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SOFTWARE SOLUTIONS FOR ANALYZING DATA OBTAINED FROM STEP DRAWDOWN TEST

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Abstract

Step-drawdown tests play a critical role in determining the hydraulic properties of aquifers and in the management of groundwater resources. The data obtained from these tests allow for the analysis of parameters such as aquifer hydraulic conductivity, specific yield, and storage coefficient. However, accurate and rapid interpretation of this data often requires complex calculations and comprehensive data management. In addition to traditional methods, software-based solutions today play an important role in optimizing these processes. In this study, a software application was developed using the Visual Basic programming language to accelerate the analysis of data obtained from step-drawdown tests and to facilitate more effective decision-making processes through data visualization. The proposed solution not only saves time but also increases the accuracy of analysis. This article aims to emphasize the importance of step-drawdown tests and to detail the contribution of the developed software to these processes. The dataset used in the study was obtained from step-drawdown tests conducted as part of the Liwa Project. The Liwa Region is located 150 km southwest of Abu Dhabi City, United Arab Emirates (UAE).

Keywords: Step-Drawdown Test, Aquifer, Visual Basic, Software, Liwa, UAE

KADEMELİ POMPA TESTİNDEN ELDE EDİLEN VERİLERİN ANALİZ EDİLMESİ İÇİN YAZILIMSAL ÇÖZÜMLER

Özet

Kademeli pompa testleri, akiferlerin hidrolik özelliklerinin belirlenmesinde ve yeraltı suyu yönetimi süreçlerinde kritik bir öneme sahiptir. Bu testler sonucunda elde edilen veriler, akifer hidrolik iletkenliği, özgül verim ve depolama katsayısı gibi parametrelerin analiz edilmesini sağlar. Ancak, bu verilerin doğru ve hızlı bir şekilde çözümlenmesi, genellikle karmaşık hesaplamalar ve kapsamlı veri yönetimi gerektirmektedir. Geleneksel yöntemlerin yanı sıra, günümüzde yazılımsal çözümler bu süreçleri optimize etmekte önemli bir rol oynamaktadır. Bu çalışmada, Visual Basic programlama dili kullanılarak, kademeli pompa testlerinden elde edilen verilerin analizini hızlandıran ve sonuçları görselleştirerek daha etkili karar alma süreçlerine olanak tanıyan bir yazılım geliştirilmiştir. Önerilen çözüm, hem zaman tasarrufu sağlamakta hem de analiz doğruluğunu artırmaktadır. Bu makale, kademeli pompa testlerinin önemini ve geliştirilen yazılımın bu süreçlere olan katkısını detaylandırmayı amaçlamaktadır. Çalışma kapsamında kullanılan veri seti Liwa Projesi'nde yapılmış olan kademeli pompa testlerinden elde edilmiştir. Liwa akiferi 80 metre kalınlığa sahip serbest bir akifer olup kum, kumtaşı ve karbonatlı birimlerden oluşmaktadır. Liwa Bölgesi, Abu-Dhabi Şehri'nin (BAE) 150 km güneybatısında yer almaktadır.

Anahtar Kelimeler: Kademeli Pompa Testi, Akifer, Visual Basic, Yazılım, Liwa, BAE

Cite

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1. Introduction

In hydrogeological studies, pumping tests are commonly used to determine aquifer properties such as hydraulic conductivity, specific yield, and storage coefficient. In order to manage water resources efficiently, the data obtained from pumping tests must be represented using reliable models [1]. The water scarcity experienced in the world has recently become a major issue in scientific studies on water from different perspectives [2-9].

