Food and Agriculture Organization
of the United Nations

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

REAL-TIME MONITORING AT KEY LOCATIONS

The project

In many areas of the world, including the Near East 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 (FAO), 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 (1) of the project 'Real time monitoring at key locations', aims at establishing a monitoring system in order to obtain discharge-related data of surface and groundwater resources. It is designed to generate a water resources information system at North Lebanon Water Establishment level (NLWE) to enhance efficient water management and resource planning through the following activities:

- selection of pilot watershed and assessment of water resources, including both surface and groundwater, in the targeted area, through remote sensing;
- provision of flow measuring equipment for each key monitoring locations;
- collection of ground-truth data and calibration of remote sensing outputs; and
- elaboration of an assessment tool to the NLWE and enhancement of its professionals' capacity on this tool.

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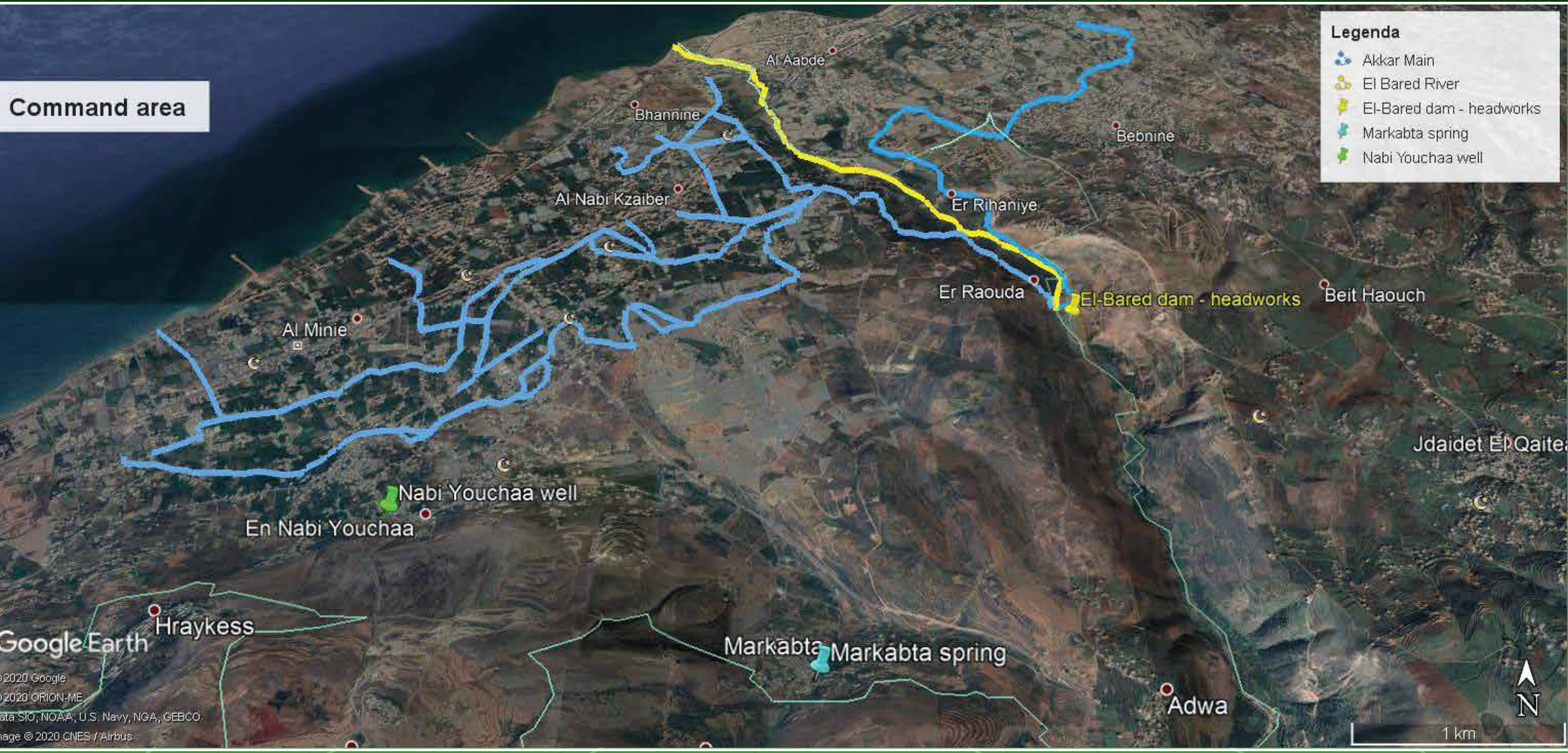
The command area

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. More specifically, the component is designed to capture two adjacent open-canal systems supplied by El-Bared water dam, namely Akkar and El-Minieh. Groundwater resources are also monitored in lands at higher altitudes, such as in Markabta and Nabi Youchaa, which are not covered by the surface-water network.

