MANAGEMENT, CONSERVATION AND OPERATION MODEL FOR THE SUPPLY NETWORK OF A LARGE METROPOLITAN AREA. CASE STUDY COMMUNITY OF MADRID.

Sub-directorate of Infrastructure Conservation Eastern Area

The Madrid Region (*Comunidad Autónoma de Madrid*) covers a geographical area of more than 8,000 km2 between the Guadarrama-Somosierra mountain range of the Central System and the right bank of the Tagus River on its border with the province of Toledo.

The geographical and territorial structure of the Community of Madrid encouraged the engineers of Canal de Isabel II since its constitution as an organisation, to favour a radial growth starting from the municipality of Madrid, incorporating an increasing number of municipalities, providing them not only with drinking water, but also, due to the environmental awareness of the Community of Madrid, with purification services, and in recent years with reuse infrastructures.

This integrated supra-municipal approach has provided important synergies in the integral water cycle, which has allowed not only efficient technical, but also economic and environmental management.

Canal de Isabel II currently manages more than 17,500 kilometres of drinking water supply networks in the Community of Madrid, more than 320 reservoirs and more than 140 lifting stations.

The network is made up of 3 types of pipelines; raw water from the catchments to the treatment stations, a strategic network that includes adduction and transport and a detailed distribution network. Most customers are supplied from the latter.

With these infrastructures, Canal de Isabel II meets the demand for drinking water of a population of 6.8 million inhabitants.

The Paper will develop a **practical case study where the supra-municipal management model** of the integral water cycle in a large territory such as the Community of Madrid will be **analysed. The main aspects that have contributed most to the success of Canal de Isabel II's integrated water cycle infrastructure management model will be discussed in depth**:

- 1) The concept of business unit of the conservation areas.

- 2º) The proximity of the work centres to the municipalities assigned to each of the areas, and the physical knowledge of the infrastructures.

- 3) Contracts for the maintenance of the distribution network outsourced to companies with proven experience, and with an economic approach based on production.

- 4) Sectorisation of the network, with actions such as control of minimum night-time flows and pressure management in the sectors.

- 5) Digitalisation and monitoring of the management of warnings, incidents, alarms.

- 6) Planning of new infrastructures to cater for urban growth and investment in the improvement of existing infrastructures.

1º) The business unit concept of conservation areas.

In the Madrid Region, the management of all supply, sewerage and reuse networks, as well as reservoirs and pumping stations, is carried out by structuring the territory into ten conservation areas. The lengths of the networks in each of the ten areas are shown in the following table:

LENGTH IN kms OF SUPPLY, SEWERAGE AND RECLAIMED WATER NETWORKS

LONGITUD EN Km DE REDES DE, ABASTECIMIENTO, SANEAMIENTO Y REGENERADA

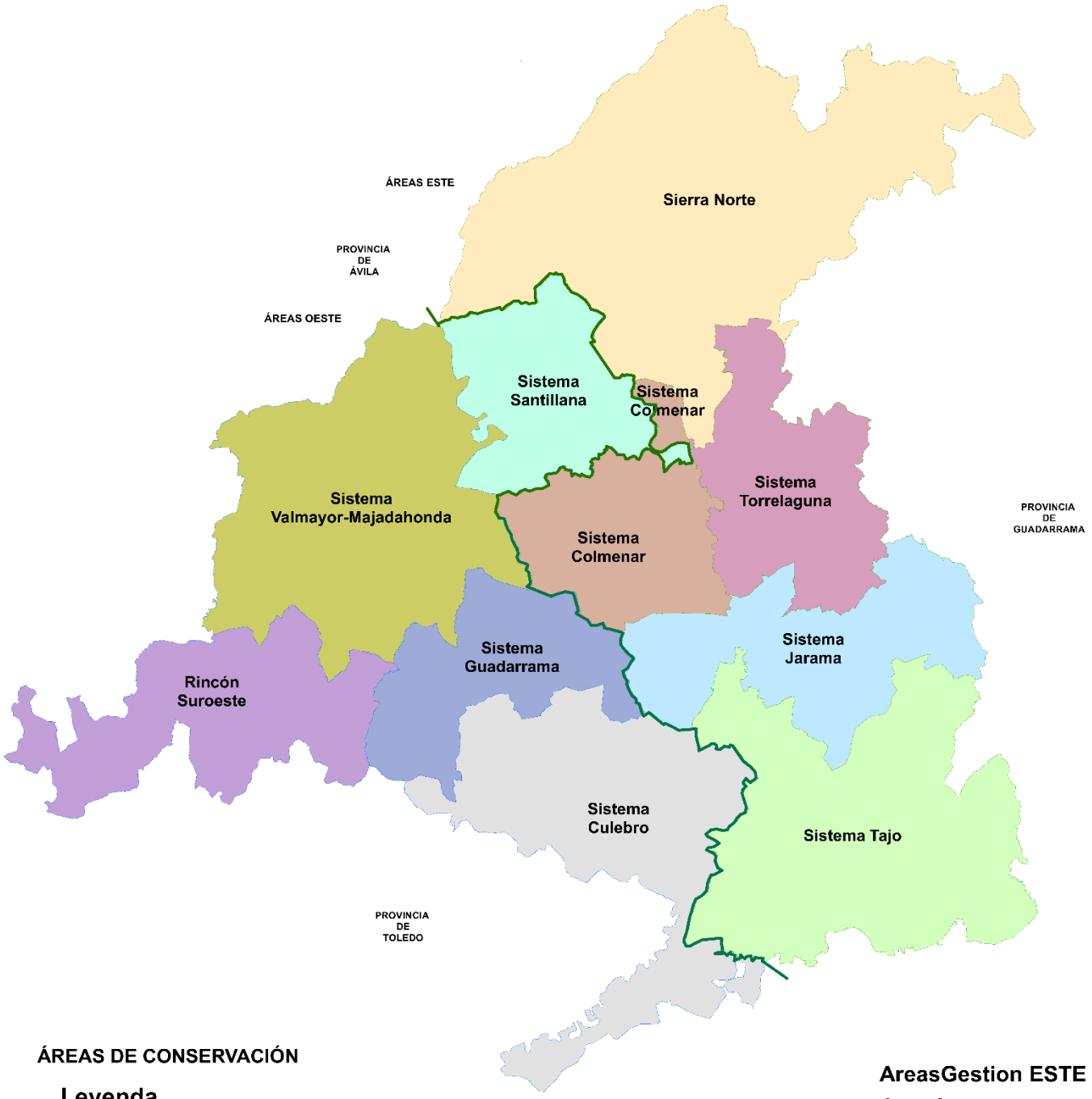
ÁREA	ABASTECIMIENTO	SANEAMIENTO	REGENERADA
Rincon Suroeste	420	276	-
Sierra Norte	924	518	-
Sistema Colmenar	2.497	1.837	134
SistemaCulebro	3.258	3.128	225
Sistema Guadarrama	2.915	1.800	96
Sistema Iarama	2.870	1.871	146
Sistema Santillana	748	128	21
Sistema Tajo	1.244	834	62
Sistema Torrelaguna	861	677	45
S. Valmayor Majadahonda	2.184	1.625	13
Total general	**17.921**	**12.694**	**742**

On the following page you will find a map of the Madrid Region with the 10 areas

Canal de Isabel II

ÁREAS DE CONSERVACIÓN DE REDES DE ABASTECIMIENTO, SANEAMIENTO Y REUTILIZACIÓN

N



ÁREAS DE CONSERVACIÓN

Leyenda

AreasGestion OESTE

Gestión

- Rincón Suroeste
- Sistema Culebro
- Sistema Guadarrama
- Sistema Santillana
- Sistema Valmayor-Majadahonda

AreasGestion ESTE

Gestión

- Sierra Norte
- Sistema Colmenar
- Sistema Jarama
- Sistema Tajo
- Sistema Torrelaguna

1:200.000

0 10 20 40 Km

Although the population and the number of infrastructures varies from one area to another due to the different population density between them, it is true that the structure of resources is similar because the incidents are of the same nature.

