Water-tightness Airborne Detection Implementation

D5.1 - WADI technique demonstration on water supply mains

Authors:

Furlanis F., Galli A., Bertoni A. (SGI); Krapez J.-C (ONERA); Olichon V., Mazel C. (AM); Le Goff I., Serra G. (SCP); Jimenez Gonzalez D. (NTGS), Sanchis Muñoz J., Barba Polo J., De Badts E. (GG); Círez F., Arnal A.J. (CIRCE)

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Technical references

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Project Coordinator	Elena Gaboardi, Alice De Ferrari youris.com (YOURIS) elena.gaboardi@youris.com, alice.deferrari@youris.com
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v	Date	Beneficiary	Author
1.01	31/08/2018	GG	Sanchis Muñoz, J., Barba Polo, J., De Badts, E.
1.02	16/08/2018	SGI	Furlanis F., Galli A., Bertoni A.
1.03	31/08/2018	ONERA	Krapez J.-C.
1.04	31/08/2018	AM	Olichon V., Mazel C.
1.05	31/08/2018	SCP	Le Goff I., Serra G.
1.06	31/08/2018	NTGS	Jimenez Gonzalez, D.
1.07	31/08/2018	CIRCE	Círez F., Arnal A.J.
1.08	31/08/2018	GG	Sanchis Muñoz, J.
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2.1	28/03/2019	ONERA	Chatelard, C.
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Executive Summary

The objective of this report is to show the results from the airborne validation demonstration on a multipurpose water infrastructure presenting a wide variety of water networks (water supply and irrigation mains) at SCP's site in the Provence region (France). The flights aim mainly at performing "technical" validation tests, meaning having all equipment working over the actual water networks and gathering data in different conditions. In particular, the purpose is to:

• Perform real flight tests over different type of water supply infrastructure site using the instrumented aircraft and UAV; and

• Provide data for a comparative assessment of WADI solution with a typical ground leak detection technique (acoustic); and

• Collect airborne measurement data and flight parameters for data processing and results analysis.

• Recommend improvements, relevant to sensor system and data processing, to be implemented during the preparation of the following operational demonstration.

Three sites have been selected by SCP as potential validation sites for the activities under WP5: Cabardèle, Vauvernagues and Verdagne. The selection was carried out in accordance with two main criteria:

- The possibility to isolate the sites
- The network performance in terms of water balance.

As regards the performance of the three sites, even though no Active Leakage Control is systematically carried out by SCP (though they follow a program for replacing pipelines in accordance with the probability of the pipe to break depending on its characteristics) it is estimated that the current NRW rate is about 20% of the supplied amount, which is already a good (low) value, compared to most European water supply systems. The description of the three sites and the proposed methodology for carrying out the step testing activities are reported herewith.

After the sites selection, the involved partners worked in the administrative clearances for flying over the different pipelines network, at this point GG had to homologue their legal RPAS operator documentation in Spain to the national authority in France, and studying which sites have restrictions or not for flying the RPAS. It was scheduled to fly during June or July both platforms (manned and the unmanned aircraft) but because of justified technical problems with the sensors integration in the manned aircraft from AM, only the WADI RPAS was able to make validation flights over the selected site during July. There are forecasted a new RPAS flight campaign together with the manned aircraft flights in October of 2018 because of the mentioned delay and after fixing all pending problems and issues with the sensors integration in the manned aircraft.

During the foreseen period, an intense field campaign has been developed by SGI and SCP using step testing technique whereby leakage volumes in each of the sectors

comprising a water supply network (generally called a Leakage Control Zone) are determined. After the analysis from this field campaign, the sectors have been ranked in accordance with the performance indicators Leak/Length (in m3/km/year) and Infrastructure Leakage Index (ILI).

The first RPAS aerial flight campaign from July has delivered multispectral and thermal orthomosaics of the pipeline section and has demonstrated the good performance of sensors integration done in the WADI drone and the correct performance of the selected processing software including the GeFolki tool from Onera. We expect to have clear water leak detection maps after completing the processing of the October campaign.

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List of Acronyms

BPT	Break Pressure Tank
BS	Booster Station
CI	Cast Iron
d/s	Downstream
DI	Ductile Iron
EU	European Union
GL	Ground Level
HDPE	High-Density PolyEthylene
MNF	Minimum Night Flow
NIR	Near InfraRed
NRW	Non Revenue Water
PRV	Pressure Reducing Valve
PS	Pump Station
PVC	PolyVinyl Chloride
SR	Storage Reservoir
TIR	Thermal InfraRed
u/s	Upstream
WP*n*	Work Package *n*
RPAS	Remotely Piloted Aircraft System
UAV	Unmanned Aerial Vehicle
GNSS	Global Navigation Satellite System
IMU	Inertial Measurement Unit
VLOS	Visual Line of Sight
NOTAM	Notice to Airmen
CTR	Controlled Traffic Region
DGAC	Direction Générale de l'Aviation Civile
DSM	Digital Surface Model
DEM	Digital Elevation Model
GCP	Ground Control Point
AGL	Above Ground Level
GIS	Geographic Information System

1 Preparation of validation tests

1.1 Identification and description of the trials site

1.1.1 Cabardèle

The Cabardèle validation site is located in the commune of Lançon-Provence, in the Bouches-du-Rhône department in south-eastern France. It extends from 5°06' E to 5°14' E in longitude, and from 43°34' N to 43°37' N in latitude. The site map is reported in Annex.

The water supply system consists of a distribution network that is fed both by direct pumping and by gravity from two adjacent reservoirs. The pumps start when the SRs reach a minimum level and shuts off at a maximum level. During winter time the pump starts twice per day for less than two hours each time, whereas in summertime – when irrigation requirements substantially increase the water demand – the pumps operating time is almost continuous.

The main features of Cabardèle validation site are summarized in the following Table.

Name	Cabardèle
Extent (km)	10 x 5
Main infrastructures	1 PS (Cabardèle) 2 SRs (Cazeneuve 1&2)
Total pipe length (km)	71.9 (63.7 w/o house connections)
Max Dia (mm)	1000
Min Dia (mm)	700
Metallic pipes (%)	99
Number of connections	709
MNF measured in winter time (l/s)	2014 – 4 [126,144 m^3] 2015 – 3.6 [113,000 m^3] 2016 – 3.33 [105,000 m^3]

Name	Cabardèle
NRW (%)	19% [193,105 m³]
Notes	There are 20 PRVs in the network.
Levels (masl)	221 at SRs 72 at PS 68 lowest GL in the network

Table 1.1 Cabardèle site characteristics.

The following graphs show the pipelines' material (expressed as percentage of total length excluding house connections) and their year of installation (expressed as absolute total length excluding house connections): most of the mains are in ductile iron and almost 70% of them were laid before 1995.

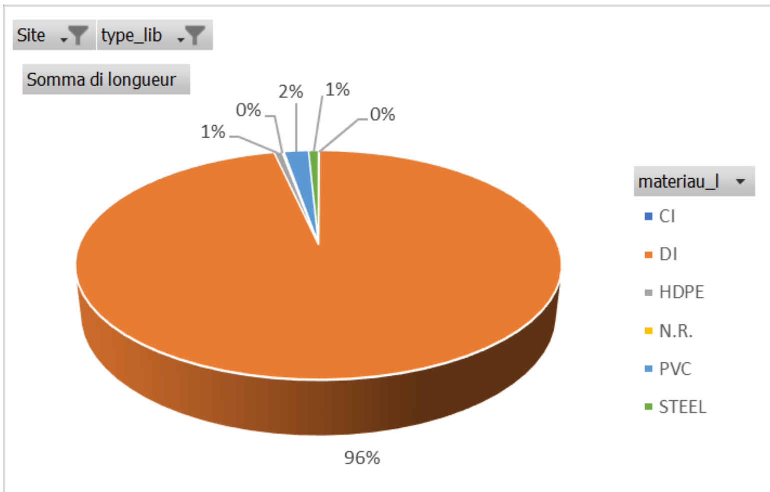


Figure 1.1 Pipe material in Cabardèle site.

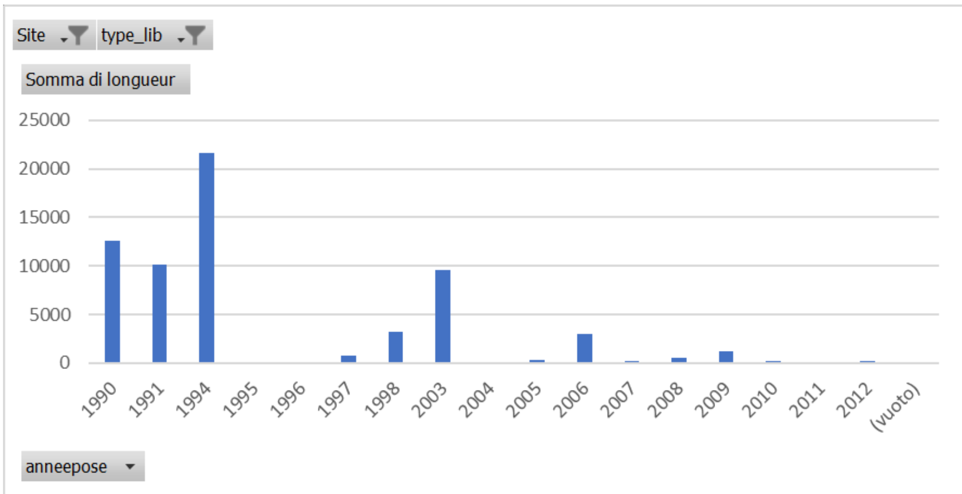


Figure 1.1 Pipe year of installation in Cabardèle site.

1.1.2 Vauvenargues

The Vauvenargues validation site is located in the communes of Vauvenargues and Saint-Marc-Jaumegarde, in the Bouches-du-Rhône department in south-easter France. It extends from 5°29' E to 5°36' E in longitude, and from 43°32' N to 43°34' N in latitude. The site map is reported in Annex.

The water supply system consists of a distribution network that is fed both by direct pumping and by gravity from a reservoir. The pumps start when the SR reaches a minimum level and shuts off at a maximum level. During winter time the pump starts twice per day for about 2-3 hours each time, whereas in summertime – when irrigation requirements substantially increase the water demand – the pumps operating time is almost continuous.

The main features of Vauvenargues validation site are summarized in the following Table.

Name	Vauvenargues
Extent (kmxkm)	9 x 2
Main infrastructures	1 PS (Saint-Marc Jaumegarde) 1 SR (Clau des Lamberts) 1 BPT (Bimont)
Total pipe length (km)	30.4 (26.6 w/o house connections)
Max Dia (mm)	1000
Min Dia (mm)	400
Metallic pipes (%)	99

Name	Vauvenargues
Number of connections	296
MNF measured in winter time (l/s)	2014 – 1.45 [45,000 m³] 2015 – 1.71 [54,000 m³] 2016 – 2.42 [76,000 m³]
NRW (%)	18 [111,285 m³]
Notes	There are 2 PRVs in the network. One artificial leak is located within this site.
Levels (masl)	488 at SR 298 lowest GL in the network

Table 1.2 Vauvenargues site characteristics.

The following graphs show the pipelines' material (expressed as percentage of total length excluding house connections) and their year of installation (expressed as absolute total length excluding house connections): most of the mains are in ductile iron and they were almost entirely (99%) laid before 2005.

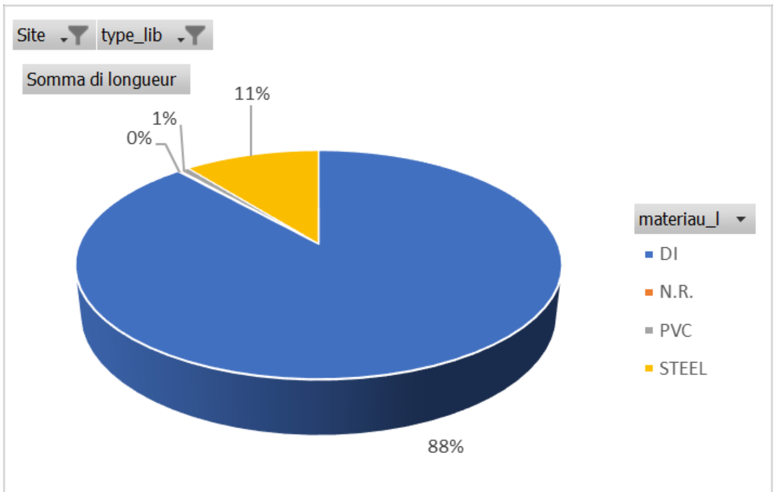


Figure 1.3 Pipe material in Vauvernagues site.

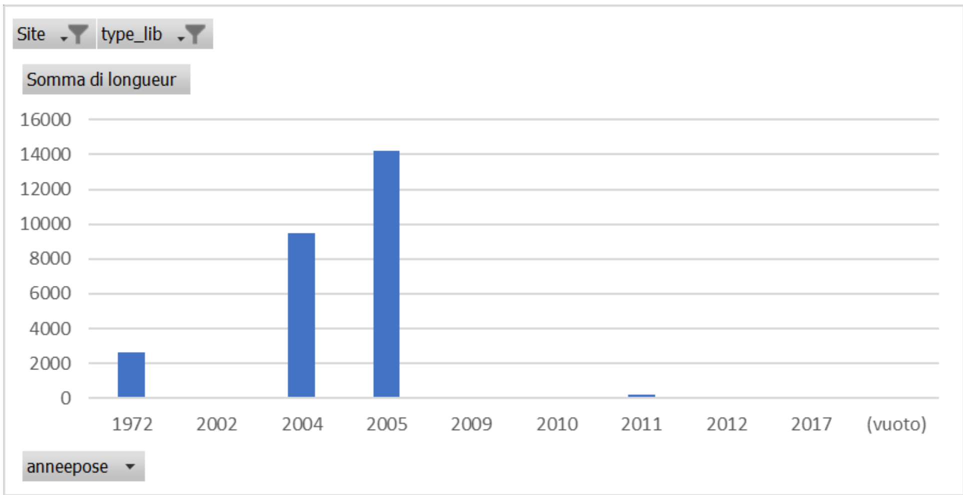


Figure 1.4. Pipe year of installation in Vauvenargues site.

1.1.3 Verdagne

The Verdagne validation site is located in the communes of Saint-Maximin-la-Sainte-Baume, Seillons-Source-d'Argens and Brue-Auriac in the Var department in south-eastern France. It extends from 5°49' E to 5°57' E in longitude, and from 43°27' N to 43°33' N in latitude. The site map is reported in Annex.

The water supply system consists of a distribution network that is fed both by direct pumping – from a pump station and an inline booster - and by gravity from two separate reservoirs. The pumps at the pump station and at the booster station start and stop automatically depending on the water level in the SR of Rabinets and Planissard, respectively. During winter time the pump starts twice per day for about 1 hour each time, whereas in summertime – when irrigation requirements substantially increase the water demand – the pumps operating time is almost continuous. SCP suspects that most of water losses are occurring in the sector of network located upstream of the BS.

The main features of Verdagne validation site are summarized in the following Table.

Name	Verdagne
Extent (kmxkm)	15 x 5
Main infrastructures	1 PS (Verdagne) 2 SRs (Rabinets, Planissard) 1 WTP (Saint Maximin) 1 BS (Brue Auriac)
Total pipe length (km)	69.5 (69.1 w/o house connections)
Max Dia (mm)	100
Min Dia (mm)	800
Metallic pipes (%)	≈100
Number of connections	285
MNF measured in winter time (l/s)	2014 – 5.4 [170,294 m^3] 2015 – 7.1 [223,905 m^3] 2016 – 5.9 [186,062 m^3]
NRW (%)	23 [341,980 m^3]

Name	Verdagne
Notes	/
Levels (masl)	402 at SR Rabinets 268 lowest GL in the network u/s of BS 276 at BS 400 at SR Planissard 263 lowest GL in the network d/s of BS

Table 1.3 Verdagne site characteristics.

The following graphs show the pipelines' material (expressed as percentage of total length excluding house connections) and their year of installation (expressed as absolute total length excluding house connections): most of the mains are in ductile iron and more than half of them were laid before 1990.

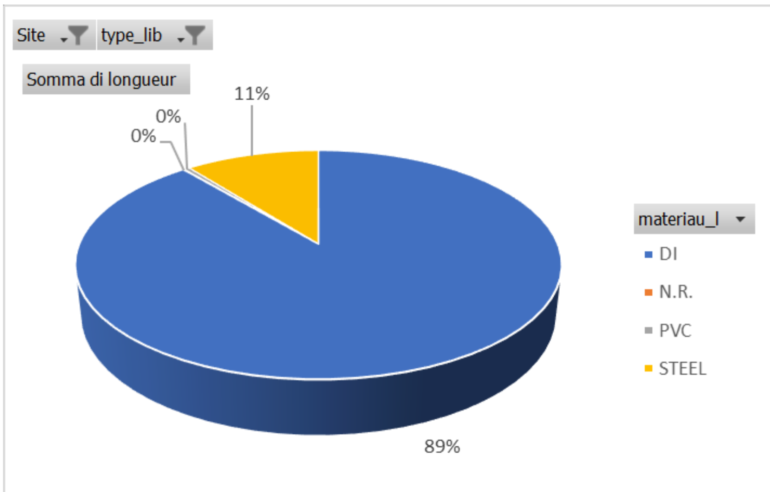


Figure 1.5 Pipe material in Verdagne site.

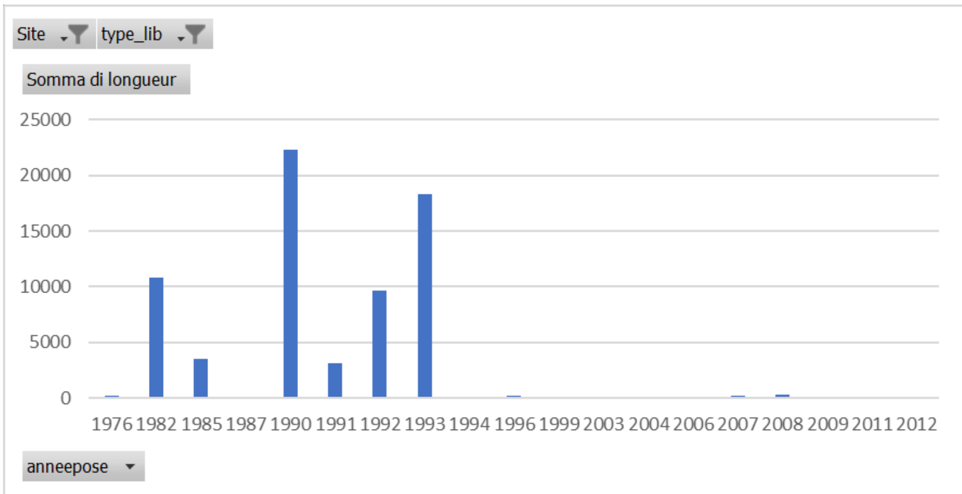


Figure 1.6 Pipe year of installation in Verdagne site.

1.2 Administrative clearances

According to the pertinent flight regulations and other legislative requirements identified within WP 2.3, the partner SCP and ONERA have given institutional support to AM and GG in the process of obtaining necessary authorisations/permits to carry out flights over Provence region.

In the case of RPAS flights, we commented in the D.2.1, that France has two main legal instruments that are relevant: A decree related to the design and conditions of use of the RPAS and the qualifications of the pilot (the 17 December 2015 law about the conception of RPAS), and on the other hand, another decree related to the conditions of integrating RPAS into French airspace. Basically, the legislation establishes the avoidance of overflying people, maximum AGL: 150 m (with restrictions around airfields and military aviation zones), only daytime Visual Line of Sight (VLOS) flights, avoidance of overflying urban public environment, minimum distance to an airfield (≤10 km for the biggest airports), avoidance of overflying protected or restricted area, preservation of privacy, mandatory information to people around the flying area and insurance or operator contract needed.

Civil remote piloted aircraft are split into seven categories, primarily dependent on mass. Except for special cases, rules are split into 4 scenarios. Regardless of the purpose of the RPAS flight, visual line of site operations are allowed for drones under 25kg in mass below 150m over unpopulated areas, and for under 4kg of mass over populated areas. Beyond visual line of sight operations are allowed without distance limitations for drones under 2kg flying under 150m, and within a 1km radius for drones of 25kg or less flying under 50m. All operations are forbidden in the vicinity of airports, and subject to prior authorization over populated areas. Illegal RPAS operation can carry a maximum sentence of a year in prison, as well as a fine. The defined scenarios are:

- **S1:** out of city, visual flight, maximum elevation of 150 meters and maximum distance of 200 meters

- **S2:** out of city, visual flight, maximum elevation of 150 meters (under 2 kg) or 50 meters (above 2kg) and maximum distance of 1000 meters
- **S3:** inside city, visual flight, maximum elevation of 150 meters and maximum distance of 100 meters, parachute needed if above 2 kg A security perimeter is needed between 30 to 50 meters. An administrative approval of Prefectural Governor is needed before the urban flight.
- **S4:** out of city, no-visual flight, maximum elevation of 150 meters and unlimited distance, maximum 2 kg, telepilot need 100h of flight on plane, glide or helicopter. Night flight are forbidden in any case.

For professional and research flights is need to be a French operator that owns a pilot license (theoretical part only): Private Pilot (PPL) pilot glider or microlight, or in case of foreign operators to follow a homologation for obtaining a permission to fly. In any case it is needed to obtain a flight approval for each flight scenario depending of the RPAS characteristics.

Therefore, as foreign operators in France, GG had to follow a homologation process translating and presenting our valid documentation as legal operators in Spain together with the flight plan, flight details, insurance and forms to the Direction Générale de l'Aviation Civile (DGAC). The main form «Demande d'autorisations specifiques pour la mise en oeuvre d'aeronefs telepilotes» can be consulted in the annexes as well as the received authorisation for flights in France.

The characteristics of the Marseille-Provence air space are quite restrictive for flights in the most of the site areas and especially for the RPAS flights. As we can see in the following picture, the area contains several civil and military airports together with other military facilities that restrict dramatically the WADI available sites for flying with RPAS and also difficult the performance of the manned flights.

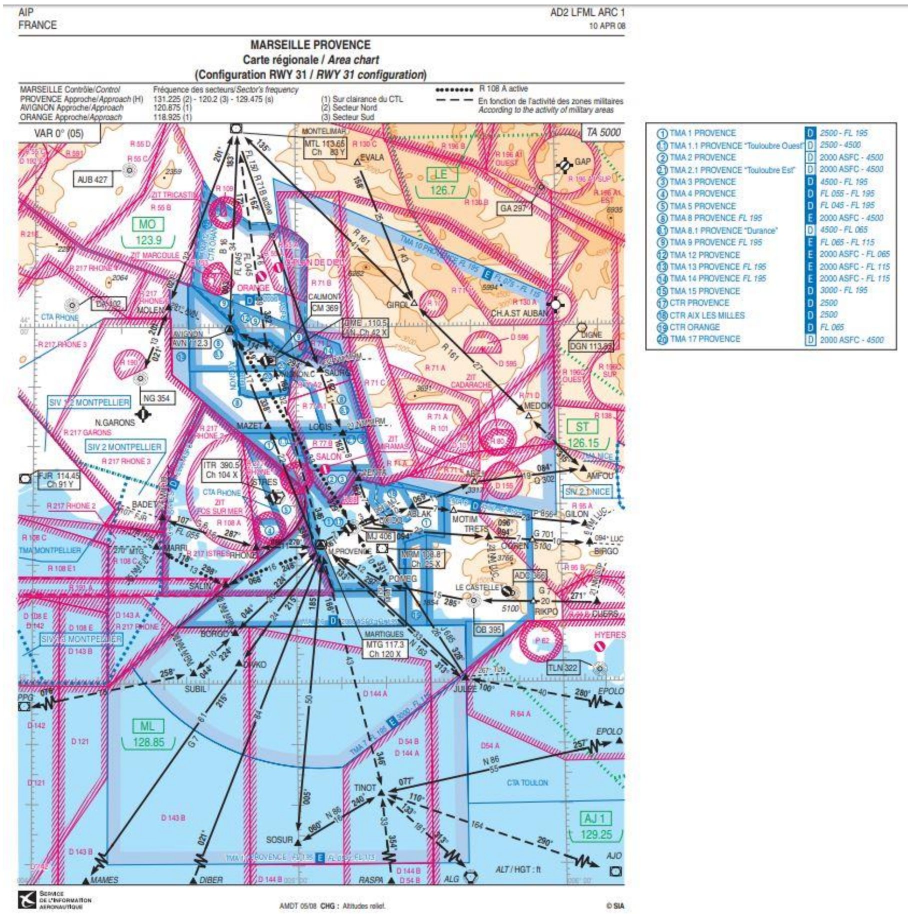


Figure 1.7 Area chart of the Marseille-Provence air space.

We selected to perform the RPAS flights in the Vauvenargues site due to the unpopulated nature of the area around the selected pipeline. By the way, the waterleaks test field is a a representative area regarding the water leaks scenarios without the flight restrictions (Controlled Traffic Region - CTR), while other areas like Cabardèle and Verdagne are included in a CTR space where it is forbidden to fly RPAS, and special permissions (Notice To Airmen - NOTAM) are very highly restrictive for the RPAS flights.

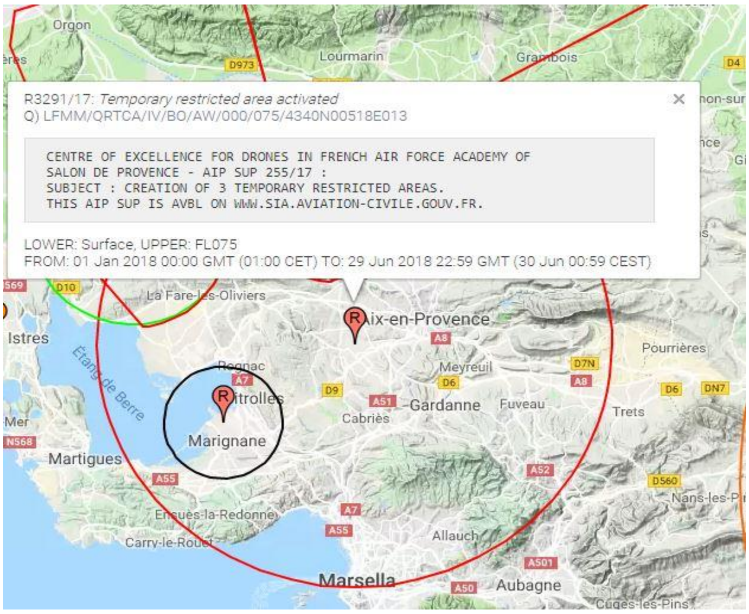


Figure 1.8 Air Force academy NOTAM until the 29th of June of 2018.

However, as we can see in the picture above, even over the Vauvenargues area existed flight restrictions (NOTAM) from the surface to Flight Level 75 (FL075) until the 29 of June of 2018, because operations of Centre of Excellence of drones in French Air Force academy as you can see in the following image. ONERA contacted the Air Force academy for including the WADI RPAS flights in their NOTAM, but it was not necessary since first test flights took place after the NOTAM period.

2 Testing techniques

2.1 Ground technique: Step testing

Step testing is a technique whereby leakage volumes in each of the sectors comprising a water supply network (generally called a Leakage Control Zone) are determined. Such technique can be considered as a *pre-leak detection* activity, as it allows to identify the area(s) of leakage so that the actual leak detection for pinpointing leaks can be more efficiently addressed where most needed, as opposed to surveying the whole system in detail, therefore reducing the time on site and the associated costs.

When planning a step test, the valves that need to be operated to isolate the several sectors of the network are to be identified. Then, during the actual implementation of the step test, these valves will have to be closed following a specified order, whilst simultaneously measurements of the rate of flow are being made. The resultant reduction in flow rate following the closure of a particular valve indicates the total leakage (plus legitimate night consumption) in that sector of the distribution system. If the resultant reduction is greater than anticipated, taking into account the number and type of customers in the isolated sector, then it is an indication of a leak.

Step tests are generally undertaken during the period of minimum night flow (often between 02.00 a.m. and 04.00 a.m.), to avoid supply problems to the majority of customers. Hence, given the short time available, a step test needs to be carefully planned and the number of valves to be operated carefully considered.

The size of the individual steps depends on the size of the Leakage Control Zone. Typically, in an urban zone of 1500 connection a step size of approximately 150 connections is often considered. Figure As is shown, the plan for a step test actually carried out in central Italy, consisting of 10 sectors isolated through 9 subsequent steps, each step consisting in the closure of 1 or 2 valves at a time.

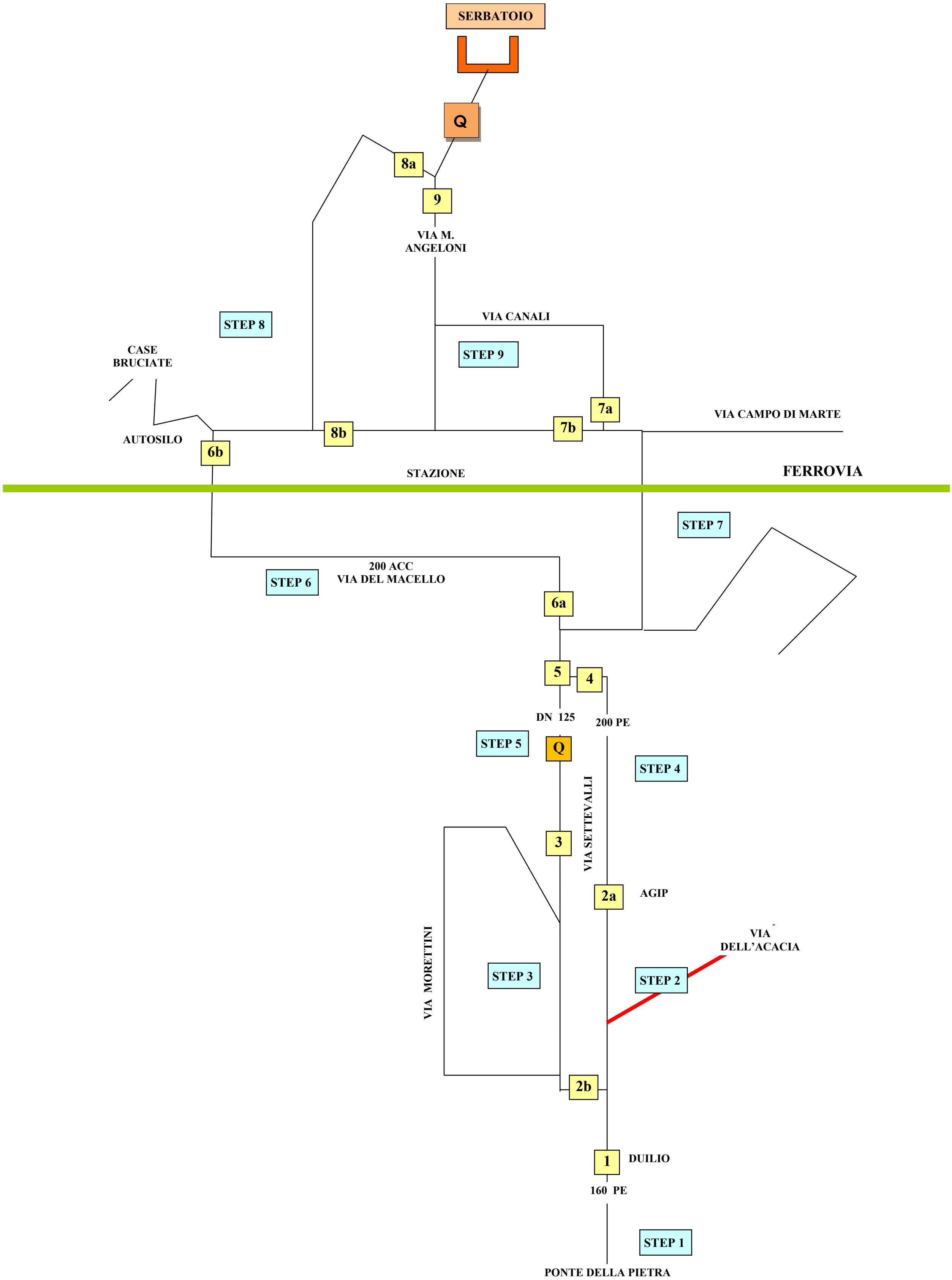


Figure 2.1 Example of a step test plan.

