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Presentation of DeMa (Decision Support Software and Database for Wellfield Management) and Its Application for the Wadi Al Arab Wellfield

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Abstract: This article aims to present the structure and the workflow of a new software DeMa (Decision Support Software and Database for Wellfield Management), to support wellfield managers in their decision-making processes. There is a recognized need to improve the management of groundwater resources, especially with the increased demand for fresh water in arid and semi-arid regions. DeMa differentiates from other available software, by combining data collected for the well's maintenance, operation, design, installations, and cost data with the collected hydrological field measurements. Additionally, DeMa links the different information and provides an effective graphical representation of the data. We applied the software to the Wadi Al Arab wellfield case study to support wellfield managers in the decision-making process of three typical problems: identification of missing data and information concerning the wells, identification of maintenance needs for a well, and identification of a suitable location for a new well. In the application to the Wadi Al Arab wellfield (Jordan), we collected data and documents from the Yarmouk Water Company (YWC), the Jordan Ministry of Water and Irrigation (MWI), and private drilling companies. The software application highlights the beneficial effects of the digitalization of water resources management by improving data availability and management and achieving data and research-based decisions on the wellfield.

Keywords: wellfield management; water management; digitalization; software; database management

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1. Introduction

As the global population continues to rise, so does the demand for water [1–3]. According to a recent report published by the UNESCO [4], the amount of abstracted fresh groundwater globally exceeds the mean annual renewable recharge by 10.5%. This abstraction rate is forecasted to increase further due to the increased water demand. The global population's continuous growth will strain the already limited water resources [5,6], especially the groundwater resources, which represent 50% of global drinking water [4]. Hence, the global water crises slow down the movement of many countries towards sustainable water management practices [7], especially in semi-arid regions, such as Jordan, where water scarcity is a leading sustainability challenge [8–10].

Therefore, it is essential to protect the water resource by applying improved groundwater management [11,12], preserving the quality of groundwater resources [13,14], and by developing more sustainable practices than those currently adopted [15,16]. Achieving improved groundwater management can be achieved through a better understanding of the groundwater system [17–19], improved groundwater information and data management [20–22], as well as upgraded modeling techniques and software [21,23,24]. In this work, we focus on improving groundwater information and data management by presenting the software DeMa (Decision Support Software and Database for Wellfield Management).

Digitalization and modeling techniques reduce costs by automating operational procedures and maintenance practices in different sectors [25–28]. Maintenance costs could reach 60% of the total cost of production [29], which, in the case of water production, can be reflected in the price of water [30,31]. When no preventive maintenance policy is implemented, the failure of a pumping system might result in stopping the water being pumped from the well, or pumping might continue, but with a reduction in energy efficiency, the so-called "economic failure" [32]. Moreover, implementing preventive maintenance would reduce the frequency of failures and time of maintenance of groundwater wells [33]. Predictive maintenance has become one of the main topics in Industry 4.0 for the above-mentioned reasons [34–40]. One of the goals of DeMa is to support water managers in this context.

Globally, the anticipation of a fourth industrial revolution can be witnessed through the improved digital technologies and increased volume of collected data across various domains (e.g., climate and natural sciences, finance, healthcare) [41,42]. Furthermore, utilizing the collected data (i.e., big data) can forge new paths for monitoring the environment [43,44] and ensuring sustainable development in the years to come [45,46]. In recent years, water research and industry have been utilizing big data to support groundwater management [47], map groundwater potential [48,49], enhance water system models [50], increase water treatment systems efficiency [51], and the accuracy of estimating water quality [44]. However, the collected data needs to be processed appropriately to generate knowledge, creating a need for sophisticated data management tools and software that can efficiently manage and extract information from the data [52]. One of the problems faced when dealing with big data is data complexity and uncertainty [53]. Nevertheless, data management tools can effectively utilize big data to make informed decisions [54–56]. DeMa addresses this problem by providing interactive graphics that allow users to explore the dataset and link different sources of information to enhance the knowledge of wellfield managers about their system.

Existing software and tools focusing on wellfield management allow the user to separately store, visualize, and analyze field measurement data [57], subsurface information [58], hydrological and water quality data [59,60], and aquifer testing data [61,62]. Other tools focus on supporting decision making in many water-related applications, such as water quality management [63–65], water resources management [66–69], water supply and demand management [70,71], and reservoir operation management [72,73]. However, there is still a practical gap between the provided solutions and its applicability in the field [74]. Hence, DeMa aims to contribute to filling the previously mentioned practical gap.

The novelty of DeMa software stems from its ability to combine in one single environment multiple options that are offered from the previously mentioned software; for example, within DeMa, the user will be able to combine hydrological field measurements with well maintenance, operation, design, installation, and cost data to make data-driven decisions. Additionally, the research-based tool (RBT) offers the user the option to benefit from scientific research studies that focus on managing groundwater wells and wellfields. This article aims to present and test DeMa or the Wadi Al Arab wellfield case study. We show the benefit of using DeMa to centralize the water company's scattered data and visualize the relationship between different parameters to support the wellfield manager in making decisions related to wellfield operation and maintenance.

2. Study Area

The Wadi Al Arab wellfield is located in the northwest of Jordan, and it is considered one of the most critical wellfields in the country [33,75], as it contributes around 35% (17.32 Mm^3/y) of the total drinking water supply to Irbid Governorate (Figure 1) the second largest governorate in Jordan in terms of number of inhabitants [76]. Between September 1982 and February 1983, the Jordanian government drilled the first five wells in the Wadi Al Arab wellfield (WA-01, WA-02, WA-03, WA-04, WA-05), all of them artesian wells, with a total production of more than 25 Mm^3/y, in 1983 [75]. Due to the increased demand for drinking water, the number of wells increased to 18 operating wells by 2018, with a total production of around 18 Mm^3/y [77]. Due to the overexploitation of the aquifer, the water level declined by around 130 m, between 1995 and 2017 [78]. It is also expected to continue declining until it reaches additional 100 m drop, by 2050 [79]. The large rate of decline in the groundwater table deteriorates the water quality [78,80,81] and increases the challenges of operating the wells and implementing maintenance activities [82]. Moreover, it increases the pumping costs from the dropping groundwater table to the first reservoir level [83], which exceeded an average of 0.13 USD/m^3 in the Wadi Al Arab wells [33]. For the reasons mentioned above, accessing the Wadi Al Arab groundwater resources will be strenuous by 2040 [84]. Therefore, there is an urgent need to enhance the wellfield's management in order to ensure a regular water supply for the next two decades. In particular, due to the lack of alternative water sources and the impossibility of further reducing water allocation per capita, a reduction in water abstraction cannot be envisaged in the short term.

All the wells tap the Upper Cretaceous limestone aquifer (the A7/B2 aquifer). According to Basem [85], the geological structure in the area dips toward the northwest. The A7/B2 aquifer comprises three formations: (i) Wadi As Sir Limestone Formation (A7), with a thickness of 190–300 m; (ii) Wadi Umm Ghudran Formation (B1), where the thickness is 35 m; (iii) Amman-Hisa (B2), with a thickness ranges between 140–200 m. The A7/B2 aquifer outcrops in the southern part of the wellfield area, where the recharge occurs and the groundwater flows toward the northeast [86]. The A7/B2 overlain with the Paleogene oil-shale aquitard (B3 aquitard) toward the northwest of the area with a thickness of up 300 m. Topographically, the Wadi Al Arab wellfield is located in a hilly area, where the elevations of the wells range from 40 m below sea level in WA-12 to 110 m above sea level in WA-19. The hydraulic conductivity for the wells ranges between 8.8×10^{-7} to 2.2×10^{-4} m/s; the abstraction rate ranges in the wells from 70 m^3/h to 180 m^3/h [87].

