Canal de Isabel II

BOOKLETS

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11

Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in the Comunidad de Madrid

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Introduction

Canal de Isabel II's Research, Development & Innovation Booklets form part of the company's Knowledge Management Strategy and of the development involved in the Research, Development and Innovation Plan.

These Booklets represent an element for diffusion of projects and initiatives that are developed and sponsored by Canal de Isabel II for innovation in those areas related with water service in the urban environment.

A series of different problems that have been undertaken in each project are put forward in the Booklets, along with the results that have been obtained. The intention behind their diffusion by means of these publications is to share the experiences and knowledge that has been acquired with the entire water services sector, with the scientific community and with all those working on investigation and innovation tasks. What is aimed with the publication of these Booklets is to contribute to improvement and efficiency in water management and, consequently, in the quality of service that is provided to the citizens.

The R&D&I booklets published to date are as shown below by their titles in the following table.

Collection Number	Research, Development and Innovation Booklets published
1	Transferences of Water Rights between Urban and Agrarian Demands. The case of the Community of Madrid
2	Identification of Hydrometeorological Runs and Tendencies within the scope of the Canal de Isabel II system
3	Contribution of Canal de Isabel II to the International Demand Management Project (IDMF)
4	Micro-components and Explanatory Factors on Domestic Water Consumption in the Comunidad de Madrid
5	Virtual Water and Hydrological footprint in the Comunidad de Madrid
6	Study on the saving potential of water for residential uses in the Comunidad de Madrid
7	Potentials of efficiency in using dishwashers
8	Accuracy in the measurement of individual water consumption in the Madrid Region
9	Research project to define and assess the applicability of a Bioassay Test to determine the toxicity of water using Zebra Fish embryos
10	Water Use Efficiency in Gardening in the Region of Comunidad de Madrid

Project Outline

Project title	Remote sensing techniques and geographical information systems for assessing water demand for outdoor uses in the Comunidad de Madrid
Research line	Guaranteeing a balance between availability and demand
Canal de Isabel II units involved	Research, Development and Innovation Deputy Direction
External participation	TERRA XXI
Aim and justification of the project	Establishing the water demand from public institutions and private users for outdoor uses, and developing a methodology that enables us to periodically following up and updating the situation using the different sources of information available.
State of the art contribution	Applying the very latest mapping, remote sensing and geographical information system techniques to manage a geographical database on outdoor water uses.
Project development summary and milestones	A complete georeferenced inventory has been prepared on the parks, public and private green areas, golf courses, swimming pools, ponds and fountains throughout the Comunidad de Madrid. A methodology has been established for updating the information through digital mapping, orthophotography and multispectral satellite imagery. A pilot study has been carried out using high-resolution satellite imagery, in the municipality of Rivas Vaciamadrid. Analysis of the 2004-2006 drought period with medium-resolution satellite imagery throughout the Comunidad Autónoma de Madrid.
Obtained results summary	The total water demand for urban outdoor uses in the Comunidad Autónoma de Madrid has been estimated at 188 million cubic meters per year, of which 70 million cubic meters, correspond to public institutional uses. In 2007, a total surface area of 10,959 hectares of lawn was inventoried (including golf courses), plus 10,428 hectares of woodland. Furthermore, 86,134 swimming pools have been identified with a total estimated volume of 6.9 million cubic meters.
Research lines open for continuing the work	The remote sensing techniques tested in this project have confirmed their ability to periodically follow up the urban development consolidation in the Comunidad Autónoma de Madrid, which is vital for estimating the way water demand will develop in the future. Use of new hyperspectral sensors (laser technology and others) for the observation and detailed modelling of the way the territory is being used and how the situation is evolving in urban zones.

Executive Summary

The work that is described in this document falls within the framework of the research being conducted to guarantee a balance between availability and demand for the Canal de Isabel II of those identified in the R&D&I Plan of the company. Its main aim is assessing outdoor-water use consumption in the Comunidad Autónoma de Madrid, and how to establish a methodology for periodically updating the information concerned.

The expression outdoor-water use refers mainly to watering in both public and private parks and gardens; also to the filling and maintenance of swimming pools, ponds and cleaning the public streets. Sports centres and especially golf courses are also considered, even though drinking water is not used for the latter in the Comunidad Autónoma de Madrid.