There are two main methods of carrying out a step test:

1) The isolation method

This method involves the successive closing of valves starting from the furthest point from the meter resulting in less of the zone being supplied by the meter. The sequence of closing valves is progressively carried out working back to the meter where the flow should drop to zero. Whilst potential leaks are identified by this method there is one major disadvantage and that is that the system is de-pressurised for some time and this can cause backsiphonage or the risk of infiltration of ground water.

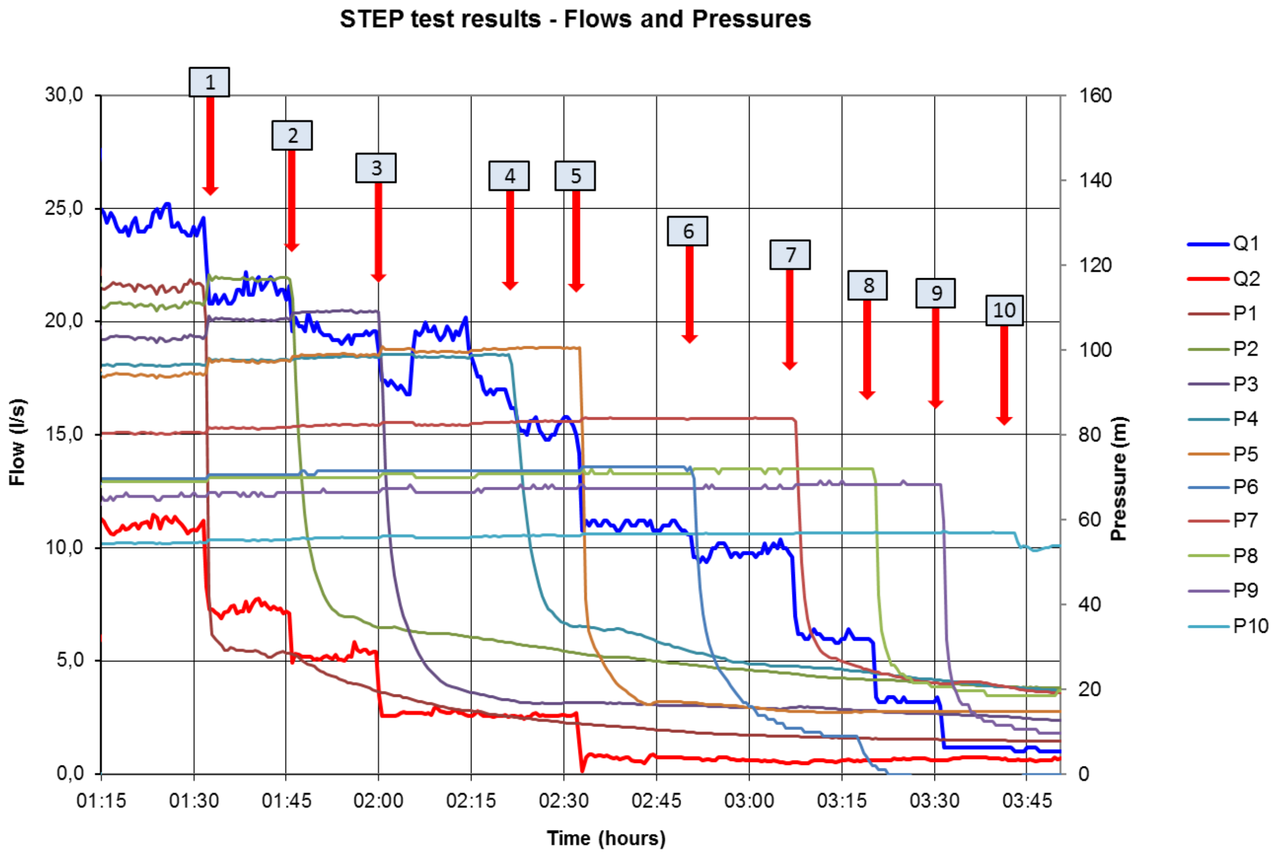


Figure 2.2 Expected results of a step test carried out with the isolation method.

2) The close and open method

This method involves closing valves to isolate each individual step and once the reduction of flow has been recorded the valves are reopened. This method does avoid parts of the system being without water for a period of time. However, it does have the disadvantage that the reduction in flow rate from some steps can include flow from previous steps recharging, thus making interpretation much more difficult, if not impossible.

For this reason, it is recommended that the step tests in the three validation sites of Cabardéèe, Vauvenargues and Verdagne are carried out by following the *isolation method*.

2.1.1 Step Testing Equipment

1) Flowmeter (clamp-on ultrasonic type)

In case a fixed flowmeter is not installed at the Leakage Control Zone's inlet, one can resort to the use of portable flowmeters such as a clamp-on ultrasonic type.

A clamp-on ultrasonic flowmeter consists of a pair of transducers and an electronic part. The transducers are to be fixed outside the pipe. Each transducer acts as both a receiver (i.e. it converts the ultrasonic pulses to electrical energy) and a transmitter (vice versa), since a series of ultrasonic pulses is alternately sent upstream and then downstream through the pipe. The meter measures the time required for the sound pulse to travel between the transducers and the velocity of the fluid is computed from these two time readings. Knowing the pipe internal diameter, the flow is calculated. The accuracy is good (typically 1 to 2%) and the installation is easy as no tapings are required.

The input values required by the clamp-on ultrasonic flowmeter are: pipe outer diameter or circumference (can be easily found using a measuring tape), wall thickness (if unknown, it can be measured using an ultrasonic thickness meter), and pipe material (i.e. the soundspeed in that particular solid, according to which the instrument calculates the flow).

Most manufacturers suggest that an ideal installation of the clamp-on ultrasonic flowmeters is to be done after a minimum 10 diameters-length and before a minimum 5 diameters-length of straight pipe.

If not already inbuilt in the instrument, the flowmeter will have to be connected to an external data logger for recording the flow readings during the step test and allow the subsequent data analysis.

Figure 2.3 Clamp-on ultrasonic flowmter installed on a horizontal pipe (Two-Traverse installation).

2) Pressure loggers

Data loggers can be used to log both flow (if connected to a flowmeter) and pressure measurements. When they already have an integrated pressure transducer, they are commonly referred to as *pressure loggers*. The inbuilt pressure transducer allows to measure and record pressure measurements by just connecting the logger to the quick-fit port inserted on the pipeline whose pressure has to be monitored, usually via a flexible spiral hose such as the one previously shown.

Figure 2.4 Data logger able to log both flow and pressure simultaneously (left) and flexible spiral hose to connect the pressure logger to the pipeline (right).

2.2 Aerial technique: Photogrammetry

Photogrammetry is a set of techniques to determine the shape, size, position in space of an object from photographs. The general principle is based on the human perception of relief by stereoscopic viewing. In aerial photogrammetry the sensor is on-board a satellite, manned aircraft, or a drone and is usually pointed vertically down toward the ground. When the sensor is pointed straight down it is referred to as vertical or nadir imagery. Multiple overlapping images are collected as the sensor flies along a flight path. The imagery is processed to produce digital elevation data and ortho imagery mosaics, which are called orthomaps. Imagery has perspective geometry that results in distortions that are unique to each image. Orthoimages have been geometrically corrected so that the resulting image has the geometric integrity of a map. Other products can be produced resulting in vector GIS layers with features such as roads, buildings, hydrology, and other ground features.

2.2.1 Orthoimagery

Orthorectification is a process that corrects for geometric distortion inherent in remotely sensed imagery to produce a map-accurate orthoimage. You can then stitch a group of orthoimages together into one layer called an orthomosaic. To accomplish this, you need imagery with known sensor positions, attitudes, and a calibrated geometric model for the sensor along with a digital terrain model (DTM). Sometimes the known positions and attitudes accompany the imagery when it is delivered to the user. If not, the imagery will need to be adjusted to ground control. The adjustment processes utilize the sensor calibration, sensor orientation information, ground control points, tie points, and a DTM to produce the accurate attitudes and positions. This in turn enables the building of map-accurate orthoimages. The individual orthoimages are then edgematched and color balanced to produce a seamless orthoimage map. This orthoimage mosaic is accurate to a specified map scale accuracy and can be used to make measurements as well as generate and update GIS feature class layers.

Digital aerial images, scanned aerial images, and satellite imagery are important in general mapping and in GIS data generation and visualization. In fact, the information contained in most maps and GIS layers was generated from imagery. First, the imagery serves as a backdrop that gives GIS layers important context from which to make geospatial associations. Second, imagery is used to create or revise maps and GIS layers by digitizing and attributing features of interest such as roads, buildings, hydrology, and vegetation.

Before this geospatial information can be digitized from imagery, the imagery needs to be corrected for different types of errors and distortions inherent in the way imagery is collected. There are two main types of distortion affecting remotely sensed imagery: radiometric and geometric. Radiometric distortion is the inaccurate translation of ground reflectance values to grey values in the image. Sometimes these values are called digital numbers (DNs), which are induced by atmospheric influences and sensor limitations. Geometric distortions are introduced due to perspective projections and instrumentation. Common kinds of distortions affecting raw remotely sensed imagery include platform and sensor errors, earth curvature, and relief displacement as well as radiometric and sun angle effects. Each of these types of distortions are removed in the orthorectification and mapping process. Orthorectification refers to the removal of geometric distortion induced by the platform, sensor, and especially terrain displacement. Mapping refers to the edgematching, cutline generation, and colour balancing of multiple images to produce an orthomosaic dataset. These combined processes are referred to as ortho mapping.

Once the distortions affecting imagery are removed and individual images or scenes are mosaicked together to produce an orthomosaic image map, it may be used like a symbolic or thematic map to make accurate distance and angle measurements. The advantage of the orthoimage map is that it contains all the information visible in the imagery, not just the features and GIS layers extracted from the image and symbolized on a map.

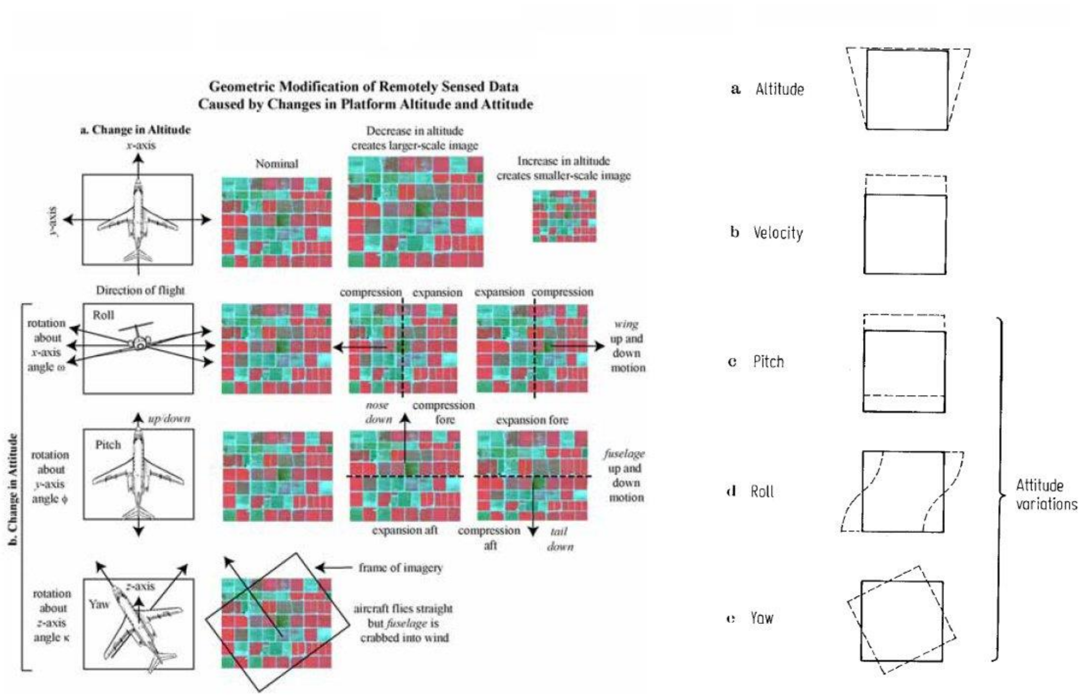


Figure 2.5 Geometric distortions of imagery from airborne sensors.

2.2.2 Elevation data

If suitable digital elevation data exists, it can be used in the orthorectification process. Otherwise, the elevation datasets, such as digital surface models (DSMs), need to be derived from stereo imagery. Stereo imagery is created from two or more images of the same feature collected from different geolocation positions. The overlapping images are collected from different points of view. This overlapping area is referred to as stereo imagery, which is suitable for generating digital elevation datasets. The model for generating these 3D datasets requires a collection of multiple overlapping images with no gaps in overlap, sensor calibration and orientation information, and ground control and tie points. The 3D datasets are then created automatically using a process called image matching, where overlapping imagery is cross-correlated to generate 3D points defined by geolocation (latitude, longitude) and elevation.

2.2.3 The orthorectification process

Orthorectification is the process of removing the effects of image distortion induced by the sensor, viewing perspective, and relief for the purpose of creating a planimetrically correct image. The resulting orthorectified images have a constant scale such that features are represented in their true positions in relation to their ground position. This enables accurate measurement of distances, angles, and areas in the orthoimage. There are several requirements to produce an orthoimage map or orthomosaic from raw imagery:

- Digital imagery, which can be in the form of a digital airborne image, scanned image, or satellite imagery.
- Camera calibration file that includes measurements of sensor characteristics, such as focal length, size and shape of the imaging plane, pixel size, and lens distortion parameters. In photogrammetry, the measurement of these parameters is called interior orientation (IO), and they are encapsulated in a camera model file. High-precision aerial mapping cameras, called metric cameras, are analyzed to provide camera calibration information in a report used to compute a camera model. Other cameras and sensors are calibrated by those operating the cameras, or they can be calibrated during the adjustment processes during orthorectification.
- Rational Polynomial Coefficients (RPC) supplied by satellite imagery providers. RPCs are computed for each image and describe the transformation from 2D image coordinates to 3D earth surface coordinates in a mathematical sensor model that is expressed as the ratio of two cubic polynomial expressions. The coefficients of these two rational polynomials are computed by the satellite company from the satellite's orbital position and orientation and the rigorous physical sensor model. RPCs replace the need for a rigorous camera model and are often referred to as replacement sensor models if the error covariance matrices are included.
- Adjustment points, which are composed of ground control points, image tie points, and check points.
  - Ground control points (GCP) are usually from ground survey. Secondary control points can also be utilized created from a map or existing orthoimage with known accuracy, as long as the known accuracy exceeds the expected outcome accuracy by a linear factor of three to five times. These points on the ground need to be visible in the imagery.
  - Image tie points generated in the overlap areas between adjacent images composing the mosaic. These are usually generated automatically using image matching techniques.
  - Check points used for assessing the accuracy of the orthorectification process. These are ground control survey points not used in computing the photogrammetric solution.

The information above is used to compute an image orientation needed to produce a digital elevation model (DEM) and an orthorectified image mosaic from imagery. The derived image orientation parameters include the position of the sensor at the instant of image capture in some global reference system such as latitude, longitude, and altitude (x, y, z). The attitude of the sensor is expressed as omega, phi, and kappa (pitch, roll, heading).

2.2.4 Image orthorectification

Orthorectification is the process of removing the effects of image distortion induced by the sensor, viewing perspective, and relief for the purpose of creating a planimetrically correct image. This is accomplished by establishing the relationship of the x,y image coordinates to the real-world GCP to determine the algorithm for resampling the image.

Similarly, the mathematical relationship between the ground coordinates represented by the DEM and the image is computed and used to determine the proper position of each pixel in the source image. The generation of the orthoimage involves warping the source image so that distance and area are uniform in relationship to real-world measurements. Thus, features measured in the orthoimages match the measurement, scale, and angle of the same features on the ground, regardless of whether they exist on steep terrain or on level ground. The resulting accuracy of the orthoimage is based on the accuracy of the triangulation, the resolution of the source image, and the accuracy of the elevation model.

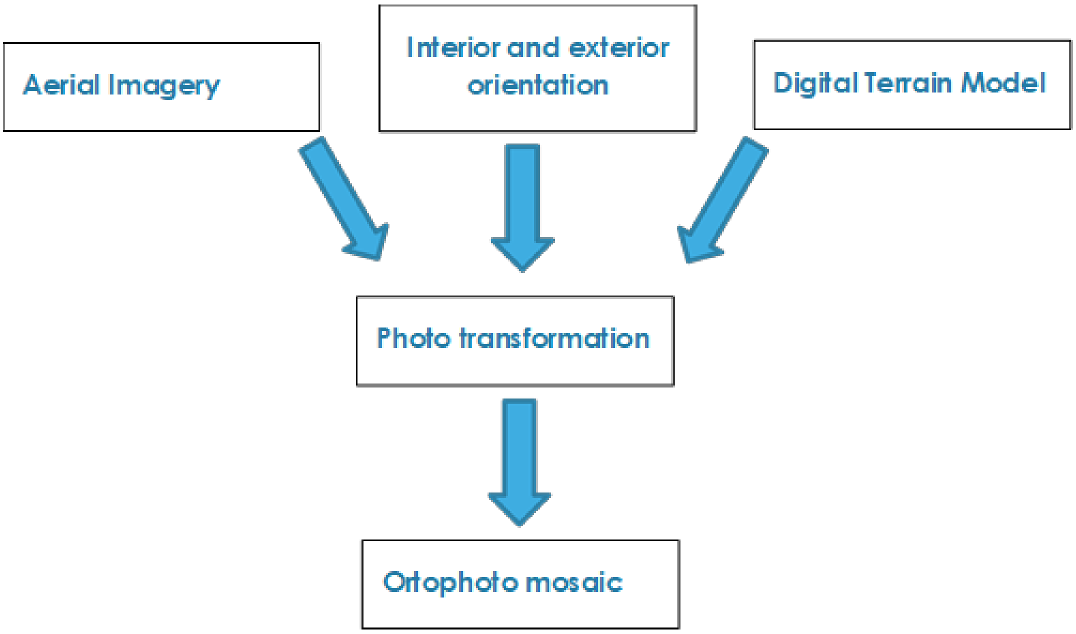


Figure 2.6 Clamp-on ultrasonic flowmeter installed on a horizontal pipe (Two-Traverse installation).

3 Aircraft and RPAS validation test flights plan

An airborne and UAV remote sensing campaign was carried out on July and October 2018 over several areas belonging to the water network infrastructure of SCP. The aircraft was a Tecnam P2006T operated by Air Marine and instrumented with a VNIR multispectral camera (SpectroCam with 8 custom selected filters: 425, 550, 640, 660, 724, 820, 832.5 and 840 nm), a cooled TIR camera (Noxant NoxCam: 7.7 – 9.3 µm) and a custom made acquisition software (WadiFl). The flights with the manned platform were performed at an altitude of 800 m above ground level which led to a spatial resolution of 0.30 m for the Spectrocam camera and 0.48 m for the Noxant camera. For aircraft manoeuvrability reasons, the flight passes within the same sector were performed with a separation around 170 m.

Figure 3.1 Tecnam P2006T owned and operated by Air Marine.

The UAV was a custom designed multicopter operated by Galileo Geosystems. It was instrumented with a VNIR multispectral camera (Micasense RedEdge 3 with five bands: 475, 560, 668, 717 and 840 nm) and a microbolometer uncooled TIR camera (FLIR Vue Pro R: 7.5 – 13.5 µm). The flights with the unmanned platform were performed at an altitude of 50 m above ground level which led to a spatial resolution of 3.4 cm for the Micasense camera and 6.5 cm for the FLIR camera.

Figure 3.2 Multicopter with on-board multispectral and thermal infrared cameras operated by Galileo Geosystems.

All the flight plans would ideally be prepared to ensure a front and side image overlap of at least 80%. Unfortunately, achieving a side overlap of an 80% is way to hard in the case of the manned aircraft as far as the flight passes are required to have a distance to short to be operatively possible. The alternance of flight passes is an alternative method to increase the side overlap but has also some drawbacks like the excessive change in the illumination geometry between side passes do to the relative movement of the Earth with respect to the Sun.

3.1 Cabardèle

The site of interest occupies an area of 41 km^2 and has been divided in 6 sectors of interest according to the figure 3.3. The survey over the Cabardèle area was done in October 2018 only with the manned aircraft.

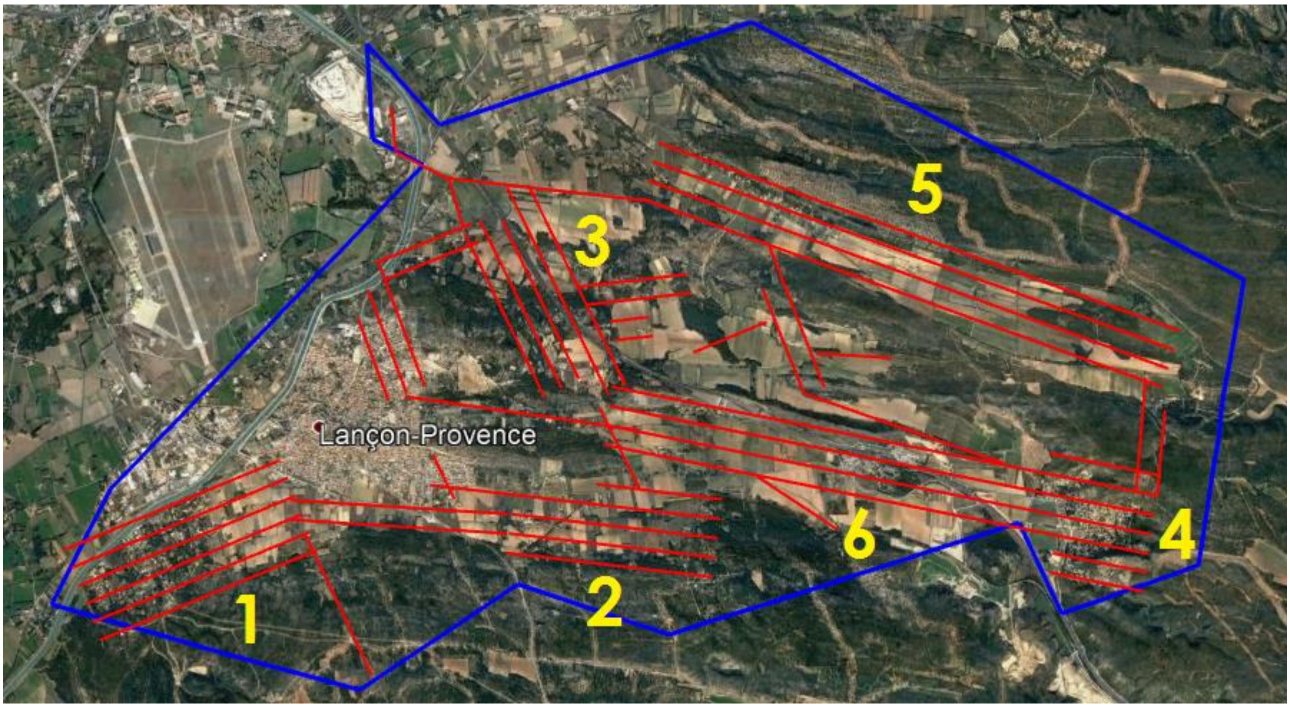


Figure 3.3 Mission plan for the Cabardèle area. The flight paths have been established to cover each sector of the water distribution network.

3.2 Vauvenargues

The site of interest is divided in 4 sectors according to the figure 3.4. The sectors 1 and 2 have been flown only with the RPA (only the unpopulated area). The sectors 3 and 4 have been flown only with the manned aircraft except a leakage area used as validation area for both airborne platforms. The pictures below show the Vauvenargues pipeline network divided into 4 sectors and the situation map of the waterleaks test field used to validate both airborne platforms, the manned aircraft and the RPAS.

Figure 3.4 Vauvenargues pipeline network, flight sectors and urban areas (red).

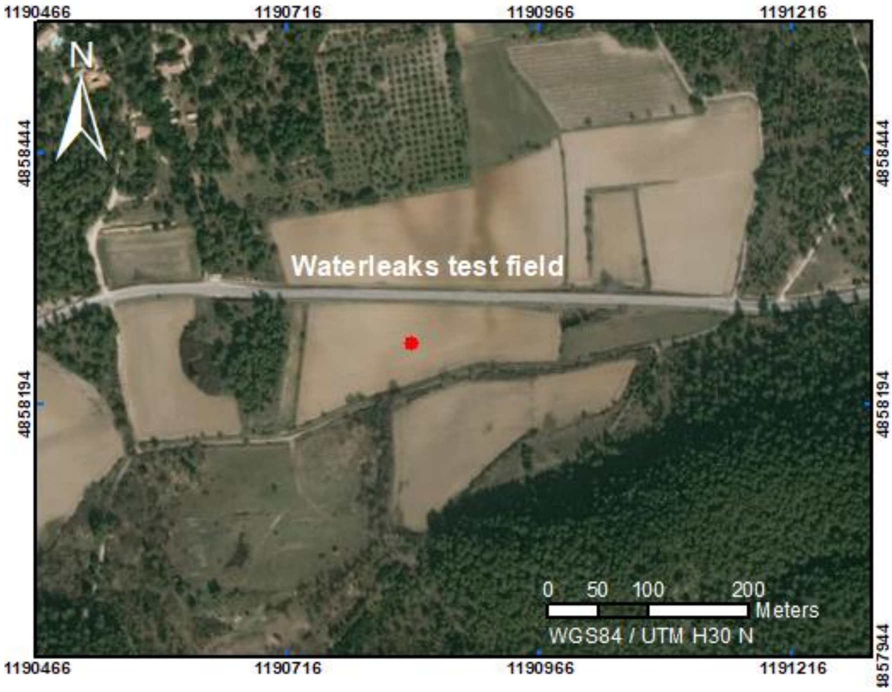


Figure 3.5 - Waterleaks test field situation map (La Jonquière sector).

3.2.1 Manned aircraft validation test flights plan (October 2018)

The survey over the sectors 3 and 4 of the Vauvenargues area was done in October 2018 only with the manned aircraft (except the waterleaks test field already mentioned).

Figure 3.6 Manned aircraft flight plan for the sectors 3 and 4. The waterleaks test field is flown by the manned aircraft as part of the sector 4.

3.2.2 RPAS validation test flights plan (July and October 2018)

The flight plan design took into account the restriction to fly urban areas (see urban areas in red in the figure 3.4).

It can be clearly seen that there are no urban areas and no highways in the surroundings and the study area is located in a rural area. On the next figure, obtained from the "Restrictions pour drones de loisir" chart it can be seen that there are no prohibited or restricted areas, so the flight is an S1 type. The flights took part of the Tour de César, painted in purple in the image and a small area near La Jonquière sector.

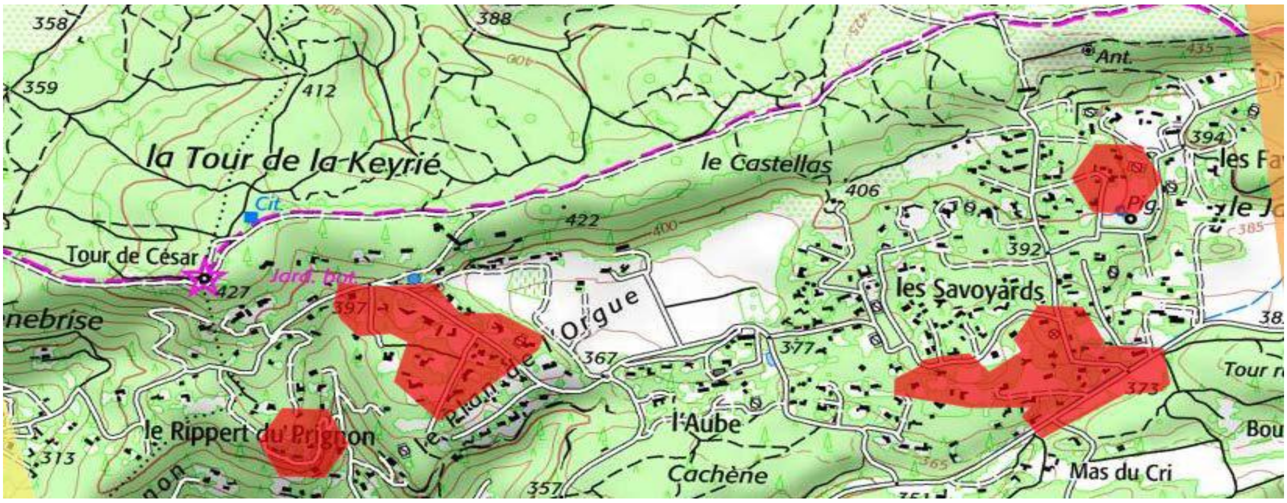


Figure 3.7 Pipeline section to be inspected (Tour de César)

The only obstacles are outside the flight area so in any moment can be loose the sight of the drone and there would be no danger of collision. As the maximum horizontal distance in an S1 is 200 meters, the flight plan polygon is divided into different flights in order to cover the complete pipeline segment.

Figure 3.8 RPAS flights distribution along the selected pipeline (sectors 1 and 2).

The pilot "home" has been chosen for each fly to ensure that the RPAS will remain during all the flight at no more than 200 meters from the pilot.

The flights were planned at a height of 50 meters to avoid lower obstacles while having complete control of the aircraft and a good image resolution. The flight plan is designed to capture the area of interest in each case. At the end of the flight, the RPAS returns to the home position and lands automatically.

Even with an automatic flight, the pilot is aware all the time so that in the event of a problem, he could immediately take the controls of the aircraft.

