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STRENGTHEN THE WATER UTILITIES CAPACITIES TO MANAGE/REDUCE NRW AND DETECT LEAKAGE

Manual of procedures to reduce NRW

T5.1

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WATER AND ENVIRONMENTAL SUPPORT IN THE ENI SOUTHERN NEIGHBOURHOOD REGION

The "Water and Environment Support (WES) in the ENI Neighborhood South Region" project is a regional technical support project funded by the European Neighbourhood Instrument (ENI South). WES aims to protect the natural resources in the Mediterranean context and to improve the management of scarce water resources in the region. WES mainly aims to solve the problems linked to pollution prevention and the rational use of water.

WES builds on previous similar regional projects funded by the European Union (Horizon 2020 CB/MEP, SWIM SM, SWIM-H2020 SM) and strives to create a supportive environment and increase the capacity of all stakeholders in the partner countries (PCs).

The WES Project Countries are Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Libya, Palestine, Syria and Tunisia. However, in order to ensure the coherence and effectiveness of EU funding or to promote regional cooperation, the eligibility of specific actions can be extended to neighbouring countries in the Southern Neighborhood region.

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ABBREVIATIONS

| | |
|----------------|--|
| <i>AWWC</i> | Asyut Water and Wastewater Company |
| <i>DB</i> | Database |
| <i>DMA</i> | District Metered Area |
| <i>DMZ</i> | District Metered Zone |
| <i>EU</i> | European Union |
| <i>HCWW</i> | Holding Company for Water and Wastewater |
| <i>GIS</i> | Geographical Information System |
| <i>O&M</i> | Operation and Maintenance |
| <i>NRW</i> | Non-Revenue Water |
| | |

1 GENERAL INTRODUCTION

The "Water and Environment Support (WES) in the ENI Neighbourhood South Region" project is a regional technical support project funded by the European Neighbourhood Instrument (ENI South). WES aims to protect the natural resources in the Mediterranean context and to improve the management of scarce water resources in the region. WES mainly aims to solve the problems linked to pollution prevention and the rational use of water.

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The WES Project Countries are Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Libya, Palestine, Syria and Tunisia. However, in order to ensure the coherence and effectiveness of EU funding or to promote regional cooperation, the eligibility of specific actions can be extended to neighbouring countries in the Southern Neighbourhood region.

Egypt has asked the WES Project to implement a national activity entitled "[Strengthen the water utilities capacities to manage/reduce NRW and detect leakage]". The activity falls under *topic 1: "Water Use Assessment, estimation "*, *topic 2 "Water Efficiency Gains at Decentralised Level"* and *3 "Water Resources Valuation, Cost Recovery, Affordability of water services"*, *sub-topic 2.2: "Non-Revenue Water (NRW) Management"* and *dimensions 1 & 2 "Technical Assistance and/or Capacity Building*.

Nationally, **the activity supports the Real Loss Reduction Strategy (2017)** prepared with the support of the second phase of the European Union's (EU) Water Sector Reform Program, which promotes an integrated nonrevenue water reduction strategy and its alignment with the real Loss Reduction Strategy.

During this activity, the project will introduce internationally accepted best management practices for improving NRW, such as hydraulic modelling, the design of Distribution Zones, water balancing to enable quantifying the individual components of losses (including commercial losses) and estimating the overall NRW rate at the decentralized level. It will equally contribute towards the adoption of other best practices such as the use of GIS to allow the analysis of the geographic distribution of leaks, and subsequently facilitate the establishment of the link between the customers' information and the GIS.

2 OBJECTIVES OF ACTIVITY

The overall objective of this activity is "to assist a selected water utility to target the reduction of Non-Revenue Water (NRW) and to continue its efforts to improve NRW management".

The specific objectives are to:

- Investigate the situation of non-revenue water management in a pilot city served by Asyut Drinking Water and Sewerage Company and prepare its network, as part of rational planning aimed at NRW reduction, to the next stage of implementation of distribution zones/sectors and their subsequent division into District Metered Areas (DMAs).

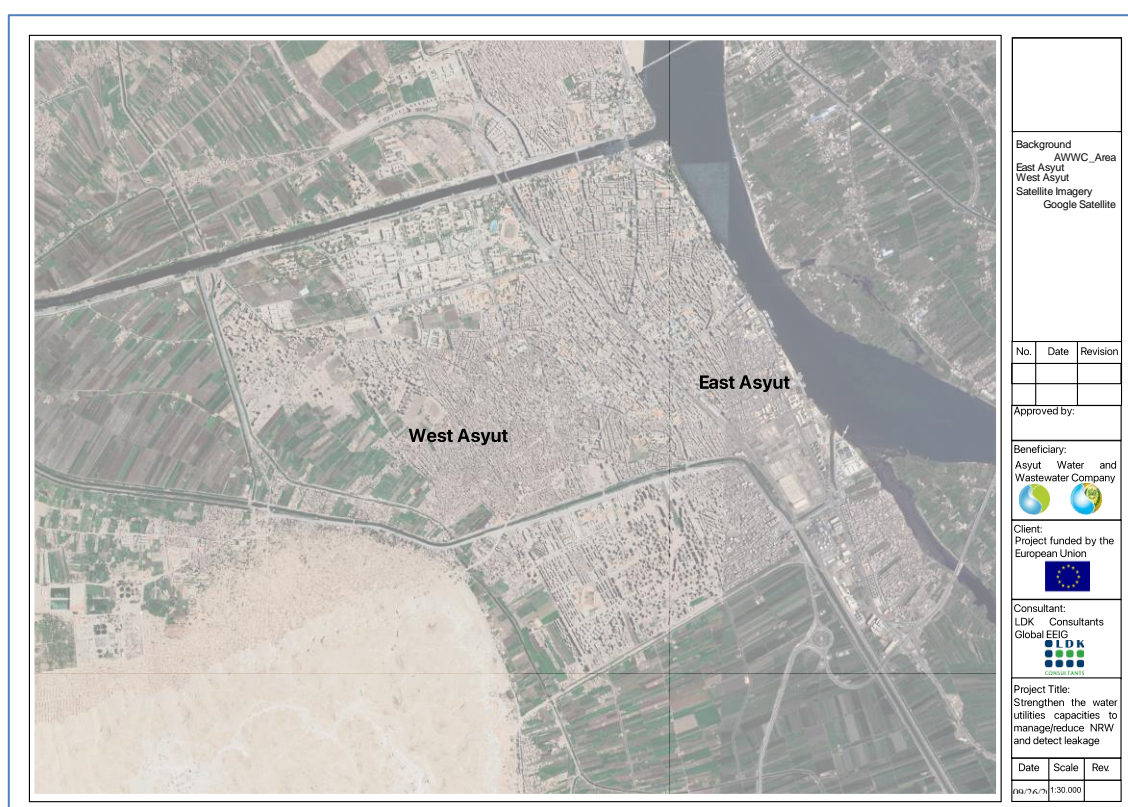
- Implement and calibrate a hydraulic model for the network of the pilot city as a tool to provide valid support to move into the design stage and establishment of DMAs.
- Introduce internationally recognised best practices for improving NRW (including the design of Distribution Zones and the use of GIS to enable an analysis of the geographical distribution of leakage).
- Build the capacity of the utility staff involved in the pilot area on the implementation of best practices for the management of non-revenue water through on-the-job training and direct involvement in the implementation of the tasks with the support of non-key experts (field data analysis, water balancing, model calibration, and fixing anomalies between the results of the model calculations and the field data).
- Develop a manual documenting the proposed procedures for reducing NRW in the Asyut city water network.

This report deals with manual documenting the proposed procedures for reducing NRW in the Asyut city water network.

3 DESCRIPTION OF THE STUDY AREA

The activity was implemented for the Asyut city water network; an extended water supply system of more than 250 km and multiple water sources served by the Asyut Drinking Water and Sewerage Company. Asyut City is customarily divided into two sub-zones: West Asyut (AlGharb) and East Asyut (AlSharq); the two zones constitute the study area of this project.

