Applying Earth observation to support the detection of non-authorised water abstractions

Proposed Guidance document

Report for the European Commission, DG Environment

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Glossary

- Crop coefficient (Kc): the ratio of evapotranspiration observed for a given crop over that observed for the calibrated reference crop under the same conditions
- Crop phenology: study of the plants' biological cycle throughout the year and its seasonal and inter-annual response to climate variations, using different parameters that describe the seasonal behaviour of the vegetation.
- Crop water requirements (CWR): "amount of water required for compensating the evapotranspiration loss from the cropped field" (Allen et al. 1998).
- Earth observation (EO): collection of data and information about the Earth system using remote sensing systems (mostly satellite-based, but also sensors on-board aircraft or drones can be used).
- Evapotranspiration (ET): transport of water from land surfaces into the atmosphere by soil evaporation and plant transpiration.
- Flow meter: an instrument for monitoring, measuring, or recording the rate of flow, pressure, or discharge of water.
- Ground truth: *in-situ* observations for the purpose of calibration and validation of EO-derived parameters.
- *In-situ*: refers to observations obtained through airborne sensors and ground based installations.
- Irrigation water requirements (IWR): crop water requirements minus effective (i.e. usable for plant) precipitation.
- Local data: all types of data (field measurements, databases, knowledge, and expertise of local/regional crops and their phenology) acquired at local scale, i.e. for a geographically-limited area.
- Non-authorised abstractions: there are two types of non-authorised abstraction for irrigation purposes. Both types can be either permanent or occurring during periods of special restrictions (e.g. drought):
    - abstraction for irrigation in areas that do not have the necessary water rights (non-authorised abstractions of the first type); and/or
    - irrigation water consumption beyond the legally allowed or assigned water volume (non-authorised abstractions of the second type).
- Normalized Differential Vegetation Index (NDVI): index that gives a measure of the vegetative cover on the land surface. Dense vegetation shows up very strongly in the imagery, and areas with little or no vegetation are also clearly identified.
- Reflectance: the ratio of the intensity of reflected radiation to that of the radiation incident on a surface.

- Satellite image: digital image (e.g. of a land surface) obtained from a satellite-borne sensor. EO sensors provide multispectral images covering several bands in the solar (and in some cases also thermal) spectrum.
- Spatial resolution (of a satellite image): size of pixel corresponding to the surface area measured on the ground (depends on the sensor used and the satellite's orbit).
- Surface water balance (SWB): equation describing the flow of water through the Earth's surface.
- Surface energy balance (SEB): flow of energy into and out of the Earth at the land surface.
- Water rights: authorisation to abstract water, characterised by a combination of criteria related to:
    - water resources used: quantity and quality of the water, the source and location;
    - characteristics of use: use, location and duration; and
    - administration of the right: ownership and transfer, security and enforcement.

Executive summary

Over-abstraction of water was highlighted in the Blueprint to Safeguard Europe's Water Resources as a significant pressure impeding the achievement of Water Framework Directive's (WFD) good status objectives. In the field, it is a significant challenge for water managers to ensure a sustainable use of water resources. Non-authorised abstractions, which remain out of record, may play a substantial role in over-abstraction[1]. Most Member States are aware of this issue but consider they lack the appropriate tools and resources to identify and tackle the issue efficiently. In many Member States, the regularisation of water rights and adaptation to available resources is still at an early stage.

The Blueprint also indicates Earth Observation (EO) - in particular the EU's Global Monitoring for Environment and Security (GMES, recently renamed Copernicus) - as a promising instrument able to support the detection of non-authorised abstractions. EO data has already been used in many areas in the EU to support detection and monitoring of water abstraction for irrigation purposes. This practical experience, in addition to significantly developed technical literature, demonstrate that such tools can be successfully developed and used by water managers, in particular when facing non-authorised abstraction issues.

This document provides guidance to water managers through 5 steps based on practical examples and lessons learnt from specific cases.

First Step - Identifying water managers' objectives and needs

There are two types of non-authorised abstraction for irrigation purposes:

1. abstraction for irrigation of areas without official water rights; and
2. abstraction of water beyond the authorised amounts.

Both these types can be either permanent or occurring during periods of special restrictions (e.g. drought).

The needs for a better management of non-authorised abstraction are following:

- monitoring of irrigated areas and the abstracted volumes on a regular basis;
- optimising field inspections to ensure compliance with legal water allocation;
- ensuring the reliability of self-declaration of water abstractions; and
- ensuring compliance with seasonal water restrictions in case of drought management.

Operational challenges encountered in the field because of lack of adequate tools and/or human resources make it necessary to consider using EO as an alternative or complementary tool to support meeting one or another of these needs. Additionally to field inspections, EO can be used as a proper control system. The proper identification of monitoring needs is important as they can be fulfilled more or less thoroughly by the use of EO.

[1] Which can also be due to over-allocation of water to users in a river basin, e.g. due to an overestimation of the available amounts, or to economic or political pressure.

Second Step - Exploring the opportunities of using Earth observation to detect and monitor water abstraction

Earth observation (EO) provides following information about water abstraction for irrigation:

- identification of irrigation activities through maps of irrigated areas; and
- estimation of abstracted volumes through time sequences of spatially-distributed information on irrigation water consumption.

The use of EO-derived data to detect water abstraction is a mature system and several service providers, with demonstrated operational capacity, are available to implement it. Practical experiences highlight the following assets:

- large geographical coverage at adequate spatial and temporal resolution providing harmonised/consistent information;
- overall good demonstrated accuracy, except in specific conditions; and
- availability of objective data.

Because EO can only provide estimates of water abstractions and not real figures, it is not intended to replace individual metering of abstraction points. It rather provides a complete territorial view of abstractions and therefore is a powerful tool that can guide inspections to areas where it is more likely infringements to occur.

In the present stage of development, EO is particularly relevant to monitor irrigation abstractions in agricultural areas with regular water shortages and high reliance on irrigation, and in areas with large parcels cultivated with annual crops. Irrigated areas and crop water requirements can be identified with great accuracy (e.g. > 90% for herbaceous crops in optimal conditions). It may be less suitable in (sub-) humid areas (where irrigation remains often supplemental), where vegetation is mostly perennial and/or where mixed patterns of crops in small parcels (<1 ha) are predominant, as it requires further supporting local data and sophisticated infrastructure (with additional costs and human resources requirements). EO is less suitable in areas with high presence of clouds, which can affect the frequency and timing at which images are produced.

Table 1 : Suitability of using EO for different objectives and in different conditions

Suitability	Low	Medium	High
Manager's objective	Detection of hydraulic works (only possible with very-high-resolution images or orthophotos)	Monitoring of restrictions for drought management	Detection of irrigated area Monitoring abstracted volumes
Crops	Perennial crops	Crops that do not reach full cover	Crops that reach full cover
Climate	(sub)-humid areas		Semi-arid/arid areas
Size of area / number of abstraction points	Small areas (<1 ha), few abstraction points	Medium areas	Large areas, many abstraction points

The overall suitability of EO for monitoring water abstraction can be estimated by combining different criteria.

The use of EO to detect and monitor water abstraction requires:

- satellite images: dense time series of EO images acquired during the entire growing season from a multi-sensor constellation of High Resolution optical satellites (currently available: IRS, Landsat8, Spot, Formosat, RapidEye) at a spatial resolution range of 5-30 m pixel size
    - one image every 4-6 weeks is sufficient for mapping irrigated areas; and
    - one image every 1-2 weeks is required for mapping abstracted volumes.
- *in-situ* data, available at EU and/or MS level:
    - meteorological data (for differentiating irrigation volumes from rain and for calculation of crop water requirements);
    - soil maps of water retention capacity (*Optional* - to increase accuracy in “difficult” crops);
    - supporting local information for main crops phenology and development (for local calibration and validation);
    - data on actual abstractions in selected locations: the use of Earth Observation is not a stand-alone option. It requires field measurements for calibration and continuous verification with data acquired locally.

Third Step - Assessing the suitability of EO in the given legal and institutional framework

While the second step consists of verifying that EO can be technically implemented in a river basin, the third step assesses the suitability of EO in the given legal and institutional framework.

Whether EO or field approaches (e.g. metering) are used, the existence and accessibility of information on water rights as well as political commitment to ensure compliance of water abstraction rules are prerequisites for the detection of non-authorised abstractions.

In addition, for EO to be suitable for the detection of non-authorised abstractions, water rights must be defined in terms of irrigable area (for non-authorised abstractions of type 1) or volume of water (for non-authorised abstractions of type 2) and these rights must be linked to specific areas.

Finally, EO-assisted estimates of water abstractions can be compared to the legal information to indicate areas where non-authorised abstractions are suspected. Targeted inspections on the field will allow establishing actual infringements.

Fourth Step - Exploring complementary applications

In addition to the detection of non-authorised abstractions, a range of complementary applications can be implemented based on these products to support water managers in their work towards more sustainable management of water resources. This includes for instance the regularisation (granting or extinction, respectively) of water rights by providing evidence of irrigation (including historical water rights prior to modification of law) or of prolonged absence of irrigation despite water rights. Complementary applications also range from the development/revision of sustainable management plans to the ex-post analysis of water consumption trends, through provisions of advice for irrigation scheduling or implementation of volume-based fees.

Fifth Step - Implementing EO in a new area: Roadmap for water managers

1. Establish peer-to-peer contacts with water managers operating at the same level (MS government, regional government, or Water User Association) in order to get a first-hand experience of the system or service in operational conditions;
2. Make a detailed description of current tasks and routine operations, and an inventory of the data needed for this purpose and the source where data is currently available;
3. Make an inventory of available data (as required for EO approach), of missing data, and of potential synergies with activities in other areas of the same institution;
4. Possibly repeat step 1 with the newly compiled information from steps 2 and 3;
5. Check options of in-house EO – and/or GIS-capabilities – capacities and compare with potential external service providers; estimate draft budget requirements;
6. Set up a pilot and evaluate with all relevant stakeholders (including financing options);
7. Set up an implementation plan and secure financing.

Introduction

1. Context

Over-abstraction, which consists in abstracting more water than what is sustainably available, is currently considered as the second most common pressure on the ecological status of water bodies in the EU. It may lower water tables and cause insufficient base flow in river basins, along with the decreasing water quality and the disruption of associated ecosystem services. In addition to these detrimental environmental impacts, water restrictions or natural shortages may trigger conflicts between competing uses and substantial socio-economic consequences. Irrigation is the main cause of over-abstraction in many Member States (MS).

In 2007, approximately 17% of the EU territory was under water scarcity, while the situation continues to deteriorate until today. Water scarcity is expected to affect half of EU river basins in 2030. Water deficits are generally more pronounced in Southern Europe, especially during summer. However, some Northern European countries including UK and Germany have also been confronted with the phenomenon in the last few years. As for Central and Eastern MS, they are showing increasing interest in more sustainable management of water resources, as they anticipate higher demand in irrigated agriculture in the near future.

The Water Framework Directive (WFD), introduced in 2000, aims to ensure the long-term sustainable use of clean water across Europe by reaching the objectives of good ecological and chemical status for all water bodies by 2015. One of its key aims, as set out in Article 1, is the promotion of sustainable water use. The need for a sufficient quantity of water is shown in the definition of objectives attached to water bodies: good ecological status in surface water bodies and good quantitative status in groundwater that should ensure sufficient recharge of groundwater systems and allow a sustainable support to connected water bodies. All Member States have to implement basic measures (Article 11.3) inter alia to promote an efficient and sustainable water use (b) and to control water abstractions from groundwater and surface waters through the maintenance of registers and a requirement of prior authorisation for abstraction (e).

Despite water use efficiency achievements in various sectors and actions towards more integrated water governance in the last decade, as a result of the implementation of the Water Framework Directive, the recorded volumes of abstracted water for irrigation have only slightly decreased. In 2011, a quantitative target was set within the Roadmap for a Resource Efficient Europe[2], which recommends that "water abstraction should stay below 20% of available renewable water resources". In the 2012 Blueprint to Safeguard Europe's Water Resources[3], the European Commission reinforced its commitment for a better water management, in line with the 3rd Implementation Report on the

[2] http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf

[3] http://ec.europa.eu/environment/water/blueprint/index_en.htm

WFD[4] and the 2012 policy review of the Strategy on Water Scarcity and Droughts[5]. The Blueprint highlights in particular the role of non-authorised abstraction in over-abstraction and the responsibility of Member States in ensuring law enforcement. Since non-authorised abstractions are not measured nor controlled, their impact in terms of water quantity cannot be quantified today in the EU, which makes it impossible to state with certainty how significant the problem is in a certain country or region.

In the field of irrigation, within the scope of this document, non-authorised abstractions are considered as of two types:

1. abstractions for irrigation of areas without official water rights;

2. abstractions of water beyond the authorised amounts.

Both types can be either permanent or occurring during periods of special restrictions (e.g. in case of drought).