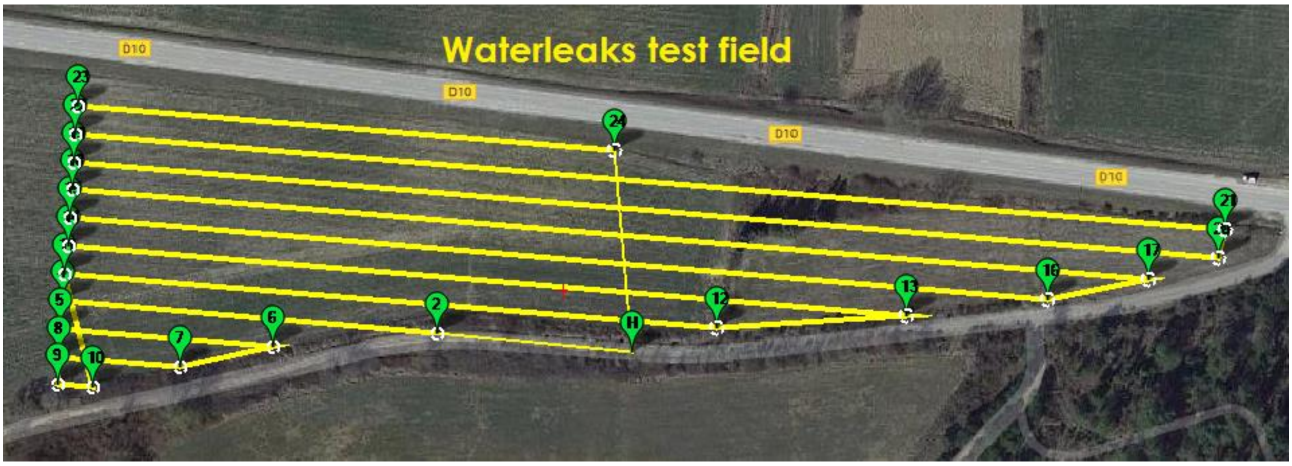


Figure 3.9 RPAS flight plan for the waterleaks test field.

The figure 3.9 shows in detail the flight path of the RPAS required to cover the waterleaks test field in order to guarantee a front and side image overlap of an 80%.

3.3 Verdagne

The site of interest occupies an area of 89 km^2 and has been divided in 4 sectors of interest according to the figure 3.10. The survey over the Verdagne area was done in October 2018 only with the manned aircraft.

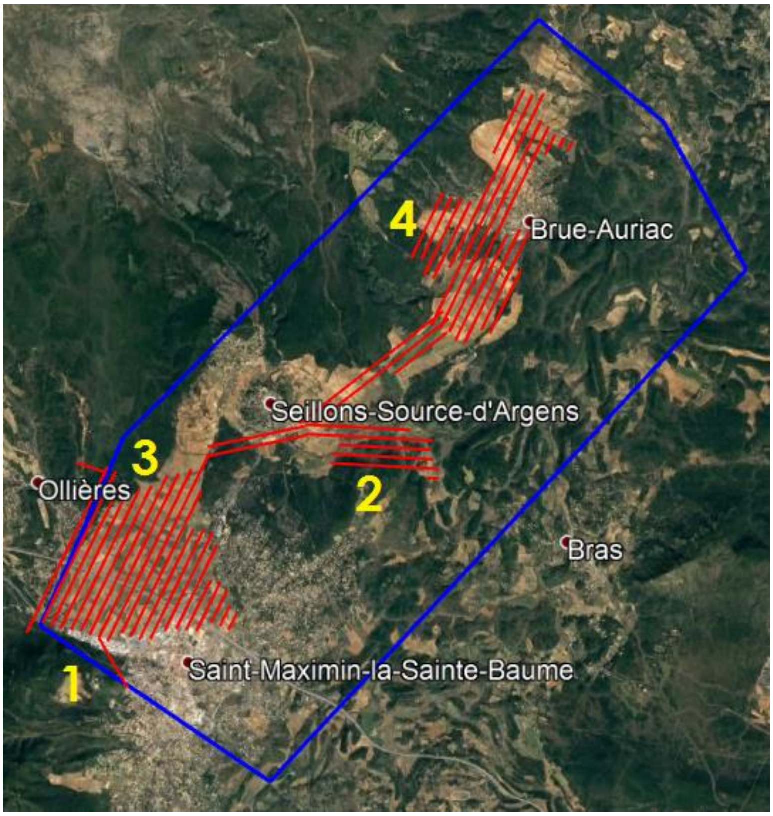


Figure 3.10 Manned aircraft flight paths over the 4 sectors of the Verdagne area.

4 Step testing plan

4.1 Cabardèle

The site of Cabardèle consists of 709 connections on a total pipeline length of 63.7 km. It is proposed to consider **6 sectors** and **5 subsequent steps**.

The equipment needed to carry out the operations is listed herewith:

- 1 flowmeter.
- 6 pressure loggers.

The flowmeter shall be installed on the outlet pipe of the western Cazeneuve SR tank, while the eastern tank shall be isolated from the rest of the system, as shown in Figure : the flowmeter installation point is indicated by the "Q" in the orange square, the valves to be closed before the start of the step test are indicated in red colour, while the valves to be left open are in green colour.

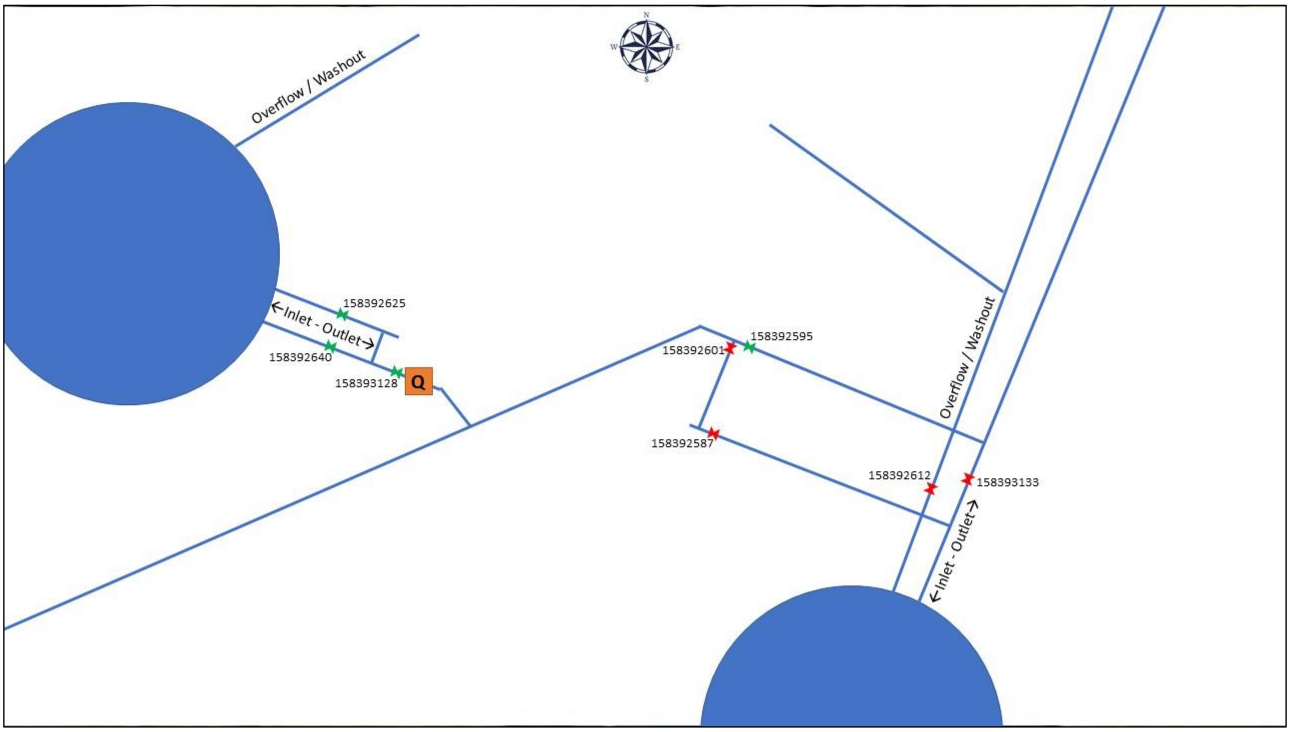
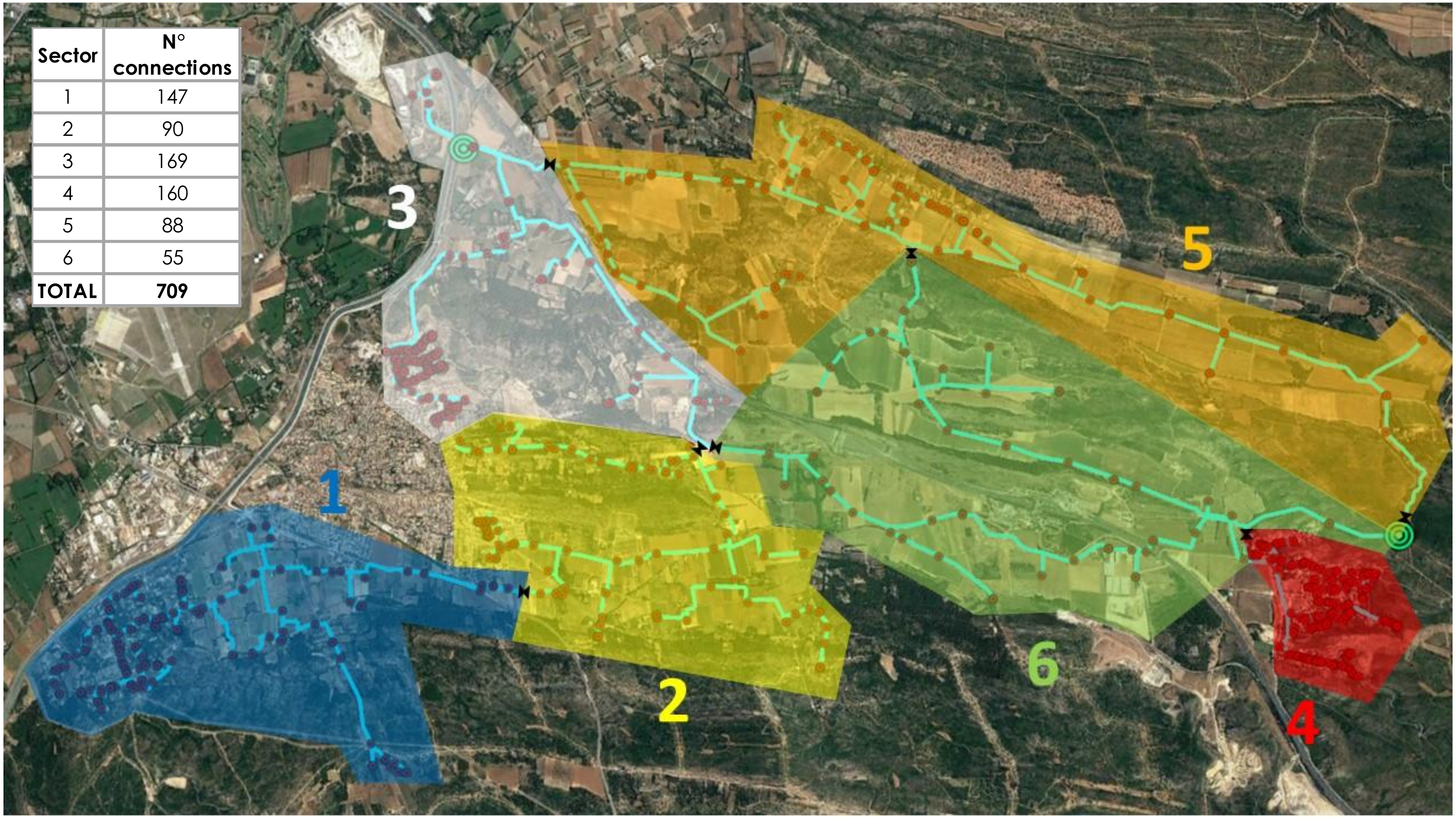


Figure 4.1 Initial valves' configuration (red = closed, green = open) and flowmeter installation point at Cazeneuve SRs.

Pressure loggers shall be installed in each separate sector, anywhere (suitable locations to be determined by SCP). The purpose of recording the pressure is checking the actual isolation of the sector at the moment of valve's closure, when the values of this parameter are expected to drastically drop.



Sector	N° connections
1	147
2	90
3	169
4	160
5	88
6	55
TOTAL	**709**

Figure 4.2 Step test plan for Cabardèle site.

The following Table indicates the valves to be operated (reference is made to the Valve id indicated in the shapefile "Pipes", received from SCP), and the number of connections isolated at each step; in some cases, it will be necessary to operate more valves simultaneously to isolate a sector. The proposed start time for the operations is 2 am.

Step	Time	Valve(s) to be closed	Sector isolated at valve's closure	Total isolated connections	Total non-isolated connections
0	2:00	158392987 ("Stations de pompage") at Cabardéle PS; 158392601, 158392587, 158392612 & 158393133 at Cazeneuve SRs	none	0	709
1	2:20	158274586	1	147	562
2	2:40	158278945	2	237	472
3	3:00	158278942 & 158392821	3	405	303
4	3:20	158394726	4	566	143
5	3:40	158395196 & 158392595	5	654	55

Table 4.1 Steps for sectorization of Cabardèle site.

4.1.1 Step-by-step instructions

4.1.1.1 Preliminary operations

- Besides obtaining all the needed administrative clearances, the date and time of the step test shall be communicated to the resident population, who shall also be strongly invited not to consume water during the time of operations.

- In the days preceding the step test, all valves expected to be operated shall be checked to ensure they are easily accessible and properly functioning[1].

- The day of the step test, check that all instruments are in good working conditions and that their batteries are charged, program all loggers to record flow and pressure measurements till 6 am (all loggers must be synchronized so that the readings are taken exactly at the same time).

- The day of the step test, install the pressure loggers and note down the positions of each logger (P1, P2, P3, P4, P5, P6); install the flowmeter on the reservoir outlet (Q).

- The day of the step test, make sure that Cazeneuve SRs are full at the start of the test (e.g. pumps at Cabardèle PS might be manually started to fill up the SRs few hours before the planned start time of the step test).

- Right before the start of the step test, switch off the pumps at Cabardéle PS and close all valves on the outlet of the PS (valve id 158392987 "Stations de pompage") to isolate it from the rest of the system.

- Right before the start of the step test, close valves 158392601, 158392587, 158392612 & 158393133 (see Figure) to isolate the eastern Cazeneuve SR tank from the rest of the system.

4.1.1.2 Step 1

- At 2:20 am close valve 158274586 to isolate sector 1.

4.1.1.3 Step 2

- At 2:40 am close valve 158278945 to isolate sector 2.

4.1.1.4 Step 3

[1] To check if a valve has closed tightly, put your ear on the metallic stick (the one used to operate the valve) placed on the valve spindle: no leak noise shall be audible.

- At 3:00 am close valves 158278942 and 158392821 to isolate sector 3.

4.1.1.5 Step 4

- At 3:20 am close valve 158394726 to isolate sector 4.

4.1.1.6 Step 5

- At 3:40 am close valves 158395196 and 158392595 to isolate sector 5.

4.1.1.7 Final operations

- After 4:00 am slowly reopen all valves in reverse order; collect instruments and download data.

4.2 Vauvernagues

The site of Vauvernagues consists of 296 connections on a total pipeline length of 26.6 km. It is proposed to consider **4 sectors** and **3 subsequent steps**.

The equipment needed to carry out the operations is listed herewith:

- 1 flowmeter.
- 4 pressure loggers.

Two different options for flowmeter installation are identified; they are reported herewith, in order of preference.

4.2.1 Flow meter installation: Option 1

The flowmeter shall be installed downstream of the bulk supply connection on the outlet pipe of Clau des Lamberts SR, as shown; this option has two main advantages:

- No need to shut down the bulk supply.

- As a general rule, measurements of flow will be more precise if obtained from a single flowmeter, compared to the alternative installation of a flowmeter upstream of the bulk supply connection while simultaneously measuring the bulk supply flow and deriving the amount of water entering Vauvernagues site from the difference between the two, as the error associated to each flowmeter will not sum up.

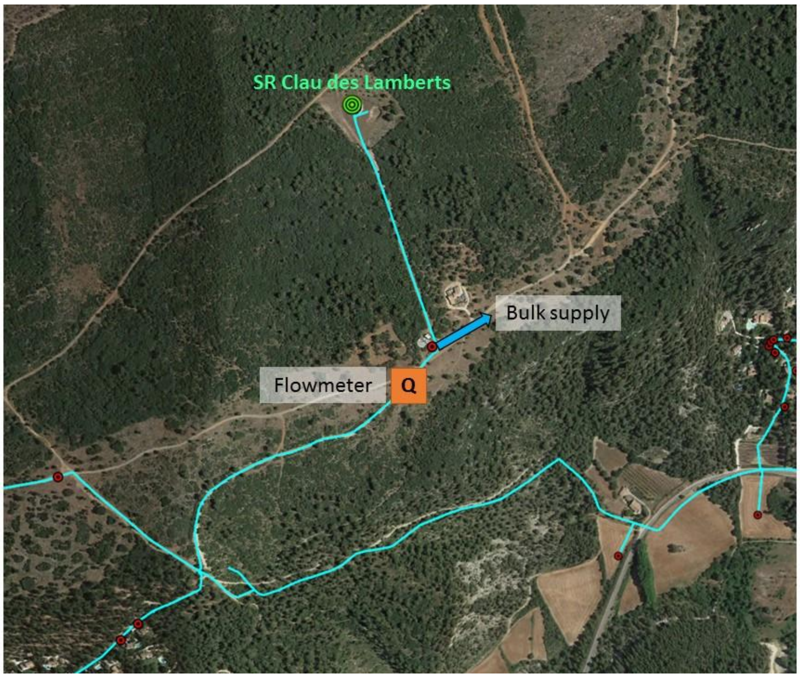


Figure 4.3 Flowmeter installation at Clau des Lamberts SR as per option 1.

4.2.2 Flow meter installation: Option 2

The flowmeter shall be installed on the outlet pipe of Clau des Lamberts SR, upstream of the bulk supply connection, which will have to be kept tightly shut during the time of operations; this option has one main advantage:

- As a general rule, measurements of flow will be more precise if obtained from a single flowmeter, compared to the alternative installation of a second flowmeter on the bulk supply connection to simultaneously measuring its flow and derive the amount of water entering Vauvernagues site from the difference between this and the one recorded at the SR outlet, as the error associated to each flowmeter will not sum up.

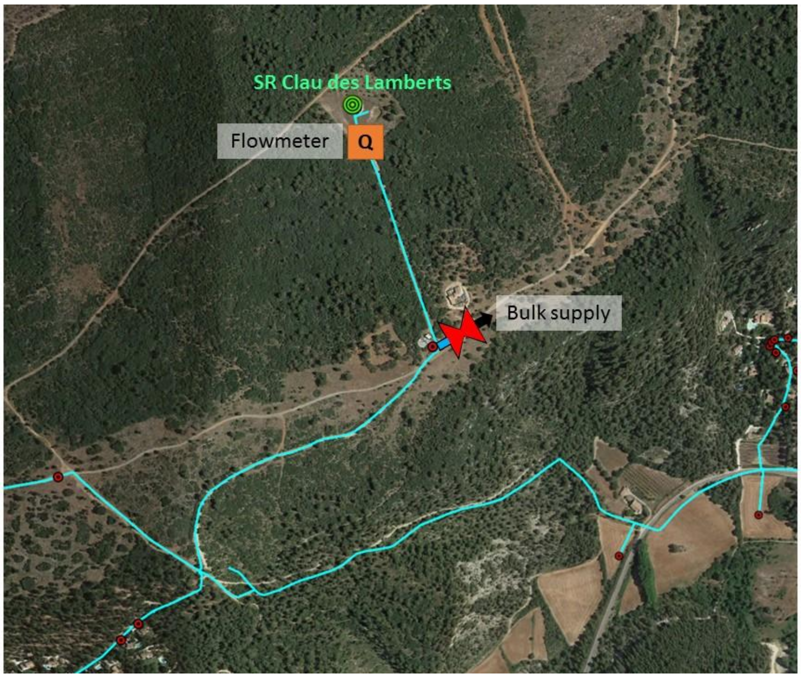
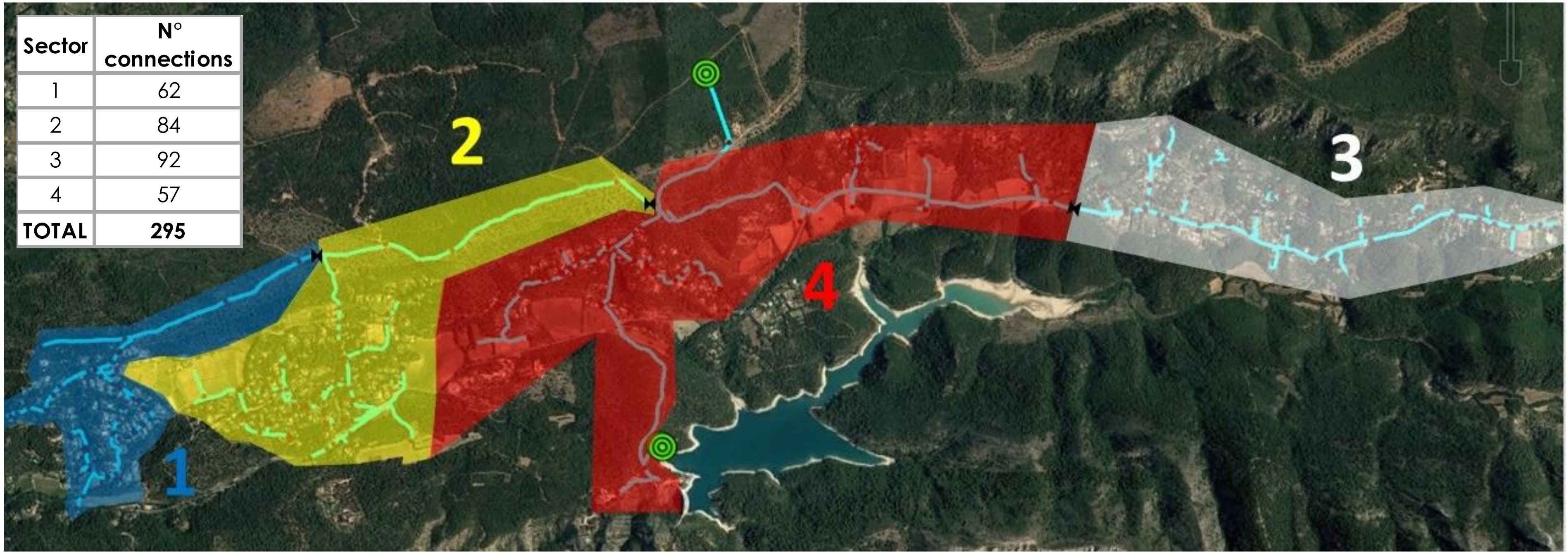


Figure 4.4 Flowmeter installation at Clau des Lamberts SR as per option 2 (bulk supply shall be shut off during the step test).

Pressure loggers shall be installed in each separate sector, anywhere (suitable locations to be determined by SCP). The purpose of recording the pressure is checking the actual isolation of the sector at the moment of valve's closure, when the values of this parameter are expected to drastically drop.



Sector	N° connections
1	62
2	84
3	92
4	57
TOTAL	**295**

Figure 4.5 Step test plan for Vauvernagues site.

The following Table indicates the valves to be operated (reference is made to the Valve id indicated in the shapefiles “Pipes” and “conduites 2411” received from SCP), and the number of connections isolated at each step, as per *Option 1* (see paragraph 4.2.1). The proposed start time for the operations is 2 am.

Step	Time	Valve(s) to be closed	Sector isolated at valve's closure	Total isolated connections	Total non-isolated connections
0	2:00	Outlet valves at Saint-Marc Jaumegarde PS[2]	none	0	295[3]
1	2:20	99073	1	62	233
2	2:40	102818	2	146	149
3	3:00	148294316	3	238	57

Table 4.2 Steps for sectorization of Vauvernagues site.

4.2.2.1 Step-by-step instructions

4.2.2.1.1 Preliminary operations

- Besides obtaining all the needed administrative clearances, the date and time of the step test shall be communicated to the resident population, who shall also be strongly invited not to consume water during the time of operations; in particular, in case Option 2 is selected (see paragraph 4.2.2) the customers fed by the bulk supply connection shall be informed that their supply will be temporarily cut during the night of the step test (this will not be the case if Option 1 is followed)

[2] In case Option 2 for flowmeter installation is selected (see paragraph 4.2.2), the valve on the bulk supply connection shall also be closed.
[3] This number is not matching with the total number of connections reported in Table (295 vs 296) because 1 connection is located upstream of the proposed flowmeter installation point as per Option 1.

- In the days preceding the step test, all valves expected to be operated shall be checked to ensure they are easily accessible and properly functioning[4].

- The day of the step test, check that all instruments are in good working conditions and that their batteries are charged, program all loggers to record flow and pressure measurements till 5 am (all loggers must be synchronized so that the readings are taken exactly at the same time).

- The day of the step test, install the pressure loggers and note down the positions of each logger (P1, P2, P3, P4); install the flowmeter as per the indications (Q).

- The day of the step test, make sure that Clau des Lamberts SR is full at the start of the test (e.g. pumps at Saint-Marc Jaumegarde PS might be manually started to fill up the SR few hours before the planned start time of the step test).

- Right before the start of the step test, switch off the pumps at Saint-Marc Jaumegarde PS and close all valves on the outlet of the PS to isolate it from the rest of the system.

- In case Option 2 for flowmeter installation is selected (see paragraph 2.2.2.2), close the valve on the bulk supply connection right before the start of the step test.

4.2.2.1.2 Step 1

- At 2:20 am close valve 99073 to isolate sector 1.

4.2.2.1.3 Step 2

- At 2:40 am close valve 102818 to isolate sector 2.

4.2.2.1.4 Step 3

- At 3:00 am close valve 148294316 to isolate sector 3.

[4] To check if a valve has closed tightly, put your ear on the metallic stick (the one used to operate the valve) placed on the valve spindle: no leak noise shall be audible.

4.2.2.1.5 Final operations

- After 3:20 am slowly reopen all valves in reverse order; collect instruments and download data.

4.3 Verdagne

The site of Verdagne consists of 285 connections on a total pipeline length of 69.1 km. It is proposed to split the site into two sub-sites i.e. upstream and downstream of Brue Auriac booster, respectively: in the upstream sub-site **3 sectors** and **2 subsequent steps** will be considered, whereas in the downstream sub-site **1 single sector** will be considered. In other words, the step testing will be carried out only in the upstream sub-site, whereas in the downstream one only the measurement of the minimum night flow (MNF) will be carried out.

The two sub-sites are shown in the following Figures.

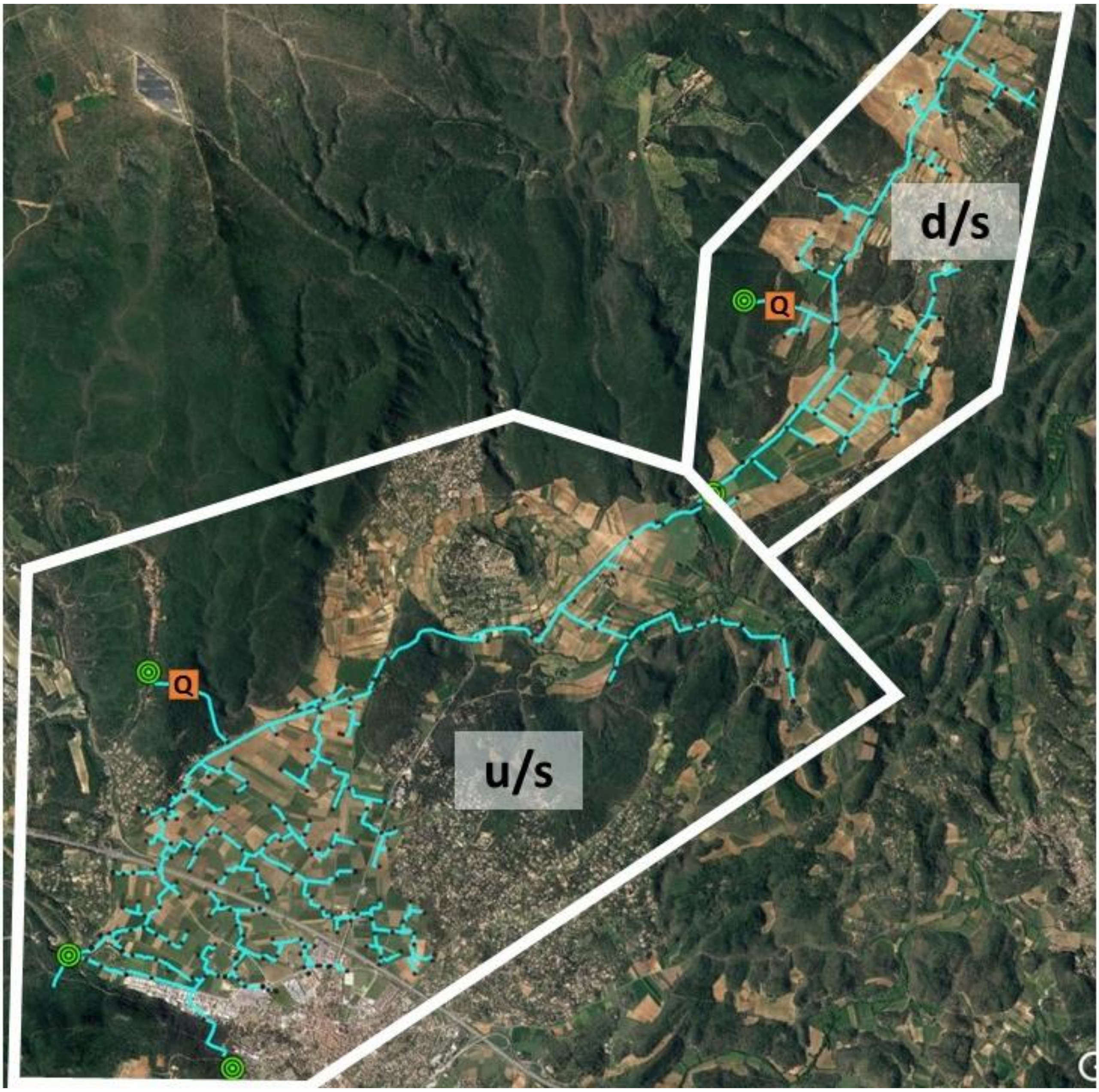


Figure 4.6 Subdivision of Verdagne site into two sub-sites – u/s of BS and d/s of BS – and flowmeters' installation points at Rabinets and Planissard SRs.