In each of the 10 areas there is a head of area, managers, engineers, foremen, foremen and highly specialised operating personnel, with physical knowledge of all the installations, reinforced by a remote-control system that records the main parameters that guarantee the continuity of service (flow, pressure, tank levels, equipment in operation, etc.).

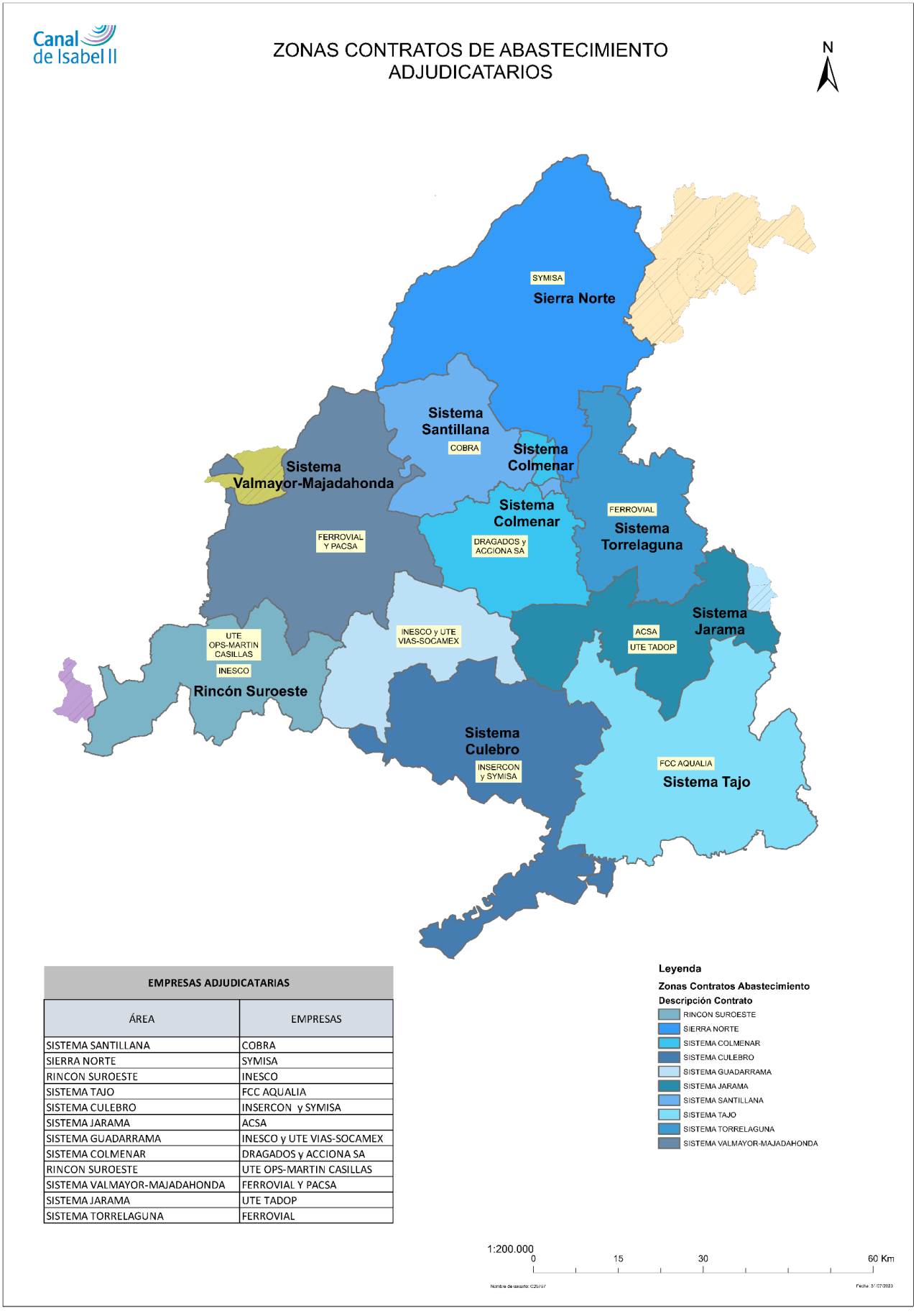
All the mentioned equipment is duly prepared and trained to deal with any incident. In addition, complex manoeuvres are conducted systematically, within a continuous process of improvement of the facilities and infrastructures of Canal de Isabel II.
One of the main advantages of the division of the territory into areas is the proximity of any incident to each of the 10 work centres where the Area Manager and his entire team are located.