Earth Observation (EO), in particular the European Union's Copernicus Programme (ex-GMES) was highlighted in the Blueprint to Safeguard Europe's Water Resources as a promising approach to address quantitative issues related to water through the detection of possible cases of non-authorised abstraction as a complement to the often limited field data available. Several EO projects were recently developed in the EU, co-funded through the Seventh Framework Programme, related to research on space-based applications serving European society (2007-2013) and the European Programme for the establishment of a European capacity for Earth Observation, now known as Copernicus. In 2014, this programme will enter a new stage with the deployment of new operational Copernicus services[6] by 2020. Copernicus is composed of three components: (i) a space component with the development of the fleet of EU Sentinels satellites and the access to space data from other satellites, (ii) a service component including atmosphere, land, marine, emergency management, security and climate change services and (iii) an in situ component. The land monitoring service addresses a broad range of environmental policies (water, biodiversity, nature, soils, forest, waste, etc.); a stepwise approach was defined starting with multi-purpose products at Global and European scale such as Pan-European land cover products (Corine LC and new High Resolution Land Cover layer). A 'local' component providing very detailed information on specific areas of interest will be progressively implemented and possibly extended to new areas of interest, taking into account the users requirements and the outcomes of precursor activities and studies like this one.

2. Objectives

This document aims to:

- inform on the EO potential for supporting the detection and monitoring of water abstraction for irrigation, including the detection of non-authorised abstractions;
- review the currently available EO tools and services and share the lessons learnt from their practical implementation in different countries;
- provide guidance on whether and how these tools and services can be used to complement conventional approaches in different local contexts.

[4] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0670

[5] http://ec.europa.eu/environment/water/quantity/pdf/non-paper.pdf

[6] Global monitoring for environment and security services

It is destined for:

- Member States' authorities in charge of the inspection of non-authorised water abstractions;
- water managers (public authorities or association of irrigators) in charge of monitoring abstractions;
- authorities in charge of developing water management plans and issuing authorisations (e.g. river basin authorities, regional and local authorities);
- authorities in charge of collecting water fees (e.g. water agencies).

In parallel to this document a discussion is being conducted to assess the opportunity for developing specific Copernicus services at the EU level dedicated to the detection and monitoring of water abstractions.

3. Approach

The present document is one of the outcomes of a study conducted by BIO by Deloitte and Universidad de Castilla-La Mancha (UCLM) since October 2013 on behalf of the European Commission about "Applying EO tools and services to detect non-authorised water abstractions". Following the terms of the contract, it focuses mostly on non-authorised abstractions for irrigation purposes, although it also explores complementary applications in the field of water management based on Earth observation. It is based on UCLM's long-standing expertise on the use of EO in irrigation management, as developed in the SIRIUS (www.sirius-gmes.es) project, lessons learnt from a literature review, case studies (Annex 1) refined through a series of four workshops[7] and the consultation of national representatives of water authorities and international EO experts. Some key examples, collected across Member States, aim to illustrate the different concepts. The focus is on countries with high risks of water shortages, high irrigation activities and/or demonstrated interest for the development of irrigation infrastructure in the near future.

The annexes also include detailed information on the status of non-authorised abstractions in the EU, on EO-based methods to monitor abstractions, on existing EO tools and services and on water rights in the EU.

Figure 1 summarises the key steps towards implementation of EO that are described in the present document.

[7] held in Spain jointly with Portugal, in Italy, in France, and in Greece

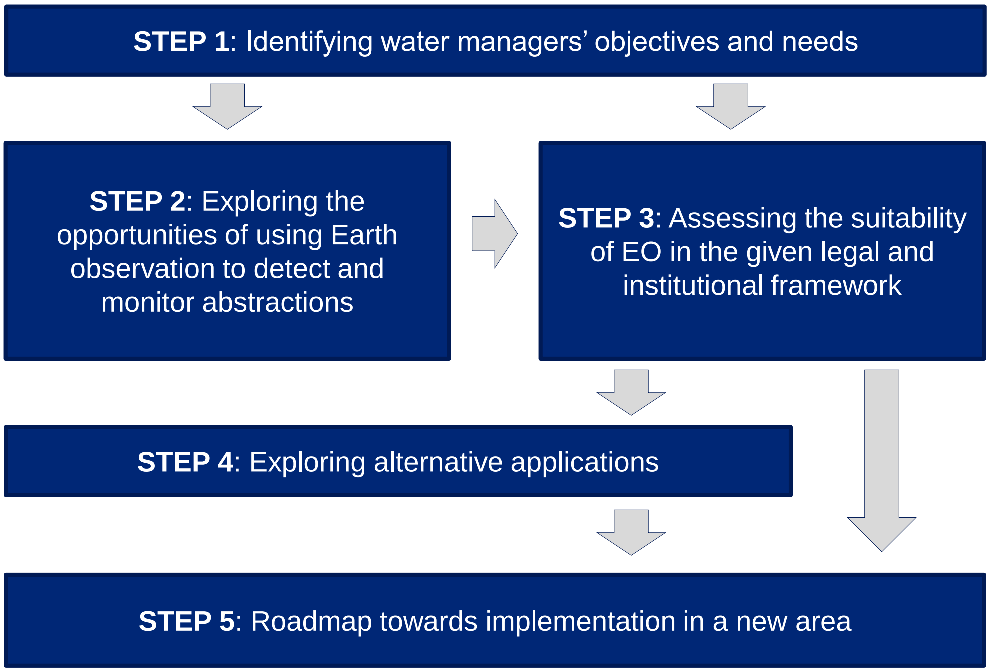


Figure 1: Key steps towards implementation of EO to support the detection and monitoring of abstractions

Step 1 - Identifying water managers' objectives and needs

Objectives:

This preparatory step consists in identifying your objectives and needs regarding the detection and monitoring of non-authorised abstractions, in order to assess how relevant implementing EO would be for you. For this purpose, it aims at helping you reflect on:

- how much do you currently know about non-authorised abstractions in your Member State or river basin;
- what are the tools and processes in place to tackle this issue;
- what are the challenges you may encounter in enforcing water rights and ensure a more sustainable water management in the river basin;
- what are the associated needs.

1.1. Current approaches for the monitoring of non-authorised water abstractions

Today most EU MS dealing with the issue of non-authorised abstractions still lack comprehensive tools and resources for detecting and managing these unsustainable practices. Therefore, there is practically very little reliable information available on the number and extent of non-authorised abstractions, in particular those from private wells (Annex 2). The qualification of water abstraction as non-authorised implies detecting this abstraction and having access to a database of individual users' water rights in order to verify:

- the existence of a water right to abstract water; and
- the compliance of water abstractions with this water right, i.e. that volumes of water abstracted do not exceed authorised amounts.

Abstracted volumes are usually monitored:

- directly, through *in-situ* metering (i.e. flow meters in the case of groundwater wells (electricity used for pumping can sometimes be used as proxy), a variety of counters in the case of surface water release from dams, reservoirs, channel networks or individual pumping devices); or
- indirectly, through the record of operation hours and channel delivery flow, in areas with irrigation channels; or
- the calculation of crop water requirements, based on the declaration of crops that are cultivated and average tabulated water requirements (FAO-56, Allen et al. 1998).

Figure 2 summarises the key steps that are necessary for monitoring individual water abstractions as well as the available tools/data that are generally used to detect non-authorised abstractions.

Approaches	Information and data to control	Possible control instruments
1 Defining the type of non-authorised abstraction to be identified		
Type 1 - No water rights		
Type 2 - Exceedance of authorised amount		
2 Identifying the areas of interest: detection of location and areal extent		
Identification of irrigated areas (1) (2)	Parcel boundaries	Parcel boundaries maps, field inspection
	Land use	Field inspections, land use map or record: e.g. CORINE Land Cover, orthophotos, CAP declaration, EO data
Identification of existing wells or surface water derivation (1)	Registered wells and surface water derivation points	Record of registered wells, field inspections, orthophotos, map of authorised surface water derivation points
3 Estimating volumes of abstracted water (optional – only relevant for Type 2)		
Measuring water abstraction (2)	Volume of abstracted water	In situ metering record (flowmeters), field inspection
OR Estimating water used for irrigation by calculating crop consumption (2)	Crop maps or crop inventories	Field inspections, land use map or record: EO data, orthophotos, CAP declaration, etc.
	Evapotranspiration	Crop coefficient database (FAO56), Earth Observation derived information (NDVI)
	Soil data (texture, structure, depth)	Soil data record, field inspection and sample, EO data
	Climate data (temperature, humidity, rainfall)	Climate data record (agrometeorological station)
4 Verifying compliance of water use with water rights		
Verifying the existence of a water right for the specific location of the identified irrigated area, well or surface water deviation point that has been identified (1)	Registry of water rights (1)	Registry of water rights that indicates the specific spatial location of the intended irrigated land / Policy documents stating seasonal restrictions
Verifying that volumes of water abstracted at the specific abstraction point comply with the authorised amount (2)	Database of authorised volumes (2)	Registry that indicates the specific spatial location of the abstraction point and the authorised amount of water to be abstracted / Policy documents stating seasonal restrictions

Figure 2: Overview of steps for the detection of non-authorised abstractions

Note: (1) and (2) refer to the type of non-authorised abstractions, see definition in introduction chapter.

1.2. Current challenges

Key challenges (see examples in Box 1) relate to:

- the legal and institutional framework, including:
    - the existence, implementation status, nature and reporting of water rights (common to both *in-situ* and EO-based approaches) (see STEP 3 p.33);
    - the knowledge about water users: all points of abstractions are not necessarily identified (especially private wells for individual users);
    - the reliance on self-declaration from the users, controlled occasionally during inspections, as automated devices are very expensive;

- the technical capacity to monitor abstractions, as metering is not systematically implemented especially with certain types of irrigation (e.g. case of open irrigation channels);
- the costs of implementing systematic metering and data collection;
- the resource availability for carrying out extensive inspections: field visits would be ideally required regularly for every abstraction site (ideally two or three visits within an irrigation period), but this is not possible to achieve given the number of users and the difficulty to access private properties and to detect tampering or maintenance problems. Inspections are therefore usually based on the random identification of candidates or focused on high-volume users.

Box 1: Examples of challenges encountered by Member States for the monitoring of water abstraction

Transition from historic private to public water rights in Spain

In Spain the status of water is under transition. Since the new Water Act came into force in 1985, water has been considered public. However, in the previous legal regulation (Water Act of 1879), groundwater was considered private water. Due to these legislative changes, the adaptation of the administrative status of these wells is necessary. The ALBERCA project was created by the government in order to update the administrative status of water uses, especially facilitating the processing of files of groundwater use and the transformation of the private water uses into public water uses, and checking the entries in The Catalogue of Historical Private Abstractions. Due to the great number of water uses (over a million water uses and more than two million of water inlets. 50% of files are groundwater use) this is a substantial undertaking. As of February 2014, about 700.000 titles of water uses could be reviewed and updated. Many more sources of water use remain to be identified.

Update of water rights and extinction procedure in Spain

Article 66.2. of the Spanish Water Law establishes that a cause of extinction of a water right is the permanent interruption by the holder of water abstractions for three consecutive years. The update of water rights is important from a water management perspective as it involves the release of committed water resources and may lead to the reorganisation of water uses within a watershed. Extinction of water rights allows the legal demolition of obsolete or abandoned hydraulic works and the legal elimination of cross barrier dams, stone walls, etc. This would accomplish the first objective of Water Framework Directive WFD and the Blueprint on improving the ecological status of water bodies, promoting river and river banks restoration actions. The extinction of water rights can, however, be difficult to identify with current management tools.

Case of predominant gravity irrigation systems in France

In South France, large agricultural areas are irrigated through gravity irrigation systems (vs. pressurised systems). The installation of flow meters in gravity irrigation is difficult in practice. Therefore, knowledge of abstractions is based essentially on declarative systems (based on registries of water rights, of self-reporting to Water Agencies for the payment of water consumption fees, and/or the General Agricultural Census) and the results of field surveys and inspection campaigns. Recently, an extensive field campaign was conducted ("*Etudes volumes prélevables*"[8]) in order to better characterise volumes that could be abstracted without threatening the quantitative and ecological balance of the aquatic environment.

[8] E.g. www.gesteau.eaufrance.fr/sites/default/files/Presentation_Etude_Volumes_Prelevables.pdf

Potential use of GSM[9] meters in Cyprus[10] and experimentation of Aquacard in Italy to optimise monitoring and inspections

In several Member States, water users have the obligation to install water-metering systems and fill a declaration of water use (Arcadis, 2011). In practice, many water users do not comply with this obligation. Field technicians are in charge of verifying that declarations of water abstraction have been correctly filled in and also of visiting measurement points to collect measurements.

Various types of water meters can be used to measure water abstraction: e.g. mechanical, ultrasonic and electromagnetic. The choice for a water meter depends mainly on the type of end user and the significance of water abstractions, as well as costs of installation and maintenance (the user capacity to pay) and accuracy requirements.