Mathematical solutions play a crucial role in hydrogeological analyses and in the interpretation of pumping tests [10]. However, these solutions often require complex equations, numerous parameters, and detailed data. As a result, manual calculations can be time-consuming and prone to errors. Software tools offer powerful solutions to overcome these challenges [11]. For instance, software used for analyzing data obtained during step-drawdown pumping tests can rapidly and accurately solve mathematical equations, generate graphs based on the resulting data, and allow for the precise evaluation of parameters [12]. Additionally, thanks to their user-friendly interfaces, software tools make these analyses accessible to a wider audience and support decision-making processes through visual representation of the results [13]. Custom software developed using programming languages such as Visual Basic (Excel VBA) can be adapted to the specific needs of the application, making the analysis process more efficient. Therefore, conducting mathematical solutions via software saves time and resources while enhancing the accuracy and reliability of the results [14]. To clarify the scope of this study, it is important to note that the primary objective is not to compare alternative software tools or evaluate their predictive accuracy. Instead, the study aims to introduce a user-friendly Excel VBA-based application that facilitates the implementation of the Rorabaugh (1953) method, making it more accessible for practitioners. Within the scope of this study, software-based approaches will be presented to analyze data sets obtained from step-drawdown pumping tests using the Rorabaugh (1953) [15] method, which accelerates the analysis process and enhances the reliability of results by eliminating manual calculations. Visual Basic was chosen as the programming language for the developed software. The primary reason for this choice is its ease of use and the ability to integrate Microsoft Excel with VBA (Visual Basic for Applications) tools. Additionally, Excel VBA, being the built-in programming language of Microsoft Excel, enables users to write macros that automate workflows and go beyond the standard functions of Excel [16]. These powerful macros capabilities of Excel VBA, built upon fundamental application development principles, significantly speed up data analysis processes by automating repetitive tasks [17,18]. VBA is used to speed up repetitive tasks, develop custom functions, and interact dynamically with Excel objects [19]. Widely used in fields such as finance, data analysis, and engineering, VBA allows users to work more effectively with large datasets and integrate Excel with other Microsoft Office applications [20]. Understanding the fundamental programming principles of VBA is crucial for developing custom analysis tools within the Excel environment [21]. In this study, the mathematical formulas of the Jacob (1947) [22] and Rorabaugh (1953) [15] methods were coded using Visual Basic, and through a template prepared in Excel, the study demonstrates how these methodologies were automated, moving away from manual calculations. Since the data set analyzed using the Rorabaugh (1953) [15] method was obtained from a step-drawdown test, it is essential that the step-drawdown test was conducted following an appropriate procedure. Step-drawdown pumping tests are single-well tests commonly used to distinguish between the laminar and turbulent components of the total drawdown and to determine the aquifer loss and well loss parameters [23]. During step drawdown tests, different constant discharge rate series (example: 10, 20, 30, 40 and 50 m3/h) are gradually increased with equal time intervals as in the example, and increasing water drawdowns in the pump well are obtained [24]. The drawdown observed in the pumping well after the pump is activated is expressed as Sw. The total drawdown (Sw) is proportional to the discharge rate (Q) and consists of two components [25].

Jacob (1947) [22] was the first to introduce the concepts of “aquifer loss” and “well loss” related to these components. Aquifer loss (BQ) represents head losses due to laminar flow within the aquifer and is directly proportional to the discharge rate (Q).

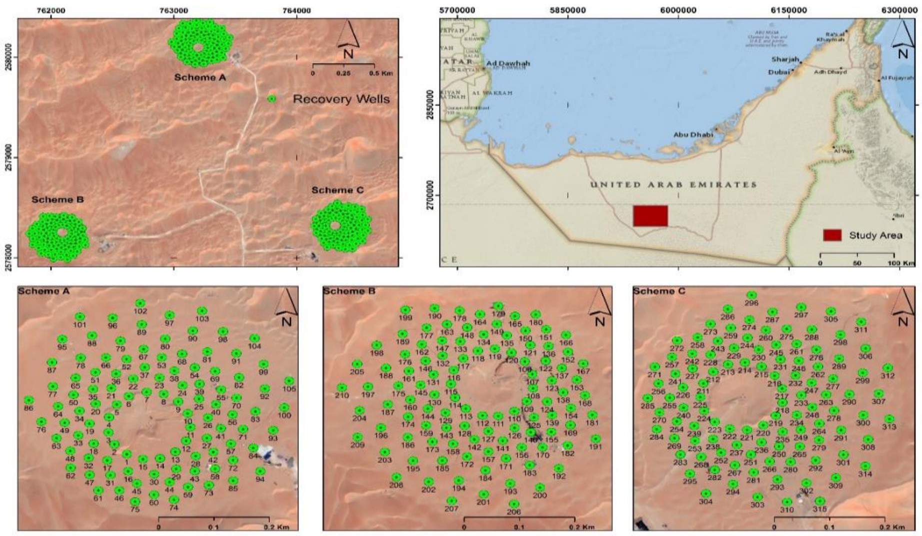

Figure 1. Study Area and Production Wells (Represents Green Circles).

