Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

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Executive summary

Water is a precious resource, and its availability is, and will increasingly become a challenge through (inter alia) climate change. Steps have already been taken by the European Union (EU) to identify measures that may reduce the pressure on water bodies. The goal is to reach the objective of the Water Framework Directive, recently renewed in the Water milestone of the Roadmap to a Resource Efficient Europe “Good status – quality, quantity and use - of waters attained in all EU river basins in 2015”. At EU level, 24% of water abstracted is for agriculture - most of which is used for irrigation (EEA, 2009). Most drought and scarcity issues occur in Southern Member States (MS) but increasingly in other locations such as certain river basins (RB) in the UK. A high part of the water used for agriculture, and more particularly irrigation, does not return to a water body, thus the sector may have much to deliver in terms of water savings.

This study provides information on the current situation in EU river basins as regards water abstracted, consumed and used for agriculture, and compiles conclusions from available studies to identify how water can be saved in agriculture. Those solutions include techniques and practices to reduce water losses in agriculture, but also alternative solutions such as water reuse, storage or harvesting. These solutions do not necessarily save water as such, but reduce pressure on water bodies through reduced abstraction or moving abstraction to times where adverse impacts are lower. Technological, best-practice and socio-economic responses have been identified.

Methodology

Data was gathered from across the EU about abstraction, consumption and use at national and river basin level, annually and where available seasonally. The study then identified where water is lost in irrigation systems. This allowed to identify the ways to reduce these losses, but also provided information on other approaches to save water, by using “alternative” sources of water; focusing on technological, best-practice and socio-economic responses. Existing studies were analysed providing scientific information on the potential of ten of the identified responses. Four case studies provided real-life information on the implementation of selected responses and their benefits. Conclusions were drawn from the information gathered.

Water use, abstraction and consumption by agriculture

The first need is to understand how much water is abstracted, consumed and used for agriculture in each river basin of the EU (Chapter 2). The study is accompanied by an excel table that details the data that has been collected. An illustration of the data collected is provided in Figure 1. While data is available at national level annually, issues of inconsistencies were identified. Data can be found at river basin level in many MS, but a significant amount of effort is required to collect the data and data contain many gaps. Even at national level, many gaps can be found, since not all MS report every year (resulting in incomplete datasets) and definitions are not always comparable.
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Figure 1-1: Illustration of the data that can be found in the accompanying excel table

The DPSIR framework\(^1\) may be used to understand the issues linked to quantitative management of water (Figure 2).

The pedo-climatic conditions (i.e. climatic conditions and soil type) are important drivers in how much water is available for use, with population growth, increase of irrigated areas, etc. driving the demand for water. Pressure is put by consumptive uses of water. Users may compete for water, in which case available water is allocated for priority uses. The water resource state of MS is assessed through the Water Exploitation Index that is being revised to more precisely reflect the local situations. The aim of measures is to reduce negative impacts such as water scarcity, including on ecosystems, through implementing adequate responses (i.e. techniques, practices or other approaches).

\(^1\) Driving forces-Pressures-State-Impacts-Responses, framework developed by the European Environment Agency.
Three types of responses have been identified, which are described in chapter 3:

- Technological and management approaches to reduce water losses
- Using water from other sources (reuse, storage, harvesting)
- Socio-economic responses (policies, pricing, awareness-raising, etc.)

Ten responses are then analysed further, based on scientific studies (Chapter 4). Their presentation includes a description, the lessons that can be learned, their transferability, and their policy implications. Additionally, selected responses are further analysed in real-life through case studies (Chapter 5).

- **Technological and management approaches to reduce water losses**

One approach to improve sustainable management of water quantities is to reduce water losses (e.g. storage losses, conveyance losses, transpiration, evaporation, run-off, drainage). Nine responses are investigated to minimise those losses: Improvement of irrigation systems, Deficit irrigation strategies, Reduction of evaporation during storage, Decreasing soil evaporation, Irrigation scheduling, Reducing runoff, Water table management, Changing planting date and Crop selection.

Some of the responses identified from the case studies provide further information on how they were implemented in certain MS. In Cyprus, efficient irrigation systems have been installed, while in France (Adour-Garonne RB), cropping patterns are changing due to reduced water availability and irrigation scheduling is in place that advises farmers on when and how much to irrigate. In Italy (Po RB) scheduling is also in place through an internet platform and remote sensing is being investigated to provide information on irrigation water management. The initiatives have shown...
to save water, through proactive (e.g. advice) or reactive (e.g. changing cropping patterns) means.

- **Using water from other sources (reuse, storage, harvesting)**

Using water from other sources, not strictly saving water, reduces pressure on water bodies by reducing abstraction, abstracting at times and places where it is not an issue or by reusing water. Water reuse is further investigated through studies in Cyprus and again in the case study. In the UK (Anglian RB), the use of winter storage reservoirs, that are created on-farm and where water abstracted in the winter is stored for use in the summer is investigated in the case study. Water reuse is found beneficial in Cyprus since it allows to use wastewater in a beneficial way, provides water with certainty to farmers; while strict rules apply for the uses that may be made of the recycled water, depending on treatment. The use of winter reservoirs is shown to deliver many benefits, the main advantage being security of supply. Reservoirs are costly and planning issues may arise, which are identified as the two main barriers to use. Shared reservoirs are an increasingly considered option.

- **Socio-economic responses (policies, pricing, awareness-raising, etc.)**

Other responses include regulation, auditing, pricing, consumer pressure, awareness-raising, and crop selection. These responses can be used for encouraging the uptake of technologies, improved management or use of alternative water sources (e.g. advice on efficient techniques, subsidies for water reuse). As part of the case studies, the French regulatory limitations of water uses, water allocation policies in Cyprus and a situation where farmers have organised water turns (i.e. organising who abstracts water when to smoothen water abstraction in time) are investigated. These initiatives deliver good results, respectively to limit water use, transparently allocate water to competing users, and smoothening water abstraction to limit impacts.

- **Findings and recommendations**

While the use of water by agriculture and more specifically irrigation is high in the EU, and especially in Southern MS, a number of issues must be taken into account when trying to find solutions. For example, water that is “lost” is not easily defined. Reducing losses in agriculture may result in reducing water available in other parts of the basin, since such losses can be beneficial to ecosystems or for replenishing certain water bodies. However, this must be assessed on a case-by-case basis. Another issue is the fact that increasing efficiency of water use may not necessarily lead to reduced pressure on water bodies. The water saved may be used for other purposes, whether still in agriculture, by expanding irrigated fields or other human uses. Lastly, water is a limiting factor in many Southern MS, and yield and/or quality requirements are set through contracts and/or through demand from the wider public for agricultural products.

Ensuring that water saved is being translated into sustainable management of water quantities i.e. “reducing the pressure by agriculture on water bodies” is necessary. Indeed, the level at which decisions can be taken and the available knowledge differ. While farmers can save water, sustainable water management requires an understanding of the needs of the farmers of the whole river basin, and from other users, to adequately allocate and use water.

Several measures can be used to ensure that this is achieved, but must be adapted to the local situation. Measuring and monitoring is required to better understand how much water is used,
where and when, and to provide the means to adequately allocate water. Regulation and appropriate pricing can be used to reflect the true value of water. Both will leave farmers with the choice of which responses to implement. Changing cropping patterns is a response that would allow adaptation to foreseen changes, but requires economic solutions that may not easily be influenced by EU policies. Increasing advice and scheduling is identified in several cases as important, and is required for ensuring that adequate technological and management solutions can be implemented by farmers. Some of those techniques and practices are investigated in the study. Water stewardship, by promoting collective organisation, helps to foster understanding and common responsibility. Lastly, and at the bottom of the water hierarchy, alternative sources of water can be used, that will at the same time, reduce wastewater (corresponding to a relatively high goal of the waste hierarchy).

As a conclusion, adequate governance and knowledge levels are crucial for ensuring that water savings deliver their benefits of reducing pressure on water bodies, so that sustainable management of water quantities in all river basins of the EU can be achieved. It also requires that all levels of governance are involved, since driving forces of irrigation go through the supply chain until consumers. Lastly, many solutions allow water saving in agriculture, but each solution must be adapted to the local situation. Advice, incentives or economic alternatives will influence farmer’s choices, and may deliver water savings. To find adapted solutions, the whole ecosystem must be considered, to account for all water needs, including environmental needs, and ensure they are met as adequately as possible.
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Chapter 1: Introduction

Water scarcity and droughts is recognised as an important issue by the European Commission (EC), who carried out an in-depth assessment of water scarcity and droughts in the European Union (EU) and released a ‘Communication on water scarcity and drought’ in 2007 (EC 2007). At the 2010 Parliamentary Intergroup on water, DG Environment underlined again the need for river maintenance and increased efficiency of using water (EWP, 2010). Furthermore, as a follow up to its 2007 Communication, the Commission has scheduled a number of policy reviews to develop a Blueprint to safeguard European waters by 2012 (Europa Press release, 2010). The Water Framework Directive (WFD) introduced requirements at EU level, including the drafting of River Basin Management Plans (RBMP). The RBMP identify a programme of measures (POM) at river basin level for achieving the environmental objectives of the Water Framework Directive cost-effectively. The WFD requirements have proven to be effective for reducing water quality issues in the EU. Water quantity issues have for the moment received less attention, but are equally important for achieving sustainable water use in the long-term.

At EU level, the largest proportion (44%) of the total amount of water extracted per year is used for the generation of energy, compared with 24% for agriculture (corresponding to 85 000 Mm$^3$ of water). However, while most of the water used for energy generation is returned to a water body, agriculture uses the largest volume of water which is not returned, and this is mainly used for irrigation (EEA, 2009). In the context of climate change and water scarcity in many EU river basins, reduced water consumption is increasingly considered an important aspect of sustainable development. Due to the large share of water used by agriculture, the growing need for adaptation to reduced water availability (as recent years have experienced reduced agricultural production due to lack of water and this is expected to increase in the future with climate change), and the availability of technologies and practices that allow for changes, the agricultural sector is seen as a key player in enhancing the sustainability of water use in the EU.

The focus of the study is on water savings in agriculture. The aim is to provide to the EC clarification on the current situation of agricultural water use in the EU river basins, as well as to compile conclusions from numerous studies available. The findings will provide input on the options that need to be considered at EU level in order to maximise savings in agricultural water use and/or reduce pressure on water bodies by agriculture. This input may be used inter alia for developing recommendations for Member States and river basin management authorities so that they are able to better integrate water savings in agriculture. The project will also feed into the Commission’s Blueprint. The study provides information about techniques and practices that may save water, but also other actions that may reduce the pressure on ecosystems (such as alternative water use, water harvesting, or scheduling collectively abstractions).
1.1 Water and agriculture

Agriculture accounts for a significant part of EU’s economy and land-use, and specifically so for certain of its Member States (MS). The EU-27 agricultural industry generated EUR 125 400 million of gross value added (at producer prices, 2009). An estimated 40,1 % of the total land area of the EU-27 was utilised agricultural area (UAA) in 2007 (Eurostat, 2011). Just over 48 million persons were employed in the EU-27 food chain in 2008; working in close to 14 million different holdings/enterprises, generating EUR 751 008 million of added value (Eurostat, 2011). In Poland for example, the Gross value added of the agricultural industry accounted for 5 651 million euro, about 2% of the national GDP (Eurostat, 2011). In Ireland, the agri-food sector contributes a value of 24 billion EUR to the national economy, generates 6.3% of gross value added, and provides 7.4% of national employment. The agri-food sector counts for around 8% of Irish GDP with primary agriculture accounting for 3% of the GDP. When employment in inputs, processing and marketing is included, the agri-food sector accounts for almost 10% of employment³.

All aspects of agricultural production require water, and are broadly subdivided in three types of uses: irrigation, as crops require water to grow; animal rearing, which require water for drinking and hygiene; and operations and on-farm processing. It takes approximately 3 500 litres of water to produce the food a typical European consumes in one day. However, a large proportion of this comes from rainfall (so called “green water”). For example, although beef fattening in the UK requires approximately 17 000 litres of water per kg of carcase weight, 84% of this water is rainfall, used at the point where it falls (Chatterton et al., 2010). On the other hand, irrigated crop production in southern Europe may be entirely dependent on surface and groundwater resources (so called “blue water”), for which there is increasing competition at the basin and regional scales.

The importance of water for agriculture evidently differs across EU regions. The water consumption of the Southern countries generally accounts for more than two-thirds of total abstraction. In Northern Europe, level of water abstracted appears much lower. In Greece, Portugal and Spain more than 90% of the overall water consumption is used in agriculture, whereas e.g. Bulgaria, Cyprus, Denmark, France, Latvia and Romania use between 50% and 90% for this purpose. The use of water also differs in different geographic regions. While water use for livestock consumption is important in northern countries, most adverse impacts in water scarce countries (e.g. Southern Member States), result from water used for crop irrigation purposes (EEA, 2009). Water management is thus especially important in crop irrigation.

Irrigation serves to provide crops with the necessary water for their growth, to reduce risks in agriculture, as it renders yields more stable, and ensures a constant quality (in particular for fruits, as regards their size), and is used but also as a strategy for reducing frost risks. In Spain, 14% of agricultural land under irrigation yields more that 60% of the total value of agricultural products and in Italy, 50% of agricultural production and 60% of the total value of agricultural products come from 21% of agricultural land that is under irrigation (Copa-Cogeca 2009).

³ Irish Agriculture and Food Development Authority, see www.teagasc.ie/agrifood/
As water is the limiting factor for agricultural production in some EU regions, the absence of irrigation could potentially lead to land abandonment, due to economic losses (EEA, 2009). Figure 1-1 shows irrigation intensity in Europe, illustrating the intensive use of irrigation in Southern Europe (Southern Romania, Greece, Po valley in Italy, South-West France) but also in the UK, Netherlands and Denmark. Importantly however, the map does not show how often, or how much, water is used in these regions, nor what the production is in the area and/or the type of products grown.

Since the years 2000’s and the implementation of the Water Framework Directive, a slight decrease has been observed in water quantities abstracted for agriculture (see the Excel table in Annex and section 2.3)

1.2 Existing information and remaining gaps

Much work around water scarcity and droughts has already been done at EU, national and local levels, in particular about agriculture. The study uses existing information and analyses case studies to draw on the information available and propose recommendations for reducing the pressure by agriculture on water bodies.

Information is available at national level and for calculating some indicators identified below. However, that scale and the indicators are debated since they are not necessarily the most relevant for understanding and enhancing water management in the EU.

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3 Irrigation intensity is illustrated here by the percentage of area equipped for irrigation, by 5' cell, derived from the Global Map of Irrigated Areas
Scales

In the EU, 168 river basins are identified in the 27 MS (as illustrated in Figure 1-2), some of which are shared internationally within or beyond EU Member States.

The river basin (RB) is the relevant scale to understand water scarcity issues, as identified by the WFD which requires RBMP to be drafted at that scale. River basins may stretch over several countries and analysing the situation at that level allows to encompass the activities going on in the river basin, which are driving requirements for both quality and quantity of the water, i.e. how much water is abstracted and discharged into the river along its course, point sources and non-point sources of pollution, etc.

Indicators

The water exploitation index (WEI) can be used to compare the level of water stress among MS. For each country, the WEI is defined as the mean annual total demand for freshwater divided by the long-term average freshwater resources. It identifies the countries that have high demand in relation to their resources and therefore are prone to suffer problems of water stress. Figure 1-3 presents the WEI of the 27 EU MS as well as some other European countries. According to Eurostat⁴, a WEI above 20% indicates water scarcity problem in a country or in a region. This is the case in Cyprus, Italy, Malta and Spain, countries that can be considered water stressed. The EEA uses this value as a warning threshold. Adapting the index to agriculture could be one way to provide further information on water use in agriculture.

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⁴ Information available from the Eurostat webpage on water statistics:
However, the WEI is criticised as it is implemented at a broad scale, i.e. national scale, and does not provide information at RB level; nor does it account for annual or seasonal variations. Indeed, water quantity generally becomes an issue at certain times of the year in particular, in which uses compete (e.g. irrigation competes for water with tourism in the summer, which is not the case in winter, because both the need is lower and the available water is higher). The climate of each year will influence water needs for most sectors, including agriculture, households, and industries. In agriculture, if the amount of rain is higher, less irrigation water will generally be required. Similarly, evapotranspiration varies depending on the season. Domestic consumption will increase during a hot summer with people taking more showers and using more air conditioning (also true for industry). Additionally, the season plays an important role, as the demand for water is higher in the summer, while rainfalls and replenishing of the groundwater sources occur in the winter/spring. Again, the use of water in large quantities may not be an issue during the winter or in certain locations where water availability is high, but is more problematic in areas or at times where the availability is low (in comparison to the needs).

Figure 1-3: Water exploitation index in the late 1990s (EEA).  
Solid bar: Water exploitation index without water abstraction for energy cooling;  
Dotted bar: WEI based on total water abstraction.

Under the Common Implementation Strategy for the Water Framework Directive, seven awareness-raising indicators have been identified and are currently being tested. These indicators provide, in combination, an overview of the developments as regards water scarcity and droughts and will allow distinguishing between the natural and man-made phenomena. The
full set of indicators will be finalised in spring 2012 in order to be fed into the Impact Assessment for the 2012 Blueprint to Safeguard Europe's Waters.

In addition, the WEI is currently being further developed as part of an EU wide indicator system for water scarcity and droughts. The current WEI presents shortcomings in relation to the identification of water scarcity trends as it is calculated on a country and annual average basis rather than at river basin level. The WEI indicator under development tries to remedy this and solve other methodological issues linked to the need for ecologic flows, the way to account for return flows, hydropower etc.

Another indicator that is used more specifically for agriculture, to understand irrigation practices, is the share of irrigated and irrigable areas in the EU. The irrigable area is defined as the maximum area which could be irrigated in the reference year using the equipment and the quantity of water normally available on the holding. The irrigated area is the area of crops which have actually been irrigated at least once during the 12 months prior to the survey date. Figure 1-4 ranks the MS in terms of how much irrigable areas there are (in ha) and adds information on how much is actually irrigated. This should be put in perspective with the number of UAA in each country, but the graph already allows to identify which countries use irrigation on a wide part of their lands. While the data on irrigated and irrigable areas do not provide any information on what amount of water is put on the fields and how effective irrigation is, it does provide a picture of the importance of irrigated areas in each MS and can provide trends over time. Further details about the data used for this graph are available in a synthetic table in Annex 2.

Figure 1-4: Irrigated and irrigable areas (in ha) in each MS (based on data from the Farm structure survey)
1.3 Content of the report

The first part of the report describes the abstraction, use and consumption of water across the EU, where possible at river basin level. An excel file is provided as a separate deliverable including all the data gathered.

The second part describes responses that can be used to encourage water saving in agriculture.

In the third part, the findings of studies that investigated certain responses are presented and analysed. Case studies in Cyprus, France, Italy and the UK provide further details on existing practices and responses that are used by the farmers.

Lastly, recommendations and conclusions are drawn.
Chapter 2: Overview of water use, abstraction and consumption by agriculture

In brief: This section draws up an overview of the figures related to water abstraction, use and consumption at the country and river basin levels and pinpoints the main gaps concerning these data. The investigation underlines differences for the definitions of the terms “water abstraction”, “water use” and “water consumption” among different data sources (Eurostat, OECD, EEA, Aquastat,) as well as discrepancies for given data between different sources. No complete dataset for a given year can be provided by existing sources. The study has compiled data at river basin level, showing that data is available for certain years, but require significant amounts of efforts to be compiled. Very few seasonal data were found. All together, these gaps make the assessment and the comparison of water issues among the different Member States difficult. The DPSIR framework is used to illustrate the issues that must be taken into account.

This section provides an overview of water use, abstraction and consumption for agriculture in the EU. A comparison of definitions is discussed first. The data collected follows. Data was gathered at national level and, where available, at river basin level. Annual, as well as seasonal data was collected. Remaining issues are discussed at the end of the section, using the DPSIR framework.

2.1 Definitions

- **Water abstraction**
  
  Water abstraction is the term used for water that has been physically removed from its natural site of occurrence (from surface or ground water resources) either temporarily (e.g. for cooling purpose) or permanently (e.g. for irrigation).

- **Water use**
  
  Water use means the total volume of water needed to satisfy the different water services, including volumes 'lost' during transport, for example leaks from pipes and evaporation, and in-stream uses (such as environmental flows).

- **Water consumption**
  
  That part of water abstracted (or withdrawn) which does not return to the water body from which it was abstracted because it has evaporated or transpired; been incorporated into products and crops, consumed by man or livestock, discharged to another basin or the sea, or has been returned to the water source in a condition that precludes it from subsequent use. Sometimes
Overview of water use, abstraction and consumption by agriculture

Water will return to the same basin, but only after such a long delay that it causes suffering downstream in which case this can also be regarded as water consumption.

It can be noted that different definitions for these terms are used in different literature sources. Comparing the definitions used by two widely accepted sources of information, the glossary of the European Environment Agency (EEA) and the definition from the Organisation for Economic Co-operation and Development (OECD) illustrates these differences (Table 2-1).

Table 2-1: Definitions of water abstraction, use and consumption

<table>
<thead>
<tr>
<th>Water abstraction</th>
<th>EEA</th>
<th>Water removed from any sources, either permanently or temporarily. Mine water and drainage are included. Similar to water withdrawal</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD</td>
<td>Freshwater taken from ground or surface water sources, either permanently or temporarily, and conveyed to the place of use. If the water is returned to a surface water source, abstraction of the same water by the downstream user is counted again in compiling total abstractions: this may lead to double counting</td>
<td></td>
</tr>
<tr>
<td>Eurostat</td>
<td>Water abstraction is the process of taking water from a source. For European Union (EU) statistical purposes, it is the groundwater and surface water collected for use</td>
<td></td>
</tr>
</tbody>
</table>

| Water use | EEA | Three types of water use are distinguished: (a) withdrawal, where water is taken from a river, or surface or underground reservoir, and after use returned to a natural water body, e.g. water used for cooling in industrial processes. Such return flows are particularly important for downstream users in the case of water taken from rivers; (b) consumptive, which starts with withdrawal but in this case without any return, e.g. irrigation, steam escaping into the atmosphere, water contained in final products, i.e. it is no longer available directly for subsequent uses; (c) non-withdrawal, i.e. the in situ use of a water body for navigation (including the floating of logs by the lumber industry), fishing, recreation, effluent disposal and hydroelectric power generation |
| OECD | Water abstractions for irrigation and other agricultural uses (such as for livestock) from rivers, lakes, and groundwater, and “return flow” from irrigation, but excludes precipitation directly onto agricultural land |
| Aquastat database (FAO) | Annual quantity of water withdrawn for irrigation, livestock and aquaculture purposes. It includes renewable freshwater resources as well as over-abstraction of renewable groundwater or withdrawal of fossil groundwater, use of agricultural drainage water, (treated) wastewater and desalinated water |
Comparing these definitions, it is clear that especially for the terms “water use”, the quantities of water referred to are different. In the definition used for this study, water use includes in-stream water use (this is less relevant for agriculture, but would apply for energy uses), while the OECD definition makes no clear difference between water abstraction and water use.

Additionally, from the definition used in this study, water use should be higher than water abstraction, while generally (see Table 2-1) water abstraction is higher than water use. Finally, for the three definitions chosen for this study, no definition refers to water applied on the field, i.e. the water coming out of the “tap”/ at the end of the pipe, which would account for losses during transport, compared to water abstraction.

2.2 Methodology

Data were first gathered at national level. Such data is easily available and provides a picture of the importance of water use, abstraction and consumption for agriculture in the different MS. Data was gathered by using EU and international databases (Eurostat, FAOstat, OECD reports, national statistics databases), as well as through a literature review (the list of consulted sources is available in Annex 1). Annual data were also gathered at MS level, mainly from OECD sources (see section 2.3.2).

Since the definitions differ (see above), it is also difficult to ensure that the data gathered from different sources encompass the same details. For example, the figures from Sweden related to agricultural water use from 1992 to 2004 in OECD data include aquaculture, because at national level aquaculture is not differentiated than other agricultural activities. In other countries the situation is different, and may be less an issue since aquaculture is not as important.

As a second step, data were gathered at river basin level. This was compiled from the literature, official sources (river basin authorities websites mostly) and from experts of the River Basin Network. This allows those RB in which water is mostly used, abstracted or consumed to be identified, as even in water-rich countries, water scarcity may occur in certain RB. In the UK no information at river basin level exists, but information was available at regional level.

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5 Experts from the River Basin Network that provided information refer to data in the Northern Appenines District (Italy), Sweden, England, Poland, Finland, Seine-Normandie (France), Guadalquivir (Spain)
2.3 Data gathered

2.3.1 National data

Information could be gathered for all the Member States for water use, and/or abstraction, volumes. Where available from the sources investigated, additional data on consumption, irrigation water, or on water used and water consumed, specifically for agriculture or per type of crop, was added.

The accompanying Excel file details the data that was gathered for each country, at national and river basin levels (an illustration of the data available in the table is available in Figure 2-2). Globally, at least one figure on water abstraction and water use has been found for each MS during the last ten years. On the contrary, data on water consumption are scarce, with data available only for Ireland and Sweden. None of these two countries have reported water consumption data in agriculture generally, but reported water consumption related to livestock (Ireland) and per crop type (Sweden).

In addition, the investigation carried out to obtain national data related to water abstraction, use and consumption has highlighted some discrepancies between different sources as well as within a certain source. The figure below (Figure 2-1) illustrates some of these contradictions. Water abstraction and water use are represented for the year 2005. In the case of water abstraction, two types of sources have been compared: data from Eurostat and data from national statistic agencies and in the case of water use the data sources are Herbke 2006 and the data from national statistic agencies. As the data set is not complete for 2005 (no complete data set was found for any year, see also the conclusions in Kristensen, 2010), the data is compared for a few countries only.

For water abstraction, only Bulgaria and Estonia can be compared. In the case of Estonia, this comparison reveals an important variation: 13 Mm$^3$ for Eurostat vs 4.2 Mm$^3$ according to the National Statistic Institute of Bulgaria. Differences have been also noticed for water use. The biggest gap between the two sources was for Lithuania, where the difference is almost 2000 Mm$^3$ of difference and there is also a discrepancy for Estonia.

Finally, the table also highlights some surprising variation between water abstraction and water use in a same country. In Belgium, Slovakia and Slovenia, the volumes of water used are higher than the volumes of water abstracted.
Overview of water use, abstraction and consumption by agriculture

Figure 2-1: Water abstraction and use in the 27 MS (different scales for the two graphs)

The figure is based on different data sources: Eurostat and National Statistic Agencies (NSA) for water abstraction and Herbke (2006) and the NSA for water use. Circles highlight a difference for a same data between two different sources and the arrows shown a discrepancy between water abstraction and water use (water abstraction is expected to be superior to water use).
Overview of water use, abstraction and consumption by agriculture

Figure 2-2: Illustration of the data available in the Excel file
2.3.2 Annual data

Annual data on water abstraction or use reveals trends. Those trends may be determined by the climatic context each year (e.g. 2003 was a drought year EU-wide), cropping patterns, changes in irrigation management, etc.

The UK data from 1995 to 2008 is illustrated in Figure 2-3, plotted against the annual precipitation. Unsurprisingly, the figure illustrates the inverse relationship between the availability of rainwater and irrigation water for several years\(^6\), except for the year 2000, which presents high water abstraction as well as high precipitation. This phenomenon is explained by seasonal variations: the summer was particularly dry that year and important floods occurred in October and November (503 mm of rain recorded for these months).

![Figure 2-3: Total water abstraction for agriculture (orange bars) and annual precipitations (blue line) in England and Wales from 1995 to 2008](image)

Data is generally available for the last decade on water abstraction for agriculture (data were found in the following MS: AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HU, LT, LUS, LV, MT, NL, PL, PT\(^7\), RO, SE, SI, SK, UK).

Some data on water use for agriculture is also found in certain countries (data were found in the following MS: AT, CZ, DE, DK, EL, ES, FI, FR, HU, IT, NL, PL, PT, SE, SK, UK).

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\(^6\) This is not always the case however, as in 2000 for example, both irrigation water and rainfall were high. This could not be explained.

\(^7\) Data for LU and PT was found only for two years, respectively 1995 and 1999, and 1998-2002 for water abstraction for agriculture.
2.3.3 River basin data

Data at river basin level are relatively scarce. For instance in four countries (Austria, Latvia, Lithuania, and Luxembourg), no data are available at RB scale as no monitoring occurs at that scale. This does not necessarily mean that farmers do not know how much water they consume, abstract and consume (or at least know one of these numbers), but that no consolidated number at that scale exists. Table 2-2 below shows the countries in which data are available at river basin scale. The table shows the number of river basins and the number of RB in which some data are available. In this table, no difference is made between the type or amount of data available at that scale. The accompanying database includes all the data gathered. In the countries in which data are available at RB scale, it can be noted that differences apply between those river basins, which can be explained by the size of the RB, the importance of agriculture or irrigated agriculture in those areas, etc. (see the discussion on weighing factors below). These differences are illustrated in Figure 2-4 for Greece and Bulgaria.

Table 2-2: Countries for which some data at river basin (RB) level was found

<table>
<thead>
<tr>
<th>Country</th>
<th>AT</th>
<th>BE</th>
<th>BG</th>
<th>CY</th>
<th>CZ</th>
<th>DE</th>
<th>DK</th>
<th>EE</th>
<th>EL</th>
<th>ES</th>
<th>FI</th>
<th>FR</th>
<th>HU</th>
<th>IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of RB (total)</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>3</td>
<td>14</td>
<td>25</td>
<td>88</td>
<td>129</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>No. of RB for which data was found</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td>8</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>No. of regions for which data was found</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>IT</th>
<th>LT</th>
<th>LU</th>
<th>LV</th>
<th>MT</th>
<th>NL</th>
<th>PT</th>
<th>PL</th>
<th>RO</th>
<th>SE</th>
<th>SI</th>
<th>SK</th>
<th>UK</th>
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<tr>
<td>No. of RB (total)</td>
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<td>2</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>No. of RB for which data was found</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>No. of regions for which data was found</td>
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<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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8 In the accompanying database 3 RB are grouped as data could not be split more specifically.

9 Five of the river basins are overseas departments.
Overview of water use, abstraction and consumption by agriculture

Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

Figure 2-4: National and RB water used volumes in agriculture for Greece and Bulgaria

Total water used Greece: 6427.5 million m³

Total water used Bulgaria: 326.2 million m³
2.3.4 Seasonal data

Finally, seasonal data are even scarcer and could be found in a few cases (in the Roxo dam area in Portugal, see Figure 2-5 and in two French river basin: the Moeze basin, a sub-basin of the Adour Garonne river basin and the Fumemorte basin, a sub-basin of the Rhone-Méditerranée river basin). The figures illustrate very well that the water abstraction for irrigation is concentrated in a few months only and do not require supply throughout the year.

![Figure 2-5: Monthly water supply for irrigation in the Roxo dam area, Beja district of Alentejo province, Portugal](image)

2.3.5 Findings of the research

Data on water abstraction for agriculture at national level is available from all EU Member States from Eurostat and FAO. It can be noted that in general more data are available in terms of how much is abstracted than how much is used or consumed (see Figure 2-1). This can also be linked to the fact that the definition of use or consumption is differs depending on the source (see the discussion on definitions above). This kind of data allows trends to be derived and to analyse where water quantities may become an issue, if data on availability are also provided. However, such data will be useful if used at river basin level, and if the use at certain periods of the year can be identified, since water is mostly used in the summer, when it is also less available. Requiring data to be gathered and reported from the river basin authorities could be a way to improve the quality and availability of data. Through the farm structure survey some data could possibly also be collected. However, it is important to streamline the requirements for data, as stakeholders tend to not respond if too many data must be reported, leading to missing data in EU datasets.

However, when trying to compare data across RB or MS, a weighing factor should be introduced. Indeed, with raw data as presented in the table, no comparison can be made across countries, or even across river basins due to differing scales. For example, the countries that abstract most
water are Spain, Italy and Portugal, which are also big countries, with large agricultural sectors, while those abstracting less water are Slovenia, Lithuania and Luxembourg, on the opposite very small countries. The WEI is the current indicator calculated (see Figure 1-3) to try to overcome these obstacles.

Finally, the results of this data collection show that different data regarding water use in agriculture were collected in different countries, partly reflecting differences in the importance of various agricultural sectors. For example, in Finland and Ireland, data mostly concern livestock farming (water used in livestock for Finland and cattle and sheep water consumption in Ireland) whereas in Spain and Sweden, there are more data available related to water consumption by crops.

### 2.3.6 Discussion

In order to understand the issues linked to quantitative management of water, the DPSIR framework is used (Figure 2-6). The DPSIR framework was developed by the EEA and allows to analyse an issue at hand by identifying the 5 following factors: Driving forces-Pressures-State-Impacts-Responses (DPSIR).


Drivers

An important driver for water availability is local pedo-climatic conditions (i.e. local interaction between soil and climate), in terms of rainfall (recharging water bodies and providing “green water” to crops), temperature (driving evapotranspiration of crops), soil retention capacity, etc. In many regions where scarcity already occurs, climate change is expected to increase the issues, and such issues may appear in certain regions currently spared. Other drivers include population growth, which can potentially be linked to a growing demand for water, urbanisation and industrialisation, intensification of agriculture as well as the expansion of irrigated areas. Such drivers determine the pressures in terms of how much water is abstracted from the water bodies. Low water efficiency or high water losses also indirectly drive water availability by requiring more water for irrigation compared to water efficient situations.