FIGURE 1: ZONES OF ASYUT CITY



4 TASKS, RESULTS AND DELIVERABLES

In accordance with the Terms of Reference, this intervention is divided into five (5) tasks according to the brief description of the tasks and the corresponding results and deliverables summarized in the following Table:

TABLE 1 : TASKS & DELIVERABLES

| Tasks | Results | Deliverables |
|--|--|---|
| Task 1: Inception Phase | <ol style="list-style-type: none"> 1. The various stakeholders concerned are identified and involved, where appropriate, in the study; 2. Initial data assessment (Background, Network, Infrastructure, Customers) is performed 3. The plan of actions necessary to carry out the activity is agreed with the partners during a one-day inception workshop. 4. The requirements and necessary resources from the stakeholders are agreed upon. 5. The scope of work and job profiles of the GIS and non-revenue partner teams members are agreed upon 6. The partner teams for GIS and non-revenue water are established | T1.1: Inception report. The report includes the results/outcomes of the Inception Workshop and the preliminary list of the main stakeholders involved in the activity |
| Task 2: Verification of GIS Maps and Customers Database (DB) | <ol style="list-style-type: none"> 1. A diagnosis of existing Customers DB and network and infrastructures maps and data of the water utility assets in the study area as well as a review of possible gaps is performed: 2. Option 1: An action plan necessary to reach an updated state for water networks and installations and for the customers' database is proposed for implementation by the partner (with the support of the project). 3. Option2: A list for the necessary and relevant data/information to collect and an action plan to collect such data and for the preparation of digital maps of | T2: GIS Database DB and Customers' DB Report reflecting the results of the workshop on GIS DB and Hydraulic Modelling |

| Tasks | Results | Deliverables |
|---|---|---|
| | <p>the network for implementation by the partner (with the support of the project).</p> <p>4. A GIS DB Conceptual and Logical Data Model is prepared and t</p> <p>5. The structure of the GIS database of the water supply network and facilities is implemented and the customers' database link to the GIS database is designed. (if any)</p> <p>6. Available water supply network and facilities' validated data are uploaded in the GIS DB</p> | |
| Task 3: Calibration of the Hydraulic Model for the network | <p>1. Water supply Network and facilities data are organized and imported into the Hydraulic Model tool for hydraulic calculation</p> <p>2. Population and Demand data, together with the data available in the customers database, are combined to prepare the demand allocation necessary to perform the hydraulic calculation</p> <p>3. Flow (Q) and Pressure (P) monitoring sites are selected</p> <p>4. Q-P monitoring field-work is performed by the local staff with support and supervision of the project team experts</p> <p>5. Analysis of the Q-P monitored data is performed and reflected in the hydraulic calculation to adapt the model results to the field work results</p> | T3: Schematic Model and Hydraulic Model Report reflecting the results of the workshop on GIS DB and Hydraulic Modelling |
| Task 4: Preliminary division and design of the network system into distribution zones (DZ) and design the zones | <p>1. The Distribution Zones (DZs) are preliminarily designed and the set of activities necessary to make the Zones controlled and isolated is developed.</p> <p>2. The DZs are established and their tightness is checked with the support of</p> | T4: Hydraulic Model and Zone Design Report reflecting the results of the workshop on GIS DB and Hydraulic Modelling |

| Tasks | Results | Deliverables |
|--|---|---|
| | <p>the local expert and the supervision of the international expert. Actions to ensure their complete insulation are proposed.</p> <p>3. The Q & P monitoring sites for the Distributing Zones are identified and the Zones' inlet flow and pressure is monitored with the support of the local expert and the supervision of the project experts.</p> <p>4. The NRW reference rate of each distribution zone is assessed (apparent and actual losses) by calculation of the water balance, with recommendations for the maximum rate of physical losses that can realistically be achieved.</p> <p>5. Based on the results of the NRW assessment, a set of interventions to reduce NRW is identified, and a priority list is proposed indicating those interventions which can be implemented immediately, while being cost effective and providing a rapid return on investment</p> | |
| Task 5: Elaboration of procedures to reduce NRW and prepare the synthesis report | <p>1. A set of procedures aimed to reduce NRW is prepared giving special attention to:</p> <ul style="list-style-type: none"> a. Data collection and GIS DB implementation, upload and maintenance b. Understanding of Hydraulic calculation as a tool to improve the performance of the water supply network c. Procedures for the operation and maintenance of the DZs d. Calculation of the water balance and analysis of results | <p>T5.1: NRW reduction procedure reflecting the results of the workshop on GIS DB and Hydraulic Modelling</p> <p>T5.2: The report on the "GIS DB and Hydraulic Modelling" workshop according to WES guidelines.</p> <p>T5.3: Synthesis report</p> |

| Tasks | Results | Deliverables |
|-------|--|--------------|
| | <p>e. Guidance on how to divide the Distribution zones further into District Metered Areas (DMAs)</p> <p>2. The results and recommendations of the activity are presented to the beneficiaries (in a one-day workshop) and are validated, and problems and potential solutions are discussed.</p> <p>3. A dialogue between the different stakeholders is established (during the one-day workshop) and a set of actions is selected for which the country commits to implement during the WES project.</p> <p>4. The Egyptian peers for the regional "Peer to Peer" exchange on Non-Revenue Water are identified and the set of topics of interest proposed.</p> | |

5 TASK RELATED TO THIS REPORT

This report pertains to task 5 of the activity, namely, “Elaboration of procedures to reduce NRW” focusing on the following:

- a. Data collection and GIS DB implementation, upload and maintenance
- b. Understanding of Hydraulic calculation as a tool to improve the performance of the water supply network
- c. Procedures for the operation and maintenance of the DZs
- d. Calculation of the water balance and analysis of results
- e. Guidance on how to divide the Distribution zones further into District Metered Areas (DMAs)

6 ELABORATION OF PROCEDURES

6.1 PROCEDURES FOR GIS DATA USE AND MAINTENANCE

Under Task 2 of this WES project (Verification of GIS Maps and Customers database), the following activities were performed:

1. checking of existing background maps (aerial photography, vector cartography, etc.), existing network maps (primary, distribution, service connections) and infrastructures (water intakes, water treatment plants, tanks/reservoirs, pumping stations, etc.) information; and
2. verification of customers' database

In addition to the verification of the availability of the customers' Database (DB) and maps, the WES team prepared the GIS DB Conceptual and Logical Data Model and performed a kind of quality control of the Customers' and Network's data to be imported/ transferred into the GIS DB.

The conclusions of those tasks were reported in the GIS Database Design and Customer DB Report.

Initially, the following can be pointed out:

- A GIS database of the **water supply network** is available at AWWC offices and is maintained/operated by a GIS expert who provides the network data to the hydraulic specialists of the company for their hydraulic analysis and calculations.
- The **customer database** is also available at the commercial department which shares data with other departments on request. At the beginning of the project, the customers' database had no geographic information associated with it. During the course of the project, AWWCAWWC started geolocation of the customers, which is still in progress and has been carried out for around 85% of the customers.

AWWC's GIS expert is doing a great job of keeping the GIS database up-to-date and in operation; in the opinion of the WES team, the following procedures should be initiated on a regular basis:

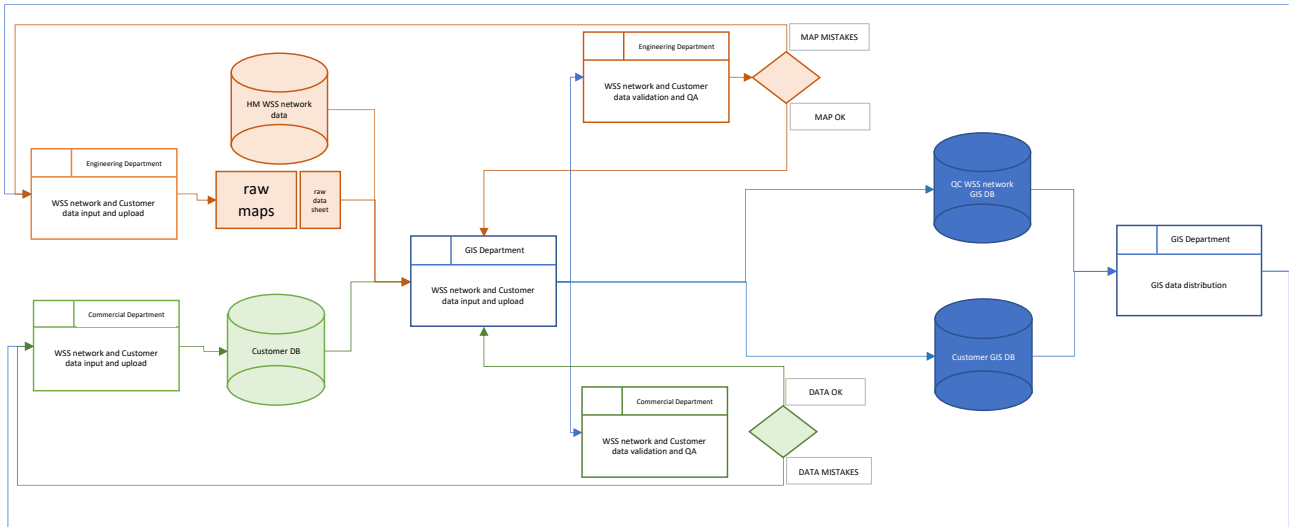
- 1) A standard procedure indicating which data should be regularly provided to the AWWC GIS department and by which AWWC departments (e.g.: the WSS network operation department should provide data on any changes/modifications made to the WSS network). In principle, there are three departments that must be involved:**
 1. The commercial department
 2. The operation department
 3. The engineering department

The procedure should make it clear who is responsible for the data. In principle, the GIS department should be in charge of the WSS network data, with the updates regularly coming from the engineering department, and the commercial department should be in charge of the commercial (customers) data. This is certainly insignificant to say but much less insignificant to do.