Well loss (CQ^P), however, is a nonlinear term and represents the turbulent flow near and inside the well. At high pumping rates, the well loss can be significantly greater than the aquifer loss [26]. Jacob proposed that well loss is proportional to the square of the discharge rate and expressed it as CQ^2. Rorabaugh (1953) [15] modified Jacob's model by generalizing the exponent of the well loss term to a parameter p, which may be greater than 2. In Jacob's proposed model, the well parameters are calculated analytically, making the determination of the B and C parameters quite practical [27]. However, as mentioned above, for the more complex methodology of the Rorabaugh (1953) [15] approach, software-based solutions offer considerable advantages. The dataset used in this study was obtained from step-drawdown pumping tests conducted as part of the Liwa Project. The Liwa Project, implemented within the strategic framework of the United Arab Emirates, aims to store groundwater in the Liwa Aquifer located in the Liwa Region and to meet the drinking water needs of the city of Abu Dhabi. The Liwa Aquifer is an unconfined aquifer with an average thickness of 80 meters, composed of geological units such as sand, sandstone, claystone, siltstone, and carbonate rocks [28]. Within the scope of the project, a total of 432 boreholes were drilled, including 315 production/injection wells, 27 observation wells, and 90 clustered wells (Figure 2). Treated seawater is injected into the production wells for storage in the Liwa Aquifer and extracted when needed.

2. Methods and Materials

2.1. Jacob Method

If the dataset obtained from the step-drawdown pumping test is to be analyzed using the Jacob (1947) method, diagnostic graphs are utilized. In this context, the S_w/Q values for each step are plotted against the corresponding Q values on an arithmetic graph. Here, Q represents the discharge rate, and S_w indicates the total drawdown measured at the end of each step (Example: Sw1, Sw2, Sw3, …$S_w$laststep). Since Jacob assumes the value of the exponent P as 2, the drawdown equation is accepted as $S_w = BQ + CQ^2$. According to this methodology, the B and C parameters can be directly obtained from the diagnostic graph of S_w/Q versus Q. This graph results in a straight line where the slope corresponds to C. The B value can then be determined from the y-intercept of this line when Q = 0 [25].

2.2. Rorabaugh Method

If the dataset from the step-drawdown pumping test is to be analyzed using the Rorabaugh (1953) method, the drawdown equation parameters (B, C, and P) cannot be directly obtained from a diagnostic graph because, when the exponent P differs from 2, the graph of Sw/Q versus Q does not yield the P parameter. In this case, the drawdown equation is expressed as Sw = BQ + CQP. Rearranging the equation and taking the logarithm of both sides results in the expression:

log (Sw/Q - B) = log(C) + (P - 1) log(Q) This equation implies that plotting log (Sw/Q - B) against log(Q) on a logarithmic scale yields a straight line. The slope of this line corresponds to (P - 1), while the C parameter can be determined from the y-intercept when Q = 1. To solve this equation, the B parameter must be provided manually. With a suitably chosen B value, the plotted points nearly form a straight line [25]. Finding the most appropriate B value until the best-fit line is achieved is of great importance. An inaccurate B value would result in discrepancies between the measured drawdown and the calculated drawdown, as it would not produce the best-fit line between Sw/Q - B and Q.

2.3. Software–Based Approach

The developed software was evaluated based on key criteria such as usability, calculation speed, and the accuracy of parameter estimation, with a focus on providing a practical tool for field applications. As indicated above, determining the appropriate B value in the Rorabaugh method can be time-consuming. Especially when the Rorabaugh analysis is to be applied to multiple wells, obtaining a suitable B value for each well would be a lengthy process. The operating principle of the developed software is to continuously assign values to the B variable within the equation log (S_w/Q - B) = log(C) + (P - 1) log(Q) to determine the most suitable C and P parameters. The assigned values are rational numbers greater than zero. The user inputs the acceptable difference (Sw_diff = |Sw_measured - Sw_calculated|) between the measured drawdown (obtained via probe, sensor, or pressure gauge) and the calculated drawdown (determined through the drawdown equation using the B, C, and P parameters). In this study, a threshold of 1 cm or less was accepted for the difference, and calculations proceeded accordingly. The program continues assigning values to the B parameter until the convergence condition (Sw_diff ≤ 1 cm) is met. This software performs rapid trial-and-error iterations, calculates C and P values, substitutes them into the drawdown equation ($S_w = BQ + CQ^P$), and computes the drawdown. Once the acceptable difference between the measured and calculated drawdowns is achieved (Sw_diff ≤ 1 cm), the software determines the most appropriate B parameter value.