In order to compare the data collected about water abstracted, used and consumed in agriculture, these drivers must be taken into account. In particular, the water efficiency can be weighed according to several of these identified drivers. Efficiency is generally defined as an amount required as input compared to an amount obtained as an output. For instance, how much water is needed to grow one ton of wheat. Other efficiency factors compare the water used per person, or per area. Those factors may help compare countries together, to account for their contexts. For water used in agriculture, it may be relevant to investigate water quantities abstracted, consumed or used: per capita, using the population of the MS; per capita of farmer; per ha of total land; per ha of cultivated land or land used for farming (incl. livestock grazing areas); per ha of irrigated land; per yield depending on the crops; or other.

Using weighing factors will give different information, with advantages and disadvantages for each. Using the population of the country is one of the easily available information, to obtain water use per inhabitant, as is the total land in each country or even in the RB (water used per hectare). However, these will not account for the importance of agriculture in the country and/or RB. Using a factor accounting for the number of farmers or area of cultivated land may thus be more relevant, but depends on how much water is used for irrigation, and this may not account for water used by livestock in that case. The most relevant factor may be irrigated land area, if it can be linked to irrigation water use, abstraction or consumption. However, the data is not available in all cases and especially not necessarily at RB scale. Linking the data to yields and/or financial value of crops that use the water is a possibility, to assess economic efficiency of the water used, and possibly to identify areas where some crops are better suited than others with respect to water use. However, economic information will change the trend for two main reasons. First of all farmers will always have the right to decide which crops they are growing, and this includes many factors other than water, e.g. contracts with the buyers, international market prices, etc. Secondly, if all farmers in a region grow the same crops the economic value will go down. Thirdly, such even landscape will bring lower ecosystem services, whether landscape, biodiversity or other is considered.

Additionally, and specifically when investigating water savings in agriculture, water losses must be clearly defined. Indeed, water lost because it is not productive for the crop in terms of its growth may still be useful, in certain contexts, for recharging groundwater sources, increasing surface flows, sustaining nearby ecosystems, and/or reducing salinity in soils. The water may however, in other contexts, be drained and take away pesticides and fertilisers, polluting
Overview of water use, abstraction and consumption by agriculture

downstream or underground waters. The savings that may be made thus always depend on a context and require a system evaluation to ensure no unforeseen effects occur.

**Pressures**

Pressure is put on water bodies, because water is abstracted to meet the needs in terms of drinking water, industrial water and agricultural water (see introduction). This may result in competition for limited water resources. The competition may result in water flows being lowered (or even stopped) if too much water is abstracted, destroying natural ecosystems that rely on water downstream, or in the need to prioritise the water uses, not meeting the demand of certain sectors, while conserving a minimal flow, in accordance with the WFD.

**State**

The fact that water is abstracted from a water body does not necessarily lead to a bad state of the water body. The impact depends on the availability of water, both in terms of location and time of the year. The aim of the WFD is not to save water per se, but to “prevent further deterioration and protect and enhance the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems” (Article 1a). The water savings relevant for an area are thus those savings that allow to reduce the pressure from users, so that enough water for environmental/ecological needs is available. Indeed, abstracting water in an area where there is a lot of water is arguably less problematic than in water scarce areas. Additionally, considering the whole ecosystem when considering water availability is important, as water transported in leaking pipes or additional water not used by crops may serve to refill groundwater sources. Water from the river basin in which the activity is located is usually used in the same basin, but in certain cases transfers of water between river basins may occur and alternative sources of water may be used (see Chapter 3: on responses). The state of water exploitation is currently assessed using the WEI (see section 1.2).

As shown in the table above, data about water abstraction at river basin level is currently not available easily in all RB and could require additional work from several countries. Including seasonal variations in the index would need further changes to the index. Further investigating this relationship is crucial to understanding how to render water use sustainable for a given region.

**Impacts**

The impacts of water uses may be water scarcity, in a specific area or at specific times of the year. This may result in negative impacts on ecosystems that depend on water availability, decreases in water quality (impacting subsequent uses) and result in the impossibility to meet human needs for water. In this case, human needs may be prioritised to meet the most important needs.

**Responses**

In order to respond to the lack of water, many initiatives may be taken, which are presented in the following chapters. Since these initiatives respond to the lack of water, by providing mitigation or adaptation answers, they are called responses. These responses go from finding 10 This can be discussed as abstracting water also has impacts on energy use, water quality, etc.
more efficient techniques and practices, collaborative solutions, to using alternative water sources.
Chapter 3: Identification of responses for water savings in agriculture

In brief: This section aims at identifying techniques, practices and socio-economic responses that contribute to (1) reducing water losses in the system through technological and management approaches, (2) reducing pressure on water bodies by using "other sources of water" and (3) changing practices through socio-economic approaches e.g. by regulating, raising awareness and giving incentives. These responses are all described, including the identification of means of action and constraints.

Water savings in agriculture relate to reducing the amount of water used for agriculture. However, this is not the only possible way to reduce the pressure on water sources (as identified aim of the WFD). Reductions in the pressure on water sources can be realised by using appropriate techniques for irrigation, relevant management practices, by using water from alternative sources or by influencing parameters that will impact the socio-economic context, resulting in water savings (e.g. awareness-raising, diffusion of best practices, regulations, pricing, financial incentives). All these possibilities are referred to as "responses" that may be used to decrease the pressure on water sources, either by reducing water abstraction, consumption and/or use in agriculture, or by using other sources of water.

The first approach aims to reduce water losses in the system being used. This is referred to in the text below as "technological and management approaches". In that case, the current system of water abstraction, transport, storage, delivery and consumption is considered. At each step of the water use chain, the relevance of trying to reduce water losses is considered, and the ways for reducing the loss are identified. The responses that may be used to increase water savings this way are described in section 3.1.

The second approach is to modify the current system by turning to other sources of water, reducing the pressure on "conventional" water sources (surface and ground water sources), or to reduce the pressure on those conventional water sources at critical times of the year. In that case, water may be re-used, stored on-farm (using water available in seasons where it is abundant) or harvested (rainwater harvesting). In that second approach (see section 3.2) no water is "saved", but the impact on water bodies and/or the impact during the water scarce season is lower.

The third approach looks at the more general socio-economic context, and aims to change practices by raising-awareness and giving incentives, through communication, regulations, training, price signals, labelling, etc. This approach (described in section 3.3) either works indirectly on the water savings, by requesting water savings (e.g. through regulation, certification, labelling), letting the farmers select the best approach for their own farming system, or directly, by promoting certain water saving techniques/management practices or alternative water uses.
Each of the responses described in the sections below have their own aims, and entail advantages and constraints. One of the constraints relate to the field applicability of the response. Certain crops may only be cultivated in certain pedoclimatic conditions and for those crops only certain irrigation systems may be appropriate. Figure 3-1 illustrates 3 types of irrigation systems used in the EU. Sprinklers are mostly used on grain crops, drip irrigation for fruits and legumes and flood irrigation for various crops, including maize and wheat. Other constraints relate to the need for support/training by the local authorities, allowing for sufficient time for the learning process and taking into account public perception (e.g. reuse of grey water and sanitary issues), as well as considering the possibilities for change by the farmers (e.g. many farmers have contracts with buyers and may not easily change their cropping patterns or practices). In addition the access to the water can also be a constraint for farmers. For example in France, between 2003 and 2005, maize producers paid on average between 2900 EUR for electricity and 2600 EUR for water. The amounts depend very much on the access to water, as extraction from individual water access is free for farmers in France. Farmers with such an access paid in 2005 in total around 30 EUR/ha and farmers without access paid around 180 EUR/ha (La France agricole, 2007).

Figure 3-1: Irrigation systems (sprinkler, left; drip irrigation, centre; and flood irrigation, right)

3.1 Technological and management approaches to reducing water losses

Figure 3-2 presents a framework for the analysis of water saving in agriculture. The total water used in crop production is derived from rainfall (green box) or water abstracted from surface and groundwater sources. In general, emphasis on water saving is placed on abstracted water, as this has the higher opportunity cost, although reducing rainwater use may also have environmental and water resource benefits.

In Figure 3-2, the red text represents non-productive water losses. Technological and management approaches to minimising these losses will result in water savings. The white boxes refer to abstracted water that is not consumed and returned to the water resource in a useable condition. There is often no benefit in reducing these losses.
The improvement of irrigation systems is further investigated in response 1 on page 65.

3.1.1 Storage losses (on-farm dams & reservoirs):

- **Description**
  
The loss of stored water from surface water reservoirs through evaporation is inevitable and can be significant in arid and semi-arid climates. Water will evaporate much faster from open water surface than from the surrounding landscape due to the lower surface resistance. Water from smaller water bodies evaporate at a faster rate than from large water bodies in the same climatic conditions due to turbulence and edge effects. Therefore, evaporative loss per unit area is greater from farm dams compared to large reservoirs. It is important to note that the impact of farm dams on storages losses will be greatest during periods of high water evaporation which are often the same as drought periods, in which irrigation is needed.

Evaporation rates are affected by latitude of the water body (solar energy input), air and water temperatures, air pressure, wind velocity over the water surface and turbulence in the water. In years with little precipitation, evaporation loss may exceed the amount of gain from rainfall.

Leaks in reservoirs can also result in water being lost and requires monitoring.

- **Means of action**

  The use of covers and shades, monolayers or wind breaks on farm dams has the potential to reduce evaporation.
Floating covers and objects

Floating covers reduce evaporation losses and assist in temperature stabilisation. Another advantage is the elimination of algae growth and contamination from airborne pollutants. Covers are suited to small dams. They may be modular or may fully encapsulate the upper surface of the reservoir by being mechanically fixed and sealed around the perimeter. They can be designed to allow for fluctuating water levels, rainwater drainage, and routine access. Floating covers are usually manufactured from reinforced polypropylene.

Rates of reduced evaporation close to 85% with suspended shade cloth covers (SSCCs) have been documented in studies in south-east Spain\(^1\). In addition to floating covers, floating objects can also be used with the same purpose. Their installation is easier and the cost cheaper.

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Biological covers

Some biological covers, such as lily pads and duckweed, have the potential to reduce the evaporation from the water surface they live on. The evaporation reduction efficiency is much lower than other methods available and have little emphasis placed on them.

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Monolayers

Monolayers are chemical films at the water / air interface that are only one molecule in thickness and serve to decrease evaporation. For example, Aquatain\(^TM\) is a commercially available, silicone-based monolayer that has been shown to reduce evaporated water by over 50%\(^1\).\(^2\)

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Wind breaks

Wind breaks reduce the speed and turbulence of air movement over the water surface and can reduce the evaporation rate by 20 – 30%\(^1\) depending on the density, height, orientation and distance from the water. Both natural (trees) and artificial windbreaks are used. Natural wind breaks provide other benefits in terms of shade and habitat.

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Design features

Water storages may be constructed or altered to proportionally reduce the evaporation rates by using methods such as:

- deeper storage with smaller surface areas or,
- cellular constructions which divides large storages into smaller ones to reduce wind action and allows water depth to be maximised by shifting water between cells.

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\(^1\) www.scopus.com/record/display.url?eid=2-s2.0-78649876845&origin=inward&txGid=GGAJABysZtXHVfLVR7TpzwRw%3a2# [Accessed 24/11/2011]

\(^2\) www.aquatain.com/

3. Constraints

Short lifetime of monolayers and displacement by wind means they have to be reapplied every 1 or 2 days (Barnes, 2008). In addition, these chemical monolayers are not as effective as the physical methods (GHD, 2003).

The evaporation reduction efficiency of the biological layers is much lower than other methods available and have received little attention.

Natural windbreaks compete for water and, in some situations, need to be irrigated especially during the establishment phase. In addition, large covers and shade could also be costly for the farmer.

3.1.2 Distribution conveyance losses

3.1.2.1 Description

Conveyance efficiency is generally a great concern for irrigation districts that supply a group of farmers. Indeed, there are significant differences in conveyance efficiency depending on the type of irrigation network. For instance, in Greece, average conveyance efficiencies are estimated at 70% for earthen channels, 85% for lined channels and 95% for pipes (Karamanos, 2005). At EU level, potential water savings can represent up to 25% of the water used for irrigation (WssTP, 2010).

3.1.2.2 Means of action

- Canal Lining

Canals that carry from 30 to 150 l/s can lose 10 to 15% of this flow by percolation and groundwater recharge in the channel zone and water consumption by weeds. Lining a canal will not completely eliminate these losses, but roughly 60 to 80% of the water that is lost in unlined irrigation canals can be saved by a hard-surface lining (FAO, 1992).

Moreover, by lining the canal, the velocity of the flow can increase because of the smooth canal surface and it fosters the prevention of soil erosion compared to earthen canals.

- Replacing open canals with low pressure piping systems

The advantages of pipeline systems over open channel systems can be listed as follows: reduced water losses from the system by evaporation, reduced land-take for the system, reduced time for water to flow through the system to fields and increased equity of distribution. In the PACA region in France, modernisation plans of irrigated systems by converting gravity irrigation networks to pressurised systems have helped save around 300 million m³ per year (Ecologic, 2007).

- Channel automation

Channel automation involves the replacement of manual flow-control structures in channels as well as outdated flow meters on farms, with gates that properly regulate and measure flow and thus provide real-time measurement data. This would allow channel remediation work to be
undertaken based on where the worst seepage and leakage losses are observed and lead to the introduction of low pressure piping, canal lining or even the removal of the channel.

- **Water measuring devices**

A water meter may be installed in a pipeline or canal to monitor water use and measure the rate of flow and/or application of water and the total amount of water applied to the irrigated field. This information can help to maximize the efficiency of irrigation scheduling and equipment. In the French case study, tensiometers (measuring soil moisture) are shown to cost between 450 and 1800 EUR depending on the reading system (used during 6-10 years).

- **System maintenance**

Consistent maintenance is to be organized in order to ensure the functionalities of the irrigation systems to address potential leakages, to avoid water lost to deep drainage or runoff and to ensure application uniformity and correct application rate.

- **Constraints**

Soil constraints are to be considered

It implies an amount of investment and effort to redesign the irrigation systems.

### 3.1.3 Transpiration

#### 3.1.3.1 Non-productive transpiration

- **Description**

There are opportunities to limit non-productive transpiration, i.e. transpiration of unwanted vegetation (such as weeds). If weeds have deep roots they can extract and transpire more water than would be lost by soil evaporation alone. Berger, McDonald et al. 2010 showed that when weed growth in maize increases total light interception, soil water depletion is increased which could exacerbate drought. However, even where total light interception is unchanged, the presence of weeds can reduce yield and crop water productivity.

- **Means of action**

  - **Tillage**

Soil tillage reduces the coverage of weeds and so reduces unproductive transpiration; however, it can bring wet soil to the surface and increase soil evaporation.

*The effect of tillage is further investigated in response 6 on page 92.*

- **Chemical weed control**

Chemical weed control can minimise the competition for water from weeds and therefore reduce soil water depletion. Herbicide resistant crops can be used. Although the removal of non-productive vegetation will reduce total transpiration, this may not result in water saving, if it is replaced by evaporation from the exposed soil.
Constraints

The practical feasibility of reducing non-productive transpiration appears limited.
The use of herbicides reduces biodiversity in the fields and may lead to soil and water pollution.

3.1.3.2 Reducing productive transpiration

Description

For most crops there is a linear relationship between plant growth and transpiration (under constant temperature and relative humidity) therefore transpiration cannot be reduced without reducing plant growth. However, genotypes may differ in their transpiration efficiency (dry matter per unit of transpiration) and there is scope for plant improvement to select more efficient plants. Over the years, selective breeding has increased the water use efficiency of crops and the partitioning of dry matter to the harvestable parts of the plant.

Means of action

Two approaches to limiting water uptake by plants, without reducing yield or quality, are deficit irrigation (DI) and partial root-zone drying (PRD).

Deficit irrigation

Deficit irrigation (DI) involves giving plants slightly less water than potential evapotranspiration so that a moderate soil water deficit develops during the season. This has been shown to increase water use efficiency, particularly in crops that are typically resistant to water stress (Costa et al., 2007) such as grapes; however, it has also been shown to be effective in temperate field crops. For example, Liu, Shahnazari et al. 2006 showed that deficit irrigation increased the dry matter in roots and tubers of potatoes compared to leaves and stems, thus increasing the water use efficiency over the fully irrigated crop. However, deficit irrigation requires very careful water management and too much stress at the wrong stage of growth can result in significant yield and quality losses.

Deficit irrigation is further investigated in response 2 on page 70.

Partial root-zone drying

Partial root-zone drying (PRD) involves alternately wetting and drying two spatially distinct parts of the plant root system. It has shown potential to increase irrigation water use efficiency without reducing crop yields. For example, Shahnazari et al. (2007) found that when potatoes were irrigated with a PRD regime, 30% of irrigation water was saved while maintaining tuber yield, leading to a 61% increase in irrigation water use efficiency. They concluded that PRD is a promising water-saving irrigation strategy for potato production in areas with limited water resources.
Constraints

Deficit irrigation and partial root-zone drying are easier to manage in arid conditions or under protected cropping systems (greenhouses or polytunnels), as unpredictable rain can interrupt drying cycles.

Deficit irrigation and partial root-zone drying rely on being able to apply irrigation water very precisely both in terms of timing and amounts. Hence these techniques are generally more suited to drip (trickle) irrigated crops rather than overhead or surface irrigated crops.

3.1.4 Evaporation losses

3.1.4.1 On-farm conveyance evaporation losses

Description

Similar to distribution conveyance systems, efforts can be made to target a higher efficiency in on-farm conveyance by preventing evaporation losses.

Means of action

Replacing open canals with low pressure piping systems

As described earlier in the means to address the distribution conveyance efficiency, the advantages of pipeline systems over open-channel systems include reduced losses of water from the system by evaporation, reduced land intake for the system, reduced time for water to flow through the system to fields and increased equity of distribution. As mentioned in section 3.1.2, in the PACA region in France, modernisation plans of irrigated systems by converting gravity irrigation networks to pressurized systems have helped saving around 300 million m$^3$ per year (Ecologic, 2007, no information on total use available).

Constraints

Soil constraints have to be considered.

It implies an amount of investment and effort to redesign the irrigation systems. The difference in maintenance costs between different types of canals is unknown.

3.1.4.2 Wind drift and spray losses

Description

The above canopy spray evaporation loss (ACSEL) represents the portion of the water that is lost to the atmosphere during the time it travels from the sprinkler nozzle to the crop canopy. Indeed, wind drift and spray losses occur as wind carries water droplets away from the irrigated area. Droplets may either evaporate while they are being transported or they may fall out of the irrigated area.

Another portion of water is intercepted by the crop canopy but part of this is evaporated back to the atmosphere. Factors affecting evaporation losses are equipment-related (such as nozzle size, angle, operating pressure and height of the sprinkler) and climatic (such as air temperature,
air friction, relative humidity, solar radiation and wind velocity) but droplet size resulting from the nozzle seems to be the most important factor (Uddin, 2010). In that regard, Lorenzini (2004) quantified, via analytical modeling, 3.7 to 8.6% droplet evaporation for droplet diameters ranging from 0.3 to 3 mm.

Moreover, any drifting process may also affect the uniformity of water application while over-application may lead to deep percolation below the root zone.

Possible irrigation systems include:

- **Surface irrigation**, based on water application by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders).
- **Sprinkler irrigation** is similar to natural rainfall. Water is pumped through a pipe system and then sprayed onto the crops through rotating sprinkler heads.
- **Drip irrigation** conveys water under pressure through a pipe system to the fields, where it drips slowly onto the soil through emitters or drippers which are located close to the plants. Only the immediate root zone of each plant is wetted.

Furrows, sprinkler and drip systems may present contrasts, mainly related to the management practices. Hence, if furrow irrigation can be very efficient if practiced on suitable soils with high levels of management, it can also be inefficient, with large losses due to runoff and drainage. Drip irrigation has the potential to be very efficient if managed correctly.

### Means of action

- **Shift from surface and sprinkler irrigation to drip irrigation**

  EEA (2009) reported typical efficiencies of around 55% for furrow irrigation; 75% for sprinklers and 90% for drip systems. Water savings are therefore possible when shifting to drip irrigation schemes if accompanied by high levels of management. Without advice and management support, switching to another irrigation system would not impact water savings. Garcia (2002) and the OECD (2006) indeed show that drip irrigation have lead respectively to increased surfaces (i.e. no water saved) in Spain or have not been used to their full potential in Crete because of insufficient advice.

- **Shift from large rain guns / sprinklers to micro-sprinklers**

  Micro-sprinklers are small devices that are designed for areas where drippers are not practical, such as larger areas of groundcover and for oddly shaped areas. They operate at relatively low pressure compared to large sprinkler irrigation systems and deliver water onto the soil surface very near the plant or below the soil surface directly into the plant root zone, thereby reducing potential evaporation. In irrigated agriculture, micro-irrigation is used extensively for row crops, mulched crops, orchards, gardens, greenhouses and nurseries.

- **Proper timing of spraying**

  The environmental conditions during irrigation may also have an impact on water savings. Playen et al. (2005) have identified the best conditions for limiting wind drift and the spray losses (under 5%).
Constraints

Drip irrigation is well adapted for vegetables production, vineyard and orchards but it is not suitable for cereals such as maize, wheat or barley. However, without advice and management support, the drip irrigation may not result in the expected water savings, due to more areas being irrigated and/or the potential of the technique not being fully used.

Sprinkler systems may also be used for frost protection (for example on soft fruit), which cannot be delivered by drip or micro-sprinkler systems.

3.1.4.3 Wet soil evaporation losses

Description

Evaporation and transpiration may occur simultaneously and are difficult to distinguish. Apart from the water availability in the upper layer of the soil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more on the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

Frequent rains, irrigation and water transported upwards in a soil from a shallow water table (through capillary action) wet the soil surface. However, where the interval between rains and irrigation becomes long and the ability of the soil to conduct moisture to the surface is small, the water content in the topsoil drops, the soil surface dries out and soil evaporation decreases rapidly. If the water could be conserved in the soil for later use, irrigation water requirements could be reduced (particularly for widely spaced row crops). Studies have shown that considerable reductions in soil evaporation can be achieved, increasing water availability later in the season (Todd et al., 1991; Yunusa et al., 1994).

Means of action

Mulching

Mulching prevents water loss by covering the topsoil with permeable materials such as sand, gravel, perforated plastic or organic wastes (e.g. straw) and thereby creating a barrier that holds in the water in the root zone. Indeed, mulching retains moisture by slowing evaporation process but also contributes to reduce rainwater runoff.

Mulching provides many other benefits. It builds soil and improves soil health, it improves nutrient absorption, it kills most grasses and weeds without herbicides, it encourages beneficial organisms within the soil and it helps to stop soil erosion.
Todds et al. (1991) showed that mean daily soil evaporation from bare unshaded soil was reduced by a straw mulch by about 0.5 mm/day under dryland conditions, over 1 mm/day under limited irrigation and over 2 mm/day under full irrigation.

The effect of mulching is further investigated in response 4 on page 85.

- **Localised irrigation**

  In localised irrigation, water is distributed under low pressure through a piped network, in a predetermined pattern, and is applied as a small discharge to each plant or adjacent to it.

  Localised irrigation improves water efficiency as most of the water used for irrigation is absorbed by the plants and crops rather than lost by evaporation or seepage into the ground. The method is generally used for high-value crops, such as fruits and vegetables.

  Localized irrigation methods range from very sophisticated computerized to simple manual methods. High-tech solutions involve precisely calibrated emitters located along lines of tubing that extend from a computerized set of valves. Both pressure regulation and filtration to remove particles are important. Local irrigation can also be as simple as a porous clay vessel sunk into the soil and occasionally filled from a hose or bucket.

- **Sub-surface drip irrigation (SDI)**

  Sub-surface drip is a low-pressure irrigation system that uses buried drip tubes or drip tape to meet crop water needs. Sub-surface irrigation improves yields by eliminating surface water evaporation. Besides, the effects of surface infiltration characteristics, such as crusting and potential surface run-off (including soil erosion) are also eliminated during irrigation. This method, similar to controlled sub-surface drainage, is especially suitable for arid, semi-arid, hot, and windy areas with limited water supply and all the areas where sub-surface drainage is already implemented using pipes and (pipe envelopes) that are suitable for subirrigation and where slope allows for it.

  As water is applied directly to the root zone of the crop and not to the soil surface where most weed seeds winter over, germination of annual weed seed is greatly reduced and it lowers weed pressure on beneficial crops. In addition, some crops may benefit from the additional heat provided by dry surface conditions, producing more crop biomass, provided water is sufficient in the root zone.

- **Zero tillage**

  Tillage breaks the capillaries that bring moisture to the surface, but also brings moist soil to the surface. No-till systems have been shown to lose less water through evaporation than conventional tillage. According to Dalmago et al. (2006), the zero tillage system tends to increase the quantity and diameter of soil pores and therefore favours water retention, in particular in the upper layers of the soil. As a consequence, soils under zero tillage may retain around 70 percent of the available water for plants from the field capacity while conventionally tilled soils may retain something more than 50 percent of the available water for plants in the same soil matrix. In addition, since zero tillage modifies the physical conditions of the soil, may affect the plant root development modifying the crop pattern of soil water absorption.
Constraints

High cost of installing and maintaining localised irrigation makes localised irrigation and subsurface drip irrigation impractical for most farming.

Soil constraints are also to be considered. In sand and sandy loam soils, lateral transfers of water during drip (localised) irrigation might be insufficient (Ecologic, 2007).

As identified above, tillage may also reduce unproductive transpiration through decreased weed occurrence.

3.1.5 On-farm conveyance losses

Description

Apart from reducing evaporation losses, on-farm conveyance efficiency can be enhanced with a better control of flushing and leakage water losses.

Means of action

- **Pipe, pump and in-field equipment maintenance**
  
  Consistent maintenance is to be organized in order to ensure the functionalities of the irrigation devices in terms of application uniformity and application rate and to avoid water to be lost in deep drainage or runoff. Maintenance notably includes the replacement of worn sprinklers and nozzles or blocked emitters.

- **Improved filters (drip irrigation) to reduce flushing equipment**
  
  Most large drip irrigation systems employ some types of filter to prevent clogging of the small emitter flow path by small waterborne particles. An ineffective or improperly managed filter station can waste a lot of water and threaten a drip system's accuracy. Filters must be managed and regularly changed. Even with filtration, drip tape must be flushed regularly. The frequency of flushing depends on the amount and kinds of sedimentation in the tape.

Constraints

Technical training on optimised operation and maintenance practices should be provided to farmers.

3.1.6 Runoff losses

Description

Runoff during irrigation can occur when the application rate exceeds the soil infiltration rate or when irrigation occurs on soil that is already wet and cannot receive the amount of water being applied. Matching irrigation application rates to soil infiltration characteristics is fundamental to system design and irrigation water runoff should not be significant in well designed and managed systems. However, runoff of irrigation water can occur where, for example, mobile irrigation equipment (e.g. rain guns) is used on a range of soil types and slopes; local patches of low
Infiltration capacity soil occur; soil management has resulted in localised compaction (e.g. in wheelings); or at the end of centre pivots.

Runoff can also occur when irrigation application depths exceed the water holding capacity of the soil. This is rare under overhead irrigation, but is typical in furrow irrigation in order to ensure adequate contact time at the bottom of the furrow.

Reducing surface runoff not only saves irrigation water, but also reduces soil erosion, phosphate and other chemical losses and increases the effectiveness of rainfall (reducing the need for irrigation in supplementary irrigation). Although the runoff water may find its way into drainage channels and eventually into watercourses or the groundwater, it may be returned at a time, place or quality that makes it less useful and can therefore be considered as a consumptive use.

Means of action

Changes in application technology, improved management, modifications to soil structure and better in-field management and scheduling can help reduce the risks of runoff and thereby help save water.

Switching irrigation technology

Use of overhead irrigation systems with small droplet sizes, such as micro-sprinklers, can reduce runoff and the risk of capping of fine textured soils (which can lead to runoff from both irrigation and rainfall) whilst very low application rate systems may be useful in problematic soils. Subsurface drip irrigation (SDI) effectively eliminates surface runoff as water is applied within the root zone.

Improved system management

Better control of irrigation equipment (e.g. through the use of smart technologies) to improve uniformity or adjust application rates in real-time in relation to soil conditions and crop development can result in reduced runoff.

Modifying soil surface condition

Practices that encourage local retention of water on the soil surface will reduce surface runoff rates. Blocking furrows (“furrow diking” in the USA) has been advocated in semi-arid agriculture for many years (e.g. Dagg and Macartney, 1968), but more recently the technique has been tried with supplementary irrigation in more temperate environments. For example, Nuti et al. (2009) evaluated the use of furrow diking for supplementary irrigated cotton in Georgia, USA. It was shown to reduce irrigation requirements and improved yield and net returns when rainfall is periodic and drought is not severe. Special rollers are now available in the UK to maximise water retention. For example, the Aqueel14 creates multi small depressions (up to 200,000/ha) on raised beds (tied ridging), ridges or over the whole soil surface and these act as mini reservoirs each holding about a litre of water. They reduce runoff and aid slow water percolation through the soil. Patrick et al. (2007) estimated that surface run-off could be reduced by 95% on some soils using this technique.

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14 Aqueel, Simba International Ltd. www.simba.co.uk/rollers_aqueel.php
Identification of responses for water savings in agriculture

[Image]

54 Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

Good agronomic practices

Maintaining good soil structural condition is important to maintain infiltration capacities. Avoiding heavy trafficking and soil compaction is central to good practice. Similarly, agronomic practices that encourage rapid and complete ground cover reduce the expose of bare soils and risk of capping on silty soils and so reduce the risk of runoff.

Better irrigation scheduling

Accurate knowledge soil the soil water status prior to irrigation means that applications can be scheduled to reduce the risk of runoff occurring from over application. On light soils, surface runoff from irrigation due to saturation overland flow is unlikely as light soils will accept water even when wetter than field capacity (although this may be lost due to drainage).

Improved furrow irrigation

Although some runoff is inevitable in furrow irrigation systems, practices such as “surge irrigation” or “furrow blocking”, when applied correctly, can minimise runoff losses. For example, Horst (2007) showed that surge-flow on alternate furrows, reduced irrigation water use by 44%.

Constraints

Reducing runoff does not automatically result in water savings as drainage may be substituted for surface runoff if irrigation scheduling is poor or rainfall is excessive.

Switching from overhead to micro (drip) irrigation potentially offers water savings, but only on appropriate soils and for selected crops.

The use of tied ridging to eliminate runoff on sloping fields can introduce other problems, including the need for additional field operations using mechanical equipment to remove them prior to harvest. For example, many farmers are reluctant to use tied ridging because it disrupts the smooth passage of heavy harvesting machinery lifting delicate crops.

3.1.7 Drainage losses

Description

In the case of light soils or other well drained conditions and gentle slopes, drainage of water downwards from the root zone may be much more significant than surface runoff. As it is not visible, it does not raise immediate concerns and can continue unnoticed. Drainage of water out of the root zone will occur when the root zone soil water content is raised above the field capacity water content. If drainage is unimpeded, this water is effectively lost and with it, nutrients dissolved in the soil water. If drainage is impeded, it can lead to localised water-logging. These situations can be avoided by controlling the drainage, or by capturing, and recycling the drainage water.

Means of action

Improved water application uniformity

Poor uniformity of water application can result in drainage losses even where part of the crop is not fully irrigated. Furrow irrigation systems, for example, will necessarily apply more water at
the top end of the field than at the bottom as the bottom end will always have a shorter “contact-time” although practices, such as “surge irrigation” can increase uniformity. For example, Horst, Shamutalov et al. 2007 showed that surge-flow on alternate furrows, reduced irrigation water use by 44% and led to application efficiency near 85%.

Many overhead irrigation systems (such as rain-guns) are often non-uniform and farmers may compensate by over-irrigating to ensure that the driest parts of the field receive sufficient water, leading to drainage losses in the wetter parts. A prerequisite for reducing drainage losses is uniform irrigation application which may be achieved with more precise application systems such as booms, centre pivots or drip irrigation.

**Irrigation scheduling**

Good scheduling of irrigation timing and amounts will aim to maintain soil water conditions drier than field capacity in order to minimise drainage losses from irrigation. However, keeping the soil close to field capacity will increase the risk of drainage losses from unpredictable rainfall. Good irrigation practice in environments where rainfall is unpredictable is to not to return the soil to field capacity with irrigation, but to maintain some storage capacity (buffer) for rainfall. This maximises the effectiveness of rainfall and reduces the need for subsequent irrigations.

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**Soil water holding capacity**

Soil texture is the major determiner of water holding capacity of a soil. The large pores in sandy soils allow water to both infiltrate and drain quickly, leaving smaller amounts stored within the soil profile. Loams, silt loams, and clay loams have a broader range of sizes of pores, many of which store water for longer time periods.

Conditioners (or amendments) can be applied to the soil to increase the water retention of the soil. Organic residues, peat and hydrophilic polymers are commonly used to improve water retention in sandy soils.