Currently, the engineering department and the GIS department process the same WSS network data (both digital and analogue) separately and don't know what changes each department makes.

NEXT ERROR! REFERENCE SOURCE NOT FOUND. SHOWS THE PROPOSED DATA FLOW WHICH GOES WITH THIS PROPOSED DATA ORGANIZATION.

FIGURE 2: PROPOSED DATA FLOW AMONG DEPARTMENTS



- 2) The second important procedure to be implemented **concerns the way the GIS department uploads the network into the GIS DB**. What they do NOT have to do is a digital drawing of the WSS network, but they have to “build” a digital WSS network; this means that they – when uploading a pipe into the GIS DB - “lay” pipes and do not draw lines; in the same way, when they upload valves into the GIS DB they “install” valves and other devices and do not draw lines or points. In a nutshell, the GIS WSS network GIS DB must follow the same rules as the real WSS network and must be constructed in the same way. The way the structure of the GIS DB is prepared strongly helps this part; for that reason, the WES team proposed in the WES GIS DB Report a DB structure that includes connectivity rules between objects, e.g., a node can be connected to one pipe (when it is a capped end) up to a maximum of four pipes (when it is a cross piece) only. These rules can be implemented in the WSS GIS and help the draftsman edit or update the network.

As an example, **Error! Reference source not found.** shows the original WSS GIS DB network provided by the AWWC GIS department on the left side and the same sector of the network provided by the AWWC engineering department on the right side. Differences are obvious (isolated nodes and wrong pipe connections) and need no explanations.

FIGURE 3: GEOGRAPHICAL DATA INCONSISTENCIES



- 3) The same procedure should include a **quality check on the consistency of the object's attribute data**, i.e., pipes with a length of less than 50 cm are not realistic and must be corrected. In general, quality control is the responsibility of the GIS department that carries out this work with the support of the department that proposed the changes.

There are two types of control that need to be done:

1. *Topological correctness*. the most important controls concern the absence of isolated nodes, a controlled number of pipes connected to nodes, a pipe must always end with a node
2. *Correctness of attributes*. E.g., the nominal diameter of a pipe depends on the material.

Next **Error! Reference source not found.** shows the pipe lengths from the WSS network database provided by the engineering department where pipes only a few millimetres long are present. This is of course unrealistic and should be avoided although it does not cause any practical problems.

FIGURE 4: ALPHANUMERICAL DATA INCONSISTENCIES

| pipes — Elementi Totali: 3456, Filtrati: 3456, Selezionati: 0 | | | | | | | | |
|---|------------|---------|-----------------|-----------|----------------------------------|-----------|-------|----------------|
| | WSS_L_feet | WSS_L_m | WSS_DN_in | WSS_DN_mm | WSS_Mat | WSS_Mat_1 | WSS_C | calc_len_m |
| 1 | 0 | 0 | 5,900000000... | 150 | Ductile Iron | DI | 130 | 0,00768635... |
| 2 | 0 | 0 | 5,900000000... | 160 | unplasticized PolyVinyl Chloride | uPVC | 120 | 0,019577483... |
| 3 | 0 | 0 | 3,950000000... | 110 | unplasticized PolyVinyl Chloride | uPVC | 120 | 0,02047095... |
| 4 | 0 | 0 | 5,900000000... | 150 | Ductile Iron | DI | 130 | 0,030980109... |
| 5 | 0 | 0 | 3,950000000... | 110 | unplasticized PolyVinyl Chloride | uPVC | 120 | 0,030980109... |
| 6 | 0 | 0 | 11,800000000... | 300 | Ductile Iron | DI | 130 | 0,038112367... |
| 7 | 0 | 0 | 5,900000000... | 150 | Ductile Iron | DI | 130 | 0,072502770... |
| 8 | 0 | 0 | 7,870000000... | 200 | Ductile Iron | DI | 130 | 0,09255408... |

- 4) A fourth set of procedures refers to the use of the **GIS to support calculations and analyses**.

In this activity, the WES team proposed the following:

1. Procedure for the selection of a simplified WSS network for hydraulic calculations.

2. Procedure to allocate to the nodes of the model the customer demand.
3. Procedure to allocate to the nodes of the model the leakage data to the nodes of the model.

Annex 1 of this report shows the proposed procedures; they can be implemented in any GIS software.

In conclusion, (i) It is important for AWWC to implement procedures that make the flow of GIS data between the relevant departments clear. (ii) It is important for AWWC to implement procedures that make data acquisition robust and reliable, avoiding errors in connection with objects and attributes of objects. (iii) Once the WSS network is well represented in the GIS database and is free of errors, the AWWC GIS department and engineering department can use the GIS DB for both data export (e.g., towards EPANET or Water GEMS) and analysis; in the latter case, GIS can also help the construction of the network schematic and allocation of demand.

No leakage reduction activity (apart from massive field work) can be undertaken without implementing a GIS DB linked to infrastructure data and to customer data that correctly represent the situation. This is the first task that every water utility should start first because the operation and maintenance of the water network and NRW reduction are strongly linked to the availability and quality of this data.

AWC has already started to invest in GIS and therefore adopting the proposed procedures will ensure that GIS will be used to initiate NRW reduction activities. This will save AWC money as soon as the data are available because reduction activities will be directed where they are needed, maximising the benefits.

With this in mind, the WES team has already recommended some adaptations to the WSS GIS DB to address leakage control. The WES WSS GIS DB database report suggested what to add to the existing WSS GIS DB to organise and manage data for NRW reduction purposes.

6.2 PROCEDURES FOR HYDRAULIC MODEL DATA UPLOAD AND MAINTENANCE

6.2.1 INTRODUCTION

Task 3 of the project activity concerns the calibration of the hydraulic model based on data collected during Task 2 and the monitored flow (Q) and pressure (P) data made available by AWWC. The results achieved during this phase are:

1. The Water Supply network data were organized and imported into the hydraulic model tool.
2. The customers' database was analysed to see if it could be used for the allocation of demands needed to develop the hydraulic model.
3. Flow (Q) and Pressure (P) monitoring sites were selected.
4. AWWC staff performed Q-P monitoring fieldwork at some of the selected monitoring sites.
5. The analysis of the Q-P data was performed and reflected in the hydraulic calculation to fit the model results to the fieldwork results.

The description and conclusions obtained by performing Task 3 - in terms of network data collection, demand allocation and monitored Pressure and Flow analysis, all focusing on model calibration - can be read in the corresponding report (WES-NW-EG1-T3 Network Analysis Report).

In terms of procedures of WSS network data collection and maintenance, what is necessary to say has been presented in the previous chapter.

In terms of procedures for demand allocation, the next pages give the sequence of steps to be followed to make an orderly analysis of customers' data as a prerequisite for conducting the Hydraulic Balance calculations.

6.2.2 AWWC CUSTOMER DATABASE ANALYSIS

AWWC engineers provided the classification they use in the AWWC Customers' database and the results of the analysis they do on the number of customers. The overall pilot area is divided into two sub-areas named Al Sharq and Al Gharb and information was provided (the data below refers to the Al Sharq sub-area only):

TABLE 2 – AL SHARQ CUSTOMER DATA SUMMARY ANALYSIS

| Category | Remarks | Customers (No.) | Zero consumption Customers (No.) | Zero consumption Customers (%) |
|-------------|---|-----------------|----------------------------------|--------------------------------|
| Undefined | Customer with no meter but supplied by the water network (unmetered) | 531 | 312 | 58,76% |
| Inoperative | Customer metered, supplied by the network, but the meter is broken (unmetered) | 3209 | 853 | 26,58% |
| Unable | Customer metered, but for any reason not read in the last meter reading period | 1444 | 133 | 9,21% |
| Working | Customer metered and supplied by the water network (metered) | 29820 | 9908 | 33,23% |
| Unclear | Customer metered, the meter is working but the reading is unclear | 17 | 4 | 26,53% |
| Closed | They are houses with a meter, but in the last reading period they were empty and therefore without consumption. | 3510 | 3510 | 100% |

Some items, however, need clarification:

It was indicated by AWWC that the category “**Undefined**” is characterized by the fact that it has no meter. Theoretically, they should be all “zero consumption customers”. Why do we know the consumption for around half of them?

