Food and Agriculture Organization of the United Nations

Improved Water Resources Monitoring System/ Integrated Water Resources Management at regional level in Lebanon

WATERSHED PROTOTYPE MONITORING SYSTEM

The project

In many areas of the world, including the Near East and North Africa (NENA) region and Lebanon, sustainable and reliable delivery of water for irrigation and municipal use has become increasingly complex. This issue also extends to affect the protection of the ecosystems from water pollution. Particularly, if the overall demand is outstripping supply, the delivery of water is often less about engineering, although it is still required. The issue is more often related to the governance of the resources to manage and protect them from pollution and over-abstraction, resolve conflicts over water, and ensure rights to water are respected. It is also about understanding water flow pathways in complex river basin systems. This is where water monitoring and accounting can play a crucial role to help water management institutions in managing complexity in light of the challenges facing the water sector.

In this context, the Food and Agriculture Organization of the United Nations, in collaboration with the North Lebanon Water Establishment (NLWE), which represents the Ministry of Water and Energy, is implementing the GCP/LEB/029/SWI project **'Improved Water Resources Monitoring System/Integrated Water Resources Management at regional level in Lebanon'**, funded by the Swiss Government. The main objective of the project is to strengthen Lebanon's water institutions improving their performance at regional level, thereby helping them to address the sector challenges for sustainable use of water resources.

In particular, **Output (3)** of the project **'Watershed Prototype Monitoring System developing'**, aims at empowering management authorities, and enhance their capacity to operate the developed monitoring system - including preparation of a business plan to operate it, through:

- Linking the flow measurement devices to a central data collection unit in the NLWE
- Developing a prototype monitoring system and train the professional staff of the NLWE on this system.

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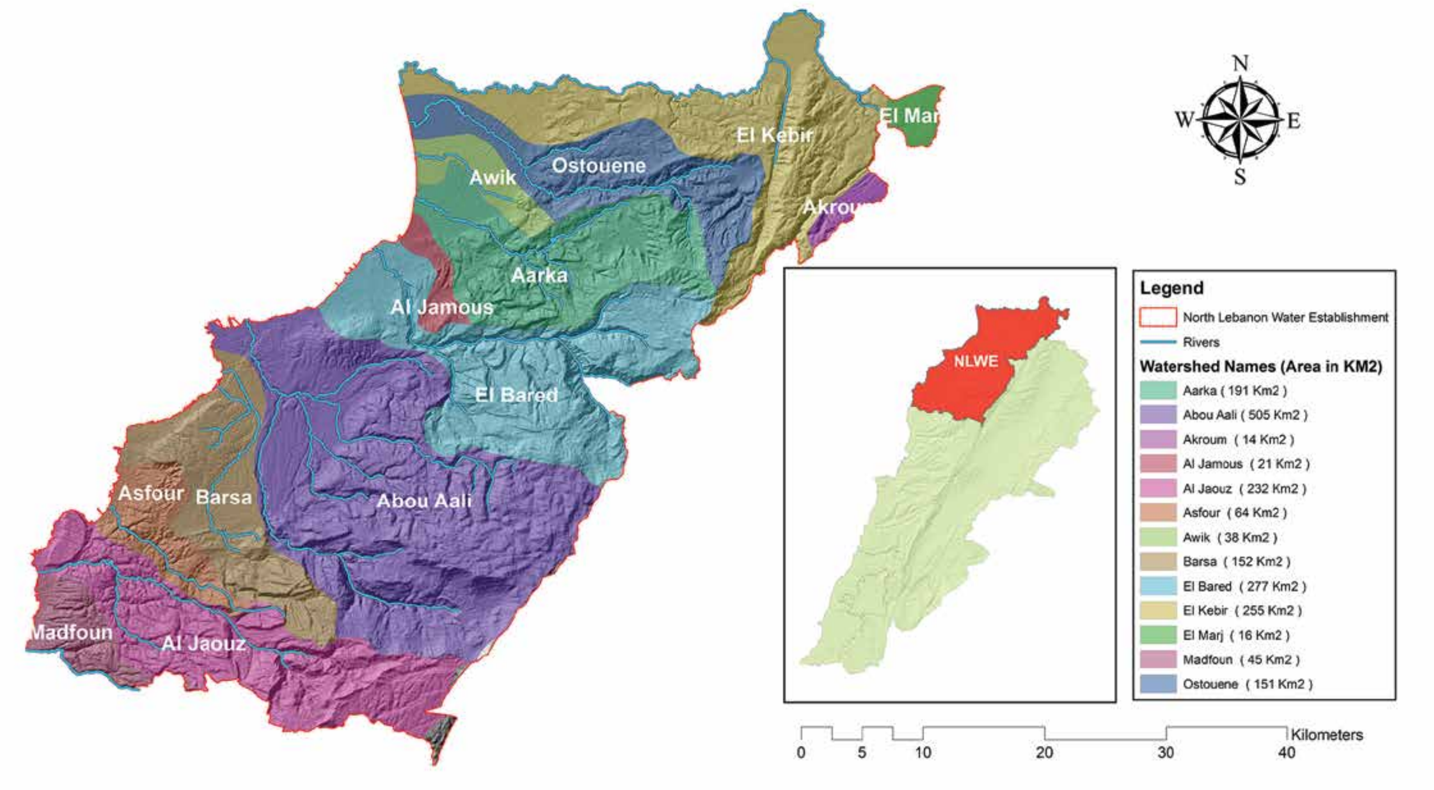
The command area