**Constraints**

In most cases there is no practical way to change the soil texture, and so other practices should be used to try to increase water-holding capacity of sandy soils. However, the high cost of soil conditioners to improve water retention mean that this technique is usually only suitable for small areas, such as for sports turf (e.g. golf courses).

### 3.2 Using water from other sources

The technology and management approaches described above can result in a reduction of non-productive water losses, and a potential to reduce the amount of water abstracted from the source (i.e. a water saving). However, in many basins, saving water, *per se*, is not the main issue – more important is reducing the impact that water use has on the environment and other water users in the basin. By definition, water for crop irrigation is needed in the places and at the times of year when it is most scarce. Therefore, if alternative sources of water can be used, pressure on
stressed water resources can be alleviated. Water re-use, on-farm storage and water harvesting do not "save" water, as the total volume of water used will be the same (or even greater) but the water can substitute for water abstracted from vulnerable resources at critical times of year.

### 3.2.1 Water re-use

Low-quality wastewater discharges may be directed to agricultural use. Urban, or occasionally industrial effluents are commonly used as a source of irrigation water. Although health risks may be associated with the use of wastewater on vegetable and horticultural crops, it can be a useful resource for grain or tree crops or landscape irrigation. However, it must be recognised that wastewater used for irrigation is not returned to the hydrological system; therefore there is no net water saving and downstream users (including environmental uses) may have been dependent on those water flows. In UK, recycled water represents 2% of the water used in agriculture. This figure corresponds to an average of 5,5 million m³ of blue water saved yearly.

Re-using wastewater in agriculture does save on water treatment costs (and energy) as the quality standards for irrigation water may be lower than permitted for direct discharge to a watercourse. Wastewater use can also recharge aquifers through infiltration or reduce the impact on surface-water bodies, as wastewater is treated before reaching them (Jiménez, 2006).

The use of desalinated water can also be an alternative. This opportunity is already implemented in Israel, but in Europe, the practice remains marginal. In Cyprus desalinated water is used for drinking purposes and in Greece, some studies are on going to evaluate the tolerance of olive orchards to high concentration of sodium salts (Chartzoulakis, 2005). Nevertheless, the main inconvenient for this method is the impact of the discharged brines on the environment. In the Mediterranean Sea, this practice has been shown to harm the beds of Posidonia, an aquatic plant ranked as priority habitat by the Habitat Directive (Sánchez-Lizaso, 2008). Moreover, desalinated water production requires high amounts of energy, also producing high quantities of greenhouse gases (Tada-ducru, 2009). Finally, the costs for desalinated water production are quite expensive and vary a lot depending on the type of energy used. The table below presents cost estimations depending on type of energy.

<table>
<thead>
<tr>
<th>Cost depending of energy type (€/m³)</th>
<th>Sea water</th>
<th>Brackish water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>0,35–2,70</td>
<td>0,21–1,06</td>
</tr>
<tr>
<td>Wind-borne</td>
<td>1,00–5,00</td>
<td></td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>3,14–9,00</td>
<td>4,50–10,32</td>
</tr>
<tr>
<td>Solar sensor</td>
<td>3,50–8,00</td>
<td></td>
</tr>
</tbody>
</table>

### Constraints

Among the disadvantages of using wastewater, sludge or excreta, the most obvious are the health risks from pathogens. These have been discussed extensively elsewhere (WHO, 2006)
Pathogens contaminate crops mainly via direct contact, though some cases of uptake by plants have been recorded (Hamilton et al., 2007).

Concerning the use of saline water, monitoring activity is required to ensure that the salt concentration does not increase in the groundwater. In addition, this technique is not suitable for all crop types: for example, many market gardening crops (bean, carrot, strawberry, onion etc.) are sensitive to salt medium (Shalaby, non dated)

**Water re-use is further investigated in response 8 on page 103**

### 3.2.2 On-farm storage

On-farm water storage allows farmers to abstract water from surface or groundwater resources at times when flow is plentiful for use during times of low flow. No water is “saved”, and due to evaporation and seepage losses from the storage, the total abstraction may be increased. However, the impacts on the environment and other water users in the basin can be substantially reduced. On-farm storage is generally limited to supplementary irrigation as the volumes of water that can be stored are limited. However, on-farm storage can provide other (recreational and aesthetic) benefits.

MAAF (1996) realised a study on the advantages of this practice. In addition to securing an irrigation supply where no summer abstraction would be licensed, the promoted benefits of discrete storage reservoirs include:

- Cheaper water charges. Winter water abstraction charges are 10% of summer charges.
- Long-term planning. Winter abstraction licences are usually issued for a longer period.
- Flexibility of supply. There are no flow rate limits on abstraction from the reservoir.
- Security of supply. Abstractions from the reservoir are not subject to Section 57 restrictions.
- Multipurpose use. Reservoirs can provide conservation habitats or generate extra income through amenity or fishery development.
- Increase in farm’s capital value.

**Winter storage reservoirs are further investigated in the UK case study (section 5.4)**

### 3.2.3 Water harvesting

Water harvesting is the collection of runoff (usually) from rainfall and subsequent storage for irrigation use. This can provide farmers with an available water resource at times or places when abstraction may be limited. Again, no water is “saved” but (green) rainwater is substituted for
Identification of responses for water savings in agriculture

Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

Abstracted water. However, it must be recognised that capturing and storing rain water has an impact on the basin water balance. Harvested rainwater therefore, cannot be considered to be “free” and the basin hydrological implications must be evaluated.

In the UK, a number of farms and organisations collect rainwater from roofs for irrigation, though the areas and volumes are generally small. In Bedfordshire, one of the drier parts of England, the MAAF study showed that one hectare of roof area might theoretically provide sufficient water to irrigate 2.5 hectares of potatoes (at 80% efficiency).

Another type of water harvesting is the use of water harvested in dams, that may be released for downstream uses at dry periods. This is used in several MS where dams are used for hydro-energy for example. However, the construction of dams has environmental impacts on biodiversity, through flooding the dam area, disrupting the water flow, etc.

3.3 Socio-economic responses

3.3.1 Water regulation and allocation

Description

Water abstraction may be regulated by the allocation of ‘water rights’ or concessions at the river basin level, such as in Guadalquivir basin (Spain). In this case, the policy aims to encourage farmers to improve their irrigation systems (changing to trickle irrigation) and to improve the distribution system level (pressurized networks) (Ecologic, 2007). The water rights are regularly reduced, year after year, switching in Guadalquivir from circa 7000 m$^3$ per ha in 1985 to circa 5000 m$^3$ per hectare in 2005, i.e. with annual reductions of circa 265 m$^3$ per ha and per year. As a result, farmers have improved their crop plans and irrigation systems (Ecologic, 2007). Water regulation aims to organise water use among the users, by sensitising them to the scarcity of the resource. For example, farmers of Vila Cova (Portugal) are following rules, which include dates of start and end of the irrigation period, losses in canals, travel time of water, user sequence, and night turns. The community authorities and the priest are involved. In practice, farmers receive a ranking number to start the summer irrigation, and a clock in the priest’s house show the irrigation time of the current user (Hoogendam et al., 1996).

When using water rights or permits to abstract water that allow for a certain amount of water to be abstracted (e.g. as is the case in France or in the UK), metering is required to monitor how much the farmer has abstracted compared to its allocated right. However, such monitoring requires compliance checks and may increase illegal abstractions to abstract sufficient water for the crops.

Means of action

Water regulation and allocation can be framed by a framework for water abstraction (from private to centrally controlled systems),

It can involve institutional arrangements within / between MS.
Constraints

Farm level
A comfortable water allocation may lead some farmers to irrigate some fields and switch to more water-demanding crops (orchards).

Technical constraints
This response is insufficient without changes in crop pattern or improved crop varieties, and changes in average water demand for irrigation.

Scale
The scale of the river basin allows flexible and responsive allocation.

3.3.2 Water auditing and benchmarking

Description
"You can't manage what you don't measure" this adage also applies to water use, while water use and reuse data would be necessary to support water-saving strategies, policies and Best Management Practices. Water audits include measurement tools that can help agricultural facility owners know their water footprint, learn where water is being wasted and tackle unrecorded water abstraction at the farm level. Benchmarking can help them identify which efficiency improvements will be most cost-effective (Wholly, 2010), e.g. by comparing on-farm water use with industry norms and reasonable needs.

Means of action

Realisation of audits
Audits are carried out by specialised firms as well as specialised organisation, which apply water measurement techniques, including several data sources, e.g. audit data, field study data, modelled audit data (Isaacson, 2010).

Techniques and management recommendations
The recommendations on water savings include advice on practices and techniques to reduce water cost/use and to improve water efficiency (Business Stream). It also promotes high-performance efficiency (Rosenblum, 2010).

Influence farmer’s behaviour
Auditing and benchmarking do not change users’ behaviour (Rosenblum, 2010) but may help them figure their relative consumption. Hence, a farmer, whose audit shows him to be using more water than other similar farmers, may wish to change to colleagues’ water consumption levels.
Constraints

Cost of the audits

Farmers may certainly be interested in being compared with colleagues and in learning ways to improve water cost-efficiency. However, farmer will first need to be convinced of the value of investing in an audit, and a consistent benchmarking feedback will be necessary.

Need for a local lobbying

A consistent role of Farm Advisory Services or other local advisors may be a key element for catching farmers’ interest.

3.3.3 Water Pricing and trading

Description

An element of the Water Framework Directive supporting the reaching of its environmental objectives are water-pricing policies that provide adequate incentives for users to use water resources efficiently\(^{15}\). Charging water use and the relevant water services – thus, including provision, consumption as well as disposal – is a complex policy instrument capable of achieving multiple policy objectives. On the supply side, water pricing may be designed from a financial perspective, i.e. to recover either costs invested in water supply systems or operation and maintenance (O&M) costs, or both. Water pricing may also be an economic tool designed to raise the productivity of water use, by allocating the resource to the use that generates the highest economic value (e.g. high-productivity crops with low water demand), while at the same time establishing the use of water saving technologies. Finally, a water charge can be an instrument to promote efficient and careful use of water and to help securing water availability. On the other hand, charging the disposal of water rather than the provision serves to reduce pollution and to enhance water quality (Molle and Berkoff, 2007).

Water can be charged both on the individual – as is the case in most modern urban water distribution systems on the household level - as well as on the collective scale –, referred to as “bulk water supply” - as is the case e.g. in agriculture (WWF, 2007, Dinar et al., 1997). A prerequisite to fulfill either of the above mentioned functions is to relate the level of the charges to the amount of water used, i.e. to apply volumetric tariffs to give incentives to use water more efficiently.

Means of action

Establishing a water pricing system has to be embedded in a political-administrative framework. This framework has to be able to guarantee:

- correct measurement of water quantities and
- reliable and fair collection of charges.

\(^{15}\) For further reading: European Commission 2000, 2003 and Interwies et al. 2006.
Constraints

Setting the price right (part I): How to guarantee at the same time the incentive function of water charges, without harming the economic development (endangering the economic existence?) of water-intensive economic sectors such as agriculture?

Setting the price right (part II): How to include (and measure or value) external environmental and social costs in water charges?

Equity issues: How to guarantee that water allocated by a pricing mechanism is not excluding low income groups or low-value economic sectors from its use?

Monitoring issues: Implementing volumetric pricing mechanisms is difficult due to high technical and monitoring costs. For volumetric pricing mechanisms, metering is generally required, which may imply installation and needs compliance checks. Additionally, illegal abstraction may increase with higher prices and/or monitoring. This issue is specifically assessed by the project “Water pricing in agriculture” which has been carried out in parallel to this study.

3.3.4 Consumer / market pressure

Description

Complex systems of beliefs, habits, products availability and life level, lead consumers to certain food choices. Market and consumers are in an equilibrium of offer and demand, which varies slightly according to cultures and mentalities, level of life but also to fashions and information. Hence, consumer pressure lead Monsanto to stop using its genetically engineered bovine growth hormone (Posilac, rGBH or rBST). Such actions require the other value chain stakeholders to pay close attention to their traceability and labelling, until basing their marketing on the market pressure. For example, firms using dairy products mentioned on labels that the products were without artificial hormone (Akre, 2008). Similar market pressure exist with regards to animal welfare (Protection Mondiale des Animaux de Ferme), to support local economics (Coordination Sud, 2006), and may occur for water issues.

Means of action

Water footprinting and water use measures, as for carbon footprint, could be calculated and displayed to consumers. For example, the products of the agrifood brand Raisio already have labels with the water consumption from field to the end product.

In general, information on water auditing and benchmarking at the farm-level and on possible ways to improve water efficiency can be delivered to consumers, so that they better understand issues on water savings at the farm level.

Constraints

Consumers associations are powerful lobbies and should not be activated intentionally or regarding very specific issues.

Having the support of citizen actions requires providing consistent and demonstrative information.
Farmers also need to feel supported by public powers, and need to have an easy and cost-efficient access to practices and techniques and information leading to reduced water use, and to local advisors to support them during implementation (see water footprint study\textsuperscript{16}).

3.3.5 Dissemination of best practice, training and awareness-raising

- **Description**
  Benchmarking of on-farm water use has shown very different patterns of water use efficiency within same farm typologies. A range of knowledge transfer and outreach approaches have been used to disseminate and share best practice, including the use of demonstration farms, open-days, technical workshops, media productions, and information literature. The metering and monitoring of the volumes of water used by farmers and growers are uneven across the EU. Raising awareness of the amount of water used and the related impacts (at the local and regional scale) may be sufficient to induce a change in behaviour.

- **Means of action**
  Technical workshops may be organised for farmers and agribusiness companies to train them to water measurement and water efficiency practices and technologies.

  Local involvement / on-site training: local advisors of farmers such as Farm Advisory Services will need to display information on water measurement and water efficiency practices and technologies, and to regularly come back to the topic to bring feedback to farmers and support them in the change.

  Larger advisory support for planning and management from local advisors.

- **Constraints**
  A learning time is necessary for farmers and for such changes they require continuous local technical support.

3.3.6 Agricultural water productivity/crop selection

- **Description**
  Water consumption and water use efficiency (WUE) of a given crop depend notably on the plants themselves and growing context and can be predicted (Mo, 2004). With driving parameters such as the type of crop, growth stage of the crop and climate, the water consumption of crop can be predicted by month from the sowing date (FAO, 1986). The influence of crop type is important on both the daily and seasonal crop water needs:

\textsuperscript{16} More information on this study available from: www.waterfootprint.org/?page=files/home
Daily water needs

The crop type has an influence on the daily water needs of a fully grown crop, i.e. a fully developed maize requires more water than a fully developed onion.

The crop type has an influence on the total crop growing season duration. Various lengths exist, from short duration crops, such as peas, with a 90-100 days long growing season, to longer duration crops, such as melons, with a 120-160 days long growing season. This does not cover perennial crops that remain in the field, such as fruit trees (FAO, 1986).

Seasonal water needs

At the seasonal scale, while the daily water need of melons may be less than the daily water need of peas, the seasonal water need of melons will be higher than that of beans because the duration of the total growing season of melons is much longer (FAO, 1986).

Means of action

Crop selection, plant breeding and genetically modified crops towards water efficient and drought tolerant crops

Training of farmers regarding water use of various species and sowing/harvesting dates

Low/ high value crops in water stressed areas, more generally: support to cooperatives (sellers) to commercialise seeds of water efficient crops

Incentives, agricultural policies: support to farmers/cooperatives (buyers) to buy various species, including water efficient crops

Marketing and advertising towards food industries and consumers regarding water efficient crops. Labelling schemes could be envisaged (at EU level or by private industrials) and/or information campaigns to EU customers to raise awareness on water efficient crops, along with awareness-raising on the benefits of local agriculture for example.

Constraints:

Need for a strong support of agricultural policies, covering issues such as research and crop selection, training and information to farmers, as well as financial support and market regulation to let space for marketing new a less developed water efficient species.

Changing planting date and crop selection are investigated in responses 9 and 10 from page 107.
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Chapter 4: Findings of existing studies on the responses to save water in agriculture

In brief: This section provides further information on a selection of the responses previously identified, based on existing studies. Among these answers, the *improvement of irrigation systems* can lead to solid water savings but efficient systems are quite expensive, specific to a soil and a crop type and do not necessarily lead to reduced water use since water saved is often reused e.g. to increase irrigated lands. *Deficit irrigation strategies* also have good results, depending on crops and type of soil. Several techniques *reduce water lost during storage or from the soil* by using cover systems (shade covers, mulches or synthetic soil cover respectively). *Irrigation scheduling* is spreading in the EU and provides good results in term of water savings, specifically in wetter years. The *reduction of runoff* through soil tillage also contributes to increase water efficiency but tillage can have negative effects on the soil structure. *Water table management* by managing drainage water may be useful if the drained water is stored and reused, but water savings are less direct. *Water reuse* is seen as a promising technique, but entails environmental and sanitary issues. *Crop selection and change in cropping date* appear both to be strategies with high potential for farmers but need to be supported by adequate policies, accompanied by seed producers and through providing markets for these varieties or crops.

A number of responses have been identified in the previous section, that may improve water savings in agriculture. The current section provides further information on ten of these responses, by presenting findings from studies across the EU that investigated each response in different contexts. Most of the studies are scientific studies, aiming to investigate the potential of the response on water savings, or water efficiency by the crops. Lessons learned, on transferability, and policy recommendations are discussed in sub-sections for each response.

4.1 Response 1: Improvement of irrigation systems

Farmers cultivating irrigated fields can choose between many different irrigation methods, such as flood irrigation, sprinklers or drip irrigation. The choice of irrigation system will depend on the soil type, crop type, crop quality requirements and water availability and/or price, as well as the investment, operation and maintenance costs required for the irrigation system itself. Irrigation systems may be improved in several ways. The existing system may be improved by maintenance, or the system may be changed completely, to account for new factors, such as increased water scarcity, new regulations, or new commercial requirements for instance.
4.1.1 Presentation of the studies

Three studies are presented for improvement of irrigation systems, in Italy, Spain (Flumen irrigation district) and the UK. Definitions involved in water use efficiency for Mediterranean countries are discussed, as well as criteria to achieve this efficiency. The UK study presents general characteristics of trickle irrigation (synonym to drip irrigation) and its possible extension to potatoes cultivation. Transition from flood irrigation to the use of sprinklers is studied in Spain, as well as its potential effects on water savings.

4.1.1.1 Water use efficiency in irrigated agriculture, Italy

The publication reviewed here (Hamdy, 2005) is an analytical review of water use efficiency in agriculture, presented criteria for efficiency in water use and definitions related to water use in agriculture, and discussed possibilities for increasing water efficiency, with a focus on Mediterranean countries.

When considering the improvement of irrigation systems, several factors should be taken into account, including in defining water use efficiency. A multi-dimensional approach is essential, and water use efficiency cannot be considered only through water quantity, since tight links with water quality, profitability of crop production, etc. occur.

Another important aspect is the geographical and hydrological approach of water use efficiency. Water can be lost on a farm but be profitable for the aquifers of the river basin for example. Moreover, technical efficiency (which considers the amounts of water abstracted vs. applied) is different from economic efficiency (which considers the price of the crops and the water abstracted or applied).

The paper presents data about the irrigation efficiency of a range of techniques in the Mediterranean region, showing high variability (see Table 4-1). On average, only 51% of water extracted reaches the crop (once the lost due to conveyance, wind drift, run-off, etc have been substracted), with high efficiencies from pipe-conveyance systems with sprinkler/drip (65%), compared to traditional open canal system with manual control (30%).
4.1.1.2 Trickle irrigation, UK

This study on trickle irrigation was a part of the final report (Knox and Weatherhead, 2006) on Irrigation demand and on-farm water conservation in England and Wales, funded by the Ministry of Agriculture, Fisheries & Food (MAAF) in 1995. The authors have republished a paper (Knox and Weatherhead, 2006) in 2006 that reports on the evolution of trickle irrigation spread in the UK, based on three surveys.

Trickle irrigation, or drip irrigation, is often cited as one of the best techniques to save water for irrigation, as less water is used than with spray irrigation, as losses through e.g. wind drift are nullified. However, use of drip irrigation cannot be used on all crops. It was initially used in greenhouses for fruits and is now used in open-fields for fruits and vegetables.

In 1995, trickle irrigation represented only 2.5% of the total area irrigated in the UK, but was growing fast, and had doubled between 1992 and 1995. The 2006 survey estimated that the total area being trickle irrigated in the UK holdings is between 10 000 and 15 000 ha, compared to about 2 000 ha in 1992 and 4 000 ha in 1995. In volumetric terms, trickle is estimated to account in 2006 for about 5% of all irrigation abstractions.

The proportion of trickle irrigation is very heterogeneous among crops irrigated and was mostly used for growing top fruit, small fruit and vegetables, up to 60% for strawberries for example whereas it represented only 0.5% for carrots in 1995. Trickle still predominated in 2006 in the soft fruit sector, accounting for a third of the trickle irrigated area (orchard fruit, potatoes and some

---

47 The water efficiency represents the ratio between yield and quantity of water applied to the field (in mm or m\(^3\))
field vegetables), being specifically interesting in specialised high-value sectors such as strawberries, runner beans and hops.

The 2006 survey confirms findings from the 1990s. Concerning water savings, results are not unanimous: trickle irrigation has to be combined with good scheduling, management and maintenance, in order to save water. Additionally, in the UK, the shift to trickle irrigation has not been driven by the need to save water, but rather by quality concerns and encouraged by the government and the regulator (Knox and Weatherhead, 2006). In those areas in which the growth of the trickle irrigation sector may simply represent a switch from spray to trickle irrigation, potentially saving water; but in other cases more volumes of water were used because the trickle irrigation system does not require a license, adding to the pressure on water bodies in water scarce areas (Knox and Weatherhead, 2006).

4.1.1.3 The impact of transition from flood to sprinkler irrigation on water district consumption, Spain

This study (Nogues and Herrero, 2003) was conducted by the Soils and Irrigation Department of the Government of Aragón, in Spain. It is focused on the Flumen irrigation district (Aragón, Spain), in the Ebro basin and its aim was to analyse the water saved when using sprinklers instead of controlled flood irrigation. The study used the ‘Irrivol’ method (already exploited by farmers), in correlation with a map of soils. The Irrivol method provides an estimation of water requirements, using crop maps and water requirement for each crop (depending on the crop and the agrometeorological data).

A soils map of the area was produced, and taxonomic units were grouped into land evaluation units (LEU) with an index of productive potential (IPP) for each LEU, following FAO. With this typology, the soils with highest productive potential were identified. On these soils, change from flooding to sprinklers was proposed, whereas on unfavourable soils agriculture was proposed to be abandoned. After this evaluation, the researchers calculated water needs of the irrigated district.

Alfalfa, barley, maize, rice, sunflower and wheat were studied, as they are the most commonly grown and most spread crops in the studied area. Net crop water requirements were calculated for the years 1993, 1994, 1996, and 1998. Lecina (1998) estimated the efficiency of flood irrigation from field measurements, and Nogués and Herrero extrapolated it for the whole district, dividing the land into morphopedological units (platforms, slopes, and fluvial terraces and valley bottoms). An estimation of the water applied in the district for the four years of the study, and for each crop was made, based on crop water requirements, surfaces of each crop and efficiency of flood irrigation. Besides, the model also takes into account the non-consumptively applied water, or the reusable fraction of the irrigation applied; a coefficient of reused water was estimated at 0,9 (90%). The calculations are compared with the volumes invoiced by the Ebro Basin Water Authority (Confederación Hidrográfica del Ebro, CHE). Figure 4-1 shows that the estimation is good, with very little differences with the volumes invoiced by CHE.
Findings of existing studies on the responses to save water in agriculture

Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

<table>
<thead>
<tr>
<th>Year</th>
<th>Whole district, a</th>
<th>Old irrigated lands, b</th>
<th>Area to be compared with the CHE invoicing</th>
<th>Water volumes involed by CHE</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(i)</td>
<td>(ii)</td>
<td>(i)</td>
<td>(ii)</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>190</td>
<td>158</td>
<td>18</td>
<td>17</td>
<td>141</td>
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<td>1994</td>
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<td>1998</td>
<td>219</td>
<td>216</td>
<td></td>
<td></td>
<td>182</td>
</tr>
</tbody>
</table>

Figure 4.1: Estimation of irrigation water volume (Nogués and Herreo, 2003)

The water volume to be applied after the modernisation, with a supposed average efficiency coefficient of 0.70 was then estimated, first without accounting for reused water and substracting reused water.

According to the results, water saving would be about 7% but, as the authors point out, this number is mitigated by a possible intensification of agriculture after setting up sprinklers over flooding irrigation. They also affirm that a better efficiency of the irrigation system produces a decrease in the reusable fraction, so the impact should be considered in the entire Ebro basin.

4.1.2 Lessons learned

Irrigation systems are often optimised for the cultivation system, but they also affect the hydrology of the sub-basin. When deciding on the irrigation system to put in place, this aspect should be taken into account.

Flood irrigation, sprinklers and trickle or drip irrigation are irrigation systems with their own positive and negative aspects. Initial investment and maintenance costs are higher for sprinklers, and trickle irrigation but the system allows for a better uniformity of water distribution and possibly better yields. These systems however imply water savings only under certain conditions. The study on trickle irrigation in the UK shows that the system is relevant for high value fruits and vegetables rather than for other crops and may lead to more cultivated areas rather than reduced water use as such.

The same point is made in the Spanish study, where it is shown that water savings with sprinkler irrigation is not necessarily as advantageous as expected, must be relevant in terms of the soil and crop types, and may lead to intensification of agriculture rather than to water savings.

4.1.3 Transferability to other river basins

The change of irrigation systems must be carefully organised, so as to ensure that it is adapted to the situation (geohydrological specificities, topography, soil types, as well as agricultural practices including crops, crop rotations, type of harvesting, etc.). Each farm will have its own targets and decision-making specificities, and may decide to change systems or not, depending on external factors too, e.g. profitability of the crops cultivated, importance of the crop quality, etc. Once all these factors have been taken into account, the measure appears rather transferable.
4.1.4 Policy recommendations

Improving irrigation systems can be a good way to reduce water use in agriculture. However, this has to be closely analysed before promoting any change in these systems, considering the positive and negative aspects at different geographical scales and including the environmental needs that may be fulfilled by irrigation systems considered “less” efficient as they do not bring water only to the crops. Additionally, perverse effects can occur through improvement of irrigation systems, through increasing the areas under irrigation or irrigating crops more, thus not changing the amount of water abstracted even if the system is more efficient, which does not lead to reduced pressure on water bodies.

References:


4.2 Response 2: Deficit irrigation strategies

The technique of deficit irrigation is defined as the application of water below full crop-water requirements (Fereres and Soriano, 2006). The technique relies on an in-depth knowledge of plant physiological response to water availability. It involves withholding irrigation at critical growth stages when the yield is insensitive to water stress.

Several techniques may be used in deficit irrigation. The crops may simply be less irrigated than usual, at certain stages of their development. Another, more recent technique, is partial root-zone drying (PRD), which involves irrigating only one part of the root zone in each irrigation event, leaving another part to dry to certain soil water content before rewetting by shifting irrigation to the dry side.

4.2.1 Presentation of the studies

The data presented here rely on four studies across Europe, in Italy, Spain, Bulgaria and Denmark on peach trees, maize, raspberries and potatoes, four very different types of crops.
4.2.1.1 *Regulated deficit irrigation in Italy on tree crops and on maize*

Two studies are presented in the report from the Mediterranean Agronomic Institute of Bari:

- Emilia-Romagna (Northern Italy) investigating peach trees
- Southern Italy (Policoro, Basilicata) for results on maize

The general irrigation technique (not only deficit irrigation) is developed in Emilia Romagna on 252,377 ha (about 45% of irrigable land). 61% of fruit-tree crops are irrigated in the region. Maize is irrigated on 622,000 ha in Italy, mainly in the North and the area has been increasing from 1990 to 2000. Italy is a contrasted country, in terms of water availability, with high water availability in the North, and rainfall balanced with high evapo-transpiration losses in the South.

Table 4-2: Phenological phases of the crop cycle

<table>
<thead>
<tr>
<th>Peach trees</th>
<th>Maize</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - from the start of flowering to the formation of small fruits (of 3-4 cm of diameter)</td>
<td>when crop has achieved 1 m height, during the crop growing stage</td>
</tr>
<tr>
<td>from 1 until the hardening of the pit</td>
<td>at the tassel emission</td>
</tr>
<tr>
<td>from 2 until the harvesting</td>
<td>at beginning of the milky stage</td>
</tr>
<tr>
<td>from 3 until the fall of the leaves</td>
<td>at the beginning of the waxy stage</td>
</tr>
</tbody>
</table>

Two studies were performed, one on peach trees and the other on maize, both subdividing the crop cycle in four principal phases (see Table 4-2). Water stress was induced in phases 2 and 4 of peach trees and for maize, one or two irrigations were suspended or the irrigation volumes were doubled in correspondence to different phenological phases.

Table 4-3: Percentage of seasonal irrigation volumes saved by controlled water stress on peach in respect to normal irrigation regime (Source: Mannini, 2004)
On peach trees, the main results show that a controlled water stress during phase 2 does not favour development of peach shoots which reduces the competition for assimilates between the shoots and fruits. Similarly, in phase 4 it reduces vegetative growth and favours the induction of buds to flowers and fruit leader. The regulated deficit irrigation technique has maintained the average weight of fruits (see Figure 4-2), has improved the flowering in the successive years and has reduced the necessity for pruning. Similar results have been obtained in the experiments on peach and nectarine trees carried out under Southern Italy climatic conditions.

However, controlled deficit irrigation must be applied on established trees since deficit irrigation can provoke negative impacts (later start of production and overall decrease of productivity) if applied during the first three-four years since plantation.

For maize, all phenological phases demonstrated certain sensitivity to water stress, with the most sensitive phase being tassel emission and, in particularly dry years, to the phase of intensive crop growth.

### 4.2.1.2 Effect of different irrigation strategies on peach trees in Spain

The effect of different irrigation strategies on water relations, vegetative growth and yield of early maturing peach trees was studied (Abrisqueta et al., 2010). The objective was to study the effect of deficit irrigation (continuous and regulated) on drip-irrigated early maturing peach trees, as well as to compare irrigation scheduling based on the soil water content (SWC), as measured by capacitance probe, with traditional scheduling based on crop evapotranspiration (ETc) calculations. Plant and soil water relations, vegetative and fruit growth, and yield were evaluated during two growing seasons (2007 and 2008) in the different irrigation treatments in Murcia, Spain.
Table 4-4: Irrigation treatments

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ – control</td>
<td>irrigated above estimated crop evapotranspiration (average 150% of ETc in both years), determined according to daily crop reference evapotranspiration (ET₀)</td>
</tr>
<tr>
<td>T₂ - continuous deficit irrigation</td>
<td>irrigated at 50% of ETc during the growing season</td>
</tr>
<tr>
<td>T₃ - regulated deficit irrigation (RDI)</td>
<td>irrigated to fully cover 100% ETc only during stage III of fruit growth, with the irrigation water reduced to 25% ETc during the rest of the growing season</td>
</tr>
<tr>
<td>T₄ – SWC based treatment</td>
<td>irrigation automatically scheduled using the capacitance probe and radio transmission system, following different criteria each year</td>
</tr>
</tbody>
</table>

The results indicated that:

- Compared with the control, peach yield was reduced in both continuous and regulated deficit irrigation treatments during both seasons (Table 4-5), although to a greater extent in 2007 (around 45% reduction) than in 2008 (around 30% reduction).

- In the SWC-based treatment, the fruit yield was significantly lower than in the control treatment in 2007, although the reduction observed (29%) was lower than that observed for both deficit treatments, whereas similar yields were recorded in 2008 (Table 4-5).

- Fruit size was similar at harvest in all the studied treatments in 2007 (parallel reduction in total fruit weight per tree and number of fruits per tree, see Table 4-6), but was lower in 2008 in continuous and regulated deficit irrigated trees (T₂ and T₃) than in control trees (Table 4-6).

Table 4-5: Effects of different irrigation treatments on vegetative growth: trunk cross sectional area (TCSA) (cm²) and winter pruning (dry matter), on Flordastar peach during the experimental period

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Trunk cross sectional area (cm²)</th>
<th>Pruning (kg tree⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>T₁ (control)</td>
<td>115.6²⁺</td>
<td>153.66⁴⁺</td>
</tr>
<tr>
<td>T₂ (50%)</td>
<td>78.30²⁺</td>
<td>102.87³⁺</td>
</tr>
<tr>
<td>T₃ (RDI)¹</td>
<td>75.94²⁺</td>
<td>101.62³⁺</td>
</tr>
<tr>
<td>T₄ (soil-based)</td>
<td>70.77²⁺</td>
<td>102.52³⁺</td>
</tr>
</tbody>
</table>

¹ RDI: regulated deficit irrigation. Values are mean of 4 replications. Average values followed by different letters are statistically significant different according to LSDₚₐ test.
Findings of existing studies on the responses to save water in agriculture

Figure 4-3: Fruit diameter growth (mm) in 2007 (a) and 2008 (b) in different irrigation treatments of Flordastar peach trees. Each point is the mean of 4 replications ± standard error. Different letters (a, b, c and d) indicate statistically significant different values according to LSD\textsuperscript{18} 0.05 test

Table 4-6: Effect of different irrigation treatments on Flordastar peach yield (kg trees\textsuperscript{-1} and number of fruits tree\textsuperscript{-1}) during the experimental period

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg tree\textsuperscript{-1})</th>
<th>No. fruit tree\textsuperscript{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>T1 (control)</td>
<td>24.29\textsuperscript{b}</td>
<td>50.13\textsuperscript{a}</td>
</tr>
<tr>
<td>T2 (50%)</td>
<td>14.03\textsuperscript{a}</td>
<td>33.23\textsuperscript{a}</td>
</tr>
<tr>
<td>T3 (RDI\textsuperscript{1})</td>
<td>13.40\textsuperscript{a}</td>
<td>35.95\textsuperscript{b}</td>
</tr>
<tr>
<td>T4 (soil-based)</td>
<td>17.27\textsuperscript{a}</td>
<td>45.51\textsuperscript{b}</td>
</tr>
</tbody>
</table>

\textsuperscript{1} RDI: Regulated deficit irrigation. Values are mean of 4 replications. Average values followed by different letters are statistically significant different according to LSD\textsuperscript{18} 0.05 test. ns: non significant.