Same as for the categories “**Inoperative**” (broken water meter) and “**Unable**” (meter with no reading in the period); if the meter is broken or not read, everyone should be a “zero customer” but we have the readings for around 75% of customers of these categories. There should be an explanation for this situation.

What is the accuracy and reliability of the readings of customers in the “Unclear” category? Can we use these readings to determine an average value? It is true that they are very few and will not change the results.

Part of the scope of the activity was to allocate demand to the nodes of the hydraulic model. The hydraulic model is made of three components:

1. The geometry of the network, which is made of pipes and nodes and facilities.
2. The inlet flow rate i.e., the amount of water that sources feed into the network and which is conveyed by pipes and facilities such as pump stations.
3. The outlet flow rate i.e., the amount of water used by consumers, exported to other water networks or lost by the water network itself.

The demand allocation in turn is made of two activities:

1. Geolocation of the customers, to allocate with the maximum possible accuracy the demand to the nodes of the modelled network.
2. Estimation of the water used by different categories of customers.

The first activity – geolocation of the customers – has been performed and largely completed by the AWWC staff and once finished all customers will be correctly allocated to the nearest network node.

In order to improve the quality of the information provided by the customer’s database, it is important to first separate domestic and non-domestic (**commercial, industrial, governmental**) customers. For each of the two categories (e.g., domestic, non-domestic) the following activities should be performed:

Domestic demand – Zero consumption customers

1. Identify all the customers whose consumption is below a selected minimum threshold (i.e., 5 cubic meters per month).
2. Make sure that these customers; even though “zero consumption customers”, are not using water, otherwise they should be considered part of the demand allocation to add to the hydraulic model.
3. Determine; based on the “non-zero consumption customers”, an average consumption that will be attributed to the “zero consumption customers”. This way we represent with a higher level of accuracy the real demand of the system and the calibration will be more accurate.
4. If large domestic customers should be detected, it is important to check whether they are real large consumers or whether their high consumption is only caused either by some mistake in the meter reading, data uploading and handling, or faulty meters.

Non-domestic demand (commercial, industrial, governmental) – Zero consumption customers

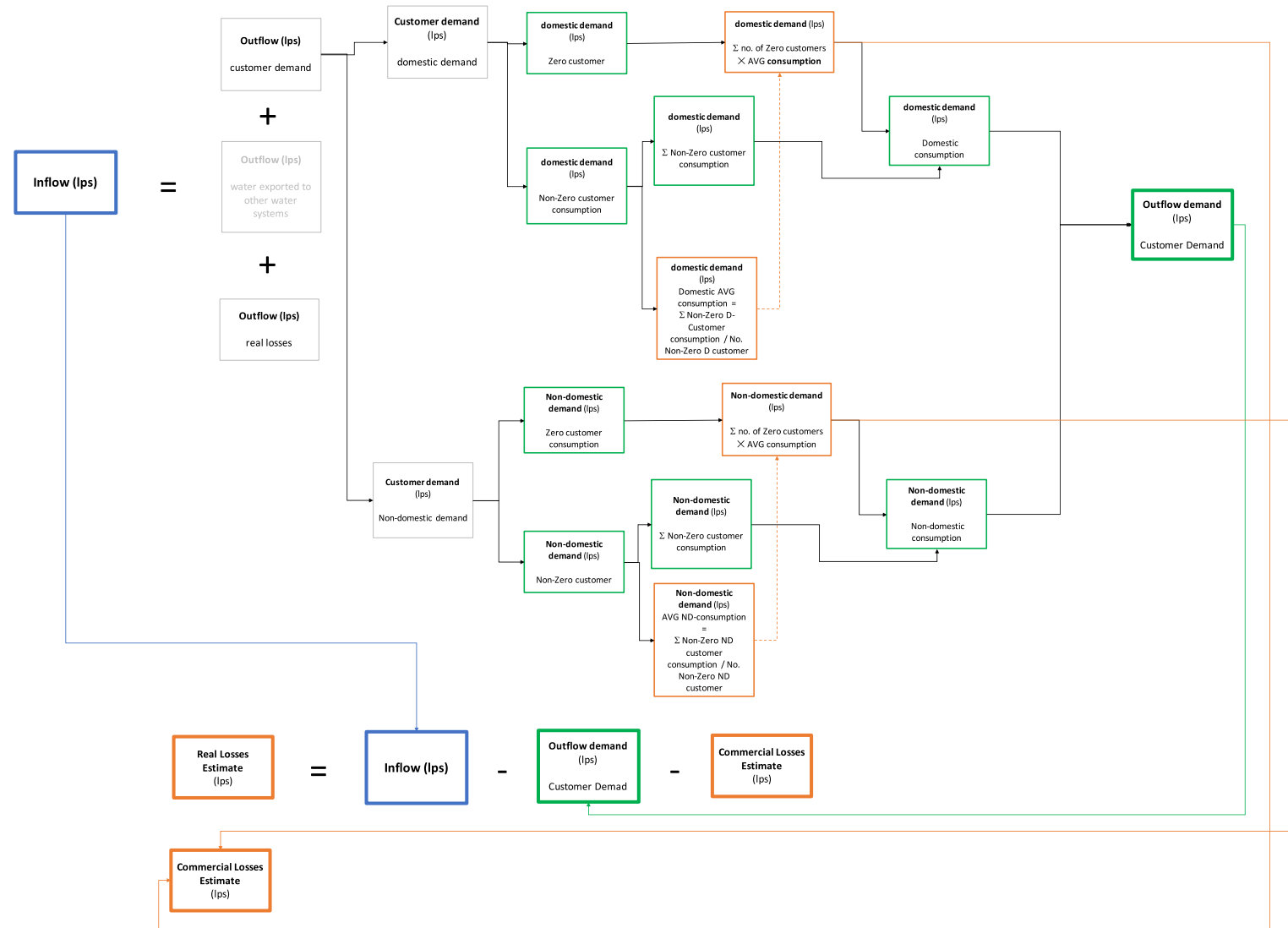
The procedure to follow for estimating the water used by the zero consumption non-domestic customers is as for the domestic demand. This procedure is sufficiently reliable because it is applied to the “standard” non-domestic consumers, but not to the large consumers within the non-domestic category, which are treated individually both for their position and for their demand allocation to the node.

In addition, as before mentioned, **for non-domestic customers, it is important to identify the largest ones amongst them**, i.e., we can select the first twenty largest consumers. For these consumers, it is important to verify that the huge consumption is not caused by any type of mistake (reading, typing etc.); and to allocate the demand exactly to the nearest node of the hydraulic model. This is because

the large consumption may have an impact on the operation of the water system (e.g.: causing a local pressure to drop).

Error! Reference source not found. shows in a schematic form the procedure to estimate the customers' demand to be allocated to the nodes of the hydraulic model considering also the water used by zero consumption customers in both domestic and non-domestic use. This procedure also provides an estimate of both commercial and real losses; the former is derived from the consumption calculations/estimation of the zero-consumption customers and the latter is derived from the difference between the input volume and the "corrected" customer demand.

FIGURE 5: PROPOSED SCHEMA OF THE PROCEDURE FOR ESTIMATING THE WATER USED BY THE ZERO CONSUMPTION CUSTOMERS IN BOTH DOMESTIC AND NON-DOMESTIC USES



In fact, once the demand of each customer has been determined (i.e.: the total demand from the customer database), then by subtracting this amount from the total inflow it will be possible to estimate the amount of real (also called physical) losses.

Once completed this task, each customer demand needs to be allocated to the corresponding node of the model. In this regard, GIS will support and facilitate the allocation of customer demand to the correct node since each customer is associated with geolocation.

Regarding allocation of demand to the nodes, the same approach can also be adopted for the real losses demand; after determining the unit of water loss per length of water mains (total amount of water loss divided by the total length of water mains), the total amount of water loss will be allocated to the nodes of the network in proportion to the length of the pipes converging at each node.