Interest in quantifying the water given over to outdoor uses lies not only in its relative importance, established at around 30 per cent of the total water supplied in the region, but also in finding out the potential for improving efficiency where applying the resources is concerned. Furthermore, most of the uses could be addressed with inferior quality resources (recycled water, not drinkable water), so the information about the quantities and their geographical allocation and distribution in time, is essential for effective implementation of a plan for using reclaimed water.

The methodology described here is based upon different territory observation techniques used to pinpoint the urban zones that potentially consume water, whether this is for watering green areas, or for filling ponds, swimming pools and fountains.

Photointerpretation techniques and the analysis of images taken during photogrammetric flights, or imagery from Earth observation satellites have proved to be effective when it comes to detecting and measuring these zones. Furthermore, the availability of multispectral images and the possibility of analysing the different bands, enables researchers to obtain information that cannot be detected by observation with the naked eye.

This document contains the results from different projects and the experience that Canal de Isabel II has gained in this area:

- Year 2003: creation of a geographical database containing the inventory of the public and private green areas, swimming pools and woodland/forests in the region. This was prepared using Geographical Information System (GIS) techniques on digital mapping to a scale of 1:5,000, supplemented by photointerpretation of the aerial orthophotos taken during the flights in 1999.
- Year 2005: this inventory was updated using the Geomadrid mapping (to a scale of 1:1,000) and the 2003 photogrammetric flight.
- Year 2007: the information about the green areas and the water surfaces was updated by using photointerpretation of the 2006 flight imagery. A map was created that showed the changes with respect to the 2003 mapping.
- Years 2007–2008: project analysing the feasibility of using satellite imagery to update the information more frequently, by means of remote sensing techniques. It consisted of the following two activities:
  - ✓ Pilot study conducted in the Municipality of Rivas Vaciamadrid using high-resolution satellite imagery (Quickbird).
  - ✓ Analysis of the whole Comunidad de Madrid, with average resolution imagery (SPOT5) to establish the effects of the 2005–2006 drought period on the green areas, urban and non-urban, by comparing the images obtained in the summers of those years.

These activities have been used to establish a methodology for assessing the water demand for outdoor uses, on the basis of the different sources of information available. Such sources of information can be topographic mapping, aerial photography or satellite imagery, each one of which has different degrees of precision or spatial resolution and different updating frequencies.

Testing and comparing the different methods has enabled the researchers to establish a precision or reliability coefficient for that assessment, based on the source of the information and its quality.

This document provides a detailed description of the methodologies used and the main results and findings obtained. The results have been included as part of the Canal de Isabel II Geographical Information System (GAUDY).