4.2.1.3 Regulated deficit drip irrigation and water efficiency of a raspberry in Bulgaria

A study was conducted on raspberry plantations of the primocane-fruiting\textsuperscript{19} variety “Lyulin” in the period of 2002-2004 (Koumanov et al., 2006). Raspberries are increasingly cultivated in Bulgaria thanks to the good international market and the quick payback on investments. However, while production is extended to more regions, irrigation is required in the lowlands due to frequent droughts. Water use may be optimised by using RDI. The present study investigates seven irrigation treatments (control, i.e. Vc-100, V1-75, V1-50, V2-75, V2-50, V3-75, V3-50, see Table 4-7). The system investigated is drip irrigation with fertigation, the amount of fertiliser being equal for all treatments.

\textsuperscript{18} LSD means Least Significant Difference

\textsuperscript{19} The primocane-fruiting varieties make fruits on their first year canes, so do not need to be overwintered for fruiting the second year, as floricane-fruiting varieties do.
Findings of existing studies on the responses to save water in agriculture

<table>
<thead>
<tr>
<th>Phenophases</th>
<th>Irrigation treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Intensive growth</td>
<td>100% of ETc</td>
</tr>
<tr>
<td>2 - Blossom</td>
<td>75% of ETc</td>
</tr>
<tr>
<td>3 - Fruiting</td>
<td>50% of ETc</td>
</tr>
</tbody>
</table>

The study focused on raspberry growth and yields, through dosing and timing of water stress. The study was conducted over three years, considered a wet (2002), dry (2003), and average (2004). The indicators calculated were integral yields and average mass of one fruit. Water use efficiency and irrigation water efficiency were obtained as ratios of the yield and the annual evapotranspiration (ET) and the yield and the annual application rate (M), respectively (see Table 4-7).

The results show that:

- The raspberry plantation used one cubic meter of water to produce 2.0-2.5 kg of fruit (i.e. 0.4-0.5 m³ of water/kg of fruit).
- RDI increased the water use efficiency
- Significant reduction in the yield, compared to the control, occurs only in the variants with 50% reduction of the application rates (V2-50 and V3-50), and an application of 75% of ETc does not appear to negatively impact yield or fruit quality.
- The size of fruits was observed to diminish during the harvest period, with bigger fruits at the beginning of the season
- Water savings between 4 to 17% may be realised without significant reductions in yield

Table 4-7: Total evapotranspiration ET (mm) and annual application rates M (mm)
4.2.1.4 Soil types and irrigation techniques for field grown potatoes in Denmark

Since potatoes are widely grown under diverse agronomic conditions (soils, irrigation amount, and weather conditions), the objective of the study presented here is to investigate the interaction of water-saving irrigation strategies and soil textures on yields and water productivities of potatoes grown under humid and temperate climate conditions (Ahmadi et al., 2010). Potato is sensitive to drought stress due to its sparse and shallow root system and tuber yield might be reduced considerably in response to soil moisture deficits. It is thus important to investigate where and how deficit irrigation techniques may be used.

<table>
<thead>
<tr>
<th>Three types of soils</th>
<th>Three irrigation treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse sand</td>
<td>full irrigation (FI)</td>
</tr>
<tr>
<td>loamy sand</td>
<td>deficit irrigation (DI)</td>
</tr>
<tr>
<td>sandy loam</td>
<td>partial root zone drying (PRD)</td>
</tr>
</tbody>
</table>

DI and PRD, as water saving treatment, received 65% of FI after tuber bulking and lasted during 6 weeks until the final harvest. This experiment was carried out in 27 drainable concrete lysimeters.

Two parameters were measured:

- yield and
- water productivity

The study was conducted at the Research Centre Foulum (56°30’ N, 9°35’ E), Faculty of Agricultural Sciences, at Aarhus University in Denmark and carried out as a part of the EU project SAFIR²⁰ from April to August 2007.

²⁰ Contract FOOD-CT-2005-023168
The results of the study show that:

- Under non-limited water resources conditions, loamy sand produces the highest yield under full irrigation.
- Under restricted water resources, it is recommended to apply water-saving irrigations (DI or PRD) in sandy loam and coarse sand to achieve the highest water productivity without any decrease in potato yield.
- PRD and DI treatments increased water productivity by, respectively, 11 and 5% in coarse sand and 28 and 36% in sandy loam relative to FI while differences in fresh yields were not significant between the three irrigation treatments.

Those results also showed that the performance of water-saving irrigation methods (DI and PRD) are dependent on the soil type. These two methods are not recommended in a loamy sand soil (i.e. in the soils with high hydraulic conductivity) where they induce a considerable loss in yield (28% in this study).
4.2.2 Lessons learned

Deficit irrigation can be a useful method to reduce water use in agriculture, but only applies to certain types of crops. When considering this method, different factors must be taken into account, including the crop cultivated, the soil type, and careful planning of when the deficit water will be provided, based on the phenological phase of the crop and including information on the soil water content. Some techniques also require certain irrigation practices to be in place (e.g. PRD can only be used with localised irrigation techniques, such as drip).

Deficit irrigation techniques have demonstrated a high validity for water saving in the case of various tree crops without particular negative effects on crop production and farmer’s income in both Southern and Northern Italy, if applied on grown trees. In Spain, in terms of water use efficiency (defined as the ratio between yield and total irrigation applied water), the deficit irrigation treatments were clearly more efficient than the over-irrigated trees of the control treatment, with RDI being the most efficient technique. However, the peach yields were reduced in both years with deficit-irrigation treatments. Thus the deficit irrigation strategies in peach trees must be adjusted to limit water deficits during the postharvest period of early maturing cultivars (the variety used in that study is Flordastar, for which that period is long). The soil-based techniques were proven to be useful and to allow precise planning, for adequate irrigation management that maintains yields.

For raspberries RDI may be an interesting technique to reduce water use while conserving high yields and fruit size, if the dosing is sufficient and water is provided at the right timing.

Maize on the other hand is very sensitive to water stress and does not respond well to deficit irrigation practices. Maize thus should be fully irrigated under climatic conditions where the spring-summer periods are characterised with scarce rainfall and very high evapotranspiration demand and should thus not be grown in these regions if reductions of water uses are sought, as if grown under deficit irrigation practices yields will significantly be reduced. Despite the fact that soil type is also expected to have an impact, nothing was mentioned on that issue in this publication.

Potatoes can be irrigated under deficit irrigation techniques, but the soil type in which they are cultivated is an important parameter to take into account when choosing the irrigation method. Additionally, in the Danish study, the water-saving irrigation techniques were scheduled three times per week, with dry and wet sites of PRD switched weekly, which would mean more work for farmers. PRD also requires careful monitoring of soil water content, which may require investments from farmers.

4.2.3 Transferability to other river basins

Under the conditions mentioned above, it seems that the technique can be used for many river basins, as the good results in the use of deficit irrigation have also been obtained in experiments on peach and nectarine trees carried out under Southern Italy climatic conditions, in addition to the study presented above in the North. Since the climate between Northern and Southern Italy are very different, deficit irrigation can potentially be used also in other Mediterranean countries.
As described in the Spanish study, a good understanding and the use of relevant cultivars should be ensured if the objective is to maintain yields, but deficit irrigation increases water efficiency even with the cultivar used.

For maize, as indicated, deficit irrigation techniques are not appropriate, as it is a crop very sensitive to water stress with high water demand and should where possible not be cultivated in certain climatic conditions (spring-summer periods are characterized with scarce rainfall and very high evapotranspiration demand). However, as it is also a crop demanding heat and sun, the combination of factors is difficult to find.

The practices described in the Danish study show the importance of choosing the right technique on the right crop and type of soil for saving water while conserving sufficient yields, which may require developing knowledge (and thus training) to farmers, as well as ensuring that monitoring methods are affordable and may be used by the farmers.

### 4.2.4 Policy recommendations

Promoting deficit irrigation techniques may be a way to reduce water use in certain regions of the EU, by reducing the amounts of water applied in the field. However, it must be noted that it cannot be applied on all crops and that many factors must be taken into account to ensure that the technique chosen will be relevant and will lead to sufficient yields for the farmers.

The technique requires a good knowledge of the crops/varieties/cultivars and of their demands for water. This may require advanced technical advice and/or preliminary studies.

Deficit irrigation has been shown to have significantly more success in tree crops and vines than in field crops (Fereres et al. 2003 in Fereres and Soriano 2006). One of the reasons is that the economic return of field crops is usually associated with biomass production, while for tree crops and vines is linked with crop quality, which is only indirectly associated to biomass production and water use. Experiments with RDI were conducted on many fruit species and nuts including almond, pistachio, citrus, apple, wine grapes, olives with generally good results (see for the references Fereres and Soriano 2006).

Implementing the techniques may also require specific devices, e.g. for monitoring soil water content. In order to implement such techniques, knowledge may be required (thus possibly training of farmers) and investments (e.g. in soil water monitoring devices). Additionally, before implementing the techniques such as PRD, a change in irrigation techniques may be required, e.g. to drip irrigation.

Finally, the following observations must be considered when considering deficit irrigation techniques:

- Irrigation is one of the ways to reduce the risk of obtaining low yields or low quality crops/fruits/vegetables, thus implementing DI will be carefully considered and must be shown to not reduce yields/quality to be implemented by farmers

- Irrigation may be used not only to provide water to the plants, but also to ensure that soil salinity stays low, otherwise it would negatively
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- Deficit irrigation requires that the water is available at the time when it is needed (i.e. the scheduling must be respected to allow for yields to reach their full potential), thus it may be more risky for the farmers in case of regulated use of water, unless other sources of water (e.g. stored water) is available.

References:


4.3 Response 3: Reduction of evaporation during storage

Reservoirs may be used to store water during the winter, so that water is available for irrigation in the summer, when water flows are lowest. This does not strictly lead to water savings, but helps to reduce the pressure on water bodies at critical times. However, evaporation during the storage may reduce water availability, especially in arid and semi-arid regions. Additionally, evaporation is expected to increase in the coming years, due to higher temperatures. Different techniques are available to reduce evaporation during storage in reservoirs, e.g. covers for reservoirs, addition of emulsions, or polypropylene covers. It is also possible to reduce the surfaces in contact with air, by modifying the shape of the reservoir.

4.3.1 Presentation of the study

A study in the Segura River Basin (southeastern Spain), assessed the economics of investing in shade-cloth covers for agricultural reservoirs in a semi-arid situation (Martinez Alvarez et al.,...
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The economic viability of investing in shade-cloths depends on several factors, which are not specific to semi-arid regions and include the potential evaporation losses, reservoir characteristics, cover effectiveness, the value of water, filtration requirements, water salinity, government subsidies and the installation, operation and maintenance costs.

4.3.1.1 Economic assessment for agricultural irrigation

The study was conducted by the Polytechnic University of Cartagena, Technical School of Agronomic Engineering. In southeastern Spain, irrigation has been widely developed, leading to an increasing demand in water, and consequently to water deficits. In this context, reservoirs are a key component for increasing water availability for irrigation.

Reservoirs are a common response to the development of new irrigated lands in the last decades and subsequent water deficit. In the Segura river basin, the water deficit is estimated at 460 million m$^3$ in the Segura River Basin, affecting 0.27 million ha of irrigated land (SRBA, 2007). Many farms and collective irrigation schemes are equipped with reservoirs.

Shade-cloth covers are known to reduce the evaporation losses from 70% (Craig et al. 2005), to over 80% (Martinez Alvarez et al. 2006 and Finn and Barnes, 2007). The objective of the study was to assess the economic viability of shade-cloth covers for agricultural irrigation reservoirs.

In order to assess a potential benefit, several parameters are taken into account, and divided into two categories: factors affecting the benefits and factors affecting the costs.

Factors affecting the benefits are:

- the potential evaporation losses, varying with air temperature, humidity, wind speed, and net radiation;
- the reservoir characteristics, considering that the type of reservoir is on-farm medium-term storages, typical of the Basin and with averages of a top surface of 3 000 m$^2$, a depth of 5m and an inner slope of 1/4, with a storing capacity of 11 920 m$^3$. This type of reservoir serves farms with an average size of 4 to 5 ha;
- cover effectiveness of the cloth, estimated at 80% (based on Martinez Alvarez et al, 2006).
- value of water and net margin per m$^3$ (Figure 4-5);
- filtration requirements, as covers prevent algal growth with the reduction of light levels, but also reduce dust brought by wind, organic materials and debris; and
- water salinity, which can reduce crop yields and can be increased with the evaporation, implying that yield losses could be minimized thanks to shade-cloth covers.

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21 No data is available on how many or what percentage however.
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Factors affecting the costs include:

- the installation cost for the entire cover, i.e. shade-cloth plus structure, which can vary with sites specificities, access, wind, storage geometry. Two scenarios are developed, with or without a wall to support the structure. Estimations for the cost are 26,832 EUR for the wall and 43,332 EUR for the no-wall scenarios.
- operation and maintenance costs, including visual checks, repairs, etc. Representative values are considered to range from between 100 and 400 EUR/ha/year, depending mainly on the reservoir size and exposure to wind.

4 scenarios are considered:

- a general scenario considering only the economic return for saved water,
- a second scenario taking into account the economic return due to reducing filtration treatments,
- a third scenario incorporating eventual government subsidies (with a range from 0% to 80%) and
- finally the effect of shade-cloth covers on water salinity is incorporated.

Results show that:

- For the general scenario, the installation of a cover is not economically viable when the saved water is valued at the current purchasing prices of water in the Basin. However, installation can be viable when water availability is the limiting factor in crop production and the saved water is valued at the crop net margin.

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22 Net margin represents the ratio of net profits to net revenues. This figure is often expressed as a percentage.
The water and power saved for filter cleaning (second scenario) has small impacts on the economic indicators, but the value is higher for poor quality water and increases with water value.

With a cover, the salinity of the water is reduced, which may increase crop production (not estimated).

The current level of government subsidies for the Segura river Basin are sufficient for the case when a wall is available but not when there is no wall for the structure.

4.3.2 Lessons learned

Shade-cloth covers may efficiently reduce evaporation and prevent water losses from storage reservoirs for irrigation. It may be particularly important for arid and semi-arid areas, where water availability is the limiting factor during dry periods. However, its economical viability depends on potential evaporation losses, reservoir characteristics, cover effectiveness, value of water, filtration requirements, water salinity, installation, maintenance costs, and government subsidies. Unfortunately, this study did not include the environmental value of the water saved.

Generally, water quality and the value of saved water are the two most important factors when considering economic viability of an investment. Shade-cloth covers’ viability was shown to increase with the value of saved water, i.e. water scarcity, whereas it decreased with water quality. Public subsidies were found to be necessary for the viability of investing in shade-cloth covers in the Segura RB.

4.3.3 Transferability to other river basins

Covers may be used in all river basins to reduce evaporation losses, but may be more relevant in arid and semi-arid areas. However, covers do not only reduce evaporation, they also maintain water salinity (which increases in non-covered reservoirs) and may decrease filtering requirements.

The price of water and its availability, but also the quality of the water stored will influence the economic returns from investing in covers. The methods used in this paper may be used to calculate the benefits of this investment and may guide public decision-makers in assessing the impacts of public subsidies.

4.3.4 Policy recommendations

Suspended shade-cloth covers may be an interesting technique to prevent evaporation and water losses from agricultural water reservoirs. The initial costs can be important and subsidies may be required to make it interesting for farmers. The water price and net margins will also highly influence the economic benefits of investing in covers.
These techniques can obviously only apply in areas where reservoirs are in place. This response seems however relatively widespread, and is e.g. implemented in Spain, France and the UK (see on case studies).

Lastly, covers will reduce water losses from the storage facility, with an indirect impact on water savings in terms of abstracted/used water. Indeed, the water saved by reducing evaporation may decrease pressure on conventional resources at critical times, by increasing water availability from alternative sources, but will not reduce the amount of water applied to the crops.

References:
Segura, P., Garcı´a, A., Costantini, B., 2006. Estudio tecnico-economico de los procesos de produccion agrıcola y de transformacio´n (manipulacion y confeccion) de las principales orientaciones hortofruticolas de la Region de Murcia. Asociacion Murciana de Organizaciones de Productores Agrarios (AMOPA), Murcia, 591 pp

4.4 Response 4: Decreasing soil evaporation

During the early part of the cropping season, a considerable amount of water is lost from the soil by evaporation. If the water could be conserved in the soil for later use, irrigation water requirements for certain crops could be reduced. Indeed studies have shown that considerable reductions in soil evaporation can be achieved, increasing water availability later in the season (Todd et al, 1991; Yunusa et al, 1994).

4.4.1 Presentation of the studies

The data presented here rely on two different studies: one in the UK and the other in Spain. The studies focus on three crops: potato, sugar beet and maize.
4.4.1.1 **MAFF study on mulches**

The former UK Ministry of Agriculture, Fisheries and Food (MAFF) study presents the results of modelling which assessed the potential saving irrigation water demand resulting from the restriction of soil evaporation by the use of mulches, for a range of crop and agroclimatic scenarios. The potential water savings in a design dry year from using varying degrees of mulch were modelled for two crops, maincrop potatoes and sugar beet. The results are summarised in Table 4-9.

Table 4-9 Water savings in a design dry year from mulching with 50% and 100% mulch for maincrop potatoes and sugar beet, at three sites in UK (Hess, 1997).

<table>
<thead>
<tr>
<th>Met station</th>
<th>Dry year irrigation need (mm/annum)</th>
<th>Water saving (mm/annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No mulch</td>
<td>50% mulch</td>
</tr>
<tr>
<td><strong>Maincrop potatoes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wattisham, Suffolk</td>
<td>258</td>
<td>38</td>
</tr>
<tr>
<td>Mepal, Cambridge</td>
<td>174</td>
<td>32</td>
</tr>
<tr>
<td>Rosewarne, Cornwall</td>
<td>131</td>
<td>25</td>
</tr>
<tr>
<td><strong>Sugar beet</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wattisham, Suffolk</td>
<td>166</td>
<td>32</td>
</tr>
<tr>
<td>Mepal, Cambridge</td>
<td>104</td>
<td>30</td>
</tr>
<tr>
<td>Rosewarne, Cornwall</td>
<td>79</td>
<td>25</td>
</tr>
</tbody>
</table>
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Figure 4-6: Ranked annual irrigation needs (mm) for maincrop potatoes grown at Mepal (Cambridge) with varying degrees of mulch cover.

The modelling shows that the water saving due to mulches may be equivalent to one or two irrigation applications (25 mm to 40 mm). These savings are similar in different agroclimatic regions of the country, i.e. there is no correlation between saving and annual need. The savings are concentrated in May and June when crop cover is low (Figure 2-4). If May and June are sufficiently wet, so that irrigation is not needed anyway, then there is no saving (e.g. potatoes in 1983 at Mepal).

The practical feasibility for reducing irrigation water demand through a reduction of soil evaporation by the use of mulches appears limited.

These results discussed have depended entirely on modelling, due to the lack of experimental data. They appear to disagree with public perception of the benefit of mulches. The use of mulches on irrigated crops is less effective than on rainfed crops, because of interception and loss of some of the irrigation applied and because rainfed crops are more dependent on retaining winter water in the soil.

4.4.1.2 Use of a hydrophobic polymer

Since the 1950's synthetic products have been used with success. They act like mulching and tillage practices by contributing to decrease soil evaporation and limiting weed emergence in the field. Guilspare® is a silicone polymer developed in 2001 in Switzerland. When applied to the soil surface, the polymer interacts with the soil particles and confers hydrophobicity to the affected soil layer, reducing soil evaporation.
A Spanish team (Fernandez et al., 2001) has tested different solutions of this hydrophobic polymer, applied to the soil surface to reduce soil evaporation, on the soil water status, soil temperature, crop performance and weed emergence. The trial was carried out on a farm located in the Guadalquivir Valley (southern Spain) with maize crop. The efficiency of the product was evaluated for a period of up to 7 months.

The results of the maize test indicated that Guilspare® was effective in maintaining water in the soil by reducing water losses from evaporation, this having a positive effect on crop development and yield. This positive result was especially noticeable for conditions of severe water stress: 50% of irrigation reduction in this experiment. For the case of 25% reduction irrigation, the positive effect of the polymer on crop development was not high enough to avoid a reduction of the yield compared to the yield recorded in the control.

4.4.2 Lessons learned

Traditional techniques, like mulching, and modern techniques, like the use of hydrophobic polymer, appear to both increase the soil water content and lead to a reduction of water loss by evaporation.

These two techniques also contribute to limit weed emergence and decrease the competition phenomenon for water between the crop and the weeds during the whole cycle.

The hydrophobic polymer presents a positive effect on crop development and yield, especially when the restriction of water was severe (50% irrigation reduction).
4.4.3 Transferability to other river basins

Mulching is already commonly used across Europe. The hydrophobic polymer has been tested only in Switzerland, Spain and in the Sultanate of Oman (on an aubergine crop) for the moment. This product seems suitable for southern countries where rainfall occurs mainly during winter and remains scarce during spring and summer. In northern countries, where the drought period is more limited and rainfall is more evenly spread between spring and summer time, this practice could have a negative impact by limiting water infiltration into the soil and favouring run-off.

4.4.4 Policy recommendations

Mulching is a practice promoted in sustainable agriculture, not only because it allows water savings but also because it helps to reduce weed emergence without any pesticides. Therefore, mulching should be encouraged specially in region with insufficient spring precipitations.

The use of polymers could be investigated to ensure its adequacy in all southern countries and ascertain any other impacts it may have e.g. on soil and water quality.

References:
Hess TM (1997) Irrigation Water Requirements (Version 2.01) [IWR]. Cranfield University, Silsoe, UK.
4.5 Response 5: Irrigation scheduling

Irrigation scheduling is the optimisation of water applied to a field, in terms of timing and quantity. The objective of irrigation scheduling is to maximise irrigation efficiency, which can lead to water savings by reducing water losses (i.e. water that the crop does not require). In general, it appears difficult to quantify the benefits of the irrigation scheduling as it is rarely compared to "no scheduling at all". Even with no tools, the farmers always plan when and how much to irrigate, according to his own experience, meteorological data, plant requirements etc.

4.5.1 Presentation of the studies

The data presented here are based on practices in the UK, Greece (Crete) and France. Some irrigation techniques are exposed in the UK study, as well as its accuracy for water savings. As for France, it is not a proper study that is presented but current practices further detailed in the French case study. In addition to these three studies, the IRRINET initiative, implemented in the Po river basin is a very good example of the benefits provided by irrigation scheduling. The initiative is developed in details in the next chapter (5.3.3.1).

4.5.1.1 The irrigation advisory service of Crete

The irrigation advisory service of Crete has developed a tele-information system for scheduling irrigation, tested in two areas (Messara plain and Varypetros plain, Chartzoulakis et al., 2001).

The requirements of the crops were based on the following parameters, to provide advice on optimum irrigation doses:

- GIS-based soil database and study of climatic conditions
- Daily crop evapotranspiration, taking into account crop, growth stage, soil type and rainfall.

Advice is given through tele-communication to farmers by phone according to location and climate. Demonstration fields are in place to test the relevance of the tool on olive, avocado, citrus in Varypetro and olive, grapevine in Messara. The demonstration fields include two parts, one irrigated with the doses advised and the other with empirical water application.

The advice provided include precise data on when and how to apply water on crop depending on the region. They can lead to water savings from 9 to 20% (see Table 4-10), compared to the empirical water application. This leads to an optimum soil water content and to lower costs for farmers, who do not need to pay for the water nor pump using private wells.

The paper shows that some limits to the use of the system are barriers to further use, including that:

- One water management authority is needed in order to maintain an integral management of the schedule.
- The use of the system by farmers is limited for sociological and other reasons (irrigation tradition, level of training and age).
Findings of existing studies on the responses to save water in agriculture

- Limitations to the efficiency of the advisory system, linked to costs, need for experts, diffusion, and link to research.
- Tools like GIS methods are necessary in evaluating the potential water saving, especially in an area where water availability is variable and climate change is likely to occur.

Table 4-10: Amount of irrigation water applied to different crops in the demonstration fields

<table>
<thead>
<tr>
<th>Crop</th>
<th>Consultive irrigation (mm)</th>
<th>Empirical irrigation (mm)</th>
<th>Water saving (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocado</td>
<td>545</td>
<td>681</td>
<td>20.0</td>
</tr>
<tr>
<td>Orange tree</td>
<td>501</td>
<td>586</td>
<td>14.5</td>
</tr>
<tr>
<td>Olive Tree</td>
<td>228</td>
<td>244</td>
<td>9.3</td>
</tr>
<tr>
<td>Grapevines</td>
<td>452</td>
<td>540</td>
<td>16.3</td>
</tr>
</tbody>
</table>

4.5.1.2 Irrigation advisory bulletins, France

In France, the farm advisory services (Chambres d’agriculture) have set up a system of bulletins that provide advices on irrigation scheduling. The bulletins are sent by post and by e-mail. Demonstration plots are in place, on which relevant parameters are measured, for important crops in the region. Advices on the water to be applied is then provided based on a model. The farmers report that the bulletins are useful for optimising irrigation.

Further information is provided in the case study about France, see the section 5.2.

4.5.2 Lessons learned

Irrigation scheduling is expected to result in a better water efficiency. Water savings are often difficult to calculate as controls are often lacking and good scheduling may even result in higher water use. However, in the Greek case, savings from 9 to 20% were obtained. In dry years, the crop needs will be high. Irrigation decisions thus do not necessarily require the fine-tuning that is offered by scheduling. Irrigation decisions in average and wet years may be usefully guided by scheduling, resulting in higher water savings.

Telecommunicating information to farmers may work on the long term but only with sufficient advertisement (the initial participation rate was low, increasing in the following years). In France, the bulletin is increasingly received by e-mail, so that information is received early in the week. Thus the use of telecommunication is increasing.

In Crete, a high integration of the Farmers Associations, taking the responsibility, was seen to be absolutely necessary, along with the Regional Agricultural and Environmental Council. For cases where the system is not centralised, this would not be necessary.
4.5.3 Transferability to other river basins

Irrigation scheduling could be used in every river basin. It must be based on information about local crops, soils, weather and hydrological flows to be efficient. The scheduling is also applicable for a broad range of crops.

In the case of centralised systems, organised by an irrigation scheduling service, and high support from local communities, e.g. farmers associations, may be required to be taken up and used by the farmers. In France, farmers are welcoming this initiative, with most irrigating farmers receiving the bulletin.

Investments costs must be included in regional budgets or in the budget from the irrigation advisory services, if uncharged to farmers, or other means to recover costs must be implemented. However, individual farmers can also schedule irrigation if they monitor the parameters and calculate evapotranspiration directly. Training may be needed in certain cases for an efficient implementation.

4.5.4 Policy recommendations

Irrigation scheduling could be promoted and supported in many regions of the EU. Farm advisory services (FAS) could be encouraged to spread advices for irrigation scheduling, by providing farmers with relevant information. Farmers can play an important role in the system, as shown by the French case study, where some farmers volunteer to take field measures.

References:


4.6 Response 6: Reducing runoff

Runoff results from precipitation or irrigation. Runoff occurs when the water flow cannot infiltrate the soil. Several reasons can explain this phenomenon: full retention capacity of the soil is achieved, soil compaction, presence of a slacking crust or an important slope. As well as wasting water, it can cause erosion and consequently losses in soil fertility. By managing the soil however, the capacity of the soil can be increased, resulting in a more efficient use of this water by crops, leading to lower needs for water from other sources.

Runoff water can be limited through changes in agricultural practices allowing a better infiltration and a better use of precipitation water. Runoff water can also be collected (water harvesting) if a catchment area, and a storage facility are in place.

4.6.1 Presentation of the studies

The study presented here (Abrisqueta et al., 2007) compares two different soil tillage practices with no tillage in order to assess the difference in runoff generation, in relation to rainfall amount and intensity. It was carried out over a 3 years period in a Spanish apricot orchard. The geographical conditions are a semi-arid area, in hillside zones and with a drip irrigation system.

4.6.1.1 Effects of soil tillage on runoff generation in a Mediterranean apricot orchard

Southeast Spain’s climate is a semi-arid Mediterranean climate, where rainfall is infrequent but very intense, causing high runoff and soil losses. In semi-arid and arid areas, soil infiltration capacity is mainly due to rainfall characteristics (intensity) and properties of the soil surface.

The study took place in a 70-ha drip-irrigated commercial 18-year-old apricots trees orchard in the Mulla river valley, Murcia (SE Spain). Three soil tillage practices were tested: control (i.e. no tillage treatment, common in the area), perforated topsoil treatment\(^{23}\) and mini-catchment treatment\(^{24}\). For each soil treatment, two runoff plots were isolated to define the runoff-producing catchments area, as shown in Figure 4-9.

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\(^{23}\) consists in mechanically perforating the soil with an adapted plough, with 20 holes/m\(^2\) with a depth of 10 cm and a volume of 130 cm\(^3\)

\(^{24}\) Mini-catchments are made with low banks at a height of 20cm and a length of 2m
The amount, intensity and runoff generation in each tillage treatment were registered for the 51 rainfall episodes that occurred during the period of the study (Table 4-11).

Table 4-11: Frequency distribution of rainfall amount and 30-min maximum intensity in various class intervals during the experimental period

<table>
<thead>
<tr>
<th>Rainfall amount (mm)</th>
<th>0-10</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>&gt;40</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>17</td>
<td>20</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>10-20</td>
<td>33.3</td>
<td>38.2</td>
<td>15.7</td>
<td>7.8</td>
<td>5.9</td>
</tr>
<tr>
<td>20-30</td>
<td>118.2</td>
<td>251.1</td>
<td>100.3</td>
<td>40.9</td>
<td>150.0</td>
</tr>
<tr>
<td>30-40</td>
<td>309.8</td>
<td>348.2</td>
<td>51.3</td>
<td>87.4</td>
<td>25.4</td>
</tr>
<tr>
<td>&gt;40</td>
<td>45.4</td>
<td>38.3</td>
<td>5.6</td>
<td>9.5</td>
<td>2.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>30-min maximum intensity (l_e. min h⁻¹)</th>
<th>&lt;10</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>&gt;40</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>27</td>
<td>16</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>10-20</td>
<td>52.9</td>
<td>31.3</td>
<td>7.8</td>
<td>5.8</td>
<td>1.9</td>
</tr>
<tr>
<td>20-30</td>
<td>309.8</td>
<td>348.2</td>
<td>51.3</td>
<td>87.4</td>
<td>25.4</td>
</tr>
<tr>
<td>30-40</td>
<td>45.4</td>
<td>38.3</td>
<td>5.6</td>
<td>9.5</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Results show that:

- Runoff was lower with tillage treatment (both cases) than with control treatment
- The runoff coefficient (total runoff/total rainfall) of the control treatment was significantly higher (28.9%) than both tillage treatments
- Rainfall characteristics had similar effects on the three soil treatments, even if the differences of runoff between control and tilled soils increased with the intensity. Rainfall intensity effect was considered to be the major factor influencing runoff in this case.

Water savings

As the water retained was beneficial for plants requirements, it can be substracted from the amount of water needed for the irrigation. Table 4-12 shows water savings in percentage with mini-catchment treatment and perforated soil treatment compared to control treatment. Used rainfall is the amount of rainfall effectively available for the plants, calculated by substracting...
amount generation and a fixed amount of 6 mm corresponding to plant interception, and adjusted to the root system from rainfalls.

Table 4-12: Irrigation water applied in the control treatment and the used rainfall in the mini-catchment and perforated soil treatments during the experimental period

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigation water (m³ ha⁻¹)</th>
<th>Used rainfall (m³ ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Mini-catchment*</td>
<td>Perforated soil*</td>
</tr>
<tr>
<td>1999 (August-December)</td>
<td>92±3.1</td>
<td>237.84 (9.3)</td>
</tr>
<tr>
<td>2000</td>
<td>705.9</td>
<td>434.95 (8.2)</td>
</tr>
<tr>
<td>2001</td>
<td>725.7</td>
<td>656.99 (8.6)</td>
</tr>
<tr>
<td>2002 (January-August)</td>
<td>534.5</td>
<td>667.68 (11.5)</td>
</tr>
</tbody>
</table>

* In brackets, percentage of irrigation water saved with respect to control treatment.

