Assessment of Irrigation Modernization Using Solar-Powered Pressurized Pipe-Line System in Egypt

Study Report

EL MURUNAH PROJECT

Centre for Environment & Development for
the Arab Region and Europe (CEDARE)

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Executive Summary

This report was prepared within the framework of national efforts to improve water-use efficiency in Egyptian agriculture, particularly in light of the growing challenges facing water security in the Nile Delta region. The West Nile Delta, one of the most productive agricultural areas in Egypt, is experiencing increasing pressure on water resources due to declining per capita water availability, inefficiencies in traditional irrigation systems, and significant water losses through evaporation and seepage.

In this context, the present study aims to evaluate the actual performance of traditional surface irrigation systems and compare them with a modern irrigation system based on a solar-powered pressurized pipeline network. The study was conducted in a 20-feddan experimental field where a comprehensive assessment of hydrological, agricultural, environmental, and economic parameters was carried out before and after irrigation modernization.

A systematic monitoring program combining field measurements and quantitative data analysis was implemented during the period February 2025 to January 2026, covering both the pre-modernization and post-modernization phases. The monitoring program included groundwater level and salinity measurements using observation wells distributed across the field, monitoring of water levels and salinity within the subsurface drainage network, and assessment of the surrounding canals that partially function as open drainage outlets. The program also included estimation of lateral seepage toward irrigation canals, quantification of deep percolation below the crop root zone using multi-depth piezometers, analysis of soil chemical properties, documentation of cropping patterns and productivity, and monitoring of actual irrigation practices and applied irrigation water volumes.

Irrigation Water Management and Efficiency

Results indicated that the traditional irrigation system, which relies on open earthen mesqas and diesel-powered pumps, suffers from irregular water distribution among fields. Irrigation water application largely depends on farmers' experience and pump operating duration, resulting in substantial variation in applied irrigation water volumes. Consequently, significant water losses occurred through lateral seepage and deep percolation, leading to relatively low irrigation efficiency.

Under the traditional system, the average irrigation efficiency was approximately 42.3%. After the implementation of the improved irrigation system based on pressurized pipelines and solar-powered pumping units, irrigation efficiency increased significantly to an average of 58.5%, representing an improvement of about 16 percentage points or a 38% relative increase in irrigation performance.

Hydrological and Environmental Impacts

Monitoring results showed that irrigation modernization contributed to improved groundwater stability by reducing excessive irrigation events that previously caused rapid groundwater rise. In addition, lateral seepage from agricultural fields toward surrounding irrigation canals decreased by approximately 41%

following irrigation improvement. Similarly, deep percolation losses below the root zone decreased by approximately 60–70%, indicating more efficient water application and improved soil–water balance.

Economic Benefits of Irrigation Modernization

Although the initial capital investment of the improved irrigation system was approximately 2.97 million EGP, compared with about 500,000 EGP for the traditional system, the economic analysis demonstrated substantial reductions in annual operating costs.

Under the traditional irrigation system, annual operating costs were estimated at approximately 288,000 EGP, primarily due to diesel fuel consumption, pump maintenance, and labor requirements. In contrast, the solar-powered irrigation system reduced annual operating costs to approximately 24,000 EGP, as it eliminates fuel consumption and significantly reduces labor and maintenance requirements. This represents an operational cost reduction exceeding 90% compared with the traditional irrigation system.

Reduction of Fossil Fuel Consumption and Carbon Emissions

The traditional irrigation system relied on ten diesel-powered pumping units, resulting in continuous fuel consumption and associated carbon dioxide emissions. By replacing these pumps with solar-powered pumping systems, the improved irrigation system effectively eliminated diesel consumption for irrigation operations within the study area. This transition contributes to substantial reductions in carbon emissions and supports the transition toward low-carbon agricultural systems, consistent with national climate change mitigation strategies.

Strategic Implications

The findings of this study demonstrate that irrigation modernization using pressurized pipeline networks powered by solar energy represents an effective solution for improving agricultural water management in the Nile Delta. The improved system contributes to higher irrigation efficiency, lower operating costs, reduced pressure on drainage systems, decreased dependence on fossil fuels, and improved environmental sustainability.

Consequently, expanding irrigation modernization programs represents a strategic pathway for enhancing water security, increasing agricultural productivity, and promoting sustainable water resource management in Egypt.

الملخص التنفيذى

يأتي هذا التقرير ضمن إطار الجهود الوطنية الرامية إلى رفع كفاءة استخدام الموارد المائية في الزراعة المصرية، خاصة في ظل التحديات المتزايدة التي تواجه الأمن المائي في منطقة دلتا النيل. وتشهد منطقة غرب الدلتا – وهي من أكثر المناطق الزراعية إنتاجية في البلاد – ضغوطاً متزايدة على الموارد المائية نتيجة تراجع نصيب الفرد من المياه، وتدهور كفاءة نظم الري التقليدية، وارتفاع معدلات الفواقد بالتبخر والتسرب. وفي هذا السياق، تهدف الدراسة الحالية إلى تقييم الأداء الفعلي لنظم الري السطحي التقليدية ومقارنتها بنظام ري حديث يعتمد على شبكة أنابيب مضغوطة تعمل بالطاقة الشمسية، وذلك في منطقة تبلغ مساحتها ٢٠ فداناً.

وقد شملت الدراسة تقييماً متكاملاً للجوانب الهيدرولوجية والزراعية والبيئية والاقتصادية، حيث تم رصد خصائص المياه الجوفية السطحية والصرف الزراعي، وتحليل الفواقد المائية الأفقية والرأسية، إضافة إلى تقييم الخواص الكيميائية للتربة والإنتاجية المحصولية قبل وبعد تنفيذ مشروع تطوير الري. ويُعد هذا التقييم أساساً علمياً لبناء قاعدة بيانات دقيقة تسمح بمقارنة أداء النظم التقليدية والحديثة وقياس العائد الفني والاقتصادي والبيئي لعمليات تطوير الري.

تم تنفيذ برنامج المتابعة بأسلوب منهجي يجمع بين القياسات الحقلية والتحليل الكمي للبيانات خلال الفترة من فبراير ٢٠٢٥ وحتى يناير ٢٠٢٦، بما يغطي مرحلتي ما قبل التطوير وما بعد تشغيل النظام المطور. وشمل البرنامج رصد مناسيب وملوحة المياه الجوفية السطحية باستخدام آبار ملاحظة موزعة داخل الحقل، وقياس مناسيب المياه وملوحتها داخل شبكة الصرف المغطى، ومتابعة سلوك القنوات المحيطة بالمنطقة والتي تعمل جزئياً كمصارف مفتوحة، إضافة إلى تقدير كميات التسرب الجانبي نحو هذه القنوات وحساب معدلات الرشح العميق أسفل منطقة الجذور باستخدام أجهزة قياس متعددة الأعماق. كما شمل البرنامج تحليل الخواص الكيميائية للتربة على أعماق مختلفة، وتوثيق التركيب المحصولي والإنتاجية، ومتابعة ممارسات الري الفعلية وكميات المياه المضافة لكل محصول.

نتائج إدارة مياه الري وكفاءة الاستخدام

أظهرت نتائج الدراسة أن نظام الري التقليدي المعتمد على المساقي المفتوحة وطلمبات الديزل يعاني من عدم انتظام توزيع المياه بين الحقول، حيث يعتمد تحديد كميات المياه المطبقة بدرجة كبيرة على خبرة المزارعين ومدة تشغيل الطلمبات. وقد أدى ذلك إلى تباين واضح في كميات مياه الري المطبقة، وارتفاع الفواقد الناتجة عن التسرب الجانبي والرشح العميق أسفل منطقة الجذور. وقد بلغ متوسط كفاءة الري في النظام التقليدي نحو ٤٢,٣ %. بعد تنفيذ نظام الري المطور القائم على شبكة الأنابيب المضغوطة والطاقة الشمسية، تحسنت كفاءة الري بشكل ملحوظ لتصل في المتوسط إلى ٥٨,٥٪، وهو ما يمثل زيادة قدرها نحو ١٦ نقطة مئوية، أي تحسن نسبي يقارب ٣٨٪ في كفاءة استخدام المياه. كما ساهم النظام المطور في تحسين انتظام توزيع المياه داخل الحقول وتقليل الفواقد المائية.

التأثيرات الهيدرولوجية والبيئية:

أظهرت نتائج المتابعة أن تحديث نظم الري أدى إلى استقرار نسبي في مناسيب المياه الجوفية السطحية وتقليل التقلبات الكبيرة التي كانت تحدث نتيجة تطبيق كميات كبيرة من المياه خلال فترات قصيرة في نظام الري بالغمر. كما أظهرت الحسابات أن التسرب الجانبي من الأراضي الزراعية نحو القنوات المحيطة انخفض بنسبة تقارب ٤١ % بعد تنفيذ النظام المطور، بينما انخفضت معدلات الرشح العميق أسفل منطقة الجذور بنسبة تتراوح بين ٦٠ و٧٠٪ مقارنة بالنظام التقليدي.

العائد الاقتصادي لتحديث نظم الري

على الرغم من أن التكلفة الاستثمارية الأولية للنظام المطور بلغت نحو ٢,٩٧ مليون جنيه مصري مقارنة بحوالي ٥٠٠ ألف جنيه للنظام التقليدي، فإن التحليل الاقتصادي أظهر أن النظام المطور يحقق وفورات كبيرة في تكاليف التشغيل السنوية. فقد بلغت تكاليف التشغيل السنوية للنظام التقليدي حوالي ٢٨٨ ألف جنيه نتيجة تكاليف الوقود والصيانة والعمالة، في حين انخفضت هذه التكاليف في النظام المطور إلى نحو ٢٤ ألف جنيه سنوياً فقط نتيجة الاعتماد على الطاقة الشمسية وعدم الحاجة إلى الوقود أو العمالة التشغيلية المكثفة. ويعني ذلك تحقيق خفض في تكاليف التشغيل السنوية يتجاوز ٩٠٪ مقارنة بالنظام التقليدي.

خفض استهلاك الوقود والانبعاثات الكربونية

كان نظام الري التقليدي يعتمد على عشر طلمبات ديزل لرفع المياه، مما يؤدي إلى استهلاك كميات كبيرة من الوقود الأحفوري وما يصاحبه من انبعاثات لثاني أكسيد الكربون. ومع التحول إلى نظام الضخ بالطاقة الشمسية تم التخلص فعلياً من استهلاك السولار في عمليات الري داخل منطقة الدراسة، وهو ما يسهم في خفض الانبعاثات الكربونية وتحقيق زراعة منخفضة الانبعاثات تتماشى مع التوجهات الوطنية لمواجهة تغير المناخ وتعزيز الاستدامة البيئية.

الدلالات الاستراتيجية للدراسة

تؤكد نتائج هذه الدراسة أن تحديث نظم الري باستخدام شبكات الأنابيب المضغوطة والطاقة الشمسية يمثل أحد الحلول الفعالة لتحسين إدارة المياه الزراعية في دلتا النيل. كما يحقق هذا التحديث مجموعة من الفوائد المتكاملة تشمل رفع كفاءة استخدام المياه، وخفض تكاليف التشغيل، وتقليل الضغط على شبكات الصرف الزراعي، والحد من الانبعاثات الكربونية، وتحسين استدامة الإنتاج الزراعي في ظل محدودية الموارد المائية.

وبناءً على ذلك، فإن التوسع في برامج تحديث الري يمثل خطوة استراتيجية مهمة لدعم الأمن المائي والغذائي وتعزيز الاستدامة الزراعية في مصر.

1. Introduction

Egyptian agriculture is currently facing increasing challenges related to limited water resources and rising water demand across different sectors, while relying almost entirely on the Nile River as its primary water source. These challenges are particularly critical in the Nile Delta, where agriculture represents a major economic activity and where most cultivated lands still depend on traditional irrigation systems characterized by relatively low efficiency, leading to substantial water losses before irrigation water effectively reaches the crop root zone. In this context, modernization and rehabilitation of agricultural irrigation systems have become a strategic necessity rather than merely a technical improvement, especially under accelerating climate change impacts, rising temperatures, and increasing evapotranspiration rates. Continued reliance on surface flood irrigation supplied through open earthen channels results in significant water losses through seepage and evaporation, while also contributing to rising groundwater levels, increased pressure on drainage systems, and gradual soil salinization within the root zone. These processes ultimately affect crop productivity and threaten the long-term sustainability of agricultural lands.

Accordingly, with funding from the British aid agency and implemented by the International Water Management Institute (IWMI), the Center for Environment and Development for the Arab Region and Europe (CEDARE), and the Ministry of Agriculture and Land Reclamation, the AL-MURUNAH Project, titled “**Building Murunah to Climate Change through Nature-Based Solutions**,” was implemented in a 20-feddan area cultivated with traditional crops and suffering from water management problems, high soil salinity, and low land productivity. Within this project, irrigation was modernized through the installation of a modern irrigation system based on water pumping through pressurized pipelines powered by solar energy, serving as an alternative to traditional irrigation practices that rely on diesel pumps. In this context, the present consultancy study was conducted to evaluate the performance of conventional irrigation practices and compare them with the modern irrigation system. The study aims to provide an integrated technical and environmental assessment of how irrigation modernization influences groundwater behavior, drainage performance, soil salinity dynamics, water losses through seepage and deep percolation, irrigation efficiency, and ultimately agricultural productivity.

A comprehensive monitoring and data analysis program was conducted, including continuous measurements of groundwater depth and salinity, monitoring of drainage system behavior, estimation of lateral and vertical water losses, soil chemical analysis, documentation of cropping patterns, and evaluation of irrigation practices and applied water quantities before and after system modernization. This approach enables a clear understanding of the interaction between irrigation management, soil and water conditions, and crop performance. The report therefore provides a reliable scientific baseline for evaluating irrigation modernization impacts on water-use efficiency and agricultural sustainability. Beyond the local scale, the findings contribute valuable practical insights for future irrigation improvement programs in similar regions. Consequently, this study supports broader national efforts toward sustainable agricultural water management, improved water productivity, and enhanced resilience of farming systems under growing water scarcity conditions.

2. Description of the Study area

The experimental site is located in Al-Hamra Village, approximately 7 km north of Abu El-Matamir and 32 km west of Damanhour, within Beheira Governorate, Egypt. The study field covers a rectangular area of approximately 400 m × 200 m, equivalent to nearly 20 feddans, and is jointly cultivated by 15 farmers using traditional agricultural practices (Figure 1).

The field is divided into two equal sections, each covering about 10 feddans. The right-hand section (RHS) is located adjacent to the 1200 Canal and the main access road, while the left-hand section (LHS) lies further inland, separated by a central dirt road. Each section is served by a traditional mesqa (field canal) supplying water for surface flood irrigation. Irrigation scheduling and water distribution are organized cooperatively among farmers through local agreements.

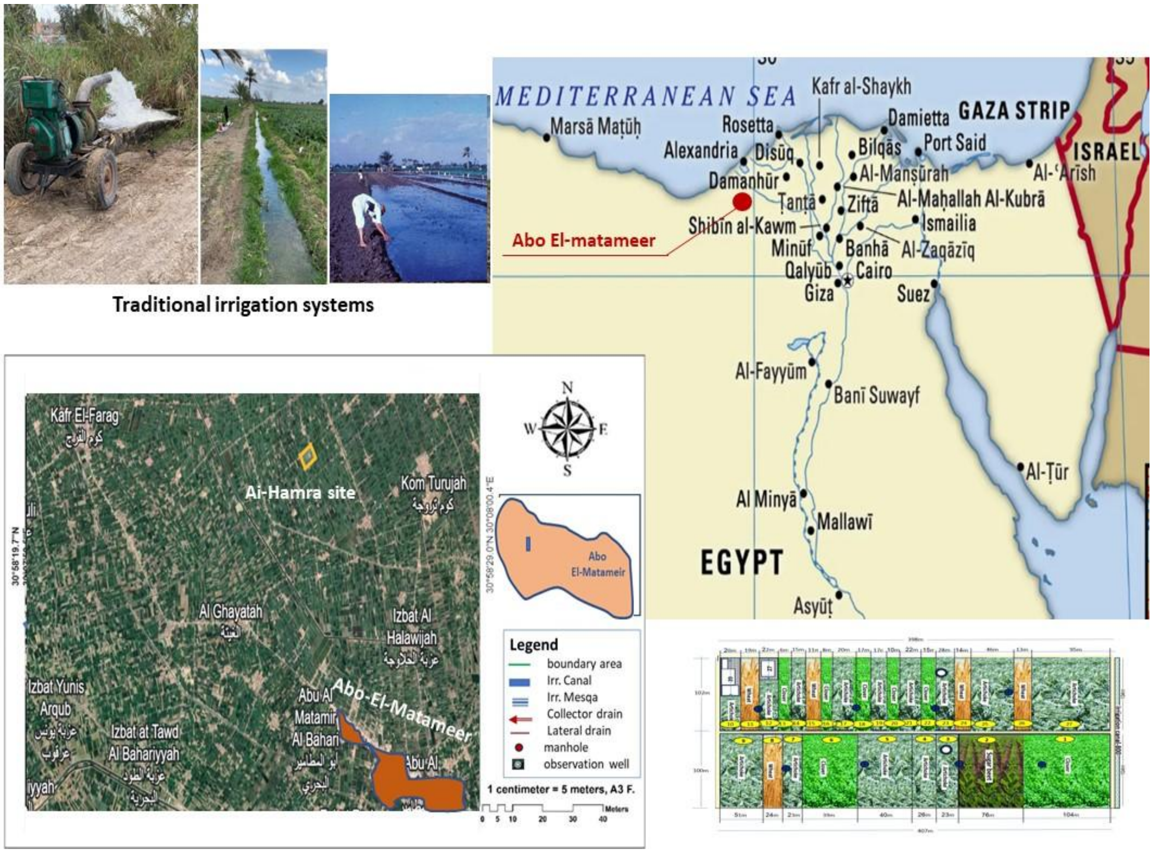

Figure 1. Location and layout of the experimental area.

1.1 Irrigation Conditions and Water Supply

Current irrigation practices represent one of the major constraints in the study area, where excessive irrigation water use has resulted in rising groundwater levels, leading to poor soil aeration, increased salinity risks, and ultimately reduced crop productivity. Irrigation in the area relies mainly on surface flood irrigation, where water is pumped using diesel-powered pumps and conveyed through open earthen mesqas to individual fields. This irrigation method is associated with significant water losses due to seepage, evaporation, and uneven distribution of water across the fields.

Water distribution among farmers often follows informal rotational arrangements, which sometimes results in irregular irrigation intervals. Consequently, farmers frequently apply large irrigation volumes in a single event to compensate for uncertain water availability. This practice increases deep percolation losses and contributes to further groundwater table rise. In addition, the open canal distribution system results in uneven water delivery, causing parts of the fields to receive excessive water while other parts may receive insufficient amounts. Such conditions negatively affect irrigation efficiency and crop uniformity. Figure 2 illustrates the traditional water conveyance system through open earthen canals supplying irrigation water to the fields, a method that remains widely used due to its low initial cost and long-standing local practice.

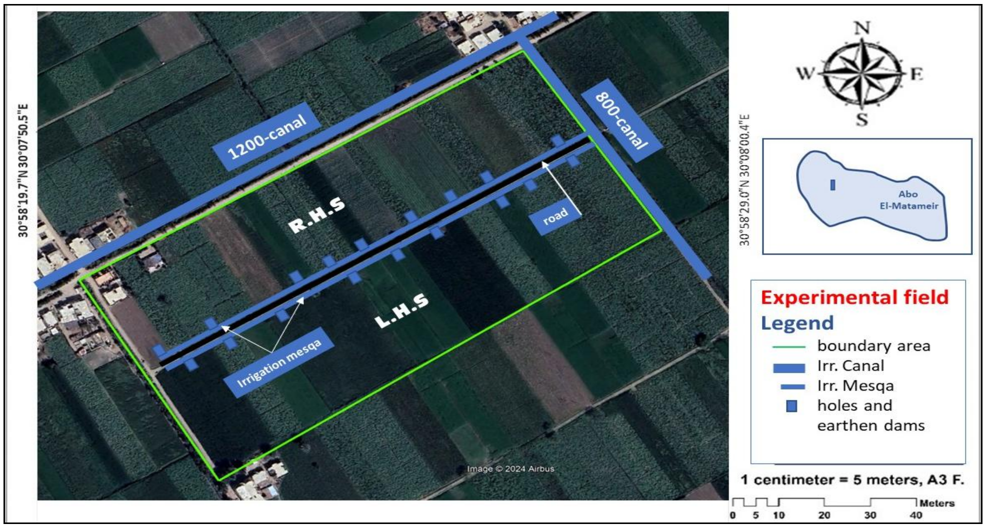

Figure 2. Traditional irrigation system applied in the experimental area.

1.2 Drainage System Conditions

A subsurface drainage system was installed approximately 30 years ago (Figure 3). The system includes cement collector drains connected to perforated PVC field drains with a diameter of 8 cm, as well as inspection manholes with a diameter of 1 meter. Field drains are installed at a depth of approximately 1.5 m and spaced at 80 m intervals. The system is connected to collectors through manholes to facilitate inspection and sediment removal. However, field inspections revealed declining system efficiency, as indicated by elevated groundwater levels and high drainage water salinity reaching approximately 8.7 dS/m. In addition, the 1200 Canal and its two branches function as open drainage channels, maintaining low water levels to support field drainage. Nevertheless, the relatively high salinity of canal water, averaging 6.37 dS/m, underscores the need for improved irrigation efficiency and more effective leaching practices.

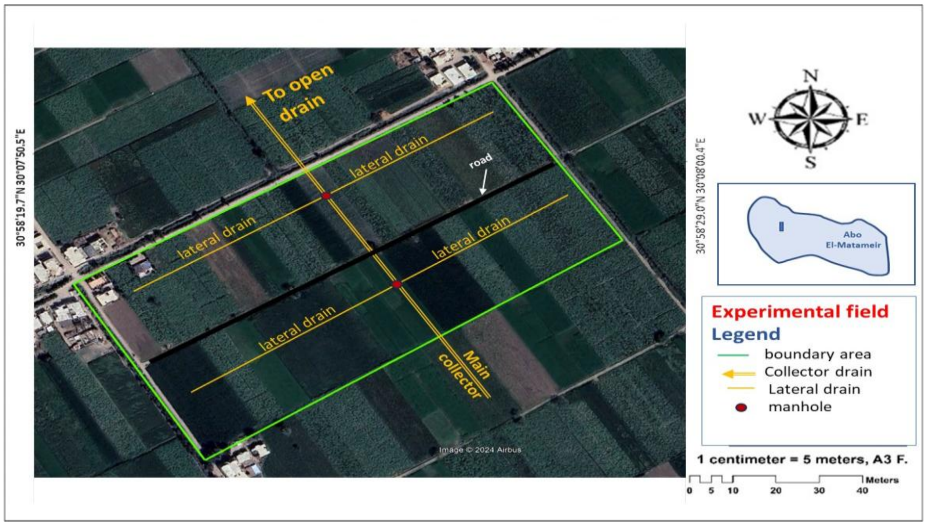

Figure 3. Layout of the subsurface drainage system in the study area.

1.3 Cropping Pattern

The cropping system in the study area reflects a diversified and seasonally adaptive agricultural practice aimed at balancing soil fertility, market demand, and water availability. During the winter season, artichoke is the dominant crop, occupying approximately 55% of the cultivated area. This is followed by alfalfa (berseem) at 25%**,** while sugar beet and wheat each account for about 10% of the area. In the summer season, cropping becomes more diversified, including sunflower (26%)**,** artichoke (20%)**,** maize (19%)**,** watermelon seed production (17%)**,** alfalfa seed production (12%)**,** and cotton (6%)**.** This rotational system contributes to sustainable land management by maintaining soil fertility, reducing pest and disease pressure, and diversifying farmers' income sources. It also provides a useful baseline for assessing future improvements in water use efficiency, crop productivity, and soil conditions following the implementation of solar-powered pressurized irrigation.

1.4 Baseline Site Characteristics

Table 1 summarizes the principal physical, hydrological, and agronomic characteristics of the experimental site. The information consolidates site conditions prior to irrigation modernization and serves as reference data for evaluating the impacts of transitioning to solar-powered pressurized irrigation systems.

Table 1. Summary of site characteristics

Parameter	Description
Location	Al-Hamra Village, 7 km north of Abu El-Matamir, Beheira Governorate (30°58'25.2"N, 30°07'59.7"E)
Total Area	20 feddans (≈ 8.4 ha)

Topography	Flat rectangular field (400 × 200 m)
Soil Type	Clay to silty clay
Average Soil Salinity	≈ 2.6 dS/m
Irrigation Source	El-Mahmoudia Canal via Canal 1200 and two branches
Irrigation Method	Traditional surface flood irrigation
Pumping System	Diesel-powered pumps
Drainage System	Subsurface PVC drains, 8 cm diameter, 1.5 m depth, 80 m spacing
Drainage Water Salinity	8.7 dS/m
Winter Crops	Artichoke, wheat, berseem, sugar beet
Summer Crops	Sunflower, maize, cotton, watermelon seed
Main Challenges	Shallow groundwater, low irrigation efficiency, high fuel consumption

1.5 Site Importance

The Al-Hamra experimental field represents a typical agricultural system in the Western Nile Delta, characterized by saline soils, inefficient flood irrigation practices, and aging drainage infrastructure. These conditions make the site an ideal pilot location for evaluating irrigation modernization strategies, particularly the transition from diesel-powered pumping to solar-powered pressurized irrigation systems. The diversified cropping structure and documented baseline challenges provide a strong foundation for assessing improvements in water productivity, soil health, and potential reductions in carbon emissions following system modernization.

3. Objectives of the Study

The study entitled **"Assessment of Irrigation Modernization using Solar-Powered Pressurized Pipe-Line System"** seeks to develop both scientific and practical insights into the performance and feasibility of solar-powered irrigation systems as a sustainable alternative to conventional surface irrigation practices.

The study aims to achieve the following objectives:

1. **Assess water losses** associated with traditional canal-based irrigation systems and estimate potential water savings achievable through solar-powered pressurized pipeline systems.
2. **Evaluate agricultural and soil responses**, including the effects of irrigation modernization on crop productivity, soil salinity, and drainage water quality.
3. **Analyze economic feasibility** by conducting a cost–benefit comparison between conventional irrigation systems and solar-powered alternatives to determine financial sustainability and long-term returns.
4. **Develop practical recommendations** to support farmers, irrigation authorities, and policymakers in promoting wider adoption and scaling-up of solar-powered irrigation technologies.

4. Scope of the Study

This study addresses the technical, environmental, and operational impacts of modernizing irrigation practices in an agricultural area of the Western Nile Delta through the replacement of traditional surface irrigation with a solar-powered pressurized pipeline irrigation system. The scope of the work responds to growing challenges related to water scarcity, low irrigation efficiency, rising energy costs, and environmental pressures associated with conventional irrigation practices.

The study integrates field-scale monitoring and system-level analysis to evaluate how irrigation modernization influences water use, groundwater behavior, drainage performance, soil conditions, and agricultural productivity. Special emphasis is placed on quantifying changes occurring before and after modernization in order to provide a reliable scientific basis for evaluating irrigation improvement programs.

The scope of the study includes the following main components:

1. Baseline Assessment of Existing Conditions

This component involved documenting and evaluating irrigation and drainage conditions prior to system modernization. Activities included monitoring groundwater depth and salinity, drainage water behavior and quality, soil chemical properties, irrigation practices, and crop productivity. The baseline assessment provided reference conditions against which improvements resulting from modernization could be measured.

2. Implementation of the Modernized Irrigation System

This phase included installation and operation of a solar-powered pumping system connected to a pressurized pipeline network replacing traditional open earthen mesqas. The system aimed to improve water conveyance efficiency, enhance irrigation control, and reduce energy consumption and operational costs.

3. Irrigation Water Management and Efficiency Evaluation

This component focused on measuring irrigation water applied under both traditional and modernized systems, estimating crop water requirements, and evaluating irrigation efficiency. Particular attention was given to changes in irrigation scheduling, distribution uniformity, and reduction of excess water application.

4. Groundwater and Drainage System Monitoring

The study included continuous monitoring of groundwater levels and salinity, assessment of drainage system performance, and analysis of hydraulic interaction between irrigation practices, groundwater recharge, and drainage behavior. Lateral seepage toward irrigation canals and vertical deep percolation below the root zone were also quantified.

5. Soil and Crop Response Assessment

Soil chemical properties were analyzed to evaluate salinity and sodicity conditions before and after modernization. Crop productivity and cropping patterns were documented to assess how improved irrigation management may influence agricultural performance over time.

6. Environmental and Economic Implications

The study assessed the environmental benefits associated with reduced water losses, improved groundwater stability, and replacement of diesel pumping with solar energy. Operational and economic implications of modernization, including potential savings in energy and water use, were also considered.

7. Replication Potential and Management Implications

Finally, the study aims to provide technical insights and practical guidance supporting future expansion of irrigation modernization programs in similar agricultural regions facing water scarcity challenges. The findings contribute to improving irrigation management strategies and enhancing long-term agricultural sustainability under constrained water resources..

5. Methodological Framework and Monitoring Program

In line with the objectives outlined in Section 3, this study adopted an integrated methodological framework to evaluate the technical, hydrological, agronomic, environmental, and economic impacts of transitioning from conventional diesel-powered surface irrigation to a solar-powered pressurized pipeline irrigation system. The adopted approach aimed to provide a scientifically sound basis for assessing improvements in irrigation efficiency, groundwater and drainage behavior, soil conditions, crop productivity, and overall agricultural sustainability under real field conditions.

The monitoring program was initiated on 2 February 2025, prior to the installation of the modernized irrigation system, in order to establish reliable baseline conditions. This allowed direct comparison between pre-modernization and post-modernization phases and enabled quantification of the impacts of improved irrigation management on water use and environmental performance.

The monitoring activities continued throughout both phases of the study, covering seasonal variations in irrigation, groundwater, and crop growth conditions.

5.1 Monitoring Components

The monitoring framework was structured to capture the main hydrological, agronomic, and environmental variables influencing irrigation performance and agricultural sustainability. The program included the following main components:

1. Groundwater monitoring, including periodic measurements of groundwater depth and salinity using observation wells distributed across the experimental area.
2. Drainage water monitoring, including measurement of water levels within drainage manholes and monitoring of drainage water salinity to assess drainage system response to irrigation practices.
3. Seepage and water loss estimation, including quantification of lateral seepage toward irrigation canals and estimation of vertical deep percolation below the crop root zone.
4. Irrigation water measurements, including calibration of pumping systems, measurement of pump discharge, and calculation of irrigation water volumes applied to fields under both traditional and modernized systems.
5. Soil testing, including analysis of soil chemical properties at multiple depths to evaluate salinity and sodicity conditions before and after modernization.
6. Land use and cropping pattern mapping, documenting cultivated areas, crop distribution, and seasonal crop rotations within the experimental field.
7. Crop productivity monitoring, including collection of yield data for major crops to establish baseline productivity conditions.

8. Documentation of agricultural practices, including fertilization schedules, irrigation frequency, and general field management practices affecting crop performance.

During the initial monitoring phase, particular emphasis was placed on groundwater fluctuations and salinity dynamics, as these parameters are key indicators of irrigation efficiency and long-term soil sustainability. The collected data formed a comprehensive baseline dataset for subsequent performance evaluation after irrigation modernization.

5.2 Post-Implementation Monitoring Phase

Following installation and commissioning of the solar-powered pressurized irrigation system, monitoring activities continued to evaluate system performance and agricultural responses under the improved irrigation conditions.

This phase focused on:

- Monitoring hydraulic performance of the irrigation network, including pumping efficiency, operating pressure, and water distribution uniformity.
- Comparing irrigation water use and energy consumption between traditional diesel-powered irrigation and the solar-powered pressurized system.
- Assessing changes in groundwater behavior and drainage response after modernization.
- Evaluating early changes in soil conditions and crop productivity under improved irrigation management.
- Estimating environmental benefits associated with reduced energy consumption and decreased reliance on fossil fuels.

5.3 Data Analysis and Performance Indicators

After completion of field and laboratory data collection, all datasets were compiled into an integrated database for analysis. Data quality checks were conducted to identify and correct missing or inconsistent records, ensuring reliability of the analytical results. Data were then organized according to monitoring locations, soil depths, and time periods, enabling consistent comparison between pre- and post-modernization conditions.

The analysis included the following components:

1. Groundwater and Drainage Analysis
   Groundwater depth and salinity trends were analyzed to assess changes associated with irrigation modernization. Similarly, drainage water behavior and salinity variations were evaluated to understand system response to improved irrigation management. Temporal variations were illustrated using graphs and comparative tables.

2. Irrigation Water Use Analysis
   Irrigation water application was analyzed using pump discharge measurements and operating time records under both traditional and modernized systems. These data allowed estimation of improvements in irrigation efficiency and reduction of excess water application.

3. Crop Productivity Assessment

Crop productivity data collected before modernization were used as a baseline for future comparison with post-modernization yields, enabling assessment of long-term impacts of improved irrigation management.

4. Soil Properties Analysis
   Soil chemical analysis results obtained before and after modernization were compared to evaluate trends in soil salinity and chemical balance, recognizing that measurable soil improvements may require multiple seasons.

5. Performance Indicator Calculation
   Two performance indicators were calculated to quantify system improvements, including:
   - Irrigation efficiency, relating crop water requirements to applied irrigation volumes.
   - Environmental indicators, including reductions in fossil fuel consumption and associated emissions.

6. Comparative Analysis
   Comparative analyses between pre- and post-modernization periods were conducted using tables and graphical representations to demonstrate changes in water use, groundwater conditions, drainage behavior, soil status, and irrigation performance.

7. Integrated Evaluation
   The combined analysis provided an integrated understanding of hydrological, agricultural, and environmental changes resulting from irrigation modernization. These findings formed the scientific basis for evaluating system performance and developing recommendations for future irrigation management and modernization programs

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6. Data Analysis, Results and Discssions

The complete study period, which covered data collection and analysis both before and after the implementation of the modernized irrigation system, resulted in the development of a comprehensive dataset that enabled evaluation of the performance of the existing conventional irrigation system as well as measurement of changes resulting from the introduction of the solar-powered pressurized pipeline irrigation system. These data provided a clear understanding of the previous constraints affecting water use efficiency and crop productivity, while also quantifying improvements achieved after system modernization.

The monitoring and data collection program extended from early February 2025 to End January 2026, covering both pre-implementation and post-implementation phases of the irrigation modernization. This timeline enabled direct comparison between operating conditions before and after system improvement.
This section presents the technical, environmental, and agronomic findings obtained from monitoring and analysis conducted throughout the study period.

6.1 Groundwater[1] levels and salinity

Groundwater conditions play a critical role in determining irrigation efficiency and long-term agricultural sustainability in irrigated areas. A continuous groundwater monitoring program was conducted during both pre-modernization and post-modernization phases in order to evaluate how irrigation system improvement influenced groundwater behavior and quality. These measurements established a reliable baseline and allowed assessment of changes associated with improved irrigation management.

The monitoring system consisted of eight observation wells installed across the experimental field (Figure 4). Each well was constructed using a perforated PVC pipe with a diameter of 5 cm and a total length of 1.8 m, with approximately 0.4 m extending above ground and protected with a cap to prevent contamination (Figure 5). To minimize hydrological interference from drainage infrastructure, wells were positioned at least 5 m away from field drains and 10 m away from collector drains.
Measurements conducted throughout the study period included:

- Groundwater depth, measured dailly from the well head and referenced to ground surface elevation.
- Groundwater salinity, measured using portable EC meters, with results expressed in dS/m.

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[1] The surface level of the groundwater sometimes called the watertable level.

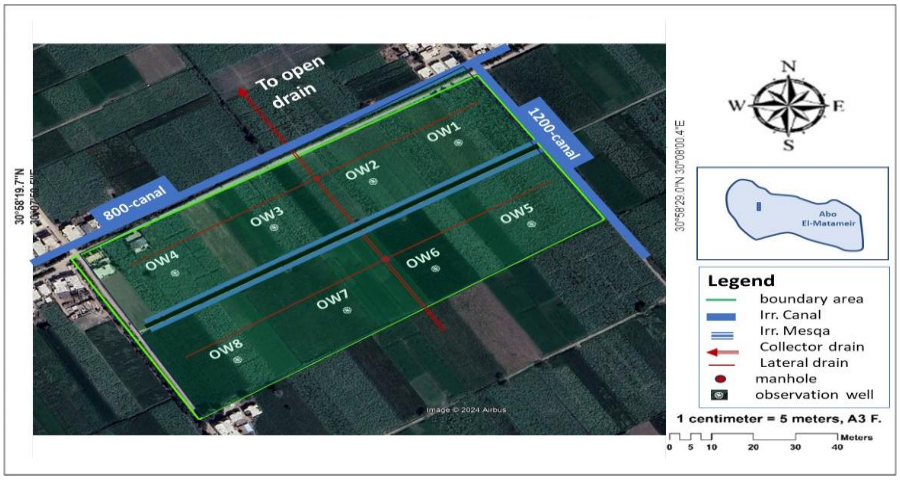

Figure 4. The location of observation well in the experimental area

Figure 5. A diagram of observation well inside the soil

Analysis of the collected data showed noticeable changes in groundwater behavior following implementation of the modernized irrigation system. Improved water management and reduced excessive irrigation contributed to lowering seasonal groundwater rise and stabilizing salinity conditions compared with pre-implementation conditions. These results demonstrate the relationship between improved irrigation practices and subsequent improvements in soil and agricultural performance, providing a scientific basis for evaluating the medium- and long-term performance of the modernized irrigation system.

6.1.1 Groundwater depth

Figure (6) presents the temporal variation of average groundwater depth in the study area from February 2025 to January 2026, covering both periods before and after irrigation system modernization, while all the data measured were presented in Appendix-B. The depths are measured downward from the soil surface, meaning that larger depth values indicate a lower groundwater table, which is generally more favorable for crop growth. The figure clearly shows three distinct periods: the winter period before improvement, the summer period before improvement, and the post-improvement period.

Winter Period Before Irrigation Improvement (February–April 2025):

During this period, groundwater depth exhibited large and rapid fluctuations associated with irrigation and rainfall events. The groundwater depth varied between approximately 0.45 m and 1.20 m below the soil surface, with an average depth of about 0.86 m.

The shallow limits (around 0.45–0.50 m) occurred shortly after irrigation or rainfall events, when excess water percolated downward, causing temporary groundwater rise. Conversely, the deeper limits (close to 1.20 m) occurred several days after irrigation when drainage and evapotranspiration gradually lowered groundwater levels. This wide fluctuation range indicates uneven irrigation practices and limited drainage response under the traditional system.

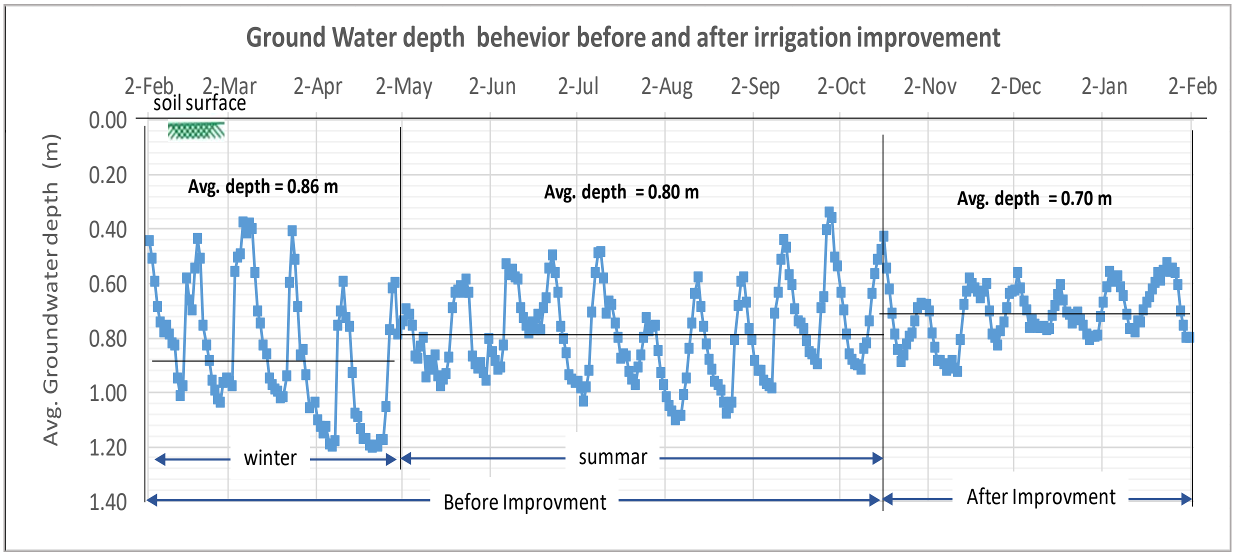

Figure 6. Average groundwater depth before and after irrigation improvement.

Summer Period Before Irrigation Improvement (May–October 2025):

During the summer season, groundwater behavior changed slightly. Although fluctuations continued, groundwater remained generally closer to the soil surface due to more frequent irrigation. Observed groundwater depths ranged approximately between 0.40 m and 1.05 m, with an average depth of about 0.80 m.

The minimum depths occurred following intensive irrigation events, while deeper levels were observed after short recovery periods between irrigation cycles. The smaller difference between maximum and minimum depths compared with the winter period indicates that groundwater remained relatively elevated, since irrigation was applied more frequently to meet the higher crop water demand during summer.

Period After Irrigation Improvement (October 2025–February 2026):

After implementation of the solar-powered pressurized irrigation system, groundwater fluctuations became noticeably smaller. Groundwater depths ranged approximately between 0.55 m and 0.90 m, with an average depth of about 0.70 m.

Unlike the earlier periods, groundwater levels no longer showed sharp rises after irrigation events. Instead, depth variations became smoother and more stable. This improvement reflects better irrigation scheduling and reduced excessive water application.

Technical Interpretation of Observed Changes:

The observed changes in groundwater behavior can be directly linked to irrigation management practices. Before modernization, irrigation was concentrated within short periods during which all fields were irrigated over several consecutive days. This resulted in large volumes of water being applied in a short time, causing rapid groundwater rise followed by gradual decline.

After modernization, irrigation events were distributed more evenly across the irrigation cycle, with smaller volumes applied per event. This reduced deep percolation losses and prevented sudden groundwater increases, leading to narrower fluctuation ranges.

Overall Evaluation:

The comparison between the three periods demonstrates that irrigation modernization improved groundwater stability and reduced extreme fluctuations. The narrower fluctuation range after improvement indicates more controlled water application, improved soil moisture conditions, and better balance between irrigation input and drainage response.

These results confirm that improved irrigation management plays a key role in stabilizing groundwater conditions and enhancing overall irrigation efficiency in the study area.

6.1.2 Groundwater Salinity

Figure (7) illustrates the variation of average groundwater salinity in the study area during the period from February 2025 to January 2026, covering both conditions before and after irrigation system modernization, while all the data measured were presented in Appendix-B. Salinity values are expressed in dS/m, and variations reflect the combined effects of irrigation practices, leaching conditions, and drainage performance.

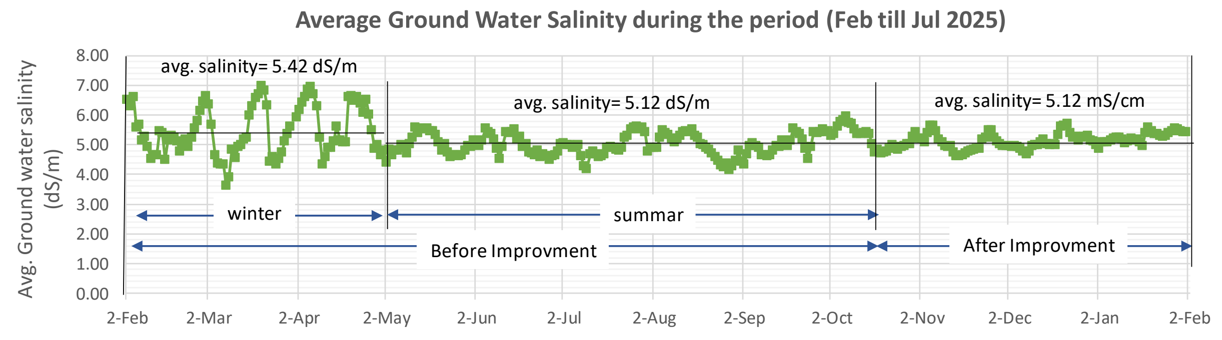

Figure 7. Average groundwater salinity before and after irrigation improvement.

Similar to groundwater depth analysis, the salinity record can be divided into three main periods: winter before improvement**,** summer before improvement**,** and after irrigation improvement.

Winter Period Before Irrigation Improvement (February–April 2025):

During the winter period, groundwater salinity exhibited noticeable fluctuations, with values ranging approximately between 4.2 and 7.0 dS/m, while the average salinity was about 5.42 dS/m.

The higher salinity values were typically recorded following periods of reduced irrigation or limited leaching, allowing dissolved salts to concentrate in groundwater. Lower salinity values occurred after rainfall or irrigation events that temporarily diluted groundwater salinity through downward movement of fresher irrigation water. The relatively wide fluctuation range indicates unstable leaching conditions and inconsistent water movement under the traditional irrigation system.

Summer Period Before Irrigation Improvement (May–October 2025):
During the summer season, groundwater salinity fluctuations became somewhat narrower. Recorded salinity values ranged approximately between 4.5 and 5.8 dS/m, with an average of about 5.12 dS/m.
The reduction in fluctuation range compared with winter reflects the impact of more frequent irrigation events during the cropping season, which maintained a more continuous recharge of groundwater and contributed to partial dilution of salts. However, salinity levels remained relatively high due to inefficient irrigation practices and limited drainage efficiency.