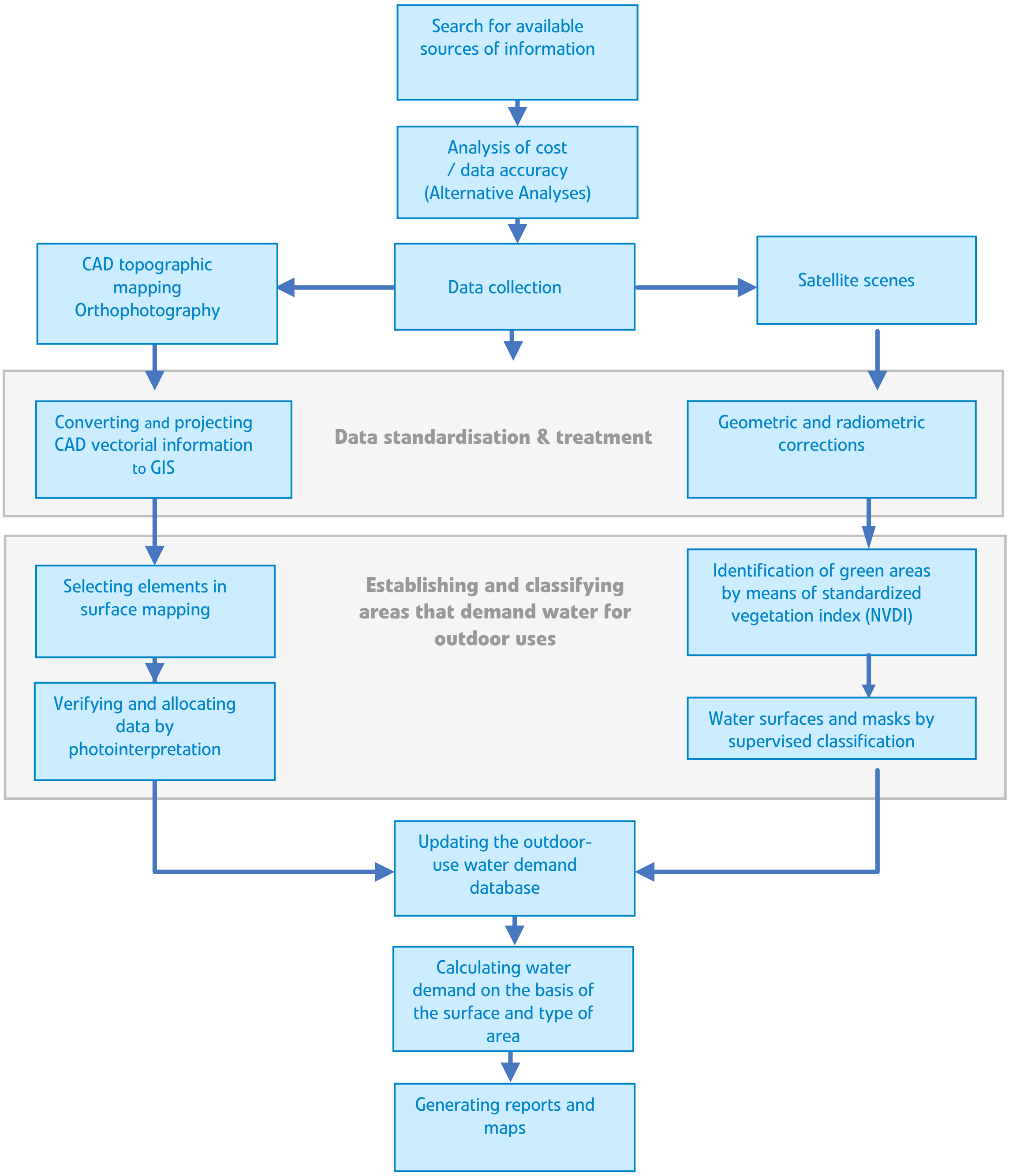
Figure a. **Photointerpretation techniques and analysis of photogrammetric flight imagery**

Figure b. **Image obtained by Earth observation satellites**

General methodology for assessing the demand using different sources of information

A water demand assessment methodology has been developed and tested for the outdoor use of the resource, based upon the most updated and accessible data at any given time (Figure c).

Figure c. **General procedure for calculating the water demand for outdoor uses**



The process begins by selecting the information on the basis of its availability, accuracy, the extent to which it is updated and the cost. The gross information will be transformed through a series of automatic, manual or semi-automatic stages, whose ultimate aim is to delimit and classify areas, enclosures, or zones that are liable to demand water for outdoor uses. The potential demand is calculated based on the surface area covered and its typology: green areas of lawn, woodland, bush, swimming pools, ponds, etc. This information is included in the GIS, where it is associated with other types of geographical information: cadastral plot, borough, district, neighbourhood, water supply connection, etc.

Photointerpretation techniques

First of all, the digital mapping is extracted, using techniques inherent to the GIS, from the areas that are already classified as likely to be demanding water for outdoor uses: green areas, woodland, swimming pools, fountains, ponds, etc.

Then, a team of specialists in photointerpretation visually examine the areas extracted automatically and compare them with the orthophotography. This process involves allocating attributes not included in the mapping, such as the percentage of lawn in watered green areas, or a more detailed classification. Any mapping errors that might have been made are also corrected, before the new areas are digitalised.

Satellite image processing

Imagery from two different satellites and taken on different date was also used in the aforementioned work:

- High-resolution images from the satellite Quickbird, with a precision of 0.6 meters per pixel in its panchromatic band and 2.4 meters per pixel in multispectral, covering 70 square kilometres, taken above the municipality of Rivas Vaciamadrid, on 29th April 2002, 14th May 2004 and 5th August 2006.
- Medium-resolution images from the satellite SPOT5, with a precision of 10 metres per pixel for bands G, R, NIR (green, red and near infrared), and 20 metres per pixel for MIR (medium infrared), covering almost the entire surface area of the Comunidad de Madrid, and obtained on different days in 2005 and 2006, mainly in the summer.