Finally, the results were mean irrigation water savings of 9.4% and 6% for mini-catchment and perforated treatments respectively.

The effect of tillage and water table control on evapotranspiration, surface runoff, tile drainage and soil water content under maize on a clay loam soil is described further in the report in the section dealing with the water table management response (section 4.7.1.2).

4.6.2 Lessons learned

Control treatment, i.e. no tillage, induced more runoff generation due to the compaction of the soil and the low infiltration possibilities of rainfall water. Consequently, less rainwater may be used by the crops, and the soil may be eroded, impacting negatively the fields. This situation leads to a higher need for irrigation water. Thus, tillage systems like mini-catchment or perforated soils can result in water savings, by increasing the soil retention capacity, providing the crops with more water from rainfalls.

4.6.3 Transferability to other river basins

Runoff behaviour can differ a lot from one system to another and the relationship between runoff and rainfall intensity is also variable. In other regions, the intensity of rainfalls will be very different for instance. The study applies for an adult apricot tree orchard, and its applicability to other crops is not proven here. Consequently, further studies are required before allowing to transfer directly these results to other river basins.

However, tillage is generally considered as increasing the soil retention capacity, among other factors, including the soil type, soil depth and soil organic matter content. Tillage also has negative effects on soil structure, soil biodiversity and carbon release.

4.6.4 Policy recommendations

Changing agricultural practices by (re)introducing tillage may be very useful in limiting water runoff, which will indirectly lead to water savings by more efficiently using rainwater. However,
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Tillage is also controversial for its effects on the soil structure and soil biodiversity. Tillage also increases the release of carbon from soils in the atmosphere, contributing to climate change. Thus advice on tillage practices must be adapted to the local context, crop type, earlier practices so as to choose the best practice in the particular situation.

References:
Abrisqueta JM, Plana V, Mounzer OH, Mendez J and Ruiz Sanchez MC (2007) effects of soil tillage on runoff generation in a Mediterranean apricot orchard
Tan CS, Drury CF, Gaynor JD, Welacky TW and Reynolds WD (2001) Effect of tillage and water table control on evapotranspiratio, surface runoff, tile drainage and soil water content under maize on a clay loan soil. Agricultural water Management 54: 177-188

4.7 Response 7: Water-table management

Water-table management is an agricultural practice to manage drainage water, by controlling the water content in the soil profile. This practice is known to increase yields and is more specifically used to reduce chemical pollution such as nitrates, by reducing their concentration of chemicals in drained waters.

Water-table management also reduces variability in soil water content throughout the year, by lowering the table during wet periods and raising it with subsurface irrigation for example during dry months. This requires careful implementation so as not to change soils qualities.

Subsurface drainage, controlled drainage and subirrigation are three techniques for water table management.

4.7.1 Presentation of the studies

The data presented here rely on two studies, both of them in Ontario, eastern province of Canada. The crops for which water table has been studied here are maize and soybean. Several parameters were measured, including yields for maize and soybean, evapotranspiration, surface runoff, tile drainage and soil water content for maize.

The study that involved maize cultivation also assessed the effects of different tillage treatments on the above-mentioned parameters (see factsheet dealing with the limitation of the runoff).

4.7.1.1 Influence of water table management on maize and soybean yields, Ontario, Canada

The study was led by McGill University, Department of Agricultural and Biosystems Engineering. It was conducted in eastern Ontario during 2 years, 1995 and 1996, and the objective was to evaluate the effects of water table management (WTM) on maize and soybeans yields under eastern Canadian field conditions. These two crops were chosen for their surface and economical importance in the region: in 1995, 0,81 million ha and 0,98 million ha of soybean and maize...
respectively were grown in Ontario and Quebec altogether. In these regions, drainage is necessary to remove excess water during water and spring, whereas water is insufficient during summer and rainfalls become the limiting factor during the growing season.

To mitigate this deficit, WTM has been identified by researchers to increase the conservation of water, increase productivity and reduce pollution. In 1995, Canadian farmers were already interested in WTM to reduce agricultural pollution and increase yields but few of them had invested in it, because of high capital costs and low commodity prices. Several benefits from WTM for subsurface-drained fields were already known. WTM:

- eliminates water losses by evaporation compared to surface irrigation
- uses rainfall and drainage more effectively
- distributes water uniformly
- may reduce pesticide and fertilizer leaching
- does not take up productive land area or create obstacles in the field

However, WTM requires specific conditions: flat topography, coarse texture soils, an impermeable soil layer at 1-2 m in depth and a pipe drainage system.

Three treatments applied: control water tables at 0.5 m (CWT_{0.5}) and 0.75 m (CWT_{0.75}) below the soil surface and conventional free drainage (FD). The data gathered include water table depth from the ground surface and soil moistures. Rainfall, air and soil temperatures were recorded daily; evapotranspiration (ET) and maize heat units (CHU)\(^{25}\) were calculated. The results were compared based on dry matter weight for maize and on the number of pods per plants for soybean. The significance of the treatments was determined and compared in pairs with a t-test statistical analysis.

Table 4-13 shows the amounts of water of irrigation and rainfall and ET demands for years 1995 and 1996. Rainfalls were insufficient to meet ET needs for the months of June, July and August for both years, and water deficits for these months were much higher in FD plots. In the same way, yields increased for maize and soybean with WTM for both years as shown in Table 4-14.

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\(^{25}\) Corn heat units (CHU) are temperature-based units that are related to the rate of development of corn and soybeans. It helps farmers to choose the best suites crop varieties for their region.
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Table 4-13: Irrigation, precipitation, ET and water deficit (mm) in 1995 and 1996 (Meija et al, 2000)

<table>
<thead>
<tr>
<th>Month</th>
<th>1995</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigation</td>
<td>Rainfall</td>
</tr>
<tr>
<td>May</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>June</td>
<td>58</td>
<td>45</td>
</tr>
<tr>
<td>July</td>
<td>96</td>
<td>189</td>
</tr>
<tr>
<td>August</td>
<td>69</td>
<td>92</td>
</tr>
<tr>
<td>September</td>
<td>0</td>
<td>69</td>
</tr>
</tbody>
</table>

Table 4-14: Effect of three water table depths on maize yield, grain yield and harvest index and on soybean grain yield, harvest index and number of pods per plant for 1995 and 1996 (Meija et al, 2000)

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Parameter</th>
<th>Water table management treatment*</th>
<th>Significance of differences between treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CWT&lt;sub&gt;0.5&lt;/sub&gt;</td>
<td>CWT&lt;sub&gt;0.75&lt;/sub&gt;</td>
</tr>
<tr>
<td>1995</td>
<td>Corn</td>
<td>Yield (t/ha)</td>
<td>12.61</td>
<td>11.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-kernel wt. (g)</td>
<td>29.82</td>
<td>26.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Harvest index</td>
<td>1.82</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
<td>Yield (t/ha)</td>
<td>3.44</td>
<td>3.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-kernel wt. (g)</td>
<td>19.02</td>
<td>19.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pods/plant</td>
<td>23.89</td>
<td>26.30</td>
</tr>
<tr>
<td>1996</td>
<td>Corn</td>
<td>Yield (t/ha)</td>
<td>7.29</td>
<td>7.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-kernel wt. (g)</td>
<td>25.73</td>
<td>27.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Harvest index</td>
<td>1.79</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
<td>Yield (t/ha)</td>
<td>3.24</td>
<td>3.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-kernel wt. (g)</td>
<td>20.72</td>
<td>21.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pods/plant</td>
<td>18.46</td>
<td>25.46</td>
</tr>
</tbody>
</table>

* CWT<sub>0.5</sub>, CWT<sub>0.75</sub>: water table controlled at 0.5 and 0.75 m from the soil surface, respectively. FD: free drainage, water table ≥ 1.0 m from the soil surface.

Maize

Three parameters were analysed to compare the results in CWT and FD plots for maize: yield (t/ha), grain sizes with 100-kernel weights (g) and harvest index (HI), which is the ratio of the above-ground plant biomass to total grain produced by the plant.

- **Yield:** in 1995, there was a significant difference between CWT<sub>0.5</sub> and FD, with an increase of 13.8%, producing 1.53 t/ha more maize. In 1996, the CWT<sub>0.5</sub> and CWT<sub>0.75</sub> plots increased the yields by 6.6% and 6.9% respectively. However, the increase was lower than in 1995, probably due to a wetter year, that reduced the relative beneficial effects of subirrigation.
Grain size: in 1995, grains produced in the CWT_{0.5} and CWT_{0.75} plots that were larger by 5.4% and 8.0% respectively. In 1996, the grain sizes were also higher for CWT plots although less than in 1995.

HI: CWT plots had higher HI compared to plant form FD plots, which means that plants produced more biomass, but the differences are not significant. Thus, water table depth had no significant effect on the ratio of plant biomass to total grain produced in maize in both years.

**Soybean**

Three parameters were analysed to compare the results in CWT and FD plots for soybean: yield (t/ha), grain sizes with 100-kernel weights (g) and number of pods per plants.

- **Yield**: CWT plots provided the highest yields for both years. Yields in CWT_{0.5} and CWT_{0.75} plots increased by 8.5% and 12.9% respectively compared to FD plots. The results were even higher in 1996 with increases of 37.3% and 32.2% even if 1996 was wetter. Researchers assumed that the late spring did not affect soybean as much as maize as it is normally planted later than maize.

- **Grain size**: WTM had also an effect on soybean grain size, with a significant increase in 1996, and soybean seeds larger by 4.8% and 8.6% for CWT_{0.5} and CWT_{0.75} plots respectively compared to FD.

- **Pods per plant**: plants produced more pods in CWT plots, with a significant increase in 1996, where the CWT_{0.5} and CWT_{0.75} plots produced 32% and 82% more pods per plants than FD plots. This result also influenced yields.

WTM allows more water to reach the crop. In this study, both maize and soybean yields were higher with water table management in 1995 and 1996. Other research findings concluded that the highest yields were obtained with a water table depth of 0.6 to 0.9 m. It has to be noted that climatic conditions significantly affects WTM’s effects and yields increases are likely to be higher during dry years.

**4.7.1.2 Effect of tillage and water table control on evapotranspiration, surface runoff, tile drainage and soil water content under maize on a clay loam soil, Ontario, Canada**

The Greenhouse and Processing Crops Research Center in Canada conducted the present study. The objective was to assess the impact of two tillage systems and controlled drainage with subsurface irrigation on evapotranspiration (ET), surface runoff (SR), tile drainage (TD), and soil water content. The amount and distribution of soil water in the crop root-zone is a key response which can be affected by tillage type, cropping practices and water table management. In Ontario, tile drainage systems are commonly found. It reduces the excess water during the spring and fall (periods of snowmelt and precipitations), but it might also reduce soil water storage and lead to water deficit during the growing season.
The study was conducted under maize grown on a clay loam soil in southwestern Ontario, Canada, with two tillage and two water management treatments, replicated four times, on sixteen 15 m wide by 67 m long field plots. The tillage treatments included moldboard plow (MP) which is conventional tillage, and soil saver (SS) which is reduced tillage. The two water management treatments were regular drainage (DR) and controlled tile drainage with subsurface irrigation (CDS). In the CDS treatment, water table was maintained at 30 cm below ground level. The data collected were soil water content, weather data (air temperature, solar radiation, rainfall, wind speed and direction and relative humidity) and ET. The study ran over 1992 (considered a wet year), 1993 and 1994 (both considered dry years).

Figure 4-10 shows the effects of the four different treatments on soil profile water content. As clearly visible on the graphs:

- The different tillage treatment had no significant impact on soil water content for 1992, 1993 and 1994.

- The CDS treatments lead to higher soil water content for both years 1993 and 1994, with only a small difference during the wet year 1992,

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**Figure 4-10:** Total soil water content (mm) in the 0-80 cm depth for MP and SS treatments and DR and CDS treatments in 1992, 1993 and 1994. The bars indicate standard error (n=8). (C.S. Tan et al, 2002)
when soil water content was on average much higher than years 1993 and 1994.

- The results are comparable for ET, with no effect from SS tillage during the growing season while CDS treatment increased ET significantly in years 1993 and 1994.
- Surface runoff (SR) was increased with SS tillage for the three years, though significant both in 1994, and during the non-cropping periods (November-March) for the three years.
- SR increased significantly with the CDS treatment for the three years and all the periods.
- Tile drainage was generally very little affected by tillage treatment.
- TD was lower with CDS treatment during the three years. Over the three years, 64% of TD occurred during the non-cropping period.

Figure 4-11, it was not affected by SS tillage on annual net change, but net change for cropping season was higher with SS tillage and lower during non-cropping season (April-November). In the dry years of 1993 and 1994, SS tillage did not affect significantly net change in soil profile water content for annual years, cropping and non-cropping seasons. CDS treatment increased significantly net change annually and during cropping periods for the years 1993 and 1994, because of the subirrigation added during the growing season.
The CDS treatment had great effects on the overall water balance: CDS increased ET, reduced soil water deficit during the cropping period, reduced TD and increased soil water content in the root zone compared to DR treatments. It also had higher SR, because of the wetter soil profile. However, the researchers point out the possibility to reduce this runoff by adjusting the near-surface soil moisture and/or by installing the tile at a deeper depth.

Tillage did not affect much water balance, nor TD, SR, soil profile water content and ET. SS treatments increased SR during non-cropping period during wet years because of a greater soil density. The researchers noted that in the study, the no-tillage system was only in place for three years and that long-term no-tillage had resulted in other studies in increased TD volumes and greater preferential flow because of increased earthworm populations.

More than half of the total annual water input (55%) was used for crop evapotranspiration, and over 65% of water loss by SR and TD occurred in the non-cropping period. A decrease of these losses could be possible by covering crops during this period and/or by increasing soil organic matter.

### 4.7.2 Lessons learned

Water table management increases yields, via a better water uptake from higher water tables. The results of water table management can however vary significantly depending on agronomic and pedoclimatic factors. Yields increases can be explained by water table management’s effects on directly related factors such as evapotranspiration but also indirectly related factors like surface runoff, tile drainage and soil water content. In both studies, it is noted that water table management is more effective during dry years, as water becomes a limiting factor. Concerning
the effects on ET, runoff and soil water content, it should be noted that the study was conducted under fine-textured soils and that the results could vary in other pedologic conditions.

These two studies do not allow to compare water table management treatments to other irrigation practices. In the first study, it is shown that a good management of the water table is beneficial to crops compared to conventional free drainage.

4.7.3 Transferability to other river basins

The two studies were conducted in the same region, in Ontario, Canada studying maize and soybean. The results cannot be transferred easily to other types of crops such as fruits or vegetables. For maize and soybean however, good results concerning yields can be transferable to European countries in which those crops are cultivated (grain maize is the third most cultivated crop in the EU in yields and soybean is cultivated mostly in Italy, Romania and France), where issues of drainage in winter and low water tables in summer occur.

4.7.4 Policy recommendations

Water table management for annual crops could be promoted for a better use of available water. However, it requires an important system of drainage and monitoring systems, including subsurface irrigation systems, that may require some investment and organisation, while it will impact the practices that may be used on the field (e.g. tillage possibilities). Furthermore, WTM is only relevant where issues of drainage in winter and low water tables in summer occur.

The possibility to reuse the water that is drained could be further investigated (see also response 8) to reuse that water, including reusing any nutrients and pesticides that are dissolved in the water.

References:

Tan CS, Drury CF, Gaynor JD, Welacky TW and Reynolds WD (2001) Effect of tillage and water table control on evapotranspiration, surface runoff, tile drainage and soil water content under maize on a clay loam soil. Agricultural water Management 54: 177-188
4.8 Response 8: Water reuse

Water is extracted from the environment, used and consumed for different purposes. However, a high amount of the water used is not consumed, i.e. the water is returned into the environment, in many cases after a process of treatment. For instance, water used by consumers in houses is taken to a treatment plant and the treated water is returned to the environment. The water may be returned downstream from where it was taken, or to another river basin. Water reuse for the studies described in this section however relates to water that is not treated, or treated only in a limited way, that may be used for irrigation. Water reuse does not lead to strict water savings, but may result in a lower pressure to “conventional” water sources and/or a lower competition for water for other uses.

Water reuse entails a number of challenges. Indeed, by definition a number of substances will be included in reused water. While certain substances may be beneficial to plants, enhancing crop growth (e.g. nitrates, phosphates and other minerals), other may not be welcome, especially if the crops are intended for consumption (e.g. heavy metals, hormones) as they may entail sanitary issues. This may be particularly important for acceptability of the irrigation practice by buyers (cooperatives, supermarkets, and consumers). Additionally, even when substances are useful for crops, a careful monitoring of what is included and in which amounts may be required to ensure efficient fertilisation.

4.8.1 Presentation of the studies

Two studies are presented in this context, showing implementation of water reuse in agricultural irrigation. The first illustrates irrigation with reclaimed water in Spain and the second discusses the application of wastewater reuse in Cyprus.

Reclaimed water is former wastewater (sewage) or grey water that has been treated to remove solids and certain impurities. Water is treated to a certain quality that matches the intended use, at a lower standard than drinking water quality. However, using non-conventional water for irrigation presents a number of ecological and health risks and poses problems connected with soil and ground water contamination. In planning that reuse, the intended water reuse application requires a certain level of wastewater treatment, to obtain finished water of sufficient quality (Kathijotes 1999).

4.8.1.1 Agricultural irrigation with reclaimed water in Spain

The paper illustrates a real case of irrigation with reclaimed water in Spain (Mujeriego, 2007), at Mas Pijoan ranch in Santa Cristina d’Aro (Catalonia). In 2006, the ranch managed 150 ha of farmland, with 40 ha dedicated to irrigated agriculture. The main crops were seed crops (barley) on dry land and fodder crops in irrigated land, with oat and triticale cultivated during the winter season and maize during the summer season. The cattle ranch included 300 cows, of which 140 milking cows.
The ranch used local groundwater resources until 2003 on 30 ha. Both the reduced availability of water in the summer and the conflict with the nearby residential and agricultural users of the same groundwater led to the need to find another source of water.

By 2000, the owner realised that a water reclamation plant was located nearby. The water was already being used by horticultural irrigation and by the golf course, which required water throughout the summer season. Thus, the only change required was to connect the Mas Pijoan ranch to the golf course, through a 3-km water pipeline, and the associated pumping station. The Catalonian Government helped funding through a grant of 70% of the investment. The change of water source allowed the ranch to increase its irrigated lands to 40 ha.

- **Advantages**

The advantages for the owner were the availability of water throughout the summer season, and increased reliability of water supply, which was the aim of the pipeline construction. Additional benefits were derived from the beneficial nutrient contribution of the reclaimed water, and higher productivity and quality of the maize fields.

- **Timing and costs**

The construction process ended in September 2003 and operation began in summer 2004. The total budget costs for the 3-km pipeline, 1800 m³ storage pond and 50 hp pumping station was 170 000 Euros, of which 100 000 EUR was covered by the government grant.

The costs of reclaimed water for Mas Pijoan is 0,084 EUR/m³ including water production, analytical controls and water pumping. This costs is becoming increasingly more favourable than that of conventional supplies, due to the cost of energy needed for groundwater pumping (no quantitative data is available on that cost however).

- **Cooperation**

The use of reclaimed water is closely scheduled between the ranch and the golf course. The golf course operates during the night and the ranch during the day, for a 20 hours/day operation that skips the 4 hours period with highest power supply rate. An agreement with the ranch is in place so that the storage pond may be used by the golf course if necessary.

Needs in terms of water retreatment may however be slightly different between the ranch and the golf, as the golf favours lower amounts of nitrogen and phosphorous in water.

- **Use**

During 2005 125 000 m³ of reclaimed water were used by the ranch, covering 55% of its needs. The rest was met by groundwater supply.

- **Requirements**

The irrigation project required a series of conditions and actions, including a detailed study of the irrigation zone, complete annual analysis of the reclaimed water, and systematic series of microbiological parameters. These analyses add relatively high costs to the ranch for the use of reclaimed water: 800-1000 EUR for the annual analysis and 300 EUR per year for the microbiological parameters.
4.8.1.2 Wastewater reuse for irrigation in Cyprus: an acceptable soil conditioner?

In Cyprus, due to a semi-arid climate, the country faces a problem of inadequacy of water for both its domestic and irrigation needs. Underground water is used to meet local water demand (no permanent surface water streams or lakes), but recently, over-exploitation has led to a need to change water sources. The paper advocates that the use of recycled water for irrigation should be considered to meet the water demand, especially of agriculture and industry (Kathijotes, 1999). This would allow the needs of those sectors to be met, but will also be beneficial as more water will then be available for domestic uses. However, ecological and health risks must be taken into account when planning the reuse. The study analysed soil samples during about 11 years from areas irrigated with treated effluent water (domestic origin), and compared to nearby plots irrigated from fresh groundwater. From chemical analyses, characteristics of both sources of water were similar, with additional elements and salts toxic to crops in wastewater.

Results show that:

- in soils irrigated with wastewater, more organic matter was found, which could be interesting if the needs of the plants match that content, especially as Cyprus soils are generally poor in organic matter. The study showed a positive effect on structural improvement and consequently improvement of soil fertility.
- humus decreased after 60 cm depth in both profiles (both types of water), reducing the risk of groundwater contamination;
- for the factors analysed (nitrate risk, magnesium risk, chloridisation, alkalinisation, sodium adsorption ratio, exchangeable sodium percentage), at most times the quality of this effluent did not meet the appropriate levels and induces some kind of risk;
- appropriate management and requesting adequate treatment of the water may overcome these negative effects, maximising benefits and minimising risks by careful planning of the intended use.

Additionally, Cyprus soils are sodic soils, and in general treated effluents must be used with care in high pH soils.

4.8.2 Lessons learned

The main response for the use of reclaimed water in Mas Pijoan was to increase the water supply reliability to render crop production independent of groundwater and rain availability. This was made possible in part thanks to the system already in place at the nearby golf course, which was already using reclaimed water for irrigation. Thus the investment required, which was helped by a government grant, was relatively low. Additionally, the added storage pond constructed at the ranch benefits the golf course when needed.
Relatively high requirements in terms of water analyses is required by the authorities, and are considered not providing more information than the analyses undertaken at the reclamation plant. However, overall, the system is satisfactory with this use.

An additional benefit from the use of reclaimed water is the nutrient availability in the water. This is further highlighted in the Cyprus paper, where the benefits from the organic matter content of the water was shown to have a positive effect on soil fertility through soil structural improvement (organic matter plays an important role in soils, including on soil structure, water holding capacity, fertility and nutrient cycling).

### 4.8.3 Transferability to other river basins

The use of reclaimed water was made possible by the fact that the nearby golf course was also using that source of water. In other situations, a high investment may be required to allow for reclaimed water use.

The reclaimed water used in this case is for seed grains, used for cattle feeding. The use of reclaimed water on other crops requires further investigation and requires a much higher treatment e.g. for legumes.

Wastewater use for agriculture requires careful planning and understanding of the subsequent use in order to minimise the risks linked to the elements contained in water. However, beneficial elements may also be included, that may improve soil structure and/or benefit crops directly. The degree and type of water treatment is thus key in efficient water reuse.

### 4.8.4 Policy recommendations

Water reuse is already happening as water flowing downstream has usually gone through a system of extraction, use and treatment. However, the use of untreated or low-treated water may be beneficial for reducing the pressure on natural water resources.

The use of wastewater for irrigation may reduce the pressure on ground and surface water sources, if not used for other purposes. It may also (or alternatively) reduce competition for water across sectors. The reuse of wastewater is an option that is increasingly considered in water scarce areas. This measure does not strictly save water, but increases the number of times it is used, thus reducing the need for abstracting water for that specific use. As shown in the Spanish case however, it must be underlined that use of reclaimed water does not necessarily reduce water use. Indeed, an additional 10 ha were irrigated thanks to the use of reclaimed water.

Issues in health and ecological risks however can arise and careful management and planning is required to ensure that a good balance is struck, as the water can also contain elements beneficial for plants and soils (e.g. organic matter). In order to deal with these risks, chemical and biological analyses may be required for approving the use of reclaimed water, including for irrigation. This may be necessary to ensure that the water used respects limits for sanitary issues and to monitor the nutrients added in the environment through that water. However, it will increase the costs for farmers when using that resource and may decrease the interest of using such water for the farmers.
4.9 Response 9: Changing planting date

In theory, it should be possible to reduce irrigation needs and thus save water in the critical summer season by advancing the planting date: it is called the “escape strategy”. This strategy is based on the fact that water efficiency is maximal during the low evaporative demand phase (the warmer and dryer the climate, the higher the evapotranspiration). Consequently, the crop needs less irrigation water. Therefore, this strategy consists of positioning the crop cycle to adjust it to the water resource availability. Two methods exist to achieve this objective:

- complete the crop cycle before the drought season, or
- avoid the coincidence between period of high evaporation demand or low rainfall with the key periods of the crop cycle.

4.9.1 Presentation of the studies

The data presented here are based on two studies from France and the UK. The studies focus on four crops: maize, sorghum, sunflower and winter wheat.

4.9.1.1 MAFF study on potatoes: changing planting date and length of the growing season

When considering altering planting date for potato crops, the limiting factors are the temperature and the soil physical conditions. A soil temperature below 9°C does not allow potatoes to sprout. Early planting also presents the risk of frost damages than can later increase the vulnerability of stem canker infection emergence, soil compaction and clod formation. All these factors can seriously affect final crop quality and yield. There appears therefore to be limited scope for advancing development by bringing forward planting dates alone without increasing the risk of yield and quality losses.

Therefore, for the potato growers in UK, two main strategies have been developed: the use of already sprouted, physiologically aged seed and earlier planting using artificial covers such as floating plastic film or fleece to raise soil temperatures.

References:

Findings of existing studies on the responses to save water in agriculture

**Chitting**

The use of potato seed that has been physiologically aged and sprouted in controlled temperature storage (which is called “chitting”) results in earlier emergence, tuber initiation and subsequent harvest. Chits can advance crop development by up to 21 days (O’Brien et al., 1983). The main advantage for farmers in using aged seeds is earlier harvesting. The financial benefits are greatest with early and second early varieties, which command significantly higher prices per tonne earlier in the season. For maincrop potatoes, using aged seed is only advantageous to avoid late harvest in unfavourable conditions. Otherwise, it adds to production costs, yields are lower, and there are other disadvantages (Addison 1986; ADAS Advisor, 1990). If seed is only slightly aged to avoid large yield losses (Buckley, 1990), development would be accelerated by less than 14 days.

**Earlier planting using floating plastic film and fleece**

Synthetic covers such as floating perforated plastic films or fleece can be used to increase soil and air temperature, accelerating sprout and leaf growth and advancing emergence and tuber initiation. Trials with first early varieties have shown that plastic films can raise daily mean soil temperatures by 2-5°C, advancing final harvest of chitted early potatoes by 10-14 days (Jenkins, 1992).

Fleece typically advances harvest by 6-10 days, and affords much better frost protection than plastic covers. It reduces temperature fluctuations, minimising growth checks and overheating, and is particularly suitable for early baking potatoes (Farmers Weekly, 1996).

The effects of these strategies on water requirements were simulated. Planting dates assumed reflect typical climate conditions in southeast England. The effects of chitting and plastic covers on crop development were based on expert opinion. Irrigation plans were based on recommended schedules and current practice (Knox et al., 1996; Bailey, 1990). The results are summarised in Table 4-15. Strategy A represents a ‘normal’ strategy, assuming no alterations to crop development. Strategy B and C represent the use of chitting to advance development by 7 and 14 days respectively. Strategy D represents the use of plastic covers to give 14 days advanced planting. Strategies E to H are similar, but with deeper rooting. Strategies I and J represent the use of second early varieties for early harvest and in place of maincrop respectively.

The results suggest that chitting reduces dry year irrigation need by up to 9%. Using plastic covers for early planting saves 17% to 19% of irrigation water. Increasing rooting depth from 0.7m to 1.0m (and scheduling appropriately) further reduces dry year irrigation need by about 12% in all cases.

However, plastic covers are not currently financially viable for maincrop production and reduce final yields relative to uncovered crops. Using chitting to advance development by 14 days would also reduce final yields. A 7 days advancement using chitted seed would not significantly reduce yields and similarly would not significantly reduce irrigation needs. Increased rooting depth therefore appears the most important factor in reducing irrigation need.

Second early potatoes grown for early harvest used 50% less water than maincrop potatoes. However, there is a limited market. Soil conditions and regional climate may also constrain a switch to earlier planting using second early. Growing a second early variety for a maincrop
harvest reduces irrigation need by 16%, and this practice could increasingly be adopted by growers, albeit for quality and marketing considerations, rather than to reduce irrigation need.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Dry year irrigation need (mm)</th>
<th>Irrigation need expressed as a % of Scenario A</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Unchitted</td>
<td>170</td>
<td>100</td>
</tr>
<tr>
<td>B Chitted 7 days advance</td>
<td>170</td>
<td>100</td>
</tr>
<tr>
<td>C Chitted 14 days advance</td>
<td>157</td>
<td>93</td>
</tr>
<tr>
<td>D Chitted Under plastic (14 days in advance)</td>
<td>141</td>
<td>83</td>
</tr>
<tr>
<td>E Chitted Chitted, second early, early harvest</td>
<td>84</td>
<td>50</td>
</tr>
<tr>
<td>F Chitted Chitted, second early, maincrop harvest</td>
<td>143</td>
<td>84</td>
</tr>
</tbody>
</table>

4.9.1.2 **French project: Sunflower 2010**

The “Sunflower 2010” project has considered different agronomic and genetic strategies to improve crop productivity. Especially, a programme has been developed in order to assess the possibilities of bringing forward the planting date in order to increase water efficiency and avoid summer drought.

Presently, sunflower is sown between April and May. An earlier sowing of about one or two months would:

- increase the potential length of the vegetative cycle which corresponds to the biomass accumulation and,
- avoid period of severe water deficit during the crop flowering stage which is a key step for the yield

**Autumnal sowing**

Several studies in the Mediterranean region (Spain, Italy and Portugal) have been performed to assess the potential of autumn sown sunflower crops (Gimeno et al. 1989; Boujghagh. 1990, 1993; Anastasi et al. 2000; Barros et al. 2004). The gain in terms of yield was between 0.5 and 1.2 t/ha. In Spain where the autumnal sowing was tested on farmers’ crops, the yield increased by 20% and the oil yield was also improved. This gain in yield was related to the effective increase in cycle time and avoidance of drought at the end of the cycle. The hydric behaviour of the sunflower is considerably improved for four reasons:

- an increase in the total evapo-transpiration due to a longer cycle, a higher cumulative rainfall and a more efficient rooting;
an increase in the ratio transpiration/evaporation due to a better coverage of the soil during the period of high availability of water

- an increase in transpiration efficiency associated with a lower evaporation demand

- an increase of the harvest index due to the avoidance of water deficit during the post-flowering stage

**Earlier spring sowing**

Other works have considered the merits of one or two months advance for sowing compared to the current practice. A yield increase is also noticed in this case but associated with a decrease of the ratio oleic/linoleic (Flagella et al, 2002) related to the thermal conditions. The main barrier for a significance advance in the sowing date remains the tolerance to cold and frost in the first stage of sunflower development.

Currently in Toulouse, France, ongoing work contributes to the characterisation of the growth and development of different genotypes of sunflowers submitted to low temperature constraints at the beginning of their cycle. The aims of this work are to:

- contribute to the development of functional models for analysing the interaction between the genotype, the environment and the crop management plan in order to obtain a varietal choice adapted to the different climatic situation and crop management plan;

- propose tools, indicators morpho-physiological and molecular markers for selection of genotype of interest.

### 4.9.2 Lessons learned

Advancing the planting date offers the advantage for the crop to complete its cycle before the drought season, where the shortage of water can be damaging for the yield. Autumnal or advanced spring sowing are feasible in southern Europe where the cold and frost do not risk to damage the seedlings during their early stage of development. In the other regions, where farmers cannot afford to sow their crop in advance without any protection, some strategies have been developed.

In the case of potatoes, planting under covers or using physiologically aged (chitted) seed can contribute to advance the crop cycle and can make small savings in irrigation need. However, in practice their scope may be wholly or partly limited by cost (approximately 460 EUR/ha for fleece and 345-370 EUR/ha for plastic films) and undesirable yield reductions: condensation returning to soil beneath the cover is highly non uniform and this can exacerbate on local points the problem of drought caused by limited or non-uniform rainwater percolation through plastic or fleece covers.

Water savings may be also achieved by encouraging the switch to second early varieties (when they are available) for maincrop harvest.
The study focused on sunflower has shown that autumnal sowing appears to be a good solution for water savings since it increases the water efficiency of the crop and reduces the evaporation due to a lower water demand from the atmosphere and a better coverage of the soil. In addition, it reduces pressure on the water sources during the drought season.

4.9.3 Transferability to other river basins

As explained in the previous section, the earlier planting alone can be done in all the river basins located in southern Europe.

In northern regions, farmers have to develop additional strategies like the use of plastic cover or the sowing of already germinated seed to reduce the duration of the cycle of the crop on the field.

4.9.4 Policy recommendations

Promoting an early planting date may be a way to reduce water use (by decreasing water irrigation consumption as well as increasing water efficiency in the crop). This strategy however needs to be applied in specific conditions when farmers are certain that the climatic conditions fit with the crop requirement (for example, the potatoes cannot germinate in a soil with a temperature below 9°C).