Period After Irrigation Improvement (November 2025–February 2026):
Following implementation of the solar-powered pressurized irrigation system, groundwater salinity showed improved stability. Values ranged approximately between 4.7 and 5.8 dS/m, with an average salinity remaining around 5.12 dS/m.
Although the average salinity did not show an immediate sharp reduction, fluctuations became more stable and less extreme compared with the pre-improvement winter period. This indicates more uniform recharge conditions and reduced salinity concentration peaks.

Technical Interpretation of Observed Changes:
The observed pattern suggests that groundwater salinity responds more slowly than groundwater levels to irrigation system improvements. While irrigation modernization improved water distribution and reduced excessive water application, changes in groundwater salinity typically occur gradually due to slow salt movement within soil and aquifer systems.
Before modernization, irrigation was applied in large volumes over short periods, leading to irregular leaching and inconsistent dilution effects. After modernization, irrigation water application became more evenly distributed with smaller volumes applied per event, resulting in more stable groundwater recharge and consequently more stable salinity conditions.

In general, watertable salinity can remain almost constant before and after irrigation improvements due to long-term hydrological dynamics, slow groundwater residence times[2], and the recycling of salts within a closed or poorly drained system. While "irrigation improvement" often refers to increasing efficiency, this may simply delay the impact on the water table by reducing the volume of return flows while increasing their individual salt concentration[3,4].

Overall Evaluation

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[2] **Long Groundwater Residence Times:** In many aquifer systems, natural groundwater residence times can exceed 100 years. Because groundwater movement is slow, the immediate effects of irrigation improvements on deep-layer salinity may not be evident in the short term.

[3] **Increased Concentration of Return Flows**: Improving irrigation efficiency typically involves reducing the amount of "waste" water that leaches beyond the root zone. However, as the volume of return flow decreases, the concentration of salts in that flow increases, as plants consume the fresh water and leave the dissolved minerals behind. This can lead to a long-term trend of increasing or constant salinity in the groundwater recharge.

[4] **Delayed Deterioration in the Vadose Zone:** The vertical hydraulic conductivity of the vadose zone (the area between the surface and the water table) controls the rate at which saline returns reach the groundwater. This creates a significant "time-lag" before any changes in irrigation practice lead to a measurable deterioration or improvement in groundwater quality.

The analysis shows that irrigation modernization contributed to stabilizing groundwater salinity conditions by reducing extreme fluctuations, even though average salinity levels remained similar during the initial monitoring period. Longer monitoring periods are expected to reveal gradual improvements in salinity conditions as improved irrigation efficiency and drainage performance continue to enhance salt leaching over time.

These results indicate that irrigation modernization provides favorable conditions for long-term groundwater quality improvement while immediately enhancing irrigation management efficiency.

6.1.3 Interaction Between Groundwater Level and Salinity

The combined analysis of groundwater depth (Figure 6) and groundwater salinity (Figure 7) provides important insight into the interaction between groundwater dynamics and salt behavior in the study area. These two parameters are closely linked, as fluctuations in groundwater levels directly influence salt concentration and movement within the soil–groundwater system.

Before irrigation improvement: groundwater levels showed large and rapid fluctuations due to the application of large irrigation volumes within short periods. During irrigation events, excess water percolated downward, temporarily diluting groundwater salinity and causing short-term decreases in salinity values. However, during the periods between irrigations, groundwater levels declined gradually while evaporation and plant uptake continued, leading to concentration of dissolved salts and temporary increases in groundwater salinity. This pattern explains why salinity fluctuations were more pronounced during the winter period, when irrigation and rainfall events alternated with relatively dry intervals, producing repeated cycles of dilution and concentration. In contrast, during the summer period, more frequent irrigation events maintained groundwater levels closer to the surface and produced more stable salinity conditions, although overall salinity remained relatively high due to inefficient leaching and drainage limitations.

After modernization of the irrigation system: groundwater level fluctuations became smaller and more stable due to improved irrigation scheduling and reduced excessive water application. Consequently, groundwater recharge occurred more gradually, preventing sudden dilution or concentration cycles. This led to more stable groundwater salinity values, even though the average salinity did not immediately decline. The results indicate that while groundwater depth responds relatively quickly to irrigation management changes, groundwater salinity responds more slowly because salt transport and removal depend on long-term leaching and drainage processes. Therefore, stabilization of groundwater levels observed after modernization represents an important first step toward gradual improvement in groundwater quality over time.

Overall, the interaction between groundwater depth and salinity confirms that improved irrigation management reduces extreme groundwater fluctuations, stabilizes recharge conditions, and creates more favorable conditions for long-term salt leaching and soil quality improvement. This is mainly due to:

- Regulated Water Table: High-efficiency irrigation prevents the "pumping" action where watertable rises too close to the surface. When the water table is kept at a stable, deeper level, it prevents capillary action—the process where salt-laden water is pulled upward into the root zone as surface water evaporates.
- Stabilized Recharge: By matching water application to crop needs, "recharge" (water entering the aquifer) becomes predictable. This prevents sudden spikes in groundwater levels that would otherwise flush buried salts back to the topsoil.

- Effective Salt Leaching: With a stable and deeper water table, excess water can move downward through the soil profile more effectively. This allows irrigation water to leach soluble salts out of the root zone and into deeper layers or drainage systems, permanently improving soil quality for plant growth.

6.2 Assessment of Agricultural Drainage System Performance

Drainage conditions in the experimental field were continuously monitored throughout the study period extending from February 2025 to January 2026, covering both the periods before and after the implementation of the solar-powered pressurized irrigation system. The monitoring program aimed to evaluate drainage system behavior under traditional irrigation practices and to assess subsequent changes following irrigation modernization. Detailed monitoring results are presented in Appendix-C.

Because of the persistent water presence inside the drains, direct measurement of drainage discharge quantities was not feasible under field conditions. Therefore, drainage system performance throughout the monitoring period was evaluated using indirect indicators, namely:

- Measurement of water surface depth inside inspection manholes distributed across the experimental field, representing the hydraulic condition within the drainage network.
- Monitoring of drainage water salinity variations to evaluate water quality responses to irrigation practices and seasonal changes.

Following the implementation of the improved irrigation system, changes in drainage behavior were assessed using the same monitoring approach, enabling direct comparison between pre- and post-modernization conditions.

6.2.1 Surface drainage water depth inside Manholes

Figure (8) presents the variation in drainage water surface depth measured inside Manholes of the subsurface drainage network, covering both pre-modernization and post-modernization irrigation conditions. The measurements represent the distance between the ground surface and the water level inside the drainage system, meaning that larger depths indicate lower drainage water levels, which generally reflects better drainage performance and reduced hydraulic pressure within the drainage network.

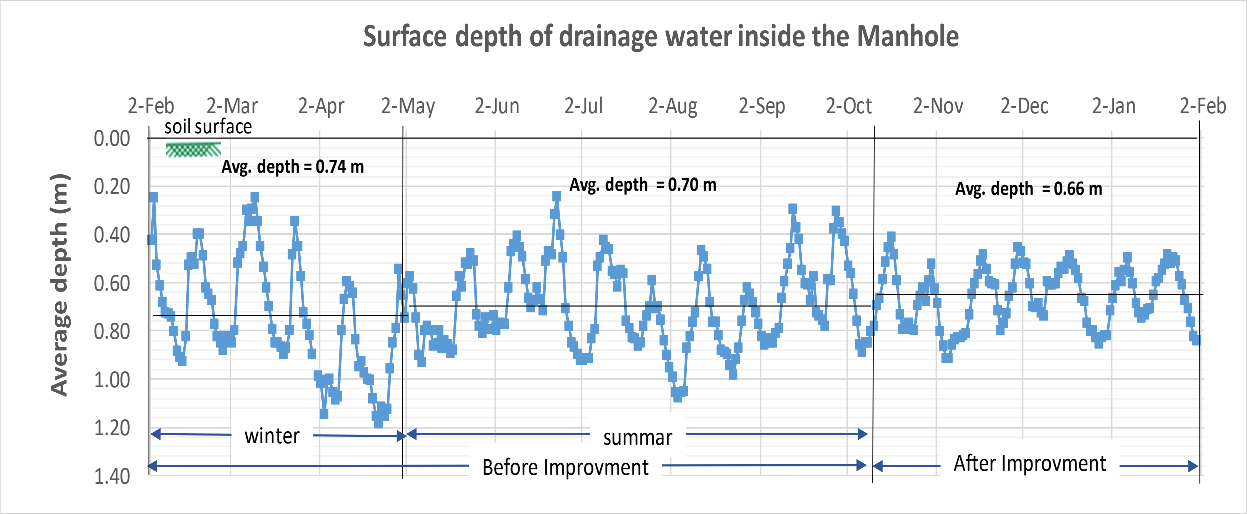

Figure 8. Average surface drainage water depth before and after irrigation improvement.

The results provide valuable insight into the performance of the drainage system and its interaction with irrigation practices and groundwater behavior.

Winter Period Before Irrigation Improvement (February–April 2025):
During the winter period, drainage water levels inside manholes fluctuated significantly. Recorded depths ranged approximately between 0.35 m and 1.20 m, with an average depth of about 0.74 m. The shallow depths occurred shortly after irrigation or rainfall events, when excess irrigation water rapidly entered the drainage network, raising the water level inside manholes. Conversely, deeper levels were observed after drainage recovery periods, when water levels declined following drainage outflow. This large fluctuation range indicates that drainage flow was highly influenced by irrigation cycles, reflecting irregular water application and temporary overloading of the drainage system.

Summer Period Before Irrigation Improvement (May–October 2025):
During the summer season, fluctuations continued but became slightly more moderate. Drainage water depths varied approximately between 0.40 m and 1.05 m, with an average depth of about 0.70 m. The relatively shallower average depth compared with winter suggests that the drainage system continuously received excess irrigation water due to frequent flood irrigation events. As a result, drainage water levels remained elevated for longer periods, indicating sustained hydraulic loading of the drainage system.
This pattern confirms that large irrigation volumes applied during the summer season increased seepage toward the drainage network, reducing the system's recovery time.

Period After Irrigation Improvement (November 2025–February 2026):
Following implementation of the solar-powered pressurized irrigation system, the drainage water levels inside manholes became more stable. Depth values ranged approximately between 0.50 m and 0.85 m, with an average depth of about 0.66 m. Although the average depth was slightly smaller, fluctuations became less pronounced and more regular compared with earlier periods. This indicates reduced sudden inflow peaks into the drainage system due to improved irrigation management and reduced excess water application. The drainage system thus operated under more controlled hydraulic conditions, reflecting improved coordination between irrigation input and drainage response.

Technical Interpretation of Observed Behavior

The depth of drainage water inside manholes reflects several interacting factors:

- Amount of irrigation water applied;
- Seepage and percolation losses;
- Groundwater levels;
- Efficiency of the drainage network;
- Timing and distribution of irrigation events

Before modernization: irrigation water was applied in large quantities over short periods, producing rapid infiltration and sudden increases in drainage discharge, which raised water levels inside the manholes. After irrigation stopped, water levels gradually declined, creating large fluctuations. After modernization: irrigation water was applied more gradually and uniformly across irrigation cycles. Consequently, drainage inflow became more evenly distributed over time, reducing sudden peaks and resulting in smoother drainage behavior.

Interaction with Groundwater Behavior:

The pattern observed in drainage water levels closely matches groundwater depth trends discussed previously. When groundwater levels rose due to heavy irrigation, drainage water levels inside manholes also increased, confirming the strong hydraulic connection between groundwater and the subsurface drainage system. After irrigation modernization, both groundwater levels and drainage water levels exhibited reduced fluctuation ranges, indicating improved water balance within the soil–drainage system.

Overall Evaluation

The results demonstrate that irrigation modernization contributed to stabilizing drainage system operation by reducing sudden inflow peaks and smoothing hydraulic responses. Although average drainage water levels did not change drastically, the reduction in fluctuation amplitude indicates improved irrigation efficiency and better water management. This stabilization helps maintain more consistent soil moisture conditions, improves root zone aeration, and reduces stress on the drainage network, contributing to improved agricultural sustainability and system performance in the study area.

6.2.2 Salinty of drainage water

Figure (9) illustrates the temporal variation of drainage water salinity measured inside the manholes of the subsurface drainage system during the period from February 2025 to January 2026, covering conditions before and after irrigation modernization.

During the winter period prior to irrigation improvement (February–April 2025), drainage water salinity showed noticeable variability, with values fluctuating approximately between 3.5 and 10.5 dS/m, and an average salinity of about 6.36 dS/m. These fluctuations reflect the alternating effects of irrigation applications and rainfall events, which temporarily diluted drainage water, followed by concentration periods when evapotranspiration and soil drainage processes increased salt concentration in percolating water. In the summer period before improvement (May–September 2025), salinity variations became more moderate, ranging generally between 5.0 and 7.5 dS/m, with an average value close to 6.33 dS/m. Under traditional flood irrigation, large irrigation volumes caused continuous leaching of salts from the soil profile into the drainage system, maintaining relatively high salinity levels in drainage water. However, fluctuations were less extreme than in winter due to more regular irrigation cycles.

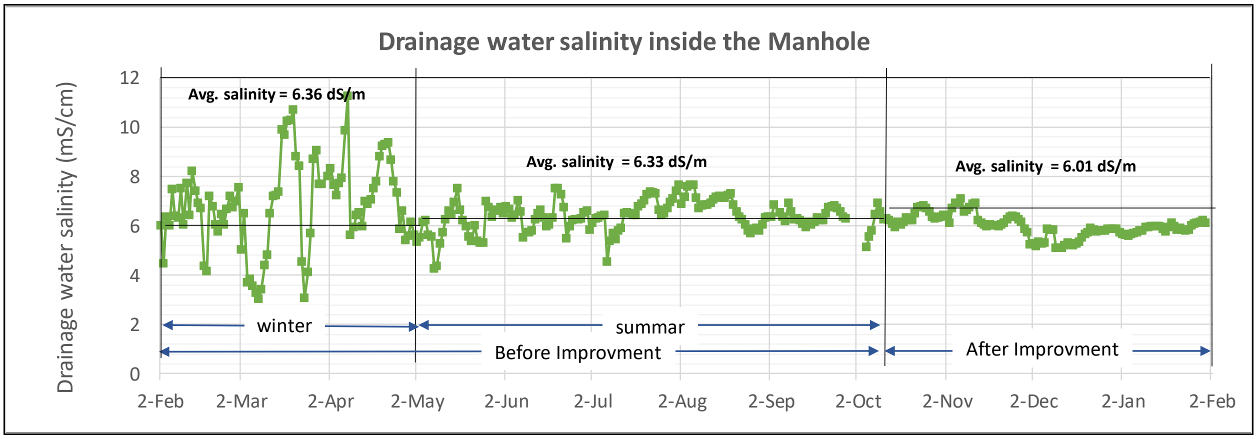

Figure 9. Average surface drainage water salinity before and after irrigation improvement.

After implementation of the solar-powered pressurized irrigation system (October 2025–January 2026), drainage water salinity exhibited a slight reduction and improved stability, with values typically ranging between 5.0 and 6.8 dS/m, and an average salinity of approximately 6.01 dS/m. Although the reduction in average salinity was moderate during this early operational stage, the narrower fluctuation range indicates more stable soil–water interactions resulting from improved irrigation management and reduced excessive deep percolation.

The results indicate that while irrigation modernization rapidly influences groundwater and drainage hydraulics, changes in salinity occur more gradually because salt removal from soil profiles requires extended leaching over multiple irrigation seasons. Therefore, the observed stabilization and slight reduction in drainage water salinity represent an early positive response, with further improvements expected over longer operational periods. Overall, the drainage salinity pattern confirms that improved irrigation scheduling and water application control reduced sudden salt flushing events while promoting more balanced leaching processes, contributing to progressive improvement in soil and drainage water conditions.

This again indicates the disconnection between how quickly two different systems respond to irrigation modernization:
The Fast Response (Hydraulics): When applying modern irrigation system, the water movement changes almost instantly. Groundwater levels and drainage flow rates stabilize quickly because water pressure and volume are easy to control.
The Slow Response (Salinity): Salt is physically trapped within the soil structure. Unlike water, which flows freely, salt must be dissolved and physically "pushed" out of the soil pores. This requires leaching (applying extra water to wash the salt down), which takes months or sometimes years of repeated cycles. However, the fact that the water flow is under control (hydraulics) and the salt levels are no longer spiking (stabilization) proves that the overall system is working. The "gradual" nature of salt removal is simply a law of soil physics, and the obtained results suggests the project is on the right trajectory for long-term soil health.

6.3 Measuring the Hydraulic Conductivity

Hydraulic conductivity (K) is a key soil parameter that describes the ability of soil to transmit water through its pore spaces under saturated conditions. It plays a critical role in understanding subsurface water movement, evaluating irrigation performance, and designing efficient drainage systems. Hydraulic conductivity is influenced by soil texture, soil structure, pore size distribution, compaction, and the degree of soil saturation. In general, coarse-textured soils allow water to move more easily than fine-textured soils, which typically exhibit lower conductivity values. It is commonly expressed in meters per day (m/day) and can be determined using laboratory analyses or field-based measurement techniques. In the present study, the auger hole method was adopted due to its suitability for field conditions characterized by shallow groundwater levels and its effectiveness in determining saturated hydraulic conductivity directly under in-situ conditions.

The auger hole method is a widely applied field technique for measuring saturated hydraulic conductivity below the groundwater table. In this method, a cylindrical hole is drilled manually using a soil auger to a depth that intersects the groundwater table. After the hole is established, water inside the hole is allowed to equilibrate with groundwater conditions. The water level inside the hole is then lowered and the rate of water level recovery or decline is measured over time, as illustrated in Figure 10.

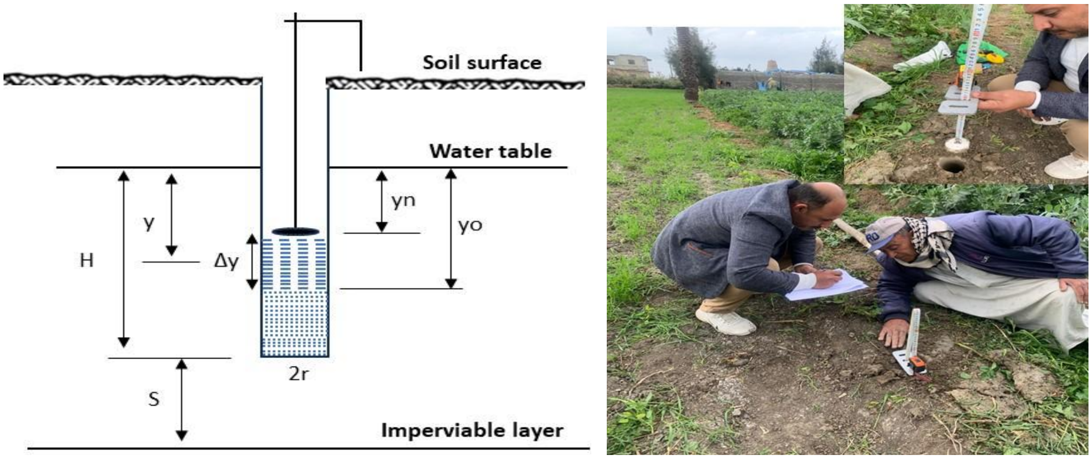

Figure 10. Measuring the hydraulic conductivity by using the Auger hole method.

The speed at which water flows between the hole and the surrounding soil reflects the soil's ability to transmit water under saturated conditions. Using standard equations developed for auger hole tests, hydraulic conductivity values are calculated from the observed changes in water level over time. This approach is particularly useful in agricultural areas where groundwater interactions strongly influence irrigation and drainage performance.

At the experimental site, hydraulic conductivity measurements were conducted at eight representative locations distributed across the 20-feddan field using the auger hole method. The measurements were taken at the same locations as the observation wells (see Figure 4). Detailed measurement records are presented in Appendix-D, while Table 2 summarizes the calculated hydraulic conductivity values for each location along with the overall field average.

Table 2. Hydraulic Conductivity Measurements.

Location	Site-1	Site -2	Site -3	Site -4	Site -5	Site -6	Site -7	Site -8	Average
K (m/day)	0.031	0.088	0.054	0.052	0.054	0.041	0.055	0.078	0.0563

Measured saturated hydraulic conductivity values ranged between 0.031 m/day and 0.088 m/day, with an average of 0.0563 m/day across the study area. These differences reflect spatial variability in soil structure, texture, and compaction conditions within the field. The relatively low conductivity values are consistent with the dominant clay to silty clay soil texture in the area, indicating slow vertical and lateral water movement. Such conditions increase the risk of water accumulation above restrictive soil layers when excessive irrigation water is applied, thereby contributing to rising groundwater levels and increased pressure on the drainage system.

The obtained hydraulic conductivity values were subsequently used in seepage and percolation analyses to estimate water losses from irrigation channels and to evaluate subsurface water movement under different irrigation management conditions. Accurate knowledge of hydraulic conductivity is essential for improving irrigation scheduling, optimizing drainage system performance, and minimizing water losses through deep percolation, ultimately contributing to more sustainable irrigation water management in the study area.

6.4 Estimation of Seepage Losses

The pilot area is bordered by three secondary irrigation canals located along the eastern, western, and northern boundaries of the study site (Figure 11). Due to the relatively low water levels in these canals compared with the surrounding agricultural fields, and because the subsurface drainage network in the area does not operate at full efficiency, these canals perform a dual hydraulic function within the study area. Water delivery through the canals follows a rotational irrigation schedule consisting of five consecutive days of water supply followed by ten days without water delivery. During irrigation supply periods, the canals function as normal irrigation conveyance channels. However, during non-supply periods, canal water levels decline significantly, causing the canals to behave as open drainage outlets.

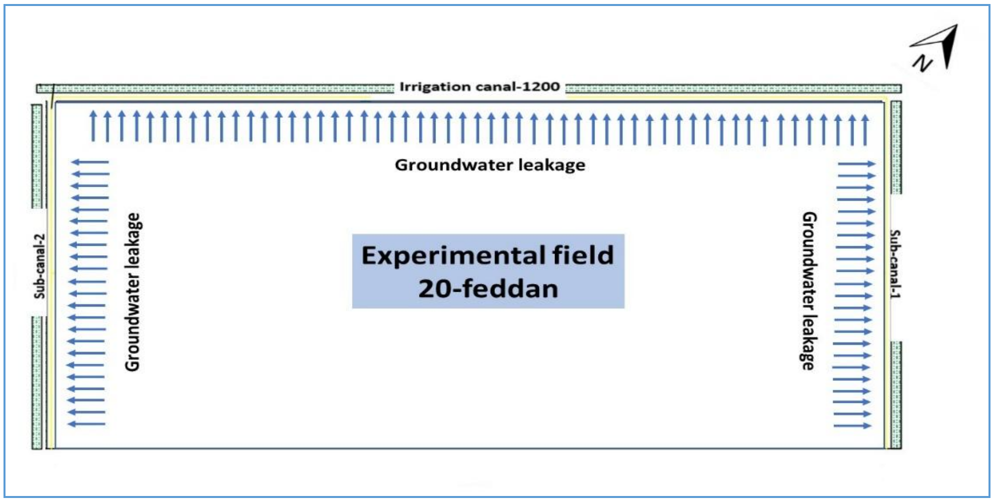

Figure 11. Groundwater leakage to the irrigation canal and to its branches.

Under these conditions, water stored in the soil profile and shallow groundwater zone flows laterally from the surrounding cultivated lands toward the canals. Consequently, the canals receive seepage and percolation water originating from irrigated fields, effectively functioning as field drains that partially compensate for the limited efficiency of the subsurface drainage system. Therefore, estimating the quantity of seepage water reaching these canals is essential for understanding water losses within the area and evaluating the interaction between irrigation practices, groundwater behavior, and drainage conditions.

Throughout the study monitoring period, extending from February 2025 to January 2026, canal conditions were regularly observed to evaluate their interaction with groundwater levels and irrigation practices under both pre- and post-modernization conditions. Monitoring activities included:

- Daily measurements of water depth in the canals;
- Periodic salinity measurements of canal water, and
- Continuous monitoring of groundwater levels in adjacent agricultural fields.

These observations provided the necessary data for estimating seepage losses and evaluating the hydraulic role of canals within the overall irrigation–drainage system of the study area.

These canal water level variations are critical for estimating seepage losses using Darcy's Law, since seepage flow between agricultural lands and canals depends on the hydraulic gradient between groundwater levels and canal water levels. When canal levels decline below groundwater levels during non-supply periods, a lateral hydraulic gradient develops toward the canal, causing groundwater and soil water to flow into the canal, effectively making the canals act as field drains. Conversely, when canal water levels rise during supply periods, limited seepage may occur from canals into adjacent soils; however, the overall net flow remains directed toward canals.

Seepage discharge is estimated using Darcy's Law: $Q = K \times A \times i$

where:

Q = seepage discharge (m^3/day),
K = saturated hydraulic conductivity (m/day), it is equal 0.056
A = seepage flow area (m^2), the area = 80,000 m2.
i = hydraulic gradient.

The hydraulic gradient is calculated as: $i = \Delta h / L$

where:

Δh = difference between groundwater depth (h) and canal water depth (d)(m),
L = horizontal seepage flow distance between the field and canal (m), it is considered (10 m)

To better quantify seepage behavior, monthly averages of groundwater depth and canal water depth were calculated, allowing estimation of seepage quantities throughout the monitoring period. As summarized in Table 3, the difference in hydraulic head (Δh) was computed monthly, and Darcy's equation was then applied to estimate seepage discharge toward canals.

Table 3. Calculation of the average monthly seepage of water to irrigation Canals.

Month	h1 (m)	h2 (m)	(Δh) (m)	q (m3)	q (mm)
Feb.	1.41	0.76	0.65	29.12	0.364
March	1.34	0.76	0.58	25.984	0.3248
April	1.39	1.01	0.38	17.024	0.2128
May	1.15	0.81	0.34	15.232	0.1904
June	1.15	0.73	0.42	18.816	0.2352
July	1.27	0.82	0.45	20.16	0.252

Aug	1.24	0.88	0.36	16.128	0.2016
Sep	0.98	0.71	0.27	12.096	0.1512
Oct	0.96	0.73	0.23	10.304	0.1288
Nov	0.95	0.75	0.2	8.96	0.112
Dec	1.05	0.72	0.33	14.784	0.1848
Jan	0.98	0.65	0.33	14.784	0.1848
Avg.	1.16	0.78	0.47	21.06	0.26

6.4.1 Analysis of Seepage Results

The results presented in Figure (12) show a clear seasonal variation in the quantity of seepage water flowing toward the surrounding irrigation canals during the study period. The calculated seepage discharge ranged between approximately 9 and 29 m³/day, with the highest values recorded during the winter and early spring months when irrigation applications were relatively high under the traditional surface flood irrigation system. This increase was mainly associated with the irrigation of artichoke crops during the flowering stage, which occupied nearly 50% of the cultivated area during the winter season of 2025. During this stage, irrigation requirements are relatively high, leading to larger irrigation applications and consequently higher deep percolation losses, which increased groundwater recharge and enhanced lateral seepage toward the surrounding canals.

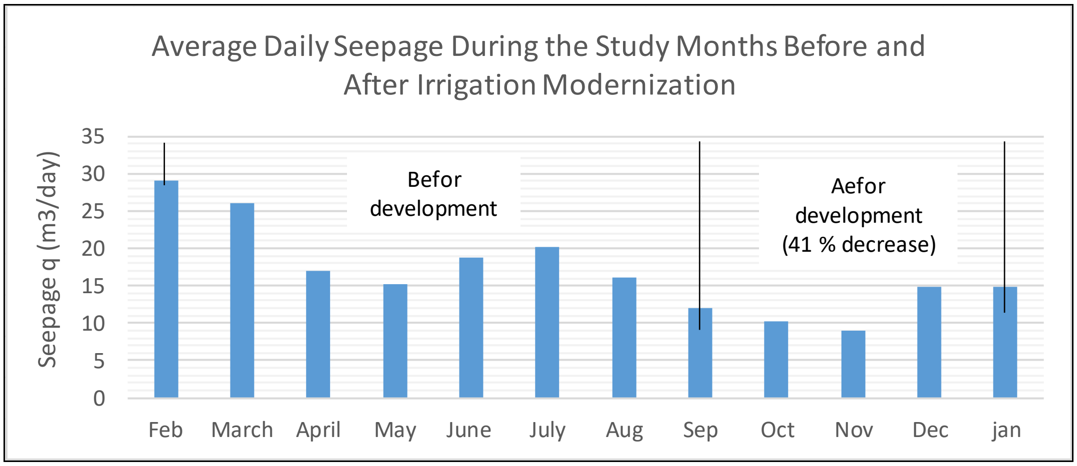

Figure 12. Average seepage per daty to the Irrigation canals.

During the period before irrigation modernization (February–Sptember 2025), seepage rates were generally higher, frequently exceeding 18–20 m³/day, and reaching a maximum of nearly 29 m³/day in February. These high values reflect excessive irrigation applications and significant deep percolation losses, which increased groundwater recharge and consequently enhanced lateral seepage toward the canals. After the implementation of the solar-powered pressurized irrigation system, corresponding to the period October 2025–January 2026, seepage quantities noticeably declined. Monthly seepage values dropped to approximately 10–15 m³/day, indicating a substantial reduction in deep percolation losses as irrigation water application became more controlled and better distributed over time.

Overall, the average seepage discharge after irrigation modernization decreased by approximately 41% compared with the pre-development period, as indicated in Figure (13). This reduction demonstrates the effectiveness of the improved irrigation system in limiting excess groundwater recharge and reducing uncontrolled water losses from the field.

When seepage volumes are expressed as an equivalent drained water depth over the contributing agricultural area, they correspond to values ranging between 0.11 and 0.36 mm/day, with an overall average close to 0.26 mm/day. Compared with the standard drainage design coefficient of about 1 mm/day, these canals effectively remove nearly 25% of the drainage requirement, thus functioning as auxiliary drainage outlets that partially compensate for the limited efficiency of the existing subsurface drainage network. These findings confirm that irrigation modernization not only improved irrigation efficiency but also contributed to better groundwater control and reduced unnecessary water losses while maintaining the hydraulic balance within the study area.

To further confirm these results, irrigation water salinity was analyzed throughout the study period (Figure 14), it illustrating the relationship between irrigation water quality and salinity behavior in the shallow groundwater system before and after irrigation modernization. During the pre-modernization period, irrigation water salinity showed considerable fluctuations throughout the agricultural season, with values ranging approximately between 1 and more than 8–10 dS/m at certain times. These variations resulted from changes in canal water quality and occasional mixing with more saline water reaching the canals through seepage from saline water stored within the soil profile, particularly during periods of low canal discharge. During the post-modernization period, irrigation water salinity became relatively more stable, with most values falling within the range of approximately 2–4 dS/m. This improvement is associated with better irrigation management and more regulated water delivery under the pressurized pipeline system, which helped reduce water stagnation and fluctuations in water quality within irrigation canals.

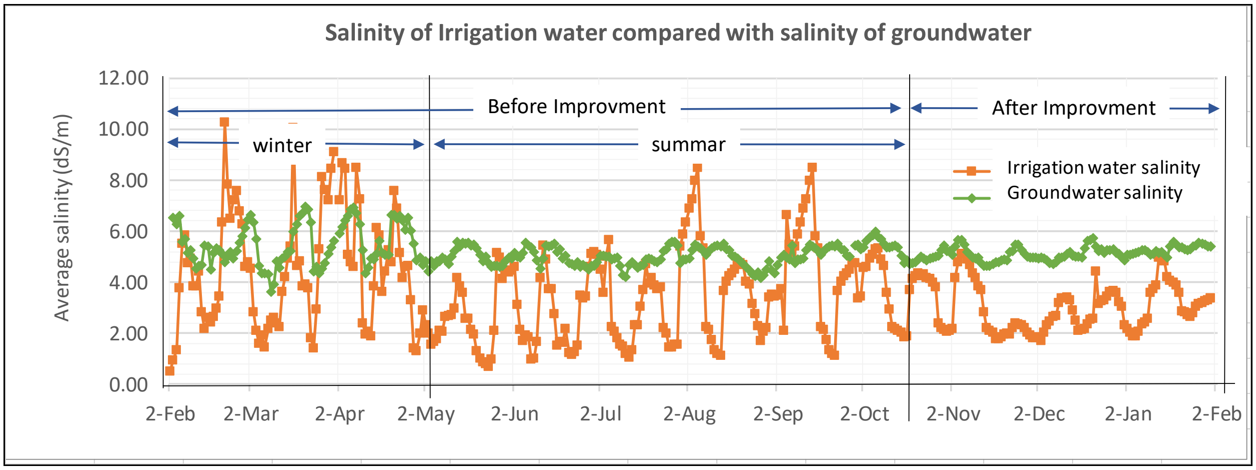

Figure 13. Salinity of irrigation water compared to average salinity of ground water.

Overall, the results indicate that irrigation modernization not only improved water-use efficiency and reduced seepage losses but also contributed to stabilizing groundwater salinity conditions, which is essential for maintaining soil productivity and supporting sustainable crop production in areas affected by salinity risks. This comparison demonstrates that improved irrigation management plays a critical role in controlling salt movement within the soil–groundwater system, thereby enhancing long-term agricultural sustainability in similar irrigated regions.

6.5 Deep Percolation and Vertical Seepage Assessment

To quantify vertical water movement below the root zone, a set of three piezometers was installed at depths of 1 m, 2 m, and 10 m below the soil surface within the experimental field (Figure 15). Continuous monitoring was conducted from June 2025 through January 2026, covering both the period before irrigation modernization and the period following system implementation, which began in September 2025. The analysis presented here focuses on the hydraulic head difference between the shallow and deep piezometers (1 m and 10 m depths), as this depth interval represents water movement below the active root zone and thus reflects deep percolation toward the groundwater system.

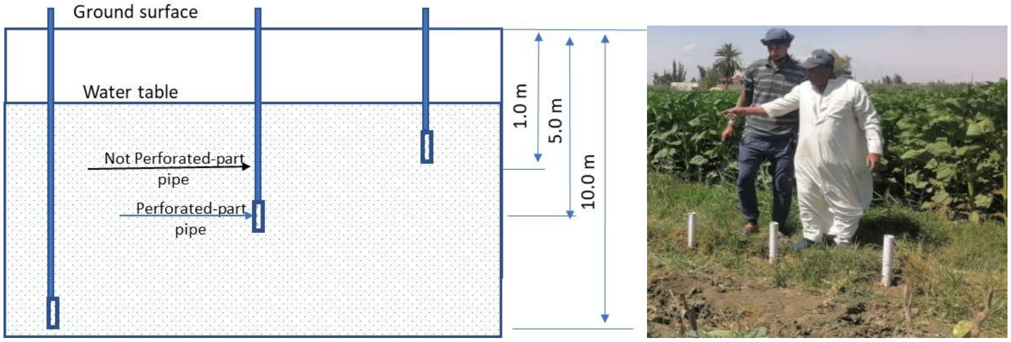

Figure 14. The set of piezometers using for calculation the deep percolations.

Vertical seepage rates were estimated using Darcy’s Law, expressed as:

$$q = K\,x\,i$$

$$q = K\,x\,\frac{\Delta h}{\Delta z}$$

where:

- q is the vertical seepage rate (m/day),
- K is the saturated hydraulic conductivity of the soil,
- i is the vertical hydraulic gradient calculated as: **I** = Δh/Δz. (Δh representing the difference in hydraulic head between the two piezometers, Δz representing the vertical distance between measurement points (9 m between 1 m and 10 m depths).

Using monthly averaged measurements, seepage rates and corresponding daily seepage volumes were computed, as summarized in Table 4.

Table 4. Calcualation of the deep percolations for the study area.

Month	h1(Piz1)	h2(Piz10)	dh	dz(10 -1)	i = (dh/dz)	q (m/d)	q(mm)	Q (m3/d)
jun	0.95	1.01	0.06	9	0.007	0.0004	0.37	29.9
jul	1.07	1.12	0.05	9	0.006	0.0003	0.31	24.9
aug	1.14	1.18	0.04	9	0.004	0.0002	0.25	19.9
sep	0.97	0.99	0.02	9	0.002	0.0001	0.12	10.0

oct	0.9	0.91	0.01	9	0.001	0.0001	0.06	5.0
nov	0.99	1	0.01	9	0.001	0.0001	0.06	5.0
dec	0.9	0.92	0.02	9	0.002	0.0001	0.12	10.0
jan	0.95	0.97	0.02	9	0.002	0.0001	0.12	10.0

Prior to system modernization, vertical head differences ranged between 0.02 and 0.06 m, producing hydraulic gradients between 0.002 and 0.007. Corresponding seepage rates varied between 0.12 and 0.37 mm/day, equivalent to seepage volumes ranging from approximately 10 to 30 m³/day over the study area. The highest seepage rates were recorded during June and July, coinciding with periods of intensive summer irrigation under the traditional surface irrigation system. Large volumes of irrigation water applied over short periods increased soil saturation and enhanced downward percolation beyond the crop root zone. A gradual reduction in seepage was observed toward September, reflecting seasonal adjustments in irrigation practices and partial groundwater stabilization.

Following the implementation of the solar-powered pressurized irrigation system in October 2025, a clear reduction in vertical seepage rates was observed. Head differences declined to approximately 0.01–0.02 m, and hydraulic gradients dropped accordingly to values near 0.001–0.002. As a result, calculated seepage rates stabilized around 0.06–0.12 mm/day, corresponding to seepage volumes of only 5–10 m³/day, representing a substantial reduction compared with pre-modernization conditions.

This reduction is attributed to:

- Improved irrigation control,
- Application of smaller water volumes per irrigation event,
- Better distribution uniformity, and
- Reduced deep percolation losses below the root zone.

The results demonstrate that under traditional irrigation practices, a considerable portion of applied water moved downward beyond the root zone, contributing to groundwater recharge rather than crop water use. After modernization, improved irrigation scheduling and distribution significantly reduced excess water application, thereby minimizing deep percolation losses. Reduced vertical seepage also contributes to stabilizing groundwater levels, lowering pressure on the already underperforming drainage network, and improving overall field water management.

On average, deep percolation rates decreased from approximately 0.26–0.37 mm/day before modernization to approximately 0.06–0.12 mm/day after modernization, representing a reduction exceeding 60–70% in vertical seepage losses. These results confirm that irrigation modernization effectively reduced non-beneficial water losses and improved water-use efficiency while maintaining more stable subsurface hydrological conditions within the study area.

6.6 Surface Irrigation Assessment and Performance Monitoring

6.6.1 General Background

The traditional irrigation system applied in the study area relies on conveying water through open earthen mesqas and canals, followed by field application using conventional surface flood irrigation (Figure 16). Although this method remains widely used in the clay soils of the Nile Delta due to its simplicity and low initial investment cost, it is commonly associated with several operational and environmental challenges that negatively affect water-use efficiency, crop productivity, and long-term land sustainability.

Figure 15. Surface flood irrigation through earthen mesqas and pump-lift systems.

As shown in Figure 16, under the conventional system, irrigation water is lifted using diesel-powered pumps and conveyed through open channels to the agricultural fields. Water distribution among farmers is typically organized through rotational arrangements, whereby irrigation is carried out over a limited number of consecutive days during which all fields receive irrigation. This practice often results in the application of large volumes of water within short time intervals, leading to significant water losses through lateral seepage, deep percolation beyond the crop root zone, and non-uniform water distribution within fields.

Excessive irrigation application also contributes to rising groundwater levels, increased pressure on the drainage network, and potential soil salinity risks in certain areas. Furthermore, reliance on diesel pumping systems increases operational costs and contributes to higher greenhouse gas emissions.

As part of the irrigation modernization program, through Al-Murounah project, the open canal conveyance system was replaced with a pressurized pipeline network supplied by solar-powered pumping units, delivering water directly to field inlets (Figure 17). This modernization allowed improved control over irrigation water quantities and better regulation of water distribution across the command area.

The improvement system consists of:
1) Solar panels
2) Pipes line
3) Control vales at each field

Figure 16. The Solar powered irrigation system: Solar panels – Pipe system – control valves.

The improved system also changed irrigation management practices, as irrigation events became distributed over the entire irrigation rotation period rather than being concentrated within a few days. Smaller, more frequent irrigation applications reduced deep percolation losses and lateral seepage, contributing to improved groundwater stability and more efficient water utilization.

Therefore, assessing irrigation performance before and after modernization is essential to quantify improvements in field water management, including distribution efficiency, reduction in water losses, and overall impacts on groundwater conditions and agricultural sustainability. This section presents the assessment of traditional surface irrigation performance and compares it with the modernized solar-powered pressurized pipeline system, focusing on irrigation practices, water application patterns, and their implications for groundwater behavior and water-use efficiency within the study area.

6.6.2 Calculation of Irrigation Water Applied to the Fields (Traditional system)

Before the introduction of the solar-powered pressurized pipeline irrigation system, a comprehensive field monitoring program was carried out to evaluate the performance of the existing traditional surface irrigation practices within the 20-feddan experimental area, which consists of 32 field strips (Appendix F). The purpose of this monitoring phase was to establish a reliable baseline for assessing water-use efficiency and quantifying the improvements expected after modernization.

Under the traditional irrigation system, irrigation water was conveyed through open earthen mesqas using diesel-powered pumps to apply surface flood irrigation. Water traveled within the earthen mesqa for distances ranging from 0 up to approximately 400 meters, depending on the distance between the field and the irrigation source, before reaching the field to be irrigated. On the following day, another farmer would operate a different pump to lift water again into the mesqa, allowing the water to repeat the same journey toward another field. This process continued sequentially among farmers. During this process, irrigation water application largely depended on farmers' experience, pump operating duration, and the availability of water in the mesqa, which often resulted in uneven water distribution among fields and excessive water application in some areas.

To quantify actual water use, the following procedures were implemented:

- Calibration of irrigation pumps operating in the area.
- Recording pump operation durations during each irrigation event.
- Collecting information on pump power ratings and estimating operating efficiency.
- Calculating the actual irrigation water volumes applied to each field.

Pump discharge was estimated using the standard pump discharge equation (Appendix F):

$$Q = \frac{P \ X \ \mu}{\gamma \ X \ H}$$

Where:

Q = Pump discharge (m^3/s);
P = Pump power input (Watts) = capacity (HP) × 746;
μ = Pump efficiency = assumed at 60%;
γ = Specific weight of water = 9,810 N/m^3; and
H = Total dynamic head = static head (Hs) + dynamic head (Hd) + friction head loss (Hf)

For the study area, the total head was calculated by considering the following assumptions:

- Hs (suction head) = 5 m;
- Hd (discharge head) = 0 m;
- Hf (friction loss) = 2 m.

Accordingly, the total dynamic head (H) was estimated at approximately 7 m.

Extensive field monitoring was conducted over five successive irrigation cycles between February and May 2025, corresponding to the winter cropping season of the monitored crops. The monitoring program covered a representative number of field strips within the experimental area in order to determine the actual irrigation water volumes applied under the traditional irrigation system. Since the monitoring program started in February, irrigation water quantities were recorded for the irrigation events that occurred between February and the end of the winter season in May. These measured irrigation quantities will later be compared with the actual crop water requirements estimated from reliable scientific references and published studies for the same crops and for the same time period.

The detailed measurement results are presented in Appendix F and summarized in Table 5, which shows the irrigation water volumes applied monthly to each monitored field strip, along with the total irrigation water applied per feddan for the monitored period.

Table 5**.** The quantity of irrigation water applied to the fields for each crop.

Field No.	Area (feddan)	Feb (m^3)	Mar (m^3)	Apr (m^3)	May (m^3)	Total Applied Water (m^3/feddan)
Artichoke						
f23	0.68	647.5	566.2	773.4	0	2922.2
f5	0.95	417.0	533.5	622.6	0	1655.8
f3	0.55	492.8	328.5	547.9	0	2489.5
f4	0.62	639.0	492.7	657.6	0	2985.0
f24	1.12	821.3	663.2	425.9	0	1705.7
f18	0.41	357.5	240.5	374.1	596.4	3960.3
f9	1.21	821.3	739.2	821.3	528.0	2404.8
f14	0.36	0	463.5	649.0	552.4	4624.7
f17	0.49	527.9	527.9	0	0	2154.7
f20	0.53	633.6	310.9	438.6	0	2694.6
f10	0.30	316.8	316.8	234.6	0	2884.0
f7	0.55	575.0	492.7	492.7	0	2837.1
f12	0.39	270.7	457.6	0	0	1857.4
Average	—	—	—	—	—	2678.3

Field No.	Area (feddan)	Feb (m^3)	Mar (m^3)	Apr (m^3)	May (m^3)	Total Applied Water (m^3/feddan)
Clover						
f6	0.93	492.8	522.3	608.4	0	1746.8
f21	0.36	214.2	422.4	352.0	0	2746.1
f1	2.48	1231.9	1478.3	1584.0	0	1731.5
f19	0.68	395.0	395.0	461.0	536.8	2625.1
f16	0.19	0	160.6	160.6	211.0	2801.1
f13	0.15	176.0	176.0	0	234.6	3910.7
Average	—	—	—	—	—	2594.2

Field No.	Area (feddan)	Feb (m^3)	Mar (m^3)	Apr (m^3)	May (m^3)	Total Applied Water (m^3/feddan)
Wheat						
f22	0.34	202.3	201.3	136.5	0	1588.3
f25	0.32	0	211.0	316.0	0	1645.6
f15	0.27	0	240.2	436.8	0	2692.4
f8	0.57	328.5	328.5	410.6	0	1873.6
f13	0.46	273.8	176.0	0	234.6	1487.7

Average	—	—	—	—	—	1858.6

Field No.	Area (feddan)	Feb (m³)	Mar (m³)	Apr (m³)	May (m³)	Total Applied Water (m³/feddan)
Sugar Beet						
f2	1.81	1149.8	1232.0	1067.7	1314.0	2631.8

The results presented in Table 5 show a considerable variation in irrigation water quantities applied to the different fields, even for the same crop. This variability is mainly attributed to several factors associated with the traditional diesel-pump irrigation system, including:

- The operating capacity and discharge rate of diesel pumps, which may vary from one farmer to another.
- Differences in farmers' irrigation practices and experience when determining irrigation duration.
- Field location relative to the water source, which affects water conveyance distance within the earthen mesqa.
- The absence of a controlled irrigation scheduling system, which often leads to either excessive or insufficient irrigation in some fields.