The isolation of the 2 sub-sites shall be obtained by closing a number of valves as below:

A. valves on the inlet of Brue Auriac booster station (valve id 152340472 "Stations de pompage") and on the BS' bypass (152339702), as well as the valve on the booster pump's delivery pipe, so that the BS is isolated from the rest of the system;

B. valves on the inlet and bypass of Saint Maximin WTP (valve id 147841951 and 147841948);

C. valve on Verdange PS outlet (valve id 147842653 "Stations de pompage").

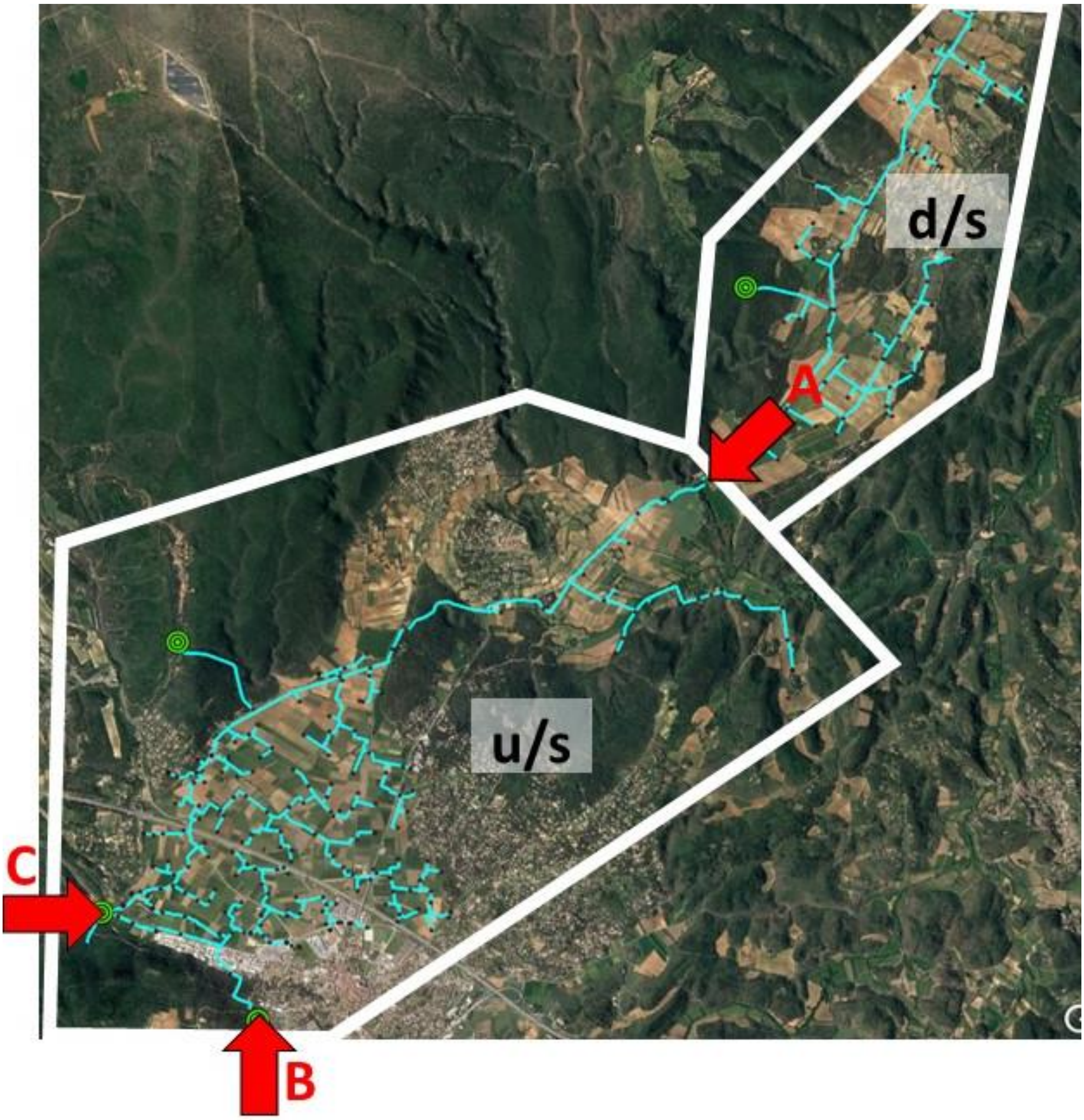


Figure 4.7 Location of the valves to be closed for isolating the two sub-sites.

4.3.1 Upstream sub-site

The Verdagne upstream sub-site consists of 212 connections on a total pipeline length of 47.2 km.

The equipment needed to carry out the step testing operations is listed herewith:

- 1 flowmeter
- 3 pressure loggers.

The flowmeter shall be installed on the outlet pipe of Rabinets SR.

Pressure loggers shall be installed in each separate sector, anywhere (suitable locations to be determined by SCP). The purpose of recording the pressure is checking the actual isolation of the sector at the moment of valve's closure, when the values of this parameter are expected to drastically drop.

Sector	N° connections
1	76
2	26
3	110
TOTAL	**212**

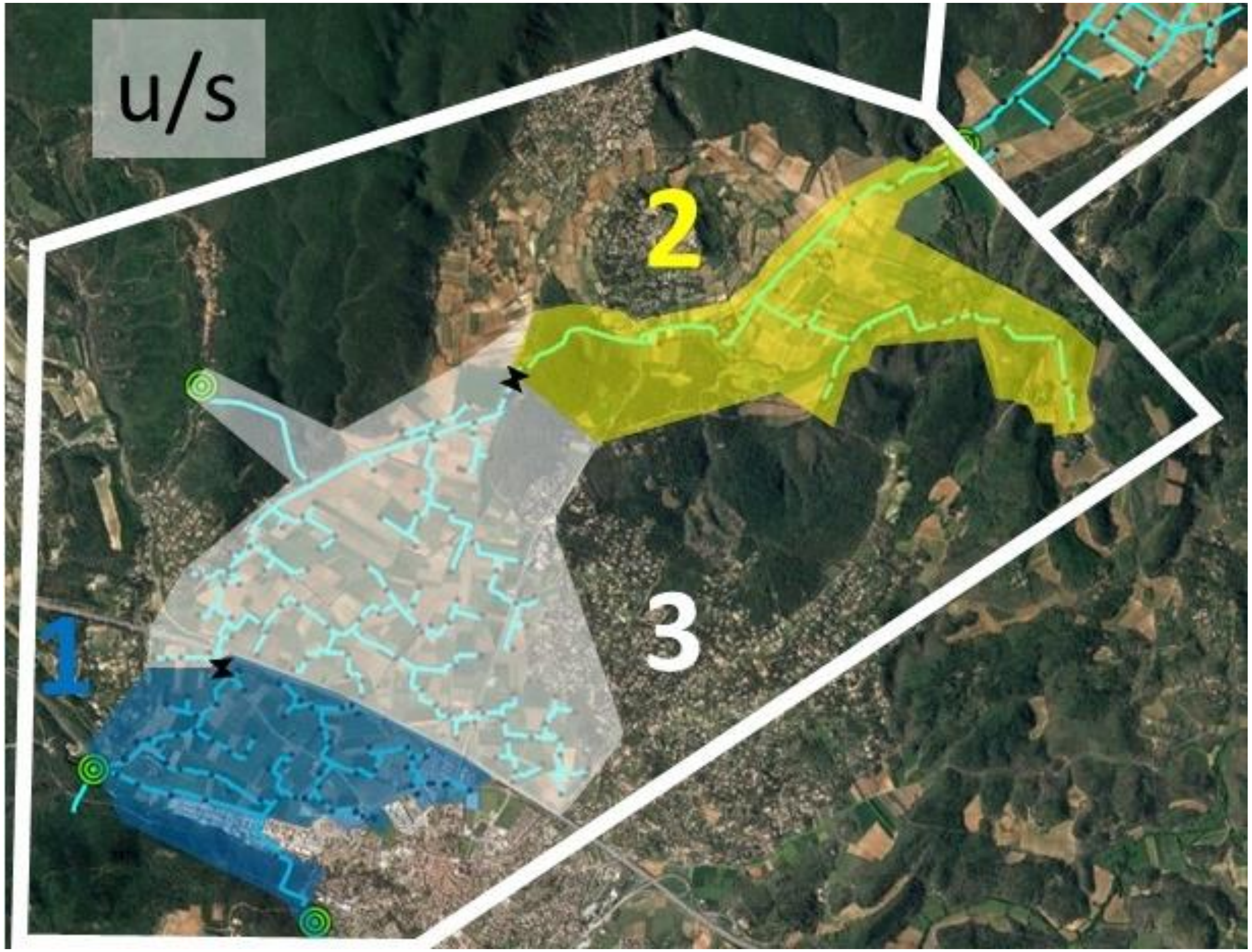


Figure 4.8 Step test plan for Verdagne upstream sub-site.

The following Table indicates the valves to be operated (reference is made to the Valve id indicated in the shapefile "Pipes" received from SCP), and the number of connections isolated at each step; in some cases, it will be necessary to operate more valves simultaneously to isolate a sector. The proposed start time for the operations is 2 am.

Step	Time	Valve(s) to be closed	Sector isolated at valve's closure	Total isolated connections	Total non-isolated connections
0	2:00	152339702 ("Stations de pompage") & 152339702 at Brue Auriac PS; 147841951 & 147841948 at Saint Maximin WTP; 147842653 ("Stations de pompage") at Verdagne PS.	none	0	212
1	2:20	147843423 & 147843411	1	76	136
2	2:40	147843371, 147843372, 147843339 & 147843329	2	102	110

Table 4.3 Steps for sectorization of Verdagne upstream sub-site.

4.3.1.1 Step-by-step instructions

4.3.1.1.1 Preliminary operations

- Besides obtaining all the needed administrative clearances, the date and time of the step test shall be communicated to the resident population, who shall also be strongly invited not to consume water during the time of operations; in particular, the customers fed by Saint Maximin WTP shall be informed that their supply will be temporarily cut during the night of the step test.

- In the days preceding the step test, all valves expected to be operated shall be checked to ensure they are easily accessible and properly functioning[5].

- The day of the step test, check that all instruments are in good working conditions and that their batteries are charged, program all loggers to record flow and pressure measurements till 5 am (all loggers must be synchronized so that the readings are taken exactly at the same time).

- The day of the step test, install the pressure loggers and note down the positions of each logger (P1, P2, P3); install the flowmeter on the reservoir outlet (Q).

- The day of the step test, make sure that Rabinets SR is full at the start of the test (e.g. pumps at Verdagne PS might be manually started to fill up the SR few hours before the planned start time of the step test).

- The day of the step test, ensure also that Planissard SR is sufficiently full at the start of the test, so that the downstream sub-site does not run out of water and sudden starts of pumping operations at Brue Auriac BS do not occur.

- Right before the start of the step test, isolate the upstream sub-site by closing the valves on the inlet of the Brue Auriac booster station and its bypass i.e. valve id 152340472 ("Stations de pompage") and 152339702, respectively.

- Right before the start of the step test, close all valves on the inlet and bypass of Saint Maximin WTP (namely valve id 147841951 and 147841948) to isolate the sub-site on the southern side.

- Right before the start of the step test, switch off the pumps at Verdange PS and close the valve on the PS outlet (valve id 147842653 "Stations de pompage") to isolate the sub-site on the western side.

4.3.1.1.2 Step 1

- At 2:20 am close valves 147843423 and 147843411 to isolate sector 1.

[5] To check if a valve has closed tightly, put your ear on the metallic stick (the one used to operate the valve) placed on the valve spindle: no leak noise shall be audible.

4.3.1.1.3 Step 2

- At 2:40 am close valves 147843371, 147843372, 147843339 and 147843329 to isolate sector 2.

4.3.1.1.4 Final operations

- After 3:00 am slowly reopen all valves in reverse order; collect instruments and download data.

4.3.2 Downstream sub-site

The Verdagne downstream sub-site consists of 73 connections on a total pipeline length of 21.9 km.

The equipment needed to carry out the MNF measurement operations is listed herewith:

- 1 flowmeter.

The flowmeter shall be installed on the outlet pipe of Planissard SR.

After having isolated the downstream sub-site from the upstream one, it is proposed to record the Minimum Night Flow exiting the SR and entering the downstream sub-site at least between 2 am and 4 am.

4.3.2.1 Step-by-step instructions

4.3.2.1.1 Preliminary operations

- Besides obtaining all the needed administrative clearances, the date and time of MNF measurement shall be communicated to the resident population, who shall also be strongly invited not to consume water during the time of operations.

- In the days preceding the MNF measurement, all valves expected to be operated shall be checked to ensure they are easily accessible and properly functioning[6].

- The day of the MNF measurement, check that the flowmeter is in good working conditions and that its batteries are charged, program the logger to record flow measurements till 5 am.

- The day of the MNF measurement, install the flowmeter on the reservoir outlet (Q).

- The day of the MNF measurement, make sure that Planissard SR is full at the start of the MNF measurement (e.g. pumps at Brua Auriac BS might be manually started to fill up the SR few hours before the planned start time of the MNF measurement).

- Right before the start of the MNF measurement, isolate the downstream sub-site by closing the valves on the inlet of the Brue Auriac booster station and its bypass i.e. valve id 152340472 ("Stations de pompage") and 152339702, respectively.

- Right before the start of the MNF measurement, switch off the pumps at Brue Auriac BS and close all valves on the outlet of the PS to isolate it from the rest of the system.

4.3.2.1.2 MNF measurement

- At 2:00 am start recording the flow.

4.3.2.1.3 Final operations

- After 4:00 am slowly reopen all valves in reverse order; collect instruments and download data.

[6] To check if a valve has closed tightly, put your ear on the metallic stick (the one used to operate the valve) placed on the valve spindle: no leak noise shall be audible.

5 Validation flights campaign

5.1 Manned aircraft flights

The manned aircraft flights were done on October 22, 2018 with a Tecnam P2006T following the mission plans presented in section 3. As mentioned before, the payload was composed by a VNIR multispectral camera (SpectroCam with 8 custom selected filters: 425, 550, 640, 660, 724, 820, 832.5 and 840 nm), a cooled TIR camera (Noxant NoxCam: 7.7 – 9.3 µm) and an on-board computer with a custom made acquisition software (WadiFI). The band 4 (RED: 660 nm), the band 7 (NIR: 832.5 nm) and the thermal infrared (TIR: 7.7 – 9.3 µm) have been selected for the present study.

The acquired data have been preprocessed with Pix4D, a photogrammetric grade mosaicking software, to obtain raw (from uncalibrated multispectral data) and brightness temperature (TIR radiometric brightness temperature data) orthomosaics. The orthomosaics have been created separately and have been co-registered by Wadileaks, the custom processing software developed in the frame of the WADI project. Wadileaks makes use of Gefolki, an opensource software developed by ONERA, to do the co-registering. With all the spectral orthomosaics co-registered, it is possible to follow the processing pipeline established to calculate the water index orthomosaic necessary to find waterleaks.

The vegetation areas are dark in the bands where the light is absorbed due to photosynthetic processes (red band). These areas are clearer in the orthomosaic corresponding to the NIR band.

During the campaign more than 500 gb of image data were acquired only with the manned aircraft. The most representative acquired data are presented in this section.

5.1.1 Cabardèle

The flights over Cabardèle were done according to the flight plan shown in figure 3.3. The 6 sectors were flown in two flights.

The figures 5.1, 5.2 show the reflectance orthomosaics corresponding to the band 4 (660 nm), band 7 (832.5 nm) and the figure 5.3 shows the brightness temperature orthomosaics corresponding to the TIR (7.7 – 9.3 µm).

Figure 5.1 Band 4 (660 nm) orthomosaic corresponding to the sector 1 of Cabardèle.

Figure 5.2 Band 7 (832.5 nm) orthomosaic corresponding to the sector 1 of Cabardèle.

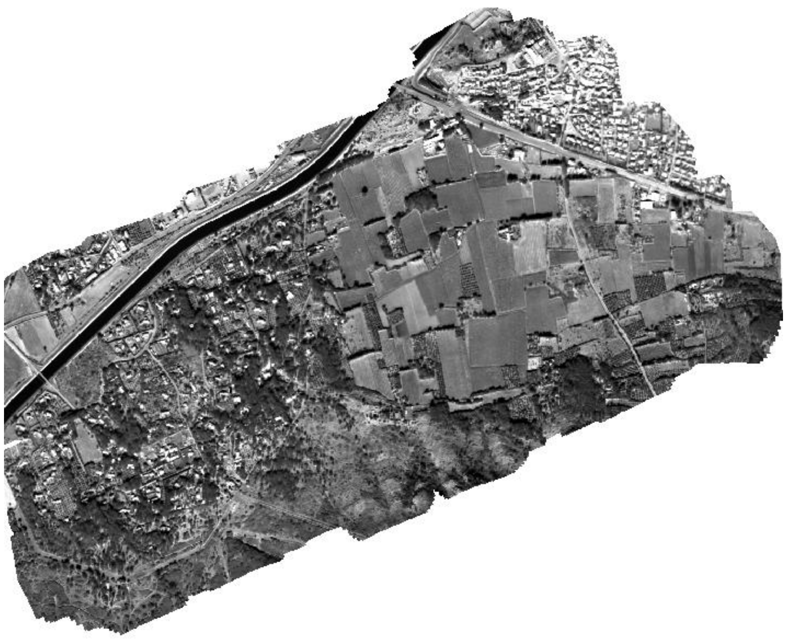


Figure 5.3 TIR (7.7 – 9.3 µm) orthomosaic corresponding to the sector 1 of Cabardèle.

5.1.2 Vauvenargues

The flights over Vauvenargues were done according to the flight plan shown in figure 3.6. The 4 sectors were flown in the same flight.

The figures 5.4, 5.5 show the reflectance orthomosaics corresponding to the band 4 (660 nm), band 7 (832.5 nm) and the figure 5.6 shows the brightness temperature orthomosaics corresponding to the TIR (7.7 – 9.3 µm).

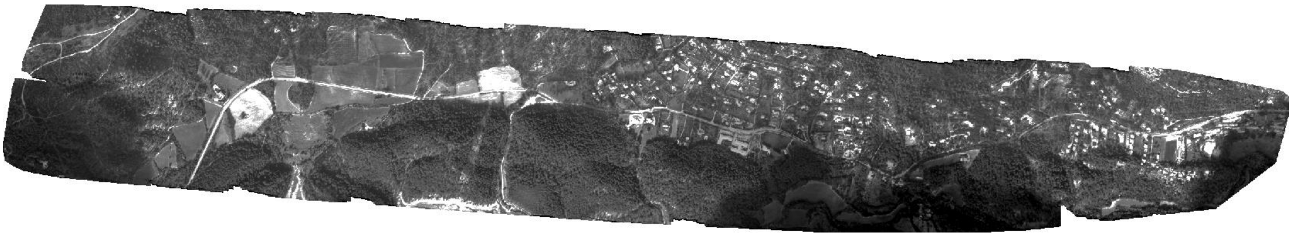


Figure 5.4 Band 4 (660 nm) orthomosaic corresponding to the sectors 3 and 4 of Vauvenargues.

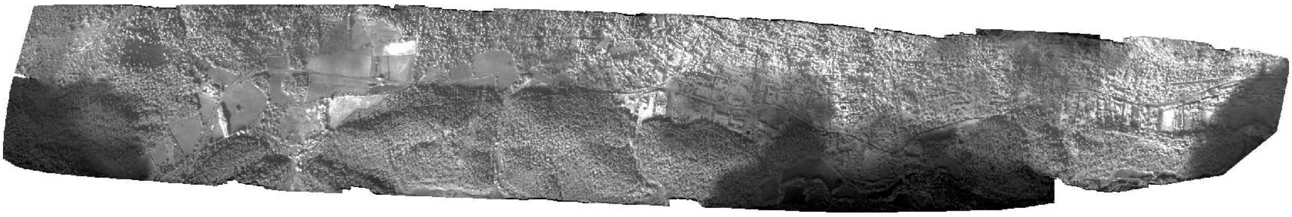


Figure 5.5 Band 7 (832.5 nm) orthomosaic corresponding to the sectors 3 and 4 of Vauvenargues.

Figure 5.6 TIR (7.7 – 9.3 µm) orthomosaic corresponding to the sectors 3 and 4 of Vauvenargues.

5.1.3 Verdagne

The flights over Verdagne were done according to the flight plan shown in figure 3.10. The 4 sectors were flown in the same flight.

The figures 5.7 and 5.8 show the reflectance orthomosaics corresponding to the band 4 (660 nm), band 7 (832.5 nm).

Figure 5.7 Band 4 (660 nm) orthomosaic corresponding to the sectors 1 and 2 of Verdagne.

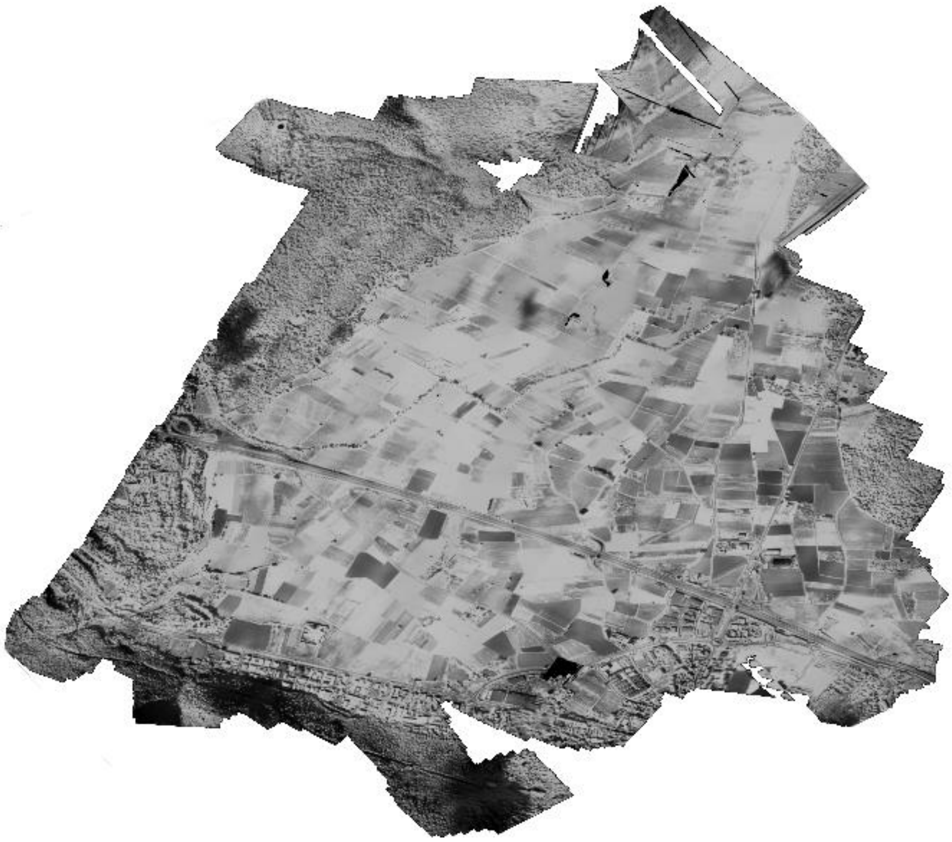


Figure 5.8 Band 7 (832.5 nm) orthomosaic corresponding to the sectors 1 and 2 of Verdagne.

5.2 Unmanned RPAS flights

The RPAS' flights were done during July and October 2018 and were performed according to the mission plans of figures 3.8 and 3.9 following the safety procedures. During the flights, we were assisted and received the support of SCP and ONERA.

A payload composed by a Micasense multispectral camera (five spectral bands: 475(20) nm, 560(20) nm, 668(10) nm, 717(10) nm, 840(40) nm) and Flir Vue Pro R uncooled thermal infrared camera made possible the image acquisition.

As in the manned flight case, the acquired images have been preprocessed with Pix4D to obtain raw (from uncalibrated multispectral data) and brightness temperature (TIR radiometric brightness temperature data) orthomosaics. The multispectral orthomosaics have been created in the same preprocessing process so the resulting orthomosaics are co-registered directly. The TIR othomosaic is computed alone. To homogenize all the orthomosaics the multispectral orthomosaics must be resampled and co-registered with Wadileaks to match the TIR orthomosaic.

Finally we have at hand six images that are perfectly registered (overlapping at pixel level). Mathematical operations can then be performed on these six spectral images.

The following images show the reflectance orthomosaics and the brightness temperature orthomosaic corresponding to the three spectral bands of interest (Reflectance RED and NIR bands from the multispectral camera and brightness temperature from the TIR camera).

5.2.1 Tour de César pipeline (Vauvenargues)

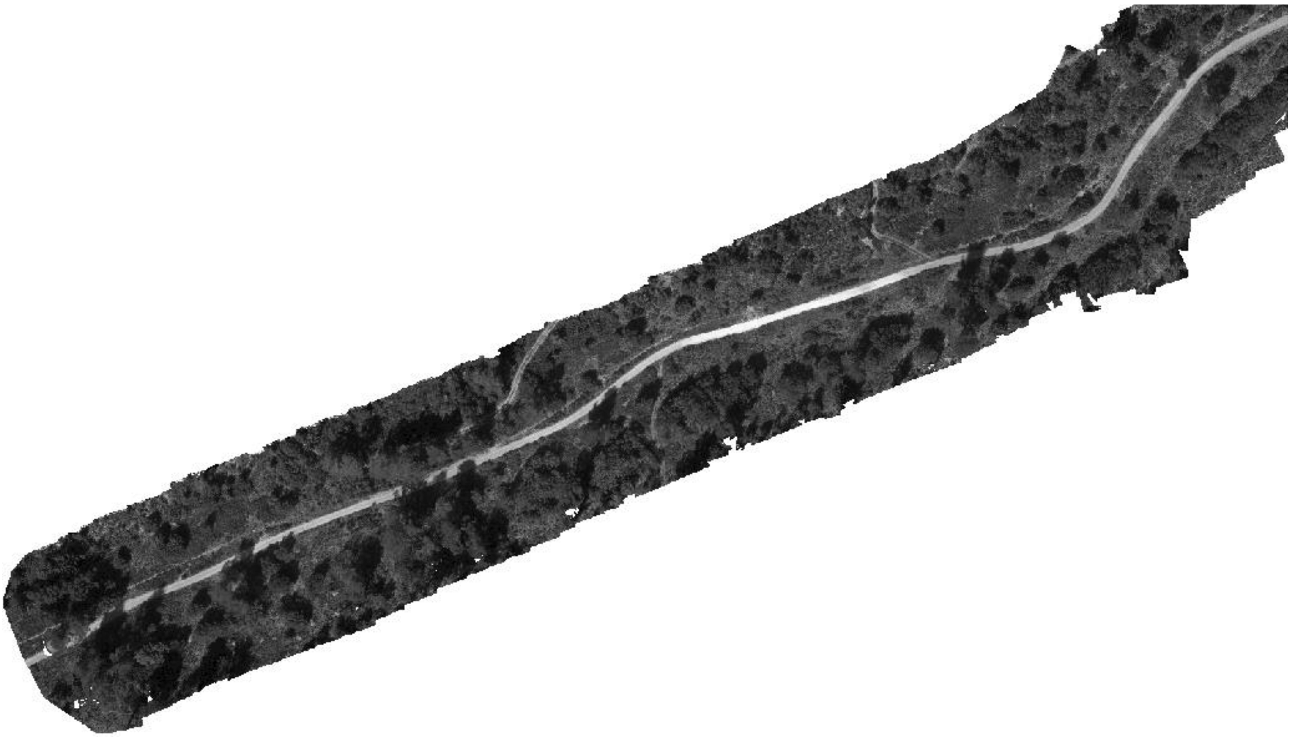


Figure 5.9 Red band (668 nm) orthomosaic corresponding to the sectors 1 and 2 of Vauvenargues.

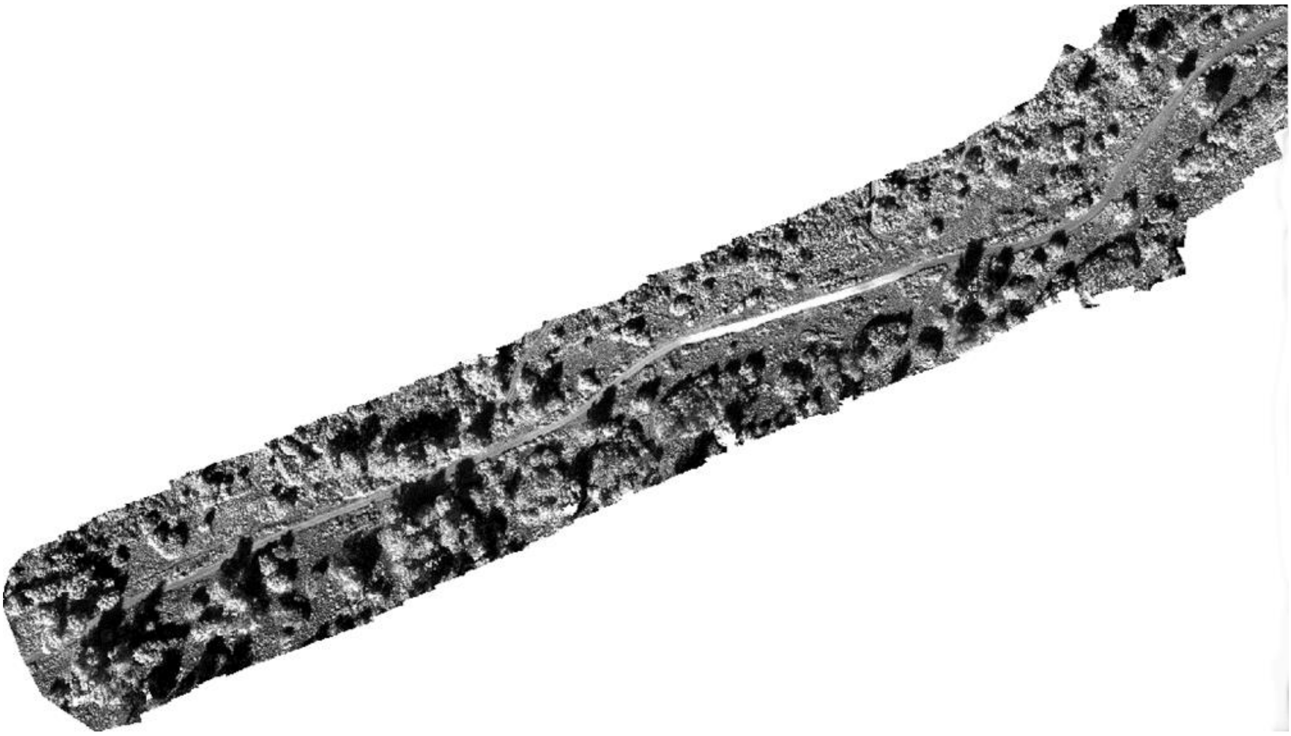


Figure 5.10 NIR band (840 nm) orthomosaic corresponding to the sectors 1 and 2 of Vauvenargues.

Figure 5.11 TIR band (840 nm) orthomosaic corresponding to the sectors 1 and 2 of Vauvenargues.

5.2.2 Waterleaks test field (Vauvenargues)

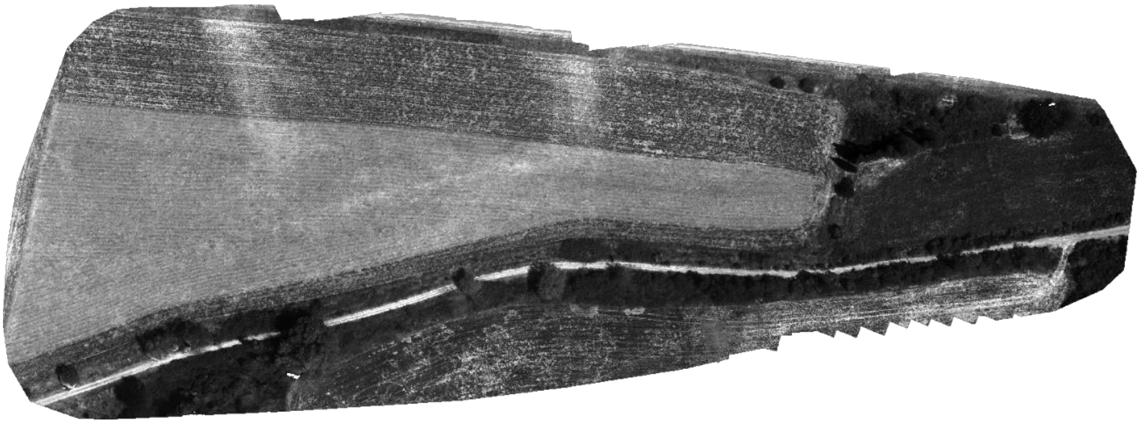


Figure 5.12 - Orthomosaic corresponding to the red band (668 nm).