6.3 PROCEDURE FOR DEMAND ALLOCATION

6.3.1 DOMESTIC AND COMMERCIAL DEMAND (PART OF NONDOMESTIC DEMAND)

The scope of the procedure is to allocate demand to the nodes of the hydraulic model schematic. To do so, the following is required:

- Shape files¹ of the WSS network to be modelled:
 - Well-field
 - Water intake
 - Washout
 - Valve
 - Tank
 - PS
 - Node
 - Monitoring point
 - Flowmeter
 - Air valve
 - Pipeline
- Shapefile of the customers' centroids (a shape file is a set of files where each customer is geometrically represented with a point and a table with the customer data, particularly consumption).

The process consists of assigning (allocating) to each node of the model the customers based on their position. This procedure refers to the customers' database from where the "large consumers" have been deducted because the large consumers are allocated to the corresponding node individually.

The procedure is divided into two sub-procedures:

- Customers who have a geographical position (around 85% of the total)
- Customers who do NOT have a geographical position (around 15% of the total)

Customers with a geographical position

The next figure shows a section of a network; whereby **points in blue are nodes** of the network schematic, and **points in red a customer centroid** (a point representing the position of the customer and the associated data table).

¹ The names of the feature classes refer to the WES GIS DB structure.

Let's consider:

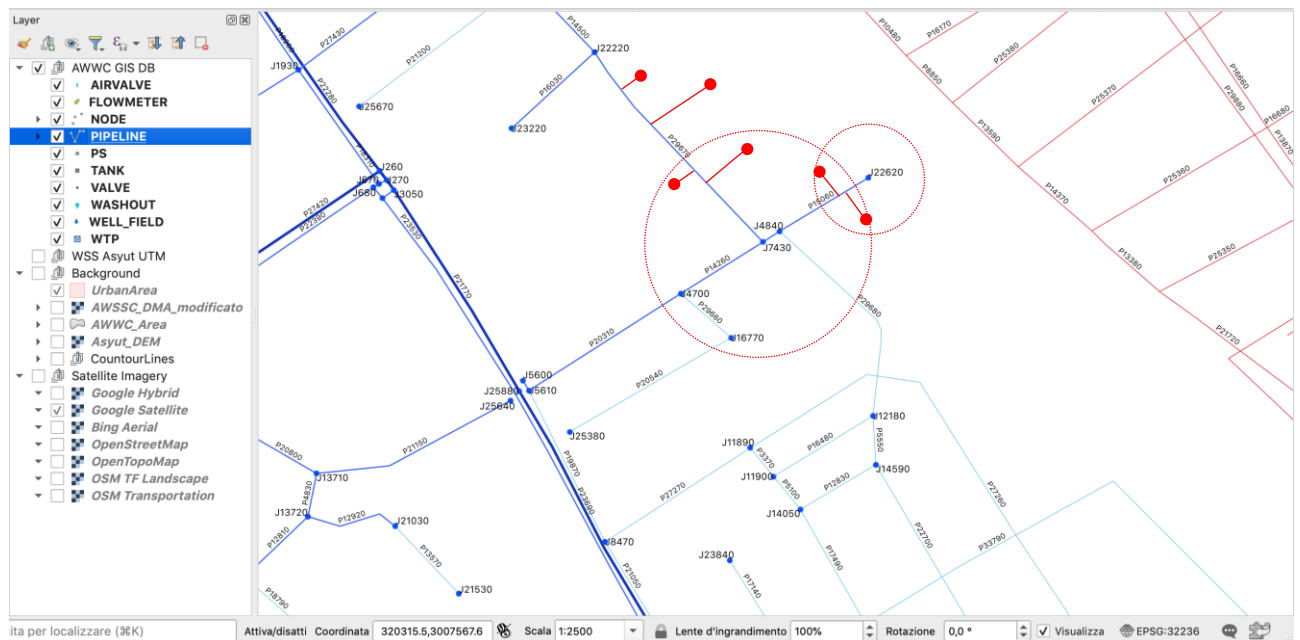
1. customers numbered from 1 to 6
2. pipes: P29670 and P15060
3. nodes: J22220, J7430, J4840 and J22620.

Before running the procedure:

It is necessary to select the pipes (and nodes) to which the customers will be allocated². To do so, it would be better to add a flag to the Pipe table that will be set at "N" if the pipes should not be considered and to "Y" if the pipe will be included in the set. The WES GIS DB has a field (P_DMDFLG) which indicated which pipe is allowed to have customers allocated to it. In general, transmission main pipes and primary distribution pipes are not considered pipes to which customers are connected.

It is necessary to select the customers that will be allocated to the nodes, giving a flag (i.e. CFLG="Y") to the "metered" and "working" customers and a flag (i.e., CFLG="N") to the "not connected" and "closed" customers.

FIGURE 6: ALLOCATION OF CUSTOMERS TO THE NODES



Activities to be performed by using the GIS software.

1. By means of the GIS functionality "Join attributes by nearest"³ assign the PIPE ID to each centroid representing AWWC DB customer; this way we know how many customers are linked to a pipe. This is not the most accurate way to link customers, but it is a reasonable approach. Once the elaboration has been performed, export the new temporary file in an Excel format by making it permanent by selecting the XLS option.

The procedure to follow is:

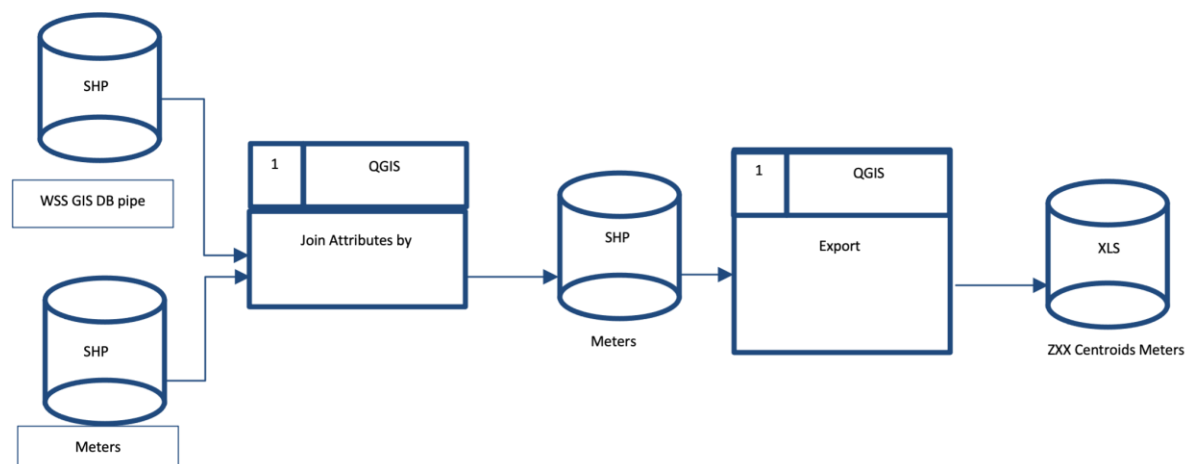
- a. Select the pipes that have "P_FLG = Y", because they are the only ones to be modelled.
- b. Select the customers centroids of the area to be modelled (i.e., Zone East)
- c. Run the plug-in "Join attributes by nearest", applying it to the selected pipes and selected customers centroids only, to link to each centroid the ID of the nearest pipe.

² Each pipe has an ID which will be inherited by the customer.

³ The GIS command indicated refer to QGIS, the same commands are available also in ArcGIS.

- d. The plug-in will create a new customers' centroid shape file in which there are both the customers' centroids' attributes and – for each centroid - the pipe attributes we added from the PIPE shape file (i.e., PIPEID, PIPEDN, PIPETYPE)

FIGURE 7: ALLOCATION OF CUSTOMERS TO NODES WORK-FLOW



2. By means of the GIS process “Export” creating an Excel table of the “meter” data
3. By means of the GIS process “Export” creating an Excel table of the WSS GIS DB “Pipes”

Activities to be performed by using Excel

After the end of the previous step, there are two files available:

- meter.xlsx
- Pipe.xlsx

These **two files have the pipe ID in common**. Therefore, in Excel, you can count the number of centroids that have the same pipe ID.

Scope of the activity is creating a set of information that will be able to be imported into the Hydraulic Modelling software.