It is important to highlight the collaboration of specialised companies equipped with the human and mechanical resources required in the administrative and technical specifications that Canal de Isabel II S.A. has.
Each of the 10 conservation areas function as business units with the same economic items, and all of them are driven by the objective of revitalising the important assets assigned to them and obtaining the best performance from the infrastructures.
Economic planning for the correct maintenance of the infrastructures is conducted every year, not only for expenditure items but also for investment items.
Periodic budget compliance analyses are conducted, anticipating any budgetary deviations.

2º) La The proximity of the work centres to the municipalities assigned to each of the areas, and the physical knowledge of the infrastructures.

In the previous section we pointed out the concepts of proximity and knowledge of the infrastructures of all the staff in each of the 10 areas. Knowledge requires effort, and this requires motivation to resolve complex situations that regularly arise in incidents involving breaks in the supply and sewerage network.
The direct contact of the incidents that affect our customers is with the staff of the conservation areas, and the pressure generated by the lack of supply, street closures for repairing faults, sinkholes that affect traffic, and water quality, among others, requires the best of our staff and contractors to reduce incident resolution times. For this reason, the proximity of the work centres to the municipalities assigned to each area is of vital importance, as well as the availability of resources of the contracting companies within the same geographical area or very close to it to save on travel costs and reduce the time required to resolve incidents.
The following map of the Community of Madrid shows the list of preventive and corrective maintenance contracts for supply and sanitation respectively in the year 2023.

SUPPLY CONTRACT AREAS
AWARDEES



EMPRESAS ADJUDICATARIAS	
ÁREA	EMPRESAS
SISTEMA SANTILLANA	COBRA
SIERRA NORTE	SYMISA
RINCON SUROESTE	INESCO
SISTEMA TAJO	FCC AQUALIA
SISTEMA CULEBRO	INSERCON y SYMISA
SISTEMA JARAMA	ACSA
SISTEMA GUADARRAMA	INESCO y UTE VIAS-SOCAMEX
SISTEMA COLMENAR	DRAGADOS y ACCIONA SA
RINCON SUROESTE	UTE OPS-MARTIN CASILLAS
SISTEMA VALMAYOR-MAJADAHONDA	FERROVIAL Y PACSA
SISTEMA JARAMA	UTE TADOP
SISTEMA TORRELAGUNA	FERROVIAL