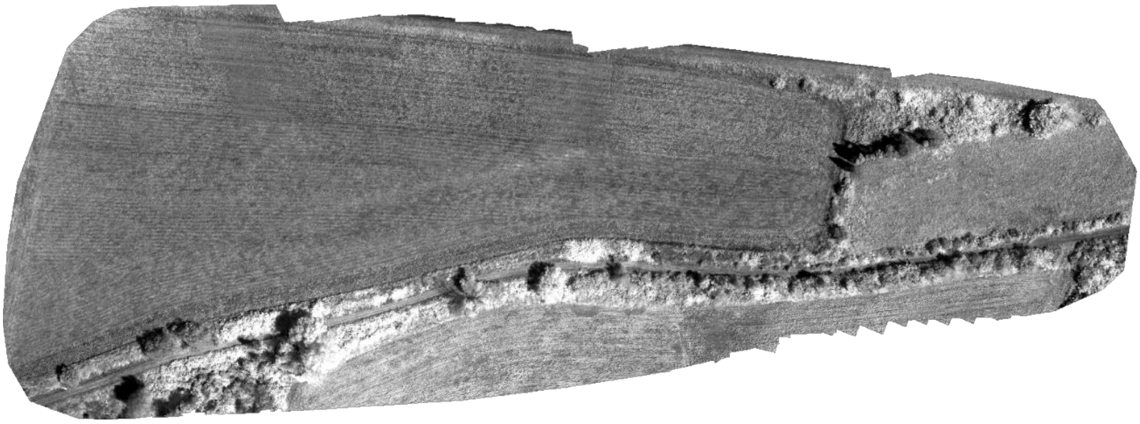


Figure 5.13 - Orthomosaic corresponding to the near infrared band (840 nm).

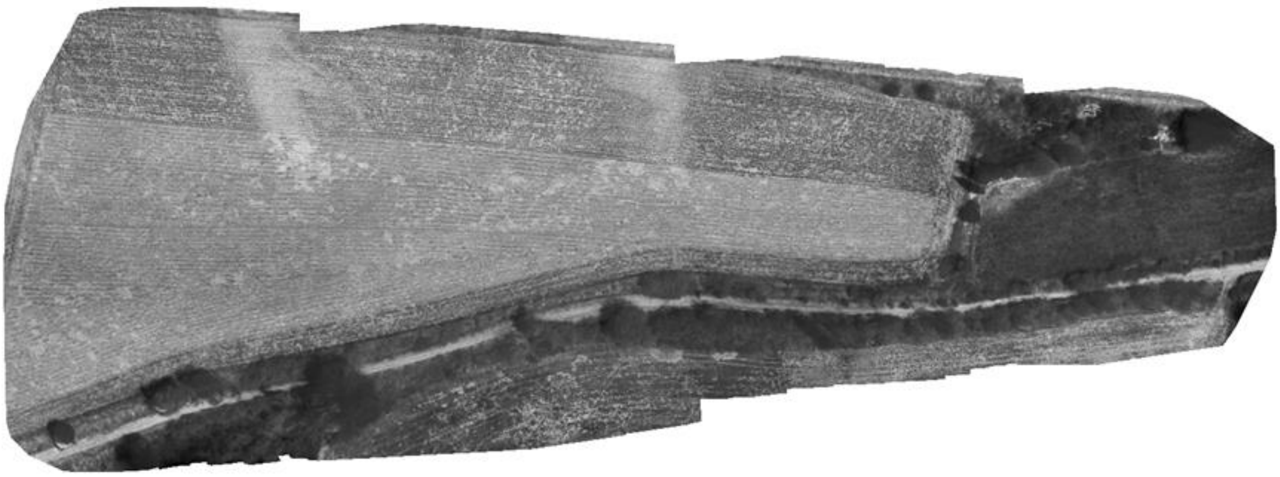


Figure 5.14 - Orthomosaic of normalized brightness temperature.

6 Ground leak detection campaign

6.1 Cabardèle

6.1.1 Description of sectorization

The sectorization in the Cabardèle site took place in the night between the 14th and the 15th of March.

The sectorization has been carried out in substantial accordance with the proposed plan for step testing, with the following modifications:

- valves between the sectors #3 and #5 and between the sectors #5 and #6 near Cazeneuve SR were kept closed during the entire duration of the test, so that each step could be accomplished by simply closing one single valve at a time;
- the duration of each step has been made longer (from 20 minutes to 1 hour).

The total pipe length appears slightly decreased with respect to what stated in the site description (see chapter 3) due to the fact that some pipes had been excluded from the analysis as result of the site's isolation.

6.1.1.1 Instrumentation for sectorization

1) An ultrasonic flowmeter installed on the outlet pipe of Cazeneuve SR #2 (the western one).
2) A level sensor with data logger in the Cazeneuve SR #2.
3) 6 pressure loggers (one in each sector).

6.1.1.2 Sectorization protocol

The field activities have been carried out as indicated in the following table.

Step	Time	Valve(s) to be closed	Sector isolated at valve's closure	Total isolated connections	Total non-isolated connections

Step	Time	Valve(s) to be closed	Sector isolated at valve's closure	Total isolated connections	Total non-isolated connections
0	22:00	158392987 ("Stations de pompage") at Cabardéle PS; 158392595 (valve between sector #5 and #6, 158392601, 158392587, 158392612 & 158393133 at Cazeneuve SRs 158392821 (valve between sector #3 and #5)	none	0	709
1	23:02	158274586	1	147	562
2	0:04	158278945	2	237	472
3	1:01	158278942	3	405	303
4	1:59	158394726	4	566	143
5	3:00	158395196	5	654	55

Table 6.1 Summary of sectorization activity in Cabardèle site.

6.1.2 Results

Average flows in each step are as follows.

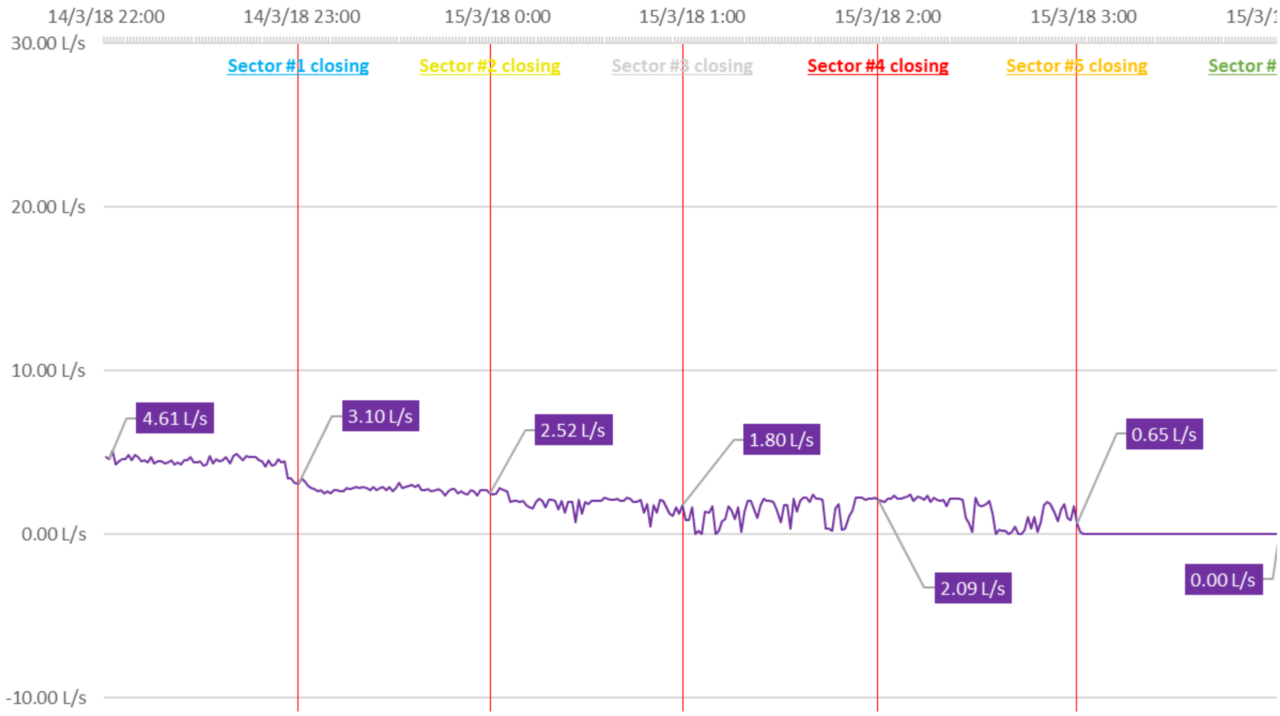


Figure 6.1 Average outflow from Cazeneuve SR #2.

Measured pressures are as follows.

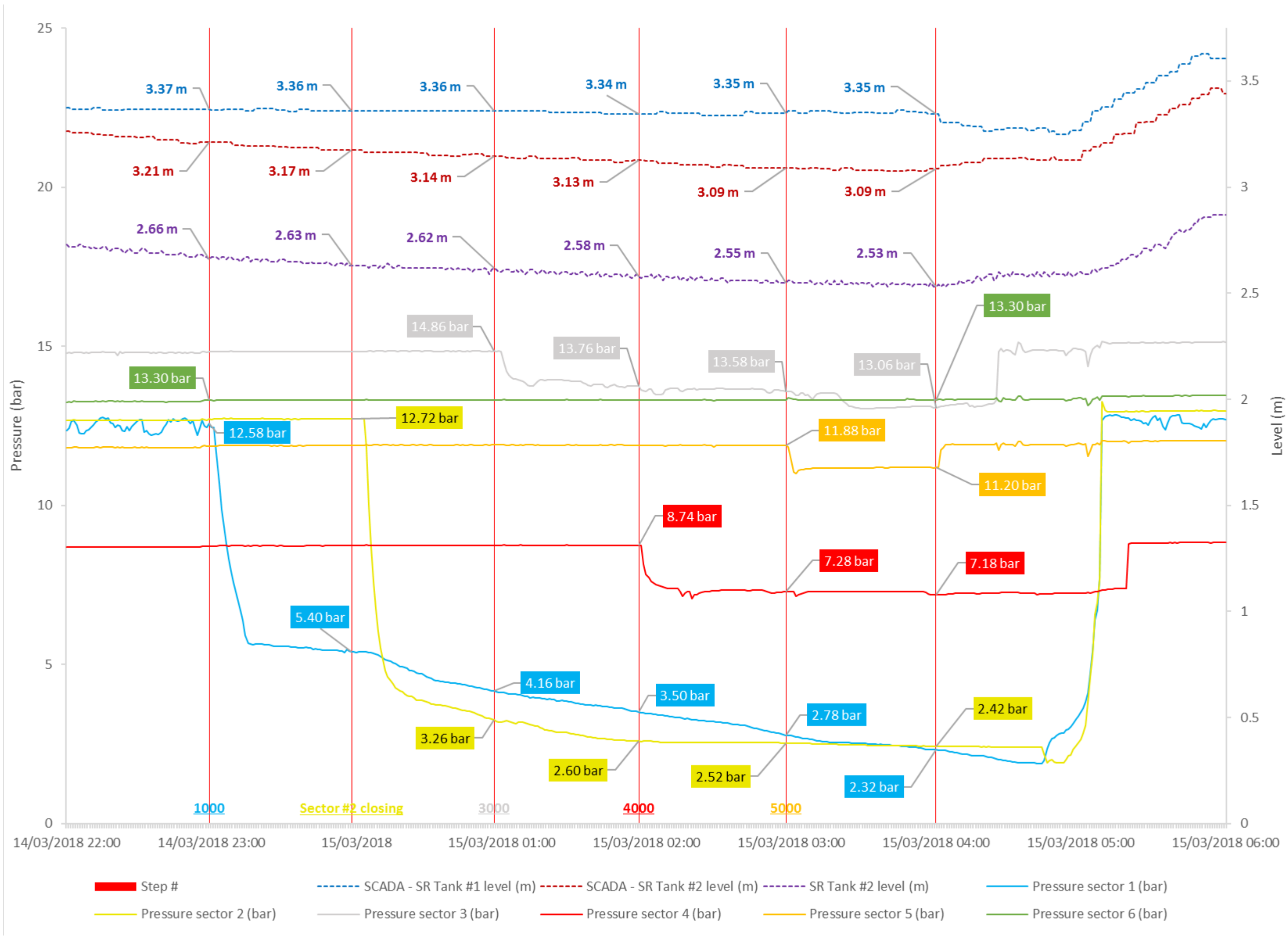


Figure 6.2 Pressure values recorded at Cabardèle site.

It appears that an average leakage rate of 4.5 l/s exists in the whole site; estimated leak flows in each sector are summarized in the following Table.

<table>
<tr><th></th><th colspan="6">Estimated leak flow (l/s)</th></tr>
<tr><td>Sector 1</td><td rowspan="6">4.52</td><td>1.82</td><td>1.82</td><td>1.82</td><td>1.82</td><td>1.82</td></tr>
<tr><td>Sector 2</td><td rowspan="5">2.70</td><td>0.82</td><td>0.82</td><td>0.82</td><td>0.82</td></tr>
<tr><td>Sector 3</td><td rowspan="4">1.89</td><td>≈0</td><td>≈0</td><td>≈0</td></tr>
<tr><td>Sector 4</td><td rowspan="3">1.89</td><td>1.07</td><td>1.07</td></tr>
<tr><td>Sector 5</td><td rowspan="2">0.82</td><td>0.82</td></tr>
<tr><td>Sector 6</td><td>≈0</td></tr>
</table>

Table 6.2 Results of the field activities carried out the night between 14th and 15th March 2018 in Cabardèle site.

6.2 Vauvenargues

6.2.1 Description of sectorization

The sectorization in the Vauvenargues site took place in the night between the 27th and the 28th of March.

The sectorization has been carried out in substantial accordance with the proposed plan for step testing (Option 2), only the duration of each step has been made longer (from 20 minutes to 2 hours).

The total pipe length appears slightly decreased with respect to what stated in the site description (see chapter 3) due to the fact that some pipes had been excluded from the analysis as result of the site's isolation.

6.2.1.1 Instrumentation for sectorization

1) A water meter DN 32 with pulse transmitter installed between the pressure tappings on the outlet pipe of Clau des Lamberts SR, with the aim of precisely measuring the amount of water coming out of the SR while keeping the valve in between the pressure tappings closed. Unfortunately, no measurements have been obtained from this meter (probably due to the valve not being tightly closed), so the outflow measurements have been deducted from level values registered at Clau des Lamberts SR.

Figure 6.2 Installation of water meter to measure outflow from Clau des Lamberts SR.

2) Two pressure loggers (20 bars) – one upstream and one downstream of the boundary valve between sectors 1 and 2.
3)

Figure 6.3 Pressure loggers at the boundary valve between sectors 1 and 2.

4) Two pressure loggers (20 bars) – one upstream and one downstream of the boundary valve between sectors 2 and 4.

5) Two pressure loggers (20 bars) – one upstream and one downstream of the boundary valve between sectors 3 and 4.

Figure 6.4 Pressure loggers at the boundary valve between sectors 3 and 4

6.2.1.2 Sectorization protocol

The field activities have been carried out as indicated in the following table.

Step	Time	Valve(s) to be closed	Sector isolated at valve's closure	Total isolated connections	Total non-isolated connections
0	22:00	Outlet valves at Saint-Marc Jaumegarde PS + bulk supply connections	none	0	296
1	0:00	99073	1	62	234
2	2:05	102818	2	146	150
3	4:07	148294316	3	238	58

Table 6.3 Summary of sectorization activity in Vauvernagues site

6.2.2 Results

Average flows in each step (derived from reservoir's level) are as follows.

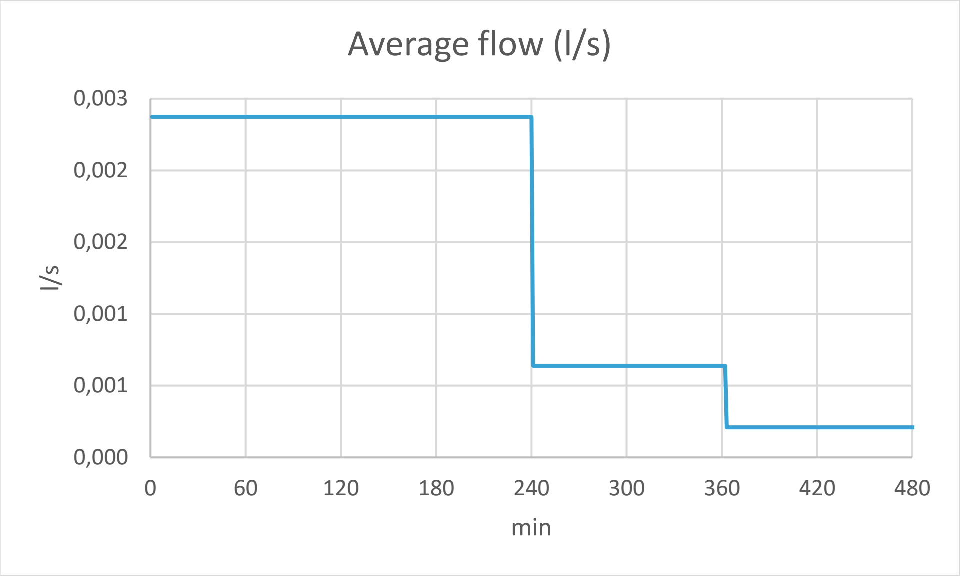


Figure 6.5 Average outflow from Clau des Lamberts SR.

Measured pressures are as follows.

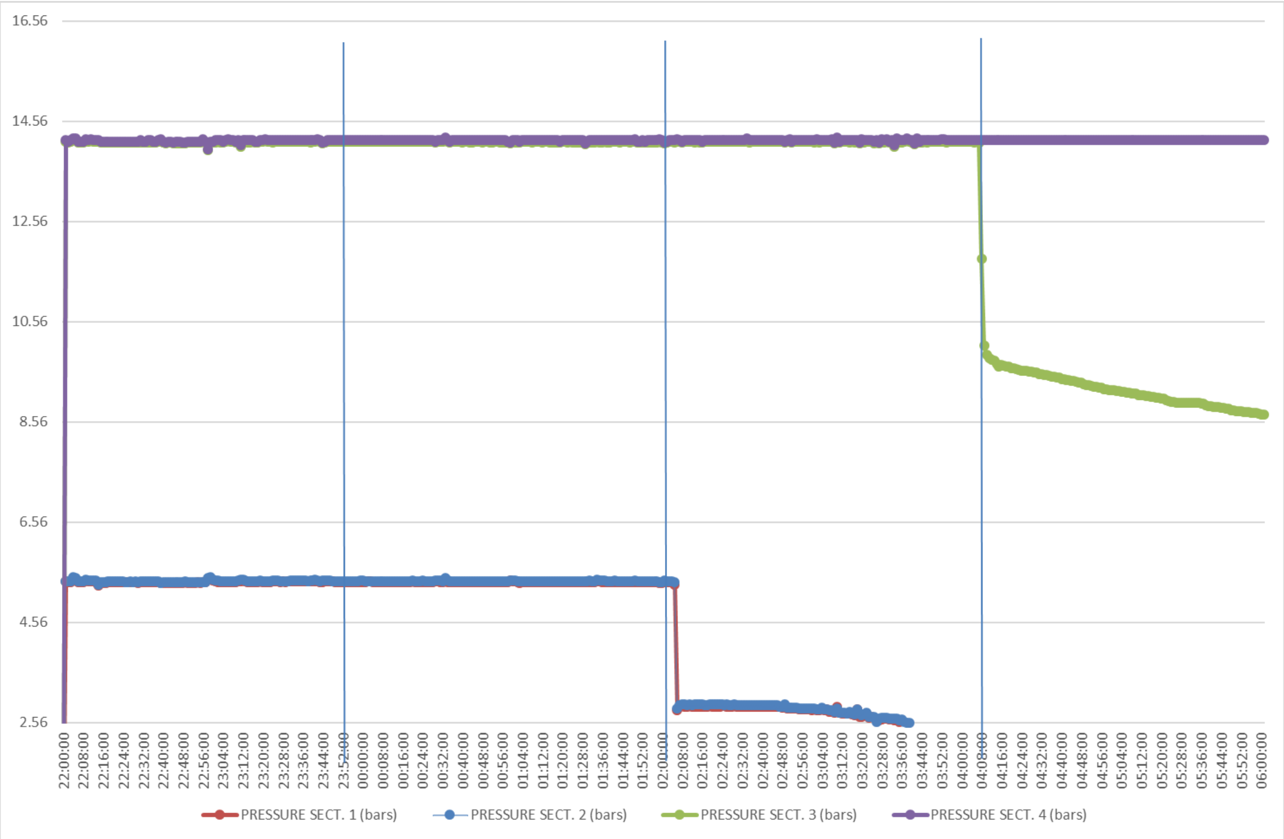


Figure 6.6 Pressure values recorded at Vauvernagues site

It is inferred from the flow and pressure measurements that the valve between sectors 1 and 2 couldn't work properly so no effective isolation of sector 1 occurred.

It appears that an average leakage rate of 2.4 l/s exists in the whole site, out of which 1.7 l/s within sectors 1 and 2 combined, 0.4 l/s in sector 3 and 0.2 l/s in sector 4, as summarized in the following Table.

<table>
<tr><th></th><th colspan="3">Estimated leak flow (l/s)</th></tr>
<tr><td>Sector 1</td><td rowspan="4">2.37</td><td rowspan="2">1.73</td><td rowspan="2">1.73</td></tr>
<tr><td>Sector 2</td></tr>
<tr><td>Sector 3</td><td rowspan="2">0.64</td><td>0.43</td></tr>
<tr><td>Sector 4</td><td>0.21</td></tr>
</table>

Table 6.4 Results of the field activities carried out the night between 27th and 28th March 2018 in Vauvernagues site

6.3 Verdagne

6.3.1 Description of sectorization

The sectorization was carried out in Verdagne site the two nights between the 21st and the 23rd of February. Some difficulties have been encountered due to the break of valves connected to the measurements devices, which caused the step testing to be postponed with respect to what was initially planned.

The sectorization has been carried out with some modification with respect to the proposed plan for step testing. In this site, a sectorization activity was already planned by SCP, so it was decided to take advantage of these results to evaluate the network performances in terms of leakage.

The 4 sectors described in the following Table and shown in the following Figure have been considered: it is noted that these sectors appear more homogeneous in terms of number of service connections with respect to the initially planned subdivision. The total pipe length appears slightly decreased with respect to what stated in the site description (see chapter 3) due to the fact that some pipes had been excluded from the analysis as result of the site's isolation.

<table>
<tr><th>Sector</th><th>N° connections</th><th>Type of pipe</th><th>Length (km)</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">76</td><td>Mains</td><td>12.84</td></tr>
<tr><td>Service connections</td><td>0.06</td></tr>
<tr><td rowspan="2">2*</td><td rowspan="2">82</td><td>Mains</td><td>7.65</td></tr>
<tr><td>Service connections</td><td>0.02</td></tr>
</table>

Sector	N° connections	Type of pipe	Length (km)
3*	53	**Mains**	**16.89**
		Service connections	*0.14*
4	74	**Mains**	**31.22**
		Service connections	*0.13*
TOTAL	**285**	**-**	**68.94**

Table 6.5 Sectors considered in Verdagne site.

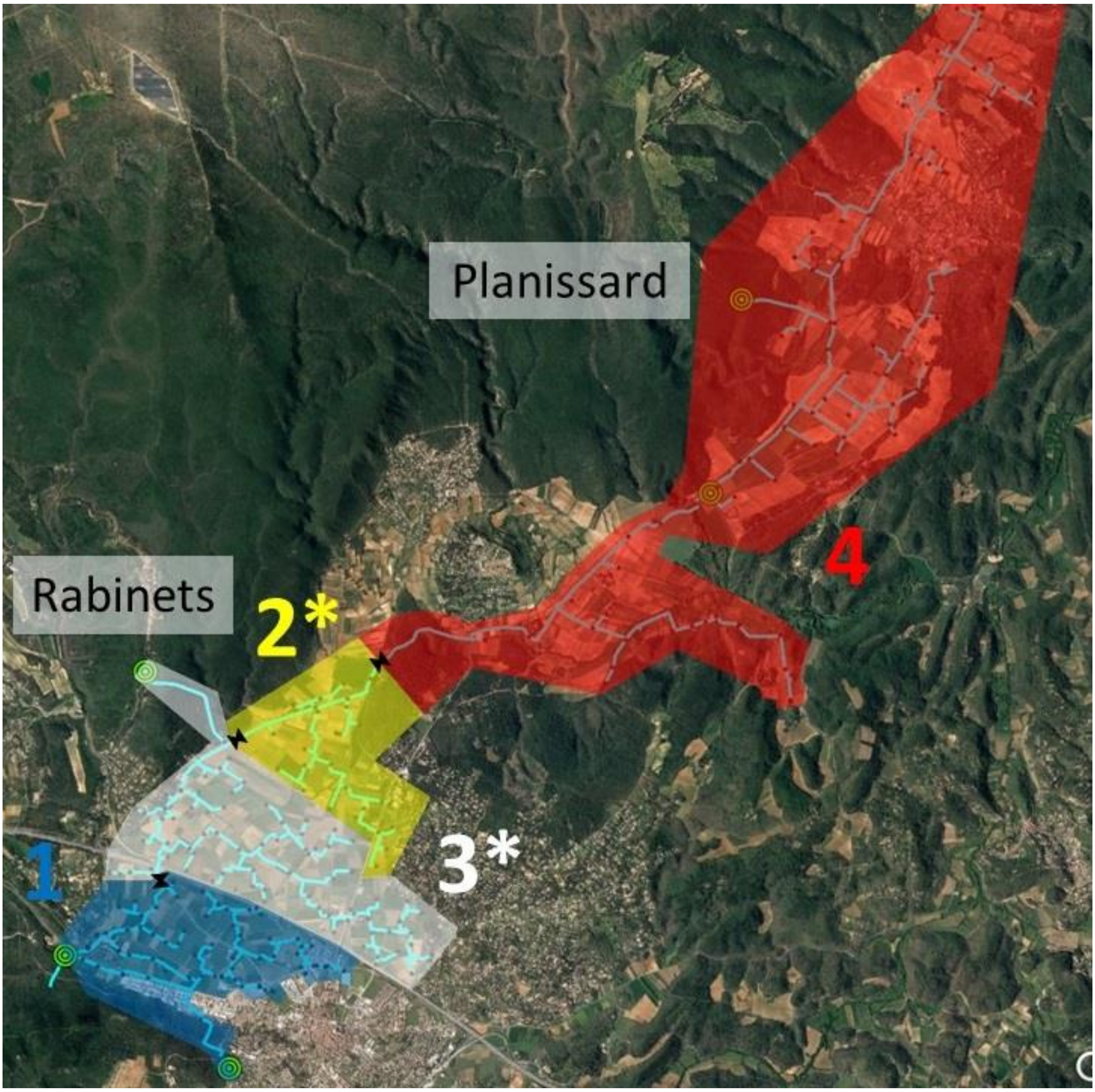


Figure 6.7 Sectors considered in Verdagne site.

The isolation of the site has been obtained by closing a number of valves as below:

A. valves on the inlet and bypass of Saint Maximin WTP (valve id 147841951 and 147841948);
B. valve on Verdange PS outlet (valve id 147842653 "Stations de pompage").

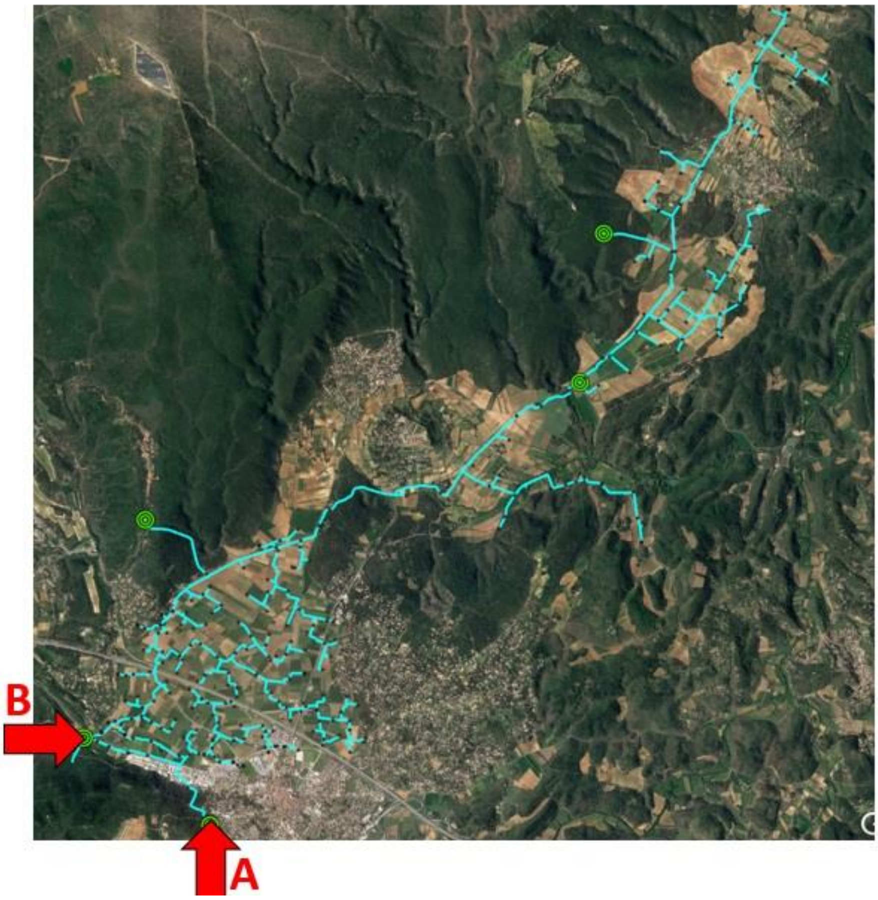


Figure 6.8 Location of the valves closed for isolating the site.

6.3.1.1 Instrumentation for sectorization

4) A level sensor with data logger in the Planissard SR - Q6.

Figure 6.9 Level sensor with data logger.

5) A level sensor with data logger in the Rabinets SR - Q4.

6) A water meter DN 32 - Q7 - with pulse transmitter installed between the pressure tappings and an ultrasonic flowmeter -Q2 - installed on the main pipe (for daytime flow measurements and checking whether at nighttime the valve is tightly closed), indicated in the screenshot below (boundary between sectors 1 and 3*).