In recent years, several studies have focused on automating the application of the Rorabaugh (1953) method or improving its practicality through software implementations [32, 33, 34 and 35]. These studies aim to simplify the analysis process or enhance result accuracy using different computational tools. The present study follows this trend by proposing a customized solution based on Excel VBA, aiming to deliver a more accessible and efficient alternative for practitioners.

3. Results

Pumping data of well RW131 were used in the study. The data obtained from the step-drawdown pumping test are entered into the appropriate rows and columns in the "Drawdowns" tab of the program's Excel-based interface. Then, by clicking the "Read Data" button in the "Main" tab, the data are retrieved into the dropdown menu. After selecting the desired well, the "Get Data" button automatically transfers the values into the corresponding table. The "B" value can be modified using the increment and decrement buttons located on the graph, or alternatively, the "Start" button initiates an iterative process that generates "B" values. The program terminates once the optimal "B" parameter is obtained, or the same process can be manually stopped using the "Stop" button. Only the cell highlighted in blue on the worksheet allows user input for the "B" value; all other cells function in coordination with embedded formulas and Visual Basic codes. The datasets provided in Table 1 and Table 2 have been analyzed separately using both the Jacob and Rorabaugh methods. Through the developed software, the analysis of step-drawdown test data has been carried out in a rapid, user-friendly, and systematic manner. The software processes the time, discharge, and drawdown data entered for each test step individually and enables automated analysis based on temporal intervals. In accordance with the user-input data, the hydraulic changes occurring during the test period are visualized graphically, thereby making the results more comprehensible (Figure 2 and Figure 3). In addition to the Rorabaugh method results, the Jacob (1947) method was also applied to the same dataset to provide a comparative perspective. This comparison aims to illustrate how the assumption of linearity (P = 2 in Jacob's model) influences the estimation of drawdown parameters compared to the nonlinear Rorabaugh approach. Including both methods under identical conditions helps to emphasize the difference in model behavior and its implications for parameter interpretation.

Table 1. Step Drawdown Test Data for Jacob (1947) method (Well ID: RW131). The table presents drawdown values and calculated S_w/Q ratios for each pumping step to facilitate the estimation of B and C parameters through diagnostic graphing.

#	Sw_{max}	$Q_{average}$	$Q_{average}$	S_w/Q
	metre	m^3/hour	m^3/day	
Step 1	2.40	30.30	727.20	3.30E-03
Step 2	4.80	60.20	1444.80	3.32E-03
Step 3	7.30	90.10	2162.40	3.38E-03
Step 4	10.10	120.10	2882.40	3.50E-03
Step 5	13.30	150.00	3600.00	3.69E-03

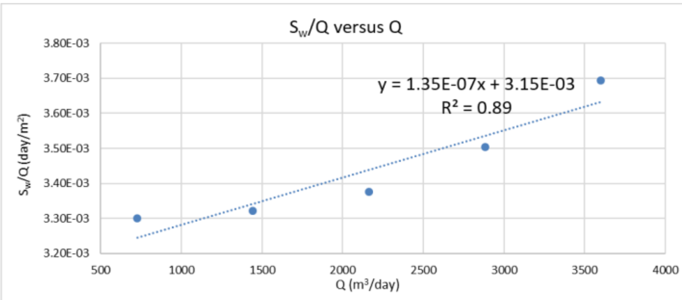

Figure 3. Sw/Q versus Q values.

When Jacob method is applied, B and C values are directly obtained from the graph, the value of 1.35E-07 days^2/m^5 represents the C parameter, and the value of 3.15E-03 days/m^2 represents the B parameter. To enhance readability, the C parameter is multiplied by $(86400)^2$, resulting in 1007.77 seconds^2/m^5, and the B parameter is multiplied by 86400, resulting in 272.16 seconds/m^2.