For example, the total irrigation water applied to artichoke fields ranged from approximately 1,655 m³/feddan to more than 4,600 m³/feddan, indicating significant differences in irrigation practices among farmers. Similar variations were also observed for clover and wheat fields, although the ranges were relatively smaller. To facilitate comparison with crop water requirements reported in the literature, the average irrigation water applied per crop was calculated and presented in the last row of each crop section in Table 5. These average values represent the representative irrigation water application under the traditional irrigation system during the monitoring period.

Based on the monitoring results, the average irrigation water applied during the winter season (February–May) was approximately:

- Artichoke: 2,678 m³/feddan
- Clover: 2,594 m³/feddan
- Wheat: 1,859 m³/feddan
- Sugar beet: 2,632 m³/feddan (single monitored field)

These average values will be used in the following sections to compare the actual irrigation water applied under traditional irrigation practices with the crop water requirements obtained from published agronomic references, in order to evaluate irrigation efficiency and the potential water savings achievable through irrigation modernization.

Discussion of Irrigation Practices:

Significant variation in the applied irrigation water was observed among different crops as well as between fields growing the same crop. This variability mainly resulted from differences in pump operating duration, irrigation scheduling, and farmer-controlled water distribution. Under the traditional irrigation system, water application largely depends on farmers' experience and pump availability rather than on scientifically determined crop water requirements.

Consequently, some fields received excessive irrigation while others received lower irrigation amounts depending on pump access and coordination among farmers. This variability reflects the limited control over irrigation water distribution under the traditional irrigation system, which often results in deep percolation losses, non-uniform soil moisture distribution, and inefficient water use.

These findings highlight the importance of improving irrigation management practices and modernizing water conveyance systems. The adoption of pressurized pipeline irrigation systems would significantly improve water distribution uniformity and reduce unnecessary water losses.

Calculation of Traditional Irrigation Efficiency:

To evaluate irrigation performance, irrigation efficiency was calculated by comparing the actual irrigation water applied with the crop evapotranspiration requirements (ETc) during the monitoring period (February–May 2025). Crop water requirements were obtained from published agricultural water requirement references commonly used in Egypt, including FAO guidelines and national irrigation water requirement studies. Table 6 summarizes the monthly crop water consumption expressed as irrigation water volume per feddan (m³/feddan) [5].

Table 6**.** Monthly Crop Water Requirements (m³/feddan) for Artichoke, Wheat, Clover and Shogerbeet.

Month	Artichoke	Wheat	Clover	Sugar Beet
October	336	—	294	—
November	378	168	336	210
December	378	210	336	252
January	357	252	294	294
February	336	252	294	336
March	357	252	294	336
April	378	252	252	336
May	—	—	210	252

Irrigation efficiency (E) was calculated using:

$$E = \frac{ET_C}{Ia} * 100$$

Where:

E = Irrigation efficiency (%)
ETc = Crop evapotranspiration (m³/feddan or mm)
Ia = Irrigation water applied (m³/feddan)

The calculated irrigation efficiencies for the monitored crops showed moderate variation among crops. Artichoke and clover fields both recorded irrigation efficiencies of approximately 40%, while wheat fields achieved a slightly higher efficiency of about 41%. Sugar beet fields demonstrated the highest efficiency among the monitored crops, reaching approximately 48% (Table 7). Overall, the traditional irrigation system achieved an average irrigation efficiency of about 42%, indicating that more than half of the applied irrigation water was lost through deep percolation, surface runoff, or non-uniform distribution rather than being directly utilized by crops.

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[5] 1) Ismail, S.A., *Effect of Water Amounts on Artichoke Productivity*, Journal of Plant Production, 2022. 2) Darwesh, R.K., *Water Productivity for Egyptian Clover*, 2018. 3) El-Marsafawy, S.M., *Water footprint of Egyptian crops and its economics*, 2021. 4) Yassin, O. et al., *Optimizing Roots and Sugar Yields and Water Use Efficiency.*

Table 7**.** Calculated irrigation efficiency for the main crops for traditional irrigation methods.

Crop	ETc (Feb–May) (m³/feddan)	Irrigation Water Applied (m³/feddan)	Irrigation Efficiency (%)
Artichoke	1071	2678.1	40
Clover	1050	2594.2	40
Wheat	756	1858.0	41
Sugar beet	1260	2631.8	48
Avg.			42.3

Interpretation of Results:

The low irrigation efficiency observed is typical of flood irrigation systems in the Nile Delta, where water losses commonly occur due to:

- Deep percolation below the root zone,
- Surface runoff during field flooding,
- Uneven land leveling,
- Over-irrigation beyond crop water requirements.

These inefficiencies not only waste water but also contribute to rising groundwater levels, increased drainage loads, and soil salinity risks. Consequently, the results strongly support the need for irrigation modernization using controlled, pressurized pipeline systems powered by renewable energy sources to improve water productivity, stabilize groundwater conditions, and enhance long-term agricultural sustainability.

6.6.3 Calculation of Irrigation Water Applied to the Fields under the Improved Pressurized Irrigation System

Under the modernized irrigation system, water is conveyed to the fields through a pressurized pipeline network supplied by solar-powered pumping units, replacing the traditional open canal conveyance and uncontrolled surface irrigation practices. This system allows more accurate measurement and control of irrigation water delivered to each field, enabling reliable estimation of applied irrigation volumes. The calculation of irrigation water applied to the fields is based on measuring pump discharge and operation time, since water delivery occurs through a controlled pumping and pipeline distribution system.

Pump discharge (Q) is measured at the pump outlet using flow meters or calibrated discharge measurements. Pump discharge is typically expressed in:

$$Q = m^3 / \text{hour}$$

Discharge measurements are periodically verified to ensure consistency under varying operating pressures and solar pumping conditions. Based on the calibrated pump discharge and the recorded pumping duration for each irrigation event, the volume of irrigation water delivered to each field was estimated with high accuracy. Pump calibration was conducted to determine the actual discharge rate under normal operating conditions, considering system pressure and the characteristics of the pressurized pipeline network. By combining the measured pump discharge with the recorded operating time for each irrigation event, the total irrigation water supplied to each field was calculated.

Using this approach, irrigation water volumes applied to each field were determined for the period from October to January, allowing detailed comparison among fields, crops, and irrigation events under the improved solar-powered pressurized irrigation system. All measurement results are presented in Appendix f and summarized in Table 8, which presents the irrigation water applied to each field on a monthly basis, including field number, cultivated area (feddan), crop type, and irrigation water applied during October, November, December, and January, in addition to the total applied irrigation water per feddan.

Table 8**.** The quantity of irrigation water applied to the fields for each crop under irrigation improvement.

Field No.	Area (feddan)	Oct (m³)	Nov (m³)	Dec (m³)	Jan (m³)	Total Applied Water (m³/feddan)
Artichoke						
F1	1.25	667	667	667	700	2702
F10	0.42	650	750	650	700	2750
F17	0.54	692	615	654	577	2539
F18	0.50	750	667	708	625	2751
F24	0.42	800	750	750	750	3050
F30	0.50	750	625	625	583	2584
F32	0.50	667	625	750	625	2668
Average	—	—	—	—	—	2720

Field No.	Area (feddan)	Oct (m³)	Nov (m³)	Dec (m³)	Jan (m³)	Total Applied Water (m³/feddan)
Clover						
F2	1.5	389	400	583	556	1930
F4	0.33	500	625	625	563	2313
F5	1.08	538	538	538	538	2153
F6	1.08	462	538	538	538	2077
F7	0.71	471	588	588	529	2177
F8	0.71	529	529	588	529	2176
F11	0.58	500	571	500	571	2143
F15	0.33	500	625	625	625	2375
F20	0.29	500	571	571	571	2213
F22	0.50	458	583	583	500	2125
Average	—	—	—	—	—	2168

Field No.	Area (feddan)	Oct (m³)	Nov (m³)	Dec (m³)	Jan (m³)	Total Applied Water (m³/feddan)
Wheat						
F14	0.33	0	375	375	375	1125
F16	0.29	0	357	357	429	1143
F19	0.29	0	357	357	429	1143
F21	0.50	292	333	333	333	1292
F23	0.58	0	286	357	286	930
F25	1.25	0	300	300	400	1001
F28	0.50	0	250	333	417	1001
Average	—	—	—	—	—	7635

Field No.	Area (feddan)	Oct (m³)	Nov (m³)	Dec (m³)	Jan (m³)	Total Applied Water (m³/feddan)
Sugar Beet						
F3	0.42	0	400	400	400	1200
F9	1.25	383	400	367	333	1484
F12	0.42	0	400	400	400	1200
F13	0.42	0	350	400	400	1150
F26	0.50	0	333	333	375	1042
F27	0.50	0	333	333	375	1042
F29	0.33	583	375	500	375	1833
F31	0.50	0	417	333	333	1084
Average	—	—	—	—	—	1254

The results show that irrigation water application varied among fields depending on crop type, field area, and irrigation scheduling. The calculated averages indicate that the average total irrigation water applied per feddan during the monitoring period reached approximately:

- 2720 m³/feddan for artichoke,
- 2168 m³/feddan for clover,
- about 1090 m³/feddan for wheat, and
- 1254 m³/feddan for sugar beet.

These values reflect the irrigation practices adopted under the improved system, where smaller but more frequent irrigation applications were distributed across the irrigation season. Such management contributed to better control of applied water volumes, reduction of excessive irrigation, and improved water-use efficiency compared with the traditional irrigation system.

Calculation of Improved Irrigation Efficiency according to the types of crops:

The evaluation of irrigation efficiency under the improved irrigation system provides important insight into the effectiveness of irrigation water management within the study area. Irrigation efficiency was calculated by comparing the crop water requirements, expressed as crop evapotranspiration (ETc), (presented in Table 6), with the total irrigation water applied per feddan during the monitoring period. The calculated values for the main crops cultivated in the study area are summarized in Table 9. The results indicate moderate variation in irrigation efficiency among the different crops, reflecting differences in crop water requirements, irrigation scheduling practices, and field management conditions.

Table 9**.** Calculated irrigation efficiency for the main crops for traditional irrigation methods.

Crop	ETc (Feb–May) (m³/feddan)	Irrigation Water Applied (m³/feddan)	Irrigation Efficiency (%)
Artichoke	1449	2720	53
Clover	1260	2194	57
Wheat	630	1117	56
Sugar beet	756	1228	61.5
Avg.			58.5

For artichoke, the seasonal crop water requirement during the monitored period was estimated at 1449 m³/feddan, while the average irrigation water applied reached 2720 m³/feddan. Based on these values, the calculated irrigation efficiency for artichoke was approximately 53%. Although artichoke fields received relatively large volumes of irrigation water due to the crop's extended growth period and relatively high evapotranspiration demand, the efficiency indicates that a significant portion of the applied water exceeded the actual crop water requirement.

For clover, the seasonal crop evapotranspiration requirement was estimated at 1260 m³/feddan, while the applied irrigation water reached 2194 m³/feddan, resulting in an irrigation efficiency of approximately 57%. The irrigation requirement of clover is relatively high due to its continuous vegetative growth and repeated cutting cycles throughout the season. Nevertheless, the calculated efficiency indicates a reasonable level of water use performance under the improved irrigation management conditions.

In the case of wheat, the seasonal crop water requirement was estimated at 630 m³/feddan, while the total irrigation water applied amounted to 1117 m³/feddan, resulting in an irrigation efficiency of approximately 56%. The relatively balanced ratio between crop water requirement and irrigation water applied indicates improved irrigation control compared with traditional irrigation practices.

For sugar beet, the seasonal crop water requirement was estimated at 756 m³/feddan, while the irrigation water applied reached 1228 m³/feddan, resulting in the highest irrigation efficiency among the monitored crops, approximately 61.5%. This relatively higher efficiency reflects improved irrigation scheduling and more appropriate water application during the critical stages of root development.

Overall, the average irrigation efficiency across all studied crops reached approximately 58.5%, indicating a significant improvement in irrigation performance compared with the traditional irrigation system previously practiced in the study area. The improvement in irrigation efficiency can be attributed to enhanced control over irrigation water delivery, better irrigation scheduling, and improved field-level water management practices enabled by the upgraded irrigation infrastructure. These results demonstrate that modernization of irrigation systems can substantially enhance water-use efficiency, reduce excessive irrigation, and contribute to more sustainable agricultural water management in the Nile Delta region.

6.6.4 Comparison Between Traditional and Improved Irrigation Systems

A comparative assessment was conducted to evaluate the performance of the traditional surface irrigation system and the improved irrigation system implemented within the study area. The comparison was based on irrigation water applied and irrigation efficiency for the main crops cultivated in the monitored fields, namely artichoke, clover, wheat, and sugar beet. The results presented in Table 7 represent the irrigation performance under the traditional irrigation system, while Table 9 reflects irrigation performance under the improved irrigation management conditions.

The results clearly indicate a substantial improvement in irrigation efficiency after the implementation of the improved irrigation system. Under the traditional irrigation system, irrigation efficiency values ranged between 40% and 48%, with an overall average efficiency of approximately 42.3%. This relatively low efficiency reflects the limitations of conventional surface irrigation practices, including uncontrolled water application, uneven field distribution, and significant water losses through deep percolation and surface runoff. Following irrigation improvement, irrigation efficiency increased significantly across all crops. The improved system achieved irrigation efficiency values ranging between 53% and 61.5%, with an overall average efficiency of approximately 58.5%. This represents an improvement of approximately 16 percentage points in overall irrigation efficiency, corresponding to an increase of nearly 38% relative improvement in irrigation performance compared with the traditional system.

Figure 18, presents a comparison of irrigation efficiency achieved under the traditional irrigation system and the improved irrigation system for the main crops cultivated in the study area, including artichoke, clover, wheat, and sugar beet. The figure clearly illustrates the significant improvement in irrigation efficiency after the implementation of the modernized irrigation infrastructure.

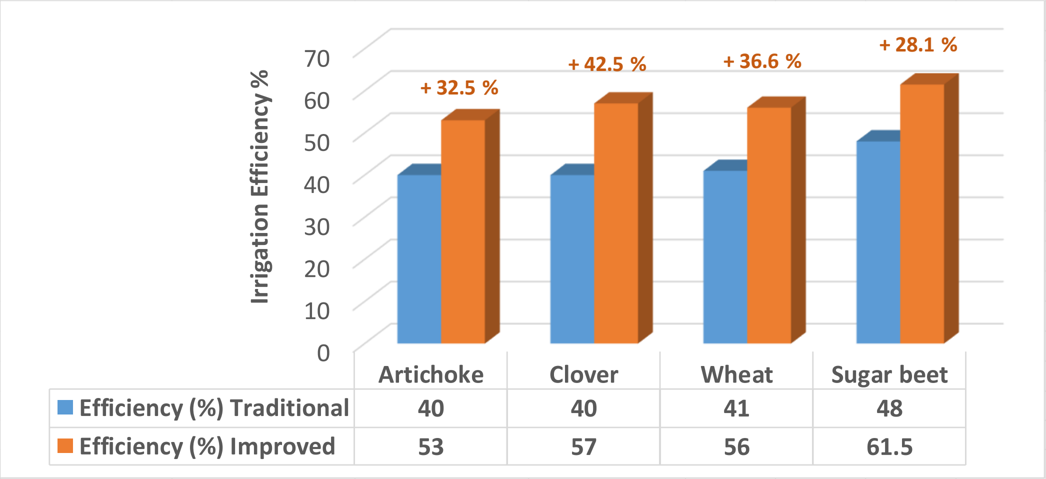


Figure 17. Comparison of irrigation performance between traditional and improved irrigation systems.

Comparative Performance of Irrigation Efficiency for Crops:

For artichoke, irrigation efficiency increased from 40% under the traditional system to 53% under the improved system, representing an improvement of approximately 32.5%. This improvement reflects better irrigation scheduling and more controlled water application. For clover, irrigation efficiency increased from 40% to 57%, representing the largest relative improvement among the studied crops (42.5%). This result indicates that irrigation modernization significantly reduced excessive irrigation commonly associated with forage crops. In the case of wheat, irrigation efficiency increased from 41% under the traditional system to 56% under the improved system, corresponding to an improvement of approximately 36.6%. The improved irrigation system allowed irrigation water to be applied more closely in line with crop water requirements during different growth stages. For sugar beet, irrigation efficiency increased from 48% to 61.5%, representing an improvement of approximately 28.1%. Although sugar beet already showed relatively higher efficiency under traditional irrigation, the improved irrigation infrastructure further enhanced water-use efficiency.

Overall, the figure demonstrates that irrigation modernization resulted in substantial improvements in irrigation performance across all studied crops. The increased irrigation efficiency reflects improved control over water delivery, better irrigation scheduling, and reduced water losses associated with traditional flood irrigation systems. These findings highlight the importance of adopting modern irrigation technologies, such as pressurized pipeline systems and solar-powered pumping units, to enhance water-use efficiency and support sustainable agricultural water management in the Nile Delta.

Benefits of Irrigation Modernization for Agricultural Water Management:

The results of this study indicate that the implementation of modern irrigation systems based on pressurized pipeline networks and solar-powered pumping units can lead to a significant improvement in water-use efficiency and agricultural water management. The comparison between the traditional irrigation system and the improved irrigation system showed that the average irrigation efficiency increased from approximately 42.3% to 58.5%, reflecting a substantial improvement in field-level water-use efficiency. These findings are particularly important in light of the growing challenges facing water resources in Egypt, where the agricultural sector accounts for approximately 80–85% of the total national water consumption. With limited available water resources and increasing demand due to population growth and agricultural expansion, improving water-use efficiency in the agricultural sector has become a critical priority. The widespread adoption of modern irrigation systems in the Nile Delta region can contribute to achieving several important benefits, including the following:

1. Reduction of irrigation water losses
2. Improvement of agricultural water productivity
3. Reduction of pressure on agricultural drainage systems
4. Reduction of agricultural operating costs
5. Reduction of carbon emissions
6. Improvement of irrigation rotation management

The findings of this study confirm that irrigation modernization plays a crucial role in improving agricultural water management in the Nile Delta. The adoption of pressurized pipeline irrigation systems powered by renewable energy can significantly enhance water-use efficiency, reduce irrigation water losses, and promote more sustainable agricultural production. Consequently, expanding irrigation modernization programs represents an effective strategy to support water security, agricultural productivity, and long-term sustainability of water resources in Egypt.

6.7 Soil and Water Characterization

6.7.1 Soil Physical analysis

To characterize the physical properties of the experimental field, disturbed soil samples were collected from four representative observation well locations **(**OW1, OW3, OW6, and OW8**)** at three standard depths: 0–40 cm (topsoil/root zone)**,** 40–80 cm (subsoil)**,** and 80–120 cm (deep subsoil). The primary objective of this investigation was to determine the soil texture, specifically the relative proportions of sand, silt, and clay, which are critical indicators for evaluating infiltration rates, water retention capacity, soil aeration, and root penetration potential**.**

Soil texture serves as a fundamental parameter for irrigation system design, crop selection, and land management strategies. The results presented in (Appendix G), indicate that all analyzed samples across the three depth intervals are classified as clay soils, with clay content ranging from 46% to 66%**,** sand from 12% to 30%**,** and silt from 18% to 38%**.**

This dominance of heavy clay texture is characteristic of soils with low infiltration rates and slow internal drainage**,** yet high water-holding capacity. While such soils can retain substantial moisture, they are also prone to waterlogging and poor aeration if not managed properly. These findings underscore the importance of adopting modernized irrigation systems, such as pressurized or low-flow solar-powered irrigation, in combination with soil structure improvement practices (e.g., deep tillage or organic amendments) to enhance water use efficiency, aeration, and root development**.**

6.7.2 Soil Chemical analysis

Soil chemical analysis represents one of the fundamental pillars in evaluating agricultural land conditions, particularly in projects aimed at modernizing irrigation systems and improving water-use efficiency. In arid and semi-arid environments such as the Nile Delta, climatic conditions combined with traditional irrigation practices often lead to gradual accumulation of salts and increased sodium levels in soils over time. These processes directly affect crop productivity, water-use efficiency, and the long-term sustainability of agricultural land resources.

Accordingly, assessing soil chemical properties was considered a key component of the present study program—not only to characterize soil conditions before implementing the modernized irrigation system, but also to quantify improvements achieved after introducing the solar-powered pressurized pipeline irrigation system. This approach allows a direct scientific comparison between pre- and post-modernization conditions, enabling accurate evaluation of irrigation improvement impacts on soil quality and long-term sustainability.

The importance of soil chemical analysis in irrigation modernization projects arises from several critical aspects, including:

- Evaluating soil salinity levels and their impact on crop growth and water uptake efficiency.
- Diagnosing sodicity risks that may degrade soil structure and reduce permeability.
- Assessing chemical balance within the soil and its suitability for agricultural production.
- Evaluating the effectiveness of irrigation and drainage systems in preventing salt accumulation within the root zone.
- Identifying future needs for soil amendments such as gypsum application or drainage improvement.
- Monitoring medium- and long-term impacts of irrigation modernization on soil conditions.

Modern irrigation systems aim not only to reduce water consumption but also to improve the root-zone environment, control groundwater rise, and prevent salt accumulation in surface soil layers.

Within the study framework, two major soil sampling campaigns were conducted:

- First campaign: Prior to implementation of the modernized irrigation system, to establish baseline soil conditions.
- Second campaign: After system operation commenced, to evaluate changes resulting from improved water management.

Soil samples were collected from representative locations across the study area at three standard depths: 0–40 cm (active root zone), 40–80 cm, and 80–120 cm. Samples were analyzed to determine key chemical parameters, including:

- Electrical conductivity (EC) as an indicator of soil salinity,
- Soil reaction (pH),
- Exchangeable Sodium Percentage (ESP),
- Major cation concentrations (Ca, Mg, Na, K),
- Major anion concentrations (Cl, SO_4, HCO_3).

These data enabled evaluation of both vertical and spatial salt distribution patterns and allowed comparison between soil conditions before and after irrigation modernization. All the laboratory analysis were presented in Apendix-G.

Soil Chemical Conditions Before Irrigation Modernization

Laboratory results obtained prior to system modernization revealed several key observations:

- Moderate soil salinity was present, with higher salt concentrations in surface layers due to evaporation and shallow groundwater influence.
- EC values commonly ranged between 2 and 4 dS/m, which can negatively affect salt-sensitive crops.
- Elevated ESP values in several locations indicated early development of sodicity risks that could reduce soil permeability.
- Sodium and chloride ions were dominant, typical of areas experiencing insufficient drainage and shallow groundwater.
- Evidence of salt accumulation within the root zone was observed due to excessive flood irrigation practices.

These findings reflect the impacts of conventional irrigation methods, where large volumes of water applied within short periods cause groundwater rise and promote salt accumulation near the soil surface.

Soil Chemical Conditions After Irrigation Modernization

Following implementation of the pressurized pipeline irrigation system powered by solar energy, subsequent analyses revealed several positive changes:

- Relative reduction in surface soil salinity at several locations due to improved water distribution and reduced over-irrigation.
- Improved vertical salt distribution within soil profiles, with reduced salt accumulation in upper soil layers.
- Slight reduction or stabilization of ESP values in some locations due to improved water movement within soil profiles.
- Reduced fluctuations in soil salinity resulting from more uniform irrigation scheduling and application of smaller water volumes over longer periods.

These improvements are attributed to characteristics of the modernized irrigation system, including:

- More uniform water distribution,
- Reduced losses associated with flood irrigation,
- Lower excess percolation to groundwater,
- Improved water-use efficiency within the crop root zone.

Comparison Between Pre- and Post-Modernization Conditions

Table 7 presents a comparison of mean soil chemical properties measured before and after irrigation modernization. The results indicate that changes observed during the monitoring period were relatively limited, with no substantial differences recorded in most soil chemical parameters between the two periods. The data show that electrical conductivity (EC), exchangeable sodium percentage (ESP), and sodium concentration (Na) recorded slight increases after modernization. However, these increases remain within the same general range previously observed and do not indicate significant deterioration in soil conditions. Slight increases were also observed in sulfate and bicarbonate concentrations, while potassium levels decreased compared with the earlier monitoring period.

Table 7. Mean Soil Chemical Properties Before and After Irrigation Improvement.

Key soil parameters	EC dS/m	ESP %	Ca (meq/L)	Mg (meq/L)	K (meq/L)	Na (meq/L)	Cl (meq/L)	SO_4 (meq/L)	HCO_3 (meq/L)
Befor Improvement	2.58	8.59	4.50	5.05	0.66	15.94	16.54	5.33	4.29
After Improvement	2.62	8.68	5.86	5.25	0.15	16.98	16.38	6.90	4.96

These findings suggest that the post-modernization monitoring period is still relatively short for clear chemical improvements to become evident. Processes such as salt leaching and redistribution within the soil profile typically require longer periods to produce measurable changes in soil chemical balance.

Comparative analysis between the two monitoring periods indicates:

- General stability in soil salinity and sodicity levels without noticeable deterioration.
- Continued redistribution of salts within soil profiles due to changes in irrigation practice.
- The need for a longer monitoring period to detect clearer improvements in soil chemical properties.
- Potential for future improvements as irrigation and drainage management continue to improve.

Therefore, the post-modernization results may be considered part of a transitional phase, with clearer soil quality improvements expected over the medium term as improved irrigation practices continue to operate.

6.7.3 Water Quality Assessment

Water samples were collected at the beginning of the study period, prior to modernization activities, to establish the initial water quality conditions, identify any potentially hazardous constituents, and evaluate the general conditions trend of water quality in the area. The objective was also to assess the compatibility between applied irrigation water, drainage outflow, and groundwater conditions within the soil profile**.** Samples were obtained from three main sources: the irrigation canal, drainage outlets, and observation wells representing shallow groundwater. Analyses included key parameters such as pH, electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and total dissolved solids salts (TDS). All the data were presented in Appendix-G**.**

Results showed that pH values were nearly neutral (7.7–7.8) across all sampled water sources. Canal water exhibited acceptable salinity levels for irrigation use, while drainage water and shallow groundwater showed relatively higher salinity levels (5.3–6.0 dS/m), with total dissolved solids (TDS) exceeding 3,000 mg/L. These elevated salinity levels are mainly attributed to limited leaching efficiency caused by inadequate drainage performance, which promotes salt accumulation within the soil–water system.

Average sodium adsorption ratio (SAR) values of approximately 12.5 indicate a moderate sodicity hazard if such water is used for prolonged irrigation. However, residual sodium carbonate (RSC) values were close to zero, suggesting that no significant carbonate or bicarbonate alkalinity hazard is present. Therefore, the potential sodicity risk is primarily related to sodium concentration rather than carbonate alkalinity.

6.8 Cropping pattern of the study area

Recording the cropping pattern before and after irrigation system modernization is a critical component in assessing the effectiveness of irrigation improvement projects. Crop distribution directly influences water consumption, soil moisture dynamics, drainage behavior, and salt distribution within the root zone. Therefore, documenting cropping conditions provides an essential baseline for evaluating how irrigation modernization affects agricultural practices and resource use efficiency. Monitoring cropping changes also allows comparison of land use patterns and estimation of crop water consumption before and after modernization. Such analysis helps determine whether improved irrigation management encourages the adoption of crops better suited to available water resources and soil conditions.

Pre-modernization:
During the winter season of 2025, artichoke dominated the cultivated area, covering approximately 55%**,** followed by alfalfa (25%), while wheat and sugar beet each occupied about 10% of the area. This cropping composition reflects farmers' preference for high-value horticultural crops alongside forage crops, despite relatively high irrigation water requirements for some of these crops. In the summer season, cropping patterns shifted in response to higher temperatures and irrigation demand. Main crops included sunflower (26%), artichoke (20%), maize (19.3%), watermelon seed (17%), clover seed (12%), and cotton (6%), indicating diversification toward crops adapted to summer climatic conditions.

Post-modernization Phase:
Data from the current winter season of 2026 show noticeable changes in crop distribution. Alfalfa now occupies about 34% of the cultivated area, followed by wheat (24%), while artichoke and sugar beet each account for approximately 21% of the area. This shift suggests a gradual movement toward field and forage crops compared with water-intensive horticultural crops, consistent with improved irrigation management and water distribution efficiency.

Comparing cropping patterns across seasons demonstrates that crop mapping plays a key role in:

- Estimating crop water consumption before and after modernization.
- Evaluating farmers' responses to improved irrigation conditions.
- Understanding impacts on soil moisture and salinity distribution.
- Supporting efficient irrigation and drainage system design.
- Guiding adaptive land and water management strategies.

Therefore, monitoring cropping patterns is an essential tool for evaluating irrigation modernization impacts not only on water management but also on farmers' cropping decisions and long-term agricultural sustainability.

6.9 Agricultural Productivity

Crop productivity is one of the most important indicators used to assess agricultural conditions within the study area, as it directly reflects the cumulative impact of all factors influencing agricultural production. These factors include soil properties, irrigation system efficiency, drainage conditions, water quality, and crop management practices. Therefore, monitoring crop productivity before and after irrigation modernization is essential for determining the overall trend in agricultural performance and production sustainability. Productivity trends provide a clear indication of whether agricultural conditions in the study area are improving or deteriorating. Crop yield represents the final outcome of the interaction between environmental and management factors within the field. Consequently, any change in water distribution, soil salinity, soil moisture availability, or nutrient status ultimately affects both the quantity and quality of agricultural production.

The study of crop productivity is particularly important in evaluating irrigation modernization projects, where improvements in water management and distribution are expected to enhance plant growth conditions and increase yields. Conversely, if problems related to water distribution, salinity, or drainage persist, these constraints will be reflected in crop productivity, making yield performance a practical indicator of the success or limitations of modernization efforts. Monitoring productivity also allows comparison of crop performance under different cropping patterns and irrigation regimes, helping to identify crops that respond positively to improved irrigation conditions and supporting future agricultural planning decisions. In addition, crop productivity serves as an important economic indicator, linking technical improvements in irrigation and soil management to farmers' actual economic returns. This enables evaluation of both the technical and economic impacts of irrigation modernization.

In this context, productivity of winter crops during the 2025 and 2026 seasons will be analyzed and compared in order to assess changes in production levels following the implementation of irrigation modernization and to determine how improvements in water management are reflected in crop performance within the study area.

6.9.1 Productivity of Winter Crops Before Irrigation Modernization

Monitoring crop productivity prior to irrigation modernization provides an essential baseline for evaluating the performance of the upgraded irrigation system. Crop yield represents the integrated outcome of soil conditions, irrigation efficiency, drainage performance, crop management practices, and climatic factors. Therefore, documenting crop productivity before modernization allows later comparison to determine the real impact of irrigation improvements on both agronomic performance and farm economic returns.

The following sections summarize productivity results of major winter crops cultivated during the 2024/2025 winter season, representing conditions before irrigation modernization.
These results will serve as a benchmark for comparison with productivity data from the current season (2025/2026), which will be incorporated into the final report upon completion of harvest operations in May 2026.

Artichoke Productivity:

The total artichoke yields for the three fields were 15,838 units for Field-12, 15,585 units for Field-4, and 12,880 units for Field-5, giving a combined total of 44,303 units, as shown in Table 8. These fields collectively covered an area of 2.6 feddans (0.4 feddan for Field-12, 1.0 feddan for Field-4, and 1.2

feddans for Field-5), resulting in an average yield of approximately 17,040 artichokes per feddan. According to the Ministry of Agriculture and Land Reclamation (MLAR) and the Food and Agriculture Organization (FAO), the typical artichoke yield in Egypt ranges from 8,000 to 12,000 kg per feddan. Assuming an average weight of 0.4 kg per artichoke, this corresponds to a national average of 20,000 to 30,000 units per feddan. Compared to this benchmark, the average yield from the three fields was approximately 15% to 43% lower than the national standard. The reduced yield is largely attributed to the absence of harvesting during the final three weeks of the season. During this period, market prices dropped significantly, making continued harvesting economically unfeasible. As a result, a portion of the crop was left unharvested, negatively impacting overall productivity.

Table 10.The productivity of Artichoke for three different field.

Yield (unit) per week		Field-1 = 0.38 fed.		Field-2 = 1 fed. (Heads)	Field-3 = 1.21 fed.		Price (LE) per (Heads)
		Yield (Heads)	yield/fed. (Heads)		Yield (Heads)	yield/fed. (Heads)	
Jan	week-1	0	0	100	5	4	4
	week-2	20	53	200	20	17	4
	week-3	70	184	500	40	33	4
	week-4	150	395	1000	50	41	4
Feb	week-5	360	947	1000	1000	826	3.5
	week-6	440	1158	1100	1500	1240	3
	week-7	400	1053	1400	2000	1653	3
	week-8	450	1184	1500	1500	1240	3
March	week-9	450	1184	1500	2000	1653	2
	week-10	645	1697	2050	1520	1256	2
	week-11	850	2237	2100	1750	1446	2
	week-12	900	2368	2050	2100	1736	2
April	week-13	1000	2632		2100	1736	1
	week-14	No harvest due to low price					Low price
	week-15						Low price
	week-16						Low price
Total		5735	15092	14500	15585	12880	
Total cost		35211		38100	29586.77686		

This robust baseline data will guide future performance evaluations of the upgraded irrigation system, particularly regarding yield optimization and economic returns.

Wheat Productivity:

Wheat productivity was assessed in five different plots of varying sizes, as shown in Table 9. The crop was harvested at the end of the winter season (May 2025), and the recorded yields serve as pre-modernization benchmarks.

Table 11.The wheat crop productivity for five-fields with different areas.

Field No.	Area (feddan)	Total Production (kg)	Yield (kg/feddan)
Field-8	0.57	950	1666
Field-15	0.27	360	1333
Field-11	0.47	900	1915
Field-8	0.57	650	1140

Field-24	0.37	780	2108

The wheat yields across the observed fields varied notably, ranging from 1,140 to 2,108 kg per feddan. Among them, Field-24 recorded the highest productivity at 2,108 kg/feddan, which may indicate more favorable soil and water conditions or more effective management practices in that field. The overall average yield across all fields was approximately 1,618 kg per feddan. When compared to the national average wheat yield in Egypt—estimated by the Ministry of Agriculture and Land Reclamation (MLAR) and the FAO to be between 2,700 and 3,100 kg per feddan—this represents a yield gap of roughly 40% to 48% below the national benchmark. This significant shortfall highlights potential areas for improvement in crop management, input application, or field conditions. These figures provide valuable insights into the influence of current irrigation practices on wheat productivity. The significant variation between plots of similar size underscores the importance of water distribution efficiency, which the solar-powered pressurized irrigation system is designed to improve.

Sugar Beet Productivity:

Sugar beet was cultivated in a single plot covering 1.81 feddans, producing a total of 33,130 kilograms, which translates to an average yield of approximately 18,302 kg per feddan. This is a strong performance, especially when compared to the national average sugar beet yield in Egypt, which typically ranges from 16,000 to 18,000 kg/feddan according to data from the Ministry of Agriculture and the FAO. The result places this field at or slightly above the upper range of national productivity, indicating efficient crop establishment and favorable growing conditions. This high yield suggests that sugar beet responded well to local environmental factors and irrigation practices, particularly considering the crop’s known sensitivity to water stress and salinity. It also provides a valuable benchmark for evaluating the potential benefits of precision irrigation in enhancing root crop productivity. The data will be particularly useful in post-modernization assessments, helping to analyze cost-effectiveness, water use efficiency, and yield stability, all of which are critical for sustainable sugar beet cultivation.

The productivity levels recorded before irrigation modernization indicate that crop performance in the study area was constrained by irrigation and soil management conditions, as reflected by yields below national averages and variability among neighboring fields. These results provide a critical baseline against which the effectiveness of irrigation modernization can be measured. Since crop productivity ultimately reflects all environmental and management factors combined, improvements or deteriorations resulting from irrigation modernization will be directly observable through subsequent productivity comparisons.

Accordingly, the inclusion of post-modernization productivity data will be essential to fully quantify the agricultural benefits of the irrigation system upgrade.

7. Economic Evaluation of Irrigation System Modernization

This section presents a comprehensive economic assessment of the irrigation system modernization implemented in the West Delta project area. The analysis compares the existing traditional diesel-operated surface irrigation system with the developed solar-powered pressurized pipeline system.
The evaluation aims to:

- Quantify capital and operational costs under both systems.
- Assess annual savings resulting from improved energy efficiency and reduced labor demand.
- Estimate additional revenues generated from enhanced agricultural productivity.
- Determine the payback period and long-term financial feasibility.

The economic analysis reflects recent market conditions, including increased diesel fuel prices, higher maintenance costs, and realistic productivity improvements resulting from improved irrigation performance. The cultivated command area considered in this assessment is 20 feddans, with an average annual net return of approximately 50,000 EGP per feddan under current agricultural production conditions.

7.1 System Description

7.1.1 Traditional Irrigation System

The traditional irrigation system currently used in the study area relies on open earthen canals and diesel-powered pumps to deliver irrigation water to agricultural fields. Understanding the structure and operational characteristics of this system is essential for evaluating its limitations and comparing its performance with the modern irrigation system.

The traditional system consists of:

- Two earthen irrigation canals (800 m total length).
- Ten diesel pumping units (7–9 HP).
- Decentralized operation requiring frequent pump relocation and manual supervision.

This irrigation method is characterized by several operational limitations, including:

- High dependency on diesel fuel.
- Intensive labor requirements.
- Frequent mechanical failures and maintenance needs.
- Significant water conveyance losses through seepage and evaporation.

7.1.2 Modern Solar-Powered Pressurized System

In contrast to the traditional irrigation system described above, the developed irrigation system introduces a centralized solar-powered pressurized pipeline network designed to improve water delivery efficiency and reduce operational constraints associated with diesel-based irrigation. The upgraded system replaces the traditional open-channel irrigation and diesel pumping units with a solar-powered pressurized pipeline network designed to improve water conveyance efficiency, reduce operational costs, and enhance overall irrigation management.

The developed system consists of:

- Two HDPE pressurized pipelines (800 m total length).
- Two electric pumps (20 HP each).
- Two independent solar pumping systems including panels, mounting structures, inverters, and electrical protection units.

The system provides:

- Centralized and stable pumping capacity.
- Uniform water distribution.
- Elimination of fuel consumption.
- Reduced operational labor.
- Improved irrigation scheduling efficiency.

7.2 Capital Investment Analysis

A capital investment analysis was conducted to compare the costs of the traditional irrigation system with those of the modernized solar-powered pressurized irrigation system implemented in the study area. Table 12 summarizes the main cost components associated with each system, highlighting the additional investment required for irrigation modernization.

Under the traditional irrigation system, the estimated total establishment cost was approximately 500,000 EGP. This amount includes the cost of water lifting pumps owned by farmers (10 diesel pumping units), in addition to the construction of earthen mesqas and other basic components required for water conveyance and distribution within the traditional irrigation system.

In contrast, the modern irrigation system required a total investment of approximately 2,971,000 EGP. This cost includes the installation of two solar-powered irrigation stations, each serving 10 feddans, as well as the solar panels, pumping units, and the HDPE pressurized pipeline network used for water conveyance and distribution to the fields.

Table 12. Comparison of estimated capital investment costs.

Component	Traditional System (EGP)	Modern System (EGP)
Earthen mesqas and water conveyance structures	50,000	—
Irrigation conveyance	10,000	—
Pumping units (10 diesel pumps)	500,000	—
HDPE pipelines + solar pumping system	—	2,891,000
Total Capital Cost	560,000	2,891,000

Based on these estimates, the modern irrigation system requires a total investment of approximately 2,891,000 EGP, while the traditional system requires approximately 560,000 EGP.

Therefore, the additional investment required for irrigation modernization is:
Additional investment = 2,891,000 − 560,000 = 2,331,000 EGP

Although the modern system requires a higher initial investment, this cost must be evaluated in relation to its long-term economic benefits, including reduced operating costs, improved irrigation efficiency, increased agricultural productivity, and reduced dependence on fossil fuels.

7.3 Annual Operating Cost Analysis

7.3.1 Traditional System

An assessment of annual operation and maintenance (O&M) costs was conducted for the traditional diesel irrigation system operating within the study area.

The system relies on 10 diesel pumps and two earthen mesqas, each approximately 400 m long, used to convey irrigation water.

Major annual cost components include:

- Diesel pump maintenance
- Fuel and lubrication costs
- Canal maintenance
- Labor required for pump installation and operation

Each diesel pump requires annual maintenance estimated at 10,000 EGP, resulting in:
10 pumps × 10,000 = 100,000 EGP/year

Fuel and lubrication costs are estimated at approximately 10,000 EGP per pump annually, assuming an average diesel price of 20 EGP/liter:
10 pumps × 10,000 = 100,000 EGP/year

Earthen canal maintenance is required twice annually, costing approximately 8,000 EGP/year.
Labor requirements are also significant, as pumps must be installed and removed during irrigation events. The total annual labor cost is estimated at 80,000 EGP.

Table 13. Estimated Annual Operational and Maintenance Costs for the Traditional Irrigation System.

Item	Annual Cost (EGP)
Earthen mesqa maintenance	8,000
Diesel pump maintenance (10 pumps)	100,000
Fuel and lubricants (20 EGP/liter)	100,000
Labor for pump installation and operation	80,000
Total Annual Cost	288,000 EGP

The traditional irrigation system is highly sensitive to several external factors, including:

- Fluctuations in diesel fuel prices

- Mechanical maintenance costs of pumping units
- Availability and cost of agricultural labor

These factors often lead to increased and unpredictable operating costs, which can significantly affect the economic sustainability of the traditional irrigation system.

7.3.2 Modern Solar System

The solar-powered irrigation system requires significantly lower operational costs due to the elimination of diesel fuel consumption and reduced labor requirements. Operational activities are mainly limited to:

- Periodic inspection of pumping units
- Cleaning of solar panels
- Minor maintenance of the pressurized pipeline network

The system requires minimal technical supervision estimated at 2,000 EGP per month.
Annual operational cost: 2,000 × 12 = 24,000 EGP/year

Table 14. Annual Operating Costs of the Solar Irrigation System.

Item	Annual Cost (EGP)
Operation and minor maintenance	24,000
Fuel	0
Total Annual Cost	24,000 EGP

7.4 Productivity Impact Assessment

Since the study period began in February 2025 and concluded in March 2026, while the winter crops of the 2026 season are expected to be harvested during May and June, actual post-modernization yield data were not yet available at the time of this assessment. Therefore, a direct comparison of crop productivity before and after irrigation modernization could not be conducted.

Consequently, the productivity evaluation was based on field interviews with local farmers and agricultural extension engineers from the Ministry of Agriculture, in addition to practical experience related to the performance of modern irrigation systems in similar agricultural areas.

The results indicate that irrigation system modernization is expected to improve agricultural productivity due to several key factors, including:

- Improved uniformity of irrigation water distribution
- Reduced salt accumulation within the crop root zone
- Improved irrigation water-use efficiency
- More stable soil moisture conditions

Based on these considerations and using conservative assumptions, agricultural productivity is expected to increase by approximately 10% following the implementation of the improved irrigation system.

Current net return: 20 feddans × 50,000 EGP/feddan = 1,000,000 EGP/year

Expected additional revenue from productivity improvement:
10% × 1,000,000 = 100,000 EGP/year.

7.5 Total Annual Economic Benefit

The total economic benefit includes:

1) Savings in operational costs
2) Additional income from productivity improvements

Operational cost savings: 288,000 − 24,000 = 264,000 EGP/year

Table 15. Estimated Annual Economic Benefits.

Source	Annual Value (EGP)
Operating cost savings	264,000
Increased productivity	100,000
Total Annual Benefit	364,000 EGP

These estimates do not include indirect benefits such as water conservation, environmental improvements, or long-term soil fertility enhancement.

7.6 Payback Period and Long-Term Viability

The economic viability of the modernization investment was assessed using a simplified financial analysis.

Additional investment required: 2,331,000 EGP
Total annual benefit: 364,000 EGP
Payback period: 2,331,000 ÷ 364,000 ≈ 6.4 years

<u>20-Year Financial Projection:</u>

- Total economic return over 20 years: 364,000 × 20 = 7,280,000 EGP
- Net benefit after capital recovery: 7,280,000 − 2,331,000 = 4,949,000 EGP
- Net benefit per feddan over 20 years: 4,949,000 ÷ 20 = 247,450 EGP/feddan
- Average annual net benefit per feddan: 247,450 ÷ 20 ≈ 12,370 EGP/feddan/year

7.7 Economic Risk and Sensitivity Considerations

The economic sustainability of irrigation systems is strongly influenced by their exposure to operational cost risks and market fluctuations. In this context, a comparison between the traditional diesel-based irrigation system and the solar-powered system highlights significant differences in financial stability and long-term cost predictability, as summarized below.

The traditional system is highly vulnerable to:

- Rising fuel prices
- Increasing maintenance costs
- Labor market variability

In contrast, the solar-powered system:

- Eliminates fuel price risk
- Stabilizes operational expenses
- Reduces exposure to inflation in energy markets
- Provides predictable long-term cost structure

This significantly improves financial resilience and investment security.

7.8 Overall Conclusion

The economic evaluation of irrigation modernization in the West Delta project area demonstrates that replacing the traditional diesel-powered irrigation system with a solar-powered pressurized pipeline network provides substantial long-term economic benefits. Although the modern system requires a higher initial investment (2.89 million EGP) compared with the traditional system (0.56 million EGP), the modernization results in a substantial reduction in annual operating costs. Operating expenses decrease from 288,000 EGP to only 24,000 EGP, representing a cost reduction of approximately 92%.