The Wadi Al Arab wellfield has been managed by the publicly owned Yarmouk Water Company (YWC) since 2013. Currently, YWC serves around three million inhabitants living in the northern part of Jordan, and it manages and operates a total of around 350 wells; 240 wells operate with a total production of around 91 Mm^3/y, and the rest are under maintenance, abandoned, or not yet activated [88]. Before 2013, YWC signed an agreement with the Veolia Aqua Company to improve the provided services for seven years, starting in September 2011. However, the contract was terminated, in March 2013, for political reasons [88,89]. The Japan International Cooperation Agency JICA [90] highlighted that one of the major activities within YWC is the well's maintenance activities. The report also stated that in October 2012, a computerized predictive system started to operate and recorded 342 maintenance orders within six months; however, the report did not show what kind of preventive maintenance was applied. Because of the termination of the agreement with the Veolia Aqua Company, the system stopped operating in April 2013.

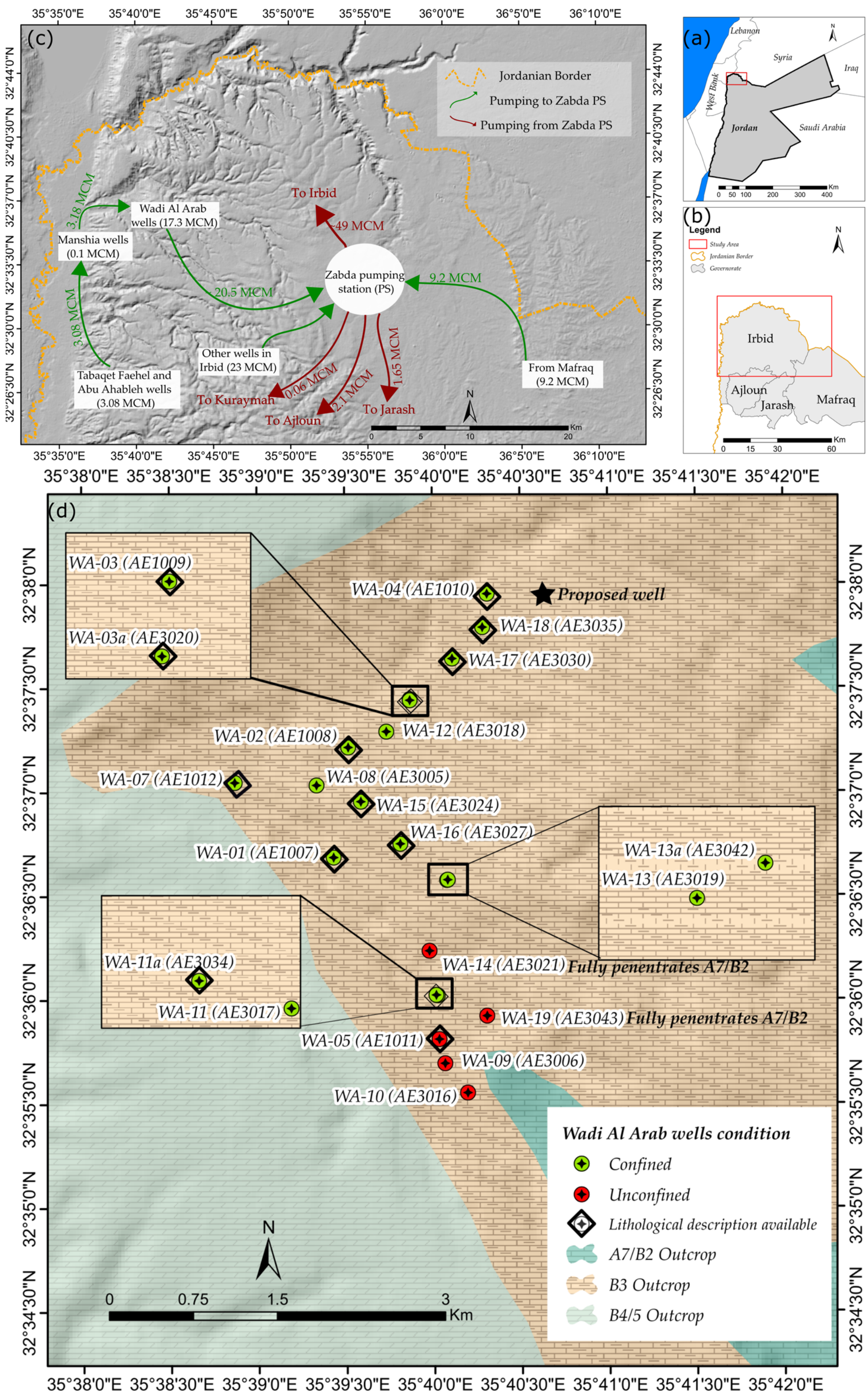

Figure 1. Overview map of the study area. (**a**) The location of Jordan and surrounding countries (**b**) The area of Irbid governorate and the study area. (**c**) Schematic diagram showing the regional water supply system in 2017 (modified after [82]) and (**d**) The Wadi Al Arab well confinement condition and lithological availability map.

The wellfield manager currently shares a monthly report with the wells department employees, including all the field measurements taken during the month. The shared data is gathered into an Excel file that contains a sheet for each well. Overall, each sheet has general data about the well (e.g., name, location, depth, casing specs), collected measurements (e.g., discharge, static water level (SWL), dynamic water level (DWL)), maintenance records (e.g., fault description and actions), installation records, and occasionally a summary of a pumping test. Moreover, this file is shared back with the wellfield manager upon request. The Excel file lacks data consistency (e.g., date format, unit of measurements). Additionally, when essential data for managing and operating the wells, such as invoices, bills, and electricity consumption are needed, they are requested from the financial department and, consequently, the information is not readily available for the user. As a result, this approach does not allow for a prompt detection of inefficient wells or upcoming maintenance needs. Hence, it is not effective as a decision support tool and only serves to store data without any sort of data engineering, analysis, or post-processing, thereby losing any further value for management purposes.

3. Materials and Methods

This section provides a short description of the concept of the DeMa software and the technical description of the tools; further technical information is available in [91].

3.1. Concept of DeMa

The driving concept behind building DeMa is to bring forward practitioner knowledge, translate scientific research into action, and digitize data/reporting processes in one software aiming to move towards evidence-based practices in groundwater management. Through the database management tool (DbMT), DeMa provides a solution for storing and managing data that practitioners use to operate and implement maintenance activities of wells and wellfields, aiming to (i) guarantee data consistency, (ii) provide easy and fast access to data, and (iii) prevent loss of historical data by providing regular backup options (manually/automatically).