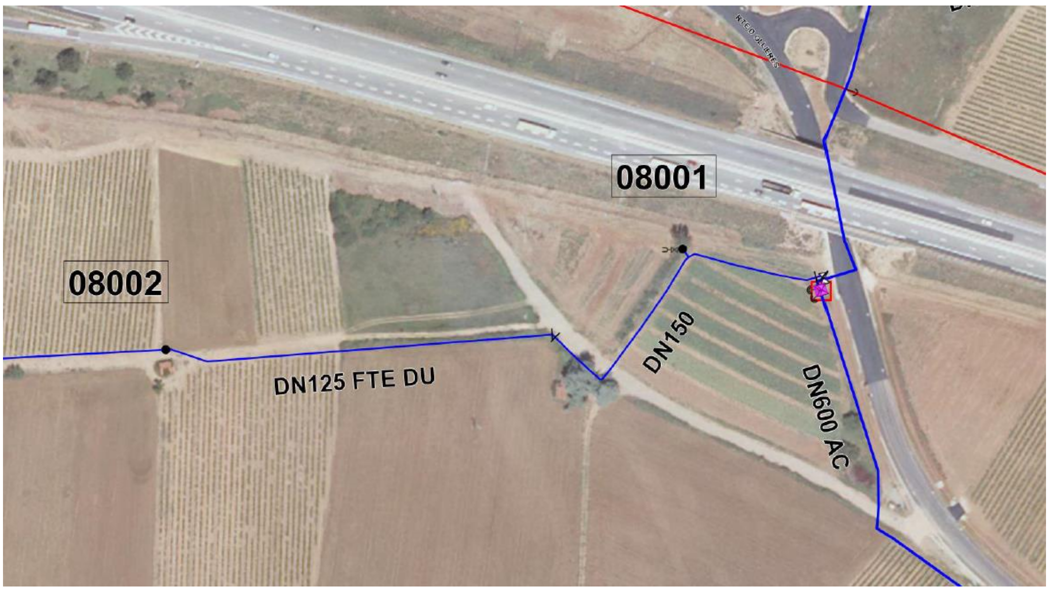


Figure 6.10 Location of flow measurement devices Q2 and Q7.

7) A water meter DN 32 – Q9 - with pulse transmitter installed between the pressure tappings and an ultrasonic flowmeter – Q5 - installed on the main pipe (for daytime flow measurements and checking whether at nighttime the valve is tightly closed), indicated in the screenshot below (boundary between sectors 2* and 4). Unfortunately, the water meter Q9 did not work.

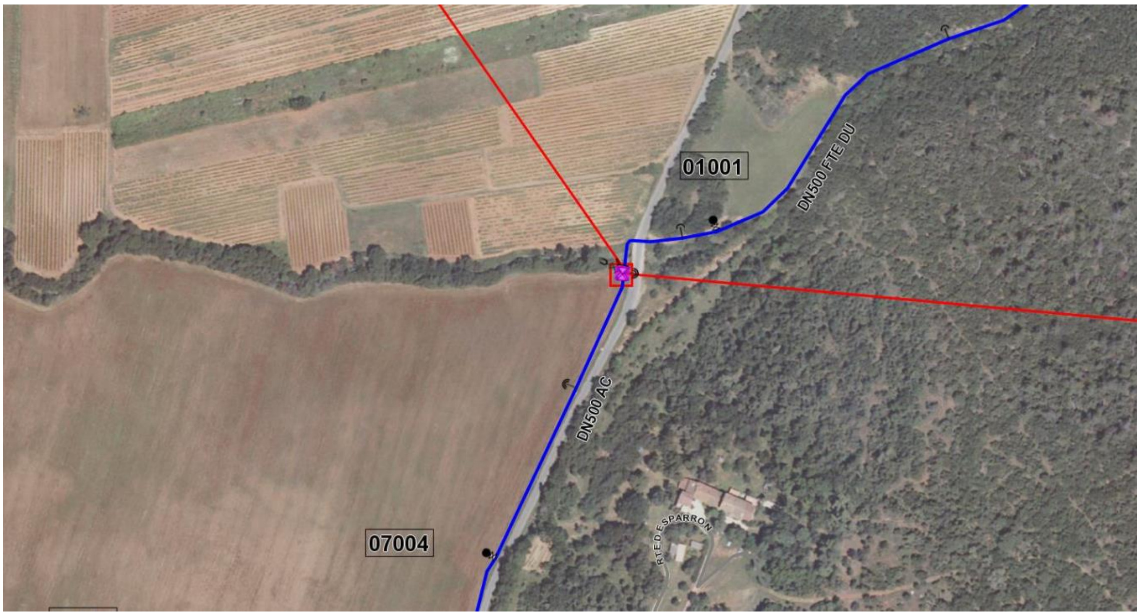


Figure 6.11 Location of flow measurement devices Q5 and Q9.

Figure 6.12 Installation of measurement device Q9.

8) A water meter DN 32 – Q8 - with pulse transmitter installed between the pressure tappings and an ultrasonic flowmeter – Q3 - installed on the main pipe (for daytime flow measurements and checking whether at nighttime the valve is tightly closed), indicated in the screenshot below (boundary between sectors 3* and 2*).

Figure 6.13 Location of flow measurement devices Q3 and Q8.

6.3.1.2 Sectorization protocol

The field activities have been carried out as indicated in the following table.

	Verdagne PS	Saint Maximin WTP	Valve between sectors 2* and 3*		Valve between sectors 1 and 3*		Valve between sectors 2* and 4	
			Main pipe	Bypass (pressure tappings)	Main pipe	Bypass (pressure tappings)	Main pipe	Bypass (pressure tappings)
21/02/2018 at 22h	Off	Closed	Closed	Closed	Closed	Open	Open	Closed
22/02/2018 at 6h	On	Open	Open	Closed	Open	Closed	Open	Closed
22/02/2018 at 22h	Off	Closed	Closed	Open	Closed	Closed	Closed	Closed
23/02/2018 at 6h	On	Open	Open	Closed	Open	Closed	Open	Closed

Table 6.6 Summary of sectorization activity in Verdagne site.

6.3.2 Results

6.3.2.1 *Night between 21st and 22nd February 2018*

The sectors under the influence of the Rabinets reservoir were sector number 1 and 3* (shown below).

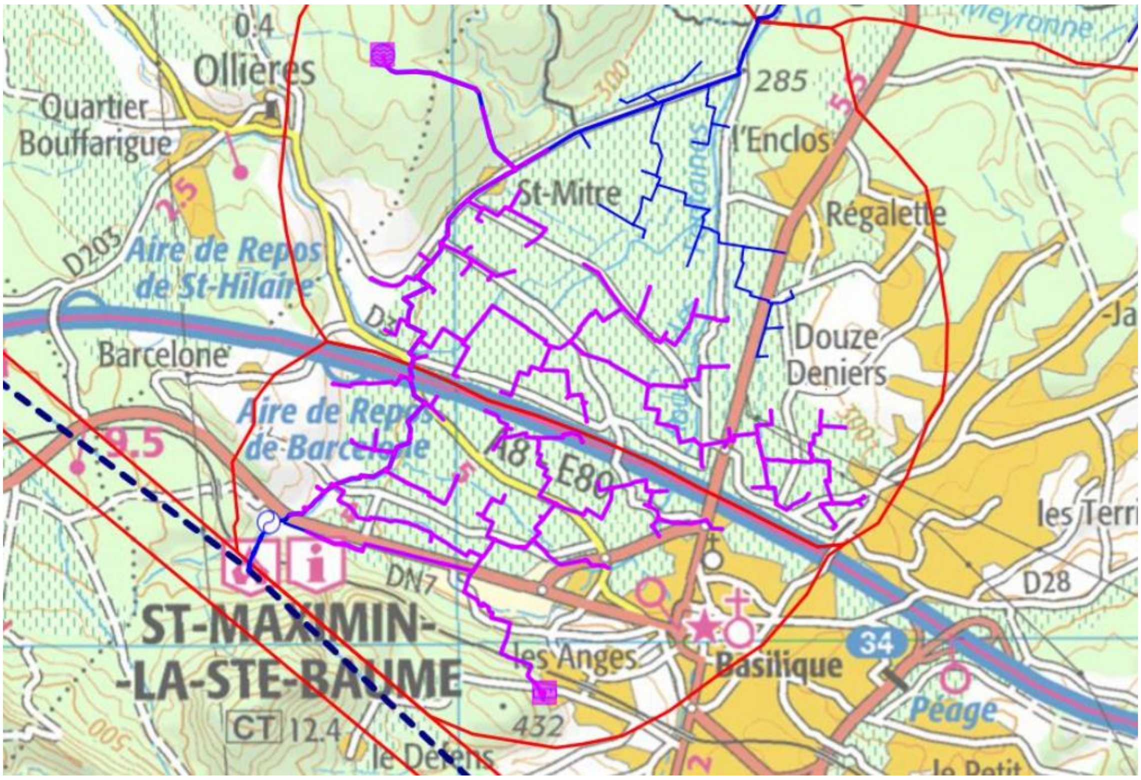


Figure 6.13 Sectors under the influence of the Rabinets reservoir during the first night.

Levels measured in the reservoir are as follows.

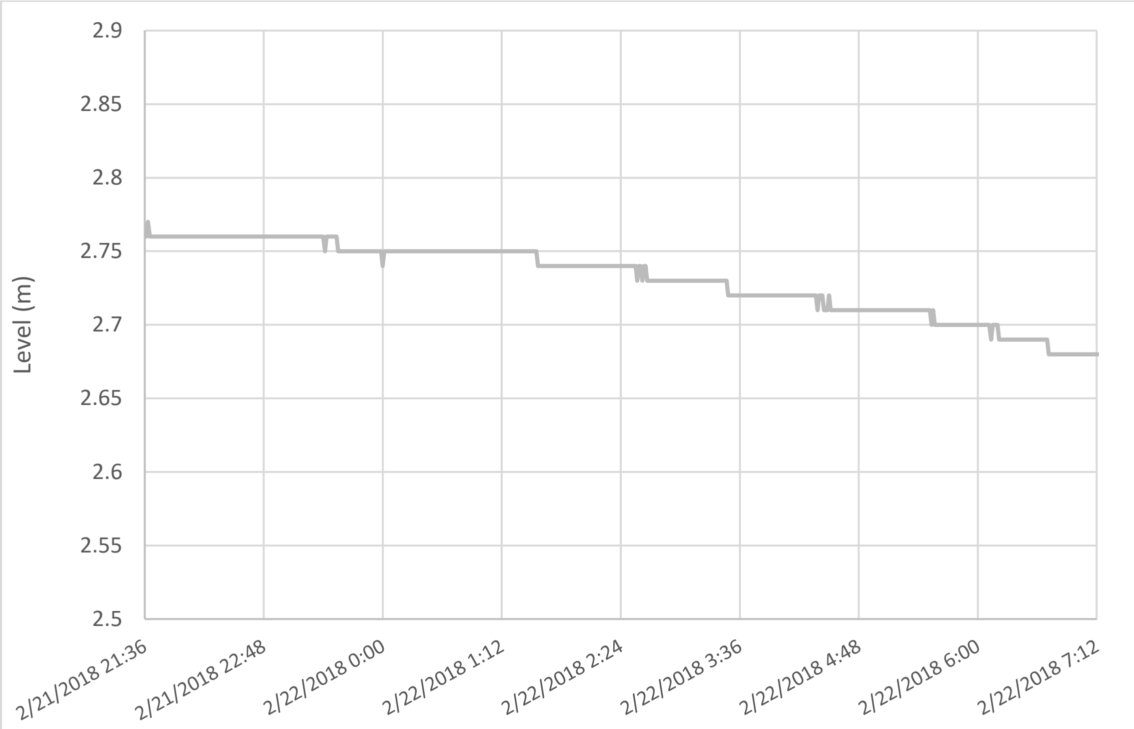


Figure 6.14 Levels measured in Rabinets reservoir during the first night.

This corresponds to an average leakage rate of 1.5 l/s ± 0.2 l/s.

Volumes transiting from north to south of the highway (i.e. from sector 3* to sector 1) have been monitored through the ultrasonic flow meter Q2 which did not record any flow over this period.

It therefore appears that the average leakage rate of 1.5 l/s ± 0.2 l/s is located in sector 3*.

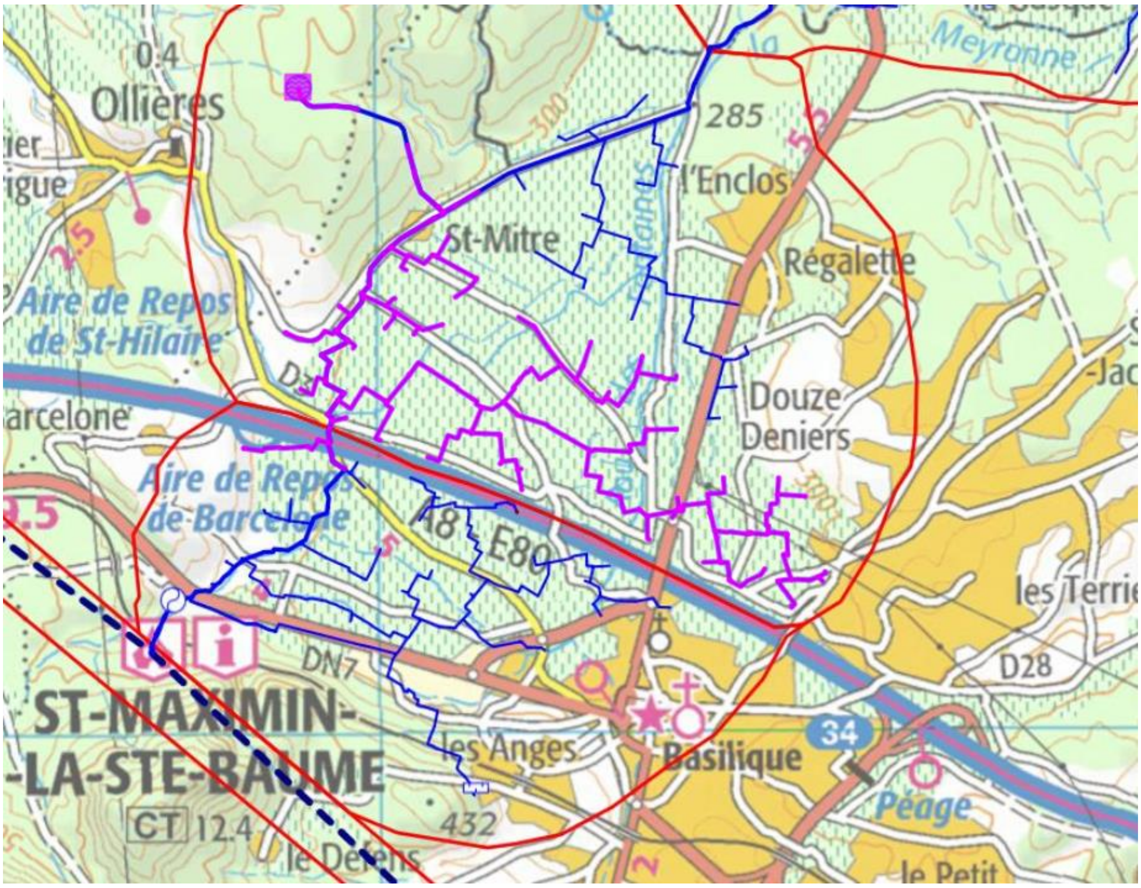


Figure 6.15 Sector 3* showing the highest leakage rate during the first night.

Likewise, the evaluation of the leakage flowrate has been carried out in the sectors 2* and 4, under the influence of Planissard SR.

An average leakage rate of 0.9 l/s ± 0.3 l/s was estimated, with negligible flow transiting from sector 4 to sector 2*.

Overall, the results of the field activities carried out the night between 21st and 22nd February 2018 are depicted in the scheme below.

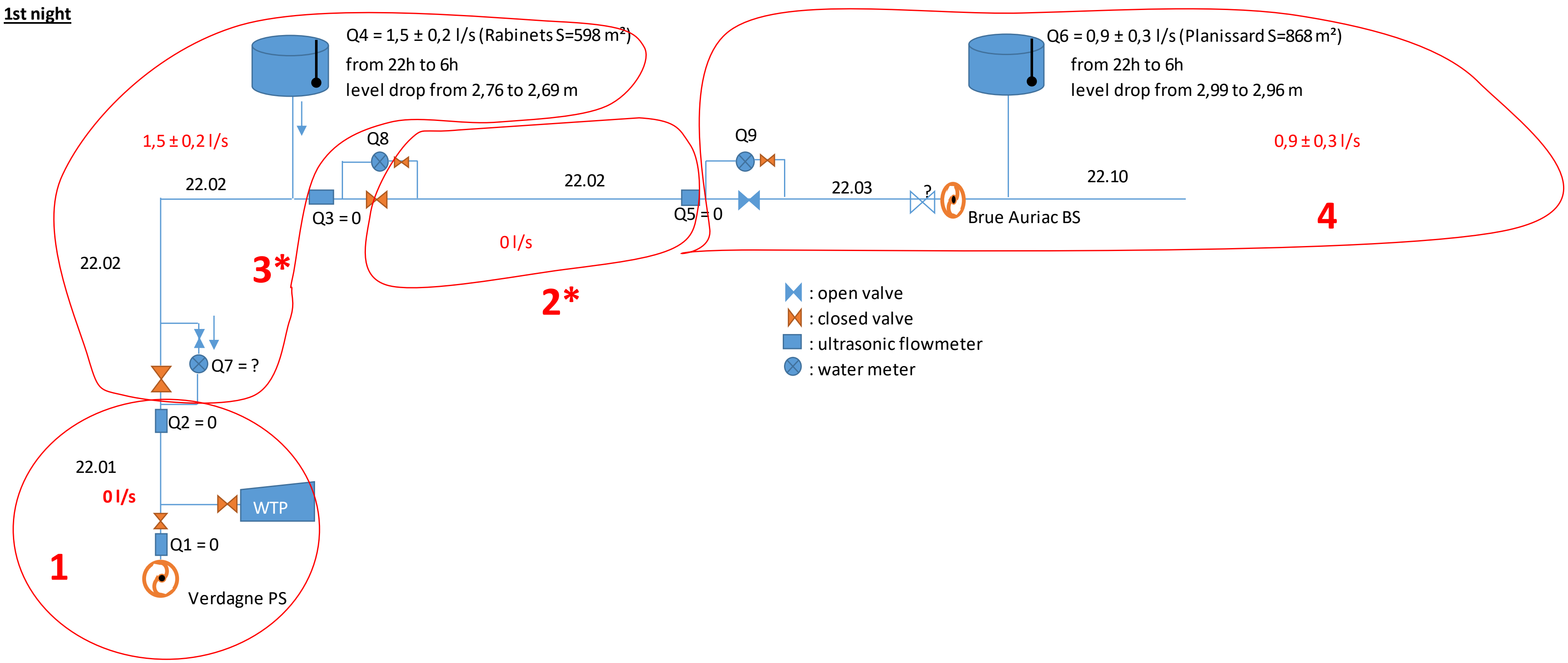


Figure 6.16 Scheme showing results of the field activities carried out the night between 21st and 22nd February 2018 in Verdagne site.

6.3.2.2 Night between 21st and 22nd February 2018

The sectors under the influence of the Rabinets reservoir were sector number 3* and 2* (shown below).

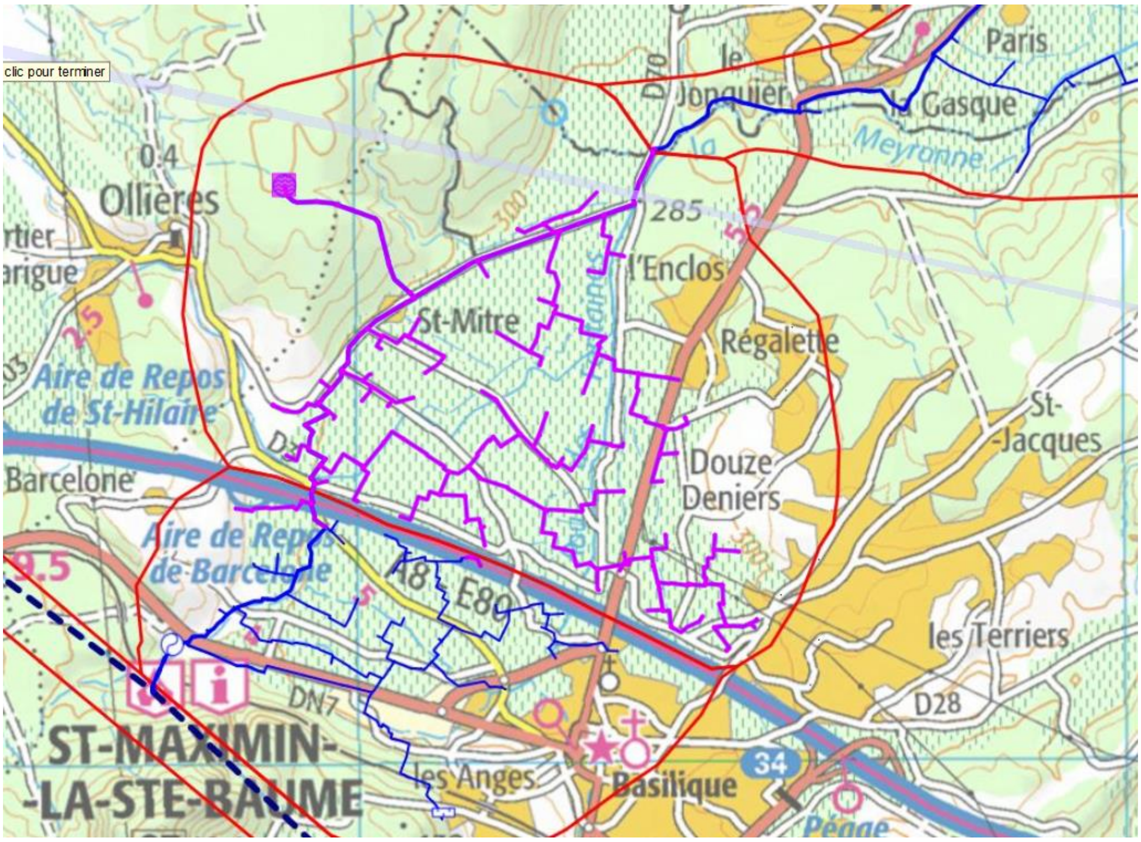


Figure 6.17 Sectors under the influence of the Rabinets reservoir during the second night.

Levels measured in the reservoir are as follows.

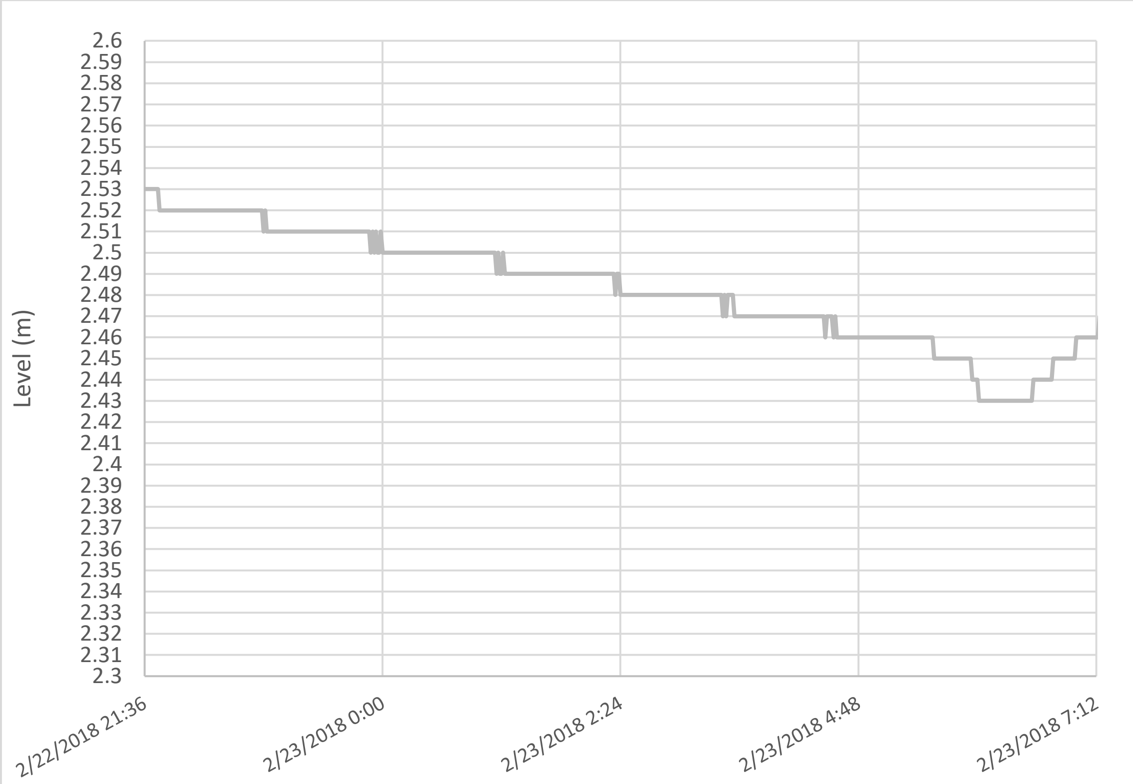


Figure 6.18 Levels measured in Rabinets reservoir during the second night.

The levels recorded in the tank confirm a flow of the same order of magnitude as what had been measured during the first night: 1.4 l/s ± 0.2 l/s.

Volumes transiting from sector 3* to sector 2* have been monitored through the water meter Q8 which measured a volume of 280 l over the 8 hours of operation i.e. an average flow rate of 0.01 l/s.

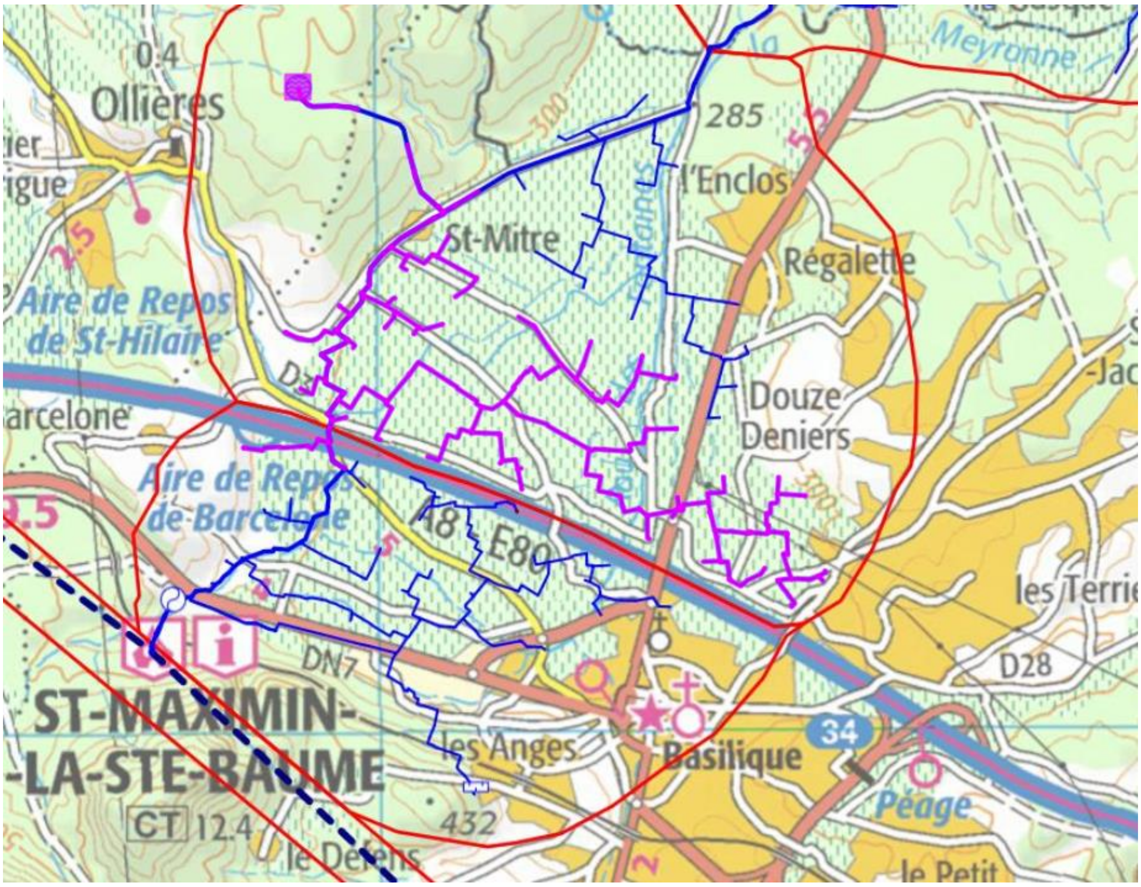


Figure 6.19 Sector 3* showing the highest leakage rate during the second night.

Likewise, the evaluation of the leakage flowrate has been carried out in the sector 4 under the influence of Planissard SR.

An average leakage rate of 0.7 l/s ± 0.3 l/s was estimated.

Overall, the results of the field activities carried out the night between 22nd and 23rd February 2018 are depicted in the scheme below.

2nd night

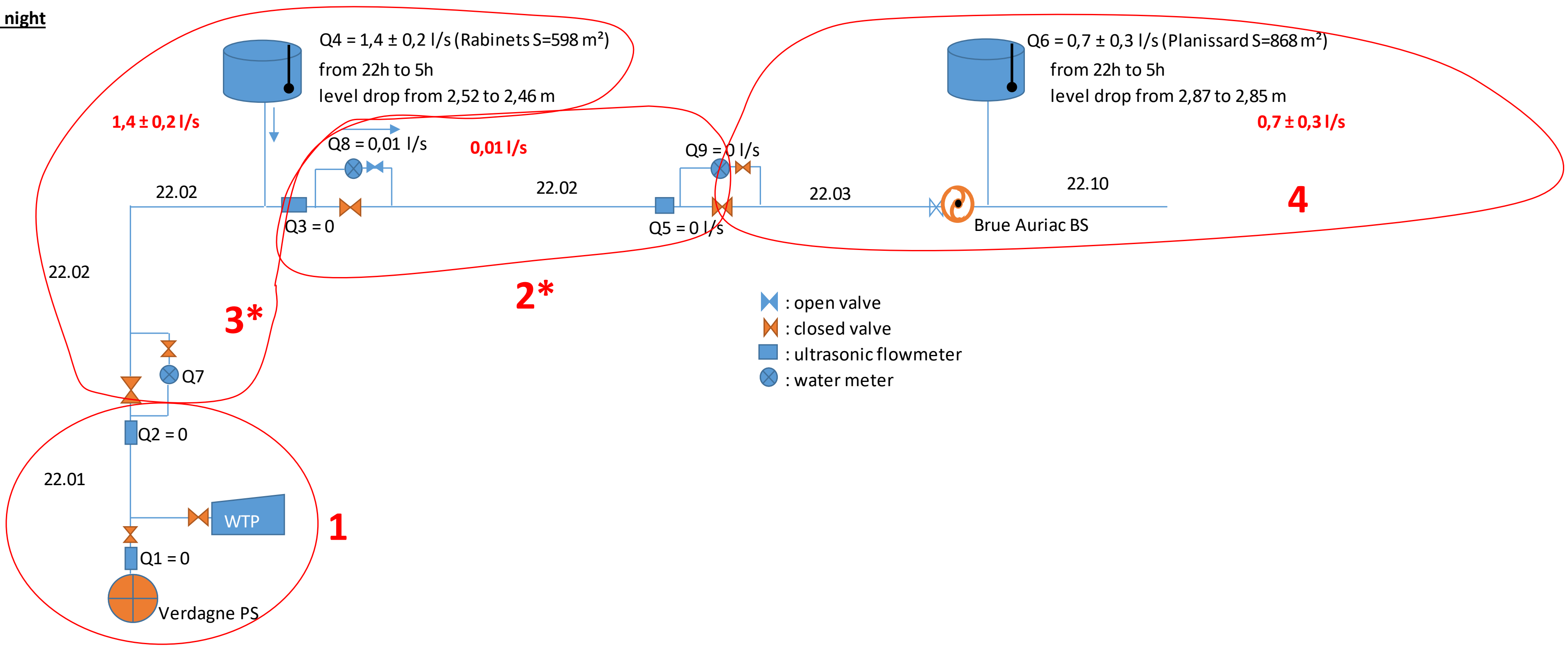


Figure 6.20 Scheme showing results of the field activities carried out the night between 22nd and 23rd February 2018 in Verdagne site.