The project follows a pilot approach, whereby the regional Water Establishment has been selected through a rapid assessment driving to the greatest possible impact. Based on well-defined selection criteria, including water availability, level of irrigation development, water quality status, scope for institutional capacity building and scalability, the North Lebanon Water Establishment (NLWE) was chosen. The authority of the establishment extends to the complex hydrological systems and diverse topography of Northern Lebanon. Amongst the involved watersheds, El-Bared is the second largest one, with its 277 km^2 catchment area and 24 km length.

Figure 1: Watersheds in North Lebanon



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The project design captures two adjacent open-canal systems supplied by El-Bared water dam, namely Akkar and El-Minieh. Groundwater resources are monitored in lands at higher altitudes such as Markabta and Nabi Youchaa villages that are not covered by the surface-water network.

The selected command area has a significant agricultural potential. In spite of this, the agricultural sector is stressed by the increased demand for municipal use, the underperforming irrigation canal systems and the contamination of urban water supplies. In addition, Lebanon is severely impacted by climate change. The projections show that in the densely populated urban areas on the coastal side, temperatures will increase by around 1.2°C-1.7°C and the rainfall pattern will decrease by 10-20% by 2040. As a result, both physical and economic water scarcity will be aggravated in the area.

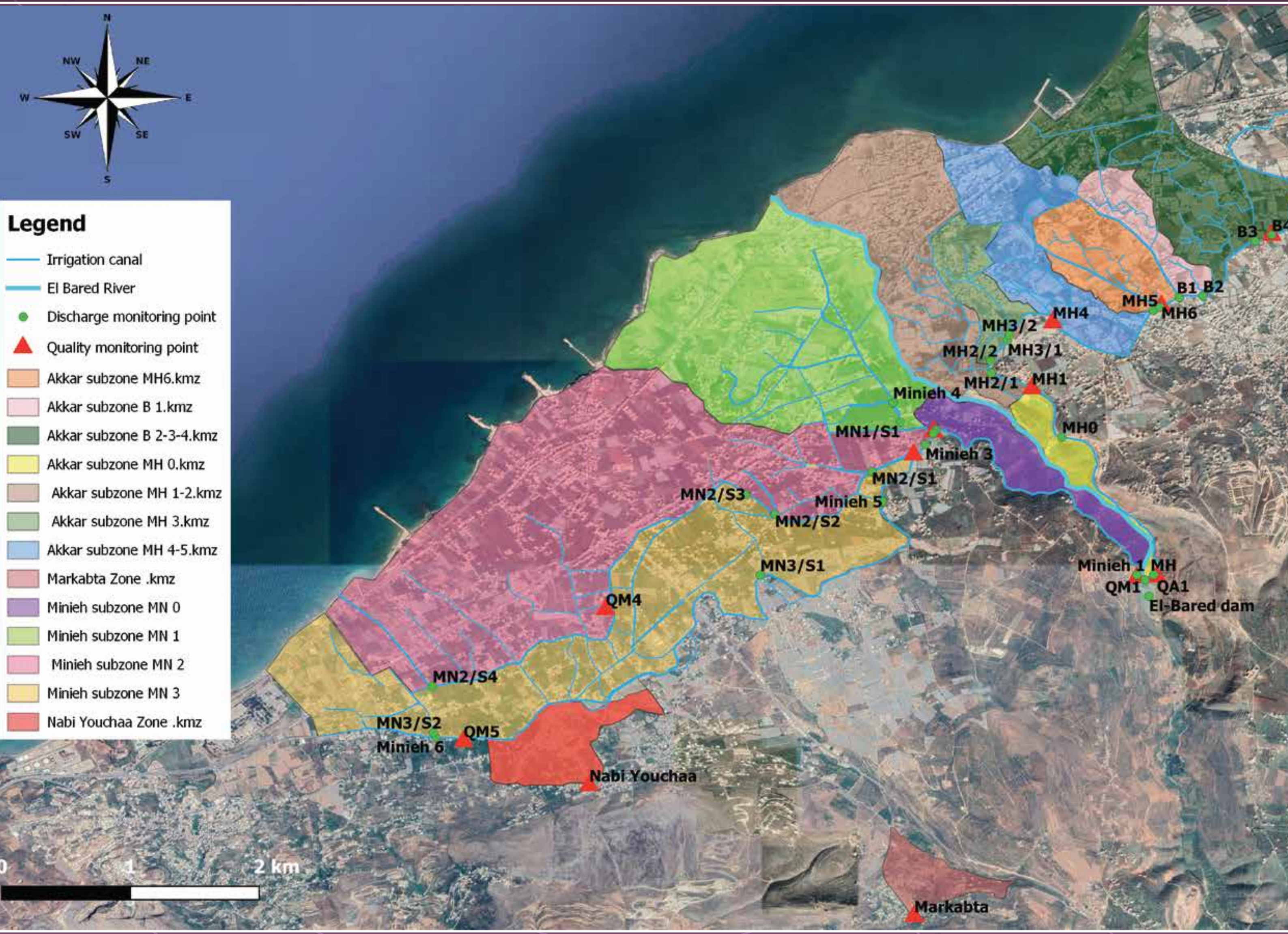
Water monitoring systems have multiple advantages to enhance water resource management. Water monitoring helps to create balance between demand and supply, preserve natural resources, facilitate the reliable and equitable water distribution, identify bottlenecks in system performance and, indirectly, improve preparedness to extreme climatic events. Nevertheless, water monitoring is particularly challenging in public open-canal system, whereas different factors can impede the proper water management. Such factors are the intervention of water users, the weather or the modified system design. This diverse environment requires accurate, real-time, flexible and comprehensive monitoring systems that can immediately respond these changes. Nevertheless, the complexity of such systems raises some concerns. Many available approaches are one-dimensional, meaning that they are developed to monitor only one or few water parameters, i.e. discharge or water quality. However, multidimensional systems are more desirable as they provide combined measures for water resource assessment, while at the same time enhance integrated water resource management (IWRM). The NLWE has yet not established either data acquisition or complex monitoring system. The developed integrated monitoring system, called Prototype Monitoring System (PMS), started from the scratch and evolved into a state-of-art tool to support decisions.

