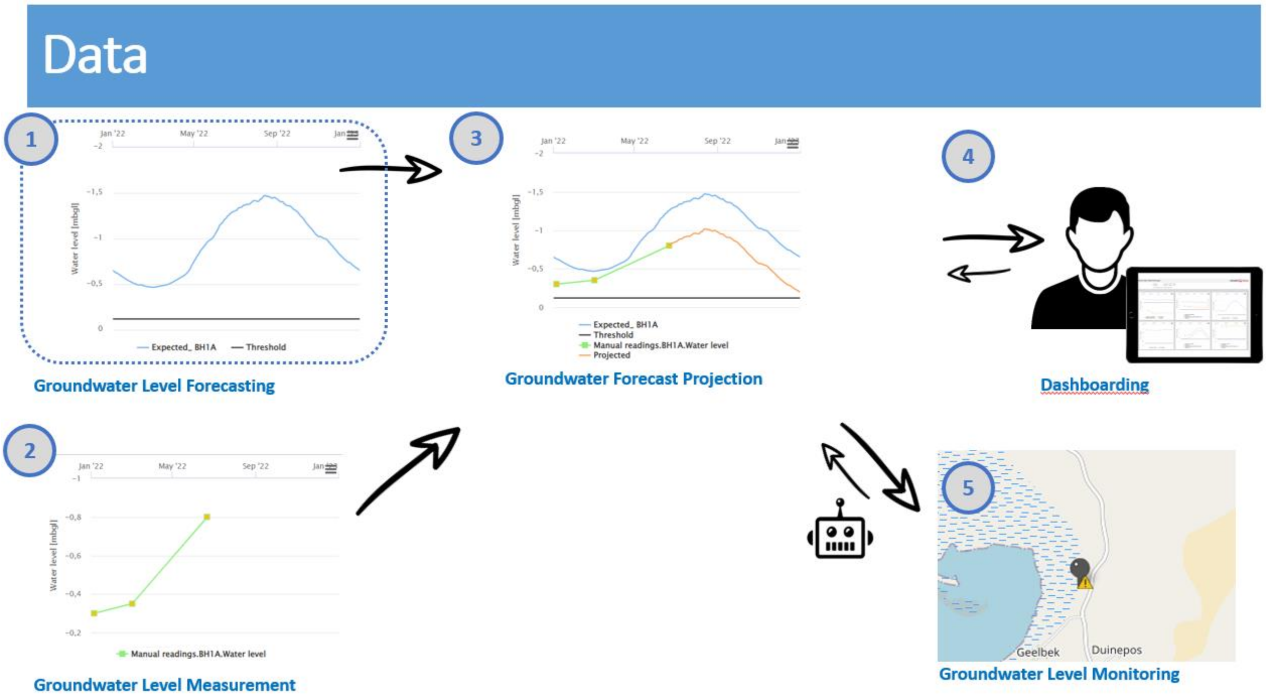
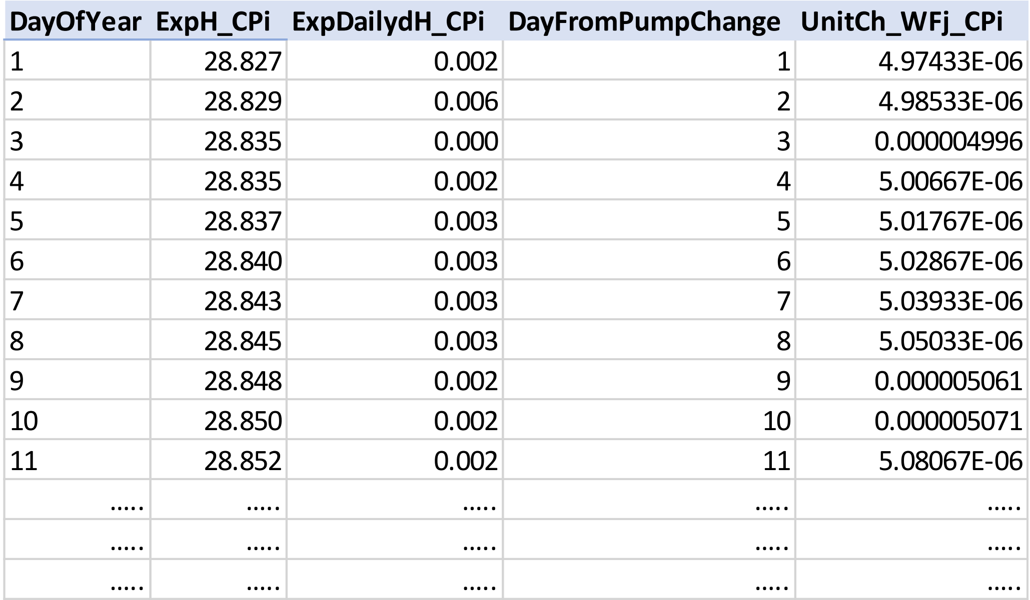


Figure 6. Data processing. 1) Forecasting groundwater level offline using a dedicated spreadsheet. 2) Direct collection of field measurements. 3) WaterMager projects the forecast based on latest measurements. 4) Data is accessible through dashboards. 5) System monitors potential violation of future groundwater level.