As is currently done in France for sunflower, it appears necessary to promote research on crop genotypes more tolerant to low temperatures.

References:


Findings of existing studies on the responses to save water in agriculture

1. Responses

4.10 Response 10: Crop selection

A possible means to save irrigation water is the use of crops or crop varieties which better tolerate water shortages and need less irrigation water; or the use of crop varieties which produce more biomass per unit of water (Tardieu and Zivy, 2006). Some crops are intrinsically more tolerant to drought (see Figure 4-12), some have developed the ability to uptake water from a deeper zone and others tolerate the lack of water thanks to adaptation mechanisms (such as decrease of the foliar surface, osmotic adjustment).

The selection varieties with a growing season that coincides with periods of water availability, such as early maturing and short season varieties are also advantageous, as the crop can be harvested before peak periods of evapotranspiration or periods of low river flows.

Variability between crops in terms of resistance to water shortage is mainly due to the efficiency of the root system. As an example, sorghum (biologically close to maize) has a very efficient deep rooting system and is able to maintain its photosynthesis and transpiration for a large range of soil water status. Sunflower also has a very efficient root system and adapts to the water resource availability by favouring grain filling over vegetative growth in certain phases.

The farmer can also choose varieties intrinsically more tolerant to drought. However, the varietal catalogues only rarely mention this trait, which is not a criterion for selection and therefore is not tested during the varietal trials.
Findings of existing studies on the responses to save water in agriculture

Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

4.10.1 Presentation of the studies

The data presented here rely on three different studies: two in France and one in UK. The studies focus on four different crops: winter wheat, sunflower, maize and sorghum.

In spite of the fact that numerous researches were carried out to obtain new crop varieties more tolerant to drought stress, in general the aim is not the concern of water savings but rather an economic issue: limiting yield losses in drought constrained areas.
4.10.1.1 **Identifying physiological traits associated with improved drought resistance in winter wheat**

In the UK, winter wheat (*Triticum aestivum*) is the most extensive arable crop, grown on about 2 million ha/year with a current average yield of about 8t/ha (DEFRA, 2005). Approximately 30% of the winter wheat area is located on drought-prone soils (Foulkes et al., 2001). Drought usually occurs after the flowering stage (also called the "post-anthesis" stage) and lead to an annual yield loss in the region of 15% (Foulkes et al. 2002). With the predicted climate change and more frequent summer drought, these losses could be exacerbated.

Therefore, researchers and plant breeders have examined new cultivars, more resistant to drought. In the present study, the research focus on the potential usefulness of four traits for maintaining yield under drought stress:

- early flowering,
- high accumulation of stem soluble carbohydrate reserves (which means important accumulation of sugars in the stem),
- presence of awns and,
- high green leaf-flag area persistence.

The association of these four specific targets traits for drought resistance with yield performance under late-season drought was analysed. The results indicate that the early flowering and the high accumulation of sugars in the stem did not affect the maintenance of yield under drought conditions. On the other hand, high green leaf persistence showed a clearer correlation with the maintenance of yield under drought.

This positive correlation between this trait and yield under drought indicates the potential use of this trait as a selection criterion for yield under drought for the future breeding programmes. These programmes could lead to the development of drought tolerant varieties which could allow the farmer to decrease the volumes of water irrigation and minimising yield loss compared to the current varieties of wheat.

4.10.1.2 **Use of sunflower to balance irrigated crop rotation, France**

Sunflower (*Helianthus annuus*) is cultivated on 3,5 million hectare in the European Union and its average seed yield is about 1,3t/ha and can reach an estimated potential close to 4,5t/ha.

Following the heavy drought of 2005 in France and southern Europe, funding granted for irrigated crops was decreased. Therefore, the farmers of the Poitou-Charentes region (France) had to find solutions to avoid a severe decrease of their income. One possibility is to rethink the crop rotation to include crops such as sunflower.

This study (Palleau, 2006) shows the potential for growing sunflower in terms of water savings but also the political and economical value of this crop.
Moderated need of water and better water extraction ability

For sunflower, the irrigation period in France starts at the beginning of July and ends in early August. It allows the use of water resources when they are still available. In years with a normal rainfall, irrigation from 30 to 100 mm (for all the crop cycle) is sufficient to meet the needs.

Compared to maize, sunflower can reach an optimum yield with a lower quantity of water thanks to genetic advances. Table 4-16 shows the total water consumption for maize, sunflower and sorghum as well as the optimum consumption. Sunflower appears able to consume more than maize crop. On the other hand, its needs are 100 mm lower compared to maize to achieve the optimum yield. The best yield for the sunflower is obtained by providing 70% of the water requirement. Beyond, the yield does not continue to increase whereas the risks for disease increase.

Table 4-16 Total and optimum water consumption (it represents the rainfall and the irrigation water) for maize, sunflower and sorghum

<table>
<thead>
<tr>
<th>Crop</th>
<th>Total consumption</th>
<th>Optimum consumption*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>520 mm</td>
<td>495 mm</td>
</tr>
<tr>
<td>Sunflower</td>
<td>550 mm</td>
<td>410 mm</td>
</tr>
<tr>
<td>Sorghum</td>
<td>450 mm</td>
<td>405 mm</td>
</tr>
</tbody>
</table>

* The optimum consumption is the quantity of water for which the sunflower reaches a plateau for the yield. After this point the yield increase only faintly.

In addition to this lower need of water, the sunflower has also an excellent ability to extract water from the soil, clearly higher than other crops, notably in the deeper soil layer.

Figure 4-14: Water extraction ability for three crops: sunflower, soy and wheat
4.10.1.3 **Increase maize tolerance to drought or sorghum productivity:**

**issue and trade offs**

Sorghum is usually considered as a drought tolerant crop compared to maize, which is responsible for half of the irrigation water consumption in France. Nevertheless, these two species are both C₄ plants which means that they present a higher efficiency in water use, compared to the C₃ plants such as wheat: their system allows them to produce more biomass per unit of transpired water. As an example, maize needs 400 litres of water to produce 1 kg of dry matter whereas wheat needs 1 500 litres/kg. The high water quantity used on maize is not linked to a higher demand in water compared to the sorghum but to a higher sensitivity to the water stress, notably during the seed formation and to a concentration of the water need during the summer season.

For the last ten years, the media have reported experiments of gene transfers, showing that it is feasible to improve the behaviour of maize plants in response to water stress. However, the experiments were carried out in conditions far away from real conditions occurring at the field level (Xu et al. 1996; Heard et al. 2005).

The genetic sequencing of sorghum (achieved in 2007) and maize (still ongoing) will probably help for the identification and then transfer of genes involved in the drought resistance from sorghum to maize. Nevertheless, this strategy remains risky as long as the answers to drought deficit are not better understood.

In the Maine et Loire region (France), sorghum is now considered as an alternative to maize. Its agronomical and fodder performances are acceptable. The yields can reach 10 t of dry weight per hectare without any irrigation. In general, between 40 and 120 mm of irrigation (depending on water availability) during the swelling of the ears is enough to obtain a good yield.

4.10.2 **Lessons learned**

The use of genetic engineering to obtain crops more resistant to drought takes time. To date, researchers are identifying markers linked with drought resistance that they could use afterwards, during varietal selection. In the case of wheat, for example, the green leaf-flag seems to be a good marker that could be used for further selection. A more complex experiment consists to transfer a gene from a species to another. This is what researchers expect to do with sorghum and maize once their respective mechanisms of drought resistance and sensitivity are better understood.

In an environment where water is becoming scarcer notably during the summer period, some alternative to high water-consuming plants need to be found. The benefits of sunflower should be considered to balance irrigated cropping with optimised margin. Sunflower needs less water and presents a watering schedule focused on periods of lower risks of restriction. In addition, in recent years, the advances in plant genetics have led to the achievement of a yield controlled at more than 4t/ha, provided that the essential points of the crop management plan are met. Sorghum, which is very similar to maize presents a totally different behaviour for water consumption and could replace its cousin since it shows acceptable yield and acceptable agronomic and fodder performance.
Since sunflower uses more soil water, due to deeper rooting, that could have a negative impact on groundwater recharge and water resources in the following season. The study provides however no information on this potential issue.

4.10.3 Transferability to other river basins

The genetic crop selection will lead to a variety of crops that are specifically adapted to specified environmental conditions. It is likely that new varieties will be adapted specifically for a defined region with certain bioclimatic parameters. Each region could thus have to use its specific adapted crop.

Concerning alternative crops, their cultivation also depend of the climate. Sorghum can easily grow in southern Europe. Sunflower has a very large distribution area and can be used in most of the European river basins: this crop require a minimum temperature of 4°C to germinate but the seedlings can tolerate an episodic decrease of temperature of -5°C exceptionally, during its cycle, the optimum daily temperature for growth are comprised between 21 and 25°C but a wider range of temperatures (17 to 33°C) shows little effect on productivity (Putnam et al., 1990).

4.10.4 Policy recommendations

A real diversification of the varieties proposed by the breeders is needed to select crops that are more resistant to drought: the criterion of drought resistance needs to be taken into account during the selection process of varietal creation.

When feasible and if the market economy can afford it, governments could promote the growth of more water efficient crops. Sunflower notably, which is grown today only in poor soils, could be extended to larger areas throughout Europe. This crop has the advantages of a high yield and be useful to various economic markets (chemistry, agro-industry, energy).

With the increase frequency of drought episodes, the sorghum can constitute a good alternative to maize in the region where rainfall are limited (Lamy, 2009). Thus, this crop should be taken more in consideration in all the southern Europe. Nevertheless, it seems also important to consider the potential impact that this crop may have on ground water recharge since its root system is more efficient and uptake more water than maize.

References:


Findings of existing studies on the responses to save water in agriculture


### 4.11 Synthesis of the findings

<table>
<thead>
<tr>
<th>Response</th>
<th>Description</th>
<th>Lessons learned</th>
<th>Transferability</th>
<th>Policy implications</th>
</tr>
</thead>
</table>
| **Improvement of irrigation systems** | - Typical rates in Mediterranean countries  
- Trickle irrigation in UK  
- Flood to trickle irrigation in ES | - Depend on crops/soils  
- Affect hydrology of system  
- May lead to increased surfaces cultivated  
- Price issue, link to yields/quality | - Changes to be evaluated on a case-by-case basis | Good option if:  
- integrated in a whole system approach, avoiding potential perverse impacts  
- adapted to crops/soils |
| **Deficit irrigation strategies** | - IT: tree crops and maize  
- ES: peach trees  
- BG: raspberry  
- DK: potatoes | - Certain types of crops only (tree crops, berries, ~potatoes)  
- Soil types are important  
- more risk (planning) | - Seems to depend on crop and soil more than on region | - Good knowledge required (and tools)  
- Adapted mainly for tree crops and vines |
| **Reduction of evaporation during storage** | - Shade-cloth cover in SE Spain | - Economic assessment  
- depends on prices  
- Filter cleaning and salinity | - Economic viability issue  
- Relevant in areas with reservoirs | - Subsidies are in place in Spain  
- No water saved, but reduced pressure, system to consider |
| **Decreasing soil evaporation** | - Mulches in UK  
- Hydrophobic polymer in ES | - Both techniques are useful in summer  
- Weed emergence reduced too  
- Reduced water infiltration in winter | - Mulching used across EU  
- Hydrophobic polymer less tested | - Mulching already promoted  
- Investigate other options |
| **Irrigation scheduling** | - Greece (Crete)  
- France | - Relies on precise data (sample plots)  
- Good results in wetter years  
- Organisation issues | - Could be transferred easily, info from local situation required | - Could be promoted by FAS  
- Reduction of water use in scarce years is still unclear and probably lower than for wetter years |
## Findings of existing studies on the responses to save water in agriculture

<table>
<thead>
<tr>
<th>Response</th>
<th>Description</th>
<th>Lessons learned</th>
<th>Transferability</th>
<th>Policy implications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reducing runoff</strong></td>
<td>- Soil tillage SE Spain</td>
<td>- Tillage increases water retention and reduces erosion</td>
<td>- Depend on local situation</td>
<td>- Depend on local situation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Negative effects of tillage too</td>
<td></td>
</tr>
<tr>
<td><strong>Water table management</strong></td>
<td>- WTM in maize and soybean, CA</td>
<td>- WTM increases yields</td>
<td>- WTM applies in areas where issues of drainage and scarcity apply</td>
<td>- Water savings are unclear</td>
</tr>
<tr>
<td></td>
<td>- water control on maize in CA</td>
<td></td>
<td>- System to be implemented may be complicated if not yet in place</td>
<td></td>
</tr>
<tr>
<td><strong>Water reuse</strong></td>
<td>- Reclaimed water in Spain</td>
<td>- Increases reliability of water availability</td>
<td>- Could be used in other river basins</td>
<td>- Increases the number of times the water is used</td>
</tr>
<tr>
<td></td>
<td>- Wastewater reuse for irrigation in Cyprus</td>
<td>- Sanitary issues</td>
<td>- Investment costs to be considered</td>
<td>- Sanitary issues to solve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Nutrient content of the water</td>
<td>- Depends on future use</td>
<td>- Awareness</td>
</tr>
<tr>
<td><strong>Changing planting date</strong></td>
<td>- Change planting data and length of irrigation season (UK)</td>
<td>- Strategies differ: chitted seeds, plastic film and fleece, genetic</td>
<td>- Depends also on temperatures for crop germination</td>
<td>- Awareness</td>
</tr>
<tr>
<td></td>
<td>- Sunflower 2010 (FR)</td>
<td>- Can improve yields</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Crop selection</strong></td>
<td>- Drought resistance in winter wheat</td>
<td>- Select a more efficient crop, or variety</td>
<td>- Adaptation of crop and variety to pedo-climatic conditions</td>
<td>- Research promotion could be necessary, but would require careful consideration of other impacts of the bred crops</td>
</tr>
<tr>
<td></td>
<td>- Use of sunflower in France</td>
<td>- Time required (selection or genetic engineering)</td>
<td>- Demand issue</td>
<td>- Estimation of economic potential of alternative crops, new markets and need to make farmers change practices for feeding these possible new alternative sectors</td>
</tr>
<tr>
<td></td>
<td>- Use of sorghum in France</td>
<td>- Benefits of “less conventional” crops</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Case studies

Chapter 5: Case studies

In brief: This section focuses on four case studies, providing further information on how responses are implemented on the ground. In Cyprus, the government has encouraged the modernisation of the irrigation system through subsidies allocations and training for the farmers. The organisation of a scheme of compliance as well as the reuse of waste water for irrigation also contribute to reducing the pressure on the ecosystems of this river basin. In the Adour-Garonne river basin (France), the initiatives presented mainly use a socio-economic approach, including regulating the use of water, providing advice for irrigation scheduling, an example of self-organisation by farmers to smoothen abstraction, but also storing water in dams and releasing it in scarce periods or testing a new governance scheme. The irrigation scheduling system IRRInet, developed in the Po river basin (Italy) allows for consistent water savings and appears to be a promising initiative for the rest of the EU. Other initiatives include the testing of remote sensing for irrigation advice. In the Anglian river basin (UK), winter storage reservoirs are being built, so that water is abstracted in the winter and used in the summer, reducing the pressure on water bodies at scarce times.

Four case studies are being investigated in this section, covering four different Member States and river basins, namely Cyprus (unique river basin), France (Adour-Garonne RB), Italy (Po RB) and the UK (Anglian RB). The case studies aim to provide an illustration of the responses from farmers, local authorities and other stakeholders to reduce pressure on water bodies by agriculture, and whether these responses are successful. An investigation of the context of the areas also gives precious indications on how the response was implemented in real-life.

The case studies investigate issues in MS that are not necessarily considered water scarce, but in river basins that are increasingly facing water shortages, especially as regards agricultural uses. This illustrates the importance of focusing on the river basin, rather than on the national level.

The Water exploitation index is presented at the beginning of the study (Figure 5-1). Cyprus has the highest WEI, Italy comes fourth, France 15th, and England & Wales 11th. Another similar index is the Water Stress Index (WSI). The WSI represents the ratio between the annual water withdrawal from ground and surface waters and the total renewable freshwater resources (i.e. same or similar figures to the WEI), giving an indication of a region/country’s potential exposure to water stress. Figure 5-1 (based on 2006 data) highlights that Cyprus is the most affected Member State, with a water stress index well-exceeding the 40% threshold for high water stress, Italy being just above the 20% threshold of medium water stress, France is above 10% of moderate water stress, while the UK is below that threshold.
5.1 Cyprus

NB: According to the provisions of Article 1 of Protocol No 10 on Cyprus, the application of the acquis is suspended in those areas of the Republic of Cyprus in which the Government of the Republic of Cyprus does not exercise effective control. This case study is only refers to the area of the island under government control.

5.1.1 Characteristics of the Cyprus RB

5.1.1.1 Geography and Climate

Cyprus is located in the northeastern region of the Mediterranean. It covers a total of 9,251 km². It has a Mediterranean climate with typical hot and dry summers from mid-May to mid-September and rainy, changeable winters from November to mid-March. There are 14 main rivers in Cyprus, which all originate in the Troodos Mountains. They are impermanent, as they are winter torrents, which go dry during the summer. Melting snow can supply water until late April.

The average annual rainfall over the part of the island is about 460 mm but it can range from 213 mm to 800 mm in exceptional years. Statistical analysis of rainfall in Cyprus reveals a decreasing trend of rainfall amounts over the last 30 years (14% in the last 100 years, Enveco et al. 2009). The average rainfall from December to February represents around 60% of the average annual total precipitation for the island and is the main source for replenishment of water bodies. Rainfall in the warmer months contributes little or nothing to water resources and agriculture.\(^\text{26}\)

\(^{26}\) Government Web Portal:
Cyprus is classified (together with Malta) as one of the “water poor countries” in Europe, with the most acute water shortage.

Figure 5-2: Precipitation Map (FAO, 2000); Data averaged over a period of 37 years

5.1.1.2 Water availability

- **Surface water**
  
The mean annual surface runoff represents 190 million m\(^3\) of which 80% is generated in the Troodos Mountains and 67% flows into governmentally-managed dams and irrigation systems. Reduction in stream flows is caused by human intervention, such as exploitation of water bodies. Given the uneven timing and geographical distribution of precipitation, water availability is highly dependent on storage capacity. Hence, more than 100 dams have been constructed on almost all rivers of the country and provide a storage capacity\(^{28}\) of around 332 m\(^3\). The total inflow in dams has significantly decreased in the last years, with 151 million m\(^3\) inflow in 2003/2004 and only 19 million m\(^3\) in 2007-2008.

- **Groundwater**
  
  During the last decades, aquifers presented depleting trends as it can directly be seen on borehole hydrographs (see Figure 5-3 as an example). In the early 2000’s, the aquifers showed an overall annual negative balance\(^{29}\) (net extraction) of 15,3 million m\(^3\). Illegal boreholes that pump water from aquifers increase the issue of over extraction (see also section 5.1.2.2). With groundwater overexploitation, saline intrusions occur in many coastal areas. It affects groundwater quality and thereby accelerates the depletion of available freshwater as valuable amounts of groundwater are spoiled.

\(^{27}\) www.cyprus.gov.cy/portal/portal.nsf/0/18e088380282f20cc2257023002b0413?OpenDocument&ExpandSection=4#_Section4

\(^{28}\) www.fao.org/countryprofiles/Maps/CYP/06/pp/index.html

Reclaimed Water

Reclaimed domestic water is a growing water resource in Cyprus. In order to sustain agricultural water needs and recharge groundwater sources, national policies have strengthened the role of recycled water in the urban and rural environments such as green areas, parks and forestry (for more information see section 5.1.3.3). At present about 10,5 million m$^3$ of tertiary treated effluent\(^\text{30}\) is reused and it is expected that this amount will significantly increase in the coming years when the constructions of new wastewater treatment plants are completed.

Desalinated water is also used in Cyprus, for drinking supply purposes.

Distribution of the freshwater sources in recent years

The water sources and their evolution is shown in Figure 5-4, where the importance taken by recycled water is clearly illustrated.

\(^\text{30}\) Communication with WDD
5.1.1.3 Water demand

The total annual water demand was around 275 million m$^3$/year in 2009 (Techneau 2009). The sectoral distribution is presented in Figure 5-5, with agriculture representing 59.1% of the water use and 3.3% used for livestock (67% of the demand in 2009 according to Techneau), use for households representing 29.6% and for tourism 4.9% (municipal supply to households and urban users 31% in Techneau 2009, of which 5% of water consumed was related to tourism/hotels). Moreover, water demand in Cyprus is characterised by an important seasonal peak in summer due to agricultural irrigation as well as intense tourism. Similar data result from the estimations of the Cyprus statistical office, in 2003, 129.49 million m$^3$ of publicly supplied water were used, 47% of which was used by agriculture, and adding self-supply water, amounting to 117 million m$^3$ in 1998, 90% of which was used for irrigation purposes. Thus the total water use would be a bit lower than 250 million m$^3$, and 166.16 million m$^3$ would be used for agriculture, i.e. about 66%.
While agriculture does not necessarily directly play a big part in the Cypriot GDP (Figure 5-6), it is important in terms of rural development, employment, land-use and as a basis for the agri-food sector. In 2007, the Eurostat farm structure survey recorded 40,100 agricultural holdings in Cyprus, on 146,000 ha, employing 23,800 equivalent full time. 79% of Cypriot farms specialise in crops; and 32% of the holdings were specialists in fruit and citrus fruit. In terms of “euros per drop”, Figure 5-6 shows the economic return of tourism and agriculture, with their relative water demands. This can be important when deciding about water allocation measures (see section 5.1.3.2). However, as will be seen in the next sections, water efficiency in agriculture has already been raised.

Figure 5-6: Sectoral water demand and contribution to GDP for year 2006 (Techneau, 2009)

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31 About 26% of the 555,060 ha controlled by the Cyprus government, about 60% of the 9,251 km² island.
32 About 3% of the population, based on 804,435 inhabitants in Cyprus estimated on 1 January 2011 according to Eurostat: epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&language=en&pcode=tps00001&plugin=1
Characterisation per water resource

The water demand is further characterised by resource and sector in Figure 5-7. The agricultural sector receives comparable shares of surface water and groundwater (i.e. conventional waters). The amount of surface water used for irrigation purposes is managed by the government via controlled irrigation schemes. This surface water comes from dams, rivers and springs and represents respectively 39.2%, 6.3% and 3.5% of the total water demand for agriculture. The influence of tertiary water effluents (i.e. reused water) is not taken into account although it is a growing water source with regard to meeting irrigation needs. Desalinated water is exclusively dedicated to domestic water use for the moment.

Figure 5-7: Water demand by resource and sector (adapted from Techneau, 2009 and Papadopoulos et al., 2005).

5.1.1.4 Water management system

According to the recent Integrated Water Management Law (2010), the implementation of the Government’s policy on water resources management in Cyprus is the responsibility of the Water Development Department (WDD) of the Ministry of Agriculture, Natural Resources & Environment, with the cooperation of other governmental departments or non-governmental organisations:

- Surface water and dam management: Water Development Department (WDD) of the Ministry of Agriculture, Natural Resources and Environment (MANRE).
- Groundwater monitoring: Water Development Department of the Ministry of Agriculture, Natural Resources and Environment (MANRE).
- Drinking and bathing water quality: Ministry of Health.

Drinking water is mainly supplied through Government Water Project (GWP), which cover 85% of the country’s domestic water needs. It is supplied “in bulk” to the Local Water Authorities which undertake its supply to the individual consumers. Nevertheless, there is a number of
communities which have their own water supply sources, mainly groundwater, which they manage themselves.

Regarding agricultural use, governmentally-managed irrigation schemes provide fresh conventional water and recycled water (see section 5.1.3.3) on a retail basis to farmers or on a bulk basis to Irrigation Divisions and Associations (local entities formed by landowners and water-rights owners). The water allocation system is further discussed in section 5.1.3.2.

Irrigation water charges paid by the farmers within governmental water management cover a considerable amount of the total financial cost of the water infrastructure (dams, conveyors, distribution, etc.), including the capital cost, the operation and maintenance costs as well as the administration costs. In the case of groundwater abstraction (i.e. private boreholes not controlled by the government), the total financial cost (well drilling, conveyance, pumping etc) is fully covered by private individuals.

Reused water is a resource that has been given increasing attention during the last years, due to freshwater supply restrictions applied to irrigation. Tertiary treatment of the treated effluent makes the water suitable for certain uses (including irrigation). The cost of this treatment, by Decision of the Council of Ministers is borne by the government. Such water is then directed for the irrigation of tree plantations or hotel gardens, as well as any other uses that do not require potable water. However, strong restrictions apply on what crops that kind of irrigation water can be used for, in particular leafy vegetables may not be irrigated by reused water (see section 5.1.3.3).

5.1.2 Water pressures and challenges in the agricultural sector

As seen in section 5.1.1.3, agriculture is the dominant water using sector in Cyprus. This section focuses on the agricultural patterns in Cyprus and identifies the main pressures and challenges that Cypriot farmers and authorities have to address in order to ensure sustainable agricultural production rates while coping with less and/or lower quality water.

5.1.2.1 Characterisation of the agricultural land

The total agricultural land in Cyprus consisted in 2005 of 198 500 ha (higher than in 2007, see 5.1.1.3), from which 38 500 ha (19.2%) were irrigable (Table 5-1). In 2007, 32.7% of the land was irrigable and 22.3% irrigated (see table in Annex 2).

Table 5-1: Land Use in Cyprus (Fatta et al., 2005)

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Irrigable Area (1000 ha)</th>
<th>Total Area (1000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops</td>
<td>35.2</td>
<td>133.6</td>
</tr>
<tr>
<td>Temporary crops</td>
<td>19.2</td>
<td>92.3</td>
</tr>
<tr>
<td>Cereals</td>
<td>4</td>
<td>56</td>
</tr>
<tr>
<td>Legumes</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Industrial crops</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Fodder crops</td>
<td>4.5</td>
<td>25.3</td>
</tr>
</tbody>
</table>
5.1.2.2 Water demand for irrigation

The percentage of water demand for permanent and temporary crops has changed in recent years, from an estimated 59% and 41% (corresponding to volumes of 95,8 and 65,5 million m$^3$) of total irrigation water in 2003 (Papadopoulos et al., 2005) to an estimated 33% and 67% in 2011 (Hadjipanteli 2011). The water demand for irrigation of various crops was distributed in 2003 as shown in Figure 5-8. The high water demand of citrus can be put in parallel with the farm structure survey of Eurostat (2011) which shows that a third of holdings in Cyprus are specialised in fruits and citrus trees.

Pressure on groundwater abstraction

The irrigation period starts in April and ends in October - December (depending on rainfall conditions). However, there might be years or crops when irrigation takes place year-round. As groundwater is often the most accessible source of water, private boreholes and wells tend to be intensively used, even where governmentally-subsidised water has been planned and allocated by WDD. This is particularly relevant when farmers have to overcome water shortages during dry years.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Irrigable Area (1000 ha)</th>
<th>Total Area (1000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables and melons</td>
<td>9,7</td>
<td>9,7</td>
</tr>
<tr>
<td>Permanent Crops</td>
<td>16</td>
<td>41,3</td>
</tr>
<tr>
<td>Vines</td>
<td>2,5</td>
<td>18,2</td>
</tr>
<tr>
<td>Citrus</td>
<td>5,4</td>
<td>5,4</td>
</tr>
<tr>
<td>Fresh fruit</td>
<td>3,6</td>
<td>3,6</td>
</tr>
<tr>
<td>Nuts</td>
<td>1,2</td>
<td>3,9</td>
</tr>
<tr>
<td>Olives and Carobs</td>
<td>3,3</td>
<td>10,2</td>
</tr>
<tr>
<td>Fallow Land</td>
<td>1,5</td>
<td>9,5</td>
</tr>
<tr>
<td>Grazing Land</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Uncultivated Land</td>
<td>1,5</td>
<td>47,8</td>
</tr>
<tr>
<td>Scrub and deserted Land</td>
<td>0</td>
<td>6,6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>38,2</strong></td>
<td><strong>198,5</strong></td>
</tr>
</tbody>
</table>

Other agricultural production is mainly livestock (e.g. sheep, goats, pigs and poultry) for which the total water needs (for drinking and hygiene) are estimated to reach 8,5 million m$^3$/year.
Illegal abstraction and overpumping happens more intensively in periods of scarcity, as governmentally-managed water is supplied in priority for drinking water (see section on water allocation), resulting in reduced water availability for farmers. This unregistered use is particularly problematic during drastic water cuts (such as in 2001 and 2008), where water is abstracted from these wells without any monitoring, leading to further depletion of water resources. Since there was no monitoring of the water meters in the past, it is difficult to estimate the illegal abstraction (mainly from groundwater). Illegal abstractions were however more common in the past, with a new law passed in November 2010 to improve the situation. New procedures are in place, with a pilot project to check licences, make sure that wells are legal, etc.

Only groundwater monitoring enables to have a view of the impacts on the aquifer levels. In that regard, piezometric levels in Cypriot aquifers may show a drop of more than 1 m per year. The "water scarcity gap" of an aquifer (i.e. the imbalance between abstraction and recharge) is estimated to 13 million m³/year (average over the last ten years)\(^3\).

**Saline intrusions**

Nowadays, most of the groundwater aquifers are still overexploited and face severe overpumping problems, which lead to (occurring or potential) seawater intrusion (see Figure 5-6) and deterioration of groundwater in terms of both quantity and quality. Through the strict implementation of the Water Framework Directive, this risk is expected to be mitigated within the next five to ten years\(^3\).

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\(^3\) Communication with WDD
Competition between the agricultural and touristic sectors concerning water availability

Water resources must be shared between the drinking water sector (domestic use, tourism and industry) and the agriculture sector. The water allocation process gives priority to drinking water over other uses, satisfying 100% of the needs. The quantities allocated for irrigation then depend on the remaining water availability, and rarely match the needs (see section 5.1.3.2 on water allocation). However, there is also usually process to discuss among the drinking water stakeholders and the irrigation water users, as to how the priorities should be given.

5.1.3 Initiatives for sustainable water management

5.1.3.1 Efficient irrigation systems (addressing evaporation losses)

Since 1965, the Government of Cyprus has implemented a Water Use Improvement programme in parallel with actions targeting an increased water availability (e.g. construction of dams, see section 5.1.3.5). The farmers were then provided with technical and financial assistance for the installation of low to medium pressure irrigation systems and the application of proper irrigation schedules.

Means of Implementation

The Ministry of Agriculture provided both an improved hydraulic design of the irrigation systems, free of charge, and financial incentives (such as subsidies and long-term low interest loans) for purchasing and installing improved irrigation systems.
This resulted in a decrease of flood-irrigated areas from about 13,400 ha in 1974 to just over 2,000 ha in 1995\textsuperscript{35}, while the agricultural land equipped for micro irrigation increased from about 2,700 ha to 35,600 ha over the same period. In addition, through extensive demonstrations, the government convinced the farmers that improved irrigation methods not only saved water but could also lead to increased yields (Iacovides, 2001).

Due to the relatively high installation cost, the drip method was initially used for irrigation of high value crops, such as greenhouse vegetables and flowers. At a later stage, the use of drippers, mini-sprinklers and low capacity sprinklers was extended for irrigating trees and field vegetables. In 2009, 95% of the total irrigated area was served by low to medium pressure advanced irrigation systems and proper irrigation schedules, leading to an overall water use efficiency of above 80%. The irrigation systems are 90% micro-irrigation, 5% sprinkler irrigation and 5% surface irrigation (Techneau, 2009).

Recommendations from the Cypriot Ministry of Agriculture depend on the type of crops (Papadopoulos et al., 2005):

- For densely spaced field vegetables like potatoes, carrots or beans, the permanent low capacity sprinkler system is suitable for efficient irrigation, but in case of limited finances, portable sprinkler can also be an option although it would be more labour intensive.

- Drip irrigation is the most suitable system for row vegetables grown in greenhouses, low-tunnels and in spaced open fields. One nozzle is usually installed to deliver water at each plant. Among permanent plantations, drippers are particularly recommended for bananas, grapes and aromatic plants. Large nozzle opening is generally preferred as it cannot be easily blocked by impurities and a uniform flow is thus ensured.

Table 5-2 further specifies the distribution of irrigated areas by crop and water use in Cyprus in 2000.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Irrigated Area (%)</th>
<th>Water use (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>30</td>
<td>19</td>
</tr>
<tr>
<td>Citrus</td>
<td>24</td>
<td>31</td>
</tr>
<tr>
<td>Deciduous</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Olives</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Table Grapes</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Bananas, Avocado</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Permanent Crops</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

\textsuperscript{35} The 2,000 ha area that was still irrigated by flooding is mostly dedicated to deciduous trees and was located in the hilly parts of the country, which are usually irrigated with small springs. In these areas, the Ministry of Agriculture focuses on irrigation improvement through partial grant assistance, land leveling and improvements in infrastructure.
## Case studies

### Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

#### Crops

<table>
<thead>
<tr>
<th>Crops</th>
<th>Irrigated Area (%)</th>
<th>Water use (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouses</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vegetables</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Clover, etc</td>
<td>3</td>
<td>9</td>
</tr>
</tbody>
</table>

#### Costs (FAO, 1997)

The cost of irrigation development varies and depends on several factors:

- the water resource (surface water or groundwater),
- the type of irrigation systems and,
- the irrigated area

Excluding the cost of the dam, the development of surface water efficient irrigation system varies from 1 153 EUR to 1 930 EUR/ha (1 560 to 2 610 $/ha), including on-farm micro irrigation system. It is comparable to the operating cost of private wells for groundwater abstraction: about 2 900 EUR/ha (3 930 $/ha) for up to one hectare, 1 670 EUR/ha (2 260 $/ha) for two hectares to 1 250 EUR/ha (1 700 $/ha) for three hectares (also including the cost of on-farm micro-irrigation systems). Regarding maintenance costs, the average annual cost varies from 220-260 EUR/ha (300 to 350$/ha) for private schemes (tubewells) and 40-90 EUR/ha (50 to 90 $/ha) for public schemes.