Figure 1. El Bared Watershed

Map conforms to United Nations Lebanon map, 01.01.2010



Akkar and El-Minieh irrigation schemes are only gravity-fed, supplied by surface water resources from the central core rock dam. The entry sections of the two main canals are almost identical so to enable the sufficient distribution of water to the two schemes. The three levels of the system, including main, secondary canals and final deliveries are operated manually based on farmers' request. Part of the runoff is collected in storm water drains and discharged into the Mediterranean Sea. The other part reaches the sea directly through the main irrigation infrastructure.

One of the rooted causes of the recent deteriorated condition of the schemes is the human interference, as large parts of the systems are located in peri-urban areas. The high rate of urbanization, the expansion of urban infrastructures, and consequently, the reduction of arable land overstretch the sustainable water resources use in the area. This risk raises an even higher concern considering that the rainfall pattern presents uneven and unpredictable distribution over the year. While around 85 percent of the annual rainfall is expected between November and March, the area runs almost dry during summer. Moreover, farming practices are currently changing, determining a major shift in water demand. Although the area is not characterized by high evapotranspiration rates, the expanding greenhouse production increases the need for more reliable water distribution and irrigation service. Equally worrying, agricultural lands in higher altitudes rely on precipitation and groundwater. The groundwater use has multiple purposes, including municipal and irrigation water. In the command area, two major groundwater sources are monitored under the project, the deep well of Nabi Youchaa and the Markabta spring. Although they provide only a small volume of water, they represent the single water source for the farms they serve. The use of surface and groundwater are directly interrelated. Encouraging users to rely on surface water to the highest extent is key strategy to preserve groundwater resources and avoid over-depletion.

Figure 2: Spring of Markabta

Furthermore, farmers crowded out from reliable irrigation services in coastal areas are forced to use groundwater, thus increasing the risk of salinization. Monitoring of water resources is, thus, crucial to enhance the overall water management of surface and groundwater resources through better allocation and distribution rules.

With its length of 7 km, Akkar main canal supplies an area of about 670 ha in the command area. It is lined over its full lengths, with a regular shape. The main canal, in conjunction with a small stream, runs directly into the sea. The lower reaches of the canal network are unlined, mainly go through urban areas and are gently tunnelled underground. The design of El-Minieh irrigation scheme differs from Akkar main canal. The main canal is split into two major branches running parallel. Large part of the sections, out of the 21 km total length of the network, is located in private lands. Unlike the large-capacity irrigation canals in Akkar and El-Minieh, the groundwater-fed areas are supplied through small canal networks that are directly operated by farmers.

Efficient water management and resource planning are particularly challenging in the peri-urban areas, where farmers practice multi-cropping, and double-cropping in small plots of lands. The heterogeneity of cropping pattern requires flexible water distribution that responds to this patchy spatial-temporal feature.

The approach

In order to enable more effective planning and management of water resources of the NLWE, a monitoring system, consistent with flexibility, reliability, accuracy and scalability objectives, is implemented. To design such a monitoring system, the planning phase evolved through the following steps:

Topographic survey based on inspection and remote-based tools → Synoptic mapping of hydrological boundaries → Identification of key monitoring location → Definition of irrigation sub-zones supplied by one offtake → Established hydraulic water balance along the main canal → Established agricultural water-balance within the sub-zones → Identification of monitoring means to maintain monitoring

1. The topographic survey consists of physical inspection and remote-based tools to understand the main topographical, hydrological and agricultural features. The applied surveying acquired data, such as elevation profile, mean discharges of canal sections, cropping pattern, average condition of irrigation facilities, and estimated water use of agriculture.

Figure 3: Site inspection and topographical surveying

2. The synoptic mapping of hydrological boundaries displays the identified irrigation canals, including both lined and unlined waterways. The mapping highlights, as well, the flow directions and the supplied area per section. Synoptic mapping is the first meaningful step to understand the allocation and distributional issues, and to detect the roots of inequity amongst users.