Table 2. Step Drawdown Test Data for Rorabaugh (1953) method (Well ID: RW131). The table includes measured drawdown values and calculated S_w/Q and S_w/Q–B values, which are used to determine B, C, and P parameters through logarithmic fitting.

#	$Q_{average}$	$Q_{average}$	Sw_{max}	S_w/Q	S_w/Q-B
	m^3/hour	m^3/day	metre	(day/m^2)	
Step 1	30.30	727.20	2.40	3.30E-03	2.88E-06
Step 2	60.20	1444.80	4.80	3.32E-03	2.48E-05
Step 3	90.10	2162.40	7.30	3.38E-03	7.84E-05
Step 4	120.10	2882.40	10.10	3.50E-03	2.07E-04
Step 5	150.00	3600.00	13.30	3.69E-03	3.97E-04

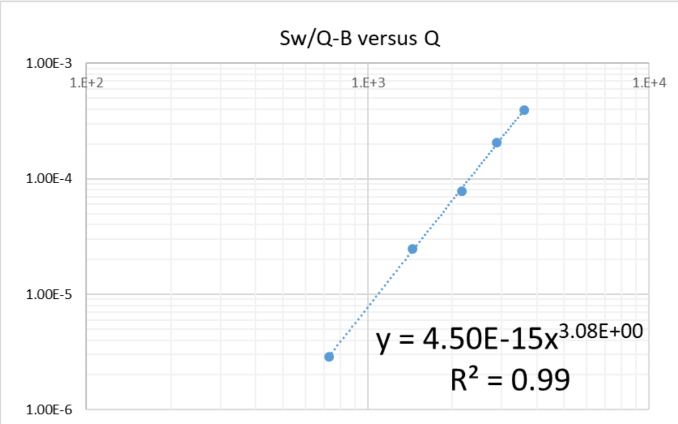

Figure 4. S_w/Q-B versus Q values.

In order to solve the equation, the B parameter was manually assigned. In the Rorabaugh method, determining a suitable B value is quite challenging on the first attempt. In fact, identifying the optimal B value that will allow the best-fit line to pass through the points representing the values of Q against Sw/Q - B via trial-and-error may take some time. For this analysis, the manually determined value was B = 0.0033 day/m². For better readability, this value can also be expressed as B = 284.9 seconds/m². As a result of the calculations performed using the Rorabaugh (1953) method, the well drawdown equation can be expressed as $S_w = 284.9Q+612356.1Q^{4.08}$. To provide a comparative perspective, the same dataset was also analyzed using the Jacob (1947) method. As shown in Table 1 and Figure 2, this method yields B and C parameters based on the assumption of a quadratic relationship between drawdown and discharge (P = 2). In contrast, the Rorabaugh (1953) method implemented in the developed software offers a more flexible fit, particularly when the drawdown data exhibit a higher degree of non-linearity. Therefore, while the Jacob method may be sufficient in linear conditions, the Rorabaugh-based software provides more accurate and adaptable results in non-linear scenarios.

Table 3. Calculations according to Rorabaugh (1953) Method.

Slope of the Line		Trend Line		Parameter of C	
Log((S_{w1}/Q_1 - B)/(S_{w5}/Q_5 - B))	-2.1399	X	10000	log(y)	-2.03
Log(Q1/Q5)	-0.6946	Coefficient	4.40E-15	log(y) - 4logcycle	-14.36
(P-1)	3.08	Power	3.08	C (day^p/m^{3p-1})	4.40E-15
P	34.08	y	0.01	C (s^p/m^{3p-1})	612353.5
4 logCycle (P-1) * 4	12.32				