The water metering approach requires the installation of water meters at all points of use at the expense of water users. Associated installation and maintenance costs, generally supported by water users, are a key barrier for the systematic development of metering. Most of these meters also require physical access for collecting measurement data and therefore regular inspections from technicians on the field, which is a key challenge considering the number of abstraction sources.

In Cyprus, in order to systematise inspections and optimise field inspections, wireless water meter systems that can send their readings directly to the collector using the GSM network are being investigated. Field inspectors receive directly the amount of water that has been consumed on their computer and do not need to visit each abstraction site. These devices are however quite expensive (approximately 1500€ per meter) and it remains difficult to equip all abstraction sites.

In Italy, in areas served by a pressurised pipeline network, delivery outlets can be equipped with an electronic activation and metering system, called AQUACARD, which controls the valve opening at the outlet and registers duration, date and volumes. The Aquacard system can be programmed to limit abstraction to a fixed amount (related to the payment of fees). However, the implementation of AQUACARD system is expensive and requires additional human resources. Currently there is connection via mobile phone modem but additional investments for this system would be required. The card was experimentally introduced in some consortia (e.g. Destra Sele), but now it is used extensively in many consortia especially in Southern Italy (e.g. Capitanata, Sannio Alifano), Sicily and Sardinia regions.

1.3. Identified needs for the detection of non-authorised abstractions

During the workshops and interviews, stakeholders expressed their overall need for better knowledge of water abstractions for irrigation, and in particular water users, irrigation infrastructure (channels, tanks), irrigated areas and abstracted volumes. Operational needs related to the detection of non-authorised abstraction include:

- ensuring the reliability of self-declaration of water abstractions;
- optimising field inspections to ensure compliance with legal water allocation;
- ensuring compliance with seasonal water restrictions in case of drought management.

[9] Global System for Mobile Communications

[10] Representative from the Ministry of Agriculture, Water development Department, Cyprus, personal communication

Step 2 - Exploring the opportunities of using EO to detect and monitor abstractions

Objectives:

This step consists in getting familiar with Earth observation products in order to better understand how they can contribute to the detection and monitoring of abstractions and under which conditions.

It aims at helping you answer the following questions:

- what are the methodology and underlying assumptions behind the detection and monitoring of abstractions with EO products?
- how reliable is this technology for the type of use I am interested in?
- is it suitable for use at the local agro-meteorological conditions where I consider its implementation?
- what are the minimum technical requirements to implement EO?
- what are the expected costs?
- are there successful examples of practical implementation?

2.1. Overall approach

Earth observation (EO) can supply two key products to support the detection of non-authorised abstractions:

- maps of irrigated areas (detection of non-authorised abstractions of the first type); and
- maps of irrigation water consumption (detection of non-authorised abstractions of the second type) at plot level and at different moments of the irrigation campaign.

Complemented with data on irrigation efficiency, EO products provide key information about water abstraction through the identification of irrigation activities and the estimation of abstracted volumes, both for standard and drought management. However, like for in-situ non EO-based approaches, this information needs to be compared to legal reference data to be able to actually detect possible cases of non-authorised abstractions. The existence of water rights and the availability of corresponding information are a prerequisite for the detection of "non-authorised" abstractions, irrespective of the method used to identify abstractions and estimate abstracted volumes. Figure 3 presents an overview of the steps leading to the detection of non-authorised abstractions by using EO images.

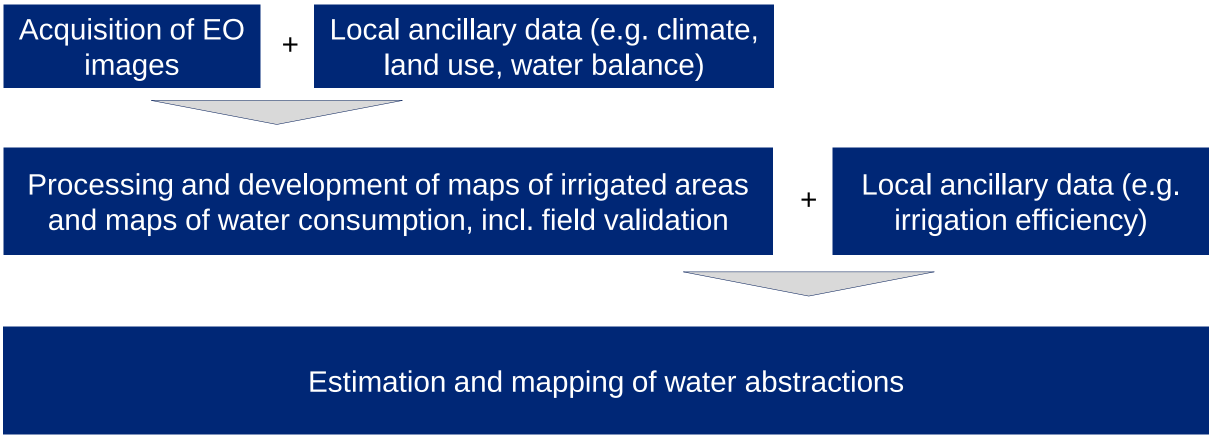


Figure 3: EO-assisted detection and monitoring of abstractions

2.2. Methodologies to detect and monitor water abstractions from EO

Both types of EO products can be obtained from the same source data and following the same initial processing steps. The basic principle here is to estimate water abstraction indirectly, via the assessment of crop water consumption based on EO-images of the vegetation.

2.2.1. Detection of irrigated areas

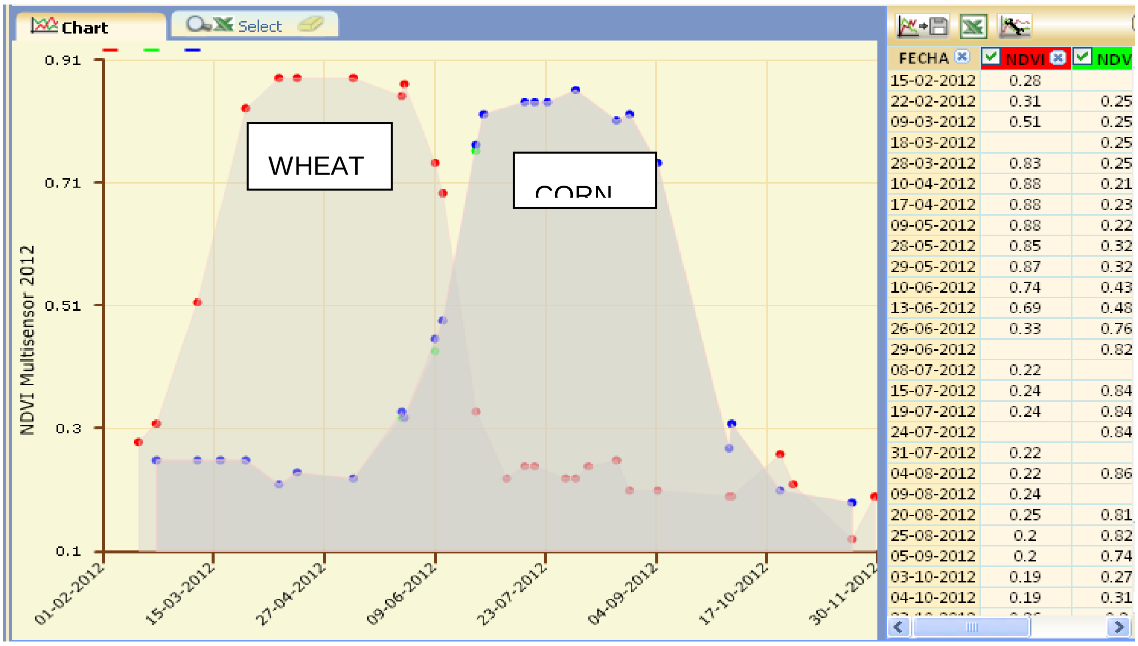
The detection of irrigated areas (defined as the identification of their location and their areal extent) requires land-use/land-cover maps that allow distinguishing irrigated from non-irrigated crops. This is accomplished by a supervised “multi-temporal classification” based on a time series of EO images. These images provide the temporal evolution of the crops and vegetation during its growing season through derived time series of Vegetation Indices (like NDVI, the Normalised Differential Vegetation Index), spectral reflectance and even, when available, surface temperature. The classification process based on temporal pattern recognition exploits the captured differences from the canopy on the above mentioned parameters to assign each pixel to a vegetation class. These classes need to be defined on the basis of field work and knowledge about the crop phenology in a given area. This crop classification is the basis for identifying irrigated areas and the point in time when this irrigation happens.

This process allows distinguishing:

- categories of crops (e.g. wheat from corn), as illustrated in Figure 4;
- within the same category of crops, irrigated crops from non-irrigated crops, as illustrated for wheat in Figure 5. To a certain extent, this process also allows detecting intermediate irrigation magnitudes (e.g. high irrigation volumes vs. lower irrigation volumes), as illustrated in Figure 6.

Identification of plots which receive supplemental irrigation (i.e. applying less amount of water than full irrigation, but in selected times) presents usually more difficulties because plots under this practice exhibit lower contrast against rain fed or irrigated plots of the same crop. Supplemental irrigation is usually applied when water stress develops and it is utilised both in extensive herbaceous annual crops and woody crops. Precipitation data are needed in this case to distinguish irrigation (the vegetation index, reflecting the plant water status, does not differentiate between water coming from rainfall or from irrigation). In crop types where the use of EO is less adequate (e.g. woody crops with sparse ground cove, like vine or olive, see section 2.5 p.29), supporting information, like cartography based on very high resolution orthophotos, can be used to identify the plots where this practice occurs.

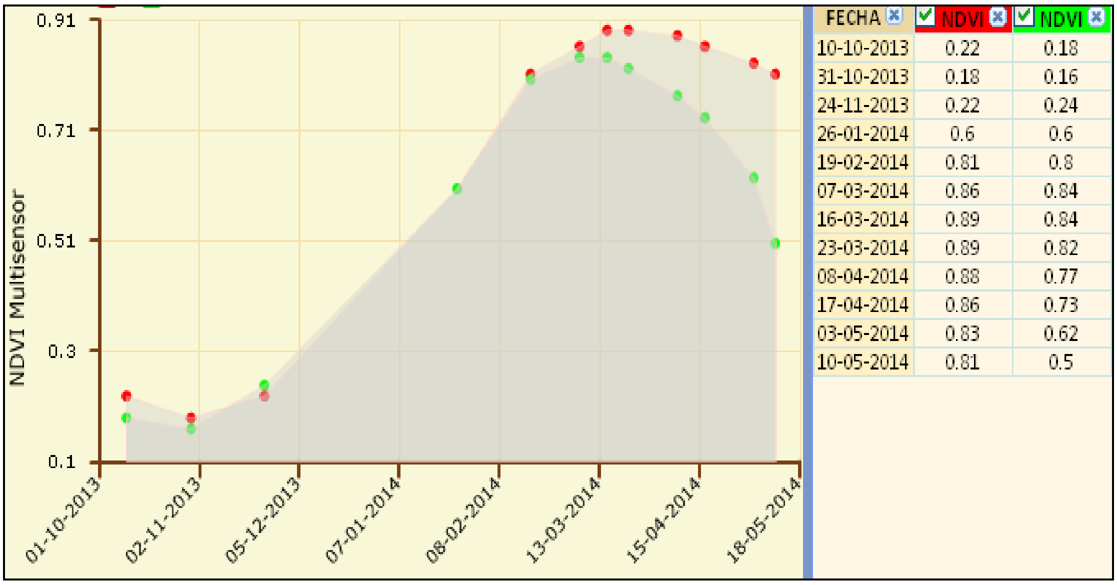
The whole procedure is not an automatic system. It requires a precise knowledge of crops and their phenology and needs further validation by an experienced operator. Figure 7 gives an example of the annual map of irrigated areas (comparison of period before and after introduction of the 1985 Water Law in Spain).