The approach

The project combines two complementary methods for data acquisition. On one hand, it provides in-situ devices for data acquisition of discharge, water quality and weather. On the other hand, it applies enhanced remote sensing technology for measuring agricultural water demand. The integrated and computerized PMS is developed to collate, analyse and report the information coming through these methods. This integrated monitoring system extends to both surface- and groundwater resources. The system design spans across different disciplines, including discharge measurement, water quality analysis, water demand estimation and weather monitoring. Adding to that, the PMS integrates an asset management module that enables the inventory, the condition and the criticality scoring of irrigation assets and the rigorous business planning. Given the fact that the open-canal system is exposed to damages, the asset management module supports decision-makers in planning the adequate operation and maintenance (O&M) of the system and the required budget.

The PMS follows a water balance approach, whereas water supply and demand are matched. This approach is suitable for identifying and evaluating the potential over-supply and/or water scarcity at different points of the system. This is an important feature as it allows for the performance assessment at both overall system and sub-system level. At a first step, the hydraulic water balance is measured between the inlet and the tail-end of the irrigation system at main canal level. In addition, agricultural water balance is measured between the water supply from the main canal and the water demand of the agricultural sub-zones.

Figure 2. Monitoring sites and sub-zones in the command area



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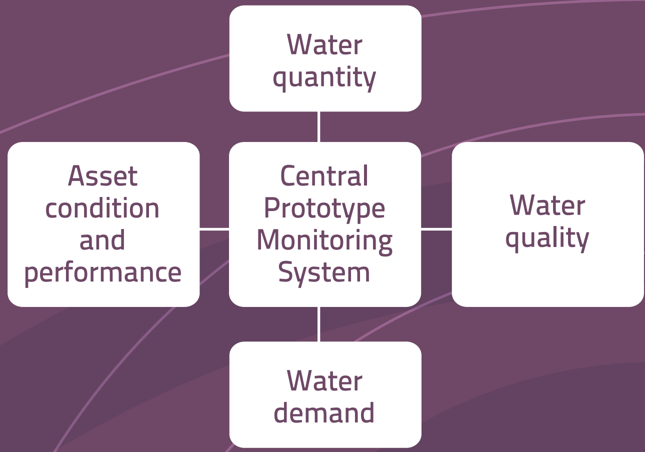
The PMS consists of four dimensions: water quantity, water quality, water demand and asset management.

These dimensions involve individual data acquisition sub-systems that are interconnected and integrated in the PMS.



1. Water quantity – discharge monitoring

In order to have real-time discharge data, a complex data acquisition system is employed in the command area. The key monitoring sites are identified through a multicriteria analysis that ensures the accuracy and relevance of measured data. The discharge is measured along the irrigation system and within the sub-zones. The command area has 21 discharge monitoring sites equipped with combined measurement techniques. Multiple techniques are proposed for each site as stop-gap strategy. In the case of measurement failure by a monitoring device, the other techniques shall ensure the measurement continuity, thus preventing any significant data loss. The discharge data is transferred both remotely and manually to the databases of the PMS software back-end.

Figure 3. Pressure sensor and datalogger

The following complementary techniques are installed in the command area:

- Pressure sensors: real-time and in-situ monitoring devices that measure and log water level and temperature in 30-minute frequency.
- Surface structure image velocimetry (SSIV) technology: a non-traditional, non-intrusive method measuring velocity through water surface observation.
- Electromagnetic flowmeters: highly flexible and in-situ devices for flow velocity measurement of groundwater sources.
- Parshall flumes: manual discharge measurement structures for secondary and tertiary canals.