To operate and implement maintenance activities of wells and wellfields, DeMa has to be applied through the following procedure: (i) a database has to be created using the database management tool (DbMT); (ii) the data and the relation between different observations can be visualized in the observation-based tool (OBT), such that the wellfield manager can plan the management according to current observations; (iii) well- and wellfield-related documents can be accessed through the documents management tool (DMT); (iv) the collected data can be used through the research-based tool (RBT) to generate new information, such as the computation of the radius of influence of a well.

The tables in the database are divided into three types: (i) standardized data tables, which contain all the data, its primary keys used as foreign keys in other tables; the tables include the standard values of specific parameters (e.g., cable, casing and drilling diameter and pump/motor brands and models), and categorization data (e.g., failure category, equipment status (new, used, repaired); (ii) basic data tables containing the data that are formed when the well is drilled and ready to operate; for instance, when a well is drilled, then data such as the location and depth of the well, lithology data, drilling diameter, casing installation, and cementation must exist; and (iii) extra tables containing all the data that frequently change over time, such as failure records, equipment installation, and measurement data. DbMT is designed to meet the current and the future need of the user, which is why it is flexible in terms of updating the parameter list and the categorization data; the adaptability feature provides the user with the responsibility of updating the list of parameters depending on the line of work and interest. For instance, the static water level (SWL) parameter is included in the database as standard. However, the user has the ability to expand the database, for example, adding additional SWL categories to the database, such as, SWL collected by manual and automatic measurements to differentiate among them and assess the consistency of the data.

Furthermore, the relationship between the stored data is visualized via the observation-based tool (OBT). The OBT helps users to compare the different observations made in one well (e.g., visualizing the current status of a well would support the user in deciding if it is possible to extend the riser pipe or reduce the pumping rate) or multiple wells (e.g., visualization of the comparison of the value of pumped water in terms of energy supplied between different wells could help the user to select which well to switch on/off according to their energetic efficiency). One of the examples of the graphical representation of the data is the well's status graph, which provides a comprehensive overview of the status of the well in terms of the borehole's design, installations (e.g., pumps specs, riser pipe (RP) specs), lithological formations, and the latest measurements. Such a comprehensive overview would help the wellfield manager to approve or disregard actions related to a well's operation.

Additionally, the document management tool (DMT) is built to organize all relevant documents to a specific well or wellfield, where the user can save and sort files by well/wellfield and/or file types (e.g., project reports, theses, final reports, articles, guides, pump curves and report, meeting minutes, internal bills, invoices, contracts, closed-circuit television (CCTVs)). The DMT does not only offer options to store and manage documents related to wells or a wellfield, but it also provides an interface for template edition, where all the previous templates used by the water company can be listed.

Moreover, aiming to bring science into practice, the research-based tool (RBT) enables users to benefit from the conducted research studies that focus on managing groundwater wells and wellfields. Although many scientific research studies (e.g., [92–94]) provide novel methods that are essential for improving wellfield management, it is not always easy for the practitioners to apply such methods as they lack a mathematic and/or programming background and skills. The RBT provides practitioners with a user-friendly graphical user interface (GUI) to select and apply certain methodologies directly to the managed wells, without requiring previous knowledge of mathematics and/or programming. For instance, there are different methods to calculate the radius of influence of a well (ROI). The method selection is based on the conditions in the field and the availability of data and information. Before the user selects a method to calculate the ROI, a list of different parameters and the conditions of the well pops up, and accordingly, the RBT selects the appropriate methods that fit the available data and conditions (Figure 2).

3.2. Technical Description

After listing the features of the existing tools and software that manage groundwater wells and the wellfield, it was compared with the features that DeMa aims to offer. The unique features that are not available in other software and tools were defined and integrated into DeMa (e.g., well failures record and installation specifications) [91].

The authors built, tested, and validated DeMa database using Structured Query Language (SQL) with the SQLite3 Python library [95]. The database, represented by 34 interconnected tables, includes all observations identified to serve the features that DeMa provides (e.g., lithology, energy consumption, maintenance costs, installation specifications, field measurements, and well design). The modules and front-end of the software were developed using the PyQt5 library, which includes a total of 53 Python files, structured as follows:

- Forty-two files to allow the user to update, delete, insert data, and run the database backup in the database management tool (DbMT);
- Four files to graphically visualize the data and the relation between different observations in the observation-based tool (OBT);
- Three files to manage the well- and wellfield-related documents in the documents management tool (DMT);
- Two files to use the best from the published scientific articles in the research-based tool (RBT);
- Two base constructor files.