SANITATION CONTRACT AREAS
CONTRACTORS

Canal de Isabel II

ZONAS CONTRATOS DE SANEAMIENTO
CONTRATAS

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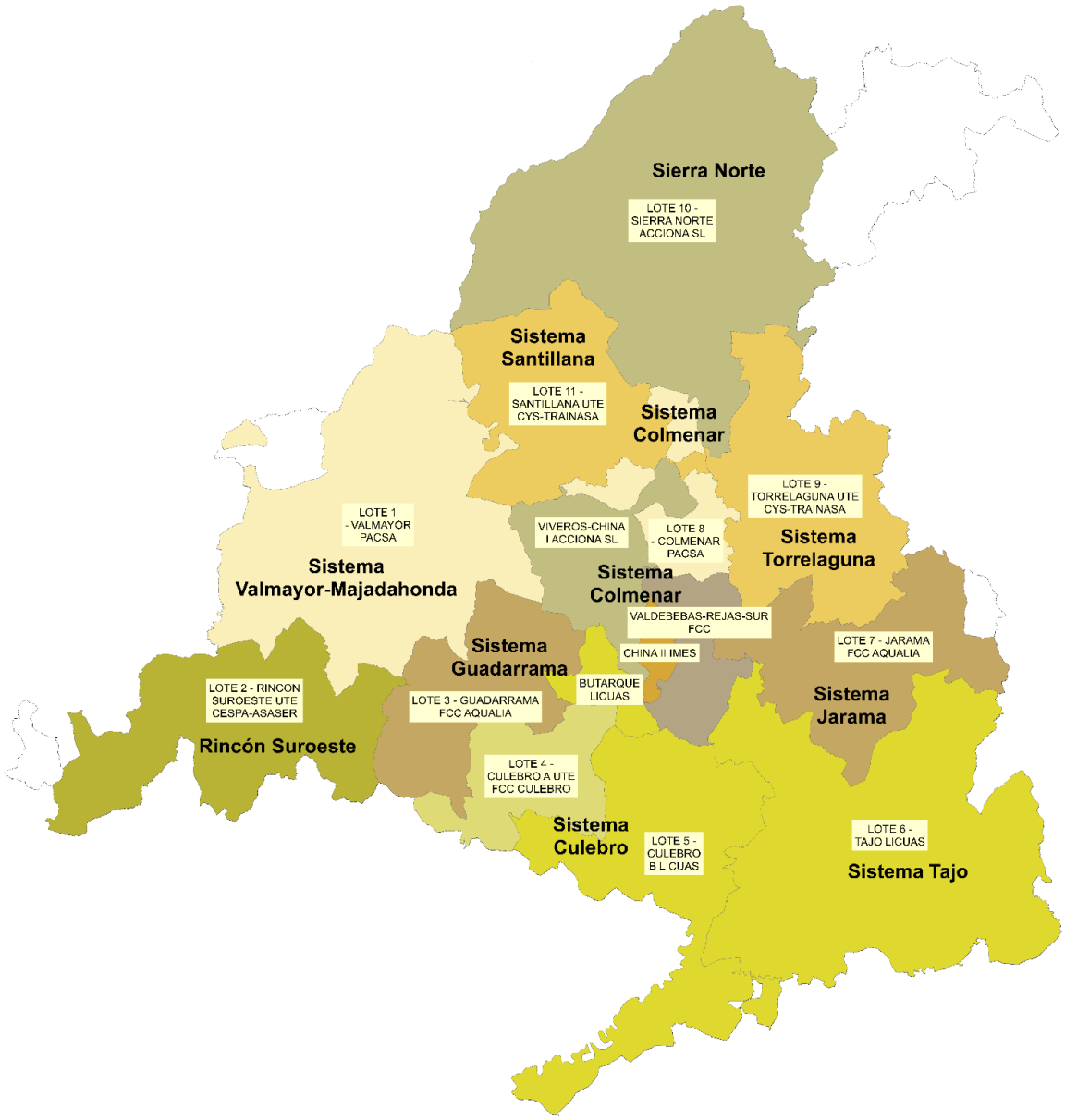

EMPRESAS ADJUDICATARIAS		
NOMBRE	**DESCRIPCIO**	**EMPRESAS**
BUTARQUE	71/2017 Saneamiento Metropolitano Butarque (zona A)	LICUAS
CHINA II	71/2017 Saneamiento Metropolitano China II (zona C)	IMES
LOTE 01 - VALMAYOR	346/2017 Saneamiento Periferico Valmayor (Lote 1)	PACSA
LOTE 02 - RINCON SUROESTE	346/2017 Saneamiento Periferico Rincon Suroeste (Lote 2)	UTE CESPA-ASASER
LOTE 03 - GUADARRAMA	346/2017 Saneamiento Periferico Guadarrama (Lote 3)	FCC AQUALIA
LOTE 04 - CULEBRO A	346/2017 Saneamiento Periferico Culebro A (Lote 4)	UTE FCC CULEBRO
LOTE 05 - CULEBRO B	346/2017 Saneamiento Periferico Culebro B (Lote 5)	LICUAS
LOTE 06 - TAJO	346/2017 Saneamiento Periferico Tajo (Lote 6)	LICUAS
LOTE 07 - JARAMA	346/2017 Saneamiento Periferico Jarama (Lote 7)	FCC AQUALIA
LOTE 08 - COLMENAR	346/2017 Saneamiento Periferico Colmenar (Lote 8)	PACSA
LOTE 09 - TORRELAGUNA	346/2017 Saneamiento Periferico Torrelaguna (Lote 9)	UTE CYS-TRAINASA
LOTE 10 - SIERRA NORTE	346/2017 Saneamiento Periferico Sierra Norte (Lote 10)	ACCIONA SL
LOTE 11 - SANTILLANA	346/2017 Saneamiento Periferico Santillana (Lote 11)	UTE CYS-TRAINASA
VALDEBEBAS-REJAS-SUR	71/2017 Saneamiento Metropolitano Valdebebas_Rejas_Sur (zona D)	FCC
VIVEROS-CHINA I	71/2017 Saneamiento Metropolitano Viveros China I (zona B)	ACCIONA SL