Data may be entered directly into WaterManager as single data points or uploaded in bulk as a csv file. In addition, operational data may be pushed to the system automatically using a dedicated data collector e.g., from a SCADA system. Figure 7 shows an example of columns to include in the input csv file, while an explanation of the columns is provided in Table 2.



DayOfYear	ExpH_CPi	ExpDailydH_CPi	DayFromPumpChange	UnitCh_WFj_CPi
1	28.827	0.002	1	4.97433E-06
2	28.829	0.006	2	4.98533E-06
3	28.835	0.000	3	0.000004996
4	28.835	0.002	4	5.00667E-06
5	28.837	0.003	5	5.01767E-06
6	28.840	0.003	6	5.02867E-06
7	28.843	0.003	7	5.03933E-06
8	28.845	0.003	8	5.05033E-06
9	28.848	0.002	9	0.000005061
10	28.850	0.002	10	0.000005071
11	28.852	0.002	11	5.08067E-06
…..	…..	…..	…..	…..
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…..	…..	…..	…..	…..

Figure 7. Example of input file for WaterManager.

Table 2. Explanation of columns in input file to WaterManager.

Column	**Explanation**	**Comment**
DayOfYear	The number of the day in the year. Leap days are not considered, hence 1. January is day 1 and 31. December is day 365 in all years	
ExpH_CP*i*	Is the expected head at the Day of the year at Control Point (CP) *i,* based on the current abstraction at the wellfield(s) to be considered. One column for each control point	ExpH_CP*i* and ExpDailydH_CP*i* are repeated for all control points considered
ExpDailydH_CP*i*	Expected change in groundwater head from the previous to the current day at Cp*i*. Calculated from the ExpH_CP*i*	
DayFromPumpChange	Number of days from an abstraction has been changed	Simulation is run until a new dynamic equilibrium has been established, and the entire time series is read in, i.e. can exceed one year
UnitCh_WF*j*_CP*i*	Is the change in groundwater head at control point *i* in response to the changes in abstraction at wellfield *j*	

The following steps are required to establish the data and file to import to the WaterManager:

Model scenario runs. A Three-dimensional flow model must be established for the area that is used to run multiple model scenarios. The scenarios all use the same climatic input and setup, and only varies with respect to the abstraction at the wellfield(s) from which the impact is to be included in the WaterManger system 1) A baseline model run is created with no abstraction at the wellfield considered, while all other abstractions are held at their actual abstraction rates, 2) A pumping scenario with all pumping included, also at the wellfield, showing the actual conditions and 3) A pumping scenario starting with no pumping at the wellfield but introducing the pumping after a spin-up time, and all other abstractions are at their actual rates, which is used to determine the temporal evolution in the impact from the pumping at the wellfield(s). If only one wellfield is considered three scenarios thus have to be run. When more wellfields are considered, like Hopefield and Langebaan, scenarios 1 and 3 have to be repeated for both wellfields, resulting in five scenario runs in total.

Calculating expected groundwater head variation.
The expected groundwater levels (ExpH_CP*i*), is based on actual pumping rates (scenario 2) and thus reflect the current variation in groundwater heads (blue curve in Figure 5). For each control point a time series of groundwater head is extracted from the simulation for all years, and a mean, groundwater head is calculated for each day of the year, i.e., a mean groundwater head for January 1st is calculated by averaging the simulated heads for all January 1st across all years in the simulation.

When the expected groundwater head is calculated the expected daily change (ExpDailydH_CP*i*) for any day can be calculated as the difference in head between the current and the previous day. This value is used internally in WaterManager for the projection of the groundwater levels based on the actual monitoring data (green curve in Figure 5).