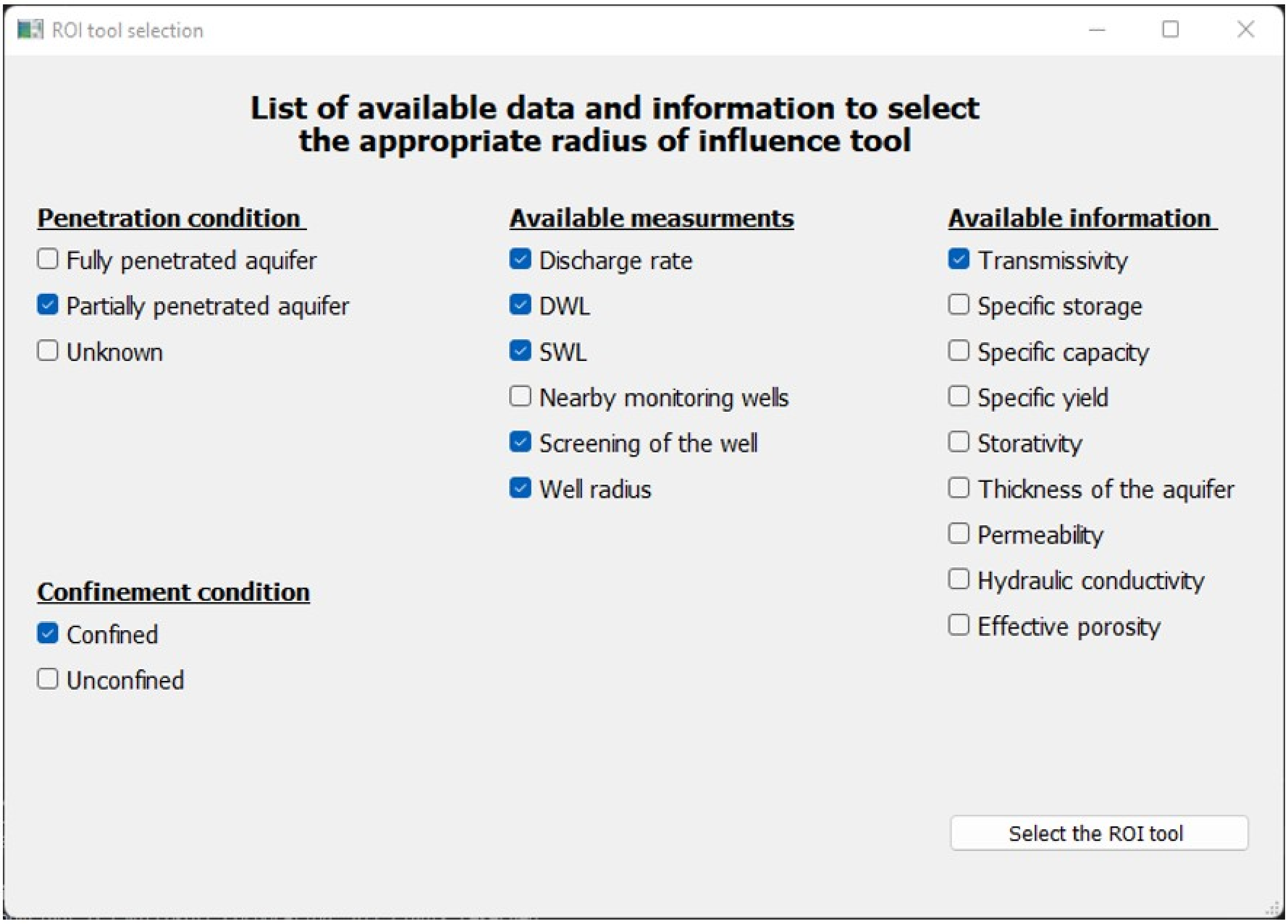

Figure 2. Selecting the appropriate ROI window based on the available data and information.

3.3. *Integrating the Study Area Data and Information into DeMa*

The required data to be uploaded into the DeMa database was collected from different departments at the YWC (e.g., wells department, pumping station department, and accounting departments), and later reorganized to fit the database design and inserted into the database via the DbMT database management tool. Furthermore, an intensive literature review was conducted to integrate all the research documents related to the Wadi Al Arab wellfield into the DMT. The research documents were collected via online search tools such as Google Scholar and Web of Science (WoS) for peer-reviewed articles and gray literature. Furthermore, unstructured interviews were conducted with employees from different departments of MWI, international organizations, and YWC to collect the unpublished documents (such as project reports, drilling completion reports, templates, invoices, internal bills, and electricity consumption). All the collected documents were uploaded to the DMT to enhance the wellfield's information management. Compared to the existing Excel sheets that are used to store and manage the data, the DbMT provides fast and easy access to consistent and updated wellfield data that employees can access from different departments in the YWC. Furthermore, the consistency of the data would help the user either to extract the data and build customized graphics or to access automatic graphical visualizations via the OBT. Figure 3 summarizes the flow process that led to the development of DeMa and its application.

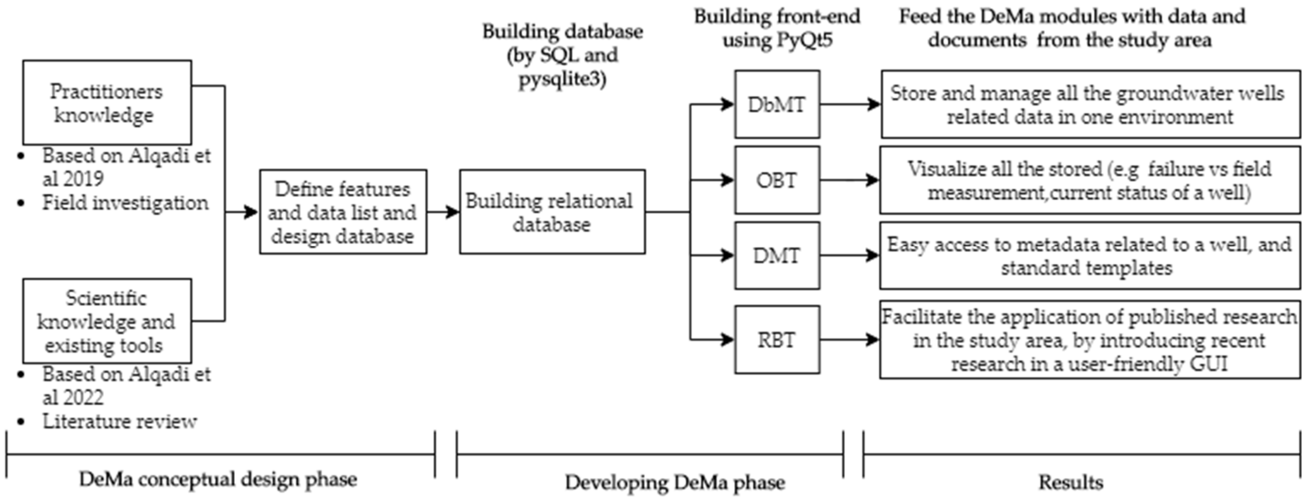

Figure 3. Schematic diagram for the method followed to apply DeMa on the Wadi Al Arab wellfield. Acronym list: database management tool (DbMT), observation-based tool (OBT), documents-based tool (DMT), research-based tool (RBT) [33,91].

3.4. Integrating the Analysis of the Radius of Influence of a Well in the Research-Based Tool

The calculation of the radius of influence (ROI) of a well is a key information for well field managers. To facilitate gathering this information, we implemented in the RBT the recent work of Bresciani [96], which includes nine different equations to calculate the ROI. These equations are mainly based on the Theis solution and assume that "horizontal flow in a homogeneous, confined aquifer of infinite extent, constant-rate pumping, fully-penetrating well, and negligible wellbore storage and skin effects" Bresciani [96] (p. 2). In this way, we aim to bring closer the results of academic research to the final user. The ROI can be calculated by choosing the "design a multiple well system" option in the RBT, which is based on the equations (Equations (1)–(3)) and considers the following parameters: pumping time t [days], transmissivity T [m^2/day], storativity S [-], well radius rw [m], and relative threshold criterion (α) [-] (i.e., the acceptable drawdown at a given distance).

$$ROI = 2\sqrt{\frac{TtE_1^{-1}(-\alpha\ln(1.78u_w))}{S}} \tag{1}$$

$$Relative\ threshold\ criterion\ (\alpha) = \frac{drawdown\ at\ the\ radius\ of\ influence}{drawdown\ at\ the\ well} \tag{2}$$

$$u_w = \frac{Sr_w^2}{4Tt} \tag{3}$$

4. Application of the DeMa

4.1. Data and Document Management for the Identification of Missing Information Concerning the Wellfield

From the operational point of view, the storage and access to documentation concerning the wellfield are of utmost importance for wellfield managers. However, very often, data and documents concerning the Wadi Al Arab wellfield are scattered among different authorities and even different departments within the water company. Therefore, DeMa aims to support the centralized storage and sharing of available information.

For example, the total number of documents focusing on water resources in the Wadi Al Arab area is 44. Among them, 16 documents were linked with the area/wellfield name, 18 with the individual wells, and 10 provided general guidelines for managing the wellfield, but they are derived from different sources, as indicated in Table 1.

Table 1. An overview of the included documents in DeMa and the sources of the documents.