Leyenda

Zonas Contratos Saneamiento

<all other values>

ADJUDICATARIO

- ACCIONA SL
- FCC
- FCC AQUALIA
- IMES
- LICUAS
- PACSA
- UTE CESPA-ASASER
- UTE CYS-TRAINASA
- UTE FCC CULEBRO
- Urbanizaciones No Gestionadas

1:200.000

0 10 20 40 Km

3º) Maintenance contracts for the distribution network outsourced to companies with proven experience, and with an economic approach based on production.

Canal de Isabel II conducts corrective maintenance of all supply, sewerage and reuse networks, drinking water tanks, reclaimed water tanks, drinking water and wastewater lifting stations, through companies specialising in these tasks. To this end, every 4 or 5 years, the corresponding administrative and technical specifications are put out to tender through open procedures.

The work of the specialised companies not only corresponds to corrective maintenance (breakdowns) of all the facilities, but also preventive maintenance under the management of Canal de Isabel II (through the personnel assigned to the conservation areas).

The technical and administrative specifications are regularly reviewed and updated to reflect the advances in the market (new technologies). The entire chain of command participates in the drafting of the specifications, from the area director, deputy directors and area heads, because the most detailed description of the work will allow us to optimise investments and reduce management costs.

4º) Digitalisation and monitoring of the management of warnings, incidents, alarms, etc.

The management of warnings and incidents in the supply, sanitation, purification and reclaimed water systems is carried out in the Control Centre, from where they are referred to the competent operating areas for their resolution.

The warnings consist of communications of anomalies occurring in the infrastructures managed by Canal and can be of internal or external origin.

In the latter case, the reception of calls from customers or third parties communicating alterations in the services provided by Canal is contracted with an External Manager, who applies a protocol to identify the caller, locate the incident and know its nature.

As for internal warnings, they can come from other areas of the company or be detected in the Control Centre itself by the generation of alarms in the Remote Control System, in which case, before communicating an anomaly warning in an installation, a series of checks are carried out, such as confirming if it is an isolated alarm, analysing the behaviour of the equipment in the previous hours, assessing the quality of the measurement, etc.

All warnings are recorded in a corporate development application (GAYTA), where the incidents that are registered because of them are also recorded.

Alerts consist of communications of anomalies occurring in the infrastructures managed by Canal and may be of internal or external origin.

In the latter case, the reception of calls from customers or third parties communicating alterations in the services provided by Canal is contracted with an External Manager, who applies a protocol to identify the caller of the warning, locate the incident and know its nature.

As for internal warnings, they can come from other areas of the company or be detected in the Control Centre itself by the generation of alarms in the Remote Control System, in which case, before communicating an anomaly warning in an installation, a series of checks are carried out, such as confirming if it is an isolated alarm, analysing the behaviour of the equipment in the previous hours, assessing the quality of the measurement, etc.

All warnings are recorded in a corporate development application (GAYTA), where the incidents that are registered because of them are also recorded.

Before generating an incident, it is checked if the anomaly concerns a municipal entity or private installation, if there is any related incident in progress or if it is caused by any previously planned active maintenance work, whose record is also made in GAYTA to have a comprehensive view of all the actions affecting Canal's installations.

The notification of incidents to the affected operation areas is done through a mobile work order management system (MC3), also of corporate development, which allows the assignment and resolution of the actions registered in GAYTA to be done from mobile devices. In this sense, the operation area determines the actions it considers necessary to solve any incident assigned to it and registers them immediately in GAYTA, via MC3, so that the Control Centre can provide information to the client in real time, either by SMS or by telephone through the External Manager.