In addition to cost savings, improved irrigation efficiency and better water management are expected to increase agricultural productivity by approximately 10%, generating an additional 100,000 EGP annually for the 20-feddan command area. When both operational savings and productivity gains are considered, the total annual economic benefit of the modern irrigation system reaches approximately 364,000 EGP. Based on the additional capital investment required (2.33 million EGP), the estimated payback period is approximately 6.4 years, which is acceptable for irrigation infrastructure with an operational lifespan exceeding 20 years.

Over a 20-year period, the project is expected to generate total economic returns of approximately 7.28 million EGP, resulting in a net benefit of about 4.95 million EGP after capital recovery. This corresponds to an average additional income of approximately 12,370 EGP per feddan per year. These estimates remain conservative because they exclude indirect benefits such as improved water conservation, reduced environmental impacts, enhanced soil quality, and increased long-term agricultural sustainability.

Overall, the results indicate that irrigation modernization using solar-powered pressurized systems represents a financially viable and strategically sustainable investment, offering substantial economic, operational, and environmental advantages compared with traditional diesel-based irrigation systems.

8. Carbon Emissions from Diesel Pumps Operation

The operation of diesel-powered irrigation pumps contributes to greenhouse gas emissions due to the combustion of fossil fuels. In agricultural irrigation systems, diesel pumps are widely used to lift groundwater and deliver irrigation water to fields. However, this practice results in carbon dioxide (CO_2) emissions, which contribute to climate change and environmental degradation. This section quantifies the carbon emissions associated with diesel-powered irrigation within the 20-feddan experimental command area and evaluates the potential emission reductions achieved by replacing diesel pumps with a solar-powered pressurized irrigation system.

The analysis includes:

- Estimation of diesel fuel consumption
- Calculation of carbon dioxide emissions
- Assessment of emissions per unit area
- Evaluation of long-term emission reduction potential
- Discussion of broader environmental implications

8.1 Carbon Emission Calculations

Carbon emissions from diesel pump operation were estimated based on field observations, operational records, and interviews with local farmers regarding irrigation schedules, pump operating hours, and fuel consumption rates. Standard emission factors reported by the Intergovernmental Panel on Climate Change (IPCC) were used to calculate the associated carbon dioxide emissions.

Pump Operating Time: The traditional irrigation system in the study area relies on ten diesel pumps used to irrigate different plots within the 20-feddan command area. Field data indicate that each irrigation cycle requires approximately 55.5 to 67.5 hours of pump operation. For calculation purposes, the average operating time per irrigation cycle was estimated as follows: Average operating time per cycle = (55.5 + 67.5) / 2 **=** 61.5 hours per irrigation cycle.

Diesel Consumption Rate: The diesel pumps used in the study area consume approximately 2.5–3.0 liters of diesel per hour, depending on operating conditions and pump efficiency. The average diesel consumption rate is therefore calculated as: Average diesel consumption = (2.5 + 3.0) / 2 **=** 2.75 liters per hour.

Fuel Consumption per Irrigation Cycle: The amount of fuel consumed during a single irrigation cycle is calculated using the following relationship: Fuel consumption per cycle = Operating time × Fuel consumption rate = 61.5 hours × 2.75 L/hour = 169.1 liters per irrigation cycle.

Annual Diesel Consumption: Based on the cropping pattern and irrigation practices in the study area, the average irrigation frequency is approximately 18 irrigation cycles per year**.** Therefore, the annual diesel consumption for the experimental area can be estimated as:
Annual diesel consumption = Fuel consumption per cycle × Number of irrigation cycles = 169.1 × 18
≈ 3,038 liters of diesel per year.

Carbon Emission Factor: According to the IPCC (2006) Guidelines for National Greenhouse Gas Inventories, the combustion of one liter of diesel fuel produces approximately: 2.68 kg of CO_2**.**

Annual Carbon Emissions: The total annual carbon emissions resulting from diesel-powered irrigation are calculated as follows:

- CO_2 emissions = Annual diesel consumption × Emission factor = 3,038 liters/year × 2.68 kg CO_2/liter = 8,141.84 kg CO_2 per year
- Converting kilograms to tons: 8,141.84 ÷ 1000 **=** 8.14 tons CO_2 per year.

Emissions per Unit Area: For the 20-feddan experimental area, the emission intensity can be estimated as: CO_2 emissions per feddan = 8.14 ÷ 20 **=** 0.41 tons CO_2 per feddan per year
Since: 1 hectare = 2.38 feddans
The emissions per hectare are approximately: CO_2 emissions per hectare = 0.41 × 2.38
≈ 0.98 tons CO_2 per hectare per year

Potential Maximum Emissions: In practical irrigation operations, more than one pump may be used simultaneously depending on irrigation demand and field layout. Under such conditions, fuel consumption may exceed the average estimate. Therefore, total emissions for the experimental area may reach approximately: 10 tons CO_2 per year for the 20-feddan command area
This corresponds approximately to: 0.5 tons CO_2 per feddan per year 1.12 tons CO_2 per hectare per year
A summary of the emission calculations is presented in Table 16.

Table 16. Summary of carbon emission calculations for diesel pump operation.

Parameter	Value
Average pump operation per irrigation cycle	61.5 hours
Average diesel consumption rate	2.75 L/hour
Fuel consumption per irrigation cycle	169 L
Irrigation cycles per year	18
Annual diesel consumption	3,038 L
CO_2 emission factor	2.68 kg CO_2/L
Total annual emissions	8.14 tons CO_2/year
Emissions per feddan	0.41 tons CO_2/feddan/year
Emissions per hectare	0.98 tons CO_2/ha/year

As shown in Table 16, diesel-powered irrigation within the experimental area results in approximately 8.14 tons of CO_2 emissions annually.

8.2 Significance of These Emissions

Although emissions of approximately 0.41–0.50 tons CO_2 per feddan per year may appear relatively small at the individual farm level, their cumulative effect becomes significant when irrigation activities are repeated across large agricultural areas and over multiple growing seasons. For perspective, an emission of 0.5 tons of CO_2 is roughly equivalent to the carbon emissions generated by driving a typical passenger vehicle for approximately 4,000 km, assuming an average emission rate of 120–150 g CO_2 per kilometer.

8.3 Environmental Impact of Switching to Solar Irrigation

Replacing diesel pumps with a solar-powered irrigation system eliminates the direct combustion of fossil fuels during irrigation operations. As a result, direct carbon emissions associated with irrigation pumping can be reduced by approximately 95–100%**.** A comparison between diesel-powered irrigation and solar-powered irrigation systems is presented in Table 17.

Table 17. Estimated reduction in carbon emissions after irrigation system modernization

Parameter	Diesel Pump System	Solar Irrigation System	Reduction (%)
Energy source	Diesel fuel	Solar photovoltaic (PV)	—
Diesel consumption	3,038 L/year	0	100%
Emission factor	2.68 kg CO_2/L	0	—
Total CO_2 emissions	8.14 tons/year	≈ 0	95–100%
Estimated emissions for 20 feddans	≈10 tons/year	≈ 0	≈ 100%

As indicated in Table 17, replacing diesel pumps with solar-powered pumping systems can almost completely eliminate carbon emissions associated with irrigation operations.

8.4 Broader Sustainability Implications

The transition from diesel-powered pumping to solar-powered irrigation represents an important step toward low-carbon and climate-resilient agriculture**.** In addition to reducing greenhouse gas emissions, solar irrigation systems offer several environmental and economic advantages, including:

1) Reduced dependence on fossil fuels
2) Lower air pollution from diesel engines
3) Reduced noise pollution during irrigation operations
4) Improved energy security for farmers
5) Lower long-term operational costs

Considering the crop composition in the experimental site—artichoke (55%), clover (25%), wheat (10%), and sugar beet (10%)—the adoption of solar irrigation ensures that water-intensive crops are supported by a clean and renewable energy source, enhancing the sustainability of agricultural production. On a broader scale, expanding solar irrigation systems across similar agricultural regions could significantly contribute to Egypt's national targets for renewable energy adoption and greenhouse gas emission reduction. Furthermore, this transition aligns with the United Nations Sustainable Development Goals, particularly:

- SDG 7 – Affordable and Clean Energy

- SDG 13 – Climate Action

Therefore, irrigation modernization through solar-powered pumping systems represents a technically feasible and environmentally sustainable strategy for reducing the carbon footprint of agricultural water management.

9. Conclusion and Recommendations

9.1 Conclusion

This study assessed the technical, hydrological, agricultural, and economic impacts of irrigation modernization within a 20-feddan experimental area through replacing the traditional surface irrigation system with a solar-powered pressurized pipeline irrigation system. A comprehensive monitoring program was implemented over a full agricultural year, covering conditions before and after system modernization, which enabled direct comparison of irrigation performance, groundwater behavior, drainage response, and economic outcomes.

1. Performance of the Traditional Irrigation System

Under the traditional irrigation system, water was conveyed through open earthen canals and mesqas and applied to fields using uncontrolled surface flood irrigation. Irrigation events were typically concentrated within short rotational periods, resulting in large volumes of water being applied within a few consecutive days.

Field monitoring confirmed that this irrigation practice caused substantial water losses through:

- Deep percolation below the crop root zone
- Lateral seepage toward surrounding canals
- Uneven soil moisture distribution across fields

These conditions led to elevated groundwater levels and increased hydraulic loading on the drainage network. The calculated average irrigation efficiency under the traditional system was approximately 42.3%, indicating that more than half of the applied irrigation water was lost before being effectively utilized by crops.

2. Improvements in Irrigation Efficiency after Modernization

Following the implementation of the modernized irrigation system, water delivery became more controlled and evenly distributed throughout the irrigation cycle. The improved irrigation management significantly enhanced water-use efficiency.

The calculated irrigation efficiency increased to an average of approximately 58.5%, representing an improvement of nearly 38% compared with the traditional system. This improvement reflects:

- Better control of irrigation volumes
- Reduced excessive water application
- More uniform water distribution within fields

The modernization also resulted in significant water savings across the studied crops. Irrigation water applications were reduced while still meeting crop water requirements, demonstrating that the improved system effectively minimized non-beneficial water losses and increased the productivity of irrigation water.

3. Groundwater Response

Groundwater monitoring revealed that under traditional irrigation conditions, groundwater levels exhibited large seasonal fluctuations due to excessive irrigation recharge. After modernization, groundwater level variations became smaller and more stable, indicating improved balance between irrigation inputs and drainage response. Although average groundwater salinity did not show an immediate reduction, the decrease in salinity fluctuations suggests improved recharge conditions and more stable hydrological behavior.

4. Drainage System Performance

Monitoring of the subsurface drainage network showed that under the traditional irrigation system, drainage water levels experienced large hydraulic fluctuations caused by sudden inflows following heavy irrigation events. After modernization, the drainage system exhibited more stable hydraulic conditions, reflecting reduced excess irrigation and improved coordination between irrigation application and drainage processes. In addition, fluctuations in drainage water salinity decreased, indicating gradual improvement in salt leaching processes within the soil profile.

5. Reduction of Seepage and Deep Percolation Losses

Seepage analysis demonstrated clear improvements following irrigation modernization. Under traditional irrigation conditions, significant seepage occurred toward surrounding irrigation canals, which often functioned unintentionally as auxiliary drainage outlets. After modernization, lateral seepage losses decreased by approximately 40%, confirming that improved irrigation control significantly reduced non-beneficial water losses. Similarly, vertical seepage measurements obtained through piezometer monitoring showed that large volumes of irrigation water previously percolated below the crop root zone under the traditional system. After the implementation of the improved irrigation system, deep percolation losses were reduced by more than 60%, indicating substantial improvement in irrigation water-use efficiency and soil moisture management.

6. Soil Conditions

Soil chemical analysis indicated moderate salinity conditions and localized sodicity risks prior to modernization. Post-modernization monitoring showed only limited short-term changes in soil chemical properties, which is expected because soil salinity improvement generally occurs gradually over longer time periods due to slow salt redistribution processes. However, improved irrigation management and stabilized groundwater conditions provide favorable conditions for gradual soil quality improvement in the future.

7. **Economic Viability**

In addition to the technical and hydrological improvements, the economic analysis demonstrated the financial viability of the modernized irrigation system. The adoption of the solar-powered pressurized irrigation system significantly reduced operating costs associated with diesel pumping while improving water productivity. The economic evaluation indicated that irrigation modernization is economically feasible, offering positive long-term financial returns for farmers through reduced energy costs and improved water-use efficiency.

Overall, the irrigation modernization program successfully:

- Improved irrigation management
- Increased irrigation efficiency
- Reduced non-beneficial water losses
- Stabilized groundwater and drainage behavior
- Demonstrated clear economic benefits

These results highlight the important role of modern irrigation technologies and renewable energy systems in improving agricultural water management and supporting the long-term sustainability of water resources and agricultural production in the Nile Delta. Continued monitoring is expected to further demonstrate improvements in soil conditions, crop productivity, and economic returns as the long-term benefits of irrigation modernization become more fully realized.

9.2 Recommendations

Based on the technical, hydrological, and economic analysis obtained during the study period, a number of practical recommendations can be proposed to enhance water-use efficiency and support the wider adoption of modern solar-powered irrigation systems in agricultural areas with conditions similar to the study area.

1. Expansion of Pressurized Pipeline Irrigation Systems

The study recommends expanding the implementation of pressurized pipeline irrigation systems instead of traditional open earthen mesqas. The results demonstrated that pipeline systems significantly reduce water losses caused by seepage and deep percolation while improving water distribution within agricultural fields.

2. Promotion of Solar Energy for Irrigation Pumping

It is recommended to expand the use of solar-powered pumping systems as a sustainable alternative to diesel-powered pumps. The adoption of solar energy contributes to:

- Reducing operational costs for farmers
- Decreasing dependence on fossil fuels
- Lowering carbon emissions associated with irrigation activities

3. Improving Irrigation Scheduling and Water Management

Irrigation management programs should be developed based on actual crop water requirements, rather than relying solely on farmers' experience. This can be achieved through:

- Better organization of irrigation schedules
- Reducing excessive water application
- Improving overall irrigation water-use efficiency

4. Strengthening Agricultural Extension and Farmer Training

Agricultural extension programs should be strengthened to train farmers in best irrigation management practices. These programs should include guidance on operation and maintenance of modern irrigation systems, determining appropriate irrigation timing and water quantities and techniques for improving water-use efficiency in agriculture.

5. Improving Agricultural Drainage System Efficiency

The study recommends improving the performance of existing agricultural drainage networks to ensure stable groundwater levels and prevent salt accumulation within the soil profile, particularly in areas affected by shallow groundwater tables or insufficient drainage capacity.

6. Continued Monitoring and Evaluation Programs

Long-term monitoring programs should continue in order to track changes in groundwater levels and salinity, soil properties and Crop productivity. Such monitoring is essential to evaluate the long-term impacts of irrigation modernization programs.

7. Supporting Financing Mechanisms for Irrigation Modernization

Given the relatively high initial investment cost of modern irrigation systems compared with traditional systems, the study recommends providing financial support mechanisms, such as:

- Low-interest agricultural loans
- Government subsidy programs for irrigation modernization
- Financial support initiatives to encourage farmers to adopt improved irrigation technologies

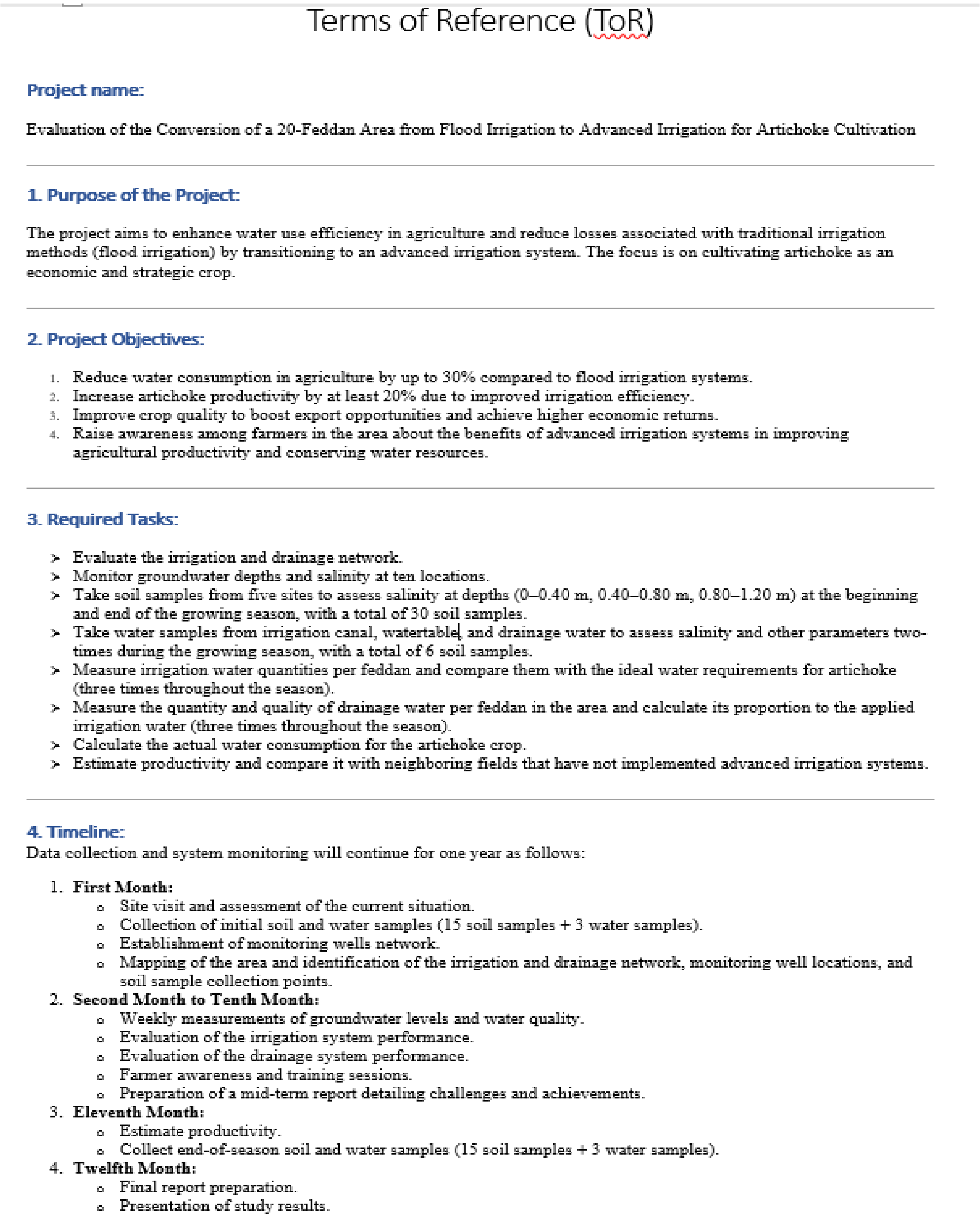
8. Replication of Irrigation Modernization Projects in Similar Areas

The study confirms that the solar-powered pressurized irrigation system can be successfully replicated in other agricultural areas of the Nile Delta and regions with similar hydrological and soil conditions. Expanding such projects would contribute to improving irrigation water-use efficiency, reducing non-beneficial water losses and enhancing long-term agricultural sustainability.

10. Appendices

10.1 Appendix-A. Consultinecy Documents

A-1. The Terms of Reference (ToR)



Terms of Reference (ToR)

Project name:

Evaluation of the Conversion of a 20-Feddan Area from Flood Irrigation to Advanced Irrigation for Artichoke Cultivation

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1. Purpose of the Project:

The project aims to enhance water use efficiency in agriculture and reduce losses associated with traditional irrigation methods (flood irrigation) by transitioning to an advanced irrigation system. The focus is on cultivating artichoke as an economic and strategic crop.

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2. Project Objectives:

1. Reduce water consumption in agriculture by up to 30% compared to flood irrigation systems.
2. Increase artichoke productivity by at least 20% due to improved irrigation efficiency.
3. Improve crop quality to boost export opportunities and achieve higher economic returns.
4. Raise awareness among farmers in the area about the benefits of advanced irrigation systems in improving agricultural productivity and conserving water resources.

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3. Required Tasks:

- Evaluate the irrigation and drainage network.
- Monitor groundwater depths and salinity at ten locations.
- Take soil samples from five sites to assess salinity at depths (0–0.40 m, 0.40–0.80 m, 0.80–1.20 m) at the beginning and end of the growing season, with a total of 30 soil samples.
- Take water samples from irrigation canal, watertable, and drainage water to assess salinity and other parameters two-times during the growing season, with a total of 6 soil samples.
- Measure irrigation water quantities per feddan and compare them with the ideal water requirements for artichoke (three times throughout the season).
- Measure the quantity and quality of drainage water per feddan in the area and calculate its proportion to the applied irrigation water (three times throughout the season).
- Calculate the actual water consumption for the artichoke crop.
- Estimate productivity and compare it with neighboring fields that have not implemented advanced irrigation systems.

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4. Timeline:

Data collection and system monitoring will continue for one year as follows:

1. **First Month:**
   - Site visit and assessment of the current situation.
   - Collection of initial soil and water samples (15 soil samples + 3 water samples).
   - Establishment of monitoring wells network.
   - Mapping of the area and identification of the irrigation and drainage network, monitoring well locations, and soil sample collection points.
2. **Second Month to Tenth Month:**
   - Weekly measurements of groundwater levels and water quality.
   - Evaluation of the irrigation system performance.
   - Evaluation of the drainage system performance.
   - Farmer awareness and training sessions.
   - Preparation of a mid-term report detailing challenges and achievements.
3. **Eleventh Month:**
   - Estimate productivity.
   - Collect end-of-season soil and water samples (15 soil samples + 3 water samples).
4. **Twelfth Month:**
   - Final report preparation.
   - Presentation of study results.

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5. Responsibilities:

1. **Implementing Agency:**
    - Design, implement, and drill monitoring wells, and determine measurement points within the area.
    - Provide necessary materials and equipment: Auger-hole equipment, monitoring well pipes (for 8 wells), groundwater depth measurement devices, and water salinity measurement devices.
2. **Farmers:**
    - Adhere to operational and maintenance instructions.
    - Participate in practical training provided by the implementing agency.
3. **Supervising Agency:**
    - Provide the necessary funding for project implementation.
    - Oversee all stages of the project implementation and ensure compliance with the project's terms and conditions.

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6. Expected Results:

- Improved water uses and reduced waste by no less than 30%.
- Increased artichoke productivity by ensuring the provision of consistent and optimized water quantities.
- Reduced operational costs in the long term by lowering water and energy consumption.
- Enhanced farmers' income and increased export opportunities.

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7. Deliverables:

- Initial report.
- Mid-term report outlining challenges and achievements (after 6 months).
- Final report.

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8. Estimated Budget:

The total cost required to prepare this study is 5000,000 Egyptian pounds, excluding the expenses for soil and water analyses

10.2 Appendix-B. Groundwater depth and salinity

Table B-1. The depth and the salinity of the observation well in the experimental field for Feb—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
2-Feb	0.92	**0.52**	10.31	0.95	**0.55**	6.3	0.6	**0.2**	5.09	0.62	**0.22**	4.94	0.95	**0.55**	5.03	0.78	**0.38**	5.06	0.95	**0.55**	6.7	0.99	**0.59**	8.77
3-Feb	0.94	**0.54**	10.2	0.98	**0.58**	4.43	0.72	**0.32**	4.58	0.71	**0.31**	5.73	1.09	**0.69**	5.8	0.85	**0.45**	5.56	0.96	**0.56**	7.82	1.03	**0.63**	6.16
4-Feb	1.03	**0.73**	10.66	1.03	**0.63**	6.9	0.84	**0.44**	4.68	0.74	**0.34**	2.42	1.2	**0.8**	5.58	0.98	**0.58**	6.64	0.97	**0.57**	7.19	1.05	**0.65**	8.71
5-Feb	1.15	**0.85**	9.97	1.11	**0.71**	5.17	0.95	**0.55**	3.88	0.84	**0.44**	3.19	1.15	**0.75**	4.26	1.1	**0.7**	4.92	1.15	**0.75**	5.6	1.15	**0.75**	7.75
6-Feb	1.15	**0.85**	6.45	1.14	**0.74**	6.1	1.07	**0.67**	4.9	1.03	**0.63**	3.61	1.19	**0.79**	4.19	1.14	**0.74**	6.46	1.17	**0.77**	7.63	1.17	**0.77**	6.14
7-Feb	1.15	**0.85**	6.75	1.15	**0.75**	5.56	1.16	**0.76**	3.9	1.14	**0.74**	3.2	1.19	**0.79**	4.4	1.2	**0.8**	4.86	1.17	**0.77**	6.7	1.19	**0.79**	5.81
8-Feb	1.16	**0.86**	6.36	1.17	**0.77**	5.62	1.1	**0.7**	5.4	1.14	**0.74**	3.84	1.18	**0.78**	4.22	1.14	**0.74**	5.54	1.17	**0.77**	5.54	1.1	**0.7**	5.56
9-Feb	1.17	**0.87**	6.35	1.18	**0.78**	5.49	1.16	**0.76**	4.26	1.15	**0.75**	3.35	1.22	**0.82**	3.62	1.2	**0.8**	4.71	1.17	**0.77**	5.9	1.14	**0.74**	5.8
10-Feb	1.22	**0.92**	6.27	1.2	**0.8**	4.27	1.2	**0.8**	3.98	1.2	**0.8**	3.21	1.25	**0.85**	4.19	1.18	**0.78**	4.53	1.2	**0.8**	4.25	1.2	**0.8**	5.51
11-Feb	1.27	**0.97**	6.58	1.19	**0.79**	5.92	1.2	**0.8**	4.3	1.2	**0.8**	2.31	1.25	**0.85**	2.46	1.2	**0.8**	4.68	1.25	**0.85**	4.93	1.15	**0.75**	5.96
12-Feb	1.4	**1.1**	6.6	1.3	**0.9**	3.37	1.2	**0.8**	3.91	1.35	**0.95**	3.4	1.4	**1**	3.84	1.3	**0.9**	4.71	1.4	**1**	5.3	1.35	**0.95**	6.2
13-Feb	1.4	**1.1**	6.71	1.4	**1**	5.96	1.3	**0.9**	5.27	1.4	**1**	3.65	1.5	**1.1**	5.19	1.37	**0.97**	4.93	1.45	**1.05**	5.54	1.4	**1**	6.37
14-Feb	1.35	**1.05**	6.5	1.35	**0.95**	6	1.27	**0.87**	5.4	1.35	**0.95**	4.1	1.44	**1.04**	5.5	1.35	**0.95**	5.2	1.4	**1**	3.8	1.4	**1**	6.6
15-Feb	1.25	**0.95**	6.21	1.15	**0.75**	5.82	1.05	**0.65**	5.51	1.15	**0.75**	4.66	1.2	**0.8**	2.98	1.15	**0.75**	5.28	0.4	**0**	3.2	0.4	**0**	2.21
16-Feb	1.15	**0.85**	10.21	0.97	**0.57**	5.97	0.96	**0.56**	5.52	1.1	**0.7**	4.61	1.25	**0.85**	3.2	1.07	**0.67**	4.97	0.9	**0.5**	3.4	1	**0.6**	3.19
17-Feb	1	**0.7**	10.33	0.95	**0.55**	6.1	1	**0.6**	5.51	1.15	**0.75**	4.58	1.3	**0.9**	3.5	1.1	**0.7**	5.13	1.1	**0.7**	3.58	1.08	**0.68**	3.78
18-Feb	0.96	**0.66**	8.1	0.45	**0.05**	3.5	0.82	**0.42**	8.15	1.05	**0.65**	4.8	1.2	**0.8**	3.64	0.9	**0.5**	6.39	1	**0.6**	3.6	1.1	**0.7**	3.8
19-Feb	0.9	**0.6**	8.67	0.75	**0.35**	4.12	0.65	**0.25**	5.32	0.35	**-0.05**	5.84	1.05	**0.65**	3.95	0.85	**0.45**	5.29	1	**0.6**	3.76	1.05	**0.65**	3.95
20-Feb	1	**0.7**	6.86	0.9	**0.5**	3.9	0.75	**0.35**	6.42	0.4	**0**	5.34	1.05	**0.65**	3.6	0.85	**0.45**	4.66	1.1	**0.7**	3.61	1.12	**0.72**	3.85
21-Feb	1.1	**0.8**	3.63	0.9	**0.5**	5.1	0.94	**0.54**	7.82	1.3	**0.9**	5.6	1.1	**0.7**	4.85	1.25	**0.85**	5	1.3	**0.9**	3.9	1.27	**0.87**	4.2
22-Feb	1.25	**0.95**	4.1	1.1	**0.7**	3.7	1	**0.6**	8.52	1.34	**0.94**	5.9	1.15	**0.75**	5.38	1.3	**0.9**	5.3	1.3	**0.9**	4.1	1.3	**0.9**	4.5
23-Feb	1.3	**1**	4.4	1.19	**0.79**	3.63	1.15	**0.75**	4.71	1.21	**0.81**	6.2	1.4	**1**	5.6	1.25	**0.85**	5.6	1.32	**0.92**	4.5	1.35	**0.95**	4.8
24-Feb	1.4	**1.1**	4.6	1.3	**0.9**	4	1.2	**0.8**	4.85	1.3	**0.9**	6.7	1.45	**1.05**	5.9	1.3	**0.9**	6	1.4	**1**	4.8	1.4	**1**	5
25-Feb	1.4	**1.1**	5	1.35	**0.95**	4.2	1.25	**0.85**	5.1	1.35	**0.95**	6.9	1.5	**1.1**	6.2	1.35	**0.95**	6.3	1.42	**1.02**	5.3	1.43	**1.03**	5.3
26-Feb	1.45	**1.15**	5.2	1.39	**0.99**	4.5	1.3	**0.9**	5.5	1.39	**0.99**	7.1	1.5	**1.1**	6.5	1.39	**0.99**	6.5	1.45	**1.05**	5.5	1.45	**1.05**	5.6
27-Feb	1.45	1.15	5.5	1.4	**1**	5	1.33	**0.93**	5.6	1.4	**1**	7.5	1.51	**1.11**	6.7	1.41	**1.01**	7	1.45	**1.05**	5.8	1.45	**1.05**	6
28-Feb	1.28	0.98	5.9	1.29	**0.89**	5.3	1.3	**0.9**	6	1.4	**1**	7.8	1.5	**1.1**	6.9	1.35	**0.95**	7.3	1.42	**1.02**	6.2	1.29	**0.89**	6.3

Table B-2. The depth and the salinity of the observation well in the experimental field for March—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	O.W-1	Ec-1	Top	O.W-2	Ec-2	Top	O.W-3	Ec-3	Top	O.W-4	Ec-4	Top	O.W-5	Ec-5	Top	O.W-6	Ec-6	Top	O.W-7	Ec-7	Top	O.W-8	Ec-8
1-Mar	1.31	1.01	5.2	1.3	0.9	5.6	1.3	0.9	6.2	1.35	0.95	8.1	1.45	1.05	7.2	1.34	0.94	7.5	1.35	0.95	6.5	1.3	0.9	6.7
2-Mar	1.4	1.1	4	1.38	0.98	6	1.25	0.85	6.5	1.3	0.9	8.2	1.37	0.97	7	1.3	0.9	6.8	1.4	1	6.1	1.39	0.99	6.2
3-Mar	1.31	1.01	3.9	1.34	0.94	6.8	1.3	0.9	6.4	1.4	1	7.1	1.5	1.1	5.5	1.35	0.95	5.1	1.4	1	5.5	1.32	0.92	5.1
4-Mar	1.2	0.9	4.88	0.95	0.55	3.76	0.5	0.1	6.35	0.8	0.4	6.35	1	0.6	3.68	0.76	0.36	3.1	1.14	0.74	4.3	1.2	0.8	4.76
5-Mar	1.16	0.86	5.13	0.93	0.53	4.81	0.5	0.1	2.5	0.75	0.35	6.22	0.8	0.4	3.75	0.74	0.34	3.23	1.08	0.68	4.14	1.18	0.78	5.12
6-Mar	1.1	0.8	4.91	0.9	0.5	4.55	0.5	0.1	2.9	0.75	0.35	6.2	0.95	0.55	3.82	0.75	0.35	3.39	1	0.6	4.21	1.11	0.71	4.81
7-Mar	0.95	0.65	5.9	0.8	0.4	4.95	0.55	0.15	2.58	0.3	-0.1	3.78	0.9	0.5	4.9	0.75	0.35	4.69	0.85	0.45	2.93	1	0.6	4.91
8-Mar	0.85	0.55	5.2	0.85	0.45	3.91	0.66	0.26	2.52	0.45	0.05	2.42	0.97	0.57	3.68	0.85	0.45	2.8	0.9	0.5	3.12	0.91	0.51	5.4
9-Mar	0.74	0.44	5.52	0.8	0.4	4.5	0.75	0.35	2.85	0.4	0	2.65	0.9	0.5	4.92	0.82	0.42	3.37	0.82	0.42	3.61	0.9	0.5	3.91
10-Mar	0.8	0.5	5.42	0.8	0.4	4.51	0.7	0.3	2.72	0.7	0.3	7.11	0.9	0.5	6.8	0.75	0.35	3.75	0.84	0.44	3.67	0.8	0.4	4.68
11-Mar	0.94	0.64	6.98	0.88	0.48	4.6	0.82	0.42	3.34	0.9	0.5	4.87	1.15	0.75	3.95	0.9	0.5	3.74	1	0.6	3.83	1	0.6	5.22
12-Mar	1.04	0.74	7.54	1	0.6	5.4	0.93	0.53	3.44	1.15	0.75	4.98	1.25	0.85	4.2	1.15	0.75	3.97	1.1	0.7	4.22	1.1	0.7	5.71
13-Mar	1.15	0.85	7.66	1.08	0.68	5.11	1	0.6	3.51	1.15	0.75	4.99	1.3	0.9	4.5	1.12	0.72	4.11	1.08	0.68	4.34	1.19	0.79	5.74
14-Mar	1.25	0.95	7.8	1.15	0.75	5.1	1.1	0.7	3.58	1.2	0.8	4.91	1.35	0.95	4.8	1.2	0.8	4.15	1.26	0.86	4.5	1.21	0.81	6.6
15-Mar	1.28	0.98	8.01	1.2	0.8	3.9	1.13	0.73	3.65	1.2	0.8	5.2	1.4	1	5	1.25	0.85	4.5	1.29	0.89	4.8	1.25	0.85	6.8
16-Mar	1.4	1.1	8.5	1.31	0.91	4.2	1.22	0.82	7.18	1.3	0.9	5.6	1.45	1.05	5.3	1.31	0.91	4.8	1.4	1	5.2	1.3	0.9	7
17-Mar	1.36	1.06	8.5	1.35	0.95	4.5	1.25	0.85	7.5	1.4	1	6.5	1.49	1.09	5.5	1.33	0.93	5.1	1.38	0.98	5.5	1.32	0.92	7.2
18-Mar	1.35	1.05	8.7	1.35	0.95	5	1.3	0.9	7.6	1.37	0.97	6.7	1.53	1.13	5.9	1.36	0.96	5.5	1.4	1	5.8	1.35	0.95	7.5
19-Mar	1.38	1.08	8.5	1.35	0.95	5.2	1.3	0.9	7.8	1.4	1	7	1.45	1.05	6.1	1.4	1	5.8	1.41	1.01	6.2	1.4	1	7.1
20-Mar	1.4	1.1	7.9	1.4	1	6	1.36	0.96	8.1	1.4	1	7.5	1.47	1.07	6.5	1.4	1	6	1.45	1.05	6.9	1.4	1	6.9
21-Mar	1.4	1.1	7.2	1.41	1.01	6.3	1.35	0.95	7.5	1.4	1	7.7	1.43	1.03	7	1.4	1	6.4	1.45	1.05	6.2	1.42	1.02	6.4
22-Mar	1.3	1	6.9	1.33	0.93	7	1.3	0.9	6	1.3	0.9	5.5	1.4	1	7.2	1.27	0.87	7	1.41	1.01	5.3	1.31	0.91	5.8
23-Mar	0.51	0.21	1.99	1	0.6	4.51	1.13	0.73	3.95	1.2	0.8	4.59	1.3	0.9	6.5	1.15	0.75	7.5	1.12	0.72	4.91	0.48	0.08	1.55
24-Mar	0.7	0.4	3.21	0.7	0.3	4.62	0.6	0.2	2.56	0.9	0.5	5.77	1.07	0.67	5.42	0.9	0.5	6.25	0.8	0.4	5.71	0.7	0.3	3.15
25-Mar	1.04	0.74	3.96	0.9	0.5	4.63	0.6	0.2	2.88	0.45	0.05	3.72	1.2	0.8	5.24	0.9	0.5	5.22	1.05	0.65	5.37	1.06	0.66	3.65
26-Mar	1.19	0.89	3.72	1.05	0.65	4.47	0.75	0.35	2.95	0.7	0.3	4.56	1.3	0.9	5.6	1.09	0.69	5.35	1.2	0.8	5.5	1.3	0.9	4.1
27-Mar	1.35	1.05	3.8	1.2	0.8	3.44	1.08	0.68	3.44	1.1	0.7	5.25	1.45	1.05	6	1.25	0.85	5.7	1.35	0.95	5.8	1.25	0.85	4.5
28-Mar	1.4	1.1	3.9	1.34	0.94	4	1.24	0.84	3.6	1.25	0.85	5.6	0.51	0.11	7.35	1.3	0.9	5.9	1.4	1	5.6	1.43	1.03	4.9
29-Mar	1.4	1.1	4.1	1.35	0.95	4.3	1.22	0.82	3.9	1.23	0.83	5.9	1.3	0.9	7.5	1.29	0.89	6.1	1.39	0.99	5.9	1.42	1.02	5.2
30-Mar	1.52	1.22	4.6	1.41	1.01	4.5	1.3	0.9	4.1	1.44	1.04	6	1.48	1.08	7.8	1.41	1.01	6.5	1.45	1.05	6	1.55	1.15	5.5

Table B-3. The depth and the salinity of the observation well in the experimental field for April—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	O.W-1	Ec-1	Top	O.W-2	Ec-2	Top	O.W-3	Ec-3	Top	O.W-4	Ec-4	Top	O.W-5	Ec-5	Top	O.W-6	Ec-6	Top	O.W-7	Ec-7	Top	O.W-8	Ec-8
1-Apr	1.5	1.2	5.2	1.5	1.1	5	1.35	0.95	4.5	1.45	1.05	6.5	1.5	1.1	6.9	1.4	1	6.9	1.5	1.1	6.6	1.22	0.82	5.8
2-Apr	1.55	1.25	5.6	1.5	1.1	5.5	1.41	1.01	4.8	1.5	1.1	6.9	1.58	1.18	6.6	1.45	1.05	7.1	1.55	1.15	6.9	1.37	0.97	5.9
3-Apr	1.53	1.23	6	1.49	1.09	5.8	1.4	1	5	1.55	1.15	7.1	1.6	1.2	7	1.47	1.07	7.4	1.55	1.15	7	1.52	1.12	6.12
4-Apr	1.55	1.25	6.2	1.55	1.15	6	1.5	1.1	5.3	1.5	1.1	7.6	1.6	1.2	7.5	1.49	1.09	6.9	1.56	1.16	7.2	1.57	1.17	6.17
5-Apr	1.5	1.2	6.5	1.5	1.1	6.6	1.45	1.05	5.5	1.55	1.15	7.8	1.6	1.2	7.9	1.45	1.05	6.5	1.55	1.15	7.4	1.53	1.13	6.54
6-Apr	1.6	1.3	7	1.55	1.15	6.9	1.51	1.11	5.8	1.6	1.2	7.9	1.61	1.21	7.6	1.59	1.19	6.1	1.6	1.2	7.2	1.57	1.17	7
7-Apr	1.6	1.3	7.3	1.55	1.15	7	1.53	1.13	5.9	1.6	1.2	8.1	1.61	1.21	6.5	1.62	1.22	5.5	1.6	1.2	6.9	1.58	1.18	6.4
8-Apr	1.55	1.25	7.8	1.56	1.16	7.2	1.5	1.1	6	1.58	1.18	7.2	1.6	1.2	5.6	1.59	1.19	5.2	1.57	1.17	5.8	1.58	1.18	5.5
9-Apr	0.45	0.15	2.12	1.54	1.14	7.5	1.32	0.92	6.5	1.44	1.04	6.5	1.5	1.1	6	1.26	0.86	4.9	1.2	0.8	5.65	0.45	0.05	2.8
10-Apr	0.95	0.65	3.3	1.15	0.75	4.25	1.12	0.72	3.65	1.15	0.75	4.58	1.3	0.9	6.2	1.15	0.75	4.71	1.12	0.72	5.72	0.78	0.38	2.36
11-Apr	0.98	0.68	3.48	0.55	0.15	2.5	1.06	0.66	4.27	1.1	0.7	4.92	1.2	0.8	7	1.05	0.65	4.6	1.1	0.7	6.22	0.82	0.42	3.66
12-Apr	1.05	0.75	3.45	1	0.6	3.37	1.12	0.72	4.45	1.17	0.77	4.78	1.3	0.9	7.5	1.15	0.75	4.61	1.14	0.74	5.91	1	0.6	5.24
13-Apr	1.2	0.9	3.48	1.1	0.7	3.29	1	0.6	4.57	1.1	0.7	4.91	1.3	0.9	7.8	1.1	0.7	4.67	1.2	0.8	5.82	1.17	0.77	4.62
14-Apr	1.3	1	4.2	1.28	0.88	4	1.25	0.85	5.2	1.3	0.9	4.8	1.45	1.05	6.5	1.33	0.93	4.7	1.38	0.98	6.5	1.25	0.85	5.1
15-Apr	1.55	1.25	4.61	1.45	1.05	4.88	1.35	0.95	6.15	1.38	0.98	4.83	1.55	1.15	5.82	1.45	1.05	4.81	1.5	1.1	8.29	1.5	1.1	5.6
16-Apr	1.5	1.2	3.59	1.45	1.05	3.56	1.39	0.99	4.73	1.45	1.05	5.46	1.6	1.2	5.48	1.42	1.02	6.85	1.5	1.1	5.92	1.52	1.12	5.57
17-Apr	1.58	1.28	3.62	1.51	1.11	3.67	1.4	1	4.86	1.5	1.1	5.66	1.65	1.25	4.88	1.46	1.06	6.52	1.55	1.15	5.9	1.54	1.14	5.48
18-Apr	1.6	1.3	3.67	1.54	1.14	3.62	1.45	1.05	5.57	1.5	1.1	5.58	1.65	1.25	5.51	1.52	1.12	6.17	1.59	1.19	5.63	1.63	1.23	4.98
19-Apr	1.55	1.25	4.77	1.49	1.09	4.72	1.5	1.1	7.38	1.55	1.15	7.32	1.68	1.28	7.28	1.5	1.1	8.99	1.6	1.2	7.36	1.59	1.19	5.16
20-Apr	1.59	1.29	4.45	1.6	1.2	6.5	1.52	1.12	6.91	1.57	1.17	6.82	1.7	1.3	6.71	1.55	1.15	8.98	1.54	1.14	7.97	1.58	1.18	4.79
21-Apr	1.65	1.35	4.48	1.55	1.15	6.52	1.5	1.1	6.94	1.6	1.2	6.93	1.69	1.29	6.45	1.55	1.15	8.98	1.56	1.16	7.25	1.62	1.22	4.32
22-Apr	1.62	1.32	4.52	1.47	1.07	6.36	1.49	1.09	7.4	1.61	1.21	6.85	1.65	1.25	6.35	1.56	1.16	6.91	1.64	1.24	7.21	1.61	1.21	7.15
23-Apr	1.65	1.35	4.71	1.48	1.08	5.25	1.55	1.15	7.27	1.58	1.18	6.58	1.6	1.2	6.24	1.56	1.16	6.15	1.67	1.27	7.1	1.62	1.22	7.9
24-Apr	1.63	1.33	4.85	1.5	1.1	5.28	1.5	1.1	6.14	1.6	1.2	6.17	1.5	1.1	6.51	1.55	1.15	4.97	1.62	1.22	7.11	1.6	1.2	7.5
25-Apr	1.6	1.3	4.98	1.48	1.08	5.8	1.53	1.13	6.95	1.55	1.15	7.51	1.6	1.2	7.12	1.54	1.14	6.41	1.61	1.21	6.71	1.58	1.18	6.72
26-Apr	1.5	1.2	4.66	1.49	1.09	5.1	1.4	1	7.63	1.45	1.05	6.15	1.4	1	7.1	1.35	0.95	6.16	1.46	1.06	5.63	1.5	1.1	5.69
27-Apr	0.4	0.1	2.49	1.4	1	4.58	1.1	0.7	6.52	1.3	0.9	6.64	1.36	0.96	6.15	1.21	0.81	5.86	1.39	0.99	6.31	1.1	0.7	5.44
28-Apr	0.9	0.6	4.25	1.11	0.71	4.62	0.79	0.39	2.75	0.8	0.4	3.25	1.2	0.8	5.64	1	0.6	5.66	1.2	0.8	6.98	1.05	0.65	5.75
29-Apr	1	0.7	4.28	1.05	0.65	4.72	0.79	0.39	2.77	0.79	0.39	3.76	1.1	0.7	5.99	1	0.6	5.68	1.15	0.75	6.95	1	0.6	5.72
30-Apr	1.25	0.95	3.93	1.2	0.8	4.12	1.1	0.7	2.81	0.95	0.55	3.58	1.3	0.9	6.65	1	0.6	5.12	1.25	0.85	6.14	1.35	0.95	4.96