FECHA	NDVI	NDV
15-02-2012	0.28	
22-02-2012	0.31	0.25
09-03-2012	0.51	0.25
18-03-2012		0.25
28-03-2012	0.83	0.25
10-04-2012	0.88	0.21
17-04-2012	0.88	0.23
09-05-2012	0.88	0.22
28-05-2012	0.85	0.32
29-05-2012	0.87	0.32
10-06-2012	0.74	0.43
13-06-2012	0.69	0.48
26-06-2012	0.33	0.76
29-06-2012		0.82
08-07-2012	0.22	
15-07-2012	0.24	0.84
19-07-2012	0.24	0.84
24-07-2012		0.84
31-07-2012	0.22	
04-08-2012	0.22	0.86
09-08-2012	0.24	
20-08-2012	0.25	0.81
25-08-2012	0.2	0.82
05-09-2012	0.2	0.74
03-10-2012	0.19	0.27
04-10-2012	0.19	0.31

Figure 4: Different temporal phenology pattern of wheat and corn both irrigated as it is described by NDVI

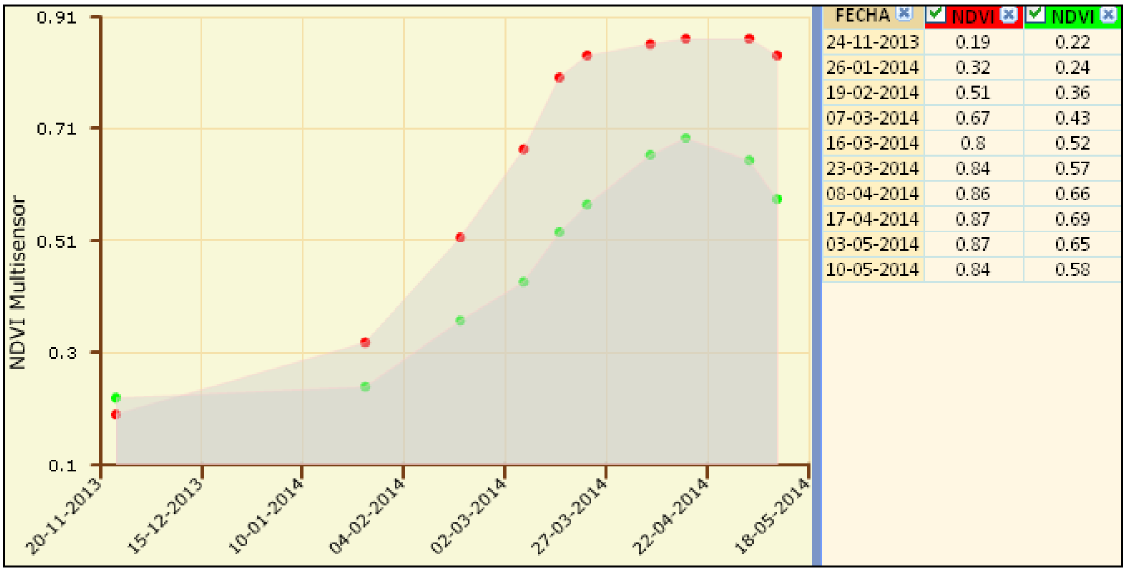
Note: NDVI represents relative photosynthetic size of the canopy. The NDVI values can be converted to crop coefficient values to estimate crop evapotranspiration.



FECHA	NDVI	NDVI
10-10-2013	0.22	0.18
31-10-2013	0.18	0.16
24-11-2013	0.22	0.24
26-01-2014	0.6	0.6
19-02-2014	0.81	0.8
07-03-2014	0.86	0.84
16-03-2014	0.89	0.84
23-03-2014	0.89	0.82
08-04-2014	0.88	0.77
17-04-2014	0.86	0.73
03-05-2014	0.83	0.62
10-05-2014	0.81	0.5

Figure 5: Different NDVI magnitude patterns of irrigated and non-irrigated wheat

Note: Two parcels of wheat with the same sowing date and similar development at the beginning of the cycle (due to sufficient amount of rainfall) exhibit a very different behaviour in the dry months as a consequence of no irrigation in one of them (green dots).



FECHA	NDVI	NDVI
24-11-2013	0.19	0.22
26-01-2014	0.32	0.24
19-02-2014	0.51	0.36
07-03-2014	0.67	0.43
16-03-2014	0.8	0.52
23-03-2014	0.84	0.57
08-04-2014	0.86	0.66
17-04-2014	0.87	0.69
03-05-2014	0.87	0.65
10-05-2014	0.84	0.58

Figure 6: Different NDVI's magnitude patterns of wheat with different levels of irrigation

Note: Two parcels of wheat under different water supply: fully irrigated (red) and not well irrigated due a failure of pumping (green). Sowing date is later in fall than in previous figure (leading to not enough rainfall during early phenology stage).

Figure 7: Example of annual map of irrigated areas in La-Mancha Oriental aquifer (Spain).

Note: Parcels in yellow indicate irrigation before 1984 (in contrast to parcels in red indicating irrigation after 1984)

2.2.2. Estimation of abstracted volumes

The detection of non-authorised abstractions of the second type (abstracted volumes) requires the mapping of crop water consumption over time during the growing season. This monitoring can be performed either during the irrigation season (real time) or after it (ex-post). This is accomplished by using the same time series of images as for the detection of irrigated areas, but processing them further (Figure 8 and Figure 9).

The basis of irrigation water requirements calculation are:

- time series of NDVI maps can be converted through a linear relationship into maps of basal crop coefficient, which is the basic input in the widely used FAO56 model for crop evapotranspiration calculation. Interpolation between consecutive maps is used to fill gaps (e.g. due to cloud cover), then the product of basal crop coefficient and daily reference evapotranspiration from agro-meteorological station provides crop water requirements in a pixel by pixel basis.

- evapotranspiration can also be calculated from images in the thermal spectrum by using an approach based on surface energy balance. Given that only Landsat8 sensor provides temperature, with a revisit time of 16 days, and regarding that its spatial resolution of thermal channel is 100 m pixel size, this procedure is complementary with that previously described, providing an independent quality control in the suitable areas.
- EO-driven soil water balance, according to FAO56, enables to calculate irrigation water requirements on a pixel by pixel basis. For this, precipitation and soil hydraulic characteristics are required. According to FAO56 procedures it is possible to calculate irrigation water requirements under water stress, as is used either in controlled deficit irrigation or in supplemental irrigation. Knowledge of the desired water stress degree is required, a fact that requires local calibration.
- abstraction estimation requires knowledge of the efficiency of both irrigation system and irrigation distribution/storage.

Figure 8 and Figure 9 show the flux diagram of the whole process (including indications about the sources of uncertainty and accuracy to be addressed in section 2.5 p.29).

More sophisticated methods have been developed, going through a series of intermediate physical parameters, like the Leaf Area Index (LAI). Comparative studies (D'Urso et al., 2010) show that the accuracy of these methods is comparable to the direct NDVI approach.

Annex 3 provides further details on EO-based methods for monitoring water abstraction.

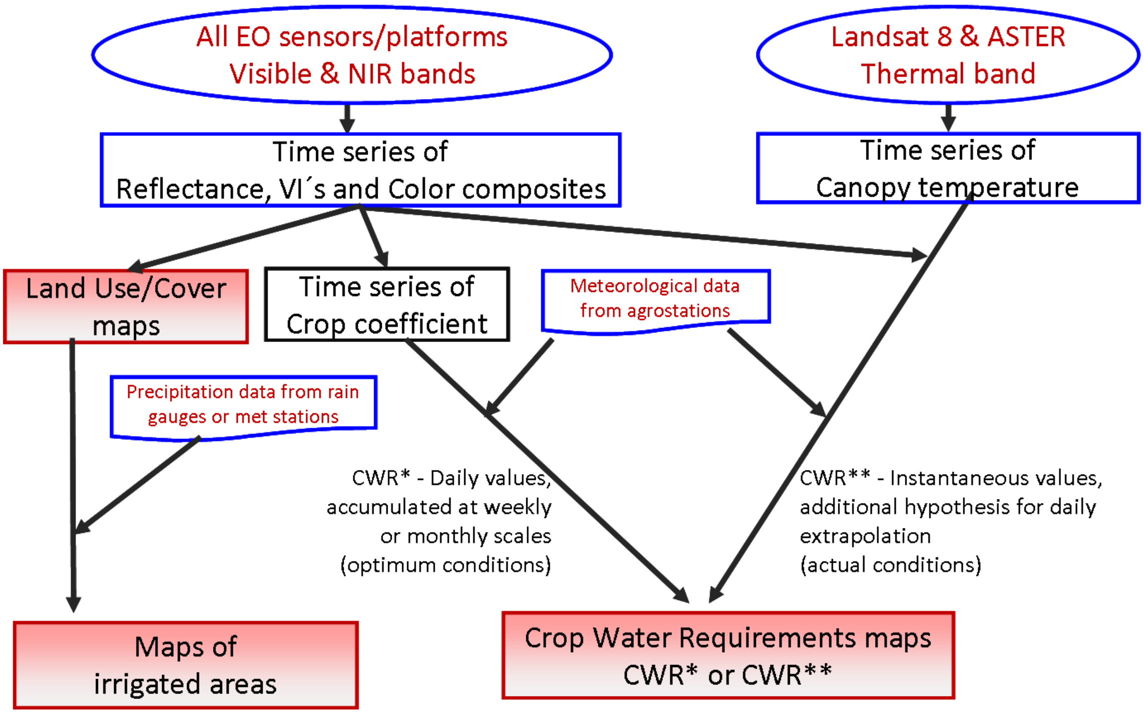


Figure 8: Overview of steps in using EO for detecting non-authorised abstractions

Note: Crop Water Requirements (CRW) can be obtained either directly from visible and near-infrared (NIR) bands (left strand*) or through the surface energy balance from additional thermal bands (right hand strand**).

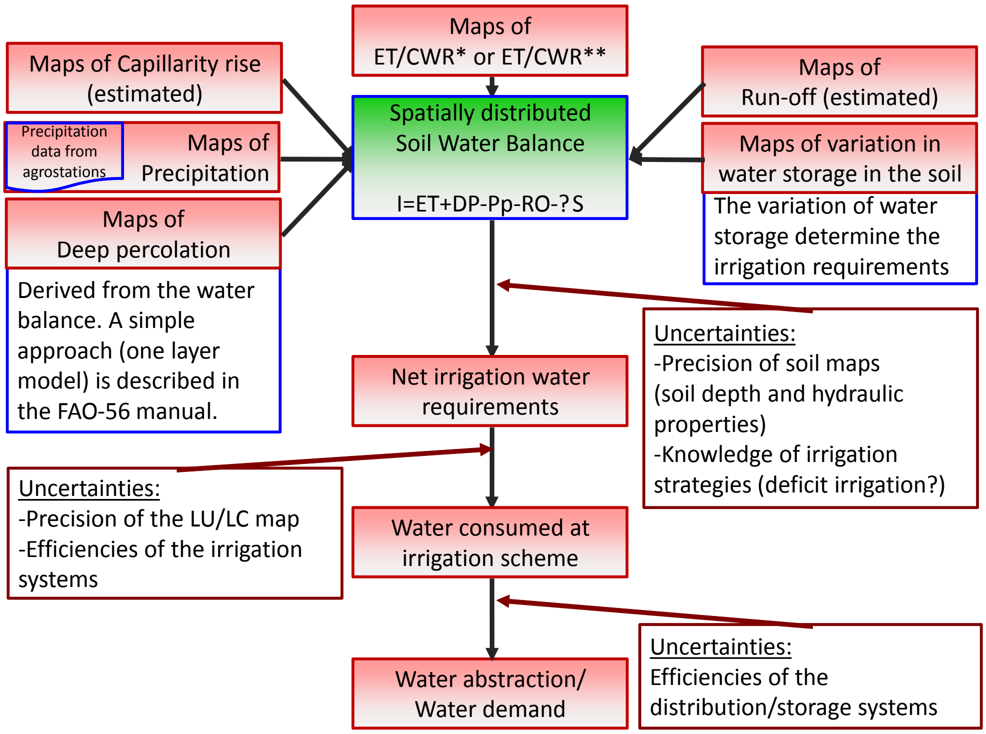


Figure 9: Overview of processing steps from crop water requirements (CWR) to water abstraction

2.2.3. EO products for monitoring seasonal water restrictions for irrigation

The possibility to identify crop water status variations based on short term and sometimes only partial water restrictions (vs. bans) has been questioned. It does not depend on technical limitations in terms of time of EO images acquisition and processing, as weekly images can be available. Currently, the processing time from image acquisition to the final product ready for use is around two days on average (according to Landsat8 production chain). The main possible shortcoming could rather be related to the magnitude and temporal response of the canopy to small and short-term water restrictions. However, the identification of irrigated areas by the time series of EO imagery is facilitated when drought happens, as lower rainfall implies usually water shortage into the root zone of crops, which increases the contrast between canopy of irrigated and non-irrigated crops, both spectrally and temporally (Figure 5 and Figure 6). Therefore, images account reliably for the impact of watering ban on vegetation development and thus enable timely reaction to drive field inspection (see STEP 3, p.33). Relevant experience has been gathered in the context of EO-assisted abstractions monitoring in the La-Mancha Oriental aquifer (project ERMOT, Calera et al. (2013)).

2.3. Conditions of implementation

The use of EO to detect and monitor water abstraction requires both satellite images and *in-situ* data. Table 2 provides an overview of data requirements and current knowledge about existing sources and availability.

The monitoring of irrigated areas and of crop water requirements and abstractions relies on dense time series of EO images acquired during the entire growing season from a multi-sensor constellation of satellites (currently available Landsat8, Spot, Formosat, RapidEye; upcoming

Sentinel-2 in 2015[11]) at a spatial resolution range of 5-30 m pixel size. For any given area, one image every 4-6 weeks is sufficient for mapping irrigated areas, while one image every 1-2 weeks is required for mapping crop water requirements (CWR) and abstracted volumes.