7 Analysis of the ground leak detection campaign

The results obtained from the field activities have been analysed in order to evaluate which sectors of the network show the highest leakage rate and to assign suitable performance indicators that enable the comparison of the network's sectors among each other, so that it becomes possible to rank the sectors located in the three sites. The final aim of the analysis of results is to select which sectors of the network shall be covered during the first ground leak detection campaign.

7.1 Performance indicators for leakage

The most traditional and easy-to-calculate performance indicator for evaluating the leakage level in a water supply system is to express the leakage as a **% of System Input Volume** (SIV). However, this indicator has several limitations: for example, it can result in substantial under- or over-estimates of true achievements in reduction of leakage volume, because % of SIV is unable to identify actual decreases in both consumption and leakage volume in the same period. Therefore, it is better always to express leakage in volumetric terms.

Another simple indicator of the level of leak in each sector is obtained by **dividing the leak by the length of the main pipes** (excluding service connections); however, this indicator shall best be used for tracking progress in an individual system's performance, rather than for comparing different systems or sub-systems, because each system has a different Unavoidable Annual Real Losses base level, which varies widely depending upon density of connections, length of connections (main to meters) and average pressure.

According to the EU Reference document "Good Practices on Leakage Management", the most appropriate indicator to make comparisons of technical leakage performance of sub-systems within a larger system (or between different systems) is **the Infrastructure Leakage Index** (ILI).

The ILI was designed by an IWA Task Force in 1999 specifically for comparisons of leakage management performance between different systems with different infrastructure characteristics (connection density, length of service connections, average pressure), as below:

$$ILI = CARL/UARL.$$

Where:

CARL is Current Annual Real Losses volume in m^3/year.

UARL is Unavoidable Annual Real Losses (UARL) in m^3/year = $(6{,}57 \times Lm + 0{,}256 \times Nc + 9{,}13 \times Lt) \times Pc$

Where:

Lm = underground mains length (km)

Nc = number of underground service connections

Lt = total length (km) of underground service connections (main to water meter)

Pc = current average operating pressure (m).

7.2 Analysis of results in the three validation sites

7.2.1 Cabardèle

Knowing the MNFs calculated in the various sectors of the site, and assuming that MNF is equal to the leakage, it was possible to calculate the Current Annual Real Losses volume in m^3/y as the Average Leak Flow times the Night-Day Factor (NDF).

The concept of NDF is explained herewith: as the Average Pressure changes in the network, so too does the rate of leakage. It would be clearly incorrect to multiply the Utility Night Leakage in $m^3/hour$ by 24 hours per day to assess the daily and annual leakage, so the parameter known as NDF needs to be theoretically calculated to act as the multiplier.

In this case, not having available a precise hydraulic model simulating the annual variation of pressures in the network, and knowing that on one hand the network is subject to higher pressures at night due to the negligible consumption (i.e. the lower headlosses in the pipes), but on the other hand it is subject to lower pressures at night due to the inactivity of the pump station (which in daytime directly injects water in the distribution network in order to meet the demand, thus raising the pressure), the NDF is simply assumed equal to 24 hours. As this site is characterized by the presence of a large number of PRVs in the network, the Average Operating Pressure for each sector was obtained from actual pressure recorded during nighttime.

Two leakage performance indicators have been calculated i.e. the Leak/Length (in $m^3/km/year$) and the Infrastructure Leakage Index (ILI). The analysis of results obtained from the field activities are shown in the following table.

Sector	Leak flow (l/s)	CARL (m3/y)	N° connections	Type of pipe	Length (km)	UARL (m3/y)	Leak/Length (m3/km/y)	ILI = CARL/UARL	
1	1.82	57466	147	**Mains**	**10.51**	15432	5466	3.7	Moderate
				Service connections	*1.83*				
2	0.82	25751	90	**Mains**	**9.72**	12361	2650	2.1	Moderate

Sector	Leak flow (l/s)	CARL (m3/y)	N° connections	Type of pipe	Length (km)	UARL (m3/y)	Leak/Length (m3/km/y)	ILI = CARL/UARL	
				Service connections	*1.14*				
3	0	0	169	**Mains**	**10.83**	19623	≈0	≈0	Very low
				Service connections	*1.99*				
4	1.07	33640	160	**Mains**	**3.17**	7463	10624	4.5	High
				Service connections	*2.63*				
5	0.82	25877	88	**Mains**	**14.50**	14533	1785	1.8	Low
				Service connections	*0.59*				
6	0	0	55	**Mains**	**14.21**	14342	≈0	≈0	Very low
				Service connections	**0.04**				
TOTAL	**4.52**	**142735**	**709**	**-**	**71.17**	**83753**	**2006**	**1.7**	**Low**

Table 7.1 Characteristics and performance indicators of the sectors in Cabardèle site.

It is therefore concluded that the sector showing the highest amount of leak/km of pipe and highest ILI, and hence giving the highest probability for us to find leaks during the ground leak detection campaign, is the sector 4.
Chances to reduce leakage level also exist – even though to a lesser extent – also in sectors 1, 2 and 5.

7.2.2 Vauvenargues

Knowing the MNFs calculated in the various sectors of the site, and assuming that MNF is equal to the leakage, it was possible to calculate the Current Annual Real Losses volume in m^3/y as the Average Leak Flow times the Night-Day Factor (NDF).

The concept of NDF is explained herewith: as the Average Pressure changes in the network, so too does the rate of leakage. It would be clearly incorrect to multiply the Utility Night Leakage in $m^3/hour$ by 24 hours per day to assess the daily and annual leakage, so the parameter known as NDF needs to be theoretically calculated to act as the multiplier.

In this case, not having available a precise hydraulic model simulating the annual variation of pressures in the network, and knowing that on one hand the network is subject to higher pressures at night due to the negligible consumption (i.e. the lower headlosses in the pipes), but on the other hand it is subject to lower pressures at night due to the inactivity of the pump station (which in daytime directly injects water in the distribution network in order to meet the demand, thus raising the pressure), the NDF is simply assumed equal to 24 hours. For the same reason, the Average Operating Pressure for each sector is calculated as the average value between the assumed highest pressure level (SR full supply level minus the lowest network elevation), and the lowest one (minimum pressure ensured at the points of delivery by contract i.e. 25m).

Two leakage performance indicators have been calculated i.e. the Leak/Length (in m³/km/year) and the Infrastructure Leakage Index (ILI). The analysis of results obtained from the field activities are shown in the following table.

<table>
<tr><th>Sector</th><th>Leak flow (l/s)</th><th>CARL (m3/y)</th><th>N° connections</th><th>Type of pipe</th><th>Length (km)</th><th>UARL (m3/y)</th><th>Leak/Length (m3/km/y)</th><th colspan="2">ILI = CARL/UARL</th></tr>
<tr><td rowspan="2">1</td><td rowspan="4">1.73</td><td rowspan="4">54721</td><td rowspan="4">146</td><td>Mains</td><td>4.75</td><td rowspan="4">14244</td><td rowspan="4">11530</td><td rowspan="4">3.8</td><td rowspan="4">Moderate</td></tr>
<tr><td>Service connections</td><td>0.53</td></tr>
<tr><td rowspan="2">2</td><td>Mains</td><td>6.75</td></tr>
<tr><td>Service connections</td><td>1.28</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">0.43</td><td rowspan="2">13538</td><td rowspan="2">92</td><td>Mains</td><td>5.80</td><td rowspan="2">5729</td><td rowspan="2">2335</td><td rowspan="2">2.4</td><td rowspan="2">Moderate</td></tr>
<tr><td>Service connections</td><td>1.04</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">0.21</td><td rowspan="2">6596</td><td rowspan="2">58</td><td>Mains</td><td>9.22</td><td rowspan="2">7218</td><td rowspan="2">715</td><td rowspan="2">1</td><td rowspan="2">Very low</td></tr>
<tr><td>Service connections</td><td>0.88</td></tr>
<tr><td>TOTAL</td><td>2.37</td><td>74855</td><td>296</td><td>-</td><td>30.25</td><td>33509</td><td>2474</td><td>2.2</td><td>Moderate</td></tr>
</table>

Table 7.2 Characteristics and performance indicators of the sectors in Vauvernagues site.

It is therefore concluded that the sector showing the highest amount of leak/km of pipe and highest ILI, and hence giving the highest probability for us to find leaks during the ground leak detection campaign, is the sector 1+2.
Chances to reduce leakage level also exist – even though to a lesser extent – also in sector 3.

7.2.3 Verdagne

Knowing the MNFs calculated in the various sectors of the site, and assuming that MNF is equal to the leakage, it was possible to calculate the Current Annual Real Losses volume in m³/y as the Average Leak Flow times the Night-Day Factor (NDF).

The concept of NDF is explained herewith: as the Average Pressure changes in the network, so too does the rate of leakage. It would be clearly incorrect to multiply the Utility

Night Leakage in m³/hour by 24 hours per day to assess the daily and annual leakage, so the parameter known as NDF needs to be theoretically calculated to act as the multiplier.

In this case, not having available a precise hydraulic model simulating the annual variation of pressures in the network, and knowing that on one hand the network is subject to higher pressures at night due to the negligible consumption (i.e. the lower headlosses in the pipes), but on the other hand it is subject to lower pressures at night due to the inactivity of the pump station and booster station (which in daytime directly injects water in the distribution network in order to meet the demand, thus raising the pressure), the NDF is simply assumed equal to 24 hours. For the same reason, the Average Operating Pressure for each sector is calculated as the average value between the assumed highest pressure level (SR full supply level minus the lowest network elevation), and the lowest one (minimum pressure ensured at the points of delivery by contract i.e. 25m).

Two leakage performance indicators have been calculated i.e. the Leak/Length (in m³/km/year) and the Infrastructure Leakage Index (ILI). The analysis of results obtained from the field activities are shown in the following table.

Sector	Leak flow (l/s)	CARL (m3/y)	N° connections	Type of pipe	Length (km)	UARL (m3/y)	Leak/Length (m3/km/y)	ILI = CARL/UARL	
1	≈0	≈0	76	**Mains**	**12.84**	7619	≈0	≈0	Very low
				Service connections	*0.06*				
2*	0.01	316	82	**Mains**	**7.65**	5858	41	≈0	Very low
				Service connections	*0.02*				
3*	1.4	44181	53	**Mains**	**16.90**	9248	2615	4.8	High
				Service connections	*0.14*				
4	0.69	21775	74	**Mains**	**31.22**	18803	698	1.2	Low
				Service connections	*0.13*				
TOTAL	**2.3**	**66271**	**285**	**-**	**68.95**	**41528**	**961**	**1.6**	**Low**

Table 7.3 Characteristics and performance indicators of the sectors in Verdagne site.

It is therefore concluded that the sector showing the highest amount of leak/km of pipe and highest ILI, and hence giving the highest probability for us to find leaks during the ground leak detection campaign, is the sector 3*.
Chances to reduce leakage level also exist – even though to a lesser extent – also in sector 4.

8 Analysis of the validation flights campaign

The waterleaks test field has been selected as a representative case for validation of both, the manned aircraft and the RPAS cases. The aim of this work is to validate the T-VI (Temperature – Vegetation Index) method at different scales by means of a manned aircraft platform and an UAV with data acquired in October 2018 over an area with artificial water leaks. The data acquired by the RPAS are going to be compared to those acquired in July 2018.

The area of study in the present work is a plot located in Vauvenargues (Aix-en-Provence, France). A secondary pipe has been connected to the existing main pipe and buried at a depth of about 1m; the connection with the existing pipe was equipped with a valve, a flow meter, a recorder and a pressure regulator; calibrated holes have been drilled in the added pipe to generate leakages. In the present work three bands have been used in both cases, manned aircraft and UAV (660 nm (red), 832,5 nm (NIR) and TIR for manned aircraft and 668 nm (red), 840 nm (NIR) and TIR for UAV). In both cases, the images have been preprocessed with the photogrammetric software Pix4D to obtain spectral orthomosaics. The multispectral aircraft data are uncalibrated raw data. A radiometric calibration based on spectralon calibration images has been applied as part of the radiometric calibration carried out by Pix4D in the case of the red and NIR bands of the UAV acquired data. Although the aircraft and the UAV TIR cameras are both radiometrically calibrated, the emissivity parameter has been set to 1 and no temperature function has been applied to the raw data to extract the true temperature from the brightness temperature.

8.1 Manned aircraft flight

A combined use of TIR and VIS-NIR data like in the Triangle Method can be used in water leak detection over water transmission pipes and canals to gain accuracy. This method consists in combining the apparent temperature and a vegetation index like NDVI to perform a temperature-NDVI scatterplot for all the pixels over an area with a wide diversity in terms of cover fraction and water content. The name is related to the (roughly) triangle shape of the obtained scatterplot. The vertex of the triangle is often truncated, giving a trapezoidal shape. The scatterplot yields to the calculation of a water index for each point or pixel by making a quotient between its relative position with respect to the dry edge and the wet edge of the triangle/trapezoid.

As explained in D4.1, an estimation of the NDVI is obtained by computing the relative contrast in reflectance (which explains the following subscript ρ): $NDVI_{\rho} = (\rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}})/(\rho_{\mathrm{NIR}} + \rho_{\mathrm{Red}})$ where $\rho_{\mathrm{NIR}} = S_{\mathrm{NIR}}\rho_{ref,\mathrm{NIR}} / \tau_{\mathrm{NIR}} S_{ref,\mathrm{NIR}}$ and $\rho_{\mathrm{red}} = S_{\mathrm{red}}\rho_{ref,\mathrm{red}} / \tau_{\mathrm{red}} S_{ref,\mathrm{red}}$. Since transmission is nearly the same in both bands, NDVI can be approximated by: NDVI

$NDVI_{\rho} \approx (\rho'_{NIR} - \rho'_{Red})/(\rho'_{NIR} + \rho'_{Red})$ where appear now the "underestimated reflectances" $\rho'_{NIR} = S_{NIR}\rho_{ref,NIR} / S_{ref,NIR}$ and $\rho'_{red} = S_{red}\rho_{ref,red} / S_{ref,red}$.

The empirical Triangle/Trapezoid method can be implemented by using either NDVI or OSAVI expression for the vegetation index as discussed in WP3. The NDVI vegetation index has been calculated in each case.

Figure 8.1 NDVI orthomosaic from the waterleaks test field (October 2018).

The artificial water leak is indicated in the NDVI orthomosaic of the figure 8.1 by a red ellipse. Inside the ellipse we can see an area predominantly green which can be due to the leaks (July and October).

The water index (WI) is obtained by plotting each pixel of the scene in the temperature – VI space (T-VI).

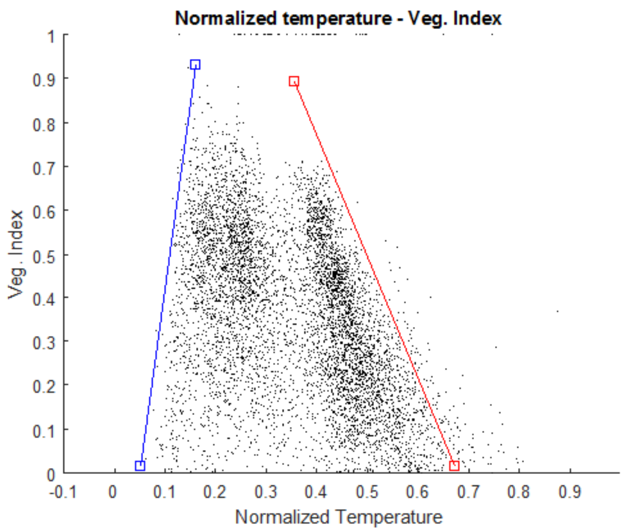


Figure 8.2 Scatterplot between the Normalized Temperature and the NDVI vegetation index corresponding to the waterleaks test field (October 2018).

The resulting T-VI scatter plot (figure 8.2) shows a triangle/trapezoid shape of the pixel distribution. The WI of a pixel at temperature T_{TIR} is calculated following the next expression:

$$WI = \frac{T_{dry} - T_{TIR}}{T_{dry} - T_{wet}}$$

where T_{wet} and T_{dry} are the lowest and highest temperature observed at the same VI as the considered pixel. The lowest temperature T_{wet} belongs to the so-called “cold” edge (or “wet” edge”) (in blue in the figure 8.2) of the triangle/trapezoid distribution, whereas the highest temperature T_{dry} belongs to the “warm” edge (or “dry” edge) (in red in the figure 8.2).

Figure 8.3 Water index orthomosaic calculated with the trapezoid method (October 2018).

The calculated water index orthomosaic shows a dark blue area inside the red ellipse which indicates the water leak. This area has lower temperature than the surrounding field and shows the presence of a water leak.

8.2 RPAS flights

The RPAS are capable of flying generally at lower altitudes than the manned aircrafts allowing the acquisition of data with higher resolutions. The flights were performed over the same area than the manned aircraft.

8.2.1 October 2018

Following the same methodology explained in 8.1 we calculate the NDVI orthomosaic from the red and NIR bands.

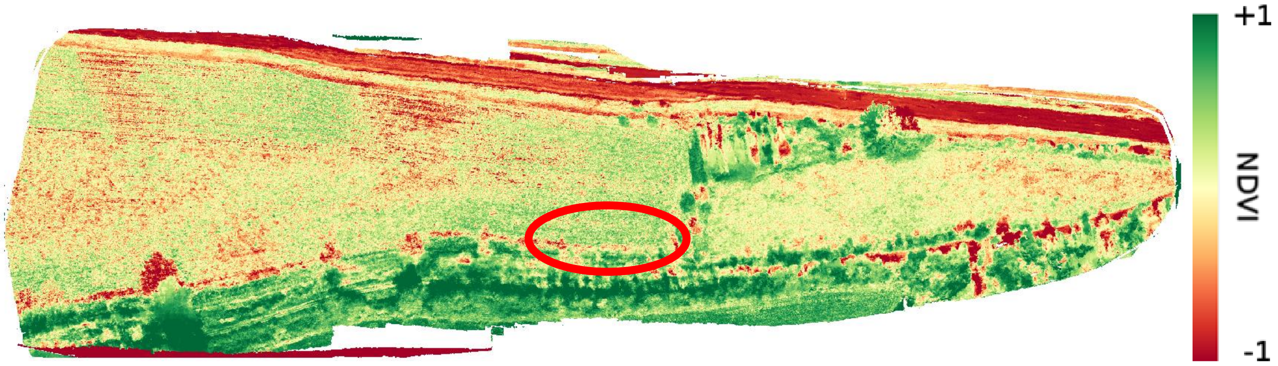


Figure 8.4 NDVI orthomosaic from the waterleaks test field acquired with RPAS (October 2018).

The water leak is indicated by the red ellipse. No special color is appreciated in this case. The dark green corresponds to tall vegetation and trees. The field shows homogeneity due to the presence of grass or growing herbs.

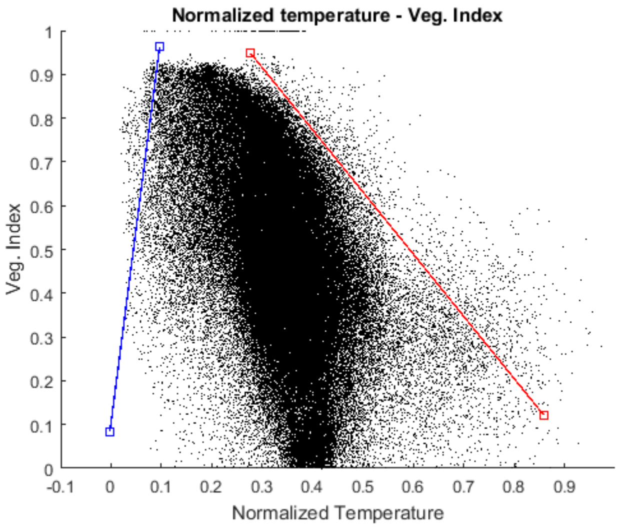


Figure 8.5 Scatterplot between the Normalized Temperature and the NDVI vegetation index (October 2018).

The RPAS orthomosaic has a greater resolution than the orthomosaic obtained from the manned aircraft data. This fact causes a bigger density of points in the scatterplot. To avoid a massive presence of points, the scatterplot can be downsampled. Downsampling the scatterplot too much will lead to the erroneous shape of the scatterplot and will make very difficult to set up correctly the cold and the warm edges.

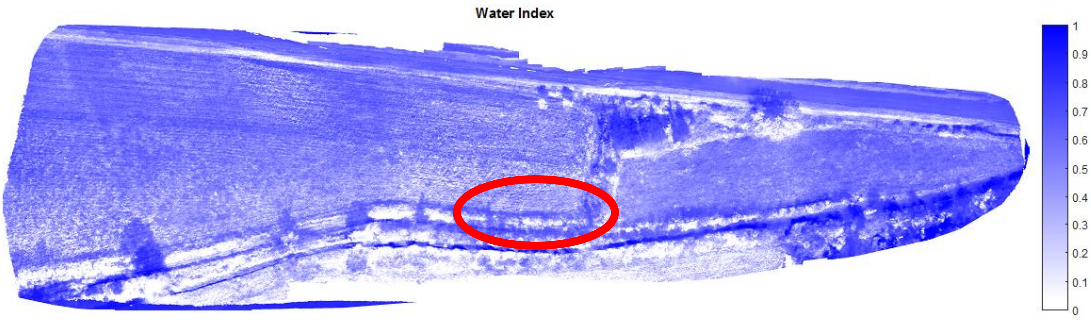


Figure 8.6 Water index from the waterleaks test field obtained with RPAS (October 2018).

The water index shows a dark blue area inside the red ellipse indicating the water leak. To make a correct interpretation it is essential to know where the pipelines are otherwise the effect of the shadows or vegetation makes increase the confusion significantly.

8.2.2 July 2018

The first flight over the waterleaks test field was done in July 2018 as a test flight. It is interesting to see the differences in the images acquired in two different periods.

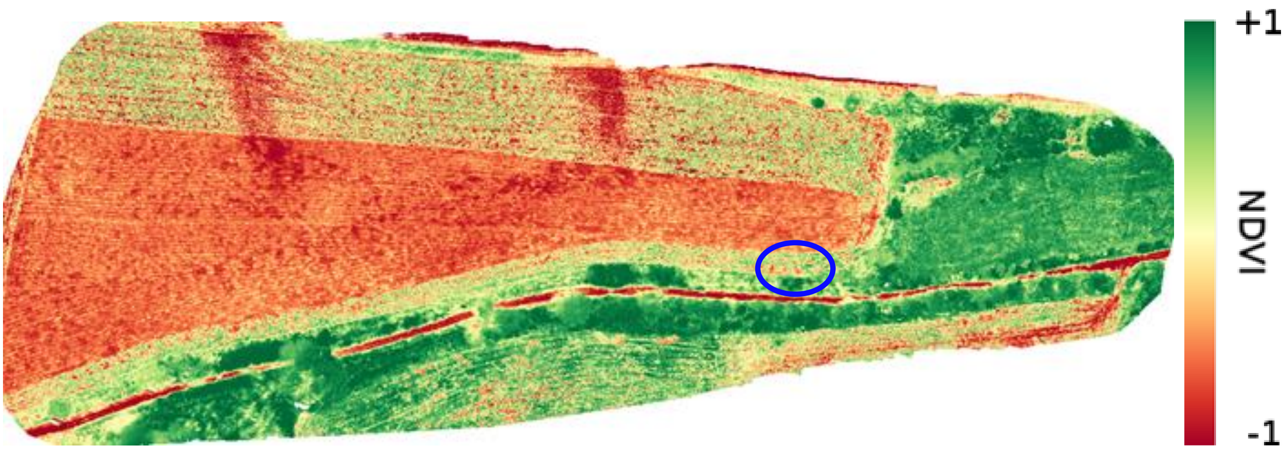


Figure 8.7 - Orthomosaic corresponding to the NDVI (840 – 668 nm) vegetation index (July 2018).

The NDVI shows two well differentiated areas. An area of bare soil in the field of interest (red color) and an area of green vegetation in the neighboring field. This two differentiated areas will lead to two well differentiated areas in the scatterplot.

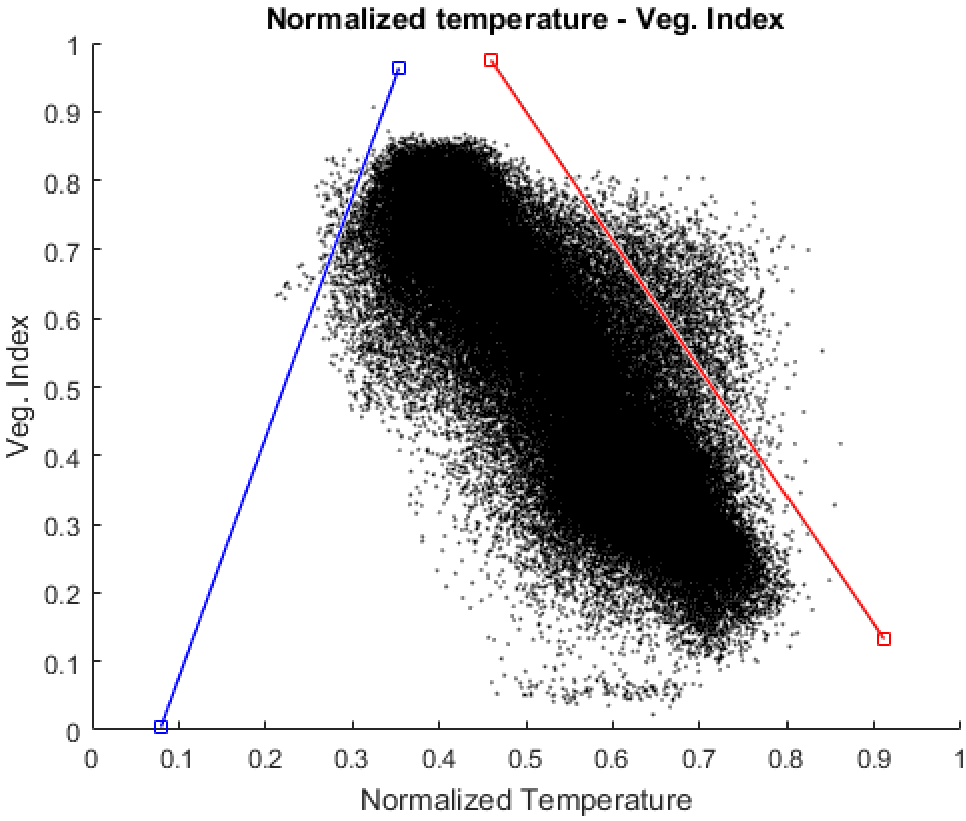


Figure 8.8 - Scatter diagram between the normalized temperature and the NDVI (840 – 668 nm) vegetation index (July 2018).

The massive presence of bare soil and green vegetation has shifted the axis of the scatterplot from right to left. When this occurs the triangle/trapezoid shape disappears, making difficult the setup of the cold and warm edges.

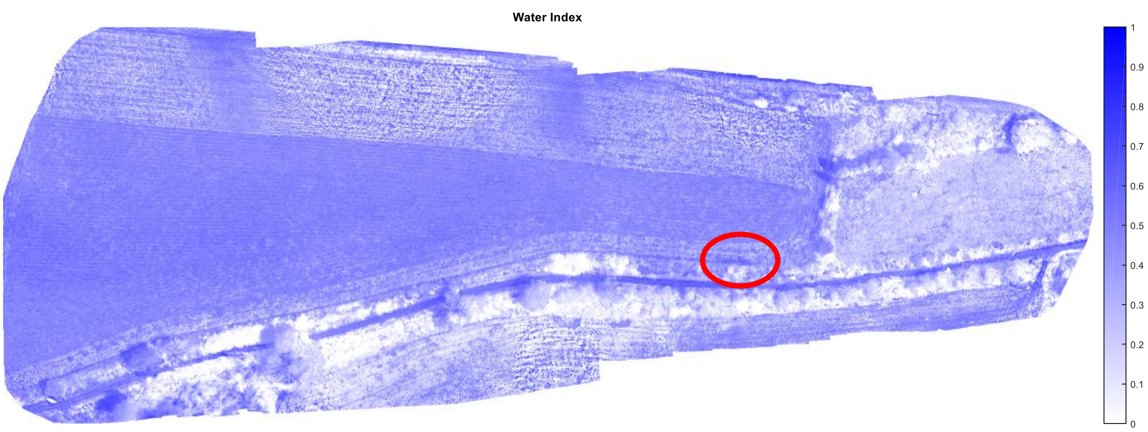


Figure 8.6 Water index from the waterleaks test field obtained with RPAS (July 2018).

The water index shows a dark blue area corresponding to the water leak. The presence of saturated pixels depends on the setup of the cold and the warm edges. This saturation is achieved when the placement of the edges lead to water index values greater than one.

9 Conclusions

The sectors have been ranked in accordance with the performance indicators Leak/Length (in m^3/km/year) and Infrastructure Leakage Index (ILI).

Therefore, priority in the selection of the sectors to be covered during the first ground leak detection campaign will have to be given as per the raking reported in the following Table.

Sector	N° connections	Type of pipe	Length (km)	Average distance between connections (m)	Leak flow (l/s)	Leak/Length (m^3/km/y)	ILI = CARL/UARL	
Verdagne - 3*	53	**Mains**	**16.9**	322	1.4	2615	4.8	High
		Service connections	*0.14*					
Cabardèle - 4	160	**Mains**	**3.17**	36	1.07	10624	4.5	High
		Service connections	*2.63*					
Vauvernagues - 1	146	**Mains**	**4.75**	91	1.73	11530	3.8	Moderate
		Service connections	*0.53*					
Vauvernagues - 2		**Mains**	**6.75**					
		Service connections	*1.28*					
Cabardèle - 1	147	**Mains**	**10.51**	84	1.82	5466	3.7	Moderate
		Service connections	*1.83*					
Vauvernagues - 3	92	**Mains**	**5.8**	74	0.43	2335	2.4	Moderate
		Service connections	*1.04*					
Cabardèle - 2	90	**Mains**	**9.72**	121	0.82	2650	2.1	Moderate
		Service connections	*1.14*					
Cabardèle - 5	88	**Mains**	**14.5**	171	0.82	1785	1.8	Low
		Service connections	*0.59*					
Verdagne - 4	74	**Mains**	**31.22**	424	0.69	698	1.2	Low
		Service connections	*0.13*					
Vauvernagues - 4	58	**Mains**	**9.22**	174	0.21	715	1	Very low
		Service connections	*0.88*					
Verdagne - 2*	82	**Mains**	**7.65**	94	0.01	41	0	Very low
		Service connections	*0.02*					
Verdagne - 1	76	**Mains**	**12.84**	170	≈0	0	0	Very low
		Service connections	*0.06*					
Cabardèle - 6	55	**Mains**	**14.21**	259	0	0	0	Very low

Sector	N° connections	Type of pipe	Length (km)	Average distance between connections (m)	Leak flow (l/s)	Leak/Length (m^3/km/y)	ILI = CARL/UARL	
		Service connections	**0.04**					
Cabardèle - 3	169	**Mains**	**10.83**	76	0	0	0	Very low
		Service connections	*1.99*					

Table 9.1 Ranking of sectors according to ILI.