Table B-4. The depth and the salinity of the observation well in the experimental field for May—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-May	1.29	0.99	3.85	1.18	0.78	4.45	1	**0.6**	3.14	0.99	0.59	4.36	1.21	**0.81**	6.75	0.95	0.55	4.56	1.19	0.79	6.92	1.3	**0.9**	4.55
2-May	1.21	0.91	3.52	1.15	0.75	4.26	1.06	**0.66**	3.38	1.11	0.71	3.82	1.1	**0.7**	5.25	1.05	0.65	4.83	1.16	0.76	5.57	1.17	**0.77**	4.62
3-May	1.17	0.87	4.8	1.12	0.72	4.22	0.96	**0.56**	3.35	1.05	0.65	4.8	1.08	**0.68**	5.61	1	0.6	4.79	1.1	0.7	5.73	1.19	**0.79**	5.32
4-May	1.06	0.76	3.75	1.1	0.7	4.12	1.07	**0.67**	3.36	1.13	0.73	4.1	1.19	**0.79**	6.12	1.08	0.68	4.88	1.06	0.66	5.61	1.12	**0.72**	5.3
5-May	1.1	0.8	2.65	1.15	0.75	4.14	1.09	**0.69**	3.37	1.19	0.79	4.75	1.25	**0.85**	6.49	1.12	0.72	5.68	1.15	0.75	5.81	1.105	**0.705**	5.62
6-May	1.22	0.92	3.46	1.24	0.84	4.25	1.18	**0.78**	3.45	1.29	0.89	4.46	1.36	**0.96**	5.92	1.26	0.86	5.45	1.3	0.9	5.56	1.2	0.8	5.96
7-May	1.21	0.91	3.45	1.26	0.86	4.26	1.2	**0.8**	3.44	1.31	0.91	5.9	1.3	**0.9**	5.9	1.29	0.89	5.44	1.33	0.93	5.54	1.22	0.82	5.94
8-May	1.25	0.95	3.75	1.27	0.87	4.14	1.15	**0.75**	3.36	1.2	0.8	4.82	1.27	**0.87**	6.25	1.17	0.77	5.46	1.25	0.85	5.66	1.2	0.8	5.77
9-May	1.28	0.98	3.95	1.25	0.85	4.11	1.13	**0.73**	3.34	1	0.6	4.52	1.24	**0.84**	5.49	1.13	0.73	4.79	1.23	0.83	5.88	1.25	0.85	5.62
10-May	1.35	1.05	3.99	1.32	0.92	4.42	1.2	**0.8**	3.86	1.25	0.85	4.79	1.39	**0.99**	5.78	1.3	0.9	5.51	1.45	1.05	6.16	1.4	1	5.58
11-May	1.38	1.08	4.18	1.28	0.88	4.67	1.11	**0.71**	3.89	1.15	0.75	4.88	1.4	**1**	5.98	1.19	0.79	5.56	1.3	0.9	6.1	1.38	0.98	6.57
12-May	1.4	1.1	4.54	1.31	0.91	4.92	1.15	**0.75**	3.95	1.25	0.85	5.12	1.31	**0.91**	6.65	1.26	0.86	5.56	1.35	0.95	7.25	1.4	1	6.64
13-May	1.25	0.95	4.51	1.2	0.8	4.55	1.15	**0.75**	3.86	1.22	0.82	5.04	1.38	**0.98**	6.67	1.25	0.85	4.82	1.25	0.85	7.31	1.31	0.91	6.33
14-May	1.37	1.07	4.63	1.31	0.91	4.62	1.24	**0.84**	3.92	1.31	0.91	5.1	1.4	**1**	6.64	1.29	0.89	5.58	1.35	0.95	7.33	1.36	0.96	6.48
15-May	1.4	1.1	4.6	1.35	0.95	4.68	1.28	**0.88**	3.95	1.35	0.95	5.27	1.44	**1.04**	6.61	1.34	0.94	5.46	1.39	0.99	6.99	1.38	0.98	6.51
16-May	1.41	1.11	4.66	1.38	0.98	4.72	1.25	**0.85**	3.66	1.21	0.81	5.29	1.4	**1**	6.68	1.3	0.9	5.51	1.4	1	7.39	1.39	0.99	6.55
17-May	1.4	1.1	4.63	1.4	1	4.75	1.27	**0.87**	3.72	1.28	0.88	5.33	1.3	**0.9**	6.25	1.27	0.87	5.16	1.35	0.95	7.17	1.3	0.9	6.57
18-May	1.35	1.05	4.6	1.38	0.98	4.74	1.29	**0.89**	3.71	0.9	0.5	5.42	1.27	**0.87**	6.22	1.29	0.89	5.17	1.34	0.94	7.19	1.27	0.87	6.64
19-May	1.1	0.8	4.68	1.15	0.75	4.38	1.07	**0.67**	3.85	1	0.6	5.51	1.15	**0.75**	6.43	1.05	0.65	4.28	1.1	0.7	7.21	1	0.6	6.34
20-May	1	0.7	4.51	1.12	0.72	4.55	1.03	**0.63**	3.79	1.08	0.68	5.46	1.14	**0.74**	6.4	1.02	0.62	5.31	1.05	0.65	6.44	0.75	0.35	4.22
21-May	1	0.7	4.68	1.1	0.7	4.39	1	**0.6**	3.91	1.06	0.66	5.43	1.1	**0.7**	5.66	1	0.6	5.11	1.07	0.67	6.22	0.78	0.38	3.16
22-May	0.95	0.65	5.12	1.05	0.65	4.61	1	**0.6**	4.18	1.03	0.63	4.96	1.05	**0.65**	6.25	0.97	0.57	5.33	1.02	0.62	6.75	0.9	0.5	2.91
23-May	1.05	0.75	5.13	1.06	0.66	4.46	1.02	**0.62**	3.97	1.05	0.65	4.89	1	**0.6**	5.88	0.95	0.55	4.9	1.05	0.65	5.69	1	0.6	2.95
24-May	1.06	0.76	5.29	0.97	0.57	4.53	0.9	**0.5**	4.18	0.95	0.55	5.91	1	**0.6**	6.15	0.97	0.57	4.77	0.93	0.53	2.56	1.02	0.62	3.41
25-May	1.1	0.8	5.38	1	0.6	4.55	0.95	**0.55**	4.21	0.98	0.58	5.95	1.16	**0.76**	6.27	0.99	0.59	4.79	0.95	0.55	2.59	1.05	0.65	3.43
26-May	1.34	1.04	5.45	1.25	0.85	4.57	1.17	**0.77**	4.5	1.1	0.7	5.48	1.4	**1**	5.98	1.19	0.79	4.88	1.31	0.91	2.99	1.3	0.9	3.32
27-May	1.33	1.03	5.6	1.31	0.91	4.58	1.2	**0.8**	4.11	1.16	0.76	5.62	1.41	**1.01**	5.99	1.23	0.83	4.79	1.33	0.93	2.97	1.31	0.91	3.3
28-May	1.34	1.04	5.63	1.34	0.94	4.62	1.22	**0.82**	4.09	1.2	0.8	5.56	1.4	**1**	6.22	1.25	0.85	4.81	1.34	0.94	2.95	1.33	0.93	3.29
29-May	1.33	1.03	5.86	1.3	0.9	4.85	1.18	**0.78**	4.22	1.19	0.79	5.44	1.39	**0.99**	6.31	1.23	0.83	5.21	1.33	0.93	3.16	1.3	0.9	3.47
30-May	1.35	1.05	5.9	1.33	0.93	4.82	1.21	**0.81**	4.24	1.25	0.85	5.62	1.42	**1.02**	6.34	1.29	0.89	5.39	1.36	0.96	3.21	1.33	0.93	4.07
31-May	1.36	1.06	5.88	1.36	0.96	4.65	1.25	**0.85**	4.2	1.28	0.88	5.43	1.43	**1.03**	6.3	1.34	0.94	5.32	1.38	0.98	3.38	1.36	0.96	4.2

Table B-5. The depth and the salinity of the observation well in the experimental field for June—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Jun	1.07	0.77	5.53	1.1	0.7	4.71	1.18	**0.78**	4.17	1.27	0.87	5.26	1.45	**1.05**	6.14	1.29	0.89	6.18	1.11	0.71	3.65	1.05	0.65	5.54
2-Jun	1.22	0.92	5.49	1.21	0.81	4.69	1.2	**0.8**	4.16	1.25	0.85	5.41	1.4	**1**	6.14	1.27	0.87	6.21	1.17	0.77	3.82	1.19	0.79	3.98
3-Jun	1.27	0.97	5.54	1.3	0.9	4.7	1.2	**0.8**	3.86	1.24	0.84	5.4	1.38	**0.98**	5.79	1.25	0.85	5.72	1.28	0.88	4.12	1.25	0.85	4.6
4-Jun	1.32	1.02	5.57	1.33	0.93	4.95	1.25	**0.85**	4.46	1.28	0.88	5.71	1.4	**1**	5.72	1.26	0.86	5.69	1.3	0.9	4.72	1.3	0.9	4.39
5-Jun	1.3	1	5.82	1.32	0.92	5.9	1.23	**0.83**	4.61	1.26	0.86	5.79	1.41	**1.01**	6.7	1.25	0.85	6.71	1.29	0.89	4.52	1.3	0.9	4.42
6-Jun	1.25	0.95	5.75	1.2	0.8	5.6	1.15	**0.75**	4.48	1.21	0.81	5.41	1.3	**0.9**	6.1	1.14	0.74	7.88	1.22	0.82	3.83	1.26	0.86	4.33
7-Jun	0.98	0.68	6.15	1.02	0.62	4.77	0.88	**0.48**	5.24	0.8	0.4	4.91	0.91	**0.51**	5.92	0.88	0.48	7.16	0.95	0.55	5.14	0.9	0.5	3.66
8-Jun	0.97	0.67	6.22	1.04	0.64	4.65	0.93	**0.53**	4.78	0.9	0.5	4.96	1	**0.6**	5.9	0.9	0.5	5.77	0.97	0.57	5.51	0.95	0.55	3.72
9-Jun	1	0.7	6.51	0.9	0.5	4.76	0.81	**0.41**	2.16	0.88	0.48	4.79	1.05	**0.65**	6.1	0.86	0.46	5.41	0.95	0.55	5.32	1.06	0.66	3.86
10-Jun	0.95	0.65	6.79	0.8	0.4	4.81	0.82	**0.42**	2.27	0.86	0.46	2.21	1.25	**0.85**	6.24	0.98	0.58	4.66	1	0.6	5.34	1.05	0.65	3.88
11-Jun	0.77	0.47	6.31	0.9	0.5	5.4	0.95	**0.55**	2.41	1	0.6	3.52	1.28	**0.88**	6.5	1.03	0.63	4.81	0.95	0.55	6.19	0.9	0.5	4.22
12-Jun	1.04	0.74	6.81	1.02	0.62	5.59	1	**0.6**	2.65	1.06	0.66	4.8	1.2	**0.8**	6.2	1.1	0.7	5.89	1.11	0.71	6.72	1.1	0.7	4.89
13-Jun	1.09	0.79	6.34	1.08	0.68	5.57	1.02	**0.62**	2.64	1.08	0.68	5.1	1.25	**0.85**	6.21	1.14	0.74	5.87	1.14	0.74	6.58	1.12	0.72	4.91
14-Jun	1.11	0.81	6.39	1.12	0.72	5.58	1.05	**0.65**	2.67	1.1	0.7	5.13	1.28	**0.88**	6.23	1.17	0.77	5.88	1.16	0.76	6.61	1.14	0.74	4.96
15-Jun	1.15	0.85	6.98	1.2	0.8	5.34	1.1	**0.7**	2.69	1.13	0.73	5.41	1.3	**0.9**	6.44	1.12	0.72	5.86	1.2	0.8	6.92	1.16	0.76	4.51
16-Jun	1.1	0.8	6.81	1.16	0.76	5.32	1.08	**0.68**	2.7	1.11	0.71	4.98	1.23	**0.83**	5.88	1.16	0.76	5.99	1.12	0.72	5.36	1.09	0.69	4.31
17-Jun	1.14	0.84	6.82	1.18	0.78	5.34	1.11	**0.71**	2.68	1.14	0.74	5.04	1.26	**0.86**	5.91	1.19	0.79	6.18	1.15	0.75	5.98	1.1	0.7	4.33
18-Jun	0.45	0.15	2.54	1.2	0.8	5.26	1.19	**0.79**	2.96	1.18	0.78	5.98	1.3	**0.9**	6.12	1.26	0.86	6.32	1.17	0.77	5.54	1.08	0.68	4.64
19-Jun	1.15	0.85	4.42	1.21	0.81	5.12	1.14	**0.74**	2.97	1.12	0.72	5.18	1.28	**0.88**	6.22	1.1	0.7	5.53	1.14	0.74	6.32	1.12	0.72	4.42
20-Jun	1.08	0.78	4.46	1.08	0.68	5.04	1	**0.6**	1.98	1	0.6	5.15	1.19	**0.79**	5.98	1.04	0.64	4.39	1.1	0.7	6.33	1.15	0.75	4.55
21-Jun	1.08	0.78	4.5	1.1	0.7	5.07	0.9	**0.5**	1.77	0.89	0.49	5.17	1.11	**0.71**	5.76	1	0.6	4.35	1.07	0.67	6.37	1.18	0.78	4.61
22-Jun	1	0.7	4.72	0.9	0.5	4.1	0.86	**0.46**	2.31	0.84	0.44	4.99	1.06	**0.66**	6.12	0.9	0.5	4.96	0.92	0.52	6.25	1	0.6	3.72
23-Jun	0.88	0.58	4.88	0.84	0.44	4.12	0.81	**0.41**	2.49	0.8	0.4	5.04	1	**0.6**	6.31	0.95	0.55	5.8	0.9	0.5	6.2	0.89	0.49	3.56
24-Jun	1	0.7	5.15	0.9	0.5	4.35	0.86	**0.46**	2.65	0.85	0.45	4.98	1.05	**0.65**	6.41	1.04	0.64	5.6	0.94	0.54	3.99	0.96	0.56	3.66
25-Jun	1.09	0.79	5.61	0.96	0.56	4.73	0.9	**0.5**	2.77	0.91	0.51	4.45	1.18	**0.78**	6.74	1.09	0.69	4.98	0.97	0.57	4.41	1.06	0.66	3.85
26-Jun	1.22	0.92	5.51	1.12	0.72	4.42	1.05	**0.65**	2.69	1.07	0.67	4.37	1.24	**0.84**	6.67	1.2	0.8	5.21	1.18	0.78	4.19	1.11	0.71	3.79
27-Jun	1.18	0.88	5.08	1.14	0.74	4.46	1.08	**0.68**	2.41	1.15	0.75	4.43	1.32	**0.92**	6.12	1.25	0.85	5.32	1.22	0.82	4.25	1.18	0.78	3.86
28-Jun	1.16	0.86	5.6	1.17	0.77	4.54	1.16	**0.76**	2.35	1.22	0.82	4.46	1.4	**1**	6.11	1.35	0.95	5.49	1.25	0.85	4.48	1.23	0.83	3.98
29-Jun	1.32	1.02	5.17	1.31	0.91	4.78	1.3	**0.9**	2.95	1.33	0.93	4.35	1.32	**0.92**	5.87	1.34	0.94	5.81	1.34	0.94	4.37	1.33	0.93	3.91
30-Jun	1.35	1.05	5.42	1.36	0.96	4.77	1.31	**0.91**	3.22	1.29	0.89	4.42	1.35	**0.95**	5.99	1.36	0.96	5.95	1.35	0.95	4.45	1.35	0.95	3.96

Table B-6. The depth and the salinity of the observation well in the experimental field for Jul—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Jul	1.37	1.07	5.67	1.4	1	4.89	1.27	**0.87**	3.25	1.31	0.91	4.45	1.37	**0.97**	6.5	1.35	0.95	5.97	1.37	0.97	4.55	1.38	0.98	4.9
2-Jul	1.35	1.05	5.71	1.35	0.95	4.91	1.27	**0.87**	3.27	1.33	0.93	4.59	1.4	**1**	6.51	1.39	0.99	6.54	1.35	0.95	4.71	1.36	0.96	4.12
3-Jul	1.4	1.1	5.52	1.36	0.96	4.76	1.3	**0.9**	3.29	1.36	0.96	4.46	1.45	**1.05**	6.71	1.4	1	6.25	1.31	0.91	4.75	1.4	1	4.25
4-Jul	1.43	1.13	5.56	1.38	0.98	4.55	1.34	**0.94**	3.31	1.4	1	4.43	1.49	**1.09**	6.78	1.42	1.02	6.31	1.46	1.06	4.82	1.44	1.04	4.3
5-Jul	1.38	1.08	5.32	1.4	1	4.87	1.27	**0.87**	3.38	1.34	0.94	4.38	1.4	**1**	5.76	1.35	0.95	5.98	1.42	1.02	4.97	1.4	1	4.42
6-Jul	1.2	0.9	5.61	1.41	1.01	4.99	1.21	**0.81**	3.43	1.3	0.9	4.32	1.31	**0.91**	5.42	1.3	0.9	5.9	1.38	0.98	5.06	1.36	0.96	4.72
7-Jul	1.05	0.75	5.77	0.97	0.57	2.89	1	**0.6**	3.89	1	0.6	4.18	1.28	**0.88**	6.32	1.1	0.7	6.28	1.11	0.71	5.54	1.24	0.84	4.98
8-Jul	0.88	0.58	5.22	0.9	0.5	2.76	0.91	**0.51**	4.8	0.9	0.5	4.1	1.1	**0.7**	5.18	1	0.6	6.27	0.9	0.5	4.08	1	0.6	4.58
9-Jul	0.76	0.46	4.86	0.84	0.44	2.78	0.85	**0.45**	4.16	0.97	0.57	3.94	1	**0.6**	4.35	0.9	0.5	6.24	0.85	0.45	3.63	0.85	0.45	4.39
10-Jul	1	0.7	5.15	1	0.6	4.67	0.84	**0.44**	4.31	0.56	0.16	2.35	0.97	**0.57**	3.42	0.82	0.42	5.76	0.9	0.5	3.47	0.9	0.5	4.42
11-Jul	1.02	0.72	5.33	1.03	0.63	4.94	0.92	**0.52**	4.41	0.9	0.5	4.56	1	**0.6**	3.66	0.95	0.55	6.18	0.98	0.58	3.54	0.94	0.54	4.88
12-Jul	1.09	0.79	5.31	1.1	0.7	4.81	1.05	**0.65**	4.52	1.06	0.66	4.87	1.22	**0.82**	4.22	1.07	0.67	6.42	1.09	0.69	3.61	1.1	0.7	4.39
13-Jul	1.12	0.82	5.24	1.12	0.72	4.76	0.72	**0.32**	4.27	0.9	0.5	4.51	1.25	**0.85**	4.12	1.05	0.65	6.45	1.15	0.75	3.64	1.12	0.72	4.35
14-Jul	1.14	0.84	5.28	1.15	0.75	4.72	0.63	**0.23**	3.99	0.95	0.55	4.32	1.28	**0.88**	3.87	1.04	0.64	6.51	1.19	0.79	3.66	1.14	0.74	4.32
15-Jul	1.18	0.88	5.31	1.17	0.77	4.68	0.91	**0.51**	4.36	1.04	0.64	4.41	1.29	**0.89**	4.33	1.1	0.7	6.32	1.21	0.81	3.35	1.19	0.79	4.28
16-Jul	1.23	0.93	5.36	1.22	0.82	4.52	1	**0.6**	4.51	1.1	0.7	4.57	1.32	**0.92**	4.96	1.15	0.75	6.16	1.24	0.84	3.25	1.24	0.84	4.22
17-Jul	1.29	0.99	5.44	1.26	0.86	4.92	1.17	**0.77**	4.68	1.19	0.79	4.59	1.38	**0.98**	4.99	1.2	0.8	6.21	1.31	0.91	3.88	1.3	0.9	4.51
18-Jul	1	0.7	5.92	1.28	0.88	4.95	1.23	**0.83**	4.74	1.3	0.9	4.28	1.36	**0.96**	4.47	1.22	0.82	6.26	1.28	0.88	4.31	1.32	0.92	4.58
19-Jul	1.02	0.72	5.85	1.3	0.9	4.98	1.29	**0.89**	4.82	1.33	0.93	4.17	1.29	**0.89**	4.28	1.26	0.86	6.31	1.3	0.9	4.34	1.25	0.85	4.42
20-Jul	1.25	0.95	6.12	1.35	0.95	4.9	1.32	**0.92**	4.81	1.27	0.87	4.31	1.31	**0.91**	3.98	1.28	0.88	5.42	1.35	0.95	3.57	1.36	0.96	5.48
21-Jul	1.3	1	6.21	1.39	0.99	4.92	1.34	**0.94**	4.89	1.25	0.85	4.39	1.34	**0.94**	3.96	1.3	0.9	5.21	1.42	1.02	3.12	1.4	1	5.69
22-Jul	1.32	1.02	4.24	1.4	1	5.32	1.32	**0.92**	5.34	1.24	0.84	4.37	1.42	**1.02**	4.98	1.36	0.96	5.99	1.44	1.04	3.21	1.39	0.99	5.72
23-Jul	1.31	1.01	6.32	1.35	0.95	5.3	1.24	**0.84**	4.71	1.16	0.76	4.35	1.35	**0.95**	5.22	1.26	0.86	6.05	1.35	0.95	4.32	1.35	0.95	5.61
24-Jul	1.3	1	6.41	1.3	0.9	5.28	1.18	**0.78**	4.67	1.11	0.71	4.28	1.3	**0.9**	5.36	1.21	0.81	6.1	1.31	0.91	4.82	1.3	0.9	5.47
25-Jul	1.25	0.95	6.42	1.25	0.85	5.25	1.11	**0.71**	4.98	1	0.6	4.3	1.27	**0.87**	5.87	1.12	0.72	6.31	1.25	0.85	4.99	1.24	0.84	5.98
26-Jul	1.21	0.91	6.42	1.19	0.79	5.23	1.04	**0.64**	5.28	0.8	0.4	4.26	1.22	**0.82**	6.11	1.06	0.66	6.41	1.2	0.8	5.12	1.21	0.81	5.81
27-Jul	1.23	0.93	6.4	1.22	0.82	5.19	1.09	**0.69**	5.32	0.9	0.5	4.3	1.27	**0.87**	6.16	1.1	0.7	6.44	1.25	0.85	5.18	1.26	0.86	5.88
28-Jul	1.2	0.9	6.36	1.15	0.75	5.24	1.05	**0.65**	5.56	1	0.6	4.22	1.28	**0.88**	6.18	1.12	0.72	6.48	1.17	0.77	4.22	1.22	0.82	6.02
29-Jul	1.18	0.88	6.34	1.11	0.71	5.32	1.08	**0.68**	5.87	1.02	0.62	4.17	1.3	**0.9**	6.2	1.14	0.74	6.51	1.12	0.72	4.16	1.19	0.79	6.05
30-Jul	1.24	0.94	5.78	1.21	0.81	5.66	1.22	**0.82**	5.98	1.12	0.72	4.96	1.37	**0.97**	5.68	1.25	0.85	5.47	1.22	0.82	3.88	1.25	0.85	6.12
31-Jul	1.32	1.02	4.39	1.33	0.93	4.99	1.35	**0.95**	6.19	1.19	0.79	4.87	1.44	**1.04**	4.88	1.29	0.89	4.45	1.31	0.91	2.48	1.3	0.9	5.84

Table B-7. The depth and the salinity of the observation well in the experimental field for Aug—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Aug	1.38	1.08	4.4	1.37	0.97	5.19	1.32	0.92	6.31	1.25	0.85	4.99	1.48	1.08	4.56	1.35	0.95	4.98	1.37	0.97	2.99	1.36	0.96	5.8
2-Aug	1.43	1.13	4.35	1.4	1	5.41	1.37	0.97	6.39	1.32	0.92	5.12	1.52	1.12	4.47	1.39	0.99	5.14	1.42	1.02	3.08	1.41	1.01	5.22
3-Aug	1.48	1.18	4.38	1.44	1.04	5.07	1.39	0.99	6.22	1.36	0.96	5.18	1.48	1.08	4.52	1.42	1.02	5.08	1.48	1.08	3.1	1.45	1.05	5.76
4-Aug	1.5	1.2	4.58	1.44	1.04	4.42	1.42	1.02	6.75	1.41	1.01	6.68	1.48	1.08	4.99	1.45	1.05	5.56	1.5	1.1	3.15	1.47	1.07	5.87
5-Aug	1.54	1.24	4.67	1.46	1.06	4.49	1.46	1.06	7.09	1.45	1.05	6.98	1.5	1.1	5.38	1.48	1.08	5.98	1.53	1.13	3.36	1.5	1.1	5.91
6-Aug	1.55	1.25	4.55	1.47	1.07	4.64	1.45	1.05	6.88	1.42	1.02	6.62	1.41	1.01	5.36	1.47	1.07	6.12	1.49	1.09	3.32	1.52	1.12	5.72
7-Aug	1.57	1.27	4.53	1.49	1.09	4.62	1.43	1.03	6.49	1.4	1	6.56	1.37	0.97	5.35	1.45	1.05	6.16	1.52	1.12	3.35	1.55	1.15	5.66
8-Aug	1.58	1.28	4.52	1.44	1.04	4.57	1.35	0.95	6.41	1.33	0.93	6.44	1.34	0.94	5.21	1.37	0.97	6.05	1.4	1	3.38	1.38	0.98	5.12
9-Aug	1.39	1.09	4.48	1.4	1	4.51	1.31	0.91	6.18	1.3	0.9	6.25	1.31	0.91	5.16	1.32	0.92	5.89	1.33	0.93	3.4	1.34	0.94	4.87
10-Aug	1.31	1.01	2.71	1.34	0.94	4.93	1.15	0.75	7.55	1.08	0.68	6.32	1.2	0.8	5.42	1.22	0.82	6.12	1.24	0.84	3.75	1.28	0.88	4.97
11-Aug	1.15	0.85	1.88	1.25	0.85	5.02	1.05	0.65	7.98	1.05	0.65	6.45	1.16	0.76	5.57	1.11	0.71	6.25	1.2	0.8	4.36	1.1	0.7	5.02
12-Aug	1	0.7	2.07	1.1	0.7	5.08	1	0.6	8.11	1	0.6	5.72	1.08	0.68	5.78	1	0.6	6.32	0.9	0.5	5.12	1.12	0.72	5.11
13-Aug	0.95	0.65	2.21	1.03	0.63	5.17	0.92	0.52	8.19	0.95	0.55	5.16	1.03	0.63	5.99	0.96	0.56	6.48	0.75	0.35	5.16	1.13	0.73	5.26
14-Aug	1.12	0.82	2.35	1.1	0.7	5.26	1	0.6	8.26	1.05	0.65	4.22	1.15	0.75	6.08	1	0.6	6.51	1	0.6	4.75	1.17	0.77	5.92
15-Aug	1.22	0.92	2.41	1.17	0.77	5.33	1.04	0.64	8.51	1.12	0.72	3.87	1.21	0.81	6.19	1.05	0.65	6.56	1.15	0.75	5.11	1.22	0.82	6.1
16-Aug	1.26	0.96	2.75	1.25	0.85	5.4	1.14	0.74	8.32	1.15	0.75	3.98	1.27	0.87	5.87	1.15	0.75	5.24	1.21	0.81	5.04	1.25	0.85	5.77
17-Aug	1.3	1	3.38	1.28	0.88	5.46	1.2	0.8	7.76	1.21	0.81	4.13	1.32	0.92	5.59	1.24	0.84	5.32	1.28	0.88	4.75	1.3	0.9	5.61
18-Aug	1.32	1.02	3.45	1.31	0.91	5.48	1.24	0.84	7.88	1.25	0.85	4.25	1.36	0.96	5.32	1.28	0.88	5.38	1.34	0.94	3.18	1.33	0.93	5.29
19-Aug	1.35	1.05	3.75	1.39	0.99	5.51	1.29	0.89	7.91	1.28	0.88	4.32	1.38	0.98	4.88	1.32	0.92	5.44	1.39	0.99	3.08	1.38	0.98	5.16
20-Aug	1.37	1.07	3.81	1.4	1	5.32	1.31	0.91	7.75	1.3	0.9	4.35	1.41	1.01	4.66	1.32	0.92	5.48	1.39	0.99	2.87	1.4	1	5.08
21-Aug	1.4	1.1	3.98	1.42	1.02	5.19	1.31	0.91	7.56	1.32	0.92	4.3	1.44	1.04	4.36	1.33	0.93	5.56	1.4	1	2.81	1.42	1.02	4.92
22-Aug	1.44	1.14	3.87	1.44	1.04	5.04	1.36	0.96	6.99	1.44	1.04	4.35	1.47	1.07	4.25	1.37	0.97	5.41	1.45	1.05	2.85	1.45	1.05	4.86
23-Aug	1.48	1.18	3.77	1.46	1.06	4.88	1.46	1.06	6.87	1.47	1.07	4.22	1.49	1.09	4.18	1.4	1	5.22	1.49	1.09	2.88	1.47	1.07	4.75
24-Aug	1.44	1.14	3.74	1.48	1.08	4.45	1.4	1	6.54	1.5	1.1	4.38	1.44	1.04	5.15	1.41	1.01	5.11	1.44	1.04	3.12	1.46	1.06	3.18
25-Aug	1.36	1.06	3.68	1.5	1.1	4.12	1.36	0.96	6.35	1.55	1.15	4.88	1.4	1	4.12	1.39	0.99	4.89	1.4	1	3.08	1.44	1.04	3.31
26-Aug	1.22	0.92	3.88	1.25	0.85	3.75	1.1	0.7	6.42	1.12	0.72	2.85	1.13	0.73	4.98	1.18	0.78	4.35	1.31	0.91	3.35	1.24	0.84	4.36
27-Aug	1.16	0.86	3.91	1.14	0.74	4.15	1	0.6	6.57	0.9	0.5	2.71	1	0.6	5.12	1	0.6	4.72	1.22	0.82	3.41	1.14	0.74	4.45
28-Aug	1.05	0.75	3.88	1.1	0.7	4.76	0.8	0.4	3.99	0.9	0.5	2.78	1.05	0.65	4.54	0.85	0.45	4.99	1.11	0.71	3.28	1	0.6	4.98
29-Aug	1	0.7	3.69	1.04	0.64	5.12	0.82	0.42	3.75	0.93	0.53	2.87	1.11	0.71	4.32	0.92	0.52	6.18	1	0.6	3.22	0.9	0.5	5.16
30-Aug	1.15	0.85	3.88	1.08	0.68	5.16	1	0.6	4.12	1	0.6	2.99	1.15	0.75	4.51	1	0.6	6.35	1.1	0.7	3.36	1	0.6	5.47
31-Aug	1.22	0.92	4.12	1.19	0.79	5.28	1.11	0.71	4.85	1.1	0.7	3.34	1.18	0.78	4.87	1.13	0.73	6.67	1.2	0.8	3.44	1.1	0.7	5.87

Table B-8. The depth and the salinity of the observation well in the experimental field for Sep—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Sep	1.26	0.96	3.97	1.19	0.79	4.75	1.16	**0.76**	4.99	1.15	0.75	3.28	1.22	**0.82**	4.57	1.17	0.77	6.55	1.26	0.86	3.45	1.16	0.76	3.97
2-Sep	1.3	1	3.66	1.26	0.86	4.82	1.28	**0.88**	5.33	1.22	0.82	3.24	1.28	**0.88**	4.26	1.22	0.82	6.32	1.3	0.9	3.41	1.31	0.91	3.72
3-Sep	1.34	1.04	3.96	1.29	0.89	5.12	1.3	**0.9**	5.41	1.3	0.9	3.88	1.32	**0.92**	4.65	1.28	0.88	6.31	1.32	0.92	3.99	1.31	0.91	4.11
4-Sep	1.36	1.06	4.2	1.33	0.93	5.2	1.2	**0.8**	5.9	1.26	0.86	4.1	1.34	**0.94**	4.7	1.3	0.9	6.8	1.33	0.93	3.7	1.34	0.94	5.2
5-Sep	1.4	1.1	4.89	1.35	0.95	5.27	1.26	**0.86**	6.31	1.3	0.9	4.28	1.37	**0.97**	4.87	1.33	0.93	5.46	1.38	0.98	3.75	1.37	0.97	5.66
6-Sep	1.43	1.13	4.75	1.37	0.97	5.29	1.3	**0.9**	6.52	1.29	0.89	3.89	1.38	0.98	4.36	1.31	0.91	5.74	1.39	0.99	3.62	1.39	0.99	5.54
7-Sep	1.44	1.14	4.52	1.4	1	5.21	1.33	**0.93**	6.79	1.27	0.87	3.76	1.4	1	4.16	1.29	0.89	5.62	1.38	0.98	3.54	1.4	1	5.51
8-Sep	1.4	1.1	5.61	1.39	0.99	4.76	1.34	**0.94**	5.41	1.31	0.91	6.62	1.4	1	5.76	1.35	0.95	5.56	1.39	0.99	3.36	1.4	1	5.66
9-Sep	1	0.7	5.77	1.24	0.84	4.55	1.05	**0.65**	5.4	1.08	0.68	6.56	1.15	0.75	5.42	1.1	0.7	5.98	1.18	0.78	3.32	1	0.6	5.12
10-Sep	0.9	0.6	5.22	1.2	0.8	4.87	1.02	**0.62**	5.71	1	0.6	6.44	1	0.6	6.32	1	0.6	6.12	1.14	0.74	3.35	0.9	0.5	4.87
11-Sep	0.85	0.55	4.86	1	0.6	4.99	0.9	**0.5**	5.79	0.75	0.35	6.25	1	0.6	5.18	0.9	0.5	6.16	0.9	0.5	3.38	0.91	0.51	4.97
12-Sep	0.8	0.5	5.15	0.86	0.46	2.89	0.81	0.41	5.41	0.7	0.3	6.32	0.95	0.55	4.35	0.8	0.4	6.05	0.85	0.45	3.4	0.84	0.44	5.02
13-Sep	0.93	0.63	5.33	0.72	0.32	2.76	0.77	0.37	4.91	0.72	0.32	6.45	1	0.6	3.42	0.88	0.48	5.89	0.9	0.5	3.75	0.94	0.54	5.11
14-Sep	1	0.7	5.31	0.75	0.35	2.78	0.86	0.46	4.96	0.85	0.45	5.72	1.1	0.7	3.66	1.08	0.68	6.12	1	0.6	4.36	1.02	0.62	5.26
15-Sep	1.05	0.75	5.24	0.78	0.38	4.67	0.88	0.48	4.79	0.9	0.5	5.16	1.12	0.72	4.22	1.1	0.7	6.25	1.06	0.66	5.12	1.07	0.67	5.92
16-Sep	1.13	0.83	5.28	1	0.6	4.94	1	0.6	2.21	1.04	0.64	4.22	1.13	0.73	4.12	1.14	0.74	6.32	1.12	0.72	5.16	1.11	0.71	6.1
17-Sep	1.18	0.88	5.31	1.04	0.64	4.81	1.05	0.65	3.52	1.1	0.7	3.87	1.15	0.75	3.87	1.2	0.8	6.48	1.18	0.78	4.75	1.12	0.72	5.77
18-Sep	1.16	0.86	5.36	1.08	0.68	4.76	1.07	0.67	4.8	1.13	0.73	3.98	1.12	0.72	4.33	1.17	0.77	6.51	1.19	0.79	5.11	1.15	0.75	5.61
19-Sep	1.19	0.89	5.44	1.15	0.75	4.72	1.12	0.72	5.1	1.14	0.74	4.13	1.11	0.71	4.96	1.15	0.75	6.56	1.21	0.81	5.04	1.18	0.78	5.29
20-Sep	1.23	0.93	5.92	1.22	0.82	4.68	1.2	0.8	5.13	1.18	0.78	4.25	1.2	0.8	4.99	1.16	0.76	5.24	1.24	0.84	4.75	1.16	0.76	5.16
21-Sep	1.24	0.94	5.85	1.25	0.85	4.52	1.18	0.78	5.41	1.22	0.82	4.32	1.27	0.87	4.47	1.28	0.88	5.32	1.26	0.86	3.18	1.21	0.81	5.08
22-Sep	1.23	0.93	6.12	1.25	0.85	4.92	1.2	0.8	4.98	1.24	0.84	4.35	1.28	0.88	4.28	1.27	0.87	5.38	1.29	0.89	3.08	1.24	0.84	4.92
23-Sep	1.26	0.96	6.21	1.27	0.87	4.95	1.25	0.85	5.04	1.23	0.83	4.3	1.32	0.92	3.98	1.24	0.84	5.44	1.31	0.91	2.87	1.26	0.86	4.86
24-Sep	1.29	0.99	4.24	1.3	0.9	4.98	1.28	0.88	5.98	1.25	0.85	4.35	1.3	0.9	3.96	1.26	0.86	5.48	1.33	0.93	2.81	1.28	0.88	4.75
25-Sep	1.17	0.87	6.32	1.15	0.75	4.9	0.8	0.4	5.18	1.19	0.79	4.22	1.18	0.78	4.98	0.85	0.45	5.56	1.15	0.75	2.85	1.14	0.74	3.18
26-Sep	1.15	0.85	6.41	1.13	0.73	4.92	0.72	0.32	5.15	1.14	0.74	4.38	1.12	0.72	5.22	0.82	0.42	5.41	1.12	0.72	2.88	1.11	0.71	3.31
27-Sep	0.9	0.6	6.42	0.75	0.35	5.32	0.7	0.3	5.17	0.62	0.22	4.88	1	0.6	5.36	0.7	0.3	5.22	0.74	0.34	3.12	0.92	0.52	4.36
28-Sep	0.84	0.54	6.42	0.67	0.27	5.3	0.65	0.25	4.99	0.55	0.15	2.85	0.9	0.5	5.87	0.64	0.24	5.11	0.7	0.3	3.08	0.87	0.47	4.45
29-Sep	0.87	0.57	6.4	0.76	0.36	5.28	0.63	0.23	5.04	0.6	0.2		0.87	0.47	6.11	0.74	0.34	4.89	0.75	0.35		0.76	0.36	
30-Sep	0.9	0.6	7.76	0.92	0.52	3.42	0.81	0.41	4.8	0.9	0.5	4.61	0.98	0.58	5.55	0.82	0.42	7.12	0.9	0.5	3.62	0.92	0.52	6.52

Table B-9 The depth and the salinity of the observation well in the experimental field for Oct—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Oct	0.93	0.63	7.92	0.95	0.55	3.48	0.84	0.44	4.84	0.93	0.53	4.65	1	0.6	5.57	0.88	0.48	6.98	0.92	0.52	3.67	0.94	0.54	6.58
2-Oct	1.05	0.75	6.22	1.03	0.63	3.67	0.92	0.52	4.89	1	0.6	4.61	1.08	0.68	5.58	1.03	0.63	6.77	1.02	0.62	3.79	1.04	0.64	6.84
3-Oct	1.12	0.82	6.34	1.08	0.68	3.75	1	0.6	5.04	1.08	0.68	4.58	1.12	0.72	5.6	1.09	0.69	6.79	1.1	0.7	3.86	1.11	0.71	6.92
4-Oct	1.18	0.88	6.88	1.15	0.75	3.99	1.14	0.74	5.1	1.16	0.76	4.87	1.2	0.8	5.89	1.18	0.78	6.99	1.21	0.81	4.12	1.17	0.77	7.15
5-Oct	1.26	0.96	7.16	1.22	0.82	4.12	1.2	0.8	5.14	1.24	0.84	4.89	1.26	0.86	6.1	1.25	0.85	7.12	1.27	0.87	4.26	1.28	0.88	7.28
6-Oct	1.3	1	7.45	1.26	0.86	4.28	1.22	0.82	5.62	1.23	0.83	4.95	1.24	0.84	6.15	1.27	0.87	6.22	1.3	0.9	4.52	1.31	0.91	7.36
7-Oct	1.31	1.01	7.55	1.28	0.88	4.42	1.24	0.84	5.74	1.24	0.84	5.11	1.25	0.85	6.17	1.29	0.89	6.37	1.32	0.92	4.89	1.33	0.93	7.49
8-Oct	1.34	1.04	7.61	1.32	0.92	4.31	1.27	0.87	5.26	1.26	0.86	4.85	1.16	0.76	5.87	1.32	0.92	6.24	1.35	0.95	4.75	1.3	0.9	7.12
9-Oct	1.37	1.07	7.65	1.35	0.95	4.26	1.32	0.92	5.14	1.3	0.9	4.76	1.14	0.74	6.12	1.31	0.91	6.16	1.37	0.97	4.63	1.28	0.88	6.85
10-Oct	1.28	0.98	7.36	1.32	0.92	4.35	1.22	0.82	5.04	1.05	0.65	4.46	1.07	0.67	6.08	1.28	0.88	6.05	1.31	0.91	4.39	1.29	0.89	6.38
11-Oct	1.3	1	7.34	1.34	0.94	4.38	1.18	0.78	4.85	1	0.6	4.25	1	0.6	5.92	1.25	0.85	5.89	1.28	0.88	4.22	1.32	0.92	6.18
12-Oct	1.16	0.86	7.45	1.25	0.85	4.52	1.1	0.7	4.36	0.96	0.56	4.23	1.02	0.62	5.79	1.18	0.78	6.16	1.14	0.74	4.36	1.19	0.79	6.12
13-Oct	1.05	0.75	7.61	1.19	0.79	4.74	1	0.6	4.22	0.92	0.52	4.19	0.98	0.58	5.58	1.04	0.64	6.12	1.02	0.62	4.76	1	0.6	6.04
14-Oct	1.02	0.72	7.35	1	0.6	4.78	0.87	0.47	4.26	0.91	0.51	4.22	1	0.6	5.51	0.97	0.57	5.97	0.95	0.55	5.53	0.92	0.52	5.88
15-Oct	0.95	0.65	7.22	0.9	0.5	4.75	0.81	0.41	4.28	0.89	0.49	4.15	0.91	0.51	5.44	0.92	0.52	5.84	0.9	0.5	5.48	0.94	0.54	5.76
16-Oct	0.93	0.63	7.51	0.85	0.45	4.46	0.77	0.37	3.78	0.82	0.42	4.22	0.85	0.45	4.32	0.87	0.47	5.44	0.93	0.53	5.24	0.91	0.51	5.32
17-Oct	0.9	0.6	7.64	0.8	0.4	4.25	0.7	0.3	3.75	0.68	0.28	4.26	0.8	0.4	3.18	0.82	0.42	5.12	0.97	0.57	4.89	0.87	0.47	4.91
18-Oct	0.98	0.68	7.75	0.84	0.44	4.62	0.88	0.48	3.37	0.95	0.55	4.32	0.86	0.46	3.34	1	0.6	5.36	1.02	0.62	4.92	0.94	0.54	5.11
19-Oct	1.03	0.73	7.46	0.87	0.47	3.94	1	0.6	3.75	1.02	0.62	4.39	1	0.6	3.55	1.05	0.65	4.57	1.06	0.66	4.99	1.05	0.65	5.17
20-Oct	1.14	0.84	7.37	1	0.6	4.11	1.07	0.67	3.72	1.11	0.71	4.26	1.08	0.68	3.67	1.12	0.72	4.68	1.13	0.73	4.91	1.15	0.75	5.15
21-Oct	1.23	0.93	7.41	1.15	0.75	4.14	1.14	0.74	3.7	1.15	0.75	4.33	1.14	0.74	3.71	1.17	0.77	4.89	1.22	0.82	4.96	1.21	0.81	5.12
22-Oct	1.26	0.96	7.22	1.2	0.8	4.38	1.23	0.83	3.89	1.22	0.82	4.39	1.2	0.8	3.85	1.23	0.83	4.95	1.26	0.86	5.12	1.25	0.85	5.21
23-Oct	1.31	1.01	7.16	1.26	0.86	4.67	1.27	0.87	4.12	1.26	0.86	4.45	1.24	0.84	4.06	1.27	0.87	5.08	1.3	0.9	5.16	1.29	0.89	5.24
24-Oct	1.28	0.98	7.09	1.24	0.84	4.38	1.25	0.85	3.98	1.21	0.81	4.27	1.26	0.86	4.46	1.25	0.85	4.88	1.27	0.87	5.12	1.26	0.86	5.15
25-Oct	1.17	0.87	6.88	1.18	0.78	4.21	1.21	0.81	3.87	1.17	0.77	4.22	1.28	0.88	4.75	1.22	0.82	4.71	1.24	0.84	5.07	1.21	0.81	5.11
26-Oct	1.19	0.89	7.08	1.16	0.76	4.26	1.18	0.78	4.05	1.16	0.76	4.25	1.25	0.85	5.14	1.23	0.83	4.74	1.11	0.71	4.89	1.18	0.78	5.08
27-Oct	1.22	0.92	7.16	1.14	0.74	4.38	1.15	0.75	4.08	1.18	0.78	4.28	1.21	0.81	5.26	1.25	0.85	4.76	1.06	0.66	4.81	1.15	0.75	4.98
28-Oct	1.23	0.93	7.23	1.16	0.76	4.45	1.05	0.65	4.39	1.11	0.71	4.37	1.22	0.82	5.18	1.16	0.76	4.85	1	0.6	4.76	1.08	0.68	4.87
29-Oct	1.21	0.91	7.19	1.19	0.79	4.57	1	0.6	4.53	1	0.6	4.46	1.18	0.78	5.12	1.11	0.71	4.88	0.94	0.54	4.71	1	0.6	4.8
30-Oct	1.18	0.88	7.35	1.14	0.74	4.98	1	0.6	4.67	0.95	0.55	4.68	1.11	0.71	5.32	1.09	0.69	5.02	1	0.6	4.99	1.02	0.62	5.07
31-Oct	1.1	0.8	7.56	1.12	0.72	5.15	1.03	0.63	4.85	1	0.6	4.88	1.08	0.68	5.59	1.06	0.66	5.08	1.08	0.68	5.09	1.06	0.66	5.16