2. Water quality monitoring

A context-tailored protocol is developed for quality monitoring of agricultural water. The monitoring sites are selected through a multicriteria assessment that considers the probability of pollution, the relevance of the location, and the resource constraints. The project equipped and trained professionals in four nearby laboratories (Tripoli, Halba, Donnieh, and Minieh) to carry-out the regular quality analysis and reporting. Given the fact that water quality is heavily deteriorated by nonpoint source pollution, the site locations capture the entire system from source to users. The irrigation system is rather a peri-urban surrounded by houses, so any contamination might have direct effects on livelihoods. Therefore, a centralized and decentralized result analysis is of vital interest, as heavy contamination requires immediate actions on the ground.

The relevant quality parameters and their threshold values are defined within three categories: physical, chemical and bacteriological parameters.

Figure 4: Monitored water quality parameters

Physical
- Turbidity
- Colour and smell
- Temperature

Chemical
- Electrical conductivity and PH
- Soluble cations
  - Natrium
  - Potassium
  - Calcium
  - Magnesium
- Soluble anions
  - Bicarbonate
  - Chlorine
  - Nitrate
  - Sulfate
- Heavy metals
  - Lead
  - Iron
  - Zink
  - Copper
  - Manganese
  - Nickel

Bacteriological
- Total coliform
- Fecal coliform
- E-coli

The crafted protocol defines the frequency, the sampling process, the required resources and equipment, and the analysis procedure. Professionals conduct sampling at monthly frequency in on-season and at bimonthly frequency in off-season. The samples are analysed in the laboratories and results are transferred to and uploaded in the PMS.

Figure 5: Laboratory of water quality analysis

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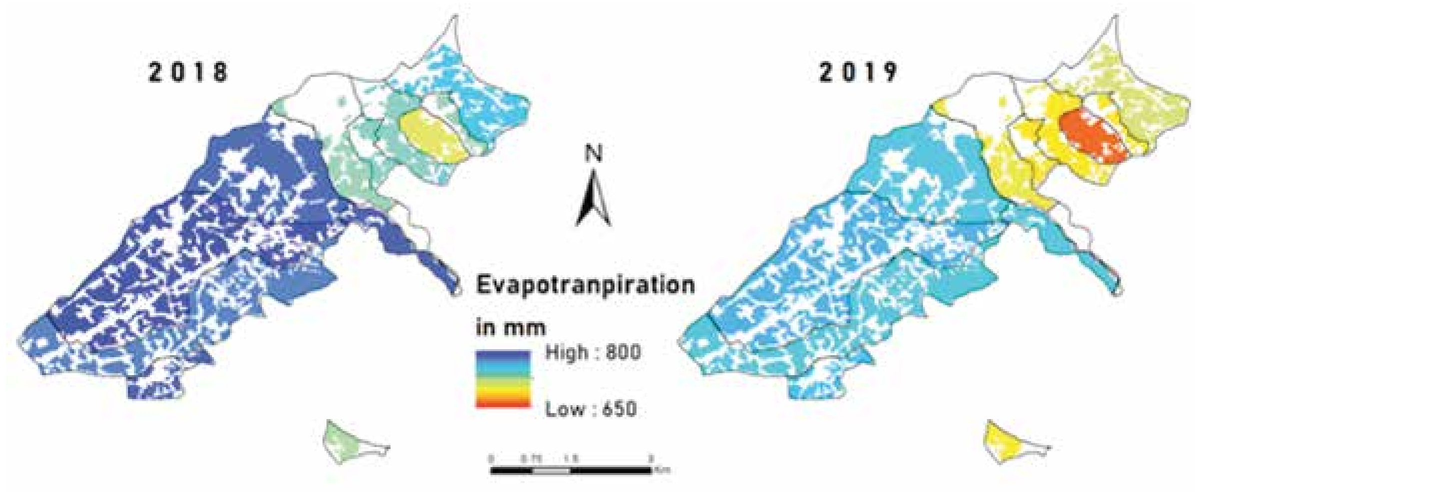
3. Water use - agricultural water demand

The project implemented an automated system for water productivity scoring. The system monitors a number of indicators related to the water use through remote-sensing. Such indicators are the land cover/land use, normalized difference vegetation index (NDVI), biomass, evapotranspiration and water productivity. The evapotranspiration-based water demand gives realistic information on the required water for irrigation at sub-zone level. Therefore, the water demand-related values are transferred to the PMS and processed to match the water supply.

Figure 6.Evapotranspiration map in the command area



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4. Weather parameters

The command areas are equipped with an agro-meteorological stations. The in-situ monitoring stations record real-time weather parameters and canopy cover, and calculate evapotranspiration. The stations are connected to the automated system for water productivity monitoring. As rainfall is considered a substantial component of water supply, precipitation values are transferred to the PMS and computed in the water balance calculation.