Content of the Document	# of Documents	# of Sources	Linked to	Sources to Collect the Documents from
CCTV report	6	2	Well	Private drilling company, water utility
Completion report	9	3	Well	MWI, Private drilling company, water utility
General guidelines	10	2	-	Online, International cooperation projects in Jordan
Project report	7	2	Area/wellfield	MWI, International cooperation projects in Jordan
Pump curves	11	1	Well	Water Utility
Scientific article	11	1	Area/wellfield	Online

Centralized storage of the information, for example, improves the management of the wells. The 18 documents linked to individual wells, in fact, are the completion reports, CCTV reports, and the installed pump curve. Unfortunately, they do not contain specific information about the aging of the well structure. Table 2 shows an overview of the drilling completion documents associated with each relevant well. We can observe that less than 50% of the wells have an accessible completion report. It is essential to highlight that if a specific report is not available for a well, it does not mean that the report does not exist; instead, it is not accessible to the wellfield manager. Such information is of pivotal importance for adequate wellfield management. Its availability allows the user to quickly identify necessary actions to be taken in order to gather the missing documents and information, track which sources have already been utilized to collect available data, prioritize funding for further data collection, as well as to identify which possible data provider needs to be contacted. In other words, it helps users to efficiently manage their data collection process.Moreover, Table 2 presents an overview of missing data about the wells' casing, drilling, and lithology. Lacking such essential data on some wells prevents the wellfield manager from taking appropriate actions during well operation or in case of a well failure.

Therefore, DeMa, through the DMT, provides fast and easy access to documents related to the wellfield and presents an overview of the available and missing data. The DMT tool indicates to the wellfield manager the missing completion reports that need to be located and uploaded to the DMT. The completion reports usually include the drilling activities, pumping tests, and installed casing specifications for each well. Thus, including these reports is vital to fill in the missing data in Table 2. This approach was applied in the Wadi Al Arab case study to fill in the missing data of the wells AE1007, AE1008, AE1009, AE3027, AE3042.

Not only were the documents related to the Wadi Al Arab wellfield organized and made easily accessible by DeMa, but also the data were collected, reorganized, and integrated into the DeMa database. The organization of data is of pivotal importance for the operational management of the wellfield, and dedicated tools to support wellfield managers in this action are generally not directly linked with post-processing tools (e.g., production of interactive graphics) as offered by DeMa.

Table 2. Availability of casing, drilling and lithology data and drilling completion reports of the Wadi Al Arab wells.

Well ID	Casing	Drilling	Lithology	Completion Report Availability
AE1007	Yes	No *	Yes	x
AE1008	Yes	No *	Yes	x
AE1009	Yes	No *	Yes	x
AE1010	Yes	No	Yes	
AE1011	Yes	No	Yes	
AE1012	No	No	Yes	
AE3005	Yes	Yes	No	
AE3006	Yes	Yes	No	
AE3016	Yes	Yes	No	
AE3017	Yes	Yes	No	
AE3018	Yes	Yes	No	
AE3019	Yes	Yes	No	
AE3020	Yes	Yes	Yes	
AE3021	Yes	Yes	No	
AE3024	Yes	Yes	Yes	x
AE3027	No *	No*	Yes	x
AE3030	Yes	Yes	Yes	x
AE3034	Yes	Yes	Yes	x
AE3035	Yes	Yes	Yes	x
AE3042	Yes	Yes	No *	x
AE3043	Yes	Yes	No	

Note: * Data that were considered to be unavailable in the collected data, but were found in the completion reports when the document management tool DMT was used.

Regarding the field measurements table, the total number of uploaded measurement data is 3187 in the period from 1982 to 2019. However, around 98.4% of these data were collected after 2012 because most of the data collected before 2012 were lost due to the termination of the signed agreement with the Veolia Aqua Company, as mentioned in Section 2 [33]. The economic and scientific loss caused by these missing data is challenging to quantify. Thus, the advantage of a software tool such as DeMa that allows for prompt storage and organization of relevant field data is evident. Figure 4 shows the different types of measurements collected. The amperage shows the highest number of recorded measurements in the graph with a value of more than 1400 records because the alternating current type is three-phase electric power, and actual amperage measurement is collected for all three wires each time. After amperage, the discharge and dynamic water level measurements have the highest collected measurements over time, with a value of around 700 measurements each. Besides the discharge and DWL, the pressure and shaft power should be frequently measured to calculate the pump efficiency and consequently detect possible performance issues [97], predicting failures and planning maintenance accordingly. Therefore, a recommendation that can be given to the wellfield managers by analyzing Figure 4 is to increase the budget and the effort to collect pressure and shaft power data.

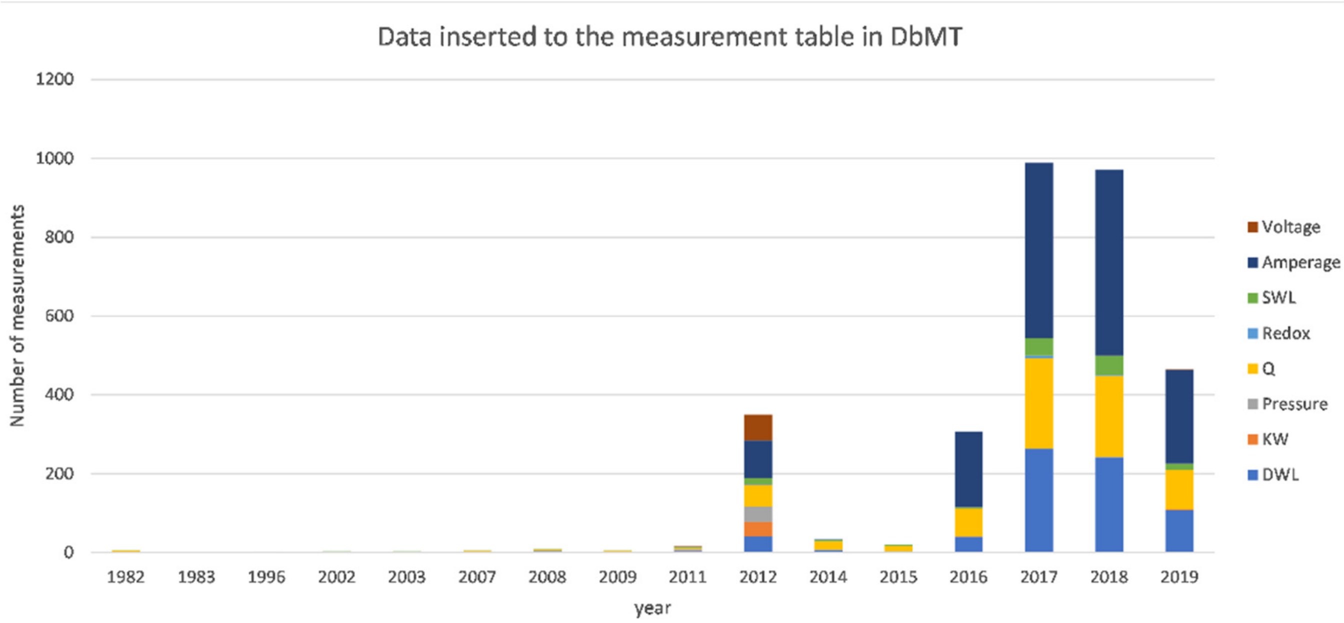

Figure 4. The collected and uploaded data to the measurement table in DbMT. List of abbreviation in the figure: SWL is static water level (m below ground level (bgl)); Q is discharge (m^3/h), KW is the power of motor (Kilowatt); DW is dynamic water level (m bgl).