#### Outcomes

The total amount of water saved due to the use and proper management of advanced irrigation systems is estimated to be **75 million m³ per year** (Hadjipanteli 2011).

Besides, modern technology introduced is continuously being tested by the Agricultural Research Institute in order to evaluate the different systems and instrumentations under local conditions along with optimization work with regard to irrigation schedule and changes in cropping patterns (see section 5.1.3.5).

#### 5.1.3.2 Water allocation to agriculture

Water is governmentally-managed by schemes depending on its availability and based on a quota system. In February, farmers apply for the volumes of water they will need for the irrigation season, giving information related to the area and the type of crops that they plan to cultivate (permanent, seasonal, greenhouses, etc.). Based on this information and taking into consideration the annual water demand per crop per area, WDD estimates the water needs for the coming irrigation period, from January to December. Depending mainly on the storage water (in dams), the WDD grants a certain amount of water for each farm, irrigation division or association and specifies the shares for permanent and seasonal crops. In complement, Cypriot farmers also use around 50 000 private boreholes - many of which are illegal (see section on illegal abstraction). Theoretically, the GWP was expected to satisfy about 50% of the irrigation water demand. However, the mean annual consumption from the GWP only is 26% of the needs due to water shortage and allocation restrictions (Hadjipanteli 2011).
The restrictions that are usually imposed on irrigation every year are based on a prioritisation scenario whereby water is first supplied for drinking water uses, to satisfy 100% of the needs (domestic, tourism, livestock, others). The remaining quantities are allocated to the irrigation sector and the different crops by priority as follows:

- first satisfy the greenhouses and permanent crops by 40% - 100% (depending on water availability) of their normal water needs,
- then water is allocated to seasonal crops, from 0% to 100% of their water needs,
- water allocated for the irrigation of green areas varies from 0% to 100%.

The WDD is the competent authority to develop, propose and apply the scenario. It is important to note that the scenario is prepared with the participation of the interested parties, including the local authorities’ representatives and the farmers’ organisations. After this consultancy procedure, the final scenario is proposed to the Consultancy Water Committee (according to the recent "Integrated Water Management Law of 2010"). This Committee includes the different interested parties, from governmental and non-governmental organisations (e.g. the Ministry of Agriculture, Natural Resources & Environment, the Department of Agriculture and other governmental authorities, the Farmers’ and the Local Water Authorities’ Organizations, other Councils etc). The final scenario is approved by the Council of Ministers and then put into force.

With the approval of the scenario (see above), each farmer is informed, in writing, about the quantities that he/she is allowed to use for each field for the coming irrigation period. If he/she exceeds them, he/she has to pay an overconsumption fee for the extra quantities, while the supply may be disconnected.

For the period of 1990 to 2011, there was only one year during which the full irrigation demand was met, and that was in 2004, when all dams were over spilling. In contrast, during 2008, strict restrictions were imposed on the supply of water from the Government Water Works (limited drinking water supply to households and 100% ban on the supply of water to agriculture).

The areas which are irrigated from tertiary treated effluent (which is a secure water source in terms of quantity, see next section) are almost independent from the dam storage and the climatic conditions and therefore they are usually supplied with enough water every year (permanent crops, forage and green areas).

### 5.1.3.3 Use of alternative water: Water Reuse

Faced with the water stress context and competition between agricultural and tourism sectors, the Water Development Department is promoting reclaimed water use as an alternative source of water supply for irrigation since 2001. The water reuse scheme is also a way to solve the issue of the way to dispose of wastewater (Aquastress, 2005).

#### Means of Implementation

Concentrations of the population in and around the urban centers and the large numbers of tourists staying in coastal resorts in Cyprus have necessitated the planning and construction of
several centralised sewerage schemes. The reuse of treated effluents provides water of sufficiently good quality for irrigation purposes. As the uptake of reuse schemes depends upon the readiness of the farmers to adopt them, a promotional campaign to convince farmers to accept treated sewage effluent was undertaken, with attractive initial prices of reused water. The promotional campaign also targeted the broader public, that was concerned about sanitary issues, and promoted best practices.

In particular, guidelines and a code are in place to specify which types of crops may be irrigated with reused water (Box 1). Most irrigated crops are trees such as citrus and olive trees, or fodder crops and cow grass. All vegetables (an in particular lettuce and other leafy vegetables) may not be irrigated by such water.

Reused water is used not only for irrigating crops, but also for e.g. irrigating golf courses, hotel lawns. In addition, reclaimed water is used for aquifer recharge. At Paphos, the Ezousa aquifer is recharged artificially with 2-3 million m$^3$ reclaimed effluent per year, which is then re-abstracted for irrigation.

### Box 1: The Cyprus standards (Aquastress, 2005)

A Mechanised methods of treatment (activated sludge e.t.c.)
B Stabilization Ponds
* These values must not be exceeded in 80% of samples per month. Min. No. samples 5.
** Maximum value allowed
(a) Irrigation of leaved vegetables, bulbs and corms eaten uncooked is not allowed
(b) Potatoes, beet-roots, colocasia.
Note 1: No substances accumulating in the edible parts of crops and proved to be toxic to humans or animals are allowed in effluent.
Note 2: Max permissible values for heavy metals annex Al.
Note 3: For treatment plants > 10,000 p.e. tests of toxicity Annex 2.
Note 4: COD< 125 mg/l

Some examples of the wastewater treatment and reuse schemes are presented in Table 5-3.
Table 5-3: Reuse of Urban Wastewater in Cyprus (Fatta et al. 2005)

<table>
<thead>
<tr>
<th>Wastewater Plant</th>
<th>Treatment</th>
<th>Wastewater Produced m$^3$/yr</th>
<th>Treatment</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicosia Sewage Board</td>
<td>Secondary</td>
<td>3,650,000</td>
<td>Secondary</td>
<td>Diverted to Pedieos River</td>
</tr>
<tr>
<td>Anthoupolis-Nicosia</td>
<td>Secondary</td>
<td>1,277,500 (max 2,56 million)</td>
<td>Secondary</td>
<td>Stored in open reservoir for evaporation</td>
</tr>
<tr>
<td>Larnaca Sewage Board</td>
<td>Tertiary</td>
<td>912,500 maximum</td>
<td>Tertiary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Agia Napa – Paralimni</td>
<td>Tertiary</td>
<td>2,500,000 maximum</td>
<td>Tertiary</td>
<td>Landscape-Forest</td>
</tr>
<tr>
<td>Limassol Sewage Board</td>
<td>Tertiary</td>
<td>3,000,000</td>
<td>Tertiary</td>
<td>Agriculture-Landscape of Hotels</td>
</tr>
<tr>
<td>Pafos Sewage Board</td>
<td>Tertiary</td>
<td>4,895,000</td>
<td>Tertiary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Bathia Gonia</td>
<td>Tertiary</td>
<td>803,000</td>
<td>Tertiary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Dhalis-Nisou</td>
<td>Tertiary</td>
<td>182,500</td>
<td>Tertiary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Platres</td>
<td>Tertiary</td>
<td>73,000</td>
<td>Tertiary</td>
<td>Not operating-Agriculture</td>
</tr>
<tr>
<td>Carlsberg</td>
<td>Tertiary</td>
<td>146,000</td>
<td>Tertiary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Nicosia New Hospital</td>
<td>Tertiary</td>
<td>182,500</td>
<td>Tertiary</td>
<td>Not operating-Landscape</td>
</tr>
<tr>
<td>Limassol Hospital</td>
<td>Tertiary</td>
<td>47,450</td>
<td>Tertiary</td>
<td>Landscape</td>
</tr>
<tr>
<td>Alassa (new site village)</td>
<td>Tertiary</td>
<td>18,250</td>
<td>Tertiary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Palechori</td>
<td>Tertiary</td>
<td>73,000</td>
<td>Tertiary</td>
<td>Diverted to the River</td>
</tr>
<tr>
<td>Apostolos Loucas</td>
<td>Secondary</td>
<td>25,550</td>
<td>Secondary</td>
<td>Used by the Agriculture Research Institute</td>
</tr>
<tr>
<td>Kofinou</td>
<td>Secondary</td>
<td>65,700</td>
<td>Secondary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Zenon-Kamares II</td>
<td>Secondary</td>
<td>109,500</td>
<td>Secondary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Agglisides</td>
<td>Secondary</td>
<td>365,000</td>
<td>Secondary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Kornos</td>
<td>Tertiary</td>
<td>25,550</td>
<td>Tertiary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Stavrovouni</td>
<td>Tertiary</td>
<td>25,550</td>
<td>Tertiary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Agios Ioannis</td>
<td>Tertiary</td>
<td>17,900</td>
<td>Tertiary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Malounda</td>
<td>Tertiary</td>
<td>7,300</td>
<td>Tertiary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Klirou</td>
<td>Tertiary</td>
<td>26,300</td>
<td>Tertiary</td>
<td>Landscape Irrigation</td>
</tr>
<tr>
<td>Kyperounda</td>
<td>Tertiary</td>
<td>109,500</td>
<td>Tertiary</td>
<td>Agriculture</td>
</tr>
<tr>
<td>Troodos</td>
<td></td>
<td>8,800</td>
<td></td>
<td>Landscape</td>
</tr>
</tbody>
</table>

As some concerns can be raised regarding the impact of the use of recycled water on the land, with salt being possibly the most serious issue in Cyprus in terms of water quality, there is some work on the Sodium Adsorption Ratio (SAR$^{36}$). Based on investigations performed in the Aglandja area (where the farm of the Agricultural Research Institute is located), treated

$^{36}$ SAR is a measure of the suitability of water for use in agricultural irrigation that is determined by the concentrations of solids dissolved in the water.
wastewater demonstrated better results (lower SAR values) in comparison to conventional waters, as shown in Table 5-4 (Kathijotes, 2009).

Table 5-4: SAR values in soil profiles irrigated with either farm conventional water or recycled water

<table>
<thead>
<tr>
<th>Depth in soil (cm)</th>
<th>SAR in farm conventional water</th>
<th>SAR in treated effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>10,8</td>
<td>8,5</td>
</tr>
<tr>
<td>15-25</td>
<td>14,4</td>
<td>9,2</td>
</tr>
<tr>
<td>25-55</td>
<td>15,2</td>
<td>12,5</td>
</tr>
<tr>
<td>55-70</td>
<td>22,8</td>
<td>10,6</td>
</tr>
<tr>
<td>70-120</td>
<td>19,5</td>
<td>17,6</td>
</tr>
</tbody>
</table>

Farmers perceptions

The social discomfort in using reclaimed water for irrigation purposes and aquifer recharge is a major drawback for the introduction of the reclaimed water in the water system of the region. Authorities, and in particular the WDD and the Sewerage Board of Limassol, where the problem is more acute, are seeking ways to share knowledge, increase awareness and enhance public acceptability of this technique (Aquastress, 2008).

In order to investigate the willingness of farmers to accept recycled water, the University of Cambridge launched a field study in the Akrotiri aquifer area and randomly questioned 97 farmers in 2007 (Birol et al., 2007). 53,9% of the farmers consider low water quantity the most important agricultural problem in Cyprus, before lack of subsidies. The majority of farmers is willing to participate in the water reuse system and to use significant amount of reused water. But 47% of the farmers think that the consumers will stop or decrease their consumption of food from recycled water-irrigated lands (see Figure 5-10). The study also showed that farmers are willing to pay even for low quality treated water, highlighting the severity of the water scarcity problem in the agricultural sector in Cyprus.

Figure 5-10: Farmer perception of consumers’ attitudes towards food produced with recycled wastewater
## Costs

For the establishment of water reuse projects, the Government assumes all the costs concerning the construction and operation of the tertiary treatment facilities and the conveyance of the treated effluent to the farms.

When implementing a recycled water supply service for irrigation (i.e. tertiary treatment), the WDD assesses an overall average cost of 0.23 EUR/m³, taking into account direct costs for 65% (corresponding to capital, operation and maintenance costs) and environmental costs for 35% (which economically represent potential environmental damage of a water body (WDD, 2010)).

An interesting case in Cyprus is the Larnaca wastewater reuse system. Since its operation in 2000, the effluent irrigates 150 hectares of agricultural land at Dromolaxia Village where corn and alfalfa are cultivated. The treated water is also used by the hotels, International Airport and Larnaca Municipality for the irrigation of gardens, parks and fields during the summer season. The total cost of the project is 50 million EUR, including 9.3 million EUR for the tertiary treatment plant and reuse system. The cost for the production of tertiary treated water in this area is assessed to around 0.5 EUR/m³ (Hidalgo et al, 2004).

Another remarkable case in Cyprus is the reuse system in Cavo Greco area, which irrigates the agricultural land in Paralimni where potatoes are mostly cultivated, but also the gardens and parks of the hotels and municipalities during summer. The total cost of the plant has been 14.4 million EUR, including 5.9 million for the tertiary treatment plant and reuse system. The cost for the production of tertiary treated water was estimated to be around 0.50 EUR/m³ (35 cents for secondary treatment and 15 cents for tertiary treatment) in 2004. The Sewerage Board of Paralimni and Ayia Napa used to sell this water at the price of 0.25 EUR/m³ for the hotels and 0.10 EUR/m³ for agriculture (Hidalgo et al, 2004). The current prices are 0.07 EUR/m³ for agriculture and 0.15 EUR/m³ for green areas etc (WDD communication).

## Outcomes

According to WDD, reclaimed water represents 7-10% of the governmentally-managed irrigation water in 2007, to be primarily used for the irrigation of agricultural land, parks, gardens and public greens. As presented in Table 5-5, the annual water recycling is expected to increase to 52 million m³ by 2012 when the constructions of new wastewater treatment plants would be completed. That would then correspond to 28.5% of the 2009 agricultural water demand. According to the RBMP, “Today 12×10⁶ m³ of recycled water is given for irrigation and about 2.5×10⁶ m³ for artificial recharge of aquifers. However, an exponential increase in the amounts available in the future is expected. In the future, the capacity of the new Waste Water Treatment Plans will reach up to 65×10⁶ m³ per year over the medium term (2015) and 85×10⁶ m³ for longterm (2025)”. The issue of pipes required for the transport of the water, necessitating separate pipes for reused water and abstracted water is also mentioned, with a study foreseen to assess whether common pipes could be implemented and under which conditions/for which uses.\(^{37}\)

The efficient use of reused/recycled water is also expected to reduce the need to construct desalination plants, which are even more expensive.

Table 5-5: Estimated volumes of treated wastewater (Techneau, 2009)

<table>
<thead>
<tr>
<th>Million m$^3$/year</th>
<th>2012</th>
<th>2015</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal wastewater</td>
<td>46</td>
<td>51</td>
<td>69</td>
</tr>
<tr>
<td>Rural wastewater</td>
<td>13</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Total wastewater</td>
<td>56</td>
<td>65</td>
<td>85</td>
</tr>
<tr>
<td>Recycled water</td>
<td>52</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

In order to allocate reused water, the water balance is taken into account on farms, where water can be substituted (from blue to reused water), it is done, but in certain cases (crops cultivated, technical issues, etc.) no substitution can occur. In that case it could be envisaged to increase the irrigated area in Cyprus. This can be debatable as it would not contribute to solving the issue.

In certain cases, in particular where the amounts of reused water available is higher than the demand (e.g. Nicosia area), such water could be used for new irrigated areas. It is also used for recharging groundwater resources. In that case, natural filtration occurs, so no further treatments are required when pumping that water out for use.

5.1.3.4 Water pricing

Currently, water pricing is an integral part of the Government policy on water. Water for municipal uses, including connected industries, commercial and tourist purposes is sold at full financial cost, while irrigation water is sold at 50% of the full financial cost or at 41% of the full cost (financial + environmental + resource cost). Note that “full financial cost,” mean the full cost of capital cost and cost for O&M of the infrastructure for storage, transport and distribution of water. Besides, irrigation water billing is based on the actual consumption metered at each individual farm.

Irrigation water pricing to individual farmers has very much changed in the last decade. Currently, according to the National Law and Loan Agreements for financing the GWP (IBRD) the price should reach at least 38% of the cost but not exceed 40% (or 65% under special conditions). Factors taken into account are the important of the primary sector, food security, preservation of rural landscape, avoidance of urbanization. Groundwater abstraction is not charged and is paid by the well owner (Hadjipanteli 2011).

5.1.3.5 Other options

Storage management

Impressive infrastructure projects to capture rainwater. “Not a Drop of Water to the Sea” policy has been implemented since the 1960s. The capacity of water storage was increased from 6 to 300 million m$^3$. Additional works are still foreseen until the period 2015, including Arminou dam (
already constructed) on Diarizos river, the construction of Tamassos Dam on Pediaios river, the construction of Kannaviou Dam on Ezousa river, and the construction of Klirou - Malounda - Akaki Dam on Akaki river.

**Water Regulation**

Several measures were introduced in order to control groundwater abstractions in agriculture. During the last 20 years, a special legislation was applied in certain areas in order to prevent the deterioration of the local coastal aquifers; the recent legislation regarding Water Management, called “The Integrated Water Management Law of 2010”, has been enforced; and WDD took over the responsibility for drilling permits and abstraction permits, which are legally required all over the country. A more stringent procedure of permitting the sinking of wells is applied, with the ability to regulate abstractions, depending on the aquifer’s condition. Generally, when the aquifer is in “poor status,” or is over-pumped, the new permits are limited only to the irrigation of existing permanent plantations. Additionally, the new procedure involves the reviews of the old boreholes with the objective to apply an abstraction charge, reflecting the environmental and resource cost to all. The procedure has been implemented since the beginning of 2011; however there is still a long way to reach the goal.

In addition to the above, the recently established River Basin Management Plan and Drought Management Plan, propose a series of management measures which aim at restoration of water balance. The document reiterates the importance of the water regulation mentioned above, that clearly gives responsibility for authorisation management of all water sources to the WDD, which now has a primary rather than advisory role. Measures to improve efficient and sustainable water use in agriculture include the preparation of a study on cultivation restructuring, subsidies for reduced use of irrigation water, awareness-raising of farmers, etc.

The RBMP notes that crop restructuring would be an interesting option, but is quite complicated. Indeed, farmers have chosen the crops they are cultivating and should thus gain new knowledge, learn new techniques and experience, for the new crops. A methodical study is proposed to specifically look at what could be done and adapting solutions for the different areas in Cyprus. The RBMP also notes that the share of domestic water demand in total demand has increased, requiring more efforts in that area in terms of water savings.

**Awareness-raising activities**

Training is implemented yearly by the Ministry for farmers, and more generally education at school about water issues and awareness campaigns on TV or on the radio are also in place.

The RBMP mentions for raising awareness among farmers the distribution of “brochures and leaflets with useful advice and suggestions for potential water savings, incentives to reduce intensive farming, with information on the rational use of fertilizers, protection of farmland and overall rational management of water resources (adequate irrigation practices, reduction of pumping, construction of drainage works)”.

---

38 Communication with WDD.

Agricultural practices

Changes in cropping patterns/crop restructuring is identified in the RBMP as a potential solution, which requires further investigation and needs careful adaptation, as well as knowledge and training of farmers (see above).

Soil-less cultivation is being investigated as a possible way to increase the water use efficiency of agriculture, with several other benefits, including higher yields, reduce energy requirements, growth control (quality improvement), use of areas not suitable for cultivation, etc. The Agricultural research institute is carrying out studies to investigate the potential of this cultivation practice on roses (Chimonidou et al. 2004).

According to ARI, the open system of soilless culture (open hydroponic systems) is at present most favoured commercially in Cyprus due to its simplicity, mainly in managing the nutrient solution. However, environmental pollution problems are linked to that practice, and a project to implement closed systems for soilless culture is in place, focusing on tomatoes in greenhouses⁴⁰. The advantages of such system are the reduction of pollution and efficient use of water and fertilisers, but water of very good quality is required, which is not easily found in Cyprus, and cost of materials is high.

5.1.4 Conclusion

Cyprus is a recognised example of a situation where irrigation efficiency has been increased significantly in recent years. This was done through an ambitious national programme with advice and incentives for farmers. The drivers for improving the situation were also significant, with Cyprus being a very dry island that was experiencing increasing negative impacts from overabstraction, such as salinisation of water bodies. Enforcement of the legislation by reducing the number of illegal boreholes was also an important measure taken by the Government. Additionally, the clear water allocation hierarchy allows for a transparent allocation of the available water.

Another technique used widely in Cyprus is wastewater reuse, which can only occur on agricultural lands for certain types of treatments, the requirement depending on the type of crop irrigated. This is a good way to reduce the likelihood of any sanitary issues. The guidelines could be adapted and used in other MS that wish to use this technique. However, waste water reuse should remain at the bottom of the water hierarchy. In this situation reuse is also interesting so that wastewater is not discharged at sea, possibly limiting tourism in those areas, but this situation is relatively specific.

5.2 France

5.2.1 Characteristics of the Adour-Garonne RB

The Adour-Garonne river basin is one of the six river basins delimited in mainland France and is located in the South-West of France (Figure 5-11). The basin covers the administrative regions of Midi-Pyrénées, Aquitaine and subparts of other regions (departments). The basin is divided in five sub-basins (Charente, Dordogne, Garonne, Adour, and coastal rivers) as illustrated in Figure 5-11. It represents 120 000 km of watercourses and 7 million inhabitants live in the area, though unequally spread, with 35 cities gathering 28% of the population.

France and in particular the Adour-Garonne river basin, faces increasing water scarcity issues every year. Agriculture is the first sector for water abstraction, representing 45% of withdrawn water. Midi-Pyrénées (361 400 ha of irrigated lands in 2007) and Aquitaine (335 000 ha in 2007) are respectively the second and third French region in terms of irrigated surfaces, behind Centre (Agreste, 2010). The volumes of water withdrawn are mainly concentrated along the coast (Les Landes, represented in blue in Figure 5-11) and its sandy soils, and in the Midi-Pyrénées region, where a large part of irrigated maize is cultivated.

5.2.1.1 Irrigated agriculture in the Adour-Garonne RB

In the Adour-Garonne river basin, 1.9 million ha are cultivated, and 580 000 ha are irrigated. More than two third of the area is cultivated with maize, the rest being planted with vegetables, fruits, seeds, tobacco, etc. The yearly water consumption for agriculture in the river basin varies between 650 million m$^3$ and 1 200 million m$^3$. Irrigated crops on the Adour-Garonne river basin represent a gross margin of 780 million EUR, to put in perspective with 430 million EUR for non-irrigated crops.
**Focus on Aquitaine region**

In Aquitaine region, maize is cultivated on about three quarters of the irrigated area, accounting for about a fourth in value of the total agricultural production in the region (Agreste, 2010). Sprinkler is the main irrigation system used for maize. Users of spray booms, mostly in the Landes, use twice as much water as sprinklers. Spray boom users bring water more frequently, but in lower quantities, gaining a 20% higher yield compared to sprinkler users, and 50% higher yield compared to farmers that do not irrigate. A quarter of the irrigators follow the advice of specialised organisations, 17% use management tools and 58% base their decision to irrigate on observation of their plots.

In 2007, two-thirds of the fruit crops were irrigated. The use of sprinklers on these crops tend to decrease, with the use of more water efficient irrigation systems, even if their use is still relevant to reduce frost risks. Drip irrigation and micro-jets represent half of the irrigated surfaces, the other half being spray irrigated. Advice is followed by half of the farms, representing three fourth of the surfaces cultivated.

Most of the vegetables are cultivated in fields, generally as a monoculture. Often cultivated under a contract, irrigation is stated in the terms of the contract.

**Focus on Midi-Pyrénées**

In Midi-Pyrénées, yields in 2008 of irrigated maize were higher than 10t/ha (100 q/ha), and about 8 t/ha (80 q/ha) for non-irrigated maize (DRAAF 2009). Difficulties underlined to change are the lack of economic alternatives to maize, even if it is also recognised that the security procured by irrigation also increases investments, and that irrigating farms are more fragile, especially in scarce years. European subsidies have played a role in maintaining irrigation, but is currently decreasing with decoupling in most cases. Genetic selection has already allowed to select better adapted maize plants, but will not provide plants providing high yields scarce climates.

### 5.2.1.2 Irrigation sources and trends

Water abstracted for irrigation has different sources: 41% comes from surface water, 7% from captive aquifer, 35% from water table/groundwater, and 17% from retained water but with an important heterogeneity depending on the areas on the river basin. In 70% of the cases, water is abstracted directly by farmers themselves, except when collective structures are set up or with the “Neste system”. The farmers are not supporting the entire cost of the irrigation system and are helped by subsidies from the State, the European Union and local authorities (collectivités territoriales).

Concerning trends for irrigation, irrigated surfaces are decreasing both in Aquitaine and in Midi-Pyrénées. In Aquitaine, while the irrigation techniques have improved regularly between 1970 and 2000, a change occurred in the years 2000 and 2003, due to the decline of small-scale irrigation and the change for crops that consume less water. Since 2003, irrigated surfaces decreased by 15 000 ha (Agreste, 2010). The irrigation trend in Midi-Pyrénées is quite similar: it has developed widely during thirty years, but decreased recently because of climatic, economic, regulatory and societal contexts. In 2000, 15 900 farms irrigated 372 700 ha, compared to 13 500 farms irrigating 361 400 ha in 2007 (DRAAF, 2009). These trends are shown in Figure 5-12.
### Case studies

#### Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

<table>
<thead>
<tr>
<th></th>
<th>Agriculture general census</th>
<th>Extrapolation</th>
<th>Provisional</th>
<th>Evolution</th>
<th>Evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers of farms nb</td>
<td>60 244</td>
<td>53 990</td>
<td>47 580</td>
<td>79%</td>
<td>88%</td>
</tr>
<tr>
<td>Including professional nb</td>
<td>36 400</td>
<td>30 250</td>
<td>83%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean arable area ha</td>
<td>39</td>
<td>44</td>
<td>49</td>
<td>126%</td>
<td></td>
</tr>
<tr>
<td>Mean professional arable area ha</td>
<td>57</td>
<td>69</td>
<td>121%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arable area ha</td>
<td>2 361 914</td>
<td>2 351 723</td>
<td>2 325 783</td>
<td>98%</td>
<td>99%</td>
</tr>
<tr>
<td>Irrigated area ha</td>
<td>269 258</td>
<td>285 864</td>
<td>245 000</td>
<td>91%</td>
<td>86%</td>
</tr>
<tr>
<td>Grain maize + seed ha</td>
<td>224 427</td>
<td>224 608</td>
<td>175 050</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain maize + irrigated seed ha</td>
<td>169 067</td>
<td>180 930</td>
<td>141 700</td>
<td>84%</td>
<td>78%</td>
</tr>
<tr>
<td>%</td>
<td>63%</td>
<td>63%</td>
<td>58%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forage maize ha</td>
<td>53 298</td>
<td>59 922</td>
<td>40 450</td>
<td>76%</td>
<td>68%</td>
</tr>
<tr>
<td>Irrigated forage maize ha</td>
<td>18 478</td>
<td>21 356</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>7%</td>
<td>7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum ha</td>
<td>30 731</td>
<td>31 250</td>
<td>20 030</td>
<td>65%</td>
<td>64%</td>
</tr>
<tr>
<td>Soybean ha</td>
<td>41 684</td>
<td>42 070</td>
<td>15 980</td>
<td>38%</td>
<td>38%</td>
</tr>
<tr>
<td>including irrigated soybean ha</td>
<td>24 906</td>
<td>25 533</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>9%</td>
<td>9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein peas ha</td>
<td>15 441</td>
<td>15 638</td>
<td>12 810</td>
<td>83%</td>
<td>82%</td>
</tr>
<tr>
<td>including irrigated peas ha</td>
<td>11 855</td>
<td>12 358</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>4%</td>
<td>4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunflower ha</td>
<td>169 654</td>
<td>174 473</td>
<td>154 340</td>
<td>91%</td>
<td>88%</td>
</tr>
<tr>
<td>including irrigated sunflower ha</td>
<td>1 813</td>
<td>2 081</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>1%</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetables ha</td>
<td>11 439</td>
<td>10 822</td>
<td>9 706</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>4%</td>
<td>4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit-growing and permanent crops ha</td>
<td>21 249</td>
<td>19 852</td>
<td>17 523</td>
<td>82%</td>
<td>88%</td>
</tr>
<tr>
<td>Tobacco and various seeds ha</td>
<td>1 813</td>
<td>2 081</td>
<td>1 205</td>
<td>66%</td>
<td>58%</td>
</tr>
</tbody>
</table>

Figure 5-12: Evolution of irrigated surfaces from 2000 to 2007 (CACG, 2009)

### 5.2.2 Water saving issues and level of water stress

In the Adour-Garonne river basin, water for irrigation is generally abstracted from June to September. However, it may start earlier, depending on the yearly climate, with a trend toward beginning earlier each year.

The water precipitation deficit has been between 50% and 90% in April 2011 in the Adour-Garonne river basin, depending of the sub-basins considered. This deficit is calculated compared to river flows that go beyond low flow limits. These low flow limits correspond to the threshold that requires water management actions (limiting abstraction). Thus in the calculation of the deficit, the water demand and water availability are included. The main demand, and thus driver
of the deficit, is due to irrigation. The water deficit in relation to surface runoff is on average about 150 hm³/year, this number being relatively stable over time.

When deficits occur and result in use limitations, conflicts of use can arise. In particular in rural areas, where potable water use is given priority compared to providing water to livestock. Regulatory limitations are not limited to the agricultural sector and usually affect all economic sectors (agriculture, industry ...) always with priority for drinking water supply networks.

5.2.3 Initiatives for sustainable water management

Different initiatives are in place to respond to the lack of water in the Adour-Garonne river basin. The initiatives include regulatory limitations decided by the authorities, an illustration of the local implementation of the WFD, the observation of cropping pattern changes, irrigation scheduling advices and organisation of water use amongst farmers by the local advisory services. They are a mix of responses by farmers to the lack of water (change of cropping patterns) and of responses organised collectively or by the authorities to manage water uses in agriculture. While the initiatives aim to manage water use, they do not necessarily lead to water savings, as described below.

5.2.3.1 Regulatory limitations of water uses

Crisis management and quantitative management of water resources are the two main issues that are targeted through the use of regulatory limitations of water uses.

In France, emergency measures exist to address a potential shortage of water resources. Prefects may take exceptional measures to limit or suspend water use in addition to common rules and pursuant to Article L. 211-3 II-1° of the Environmental Code. Articles R. 211-66 to R. 211-70 of the Environmental Code define practical details for implementation of this article.

The regulatory limitations on water use are defined at a department level, by the prefect. The first priority is to restrict water uses, but the overall objective is to manage water shortages by ensuring priority needs are met, and more specifically health services, civil safety, water supply and preservation of aquatic ecosystems. Regulatory limitations have three different levels, depending on water scarcity at the given time:

- Level 1 corresponds to limited measures, restricting water abstraction during 1 day per week or less or to 15% of water volumes on at least one river basin.
- Level 2 is a stronger measure, restricting water abstraction during 1 to 5 days per week.
- Level 3 corresponds to very strong measures, restricting water abstraction during 5 days or forbidding abstraction.

Regulatory limitations are progressive, and concern different water users:

- The general public: raising awareness of individuals, and stronger limitations for watering lawns, grassy areas, washing cars, filling pools,
up to total ban of these types of water use (excluding drinking water use)

- The agriculture sector: water irrigation restrictions one day a week, several days a week or at certain times, up to a total ban of irrigation
- The industry: measures requiring a gradual reduction of activity, recycling of certain cleaning waters, modification of some process

The measures taken by the prefect during dry seasons have to be gradual, appropriate to the situation and can only be imposed for a limited period. The regulatory limitations of water uses are generally taken at the departmental level, but can exceptionally apply to larger areas, to respect the principle of equality between users of different department and for a consistency in the action on the same watershed (arrêté cadre).

On the 11th of July 2011, 71 departments were affected by at least one regulatory limitation of water use, 20 of them being in the Adour-Garonne river basin. The most restrictive limitations (limitations during more than 5 days per week) affected river basins in 11 departments of the Adour-Garonne river basin (not necessarily the whole department). For example, in the department of Gers, 4 regulatory limitations were in force at that date, two of them until the end of August, and the others until October. All water withdrawals for irrigation were prohibited except for drinking water production, firefighting and water for livestock in case of rivers that are not fed (rivers with no upstream dam where a specific volume of water is kept for compensating water abstraction).