Figure 4. Synoptic map

Map conforms to United Nations Lebanon map, 01.01.2010

3. Irrigation sub-zone is defined as the adjacent irrigated area supplied by the same offtake from the main canal. The specific features encompassed by the distinct sub-zones are surveyed and monitored individually to ensure equal water service to users.

Figure 5. Command area sub-zones

Map conforms to United Nations Lebanon map, 01.01.2010

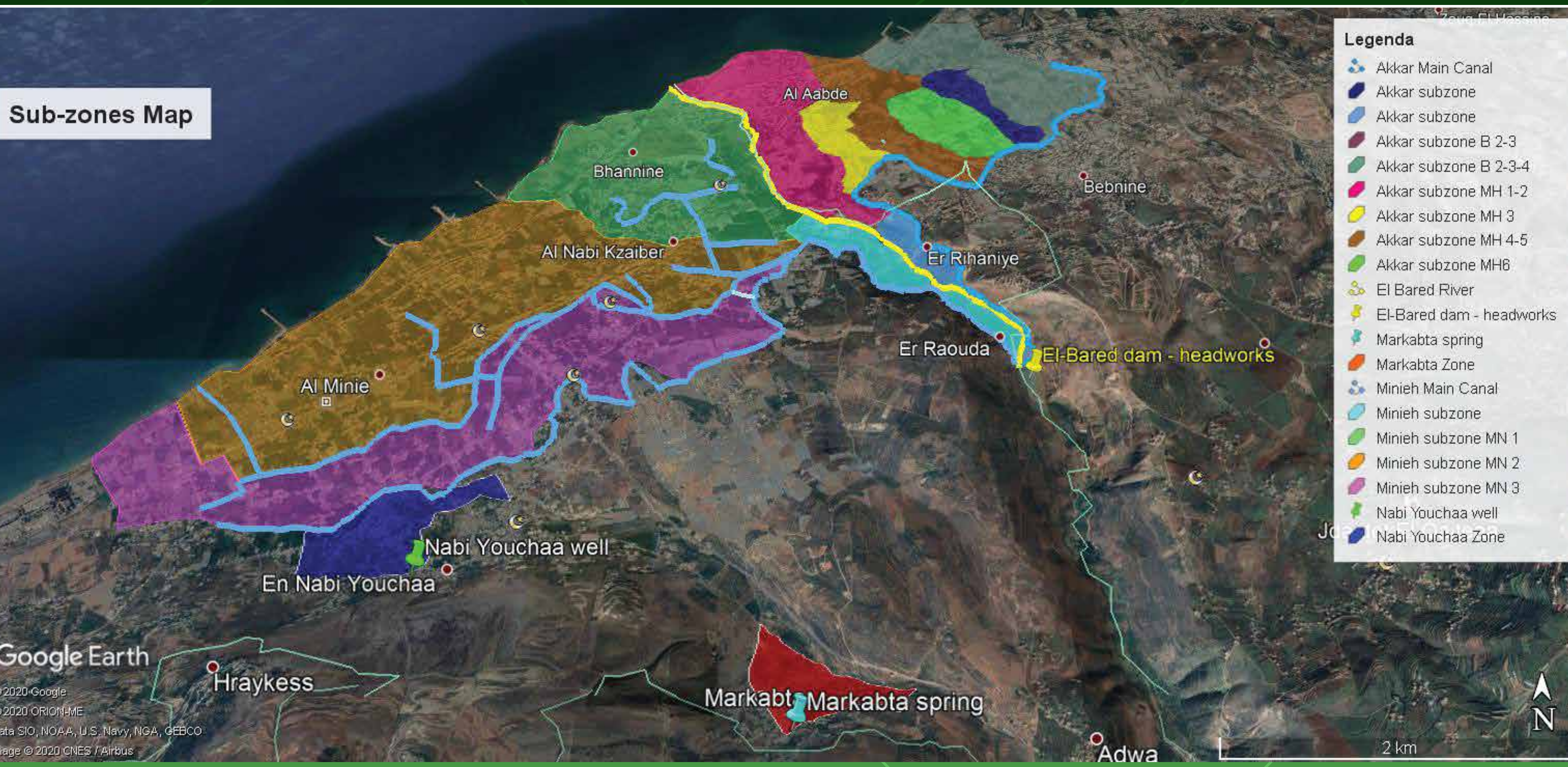


Figure 6: Sub-zone identification in El-Minieh

Figure 7: Preliminary measurements to assess site feasibility

4. The identification of key locations is based on multiple criteria to comply with the objectives of the monitoring system. The following requirements are considered when making the monitoring design:

- Measuring each significant off-takes of irrigation sub-zones by capturing upstream and downstream discharge around the off-take;
- enabling the measurement of the overall water-supply at sub-zone, irrigation zone and scheme level in the command area;
- having steady flow, regular and fix shape of canal;
- ensuring easy-to-access, visible and cleaned-up site;
- providing consistent water balance from the highest upstream point to the lowest downstream point of main canals; and
- allowing the estimation of water balance between crop water demand and water supply at sub-zone level.

5. The hydraulic water balance refers to the prevailing flow conditions along the system. This 'horizontal" water balance aims at measuring the difference in water volumes from the source to the end of the command area. However, hydraulic water balance can be established only at main canal level, whereas irrigation infrastructure enables the accurate measurement.

6. The agricultural water balance, on the contrary, is applied 'vertically" within sub-zone level by matching the crop water demand and water supply entering into the zone. In order to enhance the accuracy of gross water supply and demand, the value of effective precipitation is monitored through installed weather station in the command area. Agricultural water balance is important to ensure high-performing irrigation service in equal manner to all users.

7. The identification of monitoring means is drawn from a systematic review of available technologies. In principle, four complementary tools are selected to provide continuous measurement, validation of data storing, and sharing.

Dataloggers – pressure sensors

Selected measurement sites are equipped with 21 automated pressure sensors (15 in Akkar scheme and 6 in El-Minieh scheme). Pressure sensors are real-time monitoring devices, set to provide accurate datalogging of water level and temperature measurement in 30-minute frequency. Sensors provide actual water level recording by avoiding barometric pressure through the application of atmospheric pressure. While canal sections are calibrated and related rating curves are obtained for each measurement site, the sensors measure, validate and store data that can be transferred to users by different modalities such as cabled data extraction, wireless, and bluetooth. Water level data collected by the sensors are thus converted into discharge values to be used in the water monitoring system. In order to obtain the most accurate measurement, the techniques are adopted for canals that present specific conditions, such as stable flow, regular profile, and clean section.

Surface Structure Image Velocimetry (SSIV) technology

Surface Structure Image Velocimetry (SSIV) is a non-traditional, non-intrusive method measuring velocity directly from the surface of the flow. The method estimates flow velocity from consecutive images of the water surface based on computer vision techniques. An algorithm divides the images into interrogation areas which are compared to each other by the elapsed time. Movement pattern of objects or tracers within the interrogation area generates vectors to be processed through cross-correlation calculation to obtain the velocity. After correcting the stream velocity with the canal roughness, the discharge is estimated through area-velocity method.

The method is fully integrated into a mobile application and a web platform that measures the discharge (Discharge App), calibrates rating curve, stores, and visualizes discharge data and site conditions. The method has a number of advantages, including:

- non-intrusive, easy-to-learn;
- people-centred;
- crowd-sending option by allowing multiple members to collect data;
- integrated into Google Earth maps, thus, allowing visualization, positioning of the measurement sites on global maps and measure of parameters (area, elevation profile etc);
- discharge data and measurement videos/photos storing and data export;
- real-time and remote data collection with cloud-based storage; and
- high flexibility to adopt changes (i.e. re-location of sites).

Figure 8: Flow tranquilizers

Figure 9: Site calibration at monitoring location

Figure 10: Site calibration of SSIV technique

Within the project context, the technology has two main objectives: (1) directly involving users in discharge measurement, and (2) acting as stopgap strategy. The technology allows the involvement of direct water users and technicians who have no access to other measurement means, thus, generating information directly at user level. Moreover, it provides complementary technique to replace or supplement the other discharge measurement methods in case they fail to obtain data.

Electromagnetic flowmeter

Two electromagnetic flowmeters are installed to monitor the groundwater sources in Markabta and Nabi Youchaa. The electromagnetic flowmeter measures the flow velocity by generating a magnetic field. Based on Faraday's Law, the electromagnetic flowmeter operates by the voltage induced across the conductor. As signal voltage is dependent on the velocity, the magnetic field strength and lengths of conductor, electromagnetic flowmeters connected to properly sized pipe can continuously measure the water.