Table B-10. The depth and the salinity of the observation well in the experimental field for Nov—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Nov	1.11	0.81	7.39	1.1	0.7	5.08	1	0.6	4.87	0.97	0.57	4.91	1.1	0.7	4.89	1.07	0.67	4.97	1.08	0.68	5.22	1.1	0.7	4.31
2-Nov	1.13	0.83	7.23	1.08	0.68	4.89	1.05	0.65	4.92	1	0.6	4.95	1.12	0.72	4.97	1.11	0.71	5.08	1.1	0.7	5.31	1.14	0.74	4.34
3-Nov	1.12	0.82	7.22	1.16	0.76	4.39	1.14	0.74	4.77	1.17	0.77	4.65	1.19	0.79	4.75	1.21	0.81	5.36	1.19	0.79	4.95	1.18	0.78	4.64
4-Nov	1.21	0.91	7.56	1.23	0.83	4.71	1.19	0.79	5.08	1.2	0.8	4.91	1.25	0.85	4.98	1.24	0.84	5.84	1.26	0.86	5.18	1.22	0.82	4.88
5-Nov	1.26	0.96	7.75	1.28	0.88	5.12	1.25	0.85	5.31	1.27	0.87	5.22	1.29	0.89	5.21	1.28	0.88	5.99	1.3	0.9	5.43	1.26	0.86	5.19
6-Nov	1.26	0.96	7.75	1.28	0.88	5.12	1.25	0.85	5.31	1.27	0.87	5.22	1.29	0.89	5.21	1.28	0.88	5.99	1.3	0.9	5.43	1.26	0.86	5.19
7-Nov	1.28	0.98	6.89	1.3	0.9	4.98	1.28	0.88	5.22	1.29	0.89	5.1	1.25	0.85	5.12	1.3	0.9	5.86	1.31	0.91	5.32	1.28	0.88	5.22
8-Nov	1.3	1	6.64	1.34	0.94	4.75	1.3	0.9	5.18	1.31	0.91	4.91	1.29	0.89	4.98	1.31	0.91	4.57	1.33	0.93	5.24	1.3	0.9	5.16
9-Nov	1.3	1	6.59	1.31	0.91	4.83	1.25	0.85	4.82	1.29	0.89	4.75	1.3	0.9	4.88	1.26	0.86	4.38	1.31	0.91	5.18	1.28	0.88	5.19
10-Nov	1.28	0.98	6.32	1.27	0.87	4.89	1.22	0.82	4.77	1.31	0.91	4.36	1.32	0.92	4.71	1.24	0.84	4.32	1.28	0.88	5.12	1.25	0.85	5.22
11-Nov	1.29	0.99	6.53	1.31	0.91	4.76	1.29	0.89	4.43	1.32	0.92	4.24	1.3	0.9	4.66	1.3	0.9	4.41	1.31	0.91	5.18	1.27	0.87	5.32
12-Nov	1.31	1.01	6.67	1.33	0.93	4.49	1.32	0.92	4.57	1.34	0.94	4.16	1.25	0.85	4.57	1.33	0.93	4.59	1.3	0.9	5.22	1.31	0.91	5.54
13-Nov	1.26	0.96	6.75	1.25	0.85	4.32	1.23	0.83	3.99	1.18	0.78	3.98	1.19	0.79	3.42	1.14	0.74	4.88	1.16	0.76	5.14	1.15	0.75	5.41
14-Nov	1.12	0.82	6.81	1.15	0.75	4.21	1.07	0.67	3.81	1.16	0.76	3.79	1	0.6	3.21	1	0.6	4.95	1.02	0.62	5.07	1	0.6	5.22
15-Nov	1.06	0.76	6.44	1.08	0.68	4.25	1.05	0.65	3.92	1.09	0.69	3.86	0.95	0.55	3.34	0.97	0.57	4.88	1	0.6	5.12	0.94	0.54	5.26
16-Nov	1	0.7	6.17	1.04	0.64	4.31	1	0.6	4.06	1.05	0.65	3.92	0.9	0.5	3.46	0.93	0.53	4.81	0.95	0.55	5.17	0.89	0.49	5.29
17-Nov	0.97	0.67	6.37	1	0.6	4.36	0.97	0.57	4.15	1.03	0.63	4.12	1.02	0.62	3.52	1	0.6	4.98	0.98	0.58	5.12	0.96	0.56	5.18
18-Nov	0.95	0.65	6.43	1.03	0.63	4.47	1	0.6	4.22	1	0.6	4.21	1	0.6	3.67	1.02	0.62	5.12	1	0.6	4.98	1.04	0.64	5.14
19-Nov	1	0.7	6.42	1.05	0.65	4.54	1.02	0.62	4.25	1.03	0.63	4.33	1.06	0.66	3.75	1.05	0.65	5.07	0.9	0.5	4.85	1.04	0.64	5.16
20-Nov	1.02	0.72	6.4	1.06	0.66	4.62	1.05	0.65	4.31	1.05	0.65	4.38	1.08	0.68	3.98	1.07	0.67	5.11	0.92	0.52	4.81	1.1	0.7	5.21
21-Nov	1.05	0.75	6.51	1.07	0.67	4.67	1	0.6	4.38	1.02	0.62	4.36	1	0.6	4.15	1.03	0.63	5.07	0.9	0.5	4.72	1.08	0.68	5.18
22-Nov	1.08	0.78	6.64	1.09	0.69	4.76	0.95	0.55	4.45	0.97	0.57	4.42	0.94	0.54	4.21	0.96	0.56	4.98	0.85	0.45	4.35	1.07	0.67	5.14
23-Nov	1.12	0.82	6.76	1.18	0.78	4.68	1.06	0.66	5.61	1.05	0.65	4.55	1.08	0.68	5.32	1.08	0.68	5.12	1	0.6	4.28	1.15	0.75	5.19
24-Nov	1.17	0.87	6.81	1.22	0.82	4.56	1.13	0.73	5.69	1.16	0.76	4.72	1.19	0.79	5.41	1.17	0.77	5.21	1.14	0.74	4.22	1.22	0.82	5.26
25-Nov	1.19	0.89	6.75	1.25	0.85	5.61	1.15	0.75	5.55	1.19	0.79	5.51	1.22	0.82	5.46	1.2	0.8	5.38	1.16	0.76	4.33	1.13	0.73	5.32
26-Nov	1.21	0.91	6.54	1.27	0.87	5.65	1.17	0.77	5.41	1.22	0.82	5.37	1.25	0.85	5.41	1.23	0.83	5.47	1.2	0.8	4.38	1.19	0.79	5.59
27-Nov	1.05	0.75	6.67	1.21	0.81	5.25	1.14	0.74	5.32	1.18	0.78	5.3	1.2	0.8	5.22	1.16	0.76	5.35	1.17	0.77	4.45	1.18	0.78	4.41
28-Nov	1	0.7	6.12	1.17	0.77	5.08	1.12	0.72	5.24	1.15	0.75	5.22	1.16	0.76	5.13	1.14	0.74	5.31	1.15	0.75	4.56	1.16	0.76	4.22
29-Nov	0.95	0.65	5.89	1.06	0.66	4.91	1.08	0.68	5.18	1.09	0.69	5.12	1.14	0.74	4.98	1.12	0.72	5.12	1.1	0.7	4.48	1.1	0.7	4.43
30-Nov	0.9	0.6	5.72	1	0.6	4.67	1.03	0.63	5.12	1.05	0.65	5.08	1.08	0.68	4.91	1.07	0.67	5.06	1.03	0.63	4.41	1.04	0.64	4.65

Table B-11. The depth and the salinity of the observation well in the experimental field for Dec—2025.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	O.W-1	Ec-1	Top	O.W-2	Ec-2	Top	O.W-3	Ec-3	Top	O.W-4	Ec-4	Top	O.W-5	Ec-5	Top	O.W-6	Ec-6	Top	O.W-7	Ec-7	Top	O.W-8	Ec-8
1-Dec	0.92	0.62	5.76	1.03	0.63	4.71	1.05	0.65	5.16	1.02	0.62	5.1	1.1	0.7	5.02	1	0.6	4.98	0.95	0.55	4.22	1.06	0.66	4.71
2-Dec	0.95	0.65	5.79	1.05	0.65	4.75	1	0.6	5.14	1	0.6	5.08	1.12	0.72	5.16	1.02	0.62	4.95	0.9	0.5	4.11	1.08	0.68	4.75
3-Dec	0.93	0.63	5.82	0.94	0.54	4.77	1.02	0.62	5.16	0.9	0.5	4.75	0.91	0.51	4.88	0.95	0.55	4.91	0.92	0.52	4.38	1.03	0.63	4.66
4-Dec	0.97	0.67	5.79	1	0.6	4.85	1.05	0.65	5.18	0.96	0.56	4.82	1	0.6	4.95	1	0.6	4.97	0.98	0.58	4.42	1.07	0.67	4.75
5-Dec	1.05	0.75	5.91	1.07	0.67	4.71	1	0.6	4.98	1.02	0.62	4.75	1.1	0.7	4.79	1.04	0.64	4.81	1.06	0.66	4.57	1.1	0.7	4.85
6-Dec	1.16	0.86	5.98	1.1	0.7	4.62	1	0.6	4.91	1.08	0.68	4.69	1.13	0.73	4.61	1.09	0.69	4.77	1	0.6	4.54	1.12	0.72	4.81
7-Dec	1.18	0.88	6.05	1.15	0.75	4.59	1.13	0.73	4.46	1.12	0.72	4.51	1.17	0.77	4.55	1.14	0.74	4.69	1.16	0.76	4.49	1.15	0.75	4.78
8-Dec	1.19	0.89	5.98	1.17	0.77	4.61	1.15	0.75	4.82	1.14	0.74	4.56	1	0.6	4.12	1.16	0.76	4.61	1	0.6	4.16	1.17	0.77	4.72
9-Dec	1.2	0.9	6.05	1.19	0.79	4.68	1.17	0.77	4.85	1.16	0.76	4.89	1.03	0.63	4.15	1.1	0.7	4.65	1.05	0.65	4.22	1.2	0.8	4.76
10-Dec	1.23	0.93	5.98	1.17	0.77	4.51	1.1	0.7	5.44	1.14	0.74	4.82	1.07	0.67	4.18	1.13	0.73	4.71	1.15	0.75	5.42	1.21	0.81	4.71
11-Dec	1.21	0.91	5.95	1.18	0.78	4.53	1.09	0.69	5.42	1.14	0.74	4.83	1.08	0.68	4.22	1.14	0.74	4.73	1.16	0.76	5.41	1.22	0.82	4.74
12-Dec	1.19	0.89	5.92	1.16	0.76	4.54	1.1	0.7	5.44	1.16	0.76	4.85	1.1	0.7	4.26	1.12	0.72	4.75	1.14	0.74	5.38	1.2	0.8	4.76
13-Dec	1.2	0.9	6.05	1.21	0.81	4.51	1.12	0.72	5.52	1.13	0.73	4.93	1.12	0.72	4.88	1.14	0.74	4.81	1.17	0.77	5.22	1.18	0.78	4.89
14-Dec	1.23	0.93	6.18	1.18	0.78	4.42	1.15	0.75	5.74	1	0.6	5.06	1.14	0.74	5.04	1.16	0.76	4.88	1.21	0.81	4.98	1.16	0.76	5.04
15-Dec	1.16	0.86	5.98	1.12	0.72	4.58	1.1	0.7	5.32	1.02	0.62	4.87	1.08	0.68	4.89	1.11	0.71	4.76	1.14	0.74	4.72	1.12	0.72	5.16
16-Dec	1.11	0.81	5.86	1.08	0.68	4.67	1.05	0.65	5.26	1.06	0.66	4.78	1.05	0.65	4.81	1.07	0.67	4.55	1.08	0.68	4.77	1.06	0.66	5.21
17-Dec	1	0.7	5.71	1.05	0.65	4.54	1.02	0.62	5.21	1.03	0.63	5.19	1.07	0.67	4.86	1.02	0.62	4.62	1.04	0.64	4.81	1	0.6	5.16
18-Dec	0.9	0.6	5.59	1	0.6	4.33	1	0.6	5.16	1.04	0.64	5.08	1.06	0.66	4.93	1	0.6	4.91	1	0.6	4.89	0.95	0.55	4.98
19-Dec	1	0.7	5.82	1.1	0.7	4.88	1.05	0.65	5.46	1.09	0.69	5.39	1.1	0.7	5.62	0.9	0.5	4.85	1.1	0.7	5.48	1.05	0.65	5.21
20-Dec	1.14	0.84	6.12	1.15	0.75	5.42	1.07	0.67	5.66	1.15	0.75	5.69	1.16	0.76	5.72	0.85	0.45	4.96	1.13	0.73	5.78	1.1	0.7	5.46
21-Dec	1.15	0.85	6.17	1.17	0.77	5.46	1.1	0.7	5.68	1.08	0.68	5.71	1.14	0.74	5.75	0.9	0.5	5.04	1.15	0.75	5.81	1.13	0.73	5.51
22-Dec	1.16	0.86	6.14	1.19	0.79	5.56	1.14	0.74	5.75	1.11	0.71	5.78	1.18	0.78	5.82	0.95	0.55	5.18	1.18	0.78	5.89	1.16	0.76	5.62
23-Dec	1.13	0.83	5.98	1.16	0.76	4.88	1	0.6	4.98	1.07	0.67	5.41	1.21	0.81	5.98	0.98	0.58	4.97	1.16	0.76	5.58	1.14	0.74	5.43
24-Dec	1.15	0.85	5.79	1.14	0.74	4.67	0.9	0.5	4.76	1	0.6	5.19	1.24	0.84	6.05	1.02	0.62	4.81	1.14	0.74	5.36	1.16	0.76	5.26
25-Dec	1.16	0.86	5.81	1.17	0.77	4.75	0.96	0.56	4.83	1.05	0.65	5.21	1.22	0.82	6.02	1.06	0.66	4.95	1.16	0.76	5.39	1.2	0.8	5.31
26-Dec	1.18	0.88	5.96	1.15	0.75	4.9	1.02	0.62	5.92	1.07	0.67	4.12	1.24	0.84	5.26	1.1	0.7	5.39	1.18	0.78	5.62	1.21	0.81	4.06
27-Dec	1.2	0.9	6.04	1.19	0.79	5.19	1.1	0.7	5.76	1.11	0.71	4.16	1.24	0.84	5.28	1.15	0.75	5.62	1.2	0.8	5.87	1.22	0.82	4.03
28-Dec	1.22	0.92	5.98	1.2	0.8	5.24	1.13	0.73	5.81	1.15	0.75	4.22	1.21	0.81	5.31	1.18	0.78	5.66	1.23	0.83	5.84	1.24	0.84	4.12
29-Dec	1.2	0.9	5.94	1.19	0.79	5.28	1.15	0.75	5.84	1.12	0.72	4.28	1.2	0.8	5.36	1.19	0.79	5.64	1.21	0.81	5.86	1.22	0.82	4.16
30-Dec	1.21	0.91	5.88	1.22	0.82	5.23	1.17	0.77	5.81	1.14	0.74	4.32	1.15	0.75	5.46	1.2	0.8	4.61	1.19	0.79	5.81	1.2	0.8	4.19
31-Dec	1.23	0.93	5.82	1.21	0.81	5.19	1.19	0.79	5.84	1.15	0.75	4.35	1.1	0.7	5.56	1.22	0.82	4.28	1.17	0.77	5.67	1.18	0.78	4.26

Table B-12. The depth and the salinity of the observation well in the experimental field for Jan—2026.

Date	OW1			OW2			OW3			OW4			OW5			OW6			OW7			OW8		
	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec	depth		Ec
	Top	**O.W-1**	Ec-1	Top	**O.W-2**	Ec-2	Top	**O.W-3**	Ec-3	Top	**O.W-4**	Ec-4	Top	**O.W-5**	Ec-5	Top	**O.W-6**	Ec-6	Top	**O.W-7**	Ec-7	Top	**O.W-8**	Ec-8
1-Jan	1.12	0.82	5.72	1.15	0.75	4.98	1.11	0.71	5.75	1.07	0.67	4.16	1.12	0.72	5.42	1.12	0.72	4.31	1.11	0.71	5.54	1.1	0.7	3.98
2-Jan	1	0.7	5.66	1.08	0.68	4.78	1.06	0.66	5.61	1.04	0.64	3.98	1.15	0.75	5.32	1.05	0.65	4.37	1.06	0.66	5.35	1.02	0.62	3.85
3-Jan	0.95	0.65	5.51	1	0.6	4.62	1.02	0.62	5.64	1	0.6	4.95	1.09	0.69	5.35	1	0.6	5.31	1	0.6	5.41	0.94	0.54	3.88
4-Jan	0.9	0.6	5.48	0.95	0.55	4.51	0.97	0.57	5.66	0.94	0.54	4.91	1	0.6	5.38	0.94	0.54	5.28	0.95	0.55	5.46	0.91	0.51	3.95
5-Jan	0.95	0.65	5.43	1	0.6	4.57	0.98	0.58	5.58	0.97	0.57	4.99	1.03	0.63	5.42	0.96	0.56	5.31	1	0.6	5.48	0.95	0.55	4.02
6-Jan	1	0.7	5.51	0.92	0.52	4.75	0.9	0.5	5.47	0.92	0.52	4.92	1.06	0.66	5.45	1	0.6	5.38	0.95	0.55	5.41	1.02	0.62	4.21
7-Jan	1.02	0.72	5.68	0.88	0.48	4.82	0.85	0.45	5.56	0.87	0.47	4.81	1.08	0.68	5.47	1.04	0.64	5.42	0.9	0.5	5.47	1.05	0.65	4.36
8-Jan	1.05	0.75	5.71	0.93	0.53	4.88	0.9	0.5	5.59	0.95	0.55	4.89	1.1	0.7	5.45	1.05	0.65	5.47	0.95	0.55	5.56	1.07	0.67	4.41
9-Jan	1.07	0.77	5.74	1	0.6	4.62	0.97	0.57	5.63	1	0.6	4.95	1.12	0.72	5.56	1.02	0.62	5.51	1	0.6	5.55	1.09	0.69	4.47
10-Jan	1.16	0.86	5.56	1.08	0.68	4.45	1.07	0.67	5.57	1.05	0.65	5.22	1.15	0.75	5.61	1.07	0.67	5.56	1.08	0.68	5.31	1.15	0.75	4.16
11-Jan	1.2	0.9	5.37	1.15	0.75	4.36	1.16	0.76	5.52	1.1	0.7	5.31	1.19	0.79	5.79	1.1	0.7	5.62	1.15	0.75	4.98	1.2	0.8	3.61
12-Jan	1.17	0.87	5.41	1.16	0.76	4.48	1.18	0.78	5.57	1.12	0.72	5.36	1.15	0.75	5.61	1.12	0.72	5.53	1.17	0.77	5.07	1.18	0.78	3.79
13-Jan	1.19	0.89	5.62	1.15	0.75	4.59	1.2	0.8	5.61	1.15	0.75	5.47	1.13	0.73	5.58	1.15	0.75	5.61	1.17	0.77	5.11	1.2	0.8	4.08
14-Jan	1.13	0.83	5.48	1.1	0.7	4.65	1.15	0.75	5.54	1.12	0.72	5.35	1.11	0.71	5.62	1.12	0.72	5.56	1.13	0.73	4.98	1.15	0.75	4.12
15-Jan	1.1	0.8	5.46	1.12	0.72	4.67	1.14	0.74	5.51	1.15	0.75	5.32	1.13	0.73	5.66	1.15	0.75	5.54	1.12	0.72	5.02	1.13	0.73	4.18
16-Jan	1.07	0.77	5.22	1.09	0.69	4.71	1.08	0.68	5.42	1.09	0.69	5.21	1.1	0.7	5.54	1.1	0.7	5.46	1.09	0.69	4.95	1.08	0.68	4.1
17-Jan	1.05	0.75	5.17	1.07	0.67	4.77	1.03	0.63	5.23	1.05	0.65	4.98	1.07	0.67	5.18	1.08	0.68	5.32	1.07	0.67	4.91	1.03	0.63	4.08
18-Jan	1.03	0.73	5.26	1.05	0.65	6.12	1	0.6	5.47	1.02	0.62	5.12	1.04	0.64	5.32	1.05	0.65	5.51	1.04	0.64	6.08	1.08	0.68	4.29
19-Jan	1.02	0.72	5.38	1	0.6	6.18	0.96	0.56	5.76	1	0.6	5.52	1	0.6	5.59	1.02	0.62	5.66	1	0.6	6.12	1.07	0.67	4.39
20-Jan	1	0.7	5.31	1	0.6	5.93	0.93	0.53	5.64	0.95	0.55	5.22	0.97	0.57	5.68	1	0.6	5.61	1	0.6	5.97	1.03	0.63	4.42
21-Jan	0.97	0.67	5.26	0.95	0.55	5.67	0.91	0.51	5.46	0.9	0.5	4.98	0.93	0.53	5.76	0.95	0.55	5.57	0.97	0.57	5.76	1	0.6	4.48
22-Jan	0.98	0.68	5.28	1	0.6	5.62	0.96	0.56	5.48	0.94	0.54	4.97	0.97	0.57	5.78	1	0.6	5.61	1	0.6	5.74	0.98	0.58	4.55
23-Jan	0.95	0.65	5.31	0.97	0.57	5.24	0.9	0.5	5.51	0.91	0.51	4.99	0.99	0.59	5.81	0.95	0.55	5.58	0.9	0.5	5.52	0.96	0.56	4.41
24-Jan	0.91	0.61	5.36	0.92	0.52	5.11	0.91	0.51	5.48	0.88	0.48	5.04	1	0.6	5.84	0.91	0.51	5.52	0.86	0.46	5.38	0.92	0.52	4.35
25-Jan	0.95	0.65	5.38	0.94	0.54	5.16	0.95	0.55	5.51	0.91	0.51	5.12	1	0.6	5.82	0.95	0.55	5.64	0.9	0.5	5.41	0.97	0.57	4.42
26-Jan	1	0.7	5.41	1	0.6	5.36	0.9	0.5	5.56	0.95	0.55	5.21	0.97	0.57	5.86	1	0.6	5.7	0.95	0.55	5.71	0.71	0.31	4.49
27-Jan	1.05	0.75	5.49	1.03	0.63	5.41	0.86	0.46	5.62	1	0.6	5.32	1.04	0.64	5.88	0.95	0.55	5.76	1	0.6	5.56	0.65	0.25	4.58
28-Jan	1.07	0.77	5.61	1.05	0.65	5.65	0.92	0.52	5.68	1.02	0.62	5.46	1.07	0.67	5.82	1	0.6	5.86	1.06	0.66	5.66	0.75	0.35	4.68
29-Jan	1.12	0.82	5.42	1.15	0.75	5.41	1.03	0.63	5.62	1.07	0.67	5.54	1.16	0.76	5.86	1.08	0.68	5.76	1.1	0.7	5.51	1	0.6	5.06
30-Jan	1.18	0.88	5.34	1.17	0.77	5.19	1.12	0.72	5.58	1.09	0.69	5.66	1.2	0.8	5.91	1.17	0.77	5.57	1.12	0.72	5.42	1.1	0.7	5.12
31-Jan	1.22	0.92	5.19	1.2	0.8	5.21	1.15	0.75	5.54	1.19	0.79	5.52	1.22	0.82	5.88	1.2	0.8	5.52	1.17	0.77	5.46	1.15	0.75	4.99
1-Feb	1.22	0.92	5.19	1.2	0.8	5.21	1.15	0.75	5.54	1.19	0.79	5.52	1.22	0.82	5.88	1.2	0.8	5.52	1.17	0.77	5.46	1.15	0.75	4.99
2-Feb	1.22	0.92	5.19	1.2	0.8	5.21	1.15	0.75	5.54	1.19	0.79	5.52	1.22	0.82	5.88	1.2	0.8	5.52	1.17	0.77	5.46	1.15	0.75	4.99

10.3 Appendix-C . Drainage water depth and Salinity

Table C-1. Surface depth and salinity of the drainage water inside the Manhole, Feb-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
2-Feb	0.95	0.45	6.13	0.6	0.4	5.95	0.43	6.04
3-Feb	0.6	0.1	4.48	0.6	0.4	4.48	0.25	4.48
4-Feb	1.03	0.53	6.8	0.73	0.53	5.96	0.53	6.38
5-Feb	1.11	0.61	7.1	0.82	0.62	4.93	0.62	6.015
6-Feb	1.14	0.64	9.6	0.93	0.73	5.39	0.69	7.495
7-Feb	1.2	0.7	7.4	0.95	0.75	5.4	0.73	6.4
8-Feb	1.17	0.67	7.3	0.99	0.79	5.39	0.73	6.345
9-Feb	1.24	0.74	8.56	0.95	0.75	6.51	0.75	7.535
10-Feb	1.28	0.78	5.98	1.03	0.83	6.13	0.81	6.055
11-Feb	1.32	0.82	6.35	1.15	0.95	9.14	0.89	7.745
12-Feb	1.36	0.86	6.41	1.16	0.96	6.49	0.91	6.45
13-Feb	1.4	0.9	6.65	1.16	0.96	9.8	0.93	8.225
14-Feb	1.35	0.85	7.13	1	0.8	7.75	0.83	7.44
15-Feb	1.03	0.53	7.19	0.73	0.53	6.71	0.53	6.95
16-Feb	1	0.5	7.92	0.7	0.5	5.5	0.50	6.71
17-Feb	1	0.5	3.23	0.75	0.55	5.5	0.53	4.365
18-Feb	0.85	0.35	3.5	0.65	0.45	4.8	0.40	4.15
19-Feb	0.85	0.35	9.2	0.65	0.45	5.2	0.40	7.2
20-Feb	0.95	0.45	7.95	0.73	0.53	5.62	0.49	6.785
21-Feb	1.1	0.6	6.81	0.85	0.65	5.3	0.63	6.055
22-Feb	1.1	0.6	6.31	0.9	0.7	5.27	0.65	5.79
23-Feb	1.15	0.65	6.63	0.9	0.7	6.3	0.68	6.465
24-Feb	1.25	0.75	6.2	1	0.8	5.91	0.78	6.055
25-Feb	1.3	0.8	6.41	1.05	0.85	6.97	0.83	6.69
26-Feb	1.35	0.85	6.79	1.05	0.85	7.65	0.85	7.22
27-Feb	1.4	0.9	6.91	1.06	0.86	6.61	0.88	6.76
28-Feb	1.35	0.85	5.93	1	0.8	8.1	0.83	7.015

Table C-2. Depth and Salinity of the drainage water inside the Manhole, March-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Mar	1.39	0.89	6.34	1	0.8	8.8	0.85	7.57
2-Mar	1.4	0.9	5.2	1	0.8	4.91	0.85	5.055
3-Mar	1.3	0.8	6.81	1	0.8	6.25	0.80	6.53
4-Mar	1.05	0.55	2.64	0.69	0.49	4.75	0.52	3.695
5-Mar	1	0.5	2.95	0.66	0.46	4.75	0.48	3.85
6-Mar	0.9	0.4	1.95	0.7	0.5	5.16	0.45	3.555
7-Mar	0.8	0.3	2.26	0.5	0.3	4.3	0.30	3.28
8-Mar	0.85	0.35	2.41	0.55	0.35	3.68	0.35	3.045
9-Mar	0.75	0.25	2.48	0.54	0.34	4.4	0.30	3.44
10-Mar	0.7	0.2	4.99	0.5	0.3	3.85	0.25	4.42
11-Mar	0.8	0.3	5.82	0.6	0.4	3.82	0.35	4.82
12-Mar	0.9	0.4	8.8	0.7	0.5	4.25	0.45	6.525
13-Mar	1	0.5	9.18	0.78	0.58	5.22	0.54	7.2
14-Mar	1.1	0.6	9.22	0.85	0.65	5.28	0.63	7.25
15-Mar	1.2	0.7	9.49	0.9	0.7	5.28	0.70	7.385
16-Mar	1.3	0.8	9.42	0.99	0.79	10.41	0.80	9.915
17-Mar	1.33	0.83	9.8	1.07	0.87	9.61	0.85	9.705
18-Mar	1.35	0.85	9.81	1.05	0.85	10.72	0.85	10.265
19-Mar	1.4	0.9	9.77	1.04	0.84	10.81	0.87	10.29
20-Mar	1.4	0.9	10.56	1.1	0.9	10.85	0.90	10.705
21-Mar	1.4	0.9	9.24	1.05	0.85	8.4	0.88	8.82
22-Mar	1.3	0.8	9.49	1	0.8	7.42	0.80	8.455
23-Mar	1	0.5	2.8	0.67	0.47	6.31	0.49	4.555
24-Mar	0.85	0.35	1.65	0.55	0.35	4.52	0.35	3.085
25-Mar	0.9	0.4	4.88	0.7	0.5	3.37	0.45	4.125
26-Mar	1.05	0.55	7.1	0.8	0.6	4.3	0.58	5.7
27-Mar	1.2	0.7	10.121	0.95	0.75	7.32	0.73	8.7205
28-Mar	1.3	0.8	10.2	0.95	0.75	7.96	0.78	9.08
29-Mar	1.34	0.84	8.61	1	0.8	6.77	0.82	7.69
30-Mar	1.4	0.9	8.58	1.1	0.9	6.82	0.90	7.7
31-Mar								

Table C-3. Depth and Salinity of the drainage water inside the Manhole, April-2025.

Date	**Experimental field**							
	M.H-1			M.H-2			**Average**	
	depth	Net-depth	salinity	depth	Net-depth	salinity	**depth**	**salinity**
1-Apr	1.5	1	9.2	1.18	0.98	6.81	**0.99**	**8.005**
2-Apr	1.52	1.02	9.5	1.22	1.02	7.18	**1.02**	**8.34**
3-Apr	1.6	1.1	8.36	1.4	1.2	6.97	**1.15**	**7.665**
4-Apr	1.51	1.01	8.15	1.2	1	6.38	**1.01**	**7.265**
5-Apr	1.5	1	8.98	1.2	1	6.52	**1.00**	**7.75**
6-Apr	1.6	1.1	9.32	1.22	1.02	6.61	**1.06**	**7.965**
7-Apr	1.6	1.1	10.46	1.28	1.08	9.32	**1.09**	**9.89**
8-Apr	1.6	1.1	10.99	1.25	1.05	11.55	**1.08**	**11.27**
9-Apr	1.3	0.8	5.99	1	0.8	5.32	**0.80**	**5.655**
10-Apr	1.19	0.69	6.32	0.85	0.65	5.61	**0.67**	**5.965**
11-Apr	1.1	0.6	6.99	0.8	0.6	5.88	**0.60**	**6.435**
12-Apr	1.08	0.58	7.25	0.86	0.66	5.85	**0.62**	**6.55**
13-Apr	1.09	0.59	6.41	0.9	0.7	5.56	**0.65**	**5.985**
14-Apr	1.3	0.8	7.75	1.08	0.88	6.25	**0.84**	**7**
15-Apr	1.4	0.9	7.53	1.2	1	6.29	**0.95**	**6.91**
16-Apr	1.41	0.91	7.52	1.15	0.95	6.62	**0.93**	**7.07**
17-Apr	1.45	0.95	8.67	1.2	1	6.38	**0.98**	**7.525**
18-Apr	1.5	1	8.1	1.2	1	7.5	**1.00**	**7.8**
19-Apr	1.5	1	9.72	1.21	1.01	7.92	**1.01**	**8.82**
20-Apr	1.58	1.08	9.85	1.29	1.09	8.65	**1.09**	**9.25**
21-Apr	1.6	1.1	9.98	1.41	1.21	8.62	**1.16**	**9.3**
22-Apr	1.62	1.12	9.99	1.45	1.25	8.76	**1.19**	**9.375**
23-Apr	1.64	1.14	8.98	1.3	1.1	8.42	**1.12**	**8.7**
24-Apr	1.65	1.15	7.65	1.36	1.16	7.98	**1.16**	**7.815**
25-Apr	1.63	1.13	7.12	1.32	1.12	7.62	**1.13**	**7.37**
26-Apr	1.52	1.02	6.22	1.1	0.9	5.56	**0.96**	**5.89**
27-Apr	1.4	0.9	6.45	1	0.8	6.78	**0.85**	**6.615**
28-Apr	1.28	0.78	5.36	1	0.8	5.48	**0.79**	**5.42**
29-Apr	1.19	0.69	5.72	0.6	0.4	5.5	**0.55**	**5.61**
30-Apr	1.16	0.66	7.1	0.85	0.65	5.22	**0.66**	**6.16**

Table C-4. Depth and Salinity of the drainage water inside the Manhole, May-2025.

Date	**Experimental field**							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-May	1.2	0.7	5.98	1	0.8	5.28	0.75	5.63
2-May	1.11	0.61	6.18	0.8	0.6	4.51	0.61	5.345
3-May	1.1	0.6	6.42	0.75	0.55	4.68	0.58	5.55
4-May	1.16	0.66	6.71	0.8	0.6	5.63	0.63	6.17
5-May	1.2	0.7	6.8	1	0.8	5.67	0.75	6.235
6-May	1.3	0.8	5.71	1.21	1.01	5.54	0.91	5.625
7-May	1.33	0.83	5.58	1.24	1.04	5.56	0.94	5.57
8-May	1.3	0.8	3.62	1	0.8	4.92	0.80	4.27
9-May	1.32	0.82	3.98	0.95	0.75	4.78	0.79	4.38
10-May	1.3	0.8	5.62	1	0.8	4.96	0.80	5.29
11-May	1.31	0.81	6.64	1.12	0.92	4.88	0.87	5.76
12-May	1.35	0.85	6.75	1.06	0.86	5.78	0.86	6.265
13-May	1.3	0.8	6.71	1	0.8	6.5	0.80	6.605
14-May	1.4	0.9	6.83	1.05	0.85	6.12	0.88	6.475
15-May	1.33	0.83	7.79	1.06	0.86	6.17	0.85	6.98
16-May	1.35	0.85	8.81	1.07	0.87	6.22	0.86	7.515
17-May	1.4	0.9	7.14	1.09	0.89	6.18	0.90	6.66
18-May	1.38	0.88	6.36	1.08	0.88	6.13	0.88	6.245
19-May	1.2	0.7	6.15	0.82	0.62	5.85	0.66	6
20-May	1.1	0.6	5.38	0.75	0.55	5.79	0.58	5.585
21-May	1.12	0.62	5.41	0.82	0.62	5.39	0.62	5.4
22-May	1.04	0.54	6.7	0.7	0.5	5.32	0.52	6.01
23-May	1.05	0.55	5.58	0.7	0.5	5.24	0.53	5.41
24-May	1	0.5	5.65	0.66	0.46	4.99	0.48	5.32
25-May	1.02	0.52	5.67	0.7	0.5	4.95	0.51	5.31
26-May	1.2	0.7	8.33	0.97	0.77	5.7	0.74	7.015
27-May	1.22	0.72	7.65	1.05	0.85	5.9	0.79	6.775
28-May	1.25	0.75	7.64	1.08	0.88	5.12	0.82	6.38
29-May	1.2	0.7	7.96	1	0.8	5.33	0.75	6.645
30-May	1.25	0.75	7.88	1.04	0.84	5.37	0.80	6.625
31-May	1.29	0.79	7.72	1	0.8	5.78	0.80	6.75

Table C-5. Depth and Salinity of the drainage water inside the Manhole, June-2025.

Date	**Experimental field**							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Jun	1.18	0.68	6.88	1	0.8	6.15	0.74	6.52
2-Jun	1.3	0.8	6.81	1	0.8	6.78	0.80	6.80
3-Jun	1.24	0.74	6.9	1	0.8	6.45	0.77	6.68
4-Jun	1.27	0.77	6.35	0.98	0.78	6.34	0.78	6.35
5-Jun	1.25	0.75	6.53	1	0.8	6.39	0.78	6.46
6-Jun	1.1	0.6	7.65	0.85	0.65	6.41	0.63	7.03
7-Jun	1	0.5	6.7	0.65	0.45	6.46	0.48	6.58
8-Jun	0.95	0.45	5.81	0.64	0.44	5.29	0.45	5.55
9-Jun	0.86	0.36	6.25	0.66	0.46	5.26	0.41	5.76
10-Jun	0.86	0.36	6.38	0.75	0.55	5.1	0.46	5.74
11-Jun	0.94	0.44	6.48	0.75	0.55	5.13	0.50	5.81
12-Jun	1.08	0.58	7.12	0.8	0.6	5.42	0.59	6.27
13-Jun	1.13	0.63	6.65	0.9	0.7	6.4	0.67	6.53
14-Jun	1.16	0.66	6.68	0.95	0.75	6.6	0.71	6.64
15-Jun	1.15	0.65	5.99	0.9	0.7	6.7	0.68	6.35
16-Jun	1.15	0.65	6.32	0.8	0.6	5.65	0.63	5.99
17-Jun	1.19	0.69	6.38	0.85	0.65	5.71	0.67	6.05
18-Jun	1.21	0.71	6.96	0.93	0.73	5.74	0.72	6.35
19-Jun	1.1	0.6	8.59	0.62	0.42	6.45	0.51	7.52
20-Jun	1	0.5	8.6	0.65	0.45	6.47	0.48	7.54
21-Jun	0.97	0.47	8.59	0.7	0.5	5.95	0.49	7.27
22-Jun	0.74	0.24	7.54	0.6	0.4	5.99	0.32	6.77
23-Jun	0.6	0.1	5.21	0.59	0.39	5.82	0.25	5.52
24-Jun	0.81	0.31	6.32	0.7	0.5	5.66	0.41	5.99
25-Jun	0.95	0.45	7.18	0.75	0.55	5.32	0.50	6.25
26-Jun	1.12	0.62	7.14	1	0.8	5.37	0.71	6.255
27-Jun	1.15	0.65	7.18	1.12	0.92	5.39	0.79	6.285
28-Jun	1.21	0.71	7.22	1.19	0.99	5.42	0.85	6.32
29-Jun	1.33	0.83	7.71	1.11	0.91	5.41	0.87	6.56
30-Jun	1.36	0.86	7.65	1.14	0.94	5.56	0.90	6.605

Table C-6. Depth and Salinity of the drainage water inside the Manhole, July-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Jul	1.35	0.85	6.25	1.2	1	5.42	0.93	5.835
2-Jul	1.33	0.83	6.79	1.22	1.02	5.46	0.93	6.125
3-Jul	1.35	0.85	6.52	1.18	0.98	6.12	0.92	6.32
4-Jul	1.37	0.87	6.49	1.16	0.96	6.22	0.92	6.355
5-Jul	1.25	0.75	6.98	1.12	0.92	5.86	0.84	6.42
6-Jul	1.21	0.71	7.15	1.08	0.88	5.71	0.80	6.43
7-Jul	1.02	0.52	3.05	0.75	0.55	6.08	0.54	4.565
8-Jul	1	0.5	4.66	0.7	0.5	6.12	0.50	5.39
9-Jul	0.89	0.39	5.24	0.66	0.46	6.17	0.43	5.705
10-Jul	0.9	0.4	5.39	0.71	0.51	5.56	0.46	5.475
11-Jul	0.95	0.45	5.96	0.68	0.48	5.66	0.47	5.81
12-Jul	0.95	0.45	6.25	0.86	0.66	5.58	0.56	5.915
13-Jul	1	0.5	7.41	0.84	0.64	5.65	0.57	6.53
14-Jul	1.06	0.56	7.44	0.88	0.68	5.68	0.62	6.56
15-Jul	1.1	0.6	7.05	0.7	0.5	5.99	0.55	6.52
16-Jul	1.18	0.68	6.87	0.65	0.45	6.04	0.57	6.455
17-Jul	1.22	0.72	6.98	1	0.8	5.92	0.76	6.45
18-Jul	1.26	0.76	7.56	1.02	0.82	6.06	0.79	6.81
19-Jul	1.31	0.81	7.82	1.05	0.85	5.98	0.83	6.9
20-Jul	1.3	0.8	8.35	1.07	0.87	5.75	0.84	7.05
21-Jul	1.33	0.83	8.76	1.1	0.9	5.78	0.87	7.27
22-Jul	1.31	0.81	8.98	1.09	0.89	5.82	0.85	7.4
23-Jul	1.25	0.75	9.05	1.02	0.82	5.69	0.79	7.37
24-Jul	1.2	0.7	9.08	0.98	0.78	5.56	0.74	7.32
25-Jul	1.1	0.6	7.46	1	0.8	5.88	0.70	6.67
26-Jul	1.08	0.58	6.88	0.81	0.61	6.04	0.60	6.46
27-Jul	1.12	0.62	6.97	1	0.8	6.09	0.71	6.53
28-Jul	1.1	0.6	7.12	1	0.8	6.12	0.70	6.62
29-Jul	1.08	0.58	7.32	1.02	0.82	6.14	0.70	6.73
30-Jul	1.16	0.66	8.18	1.05	0.85	5.75	0.76	6.965
31-Jul	1.29	0.79	8.66	1.1	0.9	5.56	0.85	7.11

Table C-7. Depth and Salinity of the drainage water inside the Manhole, Aug-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Aug	1.39	0.89	9.54	1.22	1.02	5.77	0.96	7.655
2-Aug	1.44	0.94	7.58	1.25	1.05	6.19	1.00	6.885
3-Aug	1.52	1.02	7.88	1.3	1.1	6.45	1.06	7.165
4-Aug	1.5	1	8.35	1.36	1.16	6.88	1.08	7.615
5-Aug	1.52	1.02	8.79	1.3	1.1	6.57	1.06	7.68
6-Aug	1.54	1.04	8.82	1.27	1.07	6.54	1.06	7.68
7-Aug	1.26	0.76	7.86	1.19	0.99	6.44	0.88	7.15
8-Aug	1.23	0.73	7.12	1.12	0.92	6.32	0.83	6.72
9-Aug	1.18	0.68	7.18	1.05	0.85	6.45	0.77	6.815
10-Aug	1.15	0.65	7.22	1	0.8	6.52	0.73	6.87
11-Aug	1	0.5	7.35	0.85	0.65	6.35	0.58	6.85
12-Aug	0.94	0.44	7.62	0.7	0.5	6.22	0.47	6.92
13-Aug	1.02	0.52	7.89	0.67	0.47	6.25	0.50	7.07
14-Aug	1.08	0.58	8.06	0.71	0.51	6.29	0.55	7.175
15-Aug	1.17	0.67	8.25	0.9	0.7	6.15	0.69	7.2
16-Aug	1.23	0.73	8.32	1	0.8	5.98	0.77	7.15
17-Aug	1.23	0.73	8.32	1	0.8	5.98	0.77	7.15
18-Aug	1.28	0.78	8.42	1.06	0.86	6.05	0.82	7.235
19-Aug	1.34	0.84	8.56	1.12	0.92	6.08	0.88	7.32
20-Aug	1.37	0.87	7.97	1.11	0.91	5.76	0.89	6.865
21-Aug	1.4	0.9	7.65	1.1	0.9	5.51	0.90	6.58
22-Aug	1.44	0.94	7.35	1.15	0.95	5.4	0.95	6.375
23-Aug	1.48	0.98	7.18	1.19	0.99	5.35	0.99	6.265
24-Aug	1.38	0.88	6.87	1.16	0.96	5.22	0.92	6.045
25-Aug	1.31	0.81	6.48	1.14	0.94	5.15	0.88	5.815
26-Aug	1.14	0.64	5.98	1.08	0.88	5.44	0.76	5.71
27-Aug	1.05	0.55	5.86	1	0.8	5.88	0.68	5.87
28-Aug	1	0.5	6.08	0.95	0.75	5.76	0.63	5.92
29-Aug	1.1	0.6	6.25	0.9	0.7	5.36	0.65	5.805
30-Aug	1.15	0.65	6.44	0.92	0.72	5.71	0.69	6.075
31-Aug	1.2	0.7	6.67	0.95	0.75	5.99	0.73	6.33

Table C-8. Depth and Salinity of the drainage water inside the Manhole, Sep-2025.