In addition, at any time during the incident resolution process, when a difference is detected between the real data recorded in GAYTA and the cartography reflected in the geographic

information system (GIS), the Control Centre generates a cartographic correction order, so that the information contained in the GIS is as dependable as possible.

In the case of quality incidents, apart from attending to the warnings communicated by affected customers, Canal has developed an application for the automatic registration of warnings in GAYTA every time a parametric value of water quality is exceeded, as defined in the Self-Control Protocol included in the Water Health Plan (WSP) that the company has implemented and operational since 2019.

The average annual number of warnings and incidents managed by Canal is 140,000 and 80,000, respectively.

Of the total number of warnings, an average of 7,000 are registered in GAYTA because of the 250,000 annual hydraulic alarms generated by the Remote-Control System, once they have been recognised by the technicians in charge. Most of them are related to flow gradients, exceeding water level limits in reservoirs, pressure thresholds in the network, etc.

The hydraulic system managed by Canal has 30,000 measuring instruments and 150,000 control signals in the facilities, in addition to 2,150 remote stations connected to each other that provide more than 200,000 data of information in real time. This makes it possible to locate any type of anomaly and generate the corresponding alarm, not only on the hydraulic situation of the different supply, sewerage, and treatment infrastructures, but also on the state of the water quality.

Likewise, Canal has 146 installations with remote control that makes it possible to remotely control both the main infrastructures and the most isolated ones.

With regard to the management of water resources, Canal has also developed a simulation model that takes into account the availability of the facilities, the state of the different reservoirs, the probabilistic prediction of inflows and the forecast of demand by consumption areas, with the aim of determining the volume to be diverted for consumption from each of the reservoirs and catchments of the system, as well as projecting two years ahead the reservoir volumes according to their probability.

5º) The network sectorisation, with actions such as the control of minimum nocturnal flows and pressure management in the sectors.

In 2005, Canal de Isabel II implemented a plan for the compartmentalisation of its distribution network into independent sectors of limited extension, with the aim of improving the planning and management of the service, as well as knowledge of the behaviour of consumption and infrastructures.

This compartmentalisation consisted of isolating small sectors of between 20 and 100 km of pipelines, at whose inlets and outlets, which are the points of connection with the transmission network, there is remote metering equipment (flow meters, meters, and pressure gauges). The availability of real-time data for each sector makes it possible to know the efficiency of the network, identify water losses and implement advanced improvement programmes such as pressure management.

The development of a sectorisation plan in a system of the complexity of Canal de Isabel II's system requires adequate planning and the coordinated execution of multiple activities to be conducted by different areas of the company, namely:

- Design and identification of sectors.
- Development and calibration of the hydraulic models of the networks.
- Feasibility analysis and proposal of actions for each sector.
- Installation of metering equipment and accessory works.
- Implementation of the sectors, by means of confinement manoeuvres.
- Maintenance of basic information: topology, borders, alternative supplies.
- Maintenance of hydraulic models and demand models.
- Preparation, analysis, and monitoring of indicators.
- Support for the operation of the sectorised network.

There are currently 602 implemented sectors whose main efficiency indicator is the percentage of uncontrolled water (% ANR), which is obtained from the following operation:

$$\text{ANR (\%)} = \frac{V_{suministrado} - V_{registrado}}{V_{suministrado}} * 100$$

$$\frac{V_{supplied} - V_{registered}}{Vsupplied}$$

The volume supplied is obtained from the inlet and outlet flow meters and counters in each sector, and is calculated by the following arithmetic combination:

$$V_{suministrado} = \Sigma Entradas - \Sigma Salidas$$

The registered volume comprises the sum of all the volumes registered (billed or unbilled) on the commercial meters of each of the connections in the sector.

$$V_{registrado} = \Sigma \text{ Volumen de Acometidas}$$

According to the ANR value, Canal de Isabel II classifies the sectors into:

- Unstable: ANR < 0%.
- Stabilisable: 0 < ANC < 10% and ANC > 70%.
- Stable: 10 < ANC < 70%

For unstable or stabilisable sectors, the first thing to do is to analyse whether the essential data defining the sector are correct:

- Equipment > The measurement quality of the equipment determining the VS is checked.
- Tightness > Check that the sector is correctly insulated.
- Connections > It is checked that the commercial meters of the connections that determine the RV are the ones that should really be allocated to the sector.