4.2. Identification of Maintenance Needs

Figure 5 shows the status of AE3020 obtained through the OBT. As observed, the dynamic water level (DWL) gets closer to the pump depth, extending the riser pipe of this well to deepen the pump would be limited to only one segment of the riser pipe (6 m), when taking the pump length into consideration. This is because the pump should not be adjacent to the slotted section of the casing (from 165–175 m, after that open-hole). Otherwise, it will lead to sand pumping, gravel pack damage, and the pump breaking [98]. Another observation can be detected from the figure; it can be seen that the section where the B3 oil-shale aquitard is not cemented, and the casing in the last 10 m of the formation is slotted; such an observation could justify the high concentration of heavy metals in this well [82,87]. Therefore, DeMa brings the numerical and geological information of a well into a graphical representation. This process allows the wellfield manager to better grasp the maintenance needs.

Moreover, a deeper understanding of the well's history can be obtained through a "well diary graph" in the OBT. This option provides a visualization of the lithology, the historical measurements of DWL, SWL, as well as the discharge, and links them with the maintenance actions and failure incidents that have been recorded in the well. For example, the diary graph of WA-04 produced automatically by DeMa is represented in Figure 6. The figure shows that after recording a rise in the DWL level between September and December 2012, the discharge rate did not decrease. This can be an indication of a malfunctioning of the riser piper which can be easily detected through the graphical output produced by DeMa. In fact, the riser pipe was checked afterwards, and a hole was found. The data shows that after fixing the problem, the discharge increased without changing the pump specification or depth.

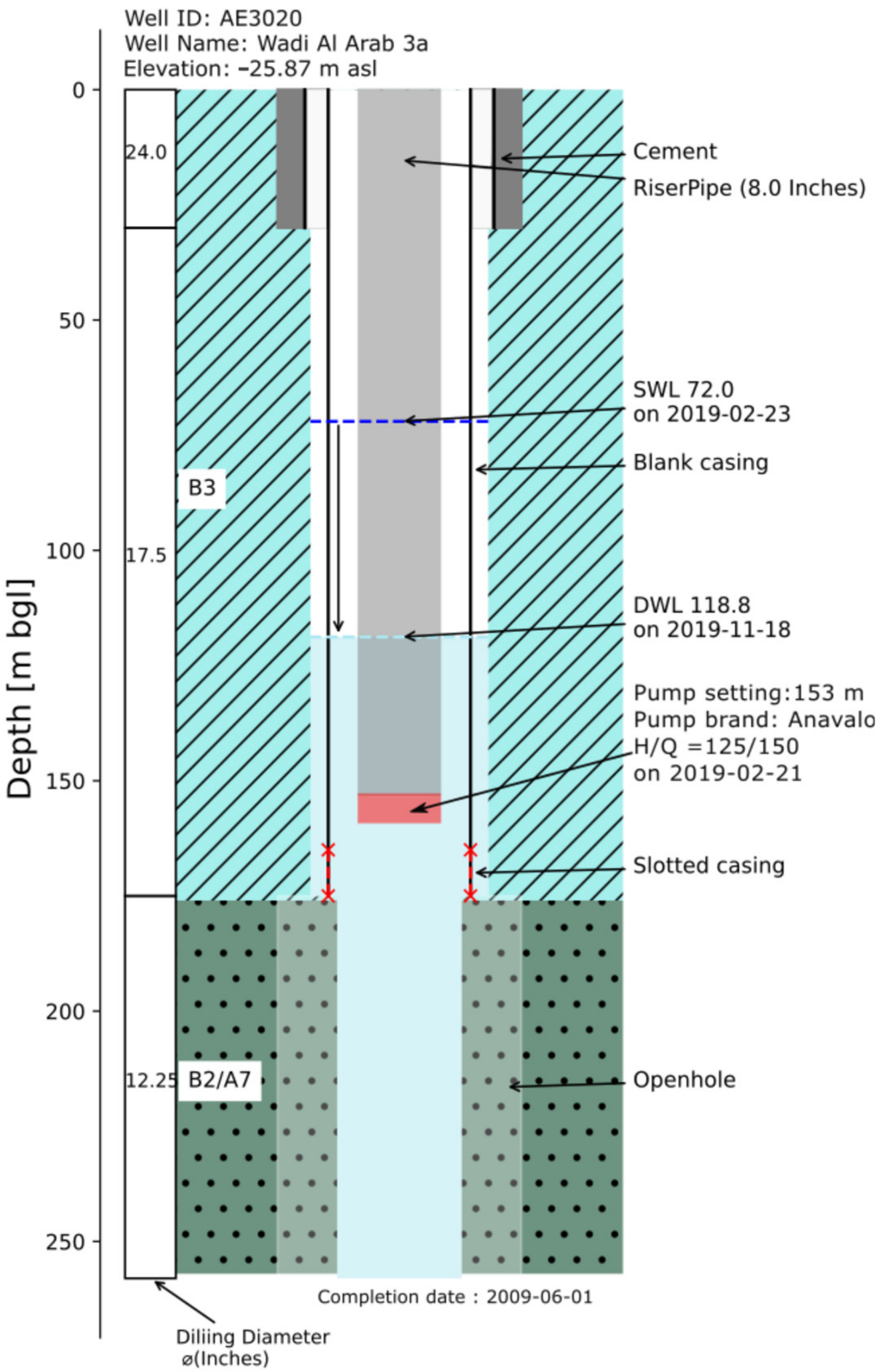

Figure 5. Well status of AE3020 as part of the OBT, a visualization of the recent collected data.

Besides, the well's diary graph gives a general overview of the reasons behind interrupting the well's operation. For instance, in Wadi Al Arab 4, it is clear that the riser pipe (RP) was the reason for stopping the well seven times between 2012 and 2017 (three times because of holes in the pipe, four times for adding extra RP to deepen the pump setting). The graph also provides an overview of the frequency measurements of a particular parameter (SWL, DWL and discharge); this would draw the wellfield manager's attention if a particular parameter was not collected for a specific well so that actions could be taken accordingly. This figure is interactive and has built-in pan/zoom, change shape and colortools. These tools would help the user to implement the comparison between different measurements and have a closer look at a specific period. For instance, the user can observe the increase in the discharge after the riser pipe is repaired. Furthermore, the figure shows that the DWL dropped after repairing the RP; therefore, in the subsequent maintenance of the RP, the user could expect the behavior of the water level after the well operation.