Calculating impact from pumping at control points. This utilises scenario 1 (no pumping at the wellfield, actual pumping elsewhere) and scenario 3, where pumping is introduced at the wellfield, and actual pumping elsewhere. For both scenarios timeseries are extracted from the model at each control point. In the pumping scenario, the initial condition for the simulation is no pumping and after a model spin-up time, the abstraction is introduced, e.g., using the current abstraction rate. Subtracting the pumping scenario from the baseline scenario from the time at which the pumping was introduced (DayFromPumpChange) yields the drawdown in response to the pumping. The unit change (UnitCh_WF*j*_CP*i*) is calculated by dividing the drawdown by the abstraction rate employed at the wellfield, providing an impact for each cubic meter abstracted. If more than one wellfield is to be considered by the WaterManager, the scenarios 1 and 3 and pre-processing of the data as described above must be repeated for each.

5. Recommendations

The objective of the current project has been to develop geological and flow models and a Water Supply Management System, while the actual implementation of the system was beyond the scope of the project. Within the time and resources allocated to the project, it was foreseen that compromises had to be made regarding the detailing of the modelling work. To ensure a correct water balance, a large model area was used that includes the various recharge areas in the region, and a model area of 5135 km2 was defined. Running large scale models puts a limit to the grid resolution in order to maintain model run-times that are practical feasible, and a 200 m grid resolution was used in the study. While this resolution is adequate to predict regional patterns in groundwater heads, it will limit the precision at small scale, e.g., around the wellfields.

However, it is recommended to focus on pumping and monitoring. It is recommended to implement and test WaterManager based on the implemented design criteria´s, and to validate the system and model against actual measurements of groundwater levels with changing pumping rates.

Groundwater monitoring is already taking place from boreholes near the wellfields. These monitoring boreholes are recommended to be included in the system as an early-warning-systems for the control points located at a longer distance from the wellfields.

Central to the evaluation of the impact of the pumping is the definition of control points, i.e., locations where a lowering of the groundwater level may cause and unacceptable impact. In the present study, the locations of the control points have been defined at a workshop based on existing knowledge regarding the importance of groundwater flow and surface water – groundwater interactions. Together with the locations a critical level for the groundwater (design criteria) has been defined for each point, based on the current knowledge/expectations on the vulnerability/robustness of the system. An example from the current project is that a constant groundwater flux must be maintained to the Langebaan lagoon, which in the WaterManager system translates to the maintenance of a gradient towards the lagoon or a minimum groundwater level at a control point between the wellfields and the lagoon. However, the minimum groundwater flux to the lagoon has not been quantified. Hence, the currently implemented design criteria´s might not be the true minimum level with respect to impact on the lagoon. This could also be the case for other control points defined in the study, and therefore the currently implemented design criteria is recommended to be improved in a future study and connected with warning boreholes (new control points), located closer to the wellfields. Setting the criteria more accurately will involve the input from various disciplines and may be a trade-off between not affecting the environment and producing the required water.

Based on design criteria, the model should thus be used to estimate the sustainable abstraction rates at the wellfields without violating the predefined criteria. Calculation of the sustainable abstraction rates will give a better foundation on how to utilize the groundwater resource during wet and dry periods. Shall the groundwater resource be used as a water resource all the time, or shall it mainly contribute when the water level in the dams becomes critically low. This depends also very much on the storage capacity in the aquifer and how fast the groundwater resource is lost (to outflows) when not using it.

If it is decided at one stage to improve the model, the phosphate mine located between the wellfields and the Langebaan lagoon should be included. A groundwater lowering is carried out locally at the mine with reinjection just downstream the mine. This manipulation of the groundwater flow will affect the flow towards the lagoon and how the pumping at the wellfields might impact the flow to the lagoon. It is also recommended to include observations from the monitoring program around the mine in the WaterManager.

The future water mix in Saldanha Bay is expected to consist of different sources: Surface water, groundwater and desalination. In addition to this, increasing the groundwater recharge by managed aquifer recharge (MAR) is planned, and several wells at Langebaan wellfield are constructed to include direct injection to the aquifer. Limited knowledge is, however, available on how to optimally run a MAR system at the site, due to limited field trials on how the aquifer react to infiltration, the expected timespan for which water can be stored as a buffer in the aquifers, and how and when water should be divided to injections and what sources should be used. In an eventually future model upgrade, it is thus recommended that a future detailed modelling study at the site will utilise the data that do exists from experiences on injection, possible supplemented by more trials, to understand the system behaviour. With this implemented in an updated model, simulation scenarios should be carried out to evaluate the effect of injection at different rates and at different times in the season, from which an optimal strategy should be formulated. In such scenarios it may be necessary not only to consider the local conditions, but also the water availabilities in the Western Cape in general, with respect to the resource stored in dams and its temporal variability in response to climatic variations.