Once stable sectors are available, measures are taken to reduce the volume of NRAs, i.e. to reduce the VS and increase the RV.

Measures affecting VS aim to reduce water lost in the form of leakage:

- Leakage detection: by installing pre-locators in the network, either routinely or upon a leakage alert in the sector.
- Network renovation works with priority given to the most critical sections due to recurrent breaks and/or the existence of obsolete materials.
- Pressure management (static or dynamic): allows for the reduction of lost flow in micro-leaks that are difficult to detect and, in the case of the dynamic system, as it is remotely controlled, pressure regulation can be modified in real time.

On the other hand, the measures affecting the RV focus on the increase in registered water:

- Regularisation of supplies to public entities without a contract.
- Fraud Regularisation
- Correction of incidents in commercial meters.

In addition, the monitoring of stable sectors is complemented by the generation of alarms in the Remote-Control System, where statistical studies of historical data are conducted which, combined by means of different operations, allow the following types of warnings to be generated:

- Metering equipment failure.
- Possible leak in the sector.
- Possible insulation problem.
- An anomalous consumption patterns.

In addition, to monitor the status of each sector, a reference value called "theoretical minimum flow" is also used, which consists of a monthly value calculated according to the uses of the connections in the sector: domestic (multi-family and single-family), industrial and irrigation. Each component is assigned a nocturnal flow for the two seasons of the year (summer and winter), and the aggregate of the three components for each month provides the value of the minimum theoretical monthly flow, which should always be higher than the minimum nocturnal flow recorded in the sector.

The application and improvement of this methodology in Canal de Isabel II means that currently the apparent percentage of unregistered water (% NRA) is 13%, although the real value is considerably lower, since the apparent value includes a series of authorised unmeasured consumptions, such as tank cleaning and network purges, as well as the error due to undercounting of the inventory of commercial meters.

6º). Planning of new infrastructures to cater for urban growth, and investments in the improvement of existing ones.

When a municipal general planning process is initiated, either by a local council or by the Community of Madrid, the approval procedure requires a series of phases subject to public information during which citizens, entities and institutions can submit reports of observations, suggestions, or allegations. These phases are advance, initial approval, provisional approval, and final approval.

In any of these phases, Canal de Isabel II may receive a request for a Municipal General Planning Report from the different bodies involved, and this report will include the observations and allegations submitted by Canal in each of the phases.

The minimum documentation required from the requesting Body to issue the report is:

- Report
- Town planning regulations
- Urban planning files of the areas defined in the planning.
- Plans of land classification and qualification

Based on this data, Canal studies the supply, sanitation and reuse infrastructure needs of the general planning that is being processed, after calculating the flows generated by the urban development areas according to the allocations defined in the internal regulations.

This initial infrastructure proposal is dealt with by the Water Supply, Drainage and Reuse Networks Commission, from where the corresponding hydraulic feasibility studies are ordered and conducted by means of mathematical network simulation models that contemplate demands and discharges at the planning ceiling.

Once the necessary infrastructures have been confirmed, Canal finalises the report including the agreement ratified in the Commission and sends it to the requesting body for its incorporation into the municipal general planning document.

From this point on, in order to solve the needs required in the approved urban planning, Canal de Isabel II and the town councils, organisations or entities interested, sign an Agreement for the Execution of Hydraulic Infrastructures (CEIH), where the supply and/or sewerage solutions are defined and assessed and the financing conditions of the works are agreed, charged to third parties, Town Council and/or developers, or shared with Canal.

Later, before the development of a specific urban area, Canal issues a Feasibility Report in which the economic and administrative commitments of the developer for the execution of the general infrastructures included in the CEIH in force are established.

Likewise, Canal has a General Infrastructure Plan that includes all the needs for improvement, expansion, or new facilities, whether due to urban developments, adaptations to regulations, technological advances or other needs detected by the operation and maintenance areas.

The document constituting the General Infrastructure Plan gathers all the information necessary to know the status of processing and the annual budget commitment of each of the actions planned by Canal.