Date	**Experimental field**							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Sep	1.25	0.75	6.98	1	0.8	5.76	0.78	6.37
2-Sep	1.31	0.81	7.24	1.04	0.84	5.52	0.83	6.38
3-Sep	1.34	0.84	7.98	1.08	0.88	5.78	0.86	6.88
4-Sep	1.35	0.85		1.02	0.82		0.84	
5-Sep	1.4	0.9	6.88	1	0.8	6.22	0.85	6.55
6-Sep	1.4	0.9	6.95	1	0.8	5.82	0.85	6.385
7-Sep	1.39	0.89	7.21	0.94	0.74	5.21	0.82	6.21
8-Sep	1.38	0.88	5.24	0.9	0.7	6.22	0.79	5.73
9-Sep	1.21	0.71	5.39	0.82	0.62	5.86	0.67	5.63
10-Sep	1.15	0.65	5.96	0.75	0.55	5.71	0.60	5.84
11-Sep	1	0.5	6.25	0.75	0.55	6.08	0.53	6.17
12-Sep	0.9	0.4	7.41	0.72	0.52	6.12	0.46	6.77
13-Sep	0.69	0.19	7.44	0.6	0.4	6.17	0.30	6.81
14-Sep	0.9	0.4	7.05	0.55	0.35	5.56	0.38	6.31
15-Sep	0.94	0.44	6.87	0.6	0.4	5.66	0.42	6.27
16-Sep	1	0.5	6.98	0.8	0.6	5.58	0.55	6.28
17-Sep	1.08	0.58	7.56	0.83	0.63	5.65	0.61	6.61
18-Sep	1.12	0.62	7.82	0.8	0.6	5.68	0.61	6.75
19-Sep	1.18	0.68	8.35	0.87	0.67	5.99	0.68	7.17
20-Sep	1.2	0.7	8.76	0.65	0.45	6.04	0.58	7.40
21-Sep	1.25	0.75	8.98	0.9	0.7	5.92	0.73	7.45
22-Sep	1.26	0.76	9.05	0.92	0.72	6.06	0.74	7.56
23-Sep	1.24	0.74	9.08	0.97	0.77	5.98	0.76	7.53
24-Sep	1.27	0.77	7.46	1	0.8	5.75	0.79	6.61
25-Sep	1.18	0.68	6.88	0.7	0.5	5.78	0.59	6.33
26-Sep	1.14	0.64	6.97	0.75	0.55	5.82	0.60	6.40
27-Sep	0.76	0.26	7.12	0.7	0.5	5.69	0.38	6.41
28-Sep	0.64	0.14	7.32	0.67	0.47	5.56	0.31	6.44
29-Sep	0.76	0.26		0.65	0.45	5.88	0.36	2.94
30-Sep	0.9	0.4	3.41	0.6	0.4	3.75	0.40	3.58

Table C-9. Depth and Salinity of the drainage water inside the Manhole, Oct-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Oct	0.92	0.42	3.45	0.64	0.44	3.79	0.43	
2-Oct	0.98	0.48	3.77	0.79	0.59	4.52	0.54	
3-Oct	1.02	0.52	3.82	0.81	0.61	4.66	0.57	
4-Oct	1.1	0.6	4.85	0.9	0.7	4.99	0.65	
5-Oct	1.22	0.72	5.18	1	0.8	5.12	0.76	5.15
6-Oct	1.25	0.75	5.71	1.17	0.97	5.46	0.86	5.585
7-Oct	1.27	0.77	5.99	1.21	1.01	5.62	0.89	5.805
8-Oct	1.3	0.8	6.75	1.1	0.9	6.22	0.85	6.485
9-Oct	1.36	0.86	6.99	1.04	0.84	6.87	0.85	6.93
10-Oct	1.31	0.81	6.74	1	0.8	6.42	0.81	6.58
11-Oct	1.32	0.82	6.31	0.95	0.75	6.22	0.79	6.265
12-Oct	1.19	0.69	6.48	0.9	0.7	6.12	0.70	6.3
13-Oct	1.11	0.61	6.71	0.92	0.72	5.75	0.67	6.23
14-Oct	1	0.5	6.45	0.88	0.68	5.72	0.59	6.085
15-Oct	0.92	0.42	6.25	0.81	0.61	5.66	0.52	5.955
16-Oct	0.87	0.37	6.18	0.74	0.54	6.12	0.46	6.15
17-Oct	0.83	0.33	5.88	0.7	0.5	6.21	0.42	6.045
18-Oct	0.91	0.41	5.91	0.76	0.56	6.42	0.49	6.165
19-Oct	1	0.5	5.99	0.89	0.69	6.71	0.60	6.35
20-Oct	1.07	0.57	6.11	1.1	0.9	6.36	0.74	6.235
21-Oct	1.15	0.65	6.17	1.14	0.94	6.29	0.80	6.23
22-Oct	1.18	0.68	6.45	1.08	0.88	6.58	0.78	6.515
23-Oct	1.24	0.74	6.77	1	0.8	6.76	0.77	6.765
24-Oct	1.27	0.77	6.82	1.02	0.82	6.78	0.80	6.8
25-Oct	1.3	0.8	6.91	1	0.8	6.74	0.80	6.825
26-Oct	1.28	0.78	6.82	0.81	0.61	6.65	0.70	6.735
27-Oct	1.26	0.76	6.78	0.76	0.56	6.41	0.66	6.595
28-Oct	1.14	0.64	6.57	0.81	0.61	6.21	0.63	6.39
29-Oct	1.08	0.58	6.46	0.98	0.78	6.13	0.68	6.295
30-Oct	1.1	0.6	6.51	0.79	0.59	6.14	0.60	6.325
31-Oct	1.04	0.54	6.65	0.71	0.51	6.09	0.53	6.37

Table C-10. Depth and Dalinity of the drainage water inside the Manhole, Nov-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Nov	1.06	0.56	6.72	0.9	0.7	6.14	0.63	6.43
2-Nov	1.08	0.58	6.68	1	0.8	6.21	0.69	6.445
3-Nov	1.15	0.65	6.12	1.16	0.96	6.14	0.81	6.13
4-Nov	1.21	0.71	6.75	1.22	1.02	6.73	0.87	6.74
5-Nov	1.27	0.77	6.98	1.26	1.06	6.86	0.92	6.92
6-Nov	1.27	0.77	6.98	1.26	1.06	6.86	0.92	6.92
7-Nov	1.3	0.8	7.25	1.12	0.92	6.94	0.86	7.095
8-Nov	1.33	0.83	7.32	1.05	0.85	5.88	0.84	6.6
9-Nov	1.28	0.78	7.35	1.08	0.88	5.96	0.83	6.655
10-Nov	1.26	0.76	7.41	1.1	0.9	6.11	0.83	6.76
11-Nov	1.3	0.8	7.52	1.04	0.84	6.28	0.82	6.9
12-Nov	1.33	0.83	7.48	1	0.8	6.36	0.82	6.92
13-Nov	1.22	0.72	6.25	0.95	0.75	6.21	0.74	6.23
14-Nov	1.12	0.62	6.09	0.88	0.68	6.17	0.65	6.13
15-Nov	1.06	0.56	6.04	0.85	0.65	6.11	0.61	6.075
16-Nov	1.04	0.54	5.92	0.8	0.6	6.08	0.57	6
17-Nov	1.03	0.53	6.12	0.69	0.49	6.02	0.51	6.07
18-Nov	1	0.5	6.18	0.67	0.47	5.89	0.49	6.035
19-Nov	1.04	0.54	6.21	0.75	0.55	5.84	0.55	6.025
20-Nov	1.1	0.6	6.18	0.8	0.6	5.82	0.60	6
21-Nov	1.06	0.56	6.24	0.85	0.65	5.87	0.61	6.055
22-Nov	1.02	0.52	6.31	0.9	0.7	5.93	0.61	6.12
23-Nov	1.14	0.64	6.47	1	0.8	6.05	0.72	6.26
24-Nov	1.21	0.71	6.58	1.09	0.89	6.14	0.80	6.36
25-Nov	1.24	0.74	6.75	1	0.8	6.04	0.77	6.395
26-Nov	1.26	0.76	6.87	0.9	0.7	5.89	0.73	6.38
27-Nov	1.18	0.68	6.71	0.84	0.64	5.84	0.66	6.275
28-Nov	1.15	0.65	6.54	0.8	0.6	5.81	0.63	6.175
29-Nov	1	0.5	6.28	0.75	0.55	5.46	0.53	5.87
30-Nov	0.91	0.41	6.11	0.7	0.5	5.38	0.46	5.745

Table C-11. Depth and Salinity of the drainage water inside the Manhole, Dec-2025.

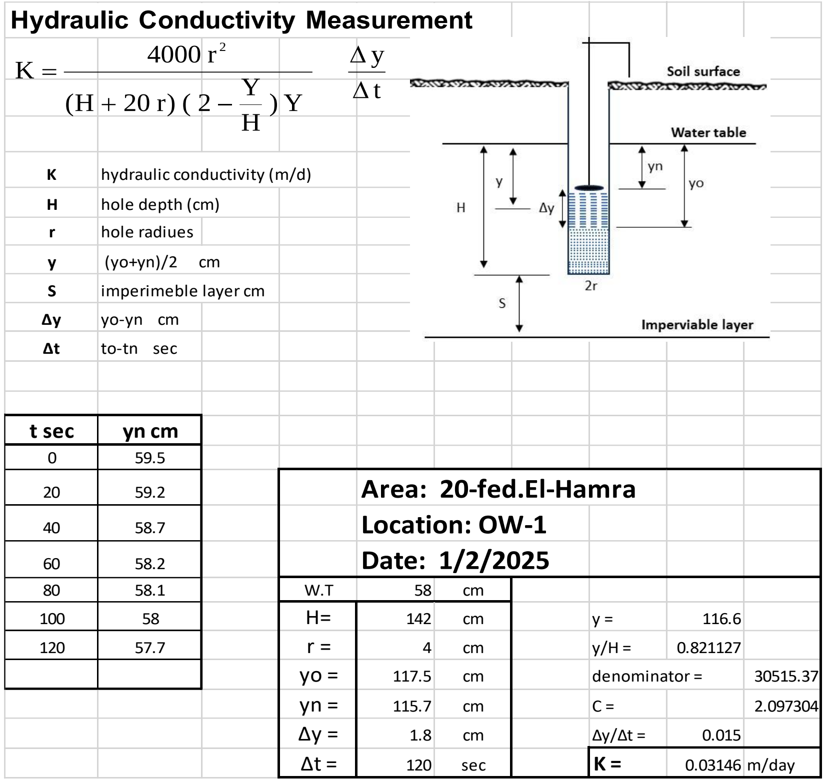
Date	**Experimental field**							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Dec	0.9	0.4	5.07	0.75	0.55	5.41	0.48	5.24
2-Dec	0.93	0.43	5.1	0.81	0.61	5.46	0.52	5.28
3-Dec	0.95	0.45	5.14	0.8	0.6	5.23	0.53	5.185
4-Dec	1	0.5	5.32	0.91	0.71	5.37	0.61	5.345
5-Dec	1.1	0.6	5.14	1	0.8	5.42	0.70	5.28
6-Dec	1.15	0.65	5.18	0.96	0.76	5.46	0.71	5.32
7-Dec	1.18	0.68	5.24	0.9	0.7	6.51	0.69	5.875
8-Dec	1.2	0.7	5.27	0.95	0.75	6.42	0.73	5.845
9-Dec	1.18	0.68	5.24	1	0.8	6.45	0.74	5.845
10-Dec	1.2	0.7	4.67	0.7	0.5	5.56	0.60	5.115
11-Dec	1.19	0.69	4.69	0.73	0.53	5.54	0.61	5.115
12-Dec	1.17	0.67	4.71	0.75	0.55	5.51	0.61	5.11
13-Dec	1.2	0.7	4.86	0.71	0.51	5.58	0.61	5.22
14-Dec	1.18	0.68	4.98	0.65	0.45	5.69	0.57	5.335
15-Dec	1.1	0.6	5.07	0.68	0.48	5.52	0.54	5.295
16-Dec	1.07	0.57	5.14	0.72	0.52	5.31	0.55	5.225
17-Dec	1.03	0.53	5.21	0.7	0.5	5.37	0.52	5.29
18-Dec	1	0.5	5.28	0.68	0.48	5.41	0.49	5.345
19-Dec	1.05	0.55	5.56	0.7	0.5	5.49	0.53	5.525
20-Dec	1.08	0.58	5.68	0.72	0.52	5.67	0.55	5.675
21-Dec	1.12	0.62	5.72	0.75	0.55	5.76	0.59	5.74
22-Dec	1.17	0.67	5.94	0.86	0.66	5.91	0.67	5.925
23-Dec	1.16	0.66	6.12	0.9	0.7	5.58	0.68	5.85
24-Dec	1.19	0.69	6.18	1.05	0.85	5.41	0.77	5.795
25-Dec	1.21	0.71	6.15	1.1	0.9	5.47	0.81	5.81
26-Dec	1.18	0.68	6.1	1.12	0.92	5.53	0.80	5.815
27-Dec	1.2	0.7	6.05	1.16	0.96	5.61	0.83	5.83
28-Dec	1.23	0.73	6.12	1.18	0.98	5.67	0.86	5.895
29-Dec	1.21	0.71	6.08	1.15	0.95	5.71	0.83	5.895
30-Dec	1.22	0.72	6.04	1.12	0.92	5.76	0.82	5.9
31-Dec	1.24	0.74	5.98	1.1	0.9	5.79	0.82	5.885

Table C-12. Depth and Salinity of the drainage water inside the Manhole, Jan-2025.

Date	Experimental field							
	M.H-1			M.H-2			Average	
	depth	Net-depth	salinity	depth	Net-depth	salinity	depth	salinity
1-Jan	1.14	0.64	5.82	1	0.8	5.68	0.72	5.75
2-Jan	1.08	0.58	5.71	0.95	0.75	5.61	0.67	5.66
3-Jan	1.03	0.53	5.62	0.9	0.7	5.65	0.62	5.635
4-Jan	0.96	0.46	5.56	0.86	0.66	5.67	0.56	5.615
5-Jan	1	0.5	5.62	0.9	0.7	5.71	0.60	5.665
6-Jan	0.95	0.45	5.65	0.85	0.65	5.74	0.55	5.695
7-Jan	0.9	0.4	5.72	0.8	0.6	5.79	0.50	5.755
8-Jan	0.95	0.45	5.77	0.87	0.67	5.84	0.56	5.805
9-Jan	1	0.5	5.73	0.91	0.71	5.87	0.61	5.8
10-Jan	1.12	0.62	5.96	0.96	0.76	5.93	0.69	5.945
11-Jan	1.15	0.65	5.91	1	0.8	6.02	0.73	5.965
12-Jan	1.18	0.68	6.02	1.02	0.82	5.97	0.75	5.995
13-Jan	1.17	0.67	6.08	1	0.8	5.93	0.74	6.005
14-Jan	1.15	0.65	6.12	0.98	0.78	5.88	0.72	6
15-Jan	1.12	0.62	6.08	1	0.8	5.91	0.71	5.995
16-Jan	1.06	0.56	5.97	0.95	0.75	5.82	0.66	5.895
17-Jan	1	0.5	5.81	0.9	0.7	5.77	0.60	5.79
18-Jan	1.02	0.52	5.94	0.85	0.65	5.96	0.59	5.95
19-Jan	1	0.5	6.13	0.8	0.6	6.15	0.55	6.14
20-Jan	0.97	0.47	5.97	0.78	0.58	5.98	0.53	5.975
21-Jan	0.92	0.42	5.81	0.75	0.55	5.92	0.49	5.865
22-Jan	0.97	0.47	5.84	0.77	0.57	5.98	0.52	5.91
23-Jan	0.95	0.45	5.81	0.75	0.55	5.92	0.50	5.865
24-Jan	0.92	0.42	5.77	0.8	0.6	5.87	0.51	5.82
25-Jan	1	0.5	5.81	0.85	0.65	5.92	0.58	5.865
26-Jan	1.02	0.52	5.98	0.9	0.7	6.09	0.61	6.035
27-Jan	1.05	0.55	6.08	1	0.8	6.14	0.68	6.11
28-Jan	1.09	0.59	6.11	1.03	0.83	6.18	0.71	6.145
29-Jan	1.15	0.65	6.18	1.08	0.88	6.15	0.77	6.165
30-Jan	1.2	0.7	6.24	1.15	0.95	6.21	0.83	6.225
31-Jan	1.22	0.72	6.12	1.17	0.97	6.14	0.85	6.13

10.4 Appendix-D . Calculation of the hydraulic conductivity

Table D-1. The calculation of the hydraulic conductivity for the locations, OW.1 and OW.2 of the experimental field



Hydraulic Conductivity Measurement

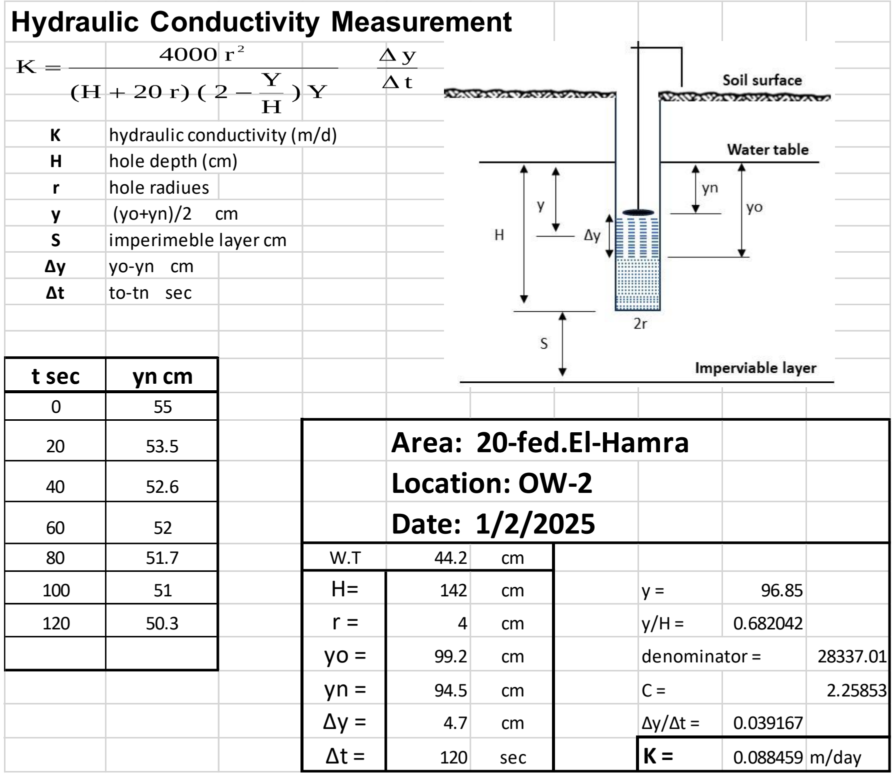
$$K = \frac{4000\,r^2}{(H + 20\,r)\,(\,2 - \frac{Y}{H}\,)\,Y}\;\frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

t sec	yn cm
0	59.5
20	59.2
40	58.7
60	58.2
80	58.1
100	58
120	57.7

Area: 20-fed.El-Hamra
Location: OW-1
Date: 1/2/2025

W.T	58	cm			
H=	142	cm	y =	116.6	
r =	4	cm	y/H =	0.821127	
yo =	117.5	cm	denominator =		30515.37
yn =	115.7	cm	C =		2.097304
Δy =	1.8	cm	Δy/Δt =	0.015	
Δt =	120	sec	**K =**	0.03146	m/day



Hydraulic Conductivity Measurement

$$K = \frac{4000\,r^2}{(H + 20\,r)\,(\,2 - \frac{Y}{H}\,)\,Y}\;\frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

t sec	yn cm
0	55
20	53.5
40	52.6
60	52
80	51.7
100	51
120	50.3

Area: 20-fed.El-Hamra
Location: OW-2
Date: 1/2/2025

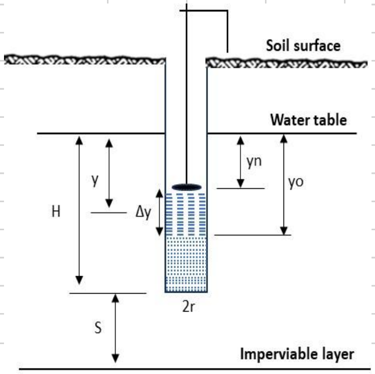
W.T	44.2	cm			
H=	142	cm	y =	96.85	
r =	4	cm	y/H =	0.682042	
yo =	99.2	cm	denominator =		28337.01
yn =	94.5	cm	C =		2.25853
Δy =	4.7	cm	Δy/Δt =	0.039167	
Δt =	120	sec	**K =**	0.088459	m/day

Table D-2. The calculation of the hydraulic conductivity for the locations, OW.3 and OW.4 of the experimental field

Hydraulic Conductivity Measurement

$$K = \frac{4000\, r^2}{(H + 20\, r)\,(2 - \frac{Y}{H})\,Y} \qquad \frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec



t sec	yn cm
0	38.5
20	38
40	37.5
60	37
80	36.5
100	36
120	36

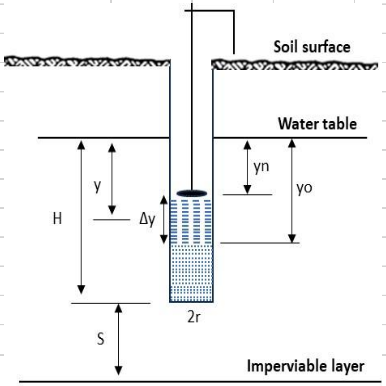
Area: 20-fed.El-Hamra
Location: OW-3
Date: 1/2/2025

W.T	39.5	cm			
H=	142	cm	y =	76.75	
r =	4	cm	y/H =	0.540493	
yo =	78	cm	denominator =	24867.81	
yn =	75.5	cm	C =	2.573608	
Δy =	2.5	cm	Δy/Δt =	0.020833	
Δt =	120	sec	**K =**	0.053617	m/day

Hydraulic Conductivity Measurement

$$K = \frac{4000\, r^2}{(H + 20\, r)\,(2 - \frac{Y}{H})\,Y} \qquad \frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

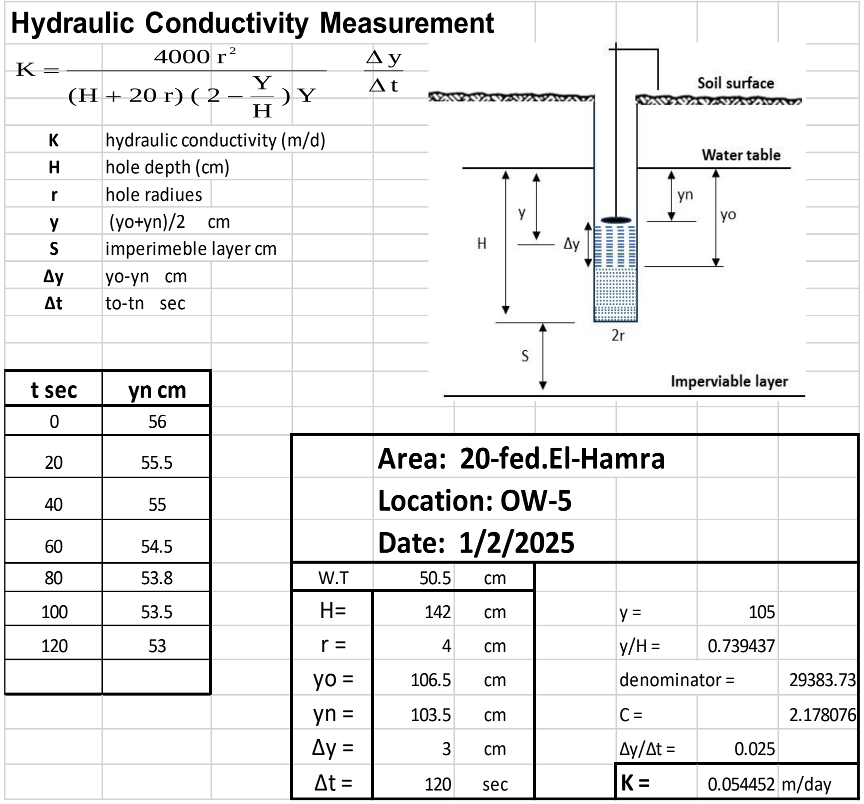


t sec	yn cm
0	46.5
20	46
40	45.8
60	45.5
80	45.3
100	44
120	43.8

Area: 20-fed.El-Hamra
Location: OW-4
Date: 1/2/2025

W.T	48.5	cm			
H=	142	cm	y =	93.65	
r =	4	cm	y/H =	0.659507	
yo =	95	cm	denominator =	27869.25	
yn =	92.3	cm	C =	2.296438	
Δy =	2.7	cm	Δy/Δt =	0.0225	
Δt =	120	sec	**K =**	0.05167	m/day

Table D-3. The calculation of the hydraulic conductivity for the locations, OW.5 and OW.6 of the experimental field



Hydraulic Conductivity Measurement

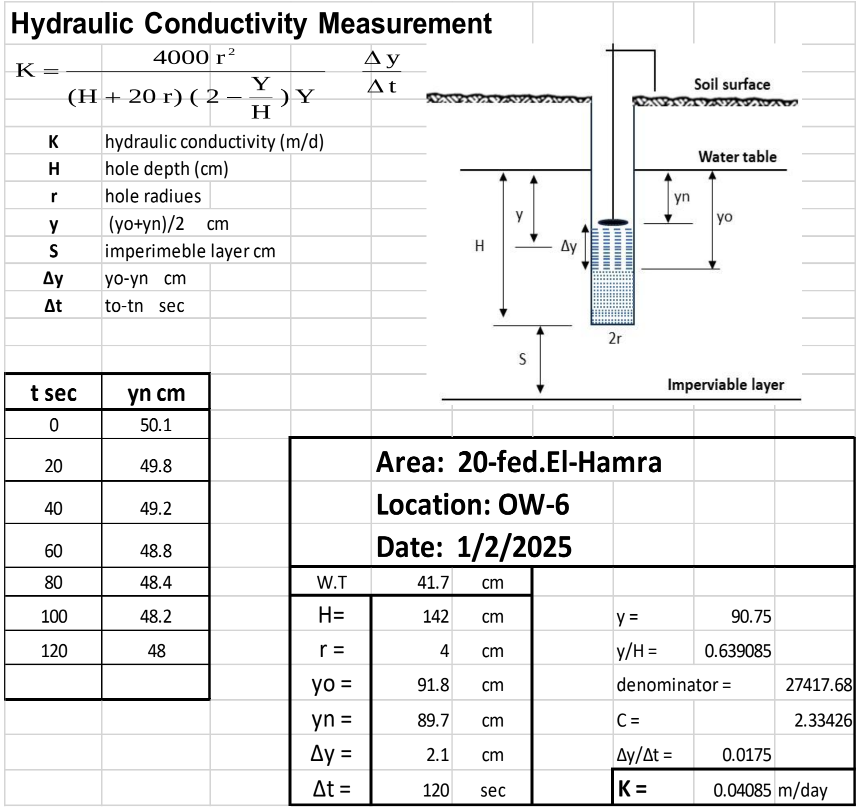
$$K = \frac{4000\, r^2}{(H + 20\, r)\,(\, 2 - \frac{Y}{H}\,)\, Y} \quad \frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

t sec	yn cm
0	56
20	55.5
40	55
60	54.5
80	53.8
100	53.5
120	53

Area: 20-fed.El-Hamra
Location: OW-5
Date: 1/2/2025

W.T	50.5	cm		
H=	142	cm	y =	105
r =	4	cm	y/H =	0.739437
yo =	106.5	cm	denominator =	29383.73
yn =	103.5	cm	C =	2.178076
Δy =	3	cm	Δy/Δt =	0.025
Δt =	120	sec	**K =**	0.054452 m/day



Hydraulic Conductivity Measurement

$$K = \frac{4000\, r^2}{(H + 20\, r)\,(\, 2 - \frac{Y}{H}\,)\, Y} \quad \frac{\Delta y}{\Delta t}$$

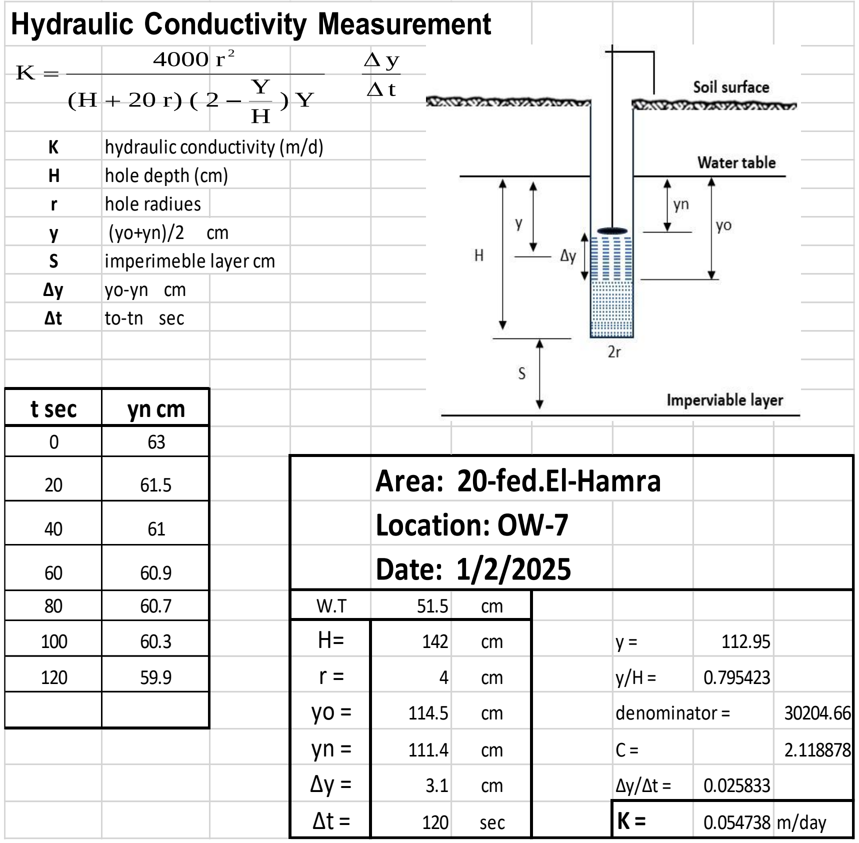
K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

t sec	yn cm
0	50.1
20	49.8
40	49.2
60	48.8
80	48.4
100	48.2
120	48

Area: 20-fed.El-Hamra
Location: OW-6
Date: 1/2/2025

W.T	41.7	cm		
H=	142	cm	y =	90.75
r =	4	cm	y/H =	0.639085
yo =	91.8	cm	denominator =	27417.68
yn =	89.7	cm	C =	2.33426
Δy =	2.1	cm	Δy/Δt =	0.0175
Δt =	120	sec	**K =**	0.04085 m/day

Table D-4. The calculation of the hydraulic conductivity for the locations, OW.7 and OW.8 of the experimental field



Hydraulic Conductivity Measurement

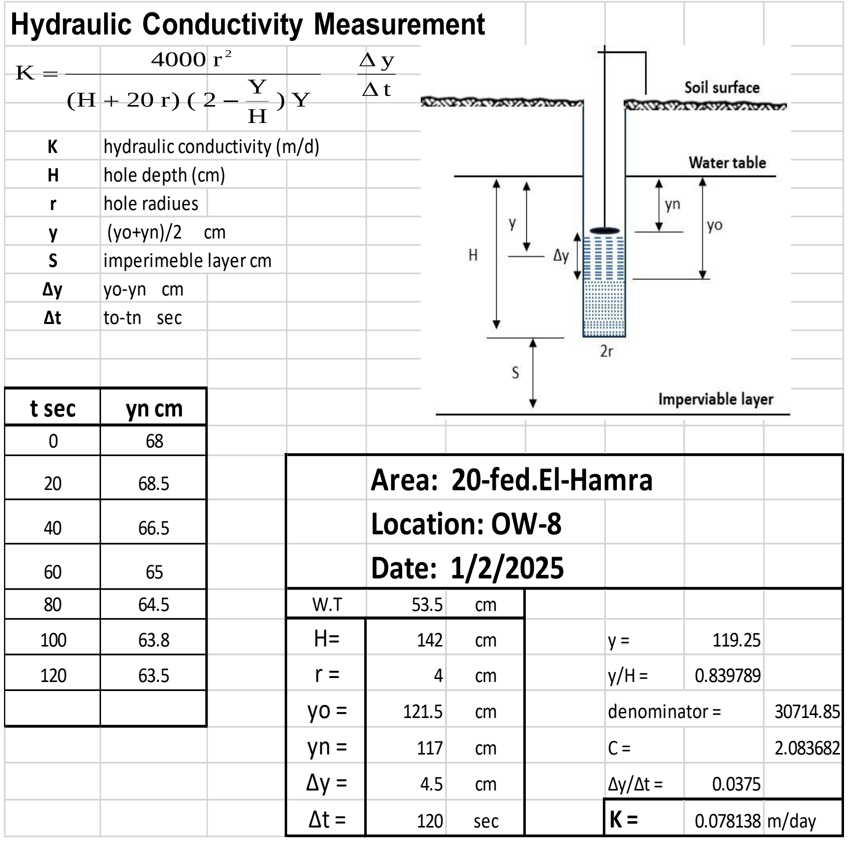
$$K = \frac{4000\, r^2}{(H + 20\, r)\,(2 - \frac{Y}{H})\, Y} \quad \frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

t sec	yn cm
0	63
20	61.5
40	61
60	60.9
80	60.7
100	60.3
120	59.9

Area: 20-fed.El-Hamra
Location: OW-7
Date: 1/2/2025

W.T	51.5	cm			
H=	142	cm	y =	112.95	
r =	4	cm	y/H =	0.795423	
yo =	114.5	cm	denominator =		30204.66
yn =	111.4	cm	C =		2.118878
Δy =	3.1	cm	Δy/Δt =	0.025833	
Δt =	120	sec	**K =**	0.054738	m/day



Hydraulic Conductivity Measurement

$$K = \frac{4000\, r^2}{(H + 20\, r)\,(2 - \frac{Y}{H})\, Y} \quad \frac{\Delta y}{\Delta t}$$

K	hydraulic conductivity (m/d)
H	hole depth (cm)
r	hole radiues
y	(yo+yn)/2 cm
S	imperimeble layer cm
Δy	yo-yn cm
Δt	to-tn sec

t sec	yn cm
0	68
20	68.5
40	66.5
60	65
80	64.5
100	63.8
120	63.5

Area: 20-fed.El-Hamra
Location: OW-8
Date: 1/2/2025

W.T	53.5	cm			
H=	142	cm	y =	119.25	
r =	4	cm	y/H =	0.839789	
yo =	121.5	cm	denominator =		30714.85
yn =	117	cm	C =		2.083682
Δy =	4.5	cm	Δy/Δt =	0.0375	
Δt =	120	sec	**K =**	0.078138	m/day

10.5 Appendix-E Surface water depth in the canals and its salinity

Table E-1. Water depth and salinity in irrigation canals, Feb/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
2-Feb	1.2	0.41	1.2	0.6	1.20	0.51
3-Feb	1.1	0.8	1.2	1.1	1.15	0.95
4-Feb	1	1.25	1.2	1.46	1.10	1.36
5-Feb	1	3.43	1.21	4.12	1.11	3.78
6-Feb	0.9	5.33	1	5.7	0.95	5.52
7-Feb	1.1	5.8	1.2	5.85	1.15	5.83
8-Feb	1.2	4.53	1.2	4.95	1.20	4.74
9-Feb	1.22	5.13	1.2	4.74	1.21	4.94
10-Feb	1.3	3.84	1.2	3.83	1.25	3.84
11-Feb	1.28	4.1	1.21	3.6	1.25	3.85
12-Feb	1.4	4.65	1.3	4.21	1.35	4.43
13-Feb	1.3	2.23	1.35	3.39	1.33	2.81
14-Feb	1.35	1.59	1.4	2.78	1.38	2.19
15-Feb	1.3	1.49	1.35	3.71	1.33	2.60
16-Feb	1.4	2.46	1.36	2.4	1.38	2.43
17-Feb	1.5	2.37	1.5	2.95	1.50	2.66
18-Feb	1.6	3.51	1.55	2.43	1.58	2.97
19-Feb	1.9	4.42	1.9	2.46	1.90	3.44
20-Feb	1.85	8.91	1.82	3.77	1.84	6.34
21-Feb	1.95	12.25	1.92	8.25	1.94	10.25
22-Feb	1.6	7.8	1.8	7.85	1.70	7.83
23-Feb	1.6	6.7	1.8	6.3	1.70	6.50
24-Feb	1.55	8.6	1.7	5.83	1.63	7.22
25-Feb	1.5	6.71	1.6	8.44	1.55	7.58
26-Feb	1.5	5.32	1.52	8.25	1.51	6.79
27-Feb	1.45	5.3	1.6	7.26	1.53	6.28
28-Feb	1.4	4.52	1.5	4.71	1.45	4.62

Table E-2. Water depth and salinity in irrigation canals, March/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Mar	1.3	3.88	1.4	5.67	1.35	4.78
2-Mar	1.28	3.48	1.39	5.57	1.34	4.53
3-Mar	1.5	2.71	1.65	2.91	1.58	2.81
4-Mar	1.15	1.52	1.2	2.66	1.18	2.09
5-Mar	1	1.9	1.2	1.32	1.10	1.61
6-Mar	1.47	1.56	1.15	2.3	1.31	1.93
7-Mar	1.2	1.31	1.2	1.62	1.20	1.47
8-Mar	1.1	2.24	1.2	2.11	1.15	2.18
9-Mar	1	1.99	1.2	2.99	1.10	2.49
10-Mar	1	2.45	1.21	2.8	1.11	2.63
11-Mar	0.9	3.16	1	1.6	0.95	2.38
12-Mar	1.1	2.74	1.2	1.75	1.15	2.25
13-Mar	1.2	4.1	1.2	3.14	1.20	3.62
14-Mar	1.22	4.54	1.2	3.86	1.21	4.20
15-Mar	1.3	5.39	1.2	4.45	1.25	4.92
16-Mar	1.28	6.29	1.21	4.5	1.25	5.40
17-Mar	1.4	10.66	1.3	9.45	1.35	10.06
18-Mar	1.3	4.79	1.35	4.48	1.33	4.64
19-Mar	1.35	4.82	1.4	4.82	1.38	4.82
20-Mar	1.3	3.52	1.35	4.15	1.33	3.84
21-Mar	1.4	3.83	1.36	3.98	1.38	3.91
22-Mar	0.9	2.82	1	4.7	0.95	3.76
23-Mar	0.95	1.8	1	1.85	0.98	1.83
24-Mar	1.2	1.13	1.3	1.66	1.25	1.40
25-Mar	1.25	2.58	1.28	3.29	1.27	2.94
26-Mar	1.9	7.35	1.8	3.22	1.85	5.29
27-Mar	1.93	9.72	2	6.5	1.97	8.11
28-Mar	1.9	7.57	1.95	7.66	1.93	7.62
29-Mar	1.81	7.11	1.9	7.33	1.86	7.22
30-Mar	1.61	8.26	1.9	8.61	1.76	8.44
31-Mar	1.5	8.99	1.7	9.21	1.60	9.10

Table E-3. Water depth and salinity in irrigation canals, April/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Apr						
2-Apr	1.42	7.56	1.5	6.89	1.46	7.23
3-Apr	1.45	9.9	1.4	7.45	1.43	8.68
4-Apr	1.42	9.5	1.44	7.39	1.43	8.45
5-Apr	1.39	4.61	1.3	5.52	1.35	5.07
6-Apr	1.45	4.97	1.4	4.62	1.43	4.80
7-Apr	1.48	3.92	1.5	5.29	1.49	4.61
8-Apr	1.45	8.52	1.35	8.45	1.40	8.49
9-Apr	1.3	5.15	1.3	9.33	1.30	7.24
10-Apr	1.41	2.36	1.2	2.45	1.31	2.41
11-Apr	1.3	1.95	1.3	1.95	1.30	1.95
12-Apr	1.38	2.18	1.3	1.95	1.34	2.07
13-Apr	1.22	1.85	1.28	1.94	1.25	1.90
14-Apr	1.7	4.47	1.55	3.18	1.63	3.83
15-Apr	1.59	6.17	1.7	6.11	1.65	6.14
16-Apr	1.6	4.13	1.6	7.51	1.60	5.82
17-Apr	1.5	3.52	1.4	3.72	1.45	3.62
18-Apr	1.51	4.19	1.45	4.65	1.48	4.42
19-Apr	1.35	4.93	1.4	5.61	1.38	5.27
20-Apr	1.34	4.91	1.39	4.64	1.37	4.78
21-Apr	1.57	6.67	1.5	8.52	1.54	7.60
22-Apr	1.31	5.82	1.45	7.99	1.38	6.91
23-Apr	1.26	4.35	1.49	5.93	1.38	5.14
24-Apr	1.4	2.34	1.45	5.97	1.43	4.16
25-Apr	1.4	2.86	1.36	6.32	1.38	4.59
26-Apr	1.39	2.99	1.37	6.3	1.38	4.65
27-Apr	1.15	2.72	1.2	3.91	1.18	3.32
28-Apr	1.11	1.22	1.29	1.62	1.20	1.42
29-Apr	1.07	1.19	1.3	1.42	1.19	1.31
30-Apr	1.15	1.2	1.39	2.77	1.27	1.99

Table E-4. Water depth and salinity in irrigation canals, May/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-May	1.5	1.45	1.7	4.33	1.60	2.89
2-May	1.19	1.72	1.3	2.88	1.25	2.30
3-May	0.75	2.2	1	1.75	0.88	1.98
4-May	0.8	1.97	0.75	1.12	0.78	1.55
5-May	1.06	1.81	1.47	1.55	1.27	1.68
6-May	1.13	1.7	1.5	1.82	1.32	1.76
7-May	1.2	2.48	1.31	1.73	1.26	2.11
8-May	1.16	2.45	1.35	1.7	1.26	2.08
9-May	1.1	2.51	1.12	2.77	1.11	2.64
10-May	1.17	2.63	1.2	2.71	1.19	2.67
11-May	1.21	1.92	1.29	3.55	1.25	2.74
12-May	1.22	2.55	1.32	3.42	1.27	2.99
13-May	1.39	2.91	1.4	5.45	1.40	4.18
14-May	1.25	2.45	1.39	5.21	1.32	3.83
15-May	1.26	3.58	1.25	3.59	1.26	3.59
16-May	1.33	2.38	1.3	2.78	1.32	2.58
17-May	1.29	2.21	1.31	2.9	1.30	2.56
18-May	0.6	2.3	0.9	1.99	0.75	2.15
19-May	0.65	1.99	1	1.94	0.83	1.97
20-May	0.75	1.12	0.8	1.52	0.78	1.32
21-May	0.67	0.98	0.6	1.05	0.64	1.02
22-May	0.7	0.94	0.9	0.81	0.80	0.88
23-May	0.67	0.72	0.77	0.9	0.72	0.81
24-May	0.7	0.55	0.75	0.85	0.73	0.70
25-May	1.05	0.99	1.1	0.98	1.08	0.99
26-May	1.17	1.22	1.3	2.99	1.24	2.11
27-May	1.45	4.89	1.4	5.44	1.43	5.17
28-May	1.42	4.55	1.39	5.41	1.41	4.98
29-May	1.4	3.86	1.33	4.37	1.37	4.12
30-May	1.4	4.12	1.25	4.77	1.33	4.45
31-May	1.39	4.33	1.28	4.45	1.34	4.39

Table E-5. Water depth and salinity in irrigation canals, June/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Jun	1.27	4.42	1.27	4.47	1.27	4.45
2-Jun	1.25	4.73	1.25	4.5	1.25	4.62
3-Jun	1.15	2.9	1.12	3.31	1.14	3.11
4-Jun	1.1	1.48	1.2	2.77	1.15	2.13
5-Jun	1.25	1.56	1.29	1.82	1.27	1.69
6-Jun	1.15	1.05	1.4	2.76	1.28	1.91
7-Jun	0.63	0.99	1.2	2.7	0.92	1.85
8-Jun	0.5	0.85	0.9	1.1	0.70	0.98
9-Jun	0.61	0.98	0.7	1.07	0.66	1.03
10-Jun	1.25	1.36	1.45	1.95	1.35	1.66
11-Jun	1.45	3.86	1.5	4.46	1.48	4.16
12-Jun	1.4	5.89	1.45	4.95	1.43	5.42
13-Jun	1.38	5.91	1.4	3.88	1.39	4.90
14-Jun	1	3.81	1.32	3.65	1.16	3.73
15-Jun	1.05	3.88	1.25	3.62	1.15	3.75
16-Jun	1	2.78	1.34	2.75	1.17	2.77
17-Jun	1.05	1.29	1.16	1.75	1.11	1.52
18-Jun	1.12	1.31	1.21	1.99	1.17	1.65
19-Jun	1.2	1.29	1.26	1.98	1.23	1.64
20-Jun	0.6	1.12	1.2	3.22	0.90	2.17
21-Jun	0.65	1.3	1.2	1.16	0.93	1.23
22-Jun	0.7	1.1	1.28	1.19	0.99	1.15
23-Jun	0.6	1.2	1.2	1.35	0.90	1.28
24-Jun	0.62	1.7	1.19	1.37	0.91	1.54
25-Jun	1	2.75	1.26	4.21	1.13	3.48
26-Jun	1.2	2.99	1.32	3.75	1.26	3.37
27-Jun	1.22	3.12	1.35	3.8	1.29	3.46
28-Jun	1.25	4.32	1.4	4.86	1.33	4.59
29-Jun	1.27	4.92	1.46	5.32	1.37	5.12
30-Jun	1.3	5.22	1.3	5.18	1.30	5.20

Table E-6. Water depth and salinity in irrigation canals, July/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Jul	1.31	5.23	1.28	4.95	1.30	5.09
2-Jul	1.05	6.51	1.4	2.49	1.23	4.50
3-Jul	1.42	4.65	1.39	2.55	1.41	3.60
4-Jul	1.41	5.98	1.44	3.99	1.43	4.99
5-Jul	1.45	6.15	1.49	5.18	1.47	5.67
6-Jul	1.22	2.35	1.4	2.14	1.31	2.25
7-Jul	1.18	2.24	1.3	1.88	1.24	2.06
8-Jul	1.15	1.78	1.44	1.84	1.30	1.81
9-Jul	1	1.32	1.4	1.81	1.20	1.57
10-Jul	0.7	1.18	1.35	1.79	1.03	1.49
11-Jul	0.82	1.05	1.12	1.37	0.97	1.21
12-Jul	0.7	0.9	1	1.22	0.85	1.06
13-Jul	1.2	1.42	1.22	1.28	1.21	1.35
14-Jul	1.26	2.56	1.32	2.07	1.29	2.32
15-Jul	1.29	2.27	1.38	2.36	1.34	2.32
16-Jul	1.28	3.55	1.27	2.57	1.28	3.06
17-Jul	1.3	3.98	1.35	3.42	1.33	3.70
18-Jul	1.33	5.07	1.38	4.33	1.36	4.70
19-Jul	1.21	4.88	1.41	2.99	1.31	3.94
20-Jul	1.18	3.96	1.44	4.36	1.31	4.16
21-Jul	1.26	3.51	1.41	4.21	1.34	3.86
22-Jul	1.32	3.36	1.45	4.12	1.39	3.74
23-Jul	1.3	3.46	1.44	4.16	1.37	3.81
24-Jul	1.18	2.04	1.34	2.35	1.26	2.20
25-Jul	1.12	1.87	1.3	2.08	1.21	1.98
26-Jul	1	1.79	1.77	1.14	1.39	1.47
27-Jul	0.82	1.74	1.52	1.19	1.17	1.47
28-Jul	1.05	1.88	1.35	1.24	1.20	1.56
29-Jul	1.29	2.31	1.39	2.04	1.34	2.18
30-Jul	1.36	4.65	1.42	6.12	1.39	5.39
31-Jul	1.42	5.22	1.44	6.55	1.43	5.89