Table 2: Overview of local data requirements, source of data and availability

Datasets	Details	Sources	Data availability
Satellite images	Dense time series of high resolution imagery covering the entire crop growing season, and more specifically bi-weekly EO images from a high-resolution (HR) Virtual Constellation (multi-sensor time series at 10-30m resolution).	Satellite imagery databases and service providers	These can be acquired with satellites like Landsat8 and DeIMOS, which are currently available. A major step forward in simplifying operations is expected from Sentinel-2, to be launched later in 2014, which will be able to “see” spatial scales from 0.1ha. In areas where smaller spatial scales prevail, RapidEye (5m by 5m) provides a high-quality reliable solution.
Meteorological data	Daily agro-meteorological data and rain gauge data for the calculation of crop water consumption (*in-situ*)	(agro)meteorological station networks Alternative options: WMO or collaboration with Agri4cast (MARS-JRC) who use those same data to drive their products (yield forecast) PROBA satellite (precipitation maps)	Available in all MS
Soil maps of water retention capacity		National databases	European products, however with limited accuracy Currently available in some MS and some areas

[11] More High Resolution optical satellite data (10m resolution) will become available with the launching of the Sentinel2 in 2015 as part of the Copernicus programme. In the context of Copernicus a Data Access mechanism coordinated by the ESA (European Space Agency) has been set up for the acquisition of space data required for the operation of the Copernicus services and full Pan-European satellite image coverage are available for the Land Monitoring service (High Resolution 20m and Very High Resolution 2-5m) and re-usable by MS public authorities. The Data Access Portfolio was defined based on the collection of users requirements and is accessible on the ESA Data Access website (http://gmesdata.esa.int/c/document_library/get_file?uuid=9f57e0f4-af57-43ca-aa26-b9418fbf40ea&groupId=10725)

Datasets	Details	Sources	Data availability
In-situ information for main crops phenology and development		FAO database can be used as basic reference National databases	Allen et al. 1998 Currently available in some MS and some areas
Abstraction monitoring data	Flow meter data in selected locations(*in-situ*) for calibration and continuous ground truthing of crop water consumption	Monitoring networks	Available in some MS, for pressurised systems. Not available for gravity irrigation systems (like in South France)
Existing land use/land cover maps *(optional)*		CORINE Land Cover and the 5 new Copernicus High Resolution Layers LPIS (for parcel delineation)	Available in all MS for 2006. Currently being produced for 2012 data (updated every 6 years for Corine LC and every 3 years for the 5 HRL). Not yet accessible in all countries.

Furthermore, it requires infrastructure and skills to run the service, including infrastructure for field measurement for the validation and calibration using *in-situ* data. There are two alternative options, either in-house (i.e. installed at and maintained by the water management authority) or outsourced (i.e. in collaboration with an external service provider). In either case (i.e. in-house or at the service provider), the required infrastructure and expertise consists of basic computing equipment (server PC) with GIS and image processing software and the expertise to use them, plus knowledge of the crops in the area and their phenology.

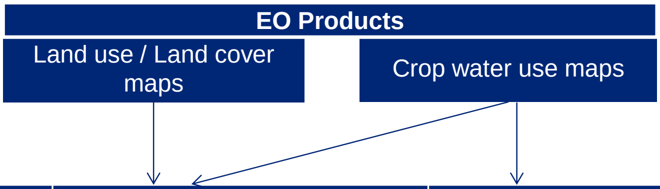
Using the service (e.g. as provided by a service provider) requires less infrastructure and expertise: a standard PC or laptop and some training of the user is normally sufficient. Users are not required to have any technical or informatics background.

2.4. Examples of concrete implementation

2.4.1. Overview

So far, EO-assisted monitoring of crop requirements has been introduced successfully in two MS (Spain and Italy) in order to detect non-authorised abstractions, at regional and/or local level (Boxes 2 and 3). In addition, EO has been extensively used for irrigation management and farm advisory in several MS, either at (pre-)operational or test/demonstration level (Figure 10). Therefore, many users (water managers, farmers, authorities) are familiar with it, at least to some extent. Irrigation Water Management Services address all issues of water management, from hydrological planning to evaluating water use efficiencies and monitoring and control of water consumption and abstractions. Farm Advisory Services are centred around irrigation scheduling, they provide farmers with information on actual crop water requirements for the current and following week (i.e. how much to irrigate where and when).

All systems/initiatives mentioned in Figure 10 use data from various Earth Observation satellites. They have all been extensively evaluated and calibrated with ground-truth data for a range of crops, and practical implementation shows that they rely on extensive field work for definition of crop classes and calibration of EO products. Further details on each initiative are provided in Annex 4. Additional *in-situ* data and/or models may be required in special cases (perennial crops, sparse ground cover, supplemental irrigation in (sub-)humid areas) in order to increase accuracy. Within the initiatives listed, only SIRIUS and METRIC-Idaho actually provide a service to their users. The others offer tools or products, which means that their users need to have the necessary technical capacity (at least a GIS platform, software, and some GIS expertise) to integrate them in their operational routines.



Application	Irrigation water management		Farm advisory	
Media	Service	Web-GIS	Service	Web-GIS
Demonstrative tools	Monidri SAMIR Water Watch	PLEIADeS	DEMETER	DEMETER eSARAS Isareg/GISareg Telerieg
Operational tools	Minaret	IRRISAT* ERMOT SIRIUS SMS Idaho-METRIC	IRRISAT*	IRRISAT* SIRIUS IFAS* TOP-SIMS* FieldLook* AGRASER

Figure 10: Overview of demonstrative and operational EO tools and services.

Note: * fully operational tools

Box 2: Use of EO to detect non-authorised abstractions in irrigation areas in Spain

La-Mancha Oriental (Spain)

The Junta Central de Regantes **La-Mancha Oriental** (JCRMO), in the upper Júcar river basin, Spain, has successfully been operating for 18 years a system of EO-assisted water management (including the monitoring and control of abstractions) based on the identification of crops with similar water requirements by means of a sequence of EO images and subsequent assignment of water volumes per class (multi-annual averages also supported by agronomic knowledge base). Beyond this multiannual average, EO-based products developed in SIRIUS can provide actual irrigation water requirements for each plot during the whole growing cycle. This service has been jointly financed by the users (Junta Central de Regantes La-Mancha Oriental) and public administration (River-basin authority and Regional government). A demonstration is available online (http://zeus.idr-ab.uclm.es/publico/webgis/).

Upper Guadiana (Spain)

The use of EO for monitoring the irrigated areas has been important in the **Upper Guadiana** from the early phase of its operational use. Recently a comprehensive control has been accomplished for the years 2008-2011, identifying the irrigated surfaces and estimating crop water consumption for each parcel (Calera et al., 2009). At the same time extensive experience has been gained in the use of volume meters. **The assessment by one of the former presidents of the Spanish Guadiana river basin authority, Díaz Mora (1995), concludes that "…the direct measurement using flow meters has proven to be useful. However, any system for controlling groundwater extractions cannot be based only on them." He proposes a three-component hybrid system, covering flow meters managed by the irrigators themselves, EO, and piezometers.**

The Duero River Basin (Spain)

The **Duero River Basin** Authority and the ITACyL (Castilla y León Agricultural Technology Institute) have used remote sensing technologies to recognise historical water rights, new concessions and modifications for RBMP review.

a) Development of Duero River Basin Management Plan (2009):

To perform the characterisation of agricultural demand units for incorporation into the River Basin Management Plan using satellite imagery of 2008 and 2009. It was based on Landsat 5 TM, with images from March to September 2009, and SPOT 5 as the support in areas with clouds. The results were used to contrast the reality with concession information available to the basin authority in their records.

b) Monitoring abstraction for irrigation of crops in the years 2010 to 2013:

The irrigated areas and theoretical irrigation abstraction have been monitored using Landsat 5 TM images, in 2011 and 2012, and Deimos-1 in 2013. This information helps to identify illegal abstractions and over-abstractions. They have also served to establish rules for conceding new allocations in poor status groundwater bodies.

Box 3: Implementation of IRRISAT in Italy, from an irrigation advisory service to an irrigation management tool

IRRISAT (www.irrisat.it) is the Irrigation Water Management and Advisory Service based on near-real time distribution of EO products, being in operation in the Campania region since 2007. The service is implemented in the framework of the Rural Development Plan of the Campania Region, Measure 124 Health Check, as a further step for the implementation of the WFD in the agricultural sector. In 2013, the Irrisat services have covered four different irrigation consortia, with about 2500 farmers and a total area of 8000 ha. The Consorzio Sannio-Alifano has been particularly active in adopting the IRRISAT procedures, which are now being progressively integrated into the ordinary irrigation management. In this area, farmers are requested to apply for using irrigation water, in order to better match resources availability with demand. The requested volumes are now directly estimated from EO based information of IRRISAT; metering devices at the outlet allow for a cross-check between actual water uptake and corresponding suggested volumes. The entire procedure is implemented on a web-GIS, which is progressively substituting the traditional “ticket” compiled by farmers. During the irrigation season 2014 the Consorzio is testing the procedure in several peripheral offices, distributed over the area served, to facilitate access to the service by farmers.

The internalisation of this new management procedure has improved also the comparison between EO-based detection of irrigated areas and water requests. On the basis of the experience from 2013 within the sub-district “Valle Telesina”, it has been possible to detect an area of about 10% of the total irrigated area which was not legally authorised. From a technical point of view, and considering the agro-climatic conditions of the area, EO analysis has been concentrated to herbaceous crops (corn and alfalfa for fodder production) which are also responsible for the highest water consumption, compared to other permanent crops (i.e. vineyards and olive trees) much less demanding to this respect. To this end, the strategy of the Consortium was to maximise the detection of crops corresponding to higher water demand, achieving a better cost-benefit ratio.

2.4.2. Services or applications for water management

MINARET (MonitorINg irrigated AgriculturRe ET) was developed by the Regional Government of Andalucía and the Spanish Research Council Córdoba as a planning and operational tool for routine monitoring of crop water consumption in the irrigated area of the Guadalquivir river basin (Southern Spain). It was made available to the corresponding river basin authority for use in their operations. Like SIRIUS, it is based on the Kc-VI approach (González-Dugo et al. 2013).

The Dutch company **WaterWatch (now under the roof of eLeaf)** has offered products and services to monitor crop water consumption for over 15 years and have carried out relevant studies in many African countries as well as in Saudi Arabia and Yemen. Their approach is based on the **SEBAL** algorithm (developed by Bastiaanssen et al., 1998), which estimates the components of the surface energy balance (SEB) from Earth Observation data. It requires Earth Observation image data both in the solar and thermal spectral range. The latter limits the achievable spatial resolution (e.g. Landsat solar channels at 30 m resolution, thermal at 120 m, which means that only parcels larger than15 ha can be resolved, in contrast to 1 ha for solar channels). SEBAL has been applied in World Bank projects as singular events (no continuous monitoring).

The **University of Idaho, Department of Water Resources** has further developed SEBAL into **METRIC** (using a simplified calibration approach). Their initial services to monitor crop water consumption and irrigation water abstractions for nearby water users associations have been extended to other areas across the USA (Allen et al., 2007a and b) (Box 4).

SAMIR is a tool for estimating agricultural water requirements based on the Kc-VI approach, combined with a distributed soil water balance model. It has been integrated with a range of models in a decision-support system for irrigation water monitoring and management to be used by the Tensift river basin authority (Morocco) (La Page et al. 2012).

Box 4: Example of application of METRIC for the detection of non-authorised abstractions in Idaho (USA)

METRIC (Mapping Evapotranspiration at high Resolution and with Internalized Calibration) is an image-processing model for calculating actual evapotranspiration (ET) by solving the energy balance at the earth's surface using satellite thermal images and weather data. This model has notably been used by the Idaho Department of Water Resources (IDWR) in order to estimate water use by irrigated agriculture and monitor compliance of water consumption with water rights in the Eastern Snake River Plain, Southern Idaho (Allen et al., 2007a; Allen et al., 2007b).

The Southern Idaho climate is semiarid and agriculture in the region relies on irrigation. The Snake River irrigates approximately 647,500 hectares on the Eastern Snake River Plain which also supports approximately 200,000 hectares of groundwater irrigation from 5,000 wells (Allen et al., 2005).

In 2002, the IDWR applied METRIC for the comparison of the allocated pumping rates with ET during the period of peak water demand in July, in the Eastern Snake River Plain (Allen et al., 2007a; Allen et al., 2007b). The comparison was done for 426 water rights within the study area.

Pumping rates rights for each place of use were compared to the minimum possible rates given the volume of ET derived from METRIC (Allen et al., 2007a).

Eighteen potential violations were identified by the IDWR, among which fifteen were proven false after field inspection due to erroneous IDWR water rights files (Allen et al., 2007a; Allen et al., 2007b).