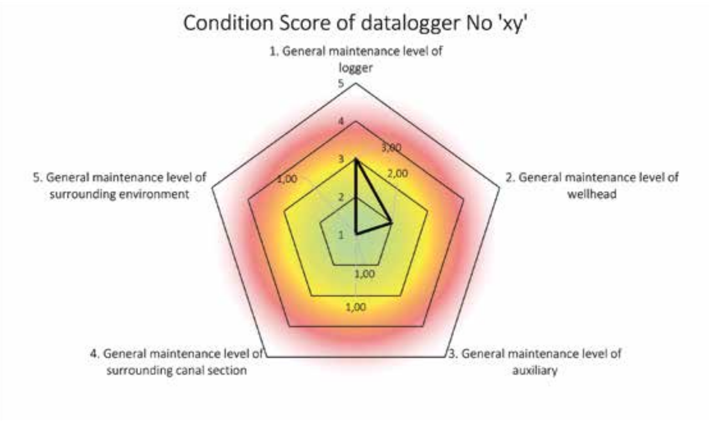
5. Asset management - business planning

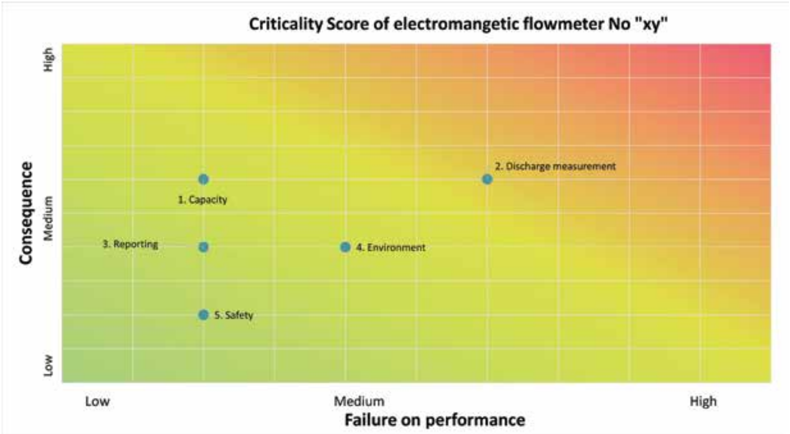
The embedded asset management module in the PMS consists of four interrelated and successive components: inventory together with O&M guidelines, condition scoring, criticality scoring and life-cycle calculation. The asset management module is a necessary building block for the efficient, sustainable and economic management of irrigation system. The module is designed for the individual assessment of irrigation assets. Site professionals are responsible to carry out the inventory and scoring exercise at asset-specific timestep. Their findings are transferred to the central office for revision and feedback, and upload into the PMS.

Figure 7: Asset inventory in the command area by expert group and users

An ID number is associated to each asset and an inventory protocol is appended to the different asset types. Scoring guidelines are crafted for condition and criticality analyses to allow for unbiased and rigorous assessments. The scoring history provides a realistic picture on the trends in the condition and criticality of the assets, which is a particularly important information since an insufficient water supply might be the reason behind an overall scarcity of available water resources and/or poor performance of the system. The asset management module gives information about the latter.

Figure 8: Condition and criticality scoring of different asset types

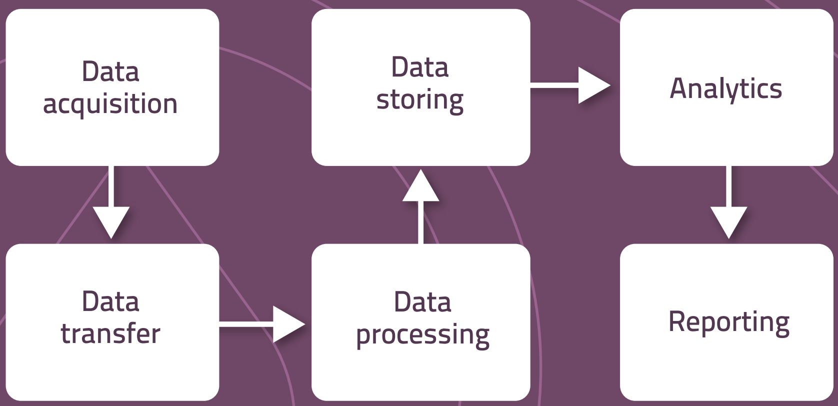




The outcome

The great challenge of the PMS is to approximate the different data qualities and collate it in the most integrated way. The PMS must, then, compress the data and provide a common ground for comprehensive and aggregated analytics and visualization. However, the data conversion into information follows identical steps from data acquisition to reporting for each data acquisition sub-system.

Figure 9: Flowchart of PMS information management



The main objective of the PMS is to provide timely information about the status of water resources for decision-makers. Although it is a tool for 360-degree assessment, each dimension (discharge, water quality, water demand, and asset management) can be operated independently. As a result, the PMS remains functional in those cases when data inconsistency or information loss occurs in a specific monitoring system. The PMS provides both numeric and chart-based indicators to explain and visualize the performance of water resource management. However, the visualization is flexible and provides different options of chart types. Both the narrative and charts can be reported and downloaded, therefore, the PMS functions also as a rich pool of information source and a basis for further quantitative analyses.

In order to more enhance the information pool, the PMS deploys a map-view as user interface, which can complement the monitoring results with spatial information.

Figure 10: Sites map view

Map conforms to United Nations Lebanon map, 01.01.2010

Source: Google Earth Pro v7.3.3.7786 (2020). Lebanon. 34°29'30 N, 35°58'33 E, elevation 40 m modified to comply with UN. 2020. Map of Lebanon, 4282 United Nations January 2010. https://www.un.org/Depts/Cartographic/map/profile/lebanon.pdf

Water balance between supply and demand

Water balancing is a twofold application: a 'horizontal" or hydraulic water balancing that measures the difference in water volumes from the source to the end of the command area; and a 'vertical" or agricultural water balance that is applied within the sub-zone level to match the crop water demand and water supply entering the zone.