Electromagnetic flowmeters are considered a suitable technology for discharge measurement of groundwater resources, whereas pressure sensors could not be installed due to various reasons. The deep well of Nabi Youchaa cannot be frequently accessed, therefore, the water pumped into the irrigation canals should be directly monitored. However, the water level and the canals' sections of the networks in both Markabta and Nabi Youchaa are not appropriate to install pressure sensors.

Manual discharge measurement – parshall flumes

The parshall flume is a complementary technique to manually collect data along secondary and tertiary canals. It is based on Venturi principles, meaning that the reduction of the flow due to the side-walls contraction and a drop in the floor elevation generates an increase of water velocity and a change in water depth. Two possible flow conditions can be considered: free flow and submerged flow. Free flow occurs when the downstream flow condition does not affect the upstream condition, hence, discharge can be obtained by measuring upstream depth. In case of submergence, the downstream flow reduces the velocity of flume and causes backwater effect. In order to estimate the discharge, the submergence ratio must be calculated from the upstream and downstream flow depth. Each parshall flume is equipped with a manual gauge for direct reading. According to the size of the parshall flume, a discharge table is provided including the conversion of stage-discharge.

Figure 11: Obtained discharge data via Discharge App

Figure 12. Installed parshall flume in secondary canal

Figure 13. Inspection of parshall flume dimensions

The data acquisition and analysis

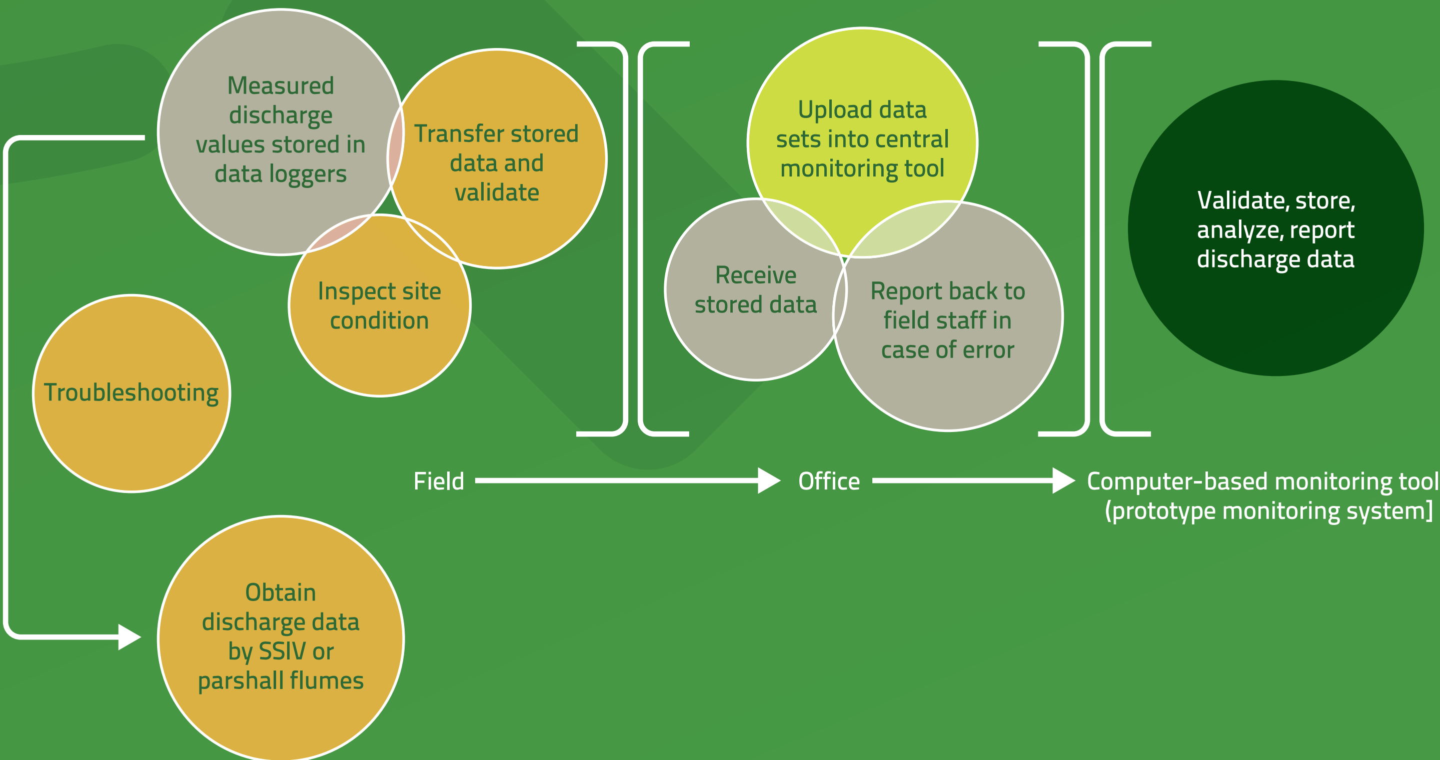
Outcomes in numbers:

- 1 310 ha irrigated area.
- 2 surface irrigation schemes.
- 2 groundwater sources.
- 11 sub-zones.
- 4 types of discharge measurement technologies.
- About 32 km length of monitored canals.
- 402 960 discharge observations per year.
- 900 l/s average discharge volume per main canal.
- Estimated 530 water users.

A customized data acquisition protocol is established for each measurement method. The protocol includes inspection form, O&M manual and data acquisition form.

Primary discharge measurement techniques, pressure sensors and flowmeters are set to record measurement every 30 minutes and store it in dataloggers. In case of inconsistency or failure to perform, alternative measurement technologies (SSIV and Parshall flumes) are activated to restore the potential data gap. After the first validation by the sensors, the discharge data is transferred to a central office and uploaded to a computer-based monitoring tool, called Prototype Monitoring System. If data inconsistency occurs, a validation process is reported to site technicians to conduct simultaneous measurement with different measurement technologies (pressure sensors and SSIV). The Prototype Monitoring System is a highly versatile tool that incorporates functions of data validation, manipulation, storing, analytics and reporting of results. Input data can be imported, and results are displayed in numeric form and visualized through dynamic charts.

Figure 14: Data collection from dataloggers



The lessons learned - best practices

The first phase of the project drew lessons from the design and implementation of the monitoring system. Such lessons can be categorized under three dimensions: water management and distribution, water monitoring, and O&M of irrigation system.

Water management and distribution	Water monitoring	O&M of irrigation system
Reliability and equity of water service must be ensured to all end-users to support high-performing agricultural production **Inequity amongst upstream and downstream farmers can be eliminated only by well-established irrigation schedule based on rigorous discharge monitoring protocol** **Better water management and distribution improves the irrigation service quality, resulting into higher users' satisfaction** **Proactive management that corresponds to users' requirement can generate income to eventually reach higher cost recovery** **Provision of sufficient surface water supply to downstream farmers in coastal areas have multiple positive impacts, such as control of salt-water intrusion and reduced risk of salinity caused by groundwater use** **Conveyance efficiency flaws can be counter-balanced by data-supported water distribution**	Water monitoring is the cornerstone of more sustainable natural resources uses to avoid environmental degradation Monitoring systems have predictive role in planning resources use in long-term and designing adaptation and mitigation measures to address the impacts of climate change The concept of no-one-size-fits-all applies to water monitoring systems as well, thus, requiring context-tailored system design Design of versatile monitoring systems combined with multiple tools must be based on multicriteria system corresponding to the requirement of technology-enabling conditions Implemented discharge measurement methods that are operated simultaneously can significantly reduce the risk of data gap Automated systems are advisable in irrigation schemes, whereas human resource is a constraining factor Managing data in computer-based tools improves the sustainability, efficiency, applicability, and scalability of monitoring systems Crowd-sensing tools, such as SSIV, help taking advantage of users' participation in monitoring system, while increasing the common sense of end-users	High-performing monitoring systems are greatly sensitive to infrastructure quality, whereas any degradation in system condition (i.e. leakage, sediment deposit, pollution) has multiple impact on the accuracy of outcomes Monitoring systems are essential, in-built part of the irrigation system, thus, require regular inspection and routine maintenance together with other equipment Proper O&M is based on institutional protocol and task-sharing. Given that the system is located in a peri-urban area, responsibility sharing with end-users is the building-block of preserving the conditions

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:

Figure 15: Stakeholder meeting in the site

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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