1. In the Excel file, prepare a list with all the Pipe IDs taken individually and the corresponding end nodes.
2. For each pipe ID (and end nodes), sum separately all the centroids with the same pipe ID and with “CFLG = N” and all the centroids with the same pipe ID and with “CFLG= Y”. In the end, check if you counted all the centroids.
3. Then half of the number of customers linked to each pipe will be allocated to each of the two end nodes of that pipe (simplified method).

Customers without a geographical position

In this case, we only know the number of customers in the zone. The total number of customers can be allocated to all “allowed” pipe end nodes, proportionally. As an example:

1. Number of customers: 100
2. Number of allowed pipes end nodes (secondary and tertiary distribution pipes) for which PFLG=Y: 20
3. In this case, each of the nodes will be allocated $100/20 = 5$ customers.

6.3.2 DEMAND FOR WATER LOSSES

Leakage could represent a significant proportion of the "demand" of a water supply system and the way in which this is accounted for, needs to be considered; normally it is adequate to allocate leakage to nodes based on the length of pipelines i.e., the total leakage will be assigned to the nodes in proportion to the length of pipelines converging in each node (half of the length of each converging pipe in each end node).

Quantitatively, leakages can be expressed as a value of litres per second per length of mains and distribution pipes (km); based on the existing literature and experience, the coefficients that can be adopted are listed in **Error! Reference source not found.** below.

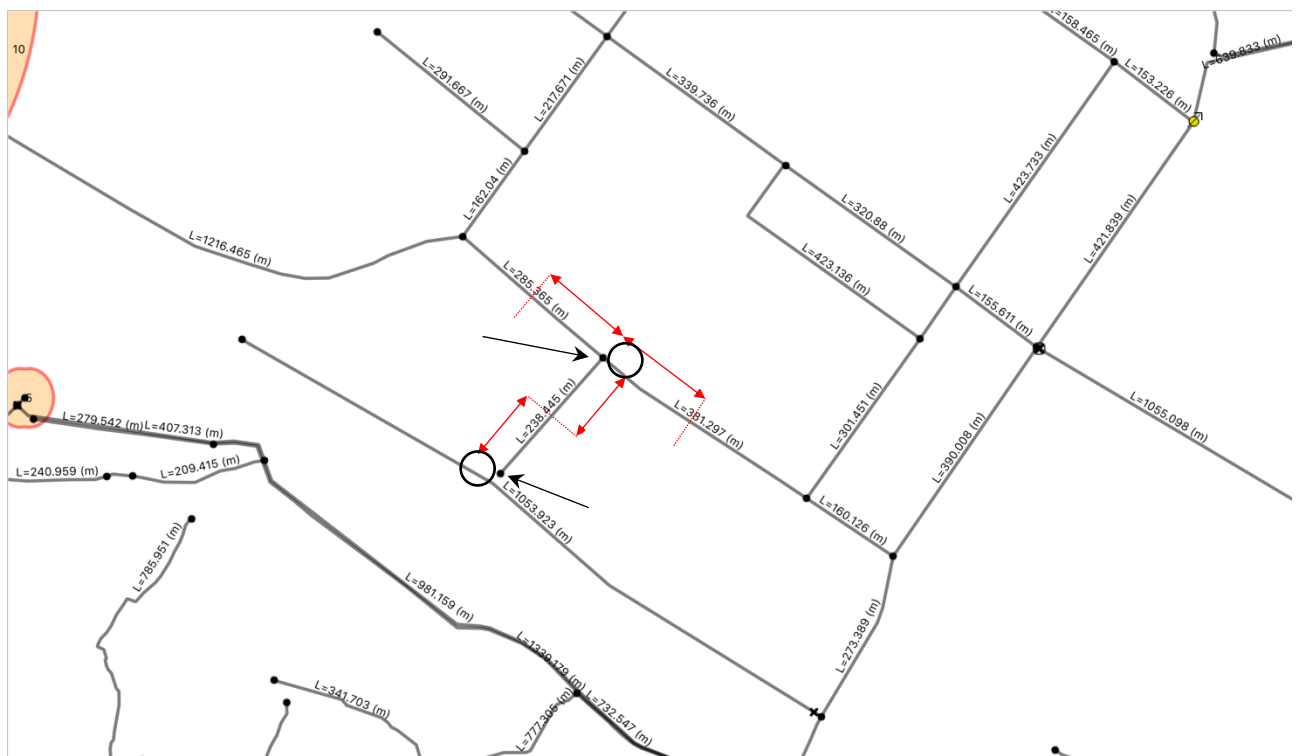
TABLE 3: REAL LOSSES TECHNICAL PERFORMANCE INDICATORS

| Description | Real Losses Performance Coefficient (l/s/km) |
|----------------|--|
| New pipes | 0,25 |
| Existing pipes | 1,0 |

Example of calculation

Error! Reference source not found. shows an example: the three sections of pipes converging in node 1 have a total length of 0,452 km (142,68 m + 190,65 m + 119,23 m) and the only section of pipe converging in node 2 has a length of 0,119 km.

FIGURE 8: ALLOCATION OF LEAKAGE DEMAND



Let's say that 142,68 m and 190,65 m are the lengths of "old" pipes, while 119,23 m is the length of an "new" pipe. Therefore, the leak demand associated with node 1 is:

$$\frac{1 \text{ [l/s/km]} \times 0,143 \text{ [km]} + 1 \text{ [l/s/km]} \times 0,191 \text{ [km]} + 0,25 \text{ [l/s/km]} \times 0,119 \text{ [km]}}{0,143 \text{ [km]} + 0,191 \text{ [km]} + 0,119 \text{ [km]}} = 0,364 \text{ l/s}$$

and the leak demand associated to node 2 is:

$$0,25 \text{ [l/s/km]} \times 0,119 \text{ [km]} = 0.02975 \text{ l/s.}$$

GIS tools can greatly facilitate the calculation of the length of pipes to be assigned to each node.

6.4 PROCEDURE FOR DMZ AND DMA IMPLEMENTATION, OPERATION AND MAINTENANCE

6.4.1 DISTRIBUTION ZONES INTO DMAS

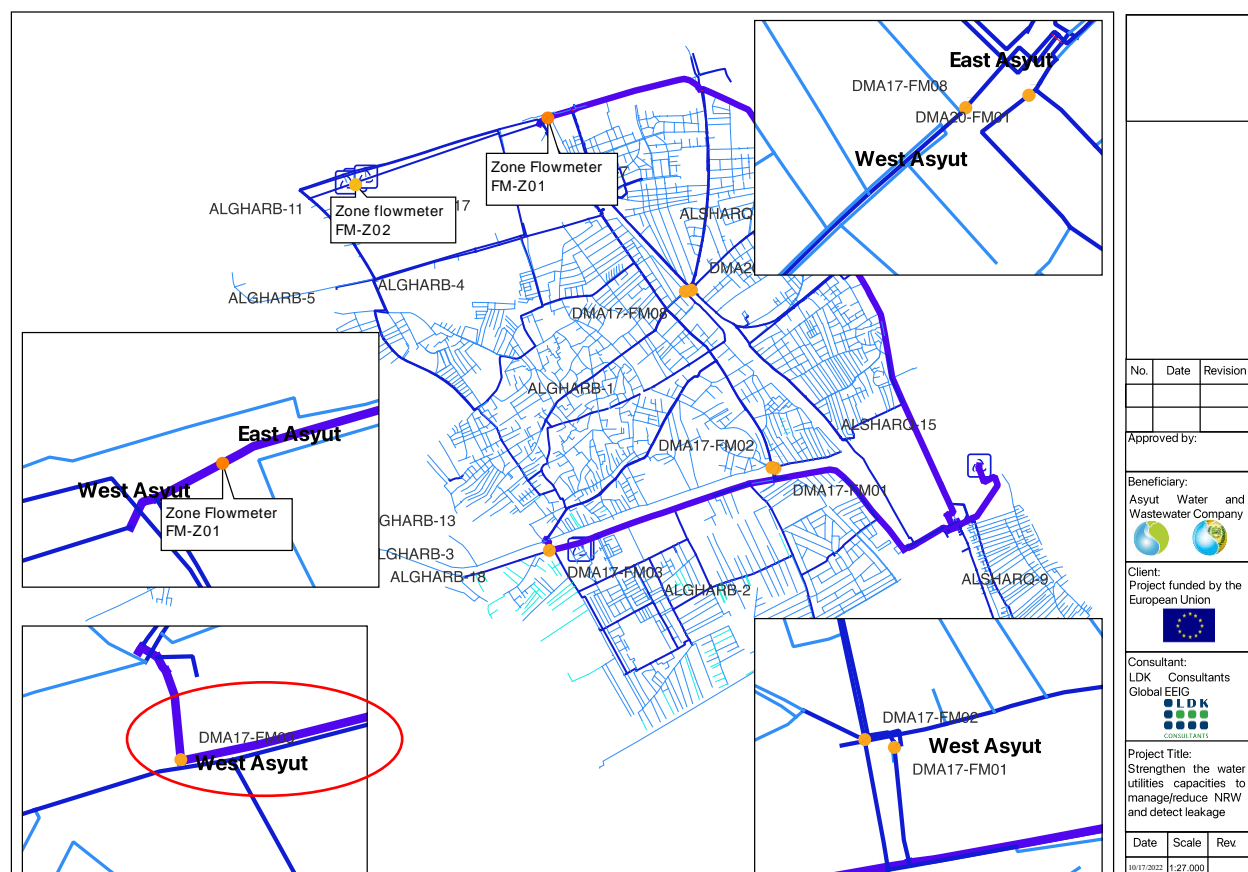
For large distribution networks, the initial planning stage should divide the distribution system into suitably sized sectors, using a large-scale map of distribution mains, which includes ground contours to draw provisional boundaries. This step utilises local knowledge of the network, available hydraulic data (pressure and flow), existing boundaries of the project area (such as railways or major roads) and natural features (such as rivers, and the topography of the city) so that as part of the process, the area is split into potential large pressure zones where appropriate. In the more complex networks, it is advisable to use a mathematical hydraulic network model to allow the hydraulic balance points to be identified. In this way, it will be possible to close line valves to create a permanent boundary without affecting the operation of the existing network.