Supply: The PMS visualizes the monitoring sites and provides site-specific discharge and water quality information. It stores and displays the time-series of historical data. The system detects outliers and anomalies to ensure data reliability. The time-series analysis of discharge data includes a number of computed indicators and charts, such as trend calculation, summary statistics, aggregation at different time-steps.

Figure 11: Water quantity analysis

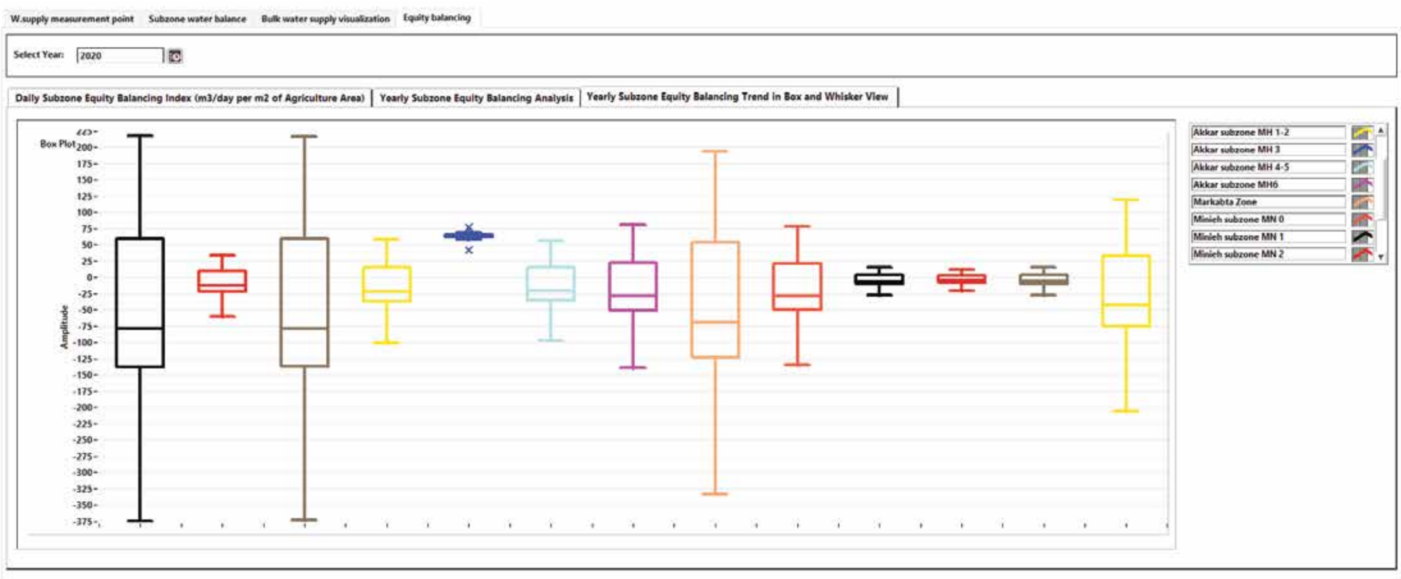
	January	February	March	April	May	June	July	August	September	October	November	December
Monthly average discharge (l/s)	NaN	NaN	NaN	NaN	NaN	863.294	NaN	NaN	NaN	NaN	NaN	NaN
Monthly maximum discharge (l/s)	0.000	0.000	0.000	0.000	0.000	893.000	0.000	0.000	0.000	0.000	0.000	0.000
Monthly Minimum discharge (l/s)	0.000	0.000	0.000	0.000	0.000	846.000	0.000	0.000	0.000	0.000	0.000	0.000
Monthly s.dev. (l/s)	-0.000	-0.000	-0.000	-0.000	-0.000	12.907	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000

Demand: The evapotranspiration-based water demand is transferred from a single standing software called 'automated water productivity scoring system". The automated system and the PMS are implemented as two single-standing software with the possibility of data transmission amongst each other. This implementation design allows a better scalability and flexibility of any of the software.

Agricultural water balance: The calculation follows the FAO-IPTRID definition, whereas water balance is expressed as the ratio of net water requirement and water supply. The agricultural water balance is calculated at sub-zone level from the supply entering the sub-zone and the water requirement of the specific cropping pattern. The equation is dynamic, meaning that it indicates the water over-supply and water scarcity with different signs. Values closer to 100 percent indicate a better balance between supply and demand.

Hydraulic water balance: The calculation has two main indicators regarding the hydraulic water balance. The first indicator is related to the overall balance along the system. It compares the water supply at the headworks with the water supply at the tail-end of the main canal. The second indicator, called 'equity balancing', measures the discharge per land unit in the specific sub-zones. If the discharge per land unit is significantly different amongst the sub-zones, the equity in distribution is considered poor.