Predicted ET data by METRIC have been compared against ET measurements from weighing lysimeters. The results suggest that METRIC holds significant promise as a method to predict actual evapotranspiration from irrigated land (Allen et al., 2005).

According to a study from 1989, the absolute error between METRIC and lysimeter measurements of ET varies depending on the time scale, from 14% if image days are compared to 1% if the results obtained during the entire growing season are considered.

Since 2002, the IDWR continues to use METRIC for the estimation of water consumption by irrigated agriculture and the monitoring of compliance of water consumption with the respective water rights, but also to estimate water budgets for hydrologic modelling, to support water resources planning, to estimate aquifer depletion, to support groundwater model calibration and operation, to estimate historical water use for water rights transfers, to develop populations of crop coefficients curves and finally to evaluate relative performance of an irrigation canal company by comparing ET with diversions (Allen et al., 2007a).

2.4.3. Services or applications for irrigation advisory (or irrigation scheduling)

These services are also based on the spatially distributed estimation of crop water requirements. Many of the Earth Observation-based irrigation advisory services offer also crop inventories, which provide the necessary information for detecting irrigated areas. Of the eight examples provided in Figure 10 four are fully operational (TOPS-SIMS, IRRISAT, SIRIUS-IFAS, FieldLook), while the others have been applied and demonstrated in individual cases.

- **TOPS-SIMS** is a fully operational prototype for mapping crop water requirements (centred on irrigation advisory), but also for monitoring crop water consumption (Melton et al. 2012). (ecocast.arc.nasa.gov/dgw/sims)
- The **SIRIUS IFAS (Integrated Farm Advisory Service)** has been established in the Spanish La Mancha area. It offers irrigation scheduling as well as advice on fertilisation and yield forecast (Calera et al., 2013a and b). (www.agrisat.es)
- **FieldLook** has been developed by eLeaf and is based on SEBAL (requiring thermal imagery). (www.fieldlook.com)
- The Italian **IRRISAT service** has been providing irrigation scheduling to large areas in the Campania region (Vuolo et al., 2013). (www.irrisat.it)
- **IrrisatSMS** (currently discontinued) offered irrigation advisory by SMS to farmers in Australia and California (Hornbuckle et al., 2009).
- **AGRASER** is a complete system of farm advisory and has been extensively used by Mexican insurance companies.
- **Isareg and GISAREG** have been developed by the University of Lisbon and applied in Portugal as well as in Latin America.
- **TELERIEG** has investigated irrigation advisory with a special focus on woody crops (e.g. citrus trees), using also very-high resolution imagery from airborne sensors (Box 5).

Box 5: TELERIEG PROJECT

The main objective of the TELERIEG project was to develop knowledge and tools on the application of remote sensing and geographic information systems for the improvement of irrigation water management and the response to natural risks affecting agriculture in Southwest Europe (Erena et López Francos, 2012). The final results were an automated image processing system that generates daily maps with useful parameters for irrigation management and a geoportal gathering agro-climatic and cartographic information adapted to the INSPIRE Directive (Berthoumieu, 2012).Concerning the application of remote sensing for the improvement of water management, three different spatial resolutions for Earth Observation have been investigated:

- Observation from a short distance or above canopy with a near infrared and visible camera coupled with a thermal camera (10cm pixels) for irrigation scheduling in vineyards (Bellvert and Girona, 2012) and irrigation management of citrus trees (Jiménez-Bello et al., 2012)
- Observation with cameras installed on small aircrafts or satellite with high resolution as SPOT or DMC for the estimation of actual evapotranspiration (García Galiano and García Cárdenas, 2012)
- Observation with satellites with a lower resolution as Landsat 5 (120 m) and 7 (60 m), HJ (China), NOAA, MODIS (240m for visible and 960 m for thermal) (50 m to 1 km pixel)

Using airborne platforms enables high spatial resolution but this system cost about 150 000 to 200 000 € for the equipment plus about 150 €/h for the flight (or slightly less depending on the aircraft cruise speed).

2.5. Lessons learnt: assets and shortcomings of using EO for the detection and monitoring of abstraction

2.5.1. Technical assets and shortcomings

Assets

Earth Observation presents a range of technical assets in contrast to field observation alone. It can provide detailed maps of irrigated areas and estimate the level of water consumption in large geographical areas (e.g. watershed scale), where field measurements provide only point values of evapotranspiration (ET) for a specific location and fail to provide the ET on a broader regional scale. Images can be obtained, e.g. on a weekly basis, depending on the resolution required.

Several comparative analyses show that Earth Observation systems have good accuracy relative to field measurement techniques of crop water requirements (Castaño et al., 2010; Cuesta et al., 2005) and water abstractions (Garrido-Rubio et al., 2014). The application of SAMIR, for example, showed that the overall difference with respect to field measurements was only 5% over 160 days. The average difference may however rise to 18% of the soil water balance on a weekly scale (Le Page et al., 2012).

Shortcomings and mitigation actions

1. The **accuracy** of the procedure to classify irrigated areas depends on **agrometeorological conditions,** as it relies on the contrast in the temporal pattern between irrigated and non-irrigated crops, which is crop and weather dependent. Accuracy in semiarid areas reaches typically over 90%, which is comparable to field work accuracy. Distinguishing non-irrigated areas from irrigated areas of winter crops - especially in years with a rainy spring as well as areas with perennial crops - can be difficult. The reason for this is the fact that the EO-derived phonological curves reflect the crop water status, thus do not distinguish between rain and irrigation (see Table 3).

Table 3: Accuracy in identification of irrigated surface by multispectral EO time series

Irrigated crops	Accuracy depending on climate		Supporting information required in order to achieve good accuracy
	Semiarid/arid	(Sub-)humid	
Annual crops (herbaceous)			
Crops that reach full cover: wheat, corn, barley, tomato, lettuce, cereals, oil crops, potato, sugar beet, forages, etc.	Very good	Good	
Crop that doesn’t reach full cover: garlic, onion	Good	Low	soil water balance model (soil map)
Perennial crops (woody)			
Crops that reach full (or near full) cover: fruit trees, table grapes	Good	Low	orthophotos or very-high-resolution (HR) EO
Crop that doesn’t reach full cover: olives, wine grapes, almonds, etc.	Very low	Very low	orthophotos or very-HR EO and soil water balance model

→ **Mitigation actions:**

- use additional information;
- increase the global accuracy by using the capacity of time series of images and by relying on a multiannual perspective, which provides an expert system of classification layers (e.g. containing previous successful classifications of perennial crops and winter crops). Detection of new irrigated areas by using this updated frame can be done through the overlay of annual irrigated maps;

2. **Calculating abstracted volumes from EO involves several steps** (see Figure 9), **each of which is associated with further uncertainties.** These uncertainties remain in the same order of magnitude as for field work. Uncertainty of EO-derived crop water requirements is around 5-10%. The subsequent calculation of irrigation water requirements depends on the accuracy of available precipitation and soil data, irrigation water consumption and abstraction estimates, which require information on efficiencies of irrigation system(s). All in all, comparison with field data gives a volume abstraction accuracy of 80-90%.

   → **Mitigation actions:** collect as accurate data as possible and ensure transparency about the degree of uncertainty.

3. In general, it is **difficult to monitor water consumption with a sufficient resolution on small cultivated parcels with mixed patterns** of crops (about 1ha or less). This is a reason why the use of Earth Observation was not retained as a priority option for the detection of non-authorised abstractions in Cyprus, which prefers the systematic development of GSM and Wi-Fi metering.

   → **Mitigation actions:** use higher resolution images (Sentinel-2 will be able to provide resolution for up to 0.1ha, while several other commercial satellites provide even much higher resolution).

4. The **presence of clouds** can also affect the frequency and timing at which images are produced. The use of multi-sensor time series can help to overcome this issue, as well as the upcoming use of Sentinel-2 data (10m resolution, 5 days revisiting period with 2 satellites).

   → **Mitigation actions:**

   - use an airborne platform to complement space data on cloudy areas;
   - use the full virtual constellation of available Earth Observation satellites (applying the corresponding inter-calibration procedures); with the advent of Sentinel-2 this risk should be greatly reduced;
   - reduce the reliance on remote sensing by combining it with other approaches, e.g. filling gaps using FAO-56 (Allen et al., 1998) and/or interpolation of images (Garrido-Rubio et al., 2014).

5. Furthermore, the use of Earth Observation is not a stand-alone option. It requires field measurement on the ground (*in-situ data*) to verify suspicions detected, and therefore specific infrastructures and capabilities are required for the processing and the calibration and validation with *in-situ* data.

   → **Mitigation actions:** rely on external service providers when capabilities are not in-house.

2.5.2. Economic assets, shortcomings and mitigation actions

Extensive assessments of costs of field measurement approaches alone, compared to their combination with Earth Observation-derived information were carried out within the FP7 SIRIUS project for pilot areas in Spain, Italy, Turkey, and Brazil. These showed that the cost of Earth Observation services was significantly lower than the cost of field measurement and inspection. Water users associations have demonstrated their willingness to pay for such services. It will be also facilitated by the free, full and open data policy of Copernicus Sentinel data which might boost the development of such applications at local or national level.

→ **Mitigation actions:**

- provide details on current costs dedicated to enforcing compliance with water rights,
- establish additional short-term costs required for the implementation of EO and long-term financial balance, and
- explore financing solutions while encouraging joint investment.

Box 6 below provides details on the case of detection of non-authorised abstraction in the La-Mancha aquifer in Spain (where the service has been financed jointly by users, the river-basin authority, and regional government).

Box 6: Example of comparative cost analysis, based on SIRIUS practical implementation

Detection of new surfaces under irrigation in La Mancha Oriental

The Irrigation User Association "Junta Central de Regantes de la Mancha Oriental" is in charge of managing the aquifer Mancha Oriental, one of the largest aquifers in Spain with an extension of about 10,000 km2 and holding about 100,000 ha of irrigated land.

Traditionally the mapping and monitoring of irrigated areas was accomplished on the basis of field inspection. The related field work requires normally a team of 2 well-trained people with car, plus previous preparation on the basis of GIS and maps. The cost per day is 350 €. This team monitors about 1000 ha/day on average. Each farm is normally visited twice a year. Additional office work, cartography, field logs and archives requires two GIS Experts over six months (to achieve a sampling of more than 25% of the area). One person over six months can achieve sampling of less than 25%. Supervision of all work requires a senior person for 9 months. In summary, the cost for mapping irrigated areas, covering 50% of the irrigated area (i.e. 50,000ha) by field inspection only is 406 250 € per year.

Mapping and monitoring irrigated areas by means of SIRIUS Integrated Water Management Service (IWMS) gives a different picture: based on temporal sequences of 12-24 images per year, for an area of about 180 km by 180 km (size of one Landsat scene) the cost is 35 000 €/year (including Landsat at no cost). Image processing, product generation and upload to SPIDER webGIS requires one senior remote sensing and GIS expert over 12 months, plus one expert in image processing, classification and GIS for 12 months, plus basic SPIDER support. It also requires a field team for validation and calibration with *in-situ* data with a cost of 32 500 €/year. All in all, this sums up to 150,000 € (including images). This cost doesn't include the field inspection itself which is however much reduced as it can be targeted at the most suspicious plots.

In summary, this EO-based service provides maps of irrigated plots at a fraction (around 40%) of the cost of the field-inspection-only mode while covering the whole area (i.e. 100,000 ha). In addition, these EO-based maps are regularly being updated (every 2-4 weeks) and are being used to direct the field inspections to strategically important plots. The field-inspection-only mode can reasonably cover only 50% of the area and without the "eye from space" may miss the crucial plots.

Source: SIRIUS project outcomes. Business cases.

2.5.3. Administrative shortcomings and mitigation actions

Availability and/or access to the necessary *in-situ* data might be difficult in some cases (e.g., agrometeorological station or soil data owned by another branch of administration). These cases have become less and less frequent, but still can be found in specific environments. Depending on the MS or local context, the implementation of EO can be made difficult by the absence of online access to data and information and the low interoperability with existing data. Public administrations may have restricted online access, e.g. to FTP (for products and images up- and download) or external servers (web-based services or webGIS). Data standard formats may or may not be compatible with new incoming data and this may or may not be easy to overcome (technically and/or administratively). The implementation of INSPIRE Directive will facilitate the access and interoperability of geospatial datasets. Furthermore, water authority personnel may be experienced and/or trained in traditional administrative skills and thus may require re-training to be able to use and fully benefit from the new EO-based services.

→ **Mitigation actions:** promote participatory approaches to raise awareness and develop knowledge sharing amongst stakeholders.

2.6. Summary of opportunities for the use of EO

The summary tables (Table 4 and Table 5) aim to support decision-making for EO implementation.