The WES team first identified potential segregation into two zones (characterised by different colours in the Figure below) and identified possible sites for flow monitoring with portable flowmeters installation and pressure monitoring, which are summarized below with reference to the next **Error! Reference source not found.**:

- DMA17-FM03: the installation of the flowmeter at this location is possible and can be done without special efforts by the AWWC team.
- DMA17-FM01: the field investigation conducted by the AWWC team identified that the pipe where the flowmeter should have been installed as reported by the available network layout does not exist; therefore, there is a need to check the GIS geodatabase to add/delete the correct pipes in that area.
- DMA17-FM02: Installation of the flowmeter is possible.
- DMA20-FM01: The field investigation conducted by the AWWC team identified that the pipe where the flowmeter should have been installed as reported by the available network layout does not exist; therefore, there is a need to check the GIS geodatabase to add/delete the correct pipes in that area.
- DMA17-FM08: The field investigation conducted during the project could not find any accessible place to install the flowmeter; main reasons are that the traffic in the area is high and the area is very crowded; therefore, it is not easy to work there and it is not easy to find an alternative place. In addition, room of the only available chamber is very small, and it does not allow the installation of the ultrasonic flowmeter. Alternative sites to install the available ultrasonic flowmeters can be identified; this solution may imply installing more flowmeters depending on the connections between pipes in the nearby area.

- FM-Z01:** The field investigation conducted during the project could not find any accessible place to install the flowmeter; the main reasons are the high traffic and the area being very crowded; therefore, it is not easy to work there, and it is not easy to find an alternative place. In addition, the room of the only available chamber is very small, and it does not allow the installation of the ultrasonic flowmeter. Alternative sites where to install the available ultrasonic flowmeters can be identified; this solution may imply installing more flowmeters depending on the connections between pipes in the nearby area.
- FM-Z02:** No major difficulties were identified to install the flowmeter at the Water Treatment Plant (WTP). One additional consideration is that a portable ultrasonic flowmeter in this specific case is not necessary because the existing permanent flowmeter installed at the WTP can be used for the purposes of monitoring.

FIGURE 9: SEGREGATION INTO TWO ZONES

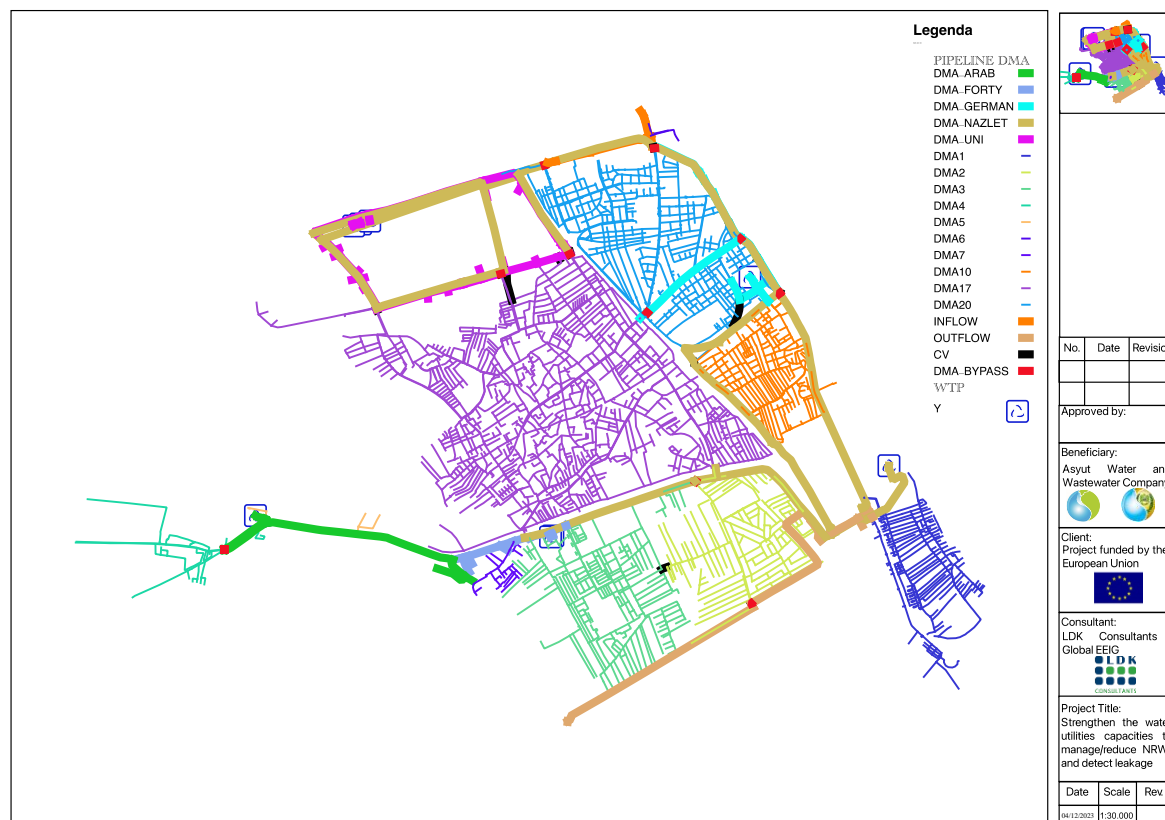


With reference to the next Figure 10 and based upon the initial segregation into two main zones, the WES team also proposed further segregation into DMAs. 18 DMAs were identified:

DMA-ARAB, DMA-FORTY, DMA-GERMAN, DMA-NAZLET, DMA-UNI, DMA-INFLOW and DMA-OUTFLOW are groups of pipes that refer to sections of transmission lines that start in a WTP and end in a node of a DMA, e.g., DMA-NAZLET indicates a pipeline that starts at Nazlet WTP and ends in one node of a DMA.

DMA's are numbered from 1 to 20 (some IDs are missing because some DMA's were cancelled during the design process).

FIGURE 10: FURTHER SEGREGATION INTO DMAS



All the details of the DMA design can be found in the EG-1 T3 & T4 HM and Zone Design Report and are not duplicated here.

To implement the proposed DMA segregation, the procedure that the WES team recommends is:

1. Create two zones (the northern part of Al Gharb and Al Sharq plus the remaining part of Al Gharb) by installing the necessary flowmeters in the indicated sites.
2. Carry out a periodic field monitoring campaign (namely every three months), recording flow (Q) and Pressure (P) at the recommended points indicated in the HM and Zone Design Report
3. After installation and monitoring, compare the monitored flow data with the flow data calculated by the WES team to size the flowmeters and check the correctness of the assumption initially made.
4. Proceed accordingly.

6.4.2 CONTROL AREA IMPLEMENTATION

Following the installation of all boundary meters and establishing the permanent boundary, it is necessary to "prove" each control area⁴ to ensure that:

- All meters are working correctly.
- There are no operational problems.
- All internal valves work correctly.
- Determine the average DMA pressure.