We can get some lessons learned:

Only two multispectral bands are needed. An alternative to the use of a multispectral wheel camera like Spectrocam, can be the use of two cameras with fixed filters connected to the on-board computer to perform the acquisition. This setup will lead to a drastic decrease of price while increasing the performance and the reliability of the image acquisition process.

A better/proper setup of the exposure time and the gain of the multispectral camera is needed for the next campaign.

Both cameras on-board the RPAS, the multispectral and the thermal infrared, perform well at the legally limited altitude of 50 m above the ground level. Both cameras georeferenced the images at acquisition time. That makes the pre-processing step easier. The selected photogrammetric software Pix4D makes the co-registration of the five bands from the multispectral camera flawless. Nevertheless, the co-registration between orthomosaics from two different cameras does not reach the expected results. The Gefolki software has been successfully used to solve the co-registration issue.

10 References

International Water Association. *Leak Location and Repair Guidance Notes. Version 1*. March 2007. London, UK.

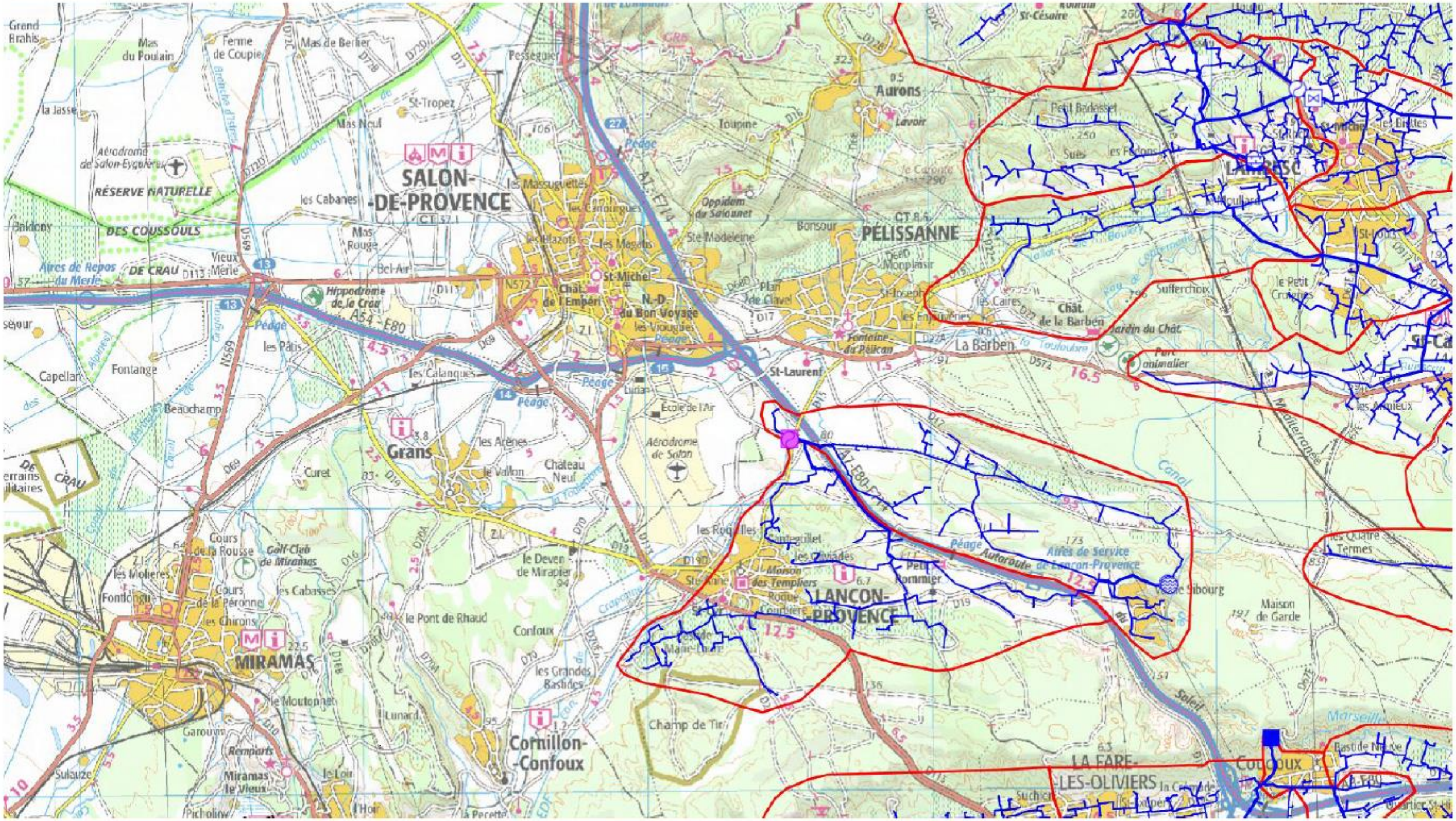
European Commission. *EU Reference document Good Practices on Leakage Management WFD CIS WG PoM. Main Report.* March 2015. European Union.

Rondeaux G., Steven M., Baret F., "Optimization of soil adjusted vegetation indices", Remote Sensing of Environment, vol. 55, 95-107, 1996

11 Annex

11.1 Sites network maps

Cabardele - networks 3560 and 3561



0m 924m 1848m 2772m

Le positionnement des réseaux SCP indiqué sur ce plan est indicatif, avec une précision de classe B. Lors d'une DT ou d'une DICT, il doit être précisé par un pré-repérage réalisé par la SCP, à la demande et à titre gracieux. Avant tous travaux à proximité, des sondages, à la charge du demandeur sont effectués en présence d'un agent SCP. Toute modification unilatérale de ce document est strictement interdite et ne sera en aucun cas opposable à la SCP.

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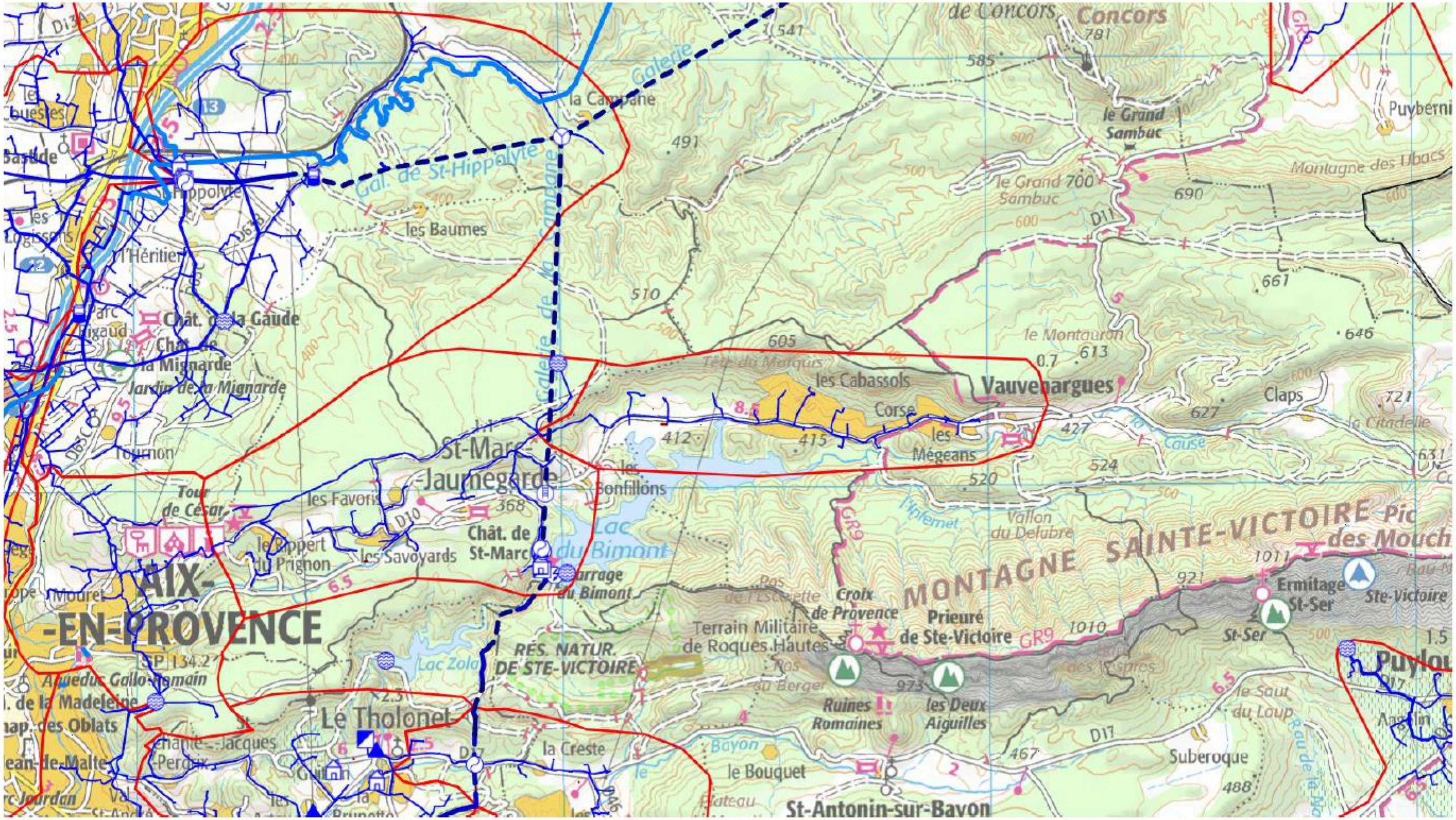
N

Vauvenargues - networks 2411 2411



0m 616m 1232m 1848m

Le positionnement des réseaux SCP indiqué sur ce plan est indicatif, avec une précision de classe B. Lors d'une DT ou d'une DICT, il doit être précisé par un pré-repérage réalisé par la SCP, à la demande et à titre gracieux. Avant tous travaux à proximité, des sondages, à la charge du demandeur sont effectués en présence d'un agent SCP. Toute modification unilatérale de ce document est strictement interdite et ne sera en aucun cas opposable à la SCP.

N

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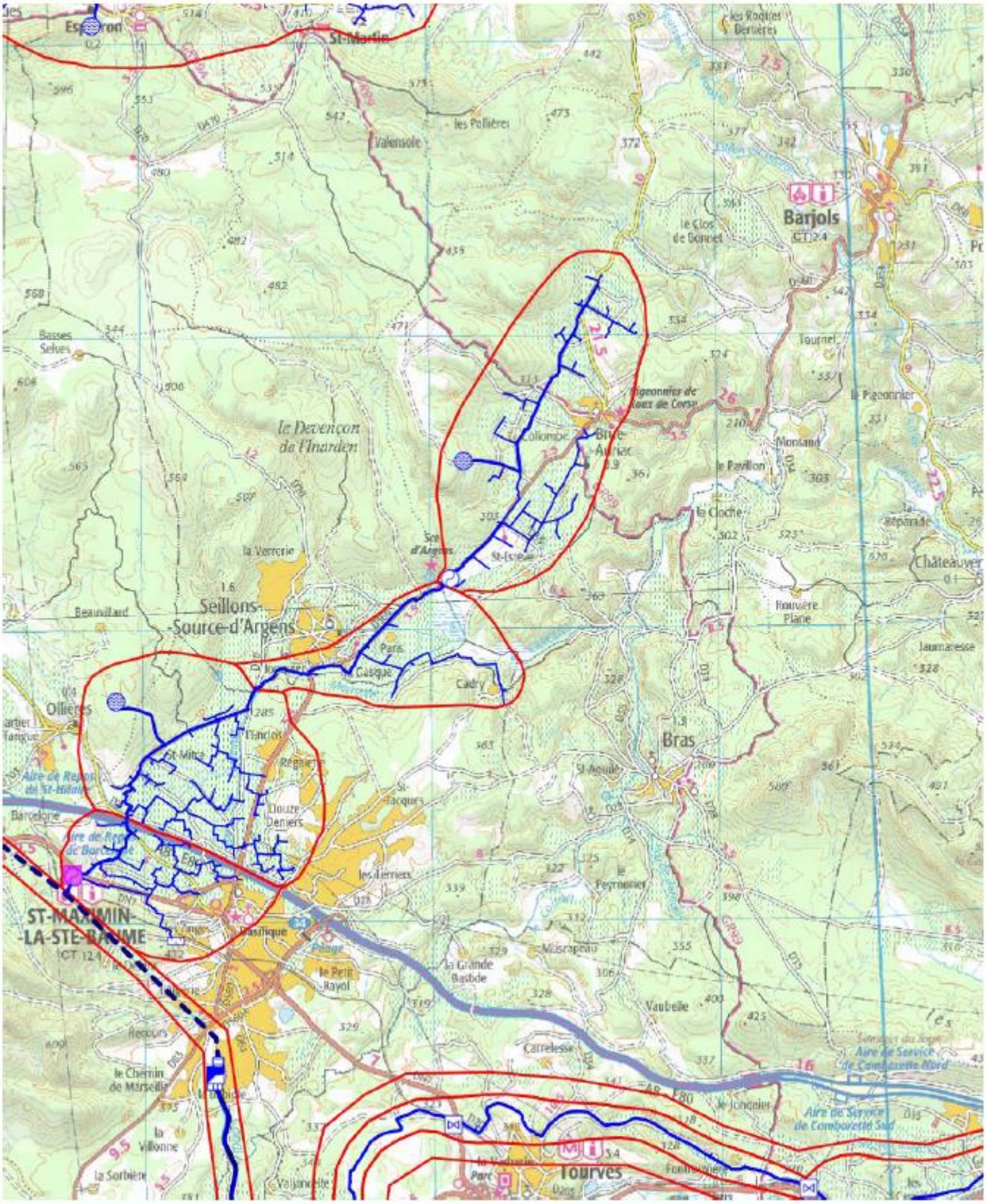
verdagne - networks 2201 2202 2203 2210



0m 885m 1771m 2656m

Le positionnement des réseaux SCP indiqué sur ce plan est indicatif, avec une précision de classe B. Lors d'une DT ou d'une DICT, il doit être précisé par un pré-repérage réalisé par la SCP, à la demande et à titre gracieux. Avant tous travaux à proximité, des sondages, à la charge du demandeur sont effectués en présence d'un agent SCP. Toute modification unilatérale de ce document est strictement interdite et ne sera en aucun cas opposable à la SCP.

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11.2 RPAS Flights request form

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RÉPUBLIQUE FRANÇAISE
Ministère chargé de l'aviation civile

Demande d'autorisations spécifiques
pour la mise en œuvre d'aéronefs télépilotés

N° R5-TAAG-6-F1-V1

Arrêté du 17/12/2015 *relatif à la conception des aéronefs civils qui circulent sans personne à bord, aux conditions de leur emploi et aux capacités requises des personnes qui les utilisent* (**Article 7**)

1. L'exploitant

Exploitant déclaré depuis le 01 janvier 2016
Nom/Raison sociale : N° d'exploitant déclaré :

Contact général :
☐ Madame ☒ Monsieur Nom : Barba Polo Prénom : Juan Fonction : Télépilote
Téléphone portable : +34625064703 Courriel : juan@galileogeosystems.com

Contact présent lors des vols prévus : ☒ idem ci-dessus
☐ Madame ☐ Monsieur Nom : Prénom : Fonction :
Téléphone portable : Courriel : @

Pour un exploitant étranger, compléter les éléments ci-dessous :

L'exploitant est un particulier : ☐ Madame ☐ Monsieur
Nom : Prénom :
Date et lieu de naissance
Date : Commune : Code postal : Pays :

L'exploitant est une personne morale :
Dénomination sociale : B97925945 Nom commercial : Galileo Geosystem S.L.
Représentant de la personne morale : ☐ Madame ☒ Monsieur Nom : Barba Polo Prénom : Juan

Adresse
Numéro : Voie : C/ Alfara del Patriarca, nº3, pta.11
Code postal : 46025 BP : Cedex : Localité : Valencia
Pays : Espagne Téléphone : +34625064703 Courriel : info@galileogeosystems.com

2. Autorisations spécifiques demandées *

A	☒	Mise en œuvre par un **exploitant étranger** d'un aéronef **EN VUE** en **zone NON PEUPLEE** dans les conditions du **scénario S1**
B	☐	Mise en œuvre par un **exploitant étranger** d'un aéronef **EN VUE** en **zone PEUPLEE** dans les conditions du **scénario S3**
C	☐	Mise en œuvre par un **exploitant étranger** d'un aéronef **HORS VUE** en **zone NON PEUPLEE**
D	☐	Mise en œuvre d'un aéronef **EN VUE** depuis un **véhicule terrestre en déplacement,** en **zone NON PEUPLEE** dans les conditions du **scénario S1**
D bis	☐	Mise en œuvre d'un aéronef **EN VUE** depuis un **véhicule terrestre en déplacement** en **zone PEUPLEE**
E	☐	Mise en œuvre d'un aéronef **EN VUE** de masse **supérieure à 8 kg** en **zone PEUPLEE**
F	☐	Mise en œuvre d'un aéronef **EN VUE** à une distance maximale horizontale du télépilote **supérieure à 200 m en zone NON PEUPLEE**
G	☐	Mise en œuvre d'un aéronef **HORS VUE**, de masse **supérieure à 2kg** et à une **hauteur supérieure à 50 m**
I	☐	Mise en œuvre d'un aéronef **HORS VUE**, de masse **supérieure à 2kg** et à une **hauteur supérieure à 50 m** de la surface et à une distance maximale horizontale du télépilote supérieure à 1000 m
J	☐	Mise en œuvre d'un aéronef avec discontinuité du critère « EN VUE » en **zone PEUPLEE**
K	☐	**Autre** *(Décrire en détail dans un dossier spécifique sous format libre avec les pièces justificatives nécessaires, le mode de réalisation d'une activité pour laquelle l'une au moins des conditions des 3 annexes de l'arrêté précité ne serait pas respectée.)*

***** : Les cases grisées correspondent à un traitement du dossier par la DSAC Locale du lieu de l'opération

2. (Suite) – Prérequis obligatoires	
A et B	L'exploitant est autorisé par son autorité d'origine à effectuer des opérations similaires en zone peuplée ou non peuplée au moyen d'aéronefs télépilotés. Le télépilote doit présenter une aptitude théorique aéronautique de type : - décris au § 4.1.1 de l'annexe III de l'arrêté précité, ou - titres spécifiques aéronef télépiloté **validés par l'autorité d'origine**. **En cas de vol en conditions S3 le drone doit être équipé conformément au §2.5 et §2.7 de l'arrêté Aéronef.** **Lors de la demande, les documents doivent être transmis en langue française ou traduits en langue anglaise.**
C	L'exploitant est autorisé par son autorité d'origine à effectuer des opérations similaires au moyen d'aéronefs télépilotés. L'aéronef est équipé selon les exigences du §2.6 de l'annexe II de l'arrêté précité.
D D bis	L'aéronef doit figurer dans le MAP et être déclaré en scénario S1 ou S3. Les conditions d'exploitation depuis un véhicule terrestre doivent être décrites dans le MAP.
E	L'aéronef doit figurer dans le MAP et être déclaré en scénario S1. L'aéronef est équipé selon les exigences du §2.7 de l'annexe II de l'arrêté précité.
F	L'aéronef doit figurer dans le MAP et être déclaré en scénario S1.
G	L'aéronef doit figurer sur le MAP être déclaré en scénario S2.
I	L'aéronef doit figurer sur le MAP qui doit présenter des procédures de mise en œuvre relatives au scénario S4. Un dossier technique S4 doit avoir été transmis au pôle DSAC/NO/NAV : dsac-nav-drones-bf@aviation-civile.gouv.fr Une ZRT doit être créée.
J	La description et la procédure relative à la phase de vol en discontinuité du critère « en vue » doit être décrite dans le MAP.

- Le cas échéant, plusieurs cases ci-dessus peuvent être cochées
- Voir la définition de « vol en vue » et « vol hors vue » à l'article 2.2 de l'Arrêté précité.
- Voir les conditions des scénarios S1 et S3 au § 1.3 et § 1.4 de l'annexe III de l'Arrêté du 17/12/2015 relatif à la conception des aéronefs civils qui circulent sans personne à bord, aux conditions de leur emploi et aux capacités requises des personnes qui les utilisent.
- Si les prérequis ci-dessus ne sont pas présentés lors de la demande, cette dernière ne sera pas traitée.

3. Date(s) des vols		
Début	Date : 15/06/2018 *(JJ/MM/AAAA)*	Heure : 9h 00 min *(heure locale, au format 24h)*
Fin	Date : 15/07/2018 *(JJ/MM/AAAA)*	Heure : 17h 00 min *(heure locale, au format 24h)*

4. Les aéronefs				
1	Constructeur : Galileo Geosystems		Modèle : GG-65B01	N° de série : AP-2015001
	Classe : Multicopter	Aéronef captif : ☐ oui ☒ non		Masse maximale prévue pour les vols : 4.9 kg
2	Constructeur :		Modèle :	N° de série :
	Classe :	Aéronef captif : ☐ oui ☐ non		Masse maximale prévue pour les vols : kg
3	Constructeur :		Modèle :	N° de série :
	Classe :	Aéronef captif : ☐ oui ☐ non		Masse maximale prévue pour les vols : kg
4	Constructeur :		Modèle :	N° de série :
	Classe :	Aéronef captif : ☐ oui ☐ non		Masse maximale prévue pour les vols : kg

5. Description des vols

Site n° 1

☐ Hors zone peuplée

☐ En agglomération ☐ A proximité d'un rassemblement de personnes (décrire) :

Code postal	Localité	Adresse
13100	Aix-en-Provence	Chemin de la Tour de César

Description de la zone de vol : (cocher la case si descriptif joint en annexe : ☒)

Aéronefs susceptibles d'être utilisés : ☐ Tous Sinon, préciser : ☒ 1 ☐ 2 ☐ 3 ☐ 4

Description des vols :

Hauteur maximale de vol : 50 m Vitesse d'évolution maximale de vol : 30 km/h

Pour cas D ou Dbis, Vitesse du véhicule terrestre : km/h

Nom du (des) télépilotes : Juan Barba Polo Javier Sanchis Muñoz

Objet des vols:

Photogrammétrie

☒ Suite de la liste des sites en annexe. Nombre de pages supplémentaires jointes :

6. Pièces à joindre

Dossier **daté et référencé avec en-tête de la société**, composé des éléments suivants :

- Pour les cas **A**, **B** et **C** :
  . Document de l'autorité du pays de l'exploitant attestant que celui-ci est apte à opérer un aéronef télépiloté
  . Manuel d'opération
  . Aptitudes théoriques aéronautique du télépilote
  . Assurances souscrites
  . Lieu/plan de masse (carte aéronautique ou autres)
  . Zone d'évolution précise du drone et position des tiers le cas échéant (plan/schémas…)
  . Description de l'aéronef utilisé (document, photos…)
  . Pour le cas **C**, un dossier technique (S2) disponible ici :
  https://www.ecologique-solidaire.gouv.fr/drones-usages-professionnels#e4
  et est à transmettre à l'adresse : dsac-nav-drones-bf@aviation-civile.gouv.fr

- Pour les cas **D-D bis**, **E**, **F**, **G**, **H**, **I** et **J**:
  . Copie de l'accusé de réception de la déclaration d'activité
  . Assurances souscrites
  . Lieu/plan de masse (carte aéronautique ou autres)
  . Zone d'évolution précise du drone et position des tiers le cas échéant (plan/schémas…)
  . Description de l'aéronef utilisé (document, photos…)
  . Pour le cas **D et D bis**: description et photos du véhiculé terrestre utilisé et du système de retenu prévu pour le télépilote
  . Pour le cas **E** : un dossier technique (S3) disponible ici :
  https://www.ecologique-solidaire.gouv.fr/drones-usages-professionnels#e4
  et est à transmettre à l'adresse : dsac-nav-drones-bf@aviation-civile.gouv.fr
  . Pour le cas **I** : Documents relatif à la création d'une ZRT et dossier technique S4 à transmettre à l'adresse :
  dsac-nav-drones-bf@aviation-civile.gouv.fr
  . Pour le cas **J** : Copie des pages du MAP décrivant la description et la procédure relative à la phase de vol en discontinuité du critère « en vue »

7. Engagement de l'exploitant

« Je soussigné, représentant l'exploitant identifié au § 1 ci-dessus

☒ Certifie l'exactitude des renseignements figurant dans la présente déclaration

☒ M'engage à :

- respecter l'ensemble des dispositions réglementaires applicables pour les opérations prévues et notamment pour les aéronefs utilisés et les télés pilotes les paragraphes suivants de l'annexe III de l'arrêté précité :
  - ☐ §2.3 « Conditions spécifiques aux aérostats »
  - ☐ §2.4.1 « Conditions spécifiques aux aéronefs captifs »
  - ☒ §2.5.1 a), b), c), d) « Conditions spécifiques aux aéronefs non captifs »
  - ☐ §2.6 « Conditions spécifiques aux aéronefs utilisés dans le cadre du scénario S2 »
  - ☐ §2.7 « Conditions spécifiques aux aérodynes non captifs de masse supérieure à 2kg utilisés en scénario S3»
  - ☐ §2.8 « Conditions spécifiques aux aéronefs utilisés dans le cadre du scénario S4»
  - ☒ §4.2.1 « Formations pratiques déterminées par l'exploitant pour réaliser les activités particulières concernées »
- ne pas mettre en œuvre l'aéronef dans des conditions où il y aurait un risque pour les autres aéronefs ou pour les personnes et les biens au sol, y compris en cas de panne probable.

☒ déclare qu'une assurance couvrant les risques liés aux opérations prévues a été contractée. »

A : Valencia Le : 14/05/2018 *(JJ/MM/AAAA)*	Nom : Juan Prénom : Barba Polo Qualité *(personnes morales)* : General Manager and Pilot

Demande à présenter au moins **30 jours** avant la date des opérations à

- **DSAC locale** territorialement compétente pour la demande **A, B, D et Dbis**
- **DSAC Echelon central** à travail-aerien-bf@aviation-civile.gouv.fr pour les demandes **C, E, F, G, H, I, J et K**

Pour les vols en vue, en zone peuplée, une déclaration préalable auprès du préfet territorialement compétent doit être effectuée au moyen du formulaire CERFA 15476*02.

Pour les vols hors vue sans ZRT, une notification préalable doit être effectuée au moyen du formulaire CERFA 15477*02.

Tout dossier incomplet et/ou transmis hors délai, sera refusé.
Pour obtenir plus d'informations sur les aéronefs circulant sans personne à bord, consulter le site de la direction générale de l'Aviation civile : https://www.ecologique-solidaire.gouv.fr/drones-usages-professionnels#e2

11.3 RPAS Flights authorization

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RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE LA TRANSITION ECOLOGIQUE ET SOLIDAIRE

Direction générale de l'Aviation civile

Direction de la sécurité de l'Aviation civile
Direction de la sécurité de l'Aviation civile Sud-Est
Département surveillance et régulation

Division aviation générale et personnel navigant

Subdivision aviation générale

Aix-en-Provence, le 29/05/2018

à l'attention de

M.BARBA POLO Juan
GALILEO GEOSYSTEMS
C/Alfara del Patriarca
N°3 puerta 11
46 025 VALENCIA

Nos réf. : DSAC - SE / DSR /AGPN-18-107
N° GED entrant : - N° GED sortant :
Vos réf. : Courriel du 16/05/2018
Affaire suivie par : Lionel Buchet
lionel.buchet@aviation-civile.gouv.fr
Tél. : +33 4 42 33 77 35 - **Fax** : +33 4 42 33 79 58

Objet : Autorisation spécifique pour un exploitant d'aéronef télépiloté étranger en vue directe

Monsieur

Par courriel du 16/05/2018, vous avez demandé à la DSAC Sud Est une autorisation pour la réalisation de prises de vues avec un aéronef télépiloté en vue directe, au-dessus d'Aix-en-Provence dans le cadre de travaux de photogrammétrie.

Après examen du dossier et en application de l'article 7 de l'Arrêté du 17/12/2015 relatif *à la conception des aéronefs civils qui circulent sans personne à bord, aux conditions de leur emploi et aux capacités requises des personnes qui les utilisent*, la DSAC Sud Est vous délivre l'autorisation spécifique suivante :

- Lieu de l'opération : *Voir demande – Plan en annexe*
- Activité : *Prises de vues aériennes*
- Type d'aéronef : Galiléo Géosystems Multicopter *Masse Max : 4,9 kg*
- Télépilotes : *Juan BARBA POLO*
  Javier SANCHIS MUNOZ
- Le(s) aéronef(s) précité(s) est(sont) exploité(s) conformément aux exigences opérationnelles et de navigabilité décrites dans l'annexe III de l'arrêté susvisé, et selon les conditions ci-dessous :
  - Vols de jour, en vue directe et en zone non peuplée, à une distance horizontale maximale du télépilote de **200** m

PJ : Plans des lieux de prises de vues
Copie à : RDD / RNA

1, rue Vincent Auriol
13617 Aix-en-Provence cedex 1
Tél : +33 (0)4 42 33 75 11

dgac DSAC

- Hauteur de vol maxi : *50m ;*
- Vitesse d'évolution max : *30 km/h ; soit 8,5 m/s*
- A tout instant du vol, une distance horizontale minimale de **30** m entre l'aéronef et les personnes non liées à l'activité doit être respectée ;
- Application des procédures du Manuel d'activités référencé dans le courriel du 16/05/2018 et des conditions imposées par l'Autorité Espagnole AESA, Document n°2018030859 du 30/04/2018

- Date de validité de l'avis : Du 15/06/2018 au 15/07/2018

L'exploitant doit prendre, le cas échéant, en collaboration avec les services locaux de l'aviation civile (DSAC IR Sud Est) et de la navigation aérienne, toutes les dispositions nécessaires pour la mise en œuvre de mesures particulières permettant d'assurer la compatibilité de la circulation de l'aéronef circulant sans personne à bord avec tous les autres aéronefs. L'exploitant doit respecter les exigences de l'arrêté du 17 décembre 2015 *relatif à l'utilisation de l'espace aérien par les aéronefs qui circulent sans personne à bord*, notamment les articles 3, 4, 6 et 7.

L'exploitant doit obtenir des informations météorologiques détaillées et pertinentes nécessaires à la réalisation des vols en toute sécurité (vitesse moyenne du vent, rafales, précipitations...). En fonction de ces éléments et des limitations préexistantes, l'exploitant devra définir et appliquer des marges de sécurité additionnelles. La prise en compte de ces marges pourra conduire l'exploitant, le cas échéant, à adapter ou à annuler les opérations prévues.

Cette autorisation est valide tant que la définition technique ou la configuration de l'aéronef n'ont pas été l'objet d'une consigne opérationnelle émise par le ministre chargé de l'aviation civile. Les consignes opérationnelles sont disponibles sur le site Internet de la DGAC.

Cette autorisation est sans préjudice des exigences de l'article D133-10 du code de l'Aviation Civile.

Raphaël Goriot
chef de la division
aviation générale et personnel navigant