Before these images can be incorporated into the GIS they have to undergo a series of processes that guarantee that those obtained on different dates can be compared, and that they are consistent with the rest of the geographical data:

- Orthorectification: projecting the photographed image, according to a system of coordinates used by the GIS. The most recent digital Orthophotography was used for horizontal reference purposes, and a Digital Terrain Model (DTM) was used to correct the effects of the relief.
- Relative standardisation: before the imagery taken on different dates can be compared, it is necessary to make atmospheric and radiometric corrections, in order to minimise the effects that have nothing to do with the change itself, such as different atmospheric conditions, sunlight, etc.
- Image fusion: this involves combining the spectral information from the multispectral image in a way that is consistent with the spatial information from the panchromatic image, with a view to ensuring that the overall quality (spatial-spectral) of the fused image is very high.

Generating areas using Vegetation Index

The specific radiometric behaviour of the vegetation and its characteristic spectral signature, with a clear contrast in the response in the red band and the near infrared band, enables the user to automatically calculate indexes that are evidence for the vegetation vigour observed.

The Normalised Difference Vegetation Index (**NDVI**) was used for this work, being calculated by using reflected red and infrared radiation values. Based upon this index, calculated for each pixel, it was possible to define areas grouped into three categories on the satellite imagery:

NDVI $<$ 0.25: there is no vegetation
NDVI between 0.25 and 0.50: green vegetation
NVDI $>$ 0.50: vigorous vegetation

In view of the fact that the index calculated in this way makes no distinction between the vegetation that has been deliberately watered and spontaneous vegetation, for example plants that have colonised wasteland, these results had to be filtered using a mask that defines the mapping blocks that, by means of a supervised classification procedure have been categorised as consolidated urban areas, i.e. where there are buildings or garden/landscaping constructions.

Generating areas by supervised classification

The supervised classification technique with satellite imagery was used in those areas where there is a demand for water but where the locations do not respond to infrared, such as water surfaces (ponds, swimming pools and fountains).

Image classification involves more or less automatically allocating each one of the pixels to a series of discrete groups or categories. This grouping into classes is based on quantitative analyses of the values contained in each pixel, taking the values inherent to the statistics as the theoretical base.

This process requires a preliminary training phase, followed by the classification process itself, after which there is a checking and verification phase.

Geographical Databases

All the results and their geographical representation have been incorporated into the GAUDY, the Canal de Isabel II Geographical Information System, which enables the company's different areas to access the studies and the results obtained in this work.

The degree of detail achieved is that of cadastral plot. Attributes concerning other geographical divisions have also been established, such as the municipality or the sector of the IECM Nomenclator and water supply connection.

It is possible to obtain reports and thematic maps to present information:

- On a municipal, district, sectorial level, or another Nomenclator's entity.
- Classified into public or private, depending on the nature of the property.
- By classifying the types of areas, the green areas being grouped into the following zones: lawn, woodland, green areas of bush and pond water surfaces, fountains and swimming pools.
- Parks and golf courses.

Figure d. Digital mapping element processed and incorporated into GAUDY

Estimating the water demand

The water requirements of the plants have been calculated by studying the water balance, based on the climate and the different plant types considered: lawn, woodland and isolated zones of bush.

The reference evapotranspiration (ETo) was calculated using the methods devised by FAO-Hargreaves and Thornwaite, the average from the two methods being adopted.

Table a contains a summary of the values calculated for an average year and for years when the climate was extremely dry and extremely wet.

Table a. Water requirements for dry, average and wet years

Area type	Gross requirements (m^3 / ha / año)		
	Dry year	Average year	Wet year
Lawn-type green zones	9,515	7,725	3,455
Green urban bush-type zones	2,860	2,035	760
Woodland-type green zones	400	400	400

It must be pointed out that these values refer strictly to the plants' water requirements, without taking into account overwatering, which can often reach values ranging from 50 to 100 per cent more than the minimum watering requirements.