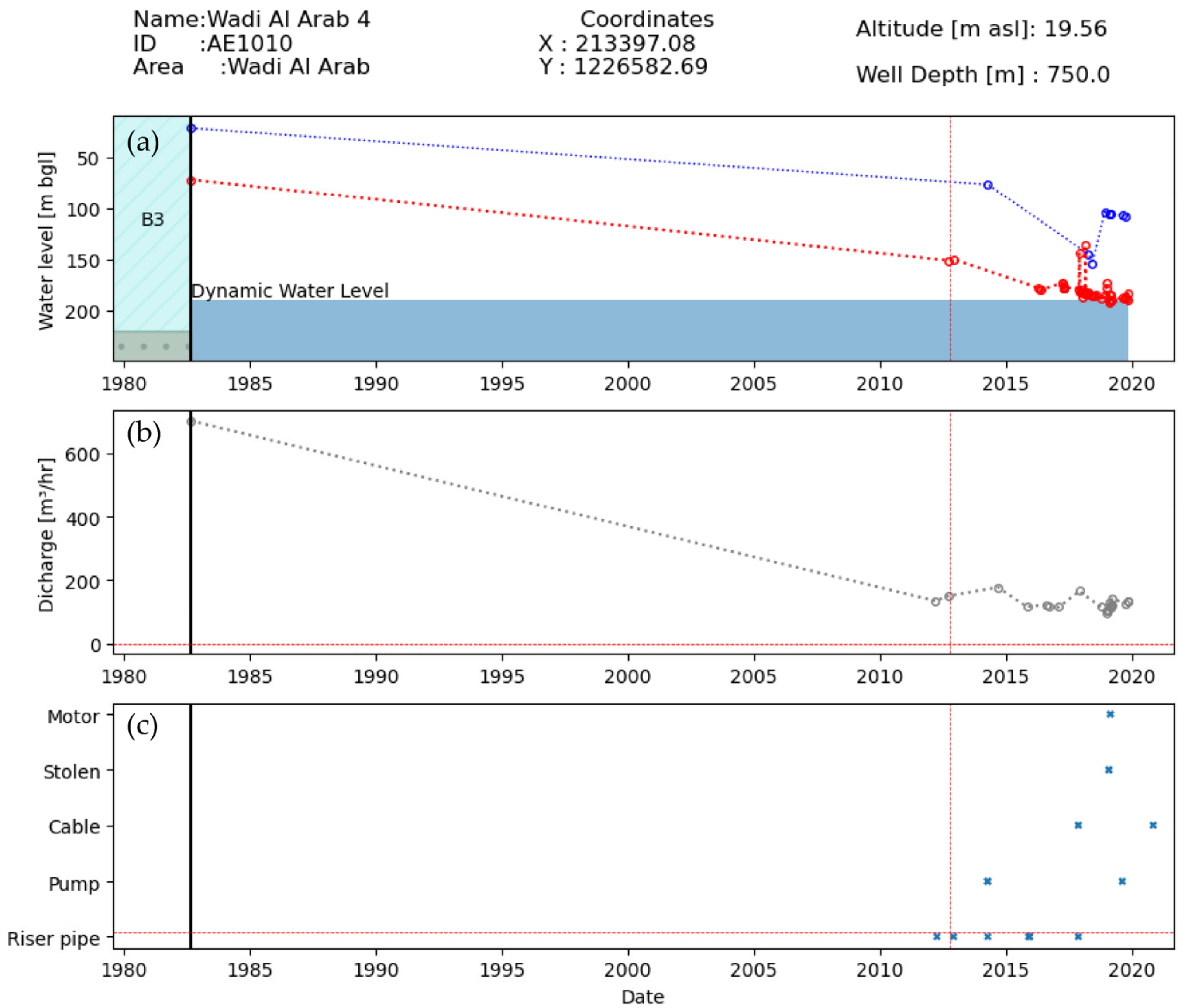

Figure 6. Wadi Al Arab 4 (AE1010) diary graph as part of the OBT. (**a**) The change in groundwater level (blue dots represent the SWL and red dots represent the DWL) since the drilling of the well, the lithological units of the well, (**b**) the changes in the discharge (m^3/h) over the same period, and (**c**) the reasons behind interrupting the well's operation over time. The red cursor is to link the three figures (**a**–**c**) visually.

4.3. Identification of a Suitable Location for a New Well

When the data availability checklist was applied to select the appropriate ROI method on the Wadi Al Arab wells, the results showed that any of the currently implemented ROI calculation methods in the RBT is applicable to the case study.

In this exercise, we can observe the importance of bridging together the different components of DeMa. The Wadi Al Arab wells did not pass the criteria mentioned above because the available lithological descriptions contained in the OBT tool indicate that the wells partially penetrated the B2A7 aquifer. To examine the confinement condition and the aquifer penetration extent of the wells lacking lithological description, they were plotted over the base of A7B2 and base B3 maps presented by Brückner [99] and contained in the DMT tool. Moreover, the bases of the hydrogeological units were compared with the depth of the wells to check the aquifer penetration extent and with the water level to check the confinement conditions. This information is readily available for the wellfield manager since it is collected in the OBT tool. As can be noticed in Table 3, the two wells that might be fully penetrating the A7B2 aquifer are under unconfined conditions; therefore, this concludes that none of the existing wells is eligible to be applied with the methods presented in the current version of the RBT to calculate the ROI.

Table 3. Confinement condition and penetrating extent test for the Wadi Al Arab wells with no lithological description.

Well ID	Well Elevation	Well Depth	Elevation of Base of A7	Fully Penetrating the Aquifer?	Confinement Condition
AE3005	−14.89	243	−632	No	Confined
AE3006	79.29	260	−329	No	Unconfined
AE3016	85.63	195	−276	No	Unconfined
AE3017	74.65	230	−420	No	Confined
AE3018	−40.89	230	−597	No	Confined
AE3019	104.87	304	−469	No	Confined
AE3021	70.98	347	−219	Yes	Unconfined
AE3042	104.87	450	−469	No	Confined
AE3043	109.59	450	−287	Yes	Unconfined

Besides calculating the ROI of existing wells, the RBT supports the wellfield manager in assessing the location of proposed new wells to avoid significant interference with other existing wells based on the relative drawdown criterion equations (Equations (1)–(3)). We now assume that a hypothetical well is proposed to be drilled and fully penetrate the A7/B2 aquifer. The proposed location is to the east of Wadi Al Arab 4 (AE1010), where the hydraulic condition is confined; the wellfield manager would be able to define the minimum distance from the Wadi al Arab well by calculating the expected ROI of the hypothetical well shown in Figure 1d.

In the Wadi Al Arab confined area, the storativity is 0.001 [100,101], while the transmissivity is 9 m^2/day [101], and such information is easily accessible thanks to the DMT and OBT tools. According to Salameh et al. [10], the rainy season in Jordan, which corresponds to the groundwater recharge, starts in October and ends in April. Therefore, we consider that the pumping time under stationary water level is during the summer (i.e., between May and September, 152 days). The typical diameter of the well in the wellfield is 17.5 inches (0.4445 m), and we assume that the maximum ROI acceptable by the water manager should not exceed 500 m, which would otherwise interfere with the ROI of Wadi Al Arab 4. The expected drawdown was considered 20 m in the proposed well according to typical drawdown values observed in the wellfield.

Figure 7 shows that after 152 days of pumping, the ROI of the proposed well is expected to reach 750 m, 1290 m, and 2480 m, where the drawdown at the ROI is 2 m, 1 m, and 0.2 m, respectively. After 60 days of pumping, the drawdown of 2 m would interfere with the Wadi Al Arab 4 ROI; such an observation will assist the wellfield manager in deciding whether the proposed location is suitable. For this hypothetical case, the wellfield manager will propose to shift the well toward the east by at least 250 m or to amend the pumping schedule to avoid significant interference between the ROIs. However, to correctly interpret the results, the assumptions for the application of the proposed analytical solutions mentioned previously should be carefully considered. To achieve better and more accurate results, the specialists could use more sophisticated models that consider the aquifer heterogeneity, geometry, topography, and boundary conditions (e.g., MODFLOW [102] and FEFLOW [103]). However, the provided solutions can be used as a simple-to-use estimate of the ROI.