Table 4: Suitability of using EO in different conditions

Suitability	Low	Medium	High
Manager's objective	Detection of hydraulic works (only possible with very-high-resolution images or orthophotos)	Monitoring of restrictions for drought management	Detection of irrigated area Monitoring abstracted volumes
Crops	Perennial crops	Crops that don't reach full cover	Crops that reach full cover
Climate	(sub)-humid areas		Semi-arid/arid areas
Size of area / number of abstraction points	Small areas (<1 ha), few abstraction points	Medium areas	Large areas, many abstraction points

Table 5: Assets and shortcomings for the detection of non-authorised abstractions

	Assets	Shortcomings	Variable factors
Technical	Large geographical coverage Good accuracy in identification of irrigated areas and estimation of abstracted volumes Access to historical data records (back to 1984)	Reliance on cloud conditions Difficulty to identify small cultivated parcels Estimation of abstracted volumes for some crop types require special ground truth calibration	Multi-sensor constellation. Future Sentinel-2 Information on water rights and land uses Need for resources and infrastructure to acquire and process EO images.
Economic	Reduced overall costs in the medium to long term and needs for human resources	Investment costs in the short term: costs of data / cost of human resources (60-80 000EUR per year for an area of 80-100 000 ha)	Existing capabilities at water management authority (GIS, image processing) Private providers to outsource the entire service or parts of it (image processing, webGIS)

Step 3 - Assessing the suitability of EO in the given legal and institutional framework

Objectives:

This step consists in assessing how EO can support the detection and monitoring of non-authorised abstractions based on current institutional and legal framework.

It aims at helping you answer the following questions:

- Does the current status of water rights allow identifying "non-authorised" abstractions or does it require first regularisation?
- If there are well defined water rights, what are the minimum conditions (e.g. nature of water rights, data availability) to be able to verify compliance with water abstractions?
- Can EO data be used directly in court?
- Are there examples of successful practical implementation?
- What are the factors of success that are likely to improve acceptability and implementation of EO for the regularisation of water rights or the detection and monitoring of non-authorised abstractions?

3.1. Approach and possible applications

In each Member State, water abstraction is "regulated" more or less formally through the allocation of water rights to different users. Further information on the types of water rights and allocation processes are provided in Annex 5 of this guidance document based on available information from the MS. The detection and monitoring of non-authorised abstractions requires the comparison of actual water abstractions with legal reference data on water rights (Figure 11).

Where water rights exist and corresponding information is available, EO products can support the detection of non-authorised abstractions by allowing:

- better targeting field inspections: this technology is recognised as providing more objective sets of data compared to field inspection methods, and appears as a powerful decision making tool to direct and guide the detailed field inspection, e.g. by providing targeted mission roadmaps for field technicians; or
- taking legal action in Member States provided there is a legal recognition of EO as evidence (e.g. in Spain): the use of Earth Observation-derived data, considered as objective, can indeed provide legal evidence in the case of legal conflicts.

Another application consists in **verifying the reliability of self-declarations** of abstracted volumes through the comparison with EO-based information on water abstractions, in particular for ensuring the correct implementation of water fees.

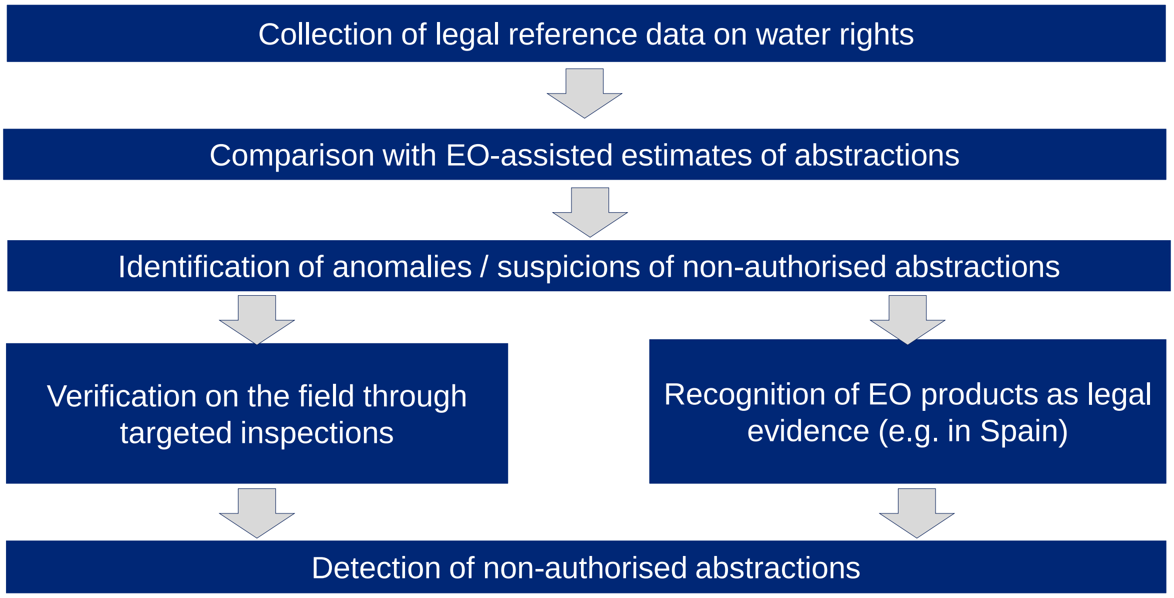


Figure 11: Steps for the detection of non-authorised abstractions

3.2. Conditions of implementation to meet managers' needs

The use of Earth Observation-derived data to detect water abstraction is a mature system and several service providers with demonstrated operational capacity have shown to be ready to implement it. However, a key condition for the detection of non-authorised abstractions, irrespective of the method used (*in-situ* or EO), remains the existence of defined water rights and the availability of corresponding geo-referenced information against which to compare the EO-assisted products (maps of irrigated areas and abstracted water volumes).

In particular, there is a need for:

- the **implementation of water rights and/or process of regularisation** [for both detection of non-authorised abstractions of types 1 and 2];
- the compilation of water rights within a registry, with cadastral limits of plots [both types 1 and 2];
- the definition of water rights in terms of irrigable area [type 1] or volume per ha [type 2], and these rights must be linked to specific areas.
- the **recognition of EO in judicial and extra-judicial proceedings** should it be used directly as evidence of infringements on water rights (Box 7).

Box 7: Practical examples of the use of EO in judicial and extra-judicial proceedings

In Spain, the Supreme Court validated in a recent sentence (2012) the identification of irrigated surfaces based on remote sensing for the recognition of water rights and detection of illegal abstractions. The observations made by the Supreme Court on the use of remote sensing based classification first established the features that this methodology must meet in order to be considered as evidence in legal proceedings: the provided service on the identification of irrigated areas must include the presence in court of the individualised report about a plot, introduced by a senior expert, who is responsible for its completion and quality.

The EU project Aperture (ENV4-CT97-437) investigated if and how high spatial resolution Earth Observation (EO) data should be in order to be accurately and effectively used in judicial and extra-judicial proceedings, concerned with the implementation of environmental law. The main outcome of the legal investigations was that, even in the absence of specific provisions for the use of satellite images in national law, there were no major constraints in the use of satellite images either in the court or in administrative proceedings as evidence or additional and supporting tool of evidence. The need for an expert, who would explain technical matters in the court cases, was however strongly supported (European Commission, 2000).

A recent ESA study report states: "Broadly, the conclusion reached is that internationally there are no major insurmountable barriers to the use of EO information by courts and administrative tribunals." (European Space Agency, 2012). Purdy and Leung (2012) provide a summary of legal consideration in the EU.

3.3. Success factors and barriers: lessons learnt from practical implementation

Depending on the existence, status of implementation and nature of water rights, non-authorised abstractions will be more or less easy to detect with EO derived tools, as illustrated in Figure 12.

From a technical perspective, water rights allocated to abstraction sources, and not to a specific irrigated area, make it difficult to check that EO-based anomalies actually correspond to an infringement of water rights, as the link between abstraction sources and irrigated areas is not always straightforward. In Cyprus and in France, for instance, the same parcel can be irrigated from different water sources (e.g. surface water from dams, groundwater, water transferred from another borehole nearby) which can, for each of them, be authorised or not. The estimation of crop water consumption, and therefore abstracted water, cannot be compared with water rights when they are defined per abstraction source, with no registered link to the irrigated area. Similarly, this kind of EO-derived information will be of little help when water rights do not consist in maximum abstracted volumes but are capped by a maximum abstraction flow and a minimum flow to be left in the river at all times, like in some areas in the South of France with collective irrigation channels. **In practice, there may be many situations where the nature of water rights does not allow a direct comparison with EO-based data and this should be carefully considered when a water manager considers the possible development of such a tool; this comparison is, however, quite straightforward for Italy and Spain where the use of EO for the detection of non-authorised water abstractions has been the most developed so far.**

More generally, the absence of complete records of water rights also makes the verification of compliance of practices with water rights very difficult or impossible. When it is available, data on water rights are held by irrigation users' associations or regional water authorities, but in most cases, this information is either completely missing, scattered or only available in non-digitised format. Box 8 highlights current attempts to develop water rights databases, in Spain, France, Slovenia and Greece. Slovenia has already developed its "Water Book", which is a joint database of all legal water rights, with the coordinates of associated irrigated areas.

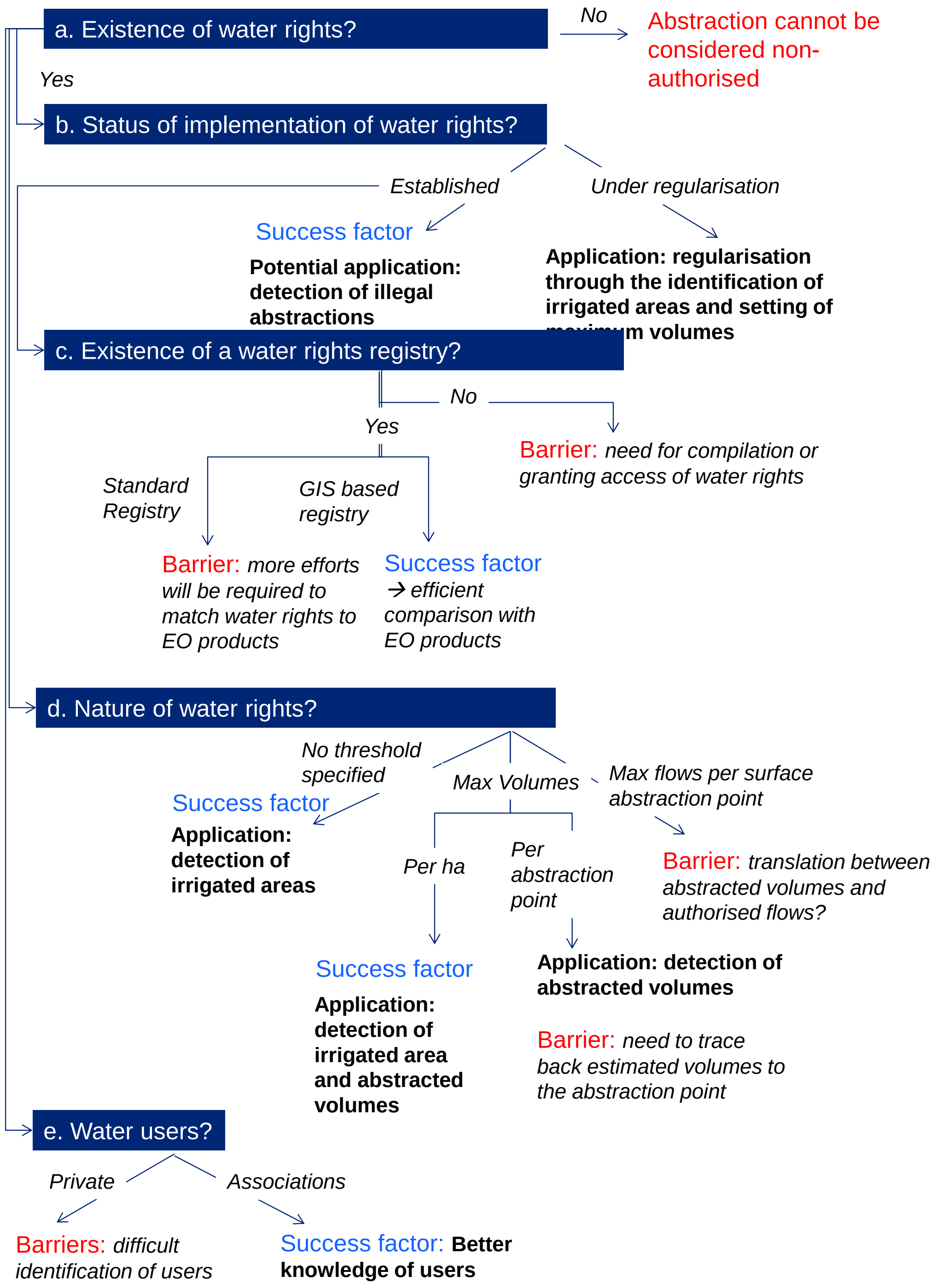


Figure 12: Characteristics of water rights and suitability for the EO-based detection of non-authorised abstractions

Box 8: Examples of development of databases of water rights

Water Register in Spain, for the regularisation of water rights

The Water Register is an integrated tool that enables to register, modify, identify and locate all water uses. It is already developed, but currently is being tested. All concessions must be properly written down in the Water Register. With the aim to improve the control over extractions and, in particular, the control on concessions, the necessary legal modifications to provide further transparency to the Water Register have been made. In this way, an electronic Water Register is being developed and implemented in each River Basin Authority, which will be available for all the citizens, so that any person could know the details of the water concessions and the uses for which the property is entitled. The e-register will help to enhance the identification of illegal abstractions.