Where swimming pools are concerned, an average depth of 1.60 meters has been taken, and it is assumed that they are filled once a year. It has also been estimated a consumption, due to losses and evaporation, of one cubic metre of water for every square metre of surface. In the case of I shower units associated to swimming-pools, 1.20 cubic metres per square metre has been taken, which amounts to 12 litres of water being used per day (one shower lasting one minute) for 100 days a year.

Main results yielded from assessing water demand for outdoor uses

Of all the techniques tested, the photointerpretation of orthophotos from photogrammetric flights, with the aid of digital mapping, was logically the technique that yielded the greatest precision. However, the updating period is considerably longer than in the case of satellite imagery.

Photointerpretation was used to obtain results in the activities carried out between 2005 and 2007, using the flights from 2003 and 2006, respectively. The results are summarised in Table b.

Table b. **Assessment of the water demand for outdoor uses, estimated from the photointerpretation of orthophotos taken during photogrammetric flights**

Water Uses	2005				2007			
	Public Ownership		Private Ownership		Public Ownership		Private Ownership	
	Surface Area	Estimated Annual Demand	Surface Area	Estimated Annual Demand	Surface Area	Estimated Annual Demand	Surface Area	Estimated Annual Demand
	(ha)	(hm^3)	(ha)	(hm^3)	(ha)	(hm^3)	(ha)	(hm^3)
Lawn	2,370	19.62	7,320	60.61	2,986	24.73	7,973	66.02
Woodland	4,516	1.81	5,978	2.39	4,988	2	5,440	2.18
Green urban bushes	160	0.34	0	0	310	0.66	0	0
Swimming pools	16	0.62	376	14.28	16	0.61	413	15.71
Ponds	62	0.43	34	0.24	109.71	0.77	60	0.42
Fountains	3	0.03	0	0	5	0.05	0	0
Roads	10,88	13.61	0	0	n/d	n/d	n/d	n/d

The total amount of swimming pools identified was 86,079 in 2005 and 86,134 in 2007, with estimated volumes of 6.27 and 6.87 million cubic meters, respectively (considering an average depth of 1.60 meters).

The total demand for outdoor uses calculated with the most recent data (2007) throughout the entire Comunidad de Madrid is 126.76 million cubic meters per year. Considering an overwatering coefficient ranging from 1.5 to 2.0 for the green areas, the total water consumption for these uses in the region of Comunidad de Madrid could reach 188 million cubic meters per year. There has been an 11 per cent increase in potential demand in three years.

The satellite imagery for the drought years (2005–2006) did not indicate that the vegetation was less lush in the urban zones, there being an increase in 21,300 hectares, compared to a decrease affecting 6,085 hectares. However, in the non-urban areas there was less vegetation in the valley floors of the River Jarama and the River Tagus in the South-West of the Comunidad de Madrid and in the northern zone of the Municipality of Alcalá de Henares.

Conclusions drawn from the work

The main conclusions that the Canal de Isabel II has drawn from this work are:

a) A methodology has been established for assessing the water demand for outdoor uses by applying different sources of information, with different precision levels, at different costs and with different update frequencies.

b) It is possible to make relatively accurate calculations of the areas and water demands without carrying out fieldwork.

c) The remote-sensing methodology analysed is considered valid for studying the outdoor-use of water, the updating frequency being once a year or less.

d) The gross results obtained by remote sensing have to be subjected to a filtering process in order to make a distinction between wild vegetation that grows spontaneously, and vegetation in built-up areas that is deliberately watered.

e) It has been possible to establish a range of dates (July–August) when the data taken by satellite is more useful for detecting urban green areas that require watering. When it comes to evaluating different options for obtaining satellite imagery, not only the cost, quality and precision must be taken into account, but also the feasibility of obtaining panoramas that cover the whole of the Comunidad de Madrid at that time of year.

Research lines open

The experience gained while this work was being undertaken has enabled those involved to establish other lines of research so that these types of techniques can be applied to other areas that are of interest to the knowledge of Canal de Isabel II:

a) Monitoring the way that urban development is taking place, so that a more exact prediction can be obtained of how water demand will develop in future scenarios and how strategic supply structures should be expanded.

b) The use of hyperspectral sensors, laser and others that have recently become available, which provide new opportunities for detailed modelling and observation of land use and the development of urban zones.

Figure e. **Observation and detailed modelling techniques, based upon the use of hyperspectral sensors and laser**

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