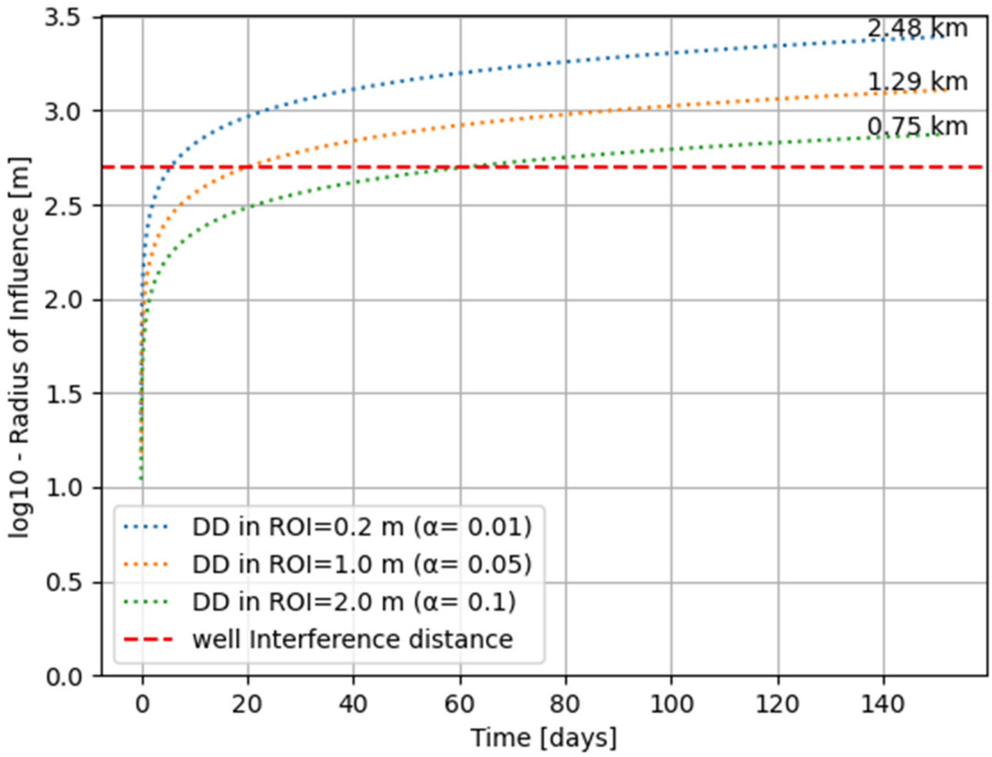

Figure 7. The application of the RBT for defining the ROI of the hypothetical well north of Wadi Al Arab 4.

5. Discussion and Outlook

A fundamental component of the software is the construction of the relational database. Indeed, the relational database is designed to ensure data consistency across different tables, allowing for quick retrieval of the well's data and aiding in automating the creation of user-friendly infographics and visualizations by the OBT. The produced graphics support the user in finding data gaps and provide an overview of the current status of a well within a wellfield, aiming to make data-driven decisions possible and simple (e.g., the pump in AE3020 cannot be further deepened due to the lack of blank sections in the lower part of the well in range of 165–304 m depth). The DMT assists in generating knowledge from the collected data. For instance, after uploading to the database the information collected by the water company in separated and unstructured Excel sheets, it was shown that four wells (AE1007, AE1008, AE1009, AE3027) lack some data related to "basic data table", so the database was updated through fast and easy access to the completion reports of the Wadi Al Arab wells. An overview of the missing data was reflected in the OBT by providing accurate visualizations of the current status of the well and the well's diary graph. The DMT also supports the research-based tool by providing a list of conducted research documents in the wellfield area (e.g., [100,101]), which can be used to identify the needed parameters (e.g., transmissivity, storativity) to calculate the radius of influence for a well in the area or any proposed wells. Accordingly, scientifically informed decisions are made.

Furthermore, we expect that providing a table of available and missing documents would encourage the user to fill in the gaps. For example, if the table presenting available CCTVs reports shows that the AE1007 has no CCTV report, although the wellfield manager is aware that a CCTV activity was conducted for this specific well, then, the manager can seek to locate and upload the report to the DMT. The previous discussion concluded that besides the benefits provided within each tool, DeMa presented that the interconnection between the four tools of DeMa are useful for data management, including the support for data availability, data accuracy and identification of missing data. For example, in the case application, we observed that certain data related to the wells (e.g., the installed motor models, riser pipe material) still need to be investigated and uploaded to the DbMT. The number of research project reports added to the DMT is probably less than the number of projects conducted in the area. It is expected that the application of DeMa by the end-users will improve data and document availability and accuracy in the study area.

Software enhancements are planned for future releases of DeMa. Mainly, (i) additional data frames related to water quality data will be added to the database, (ii) further features and analyses (e.g., water corrosivity graph) will be built into the OBT to support the wellfield manager with consideration of water quality data in the decision-making process, and (iii) the inclusion of big data analyses collected from the sensor-equipped monitoring systems of wells. Additionally, there is ample room for further development of the RBT by adding more research outcomes that support the user to determine the radius of influence in a partially penetrated aquifer (e.g., [104]) to define the best location of wells and water reservoirs for pumping cost minimization (e.g., [93,94,105]), and to analyze the pumping tests of a well (e.g., [92]). Furthermore, the future version of the software will include the option to calculate the ROI of the wells under unconfined conditions, and most probably, we will use the Dupuit formula and Thiem formula [106].

6. Conclusions

This article presented DeMa (Decision Support Software and Database for Wellfield Management) and showcased its application for the Wadi Al Arab wellfield. DeMa is a comprehensive software for managing the information about a groundwater wellfield and hence supports the decision-making process of the wellfield manager. DeMa contributed to identifying missing documents and data for the wellfield, the wells' maintenance needs, and suitable locations for new wells. The DbMT provided a comprehensive database of all available data associated with the Wadi Al Arab wellfield, which can be updated and used by wellfield managers and technicians in various departments within the water company to improve the data flow.

The data and the results from the different analyses can be visualized by the OBT and linked with the documents (e.g., CCTV, completion reports, invoices) in the DMT. These features may be relevant for water companies, given that the software can be directly used to enrich the DbMT and DMT and prevent information losses in the future. Furthermore, the OBT assists well managers in identifying missing data and information by including all the project documents in one location and by grouping them by keyword tags. Hence, DeMa supports the transformation of data into information enabling the wellfield manager to sustainably predict and manage the well needs and identify areas with gaps. In addition, the RBT aims to facilitate the use of recent scientific outcomes by practitioners. The DeMa software provided a digital solution for (i) a better understanding of the data availability to support decision making for the wellfield and (ii) improved information and data management of the Wadi Al Arab wells. These are prerequisites to achieving improved groundwater management and moving towards data-driven decisions.

Some documents and data (e.g., financial-related data and information) were not shared as they contained sensitive and confidential information; therefore, we could not apply DeMa functions to conduct maintenance and operational cost analyses. Furthermore, the current version of DeMa does not provide features to include and analyze water quality data that aid the user in the water quality-related decision-making processes.

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