Project of a national database on water rights and reporting of abstractions in France

A national database on water rights and abstractions is being developed since 2010. This database will include data on abstractions from inland surface waters, groundwater and transition waters, for all uses.

This project will include the actual database, a portal for the dissemination of data and a working tool for field inspectors, while responsible for its development will be the BRGM. This project is managed by the Ministry for Sustainable Development, the Water Agency Adour-Garonne and Onema[12].

Project on the registration of water abstractions or pending applications in Greece

The ministry of Environment is currently working on the registration of all the abstractions currently known or the water permits applications (new and old ones).

From an institutional perspective, the acceptance of Earth Observation-derived information for the monitoring of non-authorised abstractions seems to depend on local awareness of the issue and political commitment to secure compliance with water rights, as well as on the support of associations accompanying water users for such technologies and on the history of the use of Earth Observation services for other purposes.

It also depends on the governance structure of water abstractions, which may be little coordinated in the field. Water management happens in a complex web of institutions and other actors, at a range of interacting spatial and temporal scales and over a range of equally interconnected governance and policy levels (farm, local/regional, MS, EU). In the EU, water governance structures mostly depend on the source of abstracted water. In areas irrigated from groundwater, there is usually a large number of individual private farm holdings, sometimes (e.g. in Spain) grouped into an Irrigation Community. Areas mainly irrigated from surface water are rather governed by Water User Associations (which are also in charge of the land reclamation and channel networks). The monitoring and control of abstractions (areas and volumes) are easier in surface water areas, where technical and social monitoring and control mechanisms are usually already in place. Box 9 highlights the development of a new model of governance to ensure more sustainable irrigation in France.

[12] www.onema.fr/Banque-prelevements

Box 9: Examples of institutional challenges and good practice

Issue of scattered governance in Greece

In Greece, the main problem to verify the compliance of water abstractions with water rights is the existence of different authorities involved in the decision making process of water issues (e.g. ministry of Environment, ministry of Agriculture, Prefectures, water agencies). The Prefectures (Regions) are issuing the water permits and the Water Agencies are collecting the fees and managing drinking and industrial water. In general, water administration authorities in Greece are currently undergoing significant transformations in order for water governance to comply with the requirements of the WFD. The application of the WFD continues at slow pace, with a number of River Basin Management Plans (RBMPs) pending approval. Progress is impeded by the lack of an efficient fine-imposing mechanism based on an efficient and fair inspection system in line with the current legislation. The inspection systems currently in use are based on random sampling controls with limited or inexistent Decision Support Systems and only partial information from Geographical Information Systems. Source: pers. Comm. with Evagelos Kosmidis.

Development of a new model of governance for irrigation abstractions in France

In France, in order to cope with the issue of scattered governance of irrigation abstractions, *Decret* 2007-1381 of 24 September 2007[13] allows the establishment of “*Organismes Uniques de Gestion Collective*”, which represent a group of irrigators and aim to manage water resources sustainably, for both groundwater and surface water. Such organisations may become mandatory in areas with established risks of regular water shortages, or “*Zones de repartition des eaux*”.

To sum up, success factors for the detection and monitoring of non-authorised abstractions include:

- water rights defined in terms of irrigable area (for non-authorised abstractions of type 1) or volume of water (for non-authorised abstractions of type 2) and linked to specific areas. water rights that are linking a maximum volume to an irrigated area (vs. only to the abstraction point);
- the existence of a GIS-based registry of water rights;
- a clearly structured governance, at the institutional and user level (e.g. association of water users).

[13] www.ladocumentationfrancaise.fr/var/storage/rapports-publics/094000133/0000.pdf

3.4. Summary of suitability of EO to meet water manager's needs

Reminder:

Identified needs, where water rights are defined:

- monitoring of irrigated areas and the abstracted volumes on a regular basis;
- optimising field inspections to ensure compliance with legal water allocation;
- ensuring the reliability of self-declaration of water abstractions;
- ensuring compliance with seasonal water restrictions in case of drought management

If the conditions in terms of institutional and legal framework are favourable, the use of EO products in addition to existing management tools presents great added-value for water managers to enforce water rights (Table 6 and Table 7).

The use of EO products is especially useful for ensuring the respect of water management (standard water rights) and targeting field inspections, where inspections can be carried out across the whole growing season. When an anomaly is identified on the EO maps, staff can rapidly be directed to the field to verify the conformity or legality of abstractions.

The use of EO products is also valid, under specific conditions, for drought management involving seasonal water restrictions. Controlling if these restrictions are applied or not appears particularly challenging: they are generally applied on a short period of time, which requires quick reaction from water managers for identifying non-compliance. EO could be a helpful tool in this respect as it can cover large areas, help target inspections and provide an opportunity to foster equity, enabling a participatory approach and greater transparency.

The time series of EO images for drought management has been used and shown to be reliable in the following cases (e.g. Belmonte et al. 2013):

- when no irrigation was allowed in vulnerable areas where the impact of abstraction could put at risk ecological flows.
- reducing abstraction by decreasing the allowable amount of water per unit of area for each water management unit (farm or group of farms with the same source of water).

Table 6: EO products suitability for the identified water managers' needs

Identified needs of water managers	EO suitability	EO potential and assets	Shortcomings and barriers
Optimisation of inspections / Reliability of self-declarations → Detection of irrigated areas and monitoring of abstracted volumes	High	EO enables full area coverage for detecting "suspicious" land parcels and directing field inspections there	Difficulty to clearly differentiate perennial crops Technicians require training Dependent upon the existence and availability of legal reference data
Respect of restrictions for drought management	Medium	EO enables full area coverage of areas at risk (where restrictions apply) for detecting "suspicious" land parcels and directing	Difficulties to detect partial and short-term restrictions in perennial crops Requires reactivity in the

Identified needs of water managers	EO suitability	EO potential and assets	Shortcomings and barriers
		field inspections there.	processing of information and procedures in place to handle on-demand requests by organisations in charge of managing water restrictions Technicians require training Dependent upon the timescale and nature of restriction measures

Table 7: Assets and shortcomings of the use of EO for the detection and monitoring of non-authorised abstractions

	Assets	Shortcomings	Variable factors
Administrative and legal	Efficiency of surveillance and inspection Objective assessment Consideration as legal evidence in at least one country (Spain)	Still little consideration as legal evidence Access to data	Status of implementation of water rights, nature of water right, and availability of this information Political commitment to secure compliance with water rights
Societal	Acceptance and high interest demonstrated by representatives of water authorities Potential instrument for conflict resolution	Little knowledge (in MS other than Spain and Italy) of the use of such technologies for the detection and management of non-authorised water abstractions.	Local challenges related to water Support of users communities, enabling participation, collaboration (citizen science), transparency

Step 4 - Exploring complementary applications

Objectives:

This step consists in optimising the use of EO products by considering the range of intermediate applications for a more sustainable management of water resources, beyond verifying compliance with water rights.

4.1. Opportunities

Because of the prerequisite related to water rights, it is not always possible to detect non-authorised abstractions in some Member States. However, EO products described above allow for the development of a range of intermediate applications that could meet some of the water managers' needs identified in STEP 1 p.13 and could contribute more generally to the sustainable management of abstractions.

In particular, EO maps of irrigated areas and time series of water consumption can be used for the following intermediate applications:

- where water rights are under transition, from historic to modern management, EO facilitates the regularisation/update of water rights through the detection of irrigated areas without permits and/or non-irrigated areas despite permits. Maps of irrigated areas can indeed be obtained from archive satellite data for many years (back to 1972 when first Landsat satellite was launched) to assign and rectify water rights[14];
- better knowledge of irrigated areas, irrigation requirements and abstractions, in order to better inform the development and/or revision of management plans and to monitor their implementation;
- ex-post assessment of the efficiency of water saving actions taken on the catchment, at different time scales (multi-annual, annual, monthly);
- irrigation scheduling (weekly);
- implementation of volume-based water fees.

The detailed crop maps obtained with EO images can also be used to support other local land-based services (such as the production of the pan-European land use & land cover database

[14] This application must however consider the available water resources in order to avoid over-allocations and ensure the sustainable management of water.

CORINE[15] and new Copernicus High Resolution land cover Layers and/or the land parcel identification system (LPIS[16])) or the control of the implementation of agro-environmental measures for instance as in the case of South France (see Annex 1A).

Generally, maps of irrigated areas derived from satellite data can be shared and verified independently by many stakeholders and thus provide tools for participation and conflict resolution.

4.2. Suitability of EO products

Table 8: EO products suitability for the identified water managers' needs

Identified needs of water managers	EO suitability	EO potential and assets	Shortcomings and barriers
Regularisation/updates of water rights	High	Identification of irrigation back to 1972 when first Landsat satellite was launched	Recognition as legal evidence achieved e.g. in Spain but not in most MS
Knowledge of irrigated areas and abstracted volumes for better water management	High	Large area coverage at adequate spatial and temporal resolution (see text for details*)	Users in many areas not yet prepared (technical capacity, expertise, administrative structures)
Ex-post assessment of the efficiency of actions taken, at different time scales	High	EO-based indices (water abstraction vs planning; irrigated vs irrigable) enable full area coverage at adequate resolution	Users training and uptake needed
Irrigation scheduling	High	Fine estimates of water crop requirements	Users training
Implementation of volume-based fees	High	Better knowledge of volumes abstracted, compared to calculations based on irrigated areas and type of cultivated crops.	Users training and uptake needed

[15] CORINE is a pan-European land-cover classification, managed by the European Environment Agency (EEA), with data provided by MS.

[16] LPIS (land parcel information system) is part of IACS (Integrated Administration and Control System) developed for the implementation of the EU Common agricultural Pollicy, and technically managed by the JRC. http://ies.jrc.ec.europa.eu/our-activities/support-for-member-states/lpis-iacs.html

Step 5 - Roadmap for water managers towards implementation in new areas

A water manager interested in implementing EO-based abstractions monitoring would best follow a series of basic steps:

1- Establish peer-to-peer contacts with water managers operating at the same level (MS government, regional government, or Water User Association) in order to get a first-hand experience of the system or service in operational conditions;

2- Make a detailed description of current tasks and routine operations and an inventory of the data needed for this purpose and from which source data is currently available;

3- Make an inventory of available data (as required for EO approach, according to the checklist in Table 2), of missing data, and of potential synergies with activities in other areas of the same institution;

4- Possibly repeat step 1 with the newly compiled information from steps 2 and 3;

5- Check options of in-house EO- and/or GIS-capabilities –capacities and compare with potential external service providers; estimate draft budget requirements;

6- Set up a pilot and evaluate with all relevant stakeholders (including financing options);

7- Set up an implementation plan and secure financing.

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Conclusions

Whereas over-abstraction may be a significant challenge for water managers to ensure the sustainable use of available resources, EO data has already been used in many areas in the EU to support monitoring of individual abstractions. Irrigated areas and crop water requirements can be identified with great accuracy, especially in semi-arid areas, generally comparable to that of estimates from field work and from FAO56 (crop water requirements tables for major crop types). The estimation of abstracted water volumes requires information and/or data on irrigation system and conveyer system efficiencies, which may increase uncertainty, but the overall approach still achieves good accuracy.

This practical experience, in addition to the significantly developed technical literature, demonstrate that such tools can be successfully developed and used by water managers, in particular in areas with low resource availability and great pressure from irrigation. However, EO cannot be considered as a stand-alone option as it requires field measurements for calibration (*in-situ* data) as well as a set of local data to support the analysis of crop requirements and abstractions.

In the present stage of development, this kind of tools is particularly relevant to monitor irrigation abstractions in agricultural areas with regular water shortages and high reliance on irrigation, and in areas with large parcels cultivated with annual crops. It may be less adapted for (sub-)humid areas (where irrigation remains often supplemental), where vegetation is mostly perennial and/or where mixed patterns of crops in small parcels (<1 ha) are predominant, as it requires further *in-situ* data and sophisticated infrastructures (with additional costs and human resources requirements). Expected technological advances will contribute to further increase the accuracy, accessibility (technical and economic) and frequency (e.g. cloud-free images) of such procedures.
In this respect, EO tools carry a great potential to help water managers deal with non-authorised abstractions issues, although lessons learnt from practical examples show that political commitment to secure water rights as well as appropriate legal, institutional and administrative framework are key requirements for such an application.

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