Table E-7. Water depth and salinity in irrigation canals, Aug/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Aug	1.39	6.31	1.47	6.38	1.43	6.35
2-Aug	1.42	6.88	1.5	6.88	1.46	6.88
3-Aug	1.44	7.16	1.46	7.35	1.45	7.26
4-Aug	1.46	8.44	1.48	7.51	1.47	7.98
5-Aug	1.49	8.96	1.52	7.99	1.51	8.48
6-Aug	1.37	5.86	1.5	5.74	1.44	5.80
7-Aug	1.29	4.88	1.52	5.76	1.41	5.32
8-Aug	1.2	2.25	1.41	2.23	1.31	2.24
9-Aug	1.12	2.08	1.38	2.16	1.25	2.12
10-Aug	1.06	1.74	1.3	1.76	1.18	1.75
11-Aug	1	1.32	1.25	1.35	1.13	1.34
12-Aug	0.9	1.18	1.18	1.21	1.04	1.20
13-Aug	1	1.09	1.11	1.18	1.06	1.14
14-Aug	1.15	3.65	1.21	3.67	1.18	3.66
15-Aug	1.2	4.06	1.3	3.98	1.25	4.02
16-Aug	1.22	4.35	1.25	4.1	1.24	4.23
17-Aug	1.25	4.42	1.22	4.26	1.24	4.34
18-Aug	1.17	4.45	1.2	4.57	1.19	4.51
19-Aug	1.15	4.51	1.18	4.99	1.17	4.75
20-Aug	1.15	4.87	1.22	4.62	1.19	4.75
21-Aug	1.17	4.96	1.24	4.37	1.21	4.67
22-Aug	1.25	3.72	1.31	4.32	1.28	4.02
23-Aug	1.36	3.55	1.35	4.28	1.36	3.92
24-Aug	1.18	3.16	1.22	3.18	1.20	3.17
25-Aug	1.12	2.65	1.18	2.88	1.15	2.77
26-Aug	1.15	2.36	1.11	2.18	1.13	2.27
27-Aug	1	2.25	1.1	1.12	1.05	1.69
28-Aug	1	2.28	1.12	1.87	1.06	2.08
29-Aug	1.1	2.31	1.14	2.12	1.12	2.22
30-Aug	1.12	3.35	1.17	3.45	1.15	3.40
31-Aug	1.15	3.42	1.2	3.64	1.18	3.53

Table E-8. Water depth and salinity in irrigation canals, Sep/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Sep	1.18	3.46	1.22	3.44	1.20	3.45
2-Sep	1.22	3.49	1.25	3.46	1.24	3.48
3-Sep	1.23	3.75	1.22	3.68	1.23	3.72
4-Sep	1.12	4.2	1.2	1.18	1.16	2.69
5-Sep	1.21	4.88	1.25	3.67	1.23	4.28
6-Sep	1.18	3.77	1.2	3.98	1.19	3.88
7-Sep	1.15	3.54	1.16	4.1	1.16	3.82
8-Sep	1.12	3.72	1.15	4.26	1.14	3.99
9-Sep	1	3.55	1.13	4.57	1.07	4.06
10-Sep	0.9	3.16	1.1	4.99	1.00	4.08
11-Sep	0.85	2.65	1	4.62	0.93	3.64
12-Sep	0.8	2.36	0.9	4.37	0.85	3.37
13-Sep	0.82	2.25	0.95	4.32	0.89	3.29
14-Sep	0.85	2.28	0.95	4.28	0.90	3.28
15-Sep	0.9	3.65	1	3.18	0.95	3.42
16-Sep	1	4.06	0.9	2.88	0.95	3.47
17-Sep	1.08	4.35	0.95	2.18	1.02	3.27
18-Sep	0.65	4.42	0.8	1.12	0.73	2.77
19-Sep	0.7	4.45	0.85	1.87	0.78	3.16
20-Sep	1	4.51	0.8	4.32	0.90	4.42
21-Sep	1.09	4.87	0.9	4.28	1.00	4.58
22-Sep	1.12	4.96	0.95	3.18	1.04	4.07
23-Sep	1.15	2.08	1.12	2.88	1.14	2.48
24-Sep	1.18	1.74	1.15	2.18	1.17	1.96
25-Sep	0.77	1.32	0.8	1.12	0.79	1.22
26-Sep	0.65	1.18	0.78	1.87	0.72	1.53
27-Sep	0.62	1.09	0.75	1.74	0.69	1.42
28-Sep	0.64	3.65	0.72	1.32	0.68	2.49
29-Sep	0.6	4.06	0.65	1.18	0.63	2.62
30-Sep	1	3.36	0.88	3.41	0.94	3.39

Table E-9. Water depth and salinity in irrigation canals, Oct/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Oct	1.04	3.39	1	3.46	1.02	3.43
2-Oct	1.18	4.65	1.02	4.48	1.10	4.57
3-Oct	1.24	4.72	1.05	4.52	1.15	4.62
4-Oct	1.14	4.98	1.07	4.88	1.11	4.93
5-Oct	1.16	5.08	1.1	5.07	1.13	5.08
6-Oct	1.18	5.3	1.16	5.26	1.17	5.28
7-Oct	1.21	5.27	1.23	5.36	1.22	5.32
8-Oct	1.17	5.12	1.12	4.66	1.15	4.89
9-Oct	1.15	4.86	1	4.45	1.08	4.66
10-Oct	0.97	4.42	0.95	2.75	0.96	3.59
11-Oct	0.82	3.32	0.9	2.54	0.86	2.93
12-Oct	0.8	2.18	0.95	2.31	0.88	2.25
13-Oct	0.81	2.16	0.92	2.19	0.87	2.18
14-Oct	0.69	2.07	0.88	2.1	0.79	2.09
15-Oct	0.7	2.04	0.8	1.98	0.75	2.01
16-Oct	0.72	1.85	0.75	1.85	0.74	1.85
17-Oct	0.69	1.89	0.71	1.9	0.70	1.90
18-Oct	0.98	3.63	1	3.76	0.99	3.70
19-Oct	1	4.12	1.05	4.15	1.03	4.14
20-Oct	1.1	4.32	1.12	4.19	1.11	4.26
21-Oct	1.14	4.51	1.18	4.16	1.16	4.34
22-Oct	1.2	4.32	1.09	4.19	1.15	4.26
23-Oct	1.22	4.39	1	4.2	1.11	4.30
24-Oct	1.12	4.21	0.92	4.12	1.02	4.17
25-Oct	1.08	4.17	0.87	4.1	0.98	4.14
26-Oct	1	4.06	0.81	3.89	0.91	3.98
27-Oct	0.9	3.87	0.75	3.72	0.83	3.80
28-Oct	0.85	2.32	0.71	2.46	0.78	2.39
29-Oct	0.76	2.25	0.68	2.16	0.72	2.21
30-Oct	0.72	2.14	0.64	2.11	0.68	2.13
31-Oct	0.68	2.08	0.62	2.05	0.65	2.07

Table E-10. Water depth and salinity in irrigation canals, Nov/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Nov	0.9	2.1	0.7	2.08	0.80	2.09
2-Nov	0.94	2.16	0.75	2.15	0.85	2.16
3-Nov	1.16	4.08	1.12	4.22	1.14	4.15
4-Nov	1.18	4.36	1.15	5.21	1.17	4.79
5-Nov	1.2	4.75	1.17	5.46	1.19	5.11
6-Nov	1.2	4.75	1.17	5.46	1.19	5.11
7-Nov	1.09	4.56	1.05	5.24	1.07	4.90
8-Nov	1.02	4.27	1	5.09	1.01	4.68
9-Nov	1	3.72	1.06	4.97	1.03	4.35
10-Nov	0.95	3.55	1.11	4.75	1.03	4.15
11-Nov	1.02	3.26	1	4.42	1.01	3.84
12-Nov	1	3.16	0.91	4.21	0.96	3.69
13-Nov	1	2.45	0.9	3.18	0.95	2.82
14-Nov	0.85	2.16	0.81	2.26	0.83	2.21
15-Nov	0.8	2.07	0.78	2.14	0.79	2.11
16-Nov	0.74	2.02	0.76	2.06	0.75	2.04
17-Nov	0.68	1.82	0.71	1.76	0.70	1.79
18-Nov	0.76	1.88	0.67	1.68	0.72	1.78
19-Nov	0.8	1.95	0.76	1.77	0.78	1.86
20-Nov	0.82	2.04	0.85	1.88	0.84	1.96
21-Nov	0.97	1.95	0.9	2.02	0.94	1.99
22-Nov	1	1.86	0.92	2.07	0.96	1.97
23-Nov	1.04	2.06	1	2.38	1.02	2.22
24-Nov	1.12	2.25	1.12	2.56	1.12	2.41
25-Nov	1.16	2.28	1	2.44	1.08	2.36
26-Nov	1.14	2.32	0.96	2.35	1.05	2.34
27-Nov	1	2.12	0.93	2.31	0.97	2.22
28-Nov	0.95	1.75	0.9	2.28	0.93	2.02
29-Nov	0.9	1.7	0.85	2.12	0.88	1.91
30-Nov	0.82	1.72	0.8	1.92	0.81	1.82

Table E-11. Water depth and salinity in irrigation canals, Dec/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Dec	0.8	1.75	0.82	1.9	0.81	1.83
2-Dec	0.89	1.78	0.85	1.93	0.87	1.86
3-Dec	0.82	1.65	0.8	1.76	0.81	1.71
4-Dec	1.07	1.96	1.11	2.08	1.09	2.02
5-Dec	1.14	2.25	1.13	2.41	1.14	2.33
6-Dec	1.16	2.46	1.07	2.49	1.12	2.48
7-Dec	1.2	2.51	1	2.76	1.10	2.64
8-Dec	1.15	2.58	1.11	2.78	1.13	2.68
9-Dec	1.22	3.16	1.2	3.24	1.21	3.20
10-Dec	1.24	3.35	1.05	3.42	1.15	3.39
11-Dec	1.22	3.32	1.03	3.41	1.13	3.37
12-Dec	1.17	3.35	1	3.44	1.09	3.40
13-Dec	1.06	3.12	1.02	3.47	1.04	3.30
14-Dec	1	2.68	0.8	3.12	0.90	2.90
15-Dec	0.9	2.28	0.78	2.75	0.84	2.52
16-Dec	0.81	1.97	0.79	2.24	0.80	2.11
17-Dec	0.8	2.06	0.82	2.19	0.81	2.13
18-Dec	0.76	2.18	0.85	2.16	0.81	2.17
19-Dec	0.92	2.38	0.9	2.35	0.91	2.37
20-Dec	1.02	2.49	1	2.56	1.01	2.53
21-Dec	1.06	2.51	1.05	2.63	1.06	2.57
22-Dec	1.14	5.98	1.12	2.85	1.13	4.42
23-Dec	1.18	3.19	1.14	3.08	1.16	3.14
24-Dec	1.21	3.32	1.16	3.21	1.19	3.27
25-Dec	1.24	3.35	1.2	3.26	1.22	3.31
26-Dec	1.26	3.42	1.1	3.48	1.18	3.45
27-Dec	1.21	3.46	1.12	3.76	1.17	3.61
28-Dec	1.23	3.48	1.16	3.81	1.20	3.65
29-Dec	1.19	3.45	1.14	3.75	1.17	3.60
30-Dec	1.12	3.08	1.06	3.34	1.09	3.21
31-Dec	1.07	2.94	1	3.18	1.04	3.06

Table E-12. Water depth and salinity in irrigation canals, Jan/2025.

Date	C-1200		Sub-canal 1		Average	
	depth	EC	depth	EC	depth	EC
1-Jan	1.02	1.85	0.95	2.75	0.99	2.30
2-Jan	0.95	1.69	0.9	2.67	0.93	2.18
3-Jan	0.9	1.61	0.76	2.41	0.83	2.01
4-Jan	0.84	1.56	0.65	2.19	0.75	1.88
5-Jan	0.9	1.65	0.81	2.14	0.86	1.90
6-Jan	0.95	1.85	0.9	2.31	0.93	2.08
7-Jan	1.02	2.18	1	2.53	1.01	2.36
8-Jan	1.03	2.26	1.07	2.61	1.05	2.44
9-Jan	1.07	2.41	1.12	2.75	1.10	2.58
10-Jan	1	3.22	1.04	3.98	1.02	3.60
11-Jan	1.02	3.35	0.97	4.12	1.00	3.74
12-Jan	1.08	3.58	1.05	4.16	1.07	3.87
13-Jan	1.1	4.75	1.08	5.21	1.09	4.98
14-Jan	1.08	4.68	1.12	5.26	1.10	4.97
15-Jan	1.05	4.51	1.08	5.14	1.07	4.83
16-Jan	1.02	4.36	1	4.08	1.01	4.22
17-Jan	1	4.12	0.96	3.98	0.98	4.05
18-Jan	0.95	3.75	0.9	4.22	0.93	3.99
19-Jan	0.9	3.51	0.85	4.26	0.88	3.89
20-Jan	0.85	2.98	0.81	4.16	0.83	3.57
21-Jan	0.8	2.75	0.85	2.98	0.83	2.87
22-Jan	0.85	2.71	0.9	2.91	0.88	2.81
23-Jan	0.82	2.73	0.87	2.71	0.85	2.72
24-Jan	0.84	2.75	0.85	2.57	0.85	2.66
25-Jan	0.92	2.85	1	2.76	0.96	2.81
26-Jan	1	3.05	1.07	3.07	1.04	3.06
27-Jan	1.1	3.16	1.09	3.12	1.10	3.14
28-Jan	1.12	3.21	1.14	3.18	1.13	3.20
29-Jan	1.17	3.29	1.25	3.25	1.21	3.27
30-Jan	1.2	3.32	1.22	3.28	1.21	3.30
31-Jan	1.24	3.38	1.25	3.37	1.25	3.38

10.6 Appendix-F . Measurements of irrigation water quantity Applied for each crop

Table F-1. Measurements of irrigation water quantity during Feb/2025 befor irrigation development for the experimental fields.

Date	Field no.	Area	Crop	Operating hr.	Pump capacity	Pump effi. (%)/100	q-pump (m3/s)	q-pump (m3/hr)	Irr. Quantity (m3)
15/2/2025	f1	2.48	clover	7.5	7	0.6	0.05	164.26	1231.93
	f2	1.81	Shogerbeet	7	7	0.6	0.05	164.26	1149.80
	f3	0.55	artchoke	3	7	0.6	0.05	164.26	492.77
	f4	0.62	artchoke	5	9	0.6	0.06	211.19	1055.94
	f5	0.95	artchoke						
	f6	0.93	clover	3	7	0.6	0.05	164.26	492.77
	f7	0.55	artchoke	3.5	7	0.6	0.05	164.26	574.90
	f8	0.57	wheat	2	7	0.6	0.05	164.26	328.51
	f9	1.21	artchoke	5	7	0.6	0.05	164.26	821.28
	f10	0.3	artchoke	1.5	9	0.6	0.06	211.19	316.78
	f11	0.46	wheat	2	5	0.6	0.04	136.88	273.76
	f12	0.39	artchoke	4	9	0.6	0.07	246.39	985.54
	f13	0.15	clover						
	f14	0.36	artchoke	No Irrigation					
	f15	0.27	wheat						
	f16	0.19	clover						
	f17	0.49	artchoke	2.5	9	0.6	0.06	211.19	527.97
	f18	0.41	artchoke	3	9	0.6	0.06	211.19	633.56
	f19	0.68	clover						
	f20	0.53	artchoke	3	9	0.6	0.06	211.19	633.56
	f21	0.36	clover	8	7	0.6	0.05	164.26	1314.06
	f22	0.34	wheat						
	f23	0.68	artchoke						
	f24	1.12	artchoke	5	7	0.6	0.05	164.26	821.28
	f25	0.32	artchoke	7	9	0.6	0.06	211.19	1478.31
	f26	0.33	wheat						
	f27	2.31	artchoke						

Table F-2. Measurements of irrigation water quantity during March/2025 befor irrigation development for the experimental fields

Date	Field no.	Area	Crop	Operating hr.	Pump capacity	Pump effi. (%)/100	q-pump (m3/s)	q-pump (m3/hr)	Irr. Quantity (m3)
5/3/2024	f1	2.48	clover	7	9	0.6	0.06	211.19	1478.31
	f2	1.81	Shogerbeet	7.5	7	0.6	0.05	164.26	1231.93
	f3	0.55	artchoke	2	7	0.6	0.05	164.26	328.51
	f4	0.62	artchoke	3	7	0.6	0.05	164.26	492.77
	f5	0.95	artchoke	5	9	0.6	0.06	211.19	1055.94
	f6	0.93	clover						
	f7	0.55	artchoke	3	7	0.6	0.05	164.26	492.77
	f8	0.57	wheat	2	7	0.6	0.05	164.26	328.51
	f9	1.21	artchoke	4.5	7	0.6	0.05	164.26	739.16
	f10	0.3	artchoke	1.5	9	0.6	0.06	211.19	316.78
	f11	0.46	wheat	2.5	5	0.6	0.03	117.33	293.32
	f12	0.39	artchoke	3	9	0.6	0.06	211.19	633.56
	f13	0.15	clover						
	f14	0.36	artchoke	5	9	0.6	0.06	211.19	1055.94
	f15	0.27	wheat						
	f16	0.19	clover						
	f17	0.49	artchoke	2.5	9	0.6	0.06	211.19	527.97
	f18	0.41	artchoke	3	9	0.6	0.06	211.19	633.56
	f19	0.68	clover						
	f20	0.53	artchoke						
	f21	0.36	clover	2	9	0.6	0.06	211.19	422.37
	f22	0.34	wheat	7	9	0.6	0.06	211.19	1478.31
	f23	0.68	artchoke						
	f24	1.12	artchoke						
	f25	0.32	artchoke	1	9	0.6	0.06	211.19	211.19
	f26	0.33	wheat	5	9	0.6	0.06	211.19	1055.94
	f27	2.31	artchoke						

Table F-3. Measurements of irrigation water quantity during March/2025 befor irrigation development for the experimental fields

Date	Field no.	Area	Crop	Operating hr.	Pump capacity	Pump effi. (%)/100	q-pump (m3/s)	q-pump (m3/hr)	Irr. Quantity (m3)
23/3/2024	f1	2.48	clover	7.5	9	0.6	0.06	211.19	1583.91
	f2	1.81	Shogerbeet	6.5	7	0.6	0.05	164.26	1067.67
	f3	0.55	artchoke	3.5	7	0.6	0.05	164.26	574.90
	f4	0.62	artchoke	4	7	0.6	0.05	164.26	657.03
	f5	0.95	artchoke	7.5	7	0.6	0.05	164.26	1231.93
	f6	0.93	clover						
	f7	0.55	artchoke	3	7	0.6	0.05	164.26	492.77
	f8	0.57	wheat	2.5	7	0.6	0.05	164.26	410.64
	f9	1.21	artchoke	5	7	0.6	0.05	164.26	821.28
	f10	0.3	artchoke	2	5	0.6	0.03	117.33	234.65
	f11	0.46	wheat	3	5	0.6	0.03	117.33	351.98
	f12	0.39	artchoke	no irr.					
	f13	0.15	clover	no irr.					
	f14	0.36	artchoke	7	9	0.6	0.06	211.19	1478.31
	f15	0.27	wheat						
	f16	0.19	clover						
	f17	0.49	artchoke	no irr.					
	f18	0.41	artchoke	7	9	0.6	0.06	211.19	1478.31
	f19	0.68	clover						
	f20	0.53	artchoke						
	f21	0.36	clover	3	5	0.6	0.03	117.33	351.98
	f22	0.34	clover	7	7	0.6	0.05	164.26	1149.80
	f23	0.68	artchoke						
	f24	1.12	wheat						
	f25	0.32	artchoke	1.5	9	0.6	0.06	211.19	316.78
	f26	0.33	wheat	5.5	9	0.6	0.06	211.19	1161.53
	f27	2.31	artchoke						

Table F-4. Measurements of irrigation water quantity during April/2025 befor irrigation development for the experimental fields

Date	Field no.	Area	Crop	Operating hr.	Pump capacity	Pump effi. (%)/100	q-pump (m3/s)	q-pump (m3/hr)	Irr. Quantity (m3)
9/4/2024	f1	2.48	clover	7	9	0.6	0.06	211.19	1478.31
	f2	1.81	Sun-flower	8	7	0.6	0.05	164.26	1314.06
	f3	0.55	Sun-flower	No Irrigation					
	f4	0.62	Sun-flower	3	5	0.6	0.03	117.33	351.98
	f5	0.95	artchoke	No Irrigation					
	f6	0.93	clover	No Irrigation					
	f7	0.55	Sun-flower	No Irrigation					
	f8	0.57	wheat	No Irrigation					
	f9	1.21	artchoke	4.5	5	0.6	0.03	117.33	527.97
	f10	0.3	artchoke						
	f11	0.46	wheat						
	f12	0.39	artchoke	4	9	0.6	0.06	211.19	844.75
	f13	0.15	clover						
	f14	0.36	artchoke	4	9	0.6	0.06	211.19	844.75
	f16	0.19	clover						
	f15	0.27	wheat	no irr.					
	f17	0.49	artchoke						
	f18	0.41	artchoke	8	9	0.6	0.06	211.19	1689.50
	f19	0.68	clover						
	f20	0.53	artchoke						
	f21	0.36	clover	3.5	9	0.6	0.06	211.19	739.16
	f22	0.34	wheat						
	f23	0.68	artchoke	No Irrigation					
	f24	1.12	artchoke	No Irrigation					
	f25	0.32	artchoke	5	9	0.6	0.06	211.19	1055.94
	f26	0.33	wheat						
	f27	2.31	artchoke	9	9	0.6	0.06	211.19	1900.69

Table F-5. Measurements of irrigation water quantity during May/2025 befor irrigation development for the experimental fields

Date	Field no.	Area	Crop	Operating hr.	Pump capacity	Pump effi. (%)/100	q-pump (m3/s)	q-pump (m3/hr)	Irr. Quantity (m3)
27/4/2024	f1	2.48	clover	8	9	0.6	0.06	211.19	1689.50
	f2	1.81	Sun-flower	Summar					
	f3	0.55	Sun-flower	Summar					
	f4	0.62	Sun-flower	Summar					
	f5	0.95	لب-بطيخ	Summar					
	f6	0.93	لب-بطيخ	Summar					
	f7	0.55	sun-flower	3	7	0.6	0.05	164.26	492.77
	f8	0.57	wheat	No Irrigation					
	f9	1.21	artchoke	No Irrigation					
	f10	0.3	artchoke	No Irrigation					
	f11	0.46	wheat	No Irrigation					
	f12	0.39	sun-flower	3	9	0.6	0.06	211.19	633.56
	f13	0.15	clover	No Irrigation					
	f14	0.36	artchoke	No Irrigation					
	f16	0.19	clover	No Irrigation					
	f15	0.27	wheat	No Irr					
	f17	0.49	sun-flower	Summar					
	f18	0.41	artichoke	2	9	0.6	0.06	211.19	422.37
	f19	0.68	clover	No Irrigation					
	f20	0.53	artichoke	No Irrigation					
	f21	0.36	clover	No Irrigation					
	f22	0.34	wheat	No Irrigation					
	f23	0.68	artchoke	No Irrigation					
	f24	1.12	wheat	No Irrigation					
	f25	0.32	artchoke	6	9	0.6	0.06	211.19	1267.12
	f26	0.33	wheat	No Irrigation					
	f27	2.31	لب-بطيخ	2	9	0.6	0.06	211.19	422.37

Table F-6. Measurements of irrigation water quantity during Oct/2025 After irrigation development for the experimental fields

Field				Pump			Irrigation water quantity		
No	Crop type	Area	Irr. date	Freq. (Hz)	Pr. (psi)	Durations	Discharge	Volume (m3)	q (m3/f)
F1	Artichoke	1.25	13-Oct	39-42	2	200	250	833.3	667
F2	Clover	1.50	18-Oct	38-43	2	140	250	583.3	389
F3	Shogerbeet	0.42							
f4	Clover	0.33	14-Oct	39-42	2	40	250	166.7	500
F5	Clover	1.08	13-Oct	38-43	3	140	250	583.3	538
F6	Clover	1.08	14-Oct	37-43	3	120	250	500.0	462
F7	Clover	0.71	17-Oct	39-40	3	80	250	333.3	471
F8	Clover	0.71	14-Oct	39-42	2	90	250	375.0	529
F9	Shogerbeet	1.25	29-Oct	41-42	2	115	250	479.2	383
F10	Artichoke	0.42	14-Oct	39-42	2	65	250	270.8	650
F11	Clover	0.58				70	250	291.7	500
F12	Shogerbeet	0.42					250	0.0	0
F13	Shogerbeet	0.42					250	0.0	0
F14	Wheat	0.33					250	0.0	0
F15	Clover	0.33				40	250	166.7	500
F16	Wheat	0.29					250	0.0	0
F17	Artichoke	0.54	24-Oct	39-42	2	90	250	375.0	692
F18	Artichoke	0.50	24-Oct	39-42	2	90	250	375.0	750
F19	Wheat	0.29					250	0.0	0
F20	Clover	0.29	17-Oct	38-41	2	35	250	145.8	500
F21	Wheat	0.50	17-Oct	38-40	3	35	250	145.8	292
F22	Clover	0.50				55	250	229.2	458
F23	Wheat	0.58					250	0.0	0
F24	Artichoke	0.42	29-Oct	38-42	3	80	250	333.3	800
F25	Wheat	1.25					250	0.0	0
F26	Shogerbeet	0.50							
F27	Shogerbeet	0.50							
F28	Wheat	0.50					250	0.0	0
F29	Shogerbeet	0.33				30	250	125.0	375
F30	Artichoke	0.50	11-Oct	33-35	2	90	250	375.0	750
F31	Shogerbeet	0.50							
F32	Artichoke	0.50				80	250	333.3	667

Table F-7. Measurements of irrigation water quantity during Nov/2025 After irrigation development for the experimental fields

Field				Pump			Irrigation water quantity		
No	Crop type	Area	Irr. date	Freq. (Hz)	Pr. (psi)	Durations	Discharge	Volume (m3)	q (m3/f)
F1	Artichoke	1.25	13-Nov	39-42	2	200	250	833.3	667
F2	Clover	1.50	28-Nov	44-45	2	200	250	833.3	556
F3	Shogerbeet	0.42	12-Nov	39-43	2	40	250	166.7	400
F4	Clover	0.33	16-Nov	39-42	3	50	250	208.3	625
F5	Clover	1.08	12-Nov	41-42	2	140	250	583.3	538
F6	Clover	1.08	12-Nov	41-42	2	140	250	583.3	538
F7	Clover	0.71	13-Nov	38-43	3	100	250	416.7	588
F8	Clover	0.71	13-Nov	38-43	3	90	250	375.0	529
F9	Shogerbeet	1.25	29-Nov	44-46	2	120	250	500.0	400
F10	Artichoke	0.42	13-Nov	39-42	2	75	250	312.5	750
F11	Clover	0.58	16-Nov	39-42	3	80	250	333.3	571
F12	Shogerbeet	0.42	20-Nov	39-42	2	40	250	166.7	400
F13	Shogerbeet	0.42	12-Nov	39-43	2	35	250	145.8	350
F14	Wheat	0.33	28-Nov	44-46	2	30	250	125.0	375
F15	Clover	0.33	16-Nov	39-42	3	50	250	208.3	625
F16	Wheat	0.29	28-Nov	44-46	2	25	250	104.2	357
F17	Artichoke	0.54	29-Nov	42-43	2	80	250	333.3	615
F18	Artichoke	0.50	29-Nov	42-43	2	80	250	333.3	667
F19	Wheat	0.29	28-Nov	44-46	2	25	250	104.2	357
F20	Clover	0.29	16-Nov	39-42	3	40	250	166.7	571
F21	Wheat	0.50	29-Nov	44-45	2	40	250	166.7	333
F22	Clover	0.50	16-Nov	39-42	3	70	250	291.7	583
F23	Wheat	0.58	28-Nov	44-46	2	40	250	166.7	286
F24	Artichoke	0.42	20-Nov	43-45	2	75	250	312.5	750
F25	Wheat	1.25	27-Nov	44-45	2	90	250	375.0	300
F26	Shogerbeet	0.50	12-Nov	39-43	2	40	250	166.7	333
F27	Shogerbeet	0.50	12-Nov	39-43	2	40	250	166.7	333
F28	Wheat	0.50	28-Nov	44-46	2	30	250	125.0	250
F29	Shogerbeet	0.33	12-Nov	39-43	2	30	250	125.0	375
F30	Artichoke	0.50	29-Nov	42-43	2	75	250	312.5	625
F31	Shogerbeet	0.50	12-Oct	34-38	2	50	250	208.3	417
F32	Artichoke	0.50				75	250	312.5	625

Table F-8. Measurements of irrigation water quantity during Dec/2025 After irrigation development for the experimental fields.

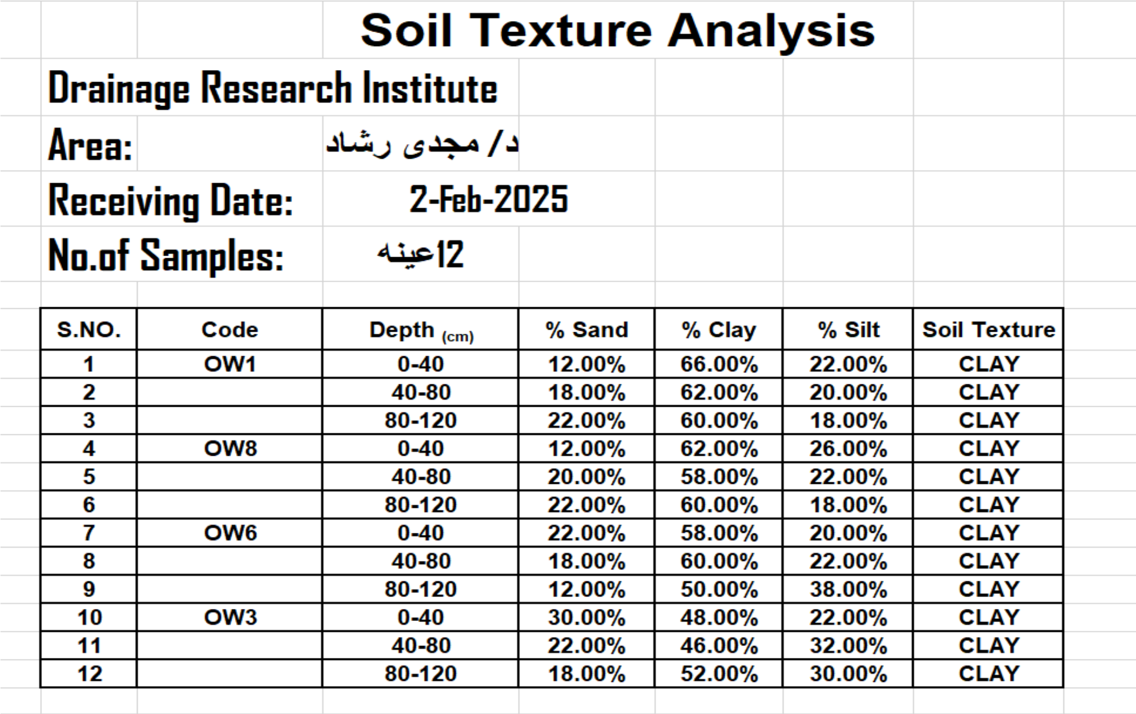
Field				Pump			Irrigation water quantity		
No	**Crop type**	**Area**	**Irr. date**	**Freq. (Hz)**	**Pr. (psi)**	**Durations**	**Discharge**	**Volume (m3)**	**q (m3/f)**
F1	Artichoke	1.25	27-Dec	48-49	2	200	250	833.3	667
F2	Clover	0.50	20-Dec	47-48	3	70	250	291.7	583
F3	Shogerbeet	0.42	29-Oct	39-42	2	40	250	166.7	400
F4	Clover	0.33	20-Dec	48-49	2	50	250	208.3	625
F5	Clover	1.08	20-Dec	48-49	2	140	250	583.3	538
F6	Clover	1.08	20-Dec	47-48	2	140	250	583.3	538
F7	Clover	0.71	20-Dec	48-49	2	100	250	416.7	588
F8	Clover	0.71	20-Dec	48-49	2	100	250	416.7	588
F9	Shogerbeet	1.25	29-Oct	39-42	2	110	250	458.3	367
F10	Artichoke	0.42	27-Dec	48-49	2	65	250	270.8	650
F11	Clover	0.58	20-Dec	48-49	2	70	250	291.7	500
F12	Shogerbeet	0.42	19-Dec	48-49	2	40	250	166.7	400
F13	Shogerbeet	0.42	29-Oct	39-42	2	40	250	166.7	400
F14	Wheat	0.33	8-Dec	44-45	2	30	250	125.0	375
F15	Clover	0.33	20-Dec	48-49	2	50	250	208.3	625
F16	Wheat	0.29	19-Dec	48-49	2	25	250	104.2	357
F17	Artichoke	0.54	27-Dec	48-49	2	85	250	354.2	654
F18	Artichoke	0.50	27-Dec	48-49	2	85	250	354.2	708
F19	Wheat	0.29	17-Dec	46-47	3	25	250	104.2	357
F20	Clover	0.29	19-Dec	46-47	2	40	250	166.7	571
F21	Wheat	0.50	19-Dec	47-48	2	40	250	166.7	333
F22	Clover	0.50	10-Dec	45-46	2	70	250	291.7	583
F23	Wheat	0.58	10-Dec	44-45	2	50	250	208.3	357
F24	Artichoke	0.42	27-Dec	48-49	2	75	250	312.5	750
F25	Wheat	1.25	15-Dec	42-43	3	90	250	375.0	300
F26	Shogerbeet	0.50	29-Oct	39-42	2	40	250	166.7	333
F27	Shogerbeet	0.50	29-Oct	39-42	2	40	250	166.7	333
F28	Wheat	0.50	15-Dec	42-43	3	40	250	166.7	333
F29	Shogerbeet	0.33	29-Oct	39-42	2	40	250	166.7	500
F30	Artichoke	0.50	27-Dec	48-49	2	75	250	312.5	625
F31	Shogerbeet	0.50	29-Oct	39-42	2	40	250	166.7	333
F32	Artichoke	0.50	27-Dec	48-49	2	90	250	375.0	750
F19	Wheat	0.4	19-Dec	47-48	2	1	250	4.2	10

Table F-9. Measurements of irrigation water quantity during Jan/2026 After irrigation development for the experimental fields.

Field				Pump			Irrigation water quantity		
No	Crop type	Area	Irr. date	Freq. (Hz)	Pr. (psi)	Durations	Discharge	Volume (m3)	q (m3/f)
F1	Artichoke	1.25	25-Jan	49-50	2	210	250	875.0	700
F2	Clover	1.50				200	250	833.3	556
F3	Shogerbeet	0.42	25-Jan	48-49	3	40	250	166.7	400
F4	Clover	0.33	25-Jan	49-50	3	45	250	187.5	563
F5	Clover	1.08	25-Jan	49-50	3	140	250	583.3	538
F6	Clover	1.08	25-Jan	49-50	3	140	250	583.3	538
F7	Clover	0.71	25-Jan	49-50	3	90	250	375.0	529
F8	Clover	0.71	25-Jan	49-50	3	90	250	375.0	529
F9	Shogerbeet	1.25	25-Jan	48-49	3	100	250	416.7	333
F10	Artichoke	0.42	26-Jan	48-49	2	70	250	291.7	700
F11	Clover	0.58	25-Jan	49-50	3	80	250	333.3	571
F12	Shogerbeet	0.42	25-Jan	48-49	3	40	250	166.7	400
F13	Shogerbeet	0.42	25-Jan	48-49	3	40	250	166.7	400
F14	Wheat	0.33				30	250	125.0	375
F15	Clover	0.33	2-Jan	48-49	2	50	250	208.3	625
F16	Wheat	0.29				30	250	125.0	429
F17	Artichoke	0.54	26-Jan	48-49	2	75	250	312.5	577
F18	Artichoke	0.50	26-Jan	48-49	2	75	250	312.5	625
F19	Wheat	0.29				30	250	125.0	429
F20	Clover	0.29	2-Jan	48-49	2	40	250	166.7	571
F21	Wheat	0.50				40	250	166.7	333
F22	Clover	0.50	2-Jan	48-49	2	60	250	250.0	500
F23	Wheat	0.58	2-Jan	47-48	2	40	250	166.7	286
F24	Artichoke	0.42	2-Jan	47-48	2	75	250	312.5	750
F25	Wheat	1.25				120	250	500.0	400
F26	Shogerbeet	0.50	25-Jan	48-49	3	45	250	187.5	375
F27	Shogerbeet	0.50	25-Jan	48-49	3	45	250	187.5	375
F28	Wheat	0.50	26-Jan	49-50	2	50	250	208.3	417
F29	Shogerbeet	0.33	25-Jan	48-49	3	30	250	125.0	375
F30	Artichoke	0.50	26-Jan	48-49	2	70	250	291.7	583
F31	Shogerbeet	0.50	12-Oct	34-38	2	40	250	166.7	333
F32	Artichoke	0.50				75	250	312.5	625

10.7 Appendix-G . Soil physical and chemical analysis

Table G-1. The physical analysis of the soil from 4-location at different depths of the experimental field.



Soil Texture Analysis

Drainage Research Institute

Area: د/ مجدى رشاد

Receiving Date: 2-Feb-2025

No.of Samples: 12عينه

S.NO.	Code	Depth (cm)	% Sand	% Clay	% Silt	Soil Texture
1	OW1	0-40	12.00%	66.00%	22.00%	CLAY
2		40-80	18.00%	62.00%	20.00%	CLAY
3		80-120	22.00%	60.00%	18.00%	CLAY
4	OW8	0-40	12.00%	62.00%	26.00%	CLAY
5		40-80	20.00%	58.00%	22.00%	CLAY
6		80-120	22.00%	60.00%	18.00%	CLAY
7	OW6	0-40	22.00%	58.00%	20.00%	CLAY
8		40-80	18.00%	60.00%	22.00%	CLAY
9		80-120	12.00%	50.00%	38.00%	CLAY
10	OW3	0-40	30.00%	48.00%	22.00%	CLAY
11		40-80	22.00%	46.00%	32.00%	CLAY
12		80-120	18.00%	52.00%	30.00%	CLAY

Table G-2. The chemical analysis of the soil from 8-location at different depths of the experimental field befor irrigation improvement.

	S.NO.	Code	Depth (cm)	pH	EC mS/cm	ESP	Cations milli equivilent /Liter				Anions milli equivilent /Liter			
							Ca	Mg	K	Na	Cl	SO4	HCO3	CO3
Before Irrigation Improvement	1	OW1	0-40	7.7	3.49	11.14	6.21	7.02	0.82	24.05	21.85	11.26	5	0
	2		40-80	7.7	2.60	9.55	4.32	4.99	0.65	17.28	17.10	5.14	5	0
	3		80-120	7.8	2.10	6.81	4.21	4.61	0.56	12.20	13.97	3.62	4	0
	4	OW2	0-40	7.8	3.37	8.93	5.67	7.07	0.84	18.94	20.90	6.62	5	0
	5		40-80	7.8	1.89	6.99	2.97	3.40	0.49	10.61	11.40	3.08	3	0
	6		80-120	7.9	1.70	6.95	2.81	3.32	0.52	10.36	10.93	3.08	3	0
	7	OW3	0-40	7.9	2.50	9.49	4.37	4.69	0.71	16.96	16.15	6.58	4	0
	8		40-80	7.9	2.00	6.02	4.05	4.28	0.48	10.61	12.35	3.08	4	0
	9		80-120	7.8	1.50	6.55	2.70	3.18	0.45	9.62	10.45	2.49	3	0
	10	OW4	0-40	7.8	3.69	9.62	6.48	7.73	0.82	21.50	23.75	7.79	5	0
	11		40-80	7.8	2.60	9.81	4.32	4.50	0.71	17.28	16.72	6.09	4	0
	12		80-120	7.8	2.20	7.10	4.21	4.71	0.60	12.75	13.30	4.97	4	0
	13	OW5	0-40	7.8	2.81	9.78	4.59	4.97	0.80	17.94	18.05	5.24	5	0
	14		40-80	7.7	2.60	9.49	4.43	4.64	0.72	16.96	16.63	6.12	4	0
	15		80-120	7.7	2.31	7.08	4.21	4.76	0.55	12.75	15.20	3.07	4	0
	16	OW6	0-40	7.9	3.60	10.35	5.94	7.29	0.81	22.34	23.75	7.63	5	0
	17		40-80	7.8	2.50	9.49	4.59	4.48	0.76	16.96	16.15	5.63	5	0
	18		80-120	7.8	2.10	7.38	3.51	4.09	0.56	12.20	13.30	3.06	4	0
	19	OW7	0-40	7.8	3.90	10.59	6.53	8.12	0.84	24.05	25.65	8.89	5	0
	20		40-80	7.8	2.80	9.50	4.81	4.95	0.72	17.61	18.05	5.03	5	0
	21		80-120	7.8	2.10	7.31	4.05	4.04	0.57	12.47	13.40	3.74	4	0
	22	OW8	0-40	7.9	3.10	9.34	5.13	6.14	0.71	18.60	19.95	5.63	5	0
	23		40-80	7.9	2.50	9.55	4.48	4.49	0.67	16.96	15.68	6.92	4	0
	24		80-120	7.9	2.00	7.21	3.46	3.80	0.54	11.66	12.35	3.10	4	0

Table G-3. The chemical analysis of the soil from 8-location at different depths of the experimental field after irrigation improvement.

	Sample	Code	Depth	pH	EC	ESP	Cations milli equivilent /Liter				Anions milli equivilent /Liter			
					mS/cm		Ca	Mg	K	Na	Cl	SO_4	HCO_3	CO_3
After Irrigation Improvement	1	O-W-1	0-40	7.9	2.90	6.51	9.90	7.30	0.33	16.34	14.25	16.62	3	0
	2		40-80	7.8	3.65	6.63	8.80	11.10	0.22	17.87	16.82	17.17	4	0
	3		80-120	7.9	2.92	9.44	7.40	3.70	0.17	18.66	16.06	8.88	5	0
	4	O-W-2	0-40	7.8	4.09	18.80	4.70	7.20	0.15	40.37	42.56	1.85	8	0
	5		40-80	7.8	3.03	12.31	4.30	4.00	0.15	21.14	19.00	3.58	7	0
	6		80-120	7.8	2.81	9.27	3.80	7.70	0.12	18.66	16.82	7.47	6	0
	7	O-W-3	0-40	7.7	2.56	7.19	5.00	3.80	0.12	12.81	11.50	5.24	5	0
	8		40-80	7.7	2.31	5.91	8.60	2.70	0.08	12.16	14.25	3.28	6	0
	9		80-120	7.7	2.15	6.30	5.40	2.70	0.11	10.90	10.26	1.85	7	0
	10	O-W-4	0-40	7.8	2.20	7.04	4.20	7.00	0.11	14.17	13.02	7.47	5	0
	11		40-80	7.7	2.72	7.57	8.40	4.60	0.16	16.34	17.10	8.40	4	0
	12		80-120	7.8	2.52	8.89	4.60	2.60	0.12	14.17	14.73	3.77	3	0
	13	O-W-5	0-40	7.9	1.59	6.06	3.10	3.80	0.15	9.71	9.98	4.78	2	0
	14		40-80	7.8	2.28	10.33	3.20	2.70	0.13	14.88	14.82	1.09	5	0
	15		80-120	7.8	2.60	18.03	3.00	1.90	0.11	24.68	22.42	3.27	4	0
	16	O-W-6	0-40	7.7	2.75	6.60	5.00	7.60	0.15	14.17	13.87	10.05	3	0
	17		40-80	7.7	4.22	17.41	7.40	6.80	0.18	40.37	40.66	10.09	4	0
	18		80-120	7.6	2.57	8.97	5.30	4.10	0.15	16.34	14.16	6.73	5	0
	19	O-W-7	0-40	7.6	2.59	3.66	8.80	9.20	0.16	10.29	11.88	11.57	5	0
	20		40-80	7.3	2.24	7.97	5.10	6.70	0.12	16.34	14.82	10.44	3	0
	21		80-120	7.7	2.44	7.36	8.50	5.20	0.12	16.34	15.01	11.15	4	0
	22	O-W-8	0-40	7.7	1.99	5.69	5.70	4.00	0.16	10.90	9.98	4.78	6	0
	23		40-80	7.8	1.93	4.30	6.10	6.30	0.13	9.71	9.69	5.55	7	0
	24		80-120	7.8	1.82	6.08	4.30	3.40	0.10	10.29	9.50	0.59	8	0

Table G-3. The chemical analysis of the water from 5-location (irrigation, drainage and groundwater) of the experimental field.

CHEMICAL AND BIOLOGICAL ANALYSIS OF WATER SAMPLES

Area:	د/ مجدى رشاد
Receiving Date:	45690
No.of Samples:	5عينات

S.NO.	Location	pH	EC	SAR	Adj.SAR	RSC	Cations m equiv /L			Anions m equiv /L			TDSCalculated		
			mS/cm				Ca	Mg	K	Na	Cl	SO4	HCO3	CO3	mg/l
1	IRR.Canal-800	7.8	1.78	6.138	6.5337	0.00	2.916	3.356	0.505	10.87	9.785	4.666	3	0	1122.4
2	IRR.Canal-1200	7.8	0.99	4.0857	3.9853	0.00	1.62	2.3	0.2676	5.72	4.275	3.2105	2	0	629.89
3	Drainage-1	7.8	6	12.3	14.036	0.00	8.64	12.43	0.811	39.925	42.275	12.579	5	0	3679.8
4	Drainage-2	7.7	5.5	12.559	14.021	0.00	7.02	12.09	0.7076	38.82	38.475	11.476	5	0	3426.1
5	Ground water	7.7	5.3	12.532	14.002	0.00	6.75	11.38	0.5974	37.731	37.525	10.466	5	0	3300.6