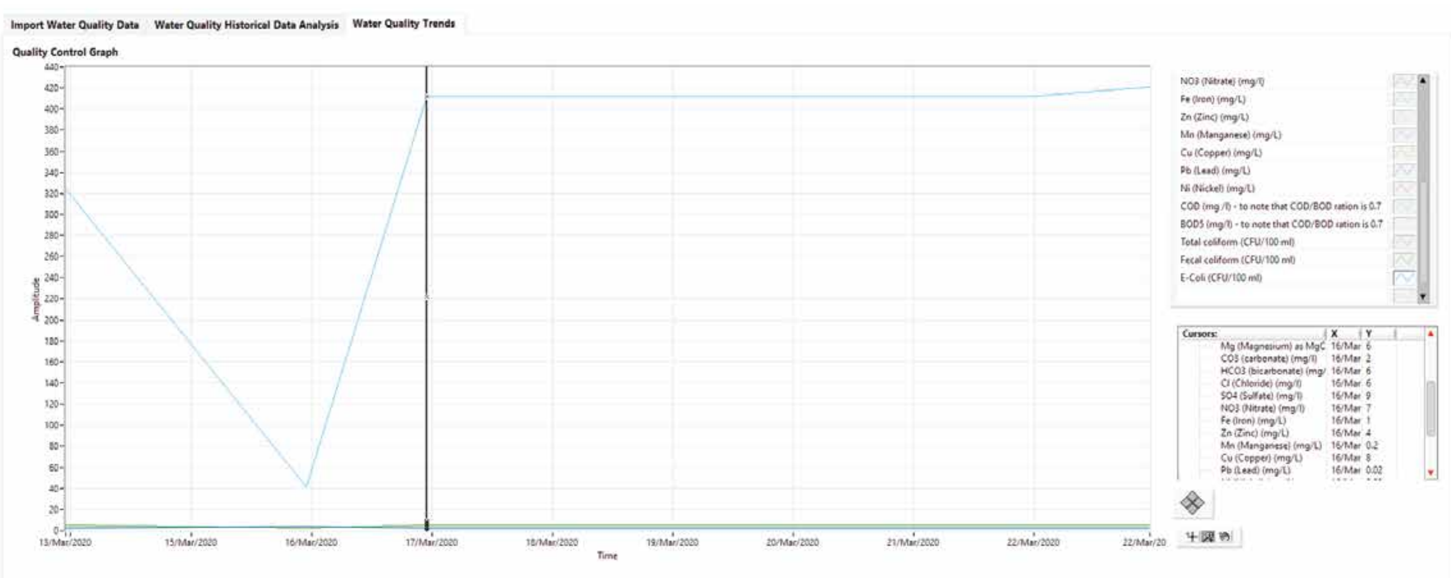
Figure 12: Comparison of equity in discharge amongst sub-zones



Water quality

The water quality module collects and visualizes all quality parameters per each monitoring site. As the quality sampling and analysis requires specific equipment and expertise of the relevant laboratories, the readily available information is delivered to the PMS. In order to reduce the risk and the cascading effect of sever water contamination, the PMS involves a function to alert users on water quality parameters surpassing the acceptable threshold.