The flow of the control area meter(s) and internal pressures should be logged for a period of a few days and the resulting data analysed to determine leakage levels.

6.4.3 CONTROL AREA OPERATION AND MAINTENANCE

Once a control area has been proved, all subsequent work relates to its management, which involves the initial setting up of procedures and the subsequent routine operation.

Initial setting up work comprises "housekeeping" issues such as:

- Set up field flow and pressure data records and recording procedures.
- Set up flowmeters and pressure transducers monitoring & data collection procedure.
- Inform appropriate staff of valving changes.
- Determine the order of priority of leakage location activities based on a water balance analysis carried out in the control area.
- Monitor customer complaints, especially for discoloration, low pressure and no-water.

The **routine operation** on the other hand involves the following activities:

- Marking DMA boundary valves clearly for identification by all staff.
- Checking the status of the closed valves regularly.
- If the boundary of a control area has to be opened in exceptional circumstances by operating a valve, the corresponding flow data is not considered for any leakage evaluation;
- Monitoring flows for consistency. The daily pattern of flows into each DMA should follow the daily pattern of consumption within the DMA. If not, it probably indicates problems with boundary valves or meters. This should be used to initiate investigation.
- When estimates of **night use and daily customer consumption** are available, a simple check can be made to ensure that the losses measured from night flows are consistent with the losses calculated by subtracting the total daily consumption from the net daily flow into the DMA. If not equal, it probably indicates problems with meters or boundary valves and should be investigated.

⁴ From now on DMZ and DMA will be called "control areas"

6.5 WATER BALANCE CALCULATION PROCEDURES

Drawing on the best practice from many countries, the International Water Association (IWA) Water Loss Task Force (WLTF) produced an international ‘best practice’ standard approach for water balance calculations with definitions of all terms involved. **Error! Reference source not found.** shows the IWA standard international water balance and terminology.

FIGURE 11: WATER BALANCE DEFINITIONS

| System Input Volume (corrected for known errors) | Authorized consumption | Billed authorized consumption | Billed metered consumption (including water exported) | Revenue water |
|--|---------------------------|---------------------------------------|--|----------------------------|
| | | | Billed unmetered consumption | |
| | Water Losses | Unbilled authorized consumption | Unbilled metered consumption | Non-Revenue Water (NRW) |
| | | | Unbilled unmetered consumption | |
| | | Commercial (apparent) Losses | Unauthorized consumption | |
| | | Physical (real) Losses | Customer Metering Inaccura- cies and Data Handling Errors | |
| | | | Leakage on transmission and/or distribution Mains | |
| | | | Leakage and overflows at util- ity's storage tanks | |
| | | | Leakage on service connections up to point of customer metering | |

The definitions of the principal components of the IWA water balance are as follows:

- System input volume is the annual water volume input to that part of the water supply system to which the water balance calculation relates.
- Authorized Consumption is the annual volume of metered and non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorized to do so (e.g., water used in government offices or fire hydrants). It includes exported water and the leaks and overflows after the point of customers’ meter.
- Non-Revenue Water (NRW) is the difference between system input volume and billed authorised consumption. NRW consists of unbilled authorised consumption (usually a minor component of the water balance) and water Losses (i.e., real losses and apparent losses).
- Water Losses is the difference between System Input Volume and Authorised Consumption (billed and unbilled authorised consumption) and consists of apparent (commercial) losses and real (physical) losses. Water losses can be considered as total

volume for the whole system or for partial systems such as raw water mains, transmission, and distribution.

- **Commercial Losses, sometimes referred to as ‘apparent losses’**, consist of unauthorised consumption and all types of metering inaccuracies. Commercial losses account for theft or illegal use and all types of inaccuracies associated with production metering and customer metering (the combined effect of any under- and over-registration) and systematic data handling errors.
- **Physical Losses, sometimes referred to as ‘real losses’**, are the annual volumes lost in the pressurized system through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering. Physical losses after the point of customer metering are excluded from this definition of Commercial losses, but these can be significant and may be worthy of separate analysis. The annual volume of all types of leaks, bursts and overflows depends on frequencies, flow rates and average duration of individual leaks.

The separation of non-revenue water into components – unbilled authorised consumption, commercial (apparent) losses and physical (real) losses – should always be attempted. Sometimes even the most basic information, such as system input volume, average pressure, supply time, length of mains, and the number of service connections, is not initially available. The process of calculating each of the water balance components and performance indicators will reveal such deficiencies. The utility management should then take corrective action to close these data gaps and improve data quality. Using incomplete or inaccurate data for the water balance calculation will not produce a useful result. When the entire system input is metered, determining the annual system input volume is a straightforward task. Meter records must be collected regularly, and the annual quantities of the individual system inputs should be calculated. This includes a utility’s own sources as well as imported water from bulk suppliers. Ideally, the accuracy of the input meters is verified using portable flow measuring devices. Water utility managers need to accurately measure water produced from the treatment facility. The total water produced is a key input for the water balance.

Billed metered consumption includes all of the water consumption that is measured and charged to domestic, commercial, industrial or institutional customers. It also includes exported water that is measured and charged. The billed metered consumption period used in the calculation of NRW should be consistent with the audit period by processing it for time lags. In addition, NRW managers should determine the general accuracy of various domestic and non-domestic consumption meters for a possible 95% confidence limit by taking a sample of existing working meters from various locations and testing them on a standard recognised and calibrated meter test rig. Independent companies provide testing services if the water utility does not own a meter test rig. If several different customer meter brands are in operation, then the sample selection should include meters from each brand.

Determining the annual billed metered consumption goes hand in hand with detecting billing and data handling errors, information that utilities also require for estimating commercial losses. The volume of unbilled metered consumption should be established using a similar approach to that for billed metered consumption. Unbilled unmetered consumption is any kind of authorised consumption that is neither billed nor metered. This component typically includes items such as firefighting, flushing of mains and sewers, street cleaning, frost protection, etc. In a well-run utility, it is a small component

that is very often substantially overestimated. Unbilled unmetered consumption, traditionally including water the utility uses for operational purposes, is often seriously overestimated. This is sometimes caused by simplification (e.g., using a percentage of total system input), or by deliberate overestimates to 'reduce' the amount of NRW.

6.5.1 KEY STEPS FOR CONDUCTING A WATER BALANCE

The utility needs to have certain information about the network to conduct a water balance such as:

- System input volume
- Billed consumption
- Unbilled consumption
- Unauthorized consumption
- Customer metering inaccuracies and data handling errors
- Network data (Length of transmission mains, distribution mains and service connections)
- Number of registered connections
- Estimated number of illegal connections
- Average pressure
- Historic burst data
- Level of supply service (24-hour, intermittent, etc)

The four basic steps to conduct an IWA water balance are summarised as follows:

- Step 1. Determine system input volume
- Step 2. Determine authorized consumption (i) Billed (total volume of water billed by the water utility), (ii) Unbilled (total volume of water provided at no charge)
- Step 3. Estimate commercial losses
 - Theft of water and fraud
 - Meter under-registration
 - Data handling errors
- Step 4. Calculate physical losses
 - Leakage on transmission mains
 - Leakage on distribution mains
 - Leakage from reservoirs and overflows
 - Leakage on customer service connections

Confidence limits of up to 95% should be applied to all water balance data where possible. These define the boundaries within which utility managers can be 95% sure that the true value for that component lies. Although the water balance is an important tool for understanding inflows, consumption, and losses, the general lack of data leads to problems. Data gaps make it difficult to quantify commercial losses and pinpoint physical losses' nature and location. However, the water balance can be improved using two other methodologies:

6.5.2 SOFTWARE FOR WATER BALANCE CALCULATION: THE WB-EASYCALC

WB-EasyCalc is one example of a tool to support water balance calculations in addressing NRW and is now a standard “de facto” for this type of activity. It is a shareware software, and everybody and therefore AWWC managers too can use this spreadsheet-based software, developed by Liemberger and partners and supported by the World Bank Institute (WBI).

One advantage of EasyCalc is that the software not only asks for physical data but also for an assessment of the accuracy of that data. For example, when entering the production volume, the user must also estimate the accuracy of this data based on the type and age of production flow meters, if any, and the amount of maintenance carried out on the meter. Using these estimates, the software calculates NRW volume and its various components, in addition to the accuracy of these volumes. For example, EasyCalc may determine that NRW is 21% with an accuracy of +/- 66%— meaning that the actual NRW ranges between 7% and 35%. WB-EasyCalc is available as a free download at http://www.liemberger.cc/diverse_uploads/WBEasyCalc.xls.