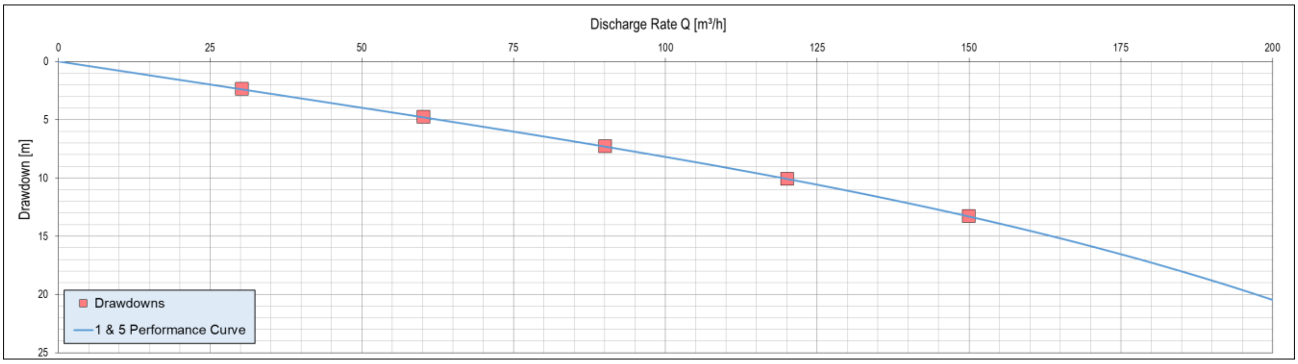

Figure 5. Well Performance Curve.

Additionally, the software generated the discharge–drawdown curve based on the B, C, and P parameters calculated using the Rorabaugh method, thereby revealing the performance characteristics of the pump. The automated calculation and the generation of the well performance graph (Figure 4) significantly reduced the analysis time.

4. Discussion

Some limitations of this study should not be overlooked. The developed software currently supports only the Rorabaugh method with five pumping steps. By developing similar software for different step numbers and pumping test methods, a broader application range can be offered for hydrogeological investigations. Furthermore, the user-friendly interface of the software could enable its use by a wider user base. In its current form, the program is presented as an Excel template integrated with Visual Basic codes running in the background. The flexible utilization possibilities of VBA within Office applications, as a foundation for application development, have allowed for the creation of customized software solutions in various disciplines [18,29].

In future studies, it is possible to transform the software into a more comprehensive hydrogeological analysis tool by adding new features. For example, specific analysis algorithms for different aquifer types could be integrated, or compatibility with Geographic Information Systems (GIS) could be achieved to present the results in a more visual format. In this way, the software could become usable not only by researchers but also by engineers and decision-makers. Additionally, by using different programming languages, the performance of the software could be further improved. The Visual Basic codes and Excel template are presented as an appendix. The effective use of VBA and macros for Microsoft Excel, grounded in established development practices, can significantly increase efficiency in data processing and analysis workflows [29,30]. The developed software is designed in a way that allows for adaptability across various hydrogeological settings. Since the Rorabaugh (1953) method is applicable to any aquifer where step-drawdown test data can be obtained, the software can be used in environments with different hydraulic conductivity or storage coefficient values. The only requirement is to enter accurate step-test data in the provided Excel fields. No specific calibration for the Liwa aquifer has been hard-coded into the tool, and users can input data from other regions. Therefore, the program is suitable for general application and can be adapted to new datasets without structural modification.

5. Conclusion

In this study, a software tool was developed to accelerate and automate the analysis of data obtained from step-drawdown pumping tests. Created using the Visual Basic for Applications (Excel VBA) programming language, the software significantly enhances the efficiency of the analysis process by simplifying the complex calculations required by the Rorabaugh method. The results indicate that the software meets expectations in terms of both accuracy and speed.

The code blocks within the software operate based on the Rorabaugh methodology. In other words, an automatic assignment loop for the variable B, a key parameter in the Rorabaugh method, has been implemented using Visual Basic. While it is possible to reach similar results through manual trial and error, the key advantage of the software lies in its iterative assignment of B values. Iteration refers to the repeated execution of a code block or operation until a specific condition is met. Through this process, the optimal values of B, C, and P parameters are obtained rapidly and reliably. As shown in Table 3, the results obtained manually can also be computed within seconds using the developed software.

Additionally, the software calculates the B, C, and P parameters based on the Rorabaugh method and generates a performance curve representing the relationship between discharge and drawdown. This curve provides a detailed understanding of the hydraulic behavior of the pumping well. Given its Excel-based structure and user-friendly design, the proposed software is especially suitable for field engineers and hydrogeologists seeking quick evaluations without the need for complex programming skills or specialized commercial software. Furthermore, the automation of calculations and the generation of a well performance graph (Figure 4) by the software not only speeds up the analysis process but also reduces the potential for user error, thereby increasing the reliability of the results.

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