Figure 13: Water quality module



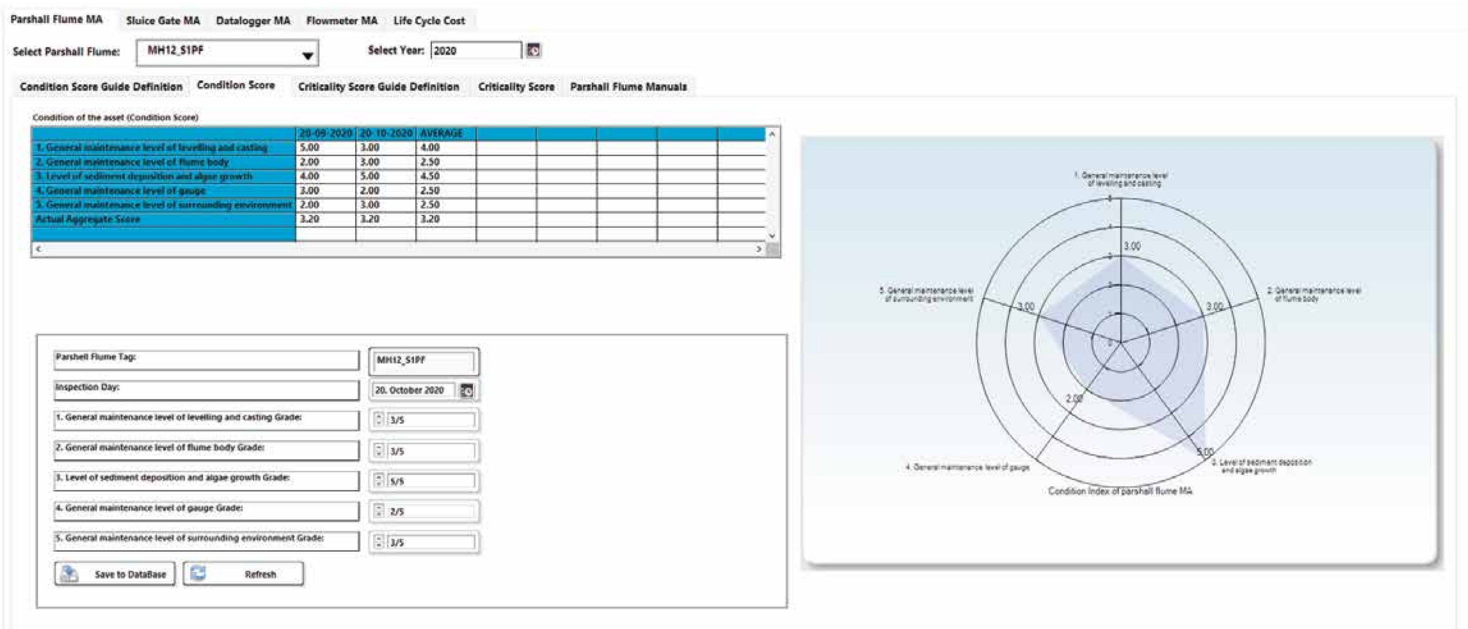
Asset management

Although the asset management consists of consecutive steps, the analysis of assets must be carried out by integrating all information. This can help identifying causal relationship between a particular external or internal factor and the status of the asset. Such relationship is often not linear; therefore, the asset management module puts emphasis on the rigor of assessment through a pre-defined protocol.

Inventory and O&M guidelines: An inventory protocol and O&M guidelines are developed for each asset type to ensure the timely and proper management. The protocols and guidelines are built on the manufacturer's recommendations and tailored to the local context.

Condition and criticality assessment: Given the diverse types of assets and their distinct objectives, the condition and criticality of these assets are assessed through composite indicators. Such composite indicators consist of four or five asset features. The asset features are scored through a 5-point Likert scale, and the sub-scores are aggregated in an overall score. Each feature plays a major role in ensuring the intended operation. Therefore, any underperforming asset feature equally lowers the overall score. While the condition assessment deploys a single composite indicator, the criticality assessment consists of two sub-indicators: performance failure and consequence of failure. The sub-scores and overall scores are displayed in numeric forms and visualized in charts. The crafted methodology for condition and criticality assessment provides a stocktaking exercise of the assets and inform decision-makers about the potential deterioration of the infrastructure.

Figure 13: Water quality module



Business planning: the asset management module involves life-cycle-cost analysis (LCC) as non-traditional business planning tool. The LCC has several advantages in irrigation management such as the accurate calculation-based cost planning, annual breakdown, the ability to highlight outstanding expenses and asset-specific cost lining. The LCC is calculated per asset and added to the overall cost of asset types. Due to a lack of historical data and accurate estimates, the LCC is re-calculated on an annual basis over the lifespan of the asset. It supports decision-makers to plan costs associated with operation, regular maintenance, condition-based maintenance and re-investment. Such a business planning tool is of high importance in irrigation systems, where expensive and sophisticated devices are deployed.

The lessons learned on best practices

The first phase of the project drew lessons from the design and implementation of the prototype monitoring system. Such lessons can be categorized under three dimensions: water resource monitoring, centralized management and planning and preparedness.

Water resource monitoring	Centralized management	Planning and preparedness
"If it cannot be measured, it cannot be managed": Water monitoring is the cornerstone of a more sustainable natural resources management. Integrated and multidimensional monitoring systems are more desirable, as they are in line with the principles of integrated water resource management and are able to detect causal relationships between external factors and the status of water resources. Water resource monitoring and the applied indicators must be in line with environmental, socio-economic and agricultural objectives. The concept of no-one-size-fits-all applies to water monitoring systems as well, thus, requiring context-tailored system design. Well-crafted monitoring systems are built on accurate measurement instead of estimates. In order to reach sustainability, the system must be flexible enough for future scaling-out. Comprehensive monitoring systems must not only acquire but collect, store, collate and analyse data to provide readily available information.	The different monitoring dimensions require centralized management that compresses and interprets data for decision-makers. The centralized management does not necessarily contradict participatory approaches, as obtained and reliable information should be re-distributed and shared with users. Central management is more likely able to target relevant audiences and share relevant information with them. As water resources are key to development, the centralized coordination is of crucial interest to provide equitable and reliable water supply to all users.	Water resource monitoring enables the planning of water resources and preparedness to extreme events. Good allocation and distribution rules can be developed only if it is based on reliable measurement, therefore, monitoring systems are the first necessary building blocks of planning. Evidence-based planning enables the efficient use of water resources and the elimination of potential conflicts amongst competing demands. Monitoring systems involving well-defined indicators, e.g. water scarcity, help avoiding the devastating consequences of climate change.

Figure 15: Management meeting

Lessons-learnt related to water management, water monitoring, and O&M of irrigation system are critical to maintain the achieved results. Training of professional staff is key to reach long-term sustainability of established monitoring system and maintain gains.

The long-term vision of the project anticipates the scaling-up of implemented and demonstrated practices both within the boundaries of the NLWE, and beyond, extending to other establishments. Dissemination is a built-on complex strategy with multiple publication outlets to reach wide audiences. The scaling-up is phased into three successive steps:

Piloting	▪ Select pilot sites based on multiple-criteria ▪ Design and implement novel approaches ▪ Draw lessons from implementation
Learning	▪ Train professional staff on traditional and non-traditional methods ▪ Extend the training to potential stakeholders at national level
Scaling-up	▪ Demonstrate results and assess replicability ▪ Implement the developed approach

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