Regulatory limitations of water uses are defined with different levels (3 levels) and their application can be checked and punished by different services, including the regional authorities, the police, agents of the French National Office for water and aquatic environments (ONEMA), etc.

### 5.2.3.2 Implementation of the water framework directive at local level

In France in general and in the Adour-Garonne river basin more specifically, each main watercourse and its uses are managed by public institutions (EPTB: Etablissement Public Territoriaux de Bassin). EPTBs act on behalf of local authorities for the management and enhancement of groundwater sources, rivers, and aquatic environments. They are the official actors for river basins and sub-basins’ water policy. For example, EPIDOR (Etablissement Public Territorial du Bassin de la Dordogne) is the structure managing the rivers of the Dordogne sub-basin. It was created by several local authorities, to unite their work around the Dordogne River, coordinate and simplify their action on water and rivers.

The EPTB is responsible for the low water management plan (plans de gestion des étiages, PGE). The PGE is an agreement between the stakeholders (State, farmers, water agency, associations, other users), at the scale of the sub-basin. It determines objectives in terms of water quantity management during periods of low water. The PGE is a tool introduced by the departmental scheme for water management (Schéma départemental d’aménagement et de gestion des eaux,

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44 France is subdivided into 101 “départements”, five of which are overseas and 27 “régions”, five of which are overseas.
SDAGE) and defines rules to share water between users. After a state of the art, an objective of flow rate is determined, called DOE (débit “objectif d’étiage”). Multiple responses may allow to reach this objective, including water savings in agriculture.

For example, the PGE Garonne-Ariège’s objective for agriculture is to set a collective management, including counting, negotiated pricing, capped authorised volumes. The objective is to reduce by 25% the use of water in agriculture during dry years. The PGE Garrone-Ariège is managed and implemented by the EPTB Garonne and it was validated by the government (through the department prefect) on February 2004. It is at the moment being reviewed, with a collective elaboration of the new PGE protocol for 2012.

The PGE’s implementation was articulated in 2 phases: the first one has begun since the government validation in 2004 and involves five major principles, required and priority:

- Respect of fixed DOE on all affluents
- Priority to struggle water wasting and make effective water savings
- Satisfaction on the volumes of water allocated to irrigation
- The implementation of a collective management of withdrawals
- The progressive pricing of water withdrawn by users

The second phase of the PGE’s implementation was relative to the mobilisation of the water resource, thanks to resources already existing (mainly hydroelectric) or the creation of new resources (i.e. reservoirs).

Table 5-6 gives examples of measures proposed for agriculture in the PGE of sub-basins in the Adour-Garonne. In most cases, the techniques such as Irrimieux (see section 5.2.3.6), technical advice and news reports (see section 5.2.3.4) and agri-environmental measures are foreseen, without providing much details on their implementation.

Table 5-6: Proposed measures for agriculture in certain PGE of the Adour-Garonne RB

<table>
<thead>
<tr>
<th>Region</th>
<th>Proposed measures for agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garonne-Ariège (2004)</td>
<td>See text above</td>
</tr>
<tr>
<td>Charente (2004)</td>
<td>Measures:</td>
</tr>
<tr>
<td></td>
<td><strong>Water savings:</strong></td>
</tr>
<tr>
<td></td>
<td>Technical advice</td>
</tr>
<tr>
<td></td>
<td>Irrigation news report</td>
</tr>
<tr>
<td></td>
<td>Irrimieux (see section 5.2.3.6)</td>
</tr>
<tr>
<td></td>
<td>Agri-environmental measures</td>
</tr>
<tr>
<td></td>
<td>Management of agricultural abstraction:</td>
</tr>
</tbody>
</table>

*42 See the section on irrigation scheduling on these news reports, that provide information on how and when to irrigate, based on meteorological, hydrological and agricultural plots data.*
### Case studies

<table>
<thead>
<tr>
<th>Region</th>
<th>Proposed measures for agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moratorium</td>
<td>Objectives per river basin</td>
</tr>
<tr>
<td></td>
<td>Progressive reduction of volumes in certain periods (see water savings)</td>
</tr>
<tr>
<td>Dropt (2003)</td>
<td><strong>Measures</strong></td>
</tr>
<tr>
<td></td>
<td>Advice to irrigators, through news reports</td>
</tr>
<tr>
<td></td>
<td>Improvement of equipments</td>
</tr>
<tr>
<td></td>
<td>Better monitoring of abstracted water</td>
</tr>
<tr>
<td></td>
<td>These measures are already in place and are considered efficient in reducing the volume of water per hectare</td>
</tr>
<tr>
<td></td>
<td>Information on agri-environmental measures is also foreseen</td>
</tr>
<tr>
<td>Isle Dronne (2004)</td>
<td>Agri-environmental measures</td>
</tr>
<tr>
<td>Lot (2007)</td>
<td><strong>Challenges in agriculture:</strong> 20 000 ha irrigated, important livestock activity</td>
</tr>
<tr>
<td></td>
<td><strong>Measure:</strong> ensure that new authorisations take into account the cumulative demand for water; ensure that water used by livestock does not negatively impact drinking water users and find alternative sources</td>
</tr>
<tr>
<td></td>
<td>Implementation of water turns and awareness-raising</td>
</tr>
<tr>
<td>Tescou (2003)</td>
<td><strong>Challenges:</strong> 706 ha irrigated</td>
</tr>
<tr>
<td></td>
<td><strong>Measures:</strong> advice, improved equipments and improved metering, irrimieux and agri-environmental measures</td>
</tr>
<tr>
<td>Neste et rivières de Gascogne (2002)</td>
<td><strong>Challenges:</strong> about 54000 ha are irrigated during the summer</td>
</tr>
<tr>
<td></td>
<td><strong>Measures:</strong> increased efficiency, by accessing modern irrigation techniques (e.g. spray boom, center pivot systems), better irrigation strategy, better technique (higher pressure, new devices in irrigation systems)</td>
</tr>
<tr>
<td>Dordogne Vézère (2008)</td>
<td><strong>Measures:</strong></td>
</tr>
<tr>
<td></td>
<td>Awareness-raising, in particular so that farmers take into account drought risk in choosing their crops</td>
</tr>
<tr>
<td></td>
<td>Technical advice</td>
</tr>
<tr>
<td></td>
<td>Monitoring of consumptions, and climatic indicator</td>
</tr>
<tr>
<td></td>
<td>Proposition of a diagnostic, followed by a plan for reducing water use</td>
</tr>
</tbody>
</table>
### Benefits of the initiative

This management seems to be appreciated by local population because it involves all stakeholders and is based on participation and dialogue, as it is drafted with all stakeholders.

The implementation of the PGE allows defining explicitly who is responsible for which actions, even if relatively often the measures are rather vague, with no timeframe or quantitative objectives other than the flow rates.

### Barriers

Conflicts can arise between stakeholders and make the development and execution of the PGE difficult. Additionally, as for any participative document, time is required to reach a consensus.

#### 5.2.3.3 Change of cropping patterns

Since 2003, when a significant drought occurred, the Adour-Garonne river basin is experiencing a change in its cropping pattern. However, this change is not specifically an initiative for water savings but comes in response to water scarcity. Maize, a quite water-demanding crop, is the major crop cultivated in Midi-Pyrénées region and represents the first irrigated crop in Aquitaine department. Without sufficient water, yields decrease rapidly and can result in low incomes for the farmers, even though these two factors are not necessarily directly linked. Good yields may not always result in good margins, because of the inputs (including water) prices.

With an increasing need for irrigation water due to dryer years and with the regulatory limitations, irrigated maize becomes less profitable and different strategies are being observed. Farmers tend to use more early maize varieties, to integrate crops with low water requirements (e.g. winter wheat) into crop rotations, or plant crops that are more resistant to water stress, such as sorghum or sunflowers. Other crops such as canola, broad bean, or horse bean also tend to appear.

However, despite the reduction in areas with irrigated maize the use of water has not necessarily decreased. Indeed, it seems that more water is applied on those reduced surfaces (higher volumes of water per hectare), leading to no net water savings.

Additionally, it was reported that in sectors with recurrent imbalances, while the cropping patterns have changed with a reduction of about 15 to 20% reduction in irrigated maize areas, the demand is still too high to be met by supply. Agricultural policies could be a way to foster changes toward dry cultures.
5.2.3.4 Irrigation scheduling

In each region, the agricultural advisory services (Chambre d’agriculture, see Box 2) publish information leaflets for the farmers to help them improve their irrigation scheduling. The initiative presented here is an illustration of what is done in the Tarn department, thanks to the contribution of Alexandre Mullens, advisor specialised in water management at the Chambre d’Agriculture du Tarn (CA Tarn). In each department, the systems are similar, but slight differences occur.

**Box 2: Chambres d’agriculture in France**

In France, the agricultural advisory services are the Chambres d’agriculture. They are present in each region and each department*. Their mission is to interact with the government and contribute to rural development. They work on the economic, social and environmental fields at local, national and European level. They provide technical advices to farmers and help in obtaining subsidies. A person is often in charge of irrigation issues.


**Presentation of the initiative**

Several types of information are provided on the website of the CA Tarn. Two types of news reports are issued regularly in the summer. One is about hydrology, watersheds levels and flow rates, and inform if any regulatory limitations are running. The second is focused on operational guidance for irrigation and includes weather forecasts, crops need for water at the period, river flow rates and irrigation advices. The irrigation advices are given for the main crops cultivated in the area. This second type of news report is the focus of the following paragraphs. Additionally, technical factsheets about irrigation equipment are available on the website.

The news reports are published for about 14-15 weeks, from early June to the end of August. They are edited weekly. They can be accessed on the website, sent per post or per e-mail. In the Tarn region, in 2010, 490 farmers received the news report by post and 60 by e-mail, with an increase of electronic mailing in 2011 (470 farmers received it per post and 95 per e-mail). This shows that most farmers receive the news report, as about 650 farmers have an authorisation to pump in the department. In total 180 e-mails are sent, around half of which to institutions, research centres, authorities, the “drought committee” in place and professionals (farm advisory services, plant breeders and suppliers, cooperatives). There are between 30 and 40 visits of the website’s page per week in general. Furthermore, guidance is published in the local periodical, which reaches 3300 persons.

The guidances, called “avertissement irrigation” (see Figure 5-13) are based on a set of reference plots, on which measures are taken. Tensiometers are implemented on a set of 16 plots, planted at different dates, with different varieties of the crops relevant in the region. The aim is to replicate the practices of the farmers so as to give relevant advice. In 2011, 12 plots of maize and 4 plots of soybean were put in place. Measures are taken several times per week on the tensiometers, by the technicians at CA Tarn and by the farmers themselves. Additionally, data on rainfall, temperature, irrigation, evapotranspiration, crop status and needs are analysed. A model, IRRINOV®, is used to analyse the data. IRRINOV® is a method of irrigation scheduling.
which has been developed by Arvalis, a research institute for agriculture. The database is complemented each year with regional data and meteorological data from Meteo France. Based on these data, the model defines recommendations for irrigation.

The system is currently undergoing an assessment, aiming to coordinate and harmonise the way the analyses are done across the region. From the data that could be accessed, the farmers find the news reports useful, and generally follow the advice provided. The news reports allow them to save the time and effort that would be required if they irrigated more. At regional level, the results show that:

- 60% of the respondents look at the advice in detail,
- 60% respect the advice to stop irrigation,
- 65% do not find such information elsewhere,
- and about 80% find the information useful to decide on their own practices.

**Benefits of the initiative**

Most of the farmers pay attention to the recommendations. The recommendations are technical advice based on regional data which help them schedule irrigation better and also reduces their workload. Alexandre Mullens reports that the advice to stop irrigation are generally followed when explanations on why the crops should not be irrigated are provided (see the results of the study on satisfaction above).
This type of advice allows to better schedule irrigation practices, which are thus meeting the demand of the crops more closely. The amounts of water saved through these practices are unclear as they depend on the conditions each year, but as a qualitative information less irrigation rounds are implemented thanks to the news report.

In parallel to the advice, news reports on the regulatory restrictions are provided, which detail for each river basin whether water may be extracted and in which conditions (days in the week where water can be extracted, per sector, or level of ‘water turns’ to put in place). This allows reducing the pressure on the water bodies and maintaining a flow in rivers that guarantees ecological functioning of the ecosystems and the needs for drinking water, industrial water and water used in agriculture.

Costs of the initiative

The costs of the initiative include three types of costs: manpower, material and data.

At CA Tarn, one person is in charge of the news reports, for between 60 and 80% of the week, for 14-15 weeks, usually helped by an intern during the summer period. This amounts to about 1,5 equivalent full time for more than a quarter of the year.

Tensiometers are used to monitor soil water content. The tensiometers are property of the CA Tarn. Associated costs are between 450 and 1800 EUR depending on the reading system for 6 of them (450 EUR for manual readings, 900 EUR for automatic readings and 1800 EUR for automatic readings from a distant location) and may be used for 6 to 10 years (for 3-4 months of use per year). They are tested every year by the person in charge of the bulletins. There are about 100 tensiometers (6 tensiometers per plot, on 16 plots) owned by CA Tarn.

Data on rainfall, maximum and minimum temperatures, ETp (potential evapotranspiration) are bought to Meteo France for 5 stations, which amount to 9 500 data, costing 380 EUR per year.

The whole system is led by the CA Tarn, through its own funding and with financial support from the Water agency (agence de l’eau) and the CASDAR. For farmers the system is completely free, apart from their involvement in measurements.

5.2.3.5 Organisation of “water turns”

“Water turns” identify who may take water when from the water source (in this case the river), in order to maintain a minimal flow in the river.

Presentation of the initiative

The initiative is described for the river Bagas, a small river in the Tarn. It is an initiative led by the Chambre d’Agriculture, with strong interest from local farmers and welcomed by the authorities. The initiative aims to improve the use of water in a (sub)river basin that is often confronted with low water flows. The idea is to organise a collective and concerted organisation amongst the water users, implementing water turns. The goal is to ensure that all do not use water at the same time. The system has been in place since 1997 and is driven by the CA Tarn.

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43 See the definition in the following section
The first step of the organisation is to identify the water abstractors. Seven farmers use water in the summer from the Bagas. For each farmer, the crops irrigated, surface, material used (i.e. pumping capacity) and time necessary to pump the water are listed. The total amounts for the basic need for the group.

The second step is to organise a planning that spreads the needs on a full week, with day and night turns. The planning is optimised to reduce as much as possible the overlaps between farmers taking water from the river.

When limits are set by the authorities through regulations, the restrictions are implemented on the turns so that it is impacting each farmer equitably.

The repartition is made taking into account the needs, the crops, the situation of the farmer (upstream or downstream). The calendar is organised by the CA Tarn, discussed with the farmers and validated after a complete update at the beginning of each irrigation season by the local authority (Préfet), during a meeting of the “drought committee”.

Benefits of the initiative

The initiative is implemented in order to retain a minimum flow in the river. If this minimum flow is not available, regulatory prohibitions to abstract water will occur, thus farmers are aware of the need to implement this type of initiatives. Rather than reducing the water extracted, the initiative aims to ensure that the amounts of water extracted are levelled across the week. Thus the flow is maintained for a longer period. This is beneficial to the environment as water is available for as long as possible in the summer. It is also especially important for farmers as they know that the last irrigation period is key to provide good yields. The later the regulatory prohibition to extract water comes (the farmers know it will come as the river experiences droughts in most years44) the better it is for them.

Costs of the initiative

The system requires a precise organisation and planning of the water turns and may only be implemented in small (sub-)river basins, with few farmers. From about 20 farmers, the system requires much more organisation and would require extensive amounts of time, that may not be spent on other important issues then. The time it takes for the Bagas river basin is estimated to about a week for one person, when based on the previous year. A meeting is also organised at the beginning with the farmers to detail and discuss the plan. To implement the system would take more time, and would request at least two meetings with the farmers. If implemented at a larger scale, more resources would be required, especially human resources for organising the meetings and identifying needs, and possibly using a computerised system. It is unknown whether at a larger scale the scheme would be as successful. A risk may be that the farmers feel less responsible if too many people are involved, decreasing the recognition that a collaborative effort is being made. No other costs were identified.

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44 The river yearly dries, not necessarily as a result of irrigation, as the region is relatively dry.
5.2.3.6 Other initiatives

From Irrimieux to the CAS-DAR project

The Irrimieux (“mieux” means “better” in French) initiative was launched in 1997-1998, to promote a global and balanced management of the water resource and its use, respecting the environment while supporting a viable agriculture. It is a voluntary initiative, promoting dialogue between water users.

From that initiative, through several regulations, and engagement by the farmers, results have been obtained in terms of reducing water usages (Le Corre-Gabens and Hernandez-Zakine, 2008). Farmers are demanding further advice and consultation with all water users. They also favour increased storage of winter resources and non-conventional sources, to adapt to future climate change.

The CASDAR project was launched in 2008, with the aim to increase adaptation and collective management confronting theoretic and applied knowledge. Possible ways forward identified are:

- Agronomic innovation, with better characterisation of water needs by species,
- Adaptation of cropping patterns
- Better meteorological previsions to drive farmer’s choices
- Socio-economic analyses, to estimate economic impacts of droughts, insurance scheme compared to preventive schemes based on water storage, etc.

In Midi-Pyrénées, a project was implemented including three actions, one of which was conducted with three associations of irrigators, where an audit was performed to inform on current performances and propose improvement actions. The results focus on the benefits of assessing collectively the estimated needs for irrigation, to ensure a shared allocation of resources, which requires monitoring of the abstraction during the year, and a relatively precise estimation of irrigation volumes and timing by each irrigator; and the benefits of technical audits to ensure efficient use of the resource, e.g. by identifying leaks.

A unique body to manage all abstractions for irrigation

In September 2007, a new regulation on water volume abstracted for irrigation (decree n° 2007-1381 of September 24th, 2007) has been published at the national level, but this text is not in force yet. The decree requires:

- a collective management by river basin for the water abstracted for irrigation,
- the end of the temporary abstraction authorisations (annual allocations to individual farmers),
- the need to undertake a public enquiry to estimate the quantity of water to be yearly abstracted for the next 10 years

The Adour-Garonne is the pilot river basin for implementation of this decree, notably regarding the evaluation of the volume of water that should be authorised to be abstracted for irrigation. This volume is determined in function of statistical availability of water resources for the next 10 years and thus respecting minimum low water flows). The methodology has been developed by...
the Water Agency (Agence de l’eau) and by the DREAL (the regional environmental authority). The protocol is almost finalised (end of 2011).

Once the proper volume is determined, a multi-annual authorisation for a maximum amount of water is delivered by the prefect (Prefet de department) to a unique body (Organisme Unique, formed of the Water Agency and the DREAL). The unique body is responsible for sharing this volume yearly between the irrigators, based on the water quantity consumed the previous years, the irrigation machinery, the type of crop planted, etc. Prior to this official “water distribution”, a public enquiry is required to make aware all the farmers and to trace any protests.

According to the Water pricing and allocation study (Arcadis et al., 2012), this new system of water management and abstraction authorisation could result in 12% less abstracted water for irrigation.

- **Release of water from dams**

In several French river basins, specific dams are in place to secure minimum river flows throughout the year. The water kept in those dams is released to support river flows in critical periods. This is beneficial both for the environment and for agriculture. Such practice is used every year to account for low river flows. However, because of the low rainfalls, the dams were not replenished, thus the release of water could not be used as extensively as usually this year. The management of the water, to sustain environmental, agricultural, drinking and industrial water needs was thus complicated.

The releases were carefully planned to match the needs. For identifying agricultural needs, an exhaustive inventory of plots, seeding dates and varieties was performed by CATarn. Arvalis added its expertise in anticipating crop needs, based on the data from CATarn, to identify when the needs for each crop would arise. The releases were then organised to match these periods, rationalising the use of water.

For the Garonne river, release from a hydro-electric dam is in place, that costs round 3 million EUR per year, with 75% financed by the Water agency. Based on the polluter-pays principle (in this case the user), an increase in the price for water abstraction, that is paid by the water users, allows to partly recover those costs (Agence de l’eau Adour-Garonne 2011).

The practice of storing water in dams, that can then be used for ensuring, as here, minimum flows, is however controversial if it had to be implemented in river basins in which it currently does not exist. Indeed, the creation of dams disrupts rivers, with environmental impacts on biodiversity, i.a. by flooding certain areas and by restricting fish migrations upstream.

- **Precision irrigation**

In horticultural crops, some farmers have changed to precision irrigation. This type of irrigation is estimated to be in place by 10% of the 3 000 irrigators in Lot-et-Garonne department. About 30% of water is estimated to be saved by farmers. However, some investment in time and in understanding the technical specificities of the technique are required and may be a barrier for farmers, that prefer to rely on their own knowledge and are suspicious of the fact that reducing water use does not necessarily reduce yields. The investment is also costly (2 000 EUR per water sensor; a farm producing about 4000 tons of fruits requires 12 sensors, between one and two per fruiting area).
Agri-environmental measures

Agri-environmental measures related to water savings are in place since 2011, with for instance the Midi-Pyrénées region proposing contracts aiming to reduce the impacts of water abstraction. For example, in Vallée de l’Autize, a contract is available to limit irrigation, which is subsidised by 253 EUR/ha/year, the same applies in further areas. In Charente an agri-environmental measure “irrigation limitation” is also in place, for arable crops or vegetables, in defined sub-river basins and irrigated during at least two of the last three years. The farmer definitively abandons the point from which he/she abstracted water, thus permanently stopping abstraction (the farmer may have access to different sources and can decide to only abandon one of them, thus not stopping irrigation, but abandoning the right to abstract a certain volume). The reference consumption is 1 800 m\(^3\)/ha. The contractual area that can be engaged is thus the authorised abstraction volume divided by 1 800.

5.2.4 Conclusion

In France, the main system for reducing water use is to implement regulatory limitations to water use by certain stakeholders, that are activated depending on defined minimum river flow thresholds. These thresholds are a quite interesting way to provide relatively objective thresholds for identifying low availability. However, it must also be recognised that in certain cases flows would dry whether or not the water is used. In any case, the thresholds for river flows could probably be spread among to other MS as a useful way to deciding when to limit water use.

Other systems are also in place so that farmers can use water for as long into the season as possible. Irrigation scheduling is provided as a service by farm advisory services (Chambres d’Agriculture) that are reported to be followed by farmers and effective in reducing water use. The organisation of water turns is also a sort of scheduling initiative, that smoothens the abstraction from a water body so that it is less disturbed. While this does not save water, it can lead to flows during a longer period, benefitting both the farmers and the environment. Advice for scheduling irrigation is already in place in several other places, but could continue to be strengthened to improve efficiency of irrigation. However, in dry periods, its efficiency may remain to be demonstrated.

Lastly, two types of behaviours can be identified through this case study. One is the adaptation and reaction to reduced water availability through changed cropping patterns, to ensure that the remaining crops can have enough water; and the other is a more preventive approach, such as the situation for water turns, to benefit from the water as long as possible.

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5.3 Italy

5.3.1 Characteristics of the Po river basin

5.3.1.1 Geographical characteristics

The Po river basin is located in the north-eastern part of Italy, covers an area of 74,000 km² (70,000 km² in Italy and 4,000 km² in France and Switzerland) and extends over 24% of Italy’s territory. The Po River originates from Monviso mountain at 2,100 m and runs on 652 km. Two thirds of this territory (more than 41,000 km²) are covered by mountains and hills and only one third (above 29,000 km²) is a plain. The regions of Piedmont, Aoste Valley, Liguria, Lombardy, Veneto, Emilia Romagna and Tuscany lie partially or completely within it, as does the Autonomous Province of Trento (UNEP, 2004).

The basin contains 141 affluents (the most important are Tanaro, Adda, Ticino and Oglio) and 450 lakes including Lugano (48,7 km² in Switzerland and the four largest lakes in Italy: Garda (370 km²), Maggiore (213 km²), Como (146 km²), and Iseo (65,3 km²). In the Alpine area, 174 water reservoirs for hydropower production, of which 143 artificial, store 1,5 billion (or 1500 million) m³ a year and another 1,29 billion (or 1290 million) m³ are controlled by the following natural regulated lakes: Garda, Maggiore, Como, Iseo, Idro; furthermore the basin comprises circa 600,000 m² of glacier areas.

The average yearly rain and snow fall in the Po River basin is estimated at 77,7 billion (or 77,700 million) m³.

The river is subject to high flow variation, frequent floods and periods of low flows. Total water abstractions account to more than 21,7 billion m³ per year, most of which (16,5 billion m³) are used in agriculture (including livestock), 2,5 billion m³ for drinking water and 1,5 billion m³ for industrial uses. Abstractions account for 14,5 billion m³ for surface waters and for 6 billion m³ for groundwater. The extremely low precipitations in 2006/2007 left a water deficit of about 380 m³ of water48. This deficit exceeds the one experienced in 2002/2003 and 2005/2006 drought years.

48 www.feem-project.net/water2adapt/01_project_02.html
The climate is typically alpine in the mountain zone, continental-warm in the flat basin area and Mediterranean on the coast. The average annual temperature is around 5°C on high Alps, 5-10°C in medium mountains, 10-15°C in the other zones. Variability of the temperature is also due to lakes mitigation effects. The average precipitation varies from a maximum of 2,000 mm in the Alpine range to slightly less than 700 mm in the eastern plains, with an annual average of 1,100 mm. About temporal distribution, the maximum rainfall is reached in the spring season. Meteorological records indicate that average annual rainfall has diminished by 20% since 1975 in the Po river basin, and the average yearly discharge at Pontelagoscuro, near the lower end of the river, has fallen by between 20% and 25%. Despite this increase of temperature and the decrease in rainfalls during the summer period, flooding remains a major issue in the Po Valley, especially in spring when melted snow and ice from the Alps can double the river’s flow within hours. Extensive dykes and levees have been built to curb this problem, along with river straightening projects to aid navigation, but these have mostly served to shift the flooding along to other parts of the river.

5.3.1.2 Economical characteristics

The Po river basin is a strategic region for the Italian economy, with significant agriculture, industry and tourism sectors, employing 47% of the national workforce and generating 40% of the national Gross Domestic Product.49

Water uses come from the electricity sector (about 890 hydro-electric power plants power and 400 thermo-electric plants produce 48% and 31% of the national hydroelectric and thermo electric production respectively), from inland navigation (although heavily reduced in the recent years due to low-flow conditions) and for an irrigation-based agriculture.

This high level of regional development has put heavy pressures on water resources and led to degradation of surface and groundwater quality. Increasing efficiency in agriculture is an issue that still needs to be addressed. The legal framework for application of the EU WFD through Legislative Decree 152/2006 and the Po River basin Management Plan adopted in February 2010, are both important efforts toward a basin wide vision agreed by all stakeholders.

5.3.1.3 Agriculture in the Po River Basin

Agriculture in the Po River basin is highly developed, accounting for more than half of the land use in the basin. In fact, with about 2.7 million ha, it is the largest cultivated area in Italy, and accounts for 36% of the country’s agricultural production (2009 data).

This region grows a large variety of cultivated crops: wheat, maize, fodder, barley, sugar beet, rice and vineyards. The irrigation season usually starts in April and ends in September. It uses yearly 16.5 billion m³ of water which comes almost exclusively from surface watercourses (83%). This large use of surface water is possible thanks to the regulated lakes and the water available from the glacier.

49 www.grid.unep.ch/product/publication/freshwater_europe/po.php
The irrigated areas, representing a high share of the agricultural areas, are presented in Table 5-7 below.

### Table 5-7: Entities using irrigation water in the Po basin

<table>
<thead>
<tr>
<th>Region</th>
<th>Enti irrigui (n)</th>
<th>Superfici (ha)</th>
<th>Indici (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amministrativa</td>
<td>Attrezzate</td>
<td>Irrigata</td>
</tr>
<tr>
<td>Valle d'Aosta</td>
<td>159</td>
<td>176.767</td>
<td>20.636</td>
</tr>
<tr>
<td>Piemonte</td>
<td>35</td>
<td>1,382.379</td>
<td>630.088</td>
</tr>
<tr>
<td>Lombardia, Piemonte ¹</td>
<td>1</td>
<td>110.000</td>
<td>177.345</td>
</tr>
<tr>
<td>Lombardia</td>
<td>16</td>
<td>952.496</td>
<td>461.934</td>
</tr>
<tr>
<td>Lombardia:Emilia-Romagna ²</td>
<td>2</td>
<td>246.074</td>
<td>114.480</td>
</tr>
<tr>
<td>Emilia-Romagna</td>
<td>13</td>
<td>2,038.445</td>
<td>484.745</td>
</tr>
<tr>
<td>Veneto</td>
<td>3</td>
<td>171.929</td>
<td>110.000</td>
</tr>
<tr>
<td>Provincia di Trento</td>
<td>10</td>
<td>17.465</td>
<td>2.572</td>
</tr>
<tr>
<td><strong>Totale</strong></td>
<td><strong>247</strong></td>
<td><strong>5,190.555</strong></td>
<td><strong>1,912.807</strong></td>
</tr>
</tbody>
</table>

**Note:**
1. Associazione irrigazione Est-Siesta
2. Consorzi di bonifica e irrigazione Agro Mantovano Reggiana e Burana Leo Sclitenne

FONTE: SISIRAM-INEA, 2009

In total, irrigated areas cover almost 20% of the Po river basin total area. The irrigation methods vary according to the irrigated crops, the quantity and quality of available water, the size and type of management of irrigated farms, and the soil and climatic characteristics. In general, the sprinkler irrigation method is the most utilised (on more than 450 000 ha), followed by surface and furrow irrigation (on more than 342 000 ha), flooding irrigation (200 000 ha) and other methods (36 000 ha) as illustrated in Figure 5-15 (Todorovic et al. 2005). Moreover, in Lombardy, where the winter temperatures are very low and frequently below zero, the surface irrigation is used with anti-frost purpose on permanent forage crops in order to have green forage during the winter season (Todorovic et al. 2005).

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**5.3.2 Water saving issue and level of water stress**

#### 5.3.2.1 Water management structure

In the Po river basin, there is lot of fresh water available thanks to presence of the Alps as well as the presence of several big lakes (see section 5.3.1.1). Irrigation water extracted from surface
water is controlled by the irrigation water boards. Farmers do not have to extract the water themselves.

The management cost for the maintenance of the extraction systems is covered by the irrigation boards. Water is mainly provided by irrigation boards who own the licence for water abstraction and pay an annual fee for the licence. Agricultural users, associated to the irrigation boards, pay them a charge for the service provided. In addition, the general cost is paid mainly by the region (80%) and by consortiums (20%). Some national funds exist and can be used, but they are more episodic.

Since 1989, an official authority has been created: the Po River basin Authority which is in charge of the elaboration of the different basin plans (see Box 3).

### Box 3 Role and structure of the Po River Basin Authority

National river basin authorities include representatives of the central and regional administrations. Their main responsibility is the drafting and implementing of the Basin Plan, which aims to protect water resources, mitigate hydrogeological risks (such as flood, landslide and erosion) and promote sustainable use of water resources in an environmentally conscious way. The Po River Basin Authority and five other national river basin authorities (along with a pilot basin authority) were created by law 183 in 1989. As the European Water Framework Directive imposes to the Member States the institution of River District Authorities, the Italian National river basin authorities are going to be transformed into River District Authorities.

The Po Authority is composed of the secretary general, an institutional committee and a technical-operational secretariat. The institutional committee supervises the implementation of the basin plan. The technical committee is the consultative body of the institutional committee. The secretary general plays a central role in the basin authority by overseeing and coordinating its activities and directing the secretariat. The secretariat drafts the basin plan in cooperation with the technical committee. The institutional committee then adopts it as a project proposal. The proposal is published in the official gazette and regional newspapers so all stakeholders may comment. The region analyses all comments collected within their jurisdiction and send a revised basin plan to the institutional committee for adoption. After a second approval by the institutional committee, the basin plan is passed to the national level for final validation by the National Council of Ministers. Although the basin plan has an implementation period of three years, there is no fixed schedule for reviewing progress or outcomes.

To date (October 2011), Italy has completely taken in instructions from the WFD, and all River Basin Management Plans have been adopted.

### 5.3.2.2 Issues encountered

In both mountainous and plain areas water flow is largely regulated through stream maintenance, artificial canals, water drainage and water lift. The water management is regulated  

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59 www.adbpo.it/on-multi/ADBPO/Home/PianodiGestioneepartecipazionepubblica/PianodiGestionedelDistrettoidrograficodelfiumePo.html
by the Regions and irrigation water board with the cooperation and the coordination of the river basin authorities. They manage various morphological-related facilities such as expansion ponds, waterproofing of canals, and flood activities needed for irrigation use. Expansion cases in the basin are addressed to control a river flow to prevent flooding. Nevertheless, the maintenance of the minimum water flow requirement is a real issue in the Po river Valley during the summer. In general in summer, the water flow is mainly affected by water abstraction for irrigation purpose but also for the energy sector, which, even if it does not cause additional abstraction (as water is returned to the water body), severely affects water flows.

During the last ten years, the region has had to face several exceptionally dry years (in particular 2003, 2005 and to a lesser extent 2006). During these years in summer, the river authorities limited the quantity of water abstracted. However, restriction on surface water abstraction are generally causing an increasing over exploitation of the groundwater, decreasing the water reserve.

In general in summer, the water flow is mainly affected by water abstraction for irrigation purpose but also for the energy sector, which, even if it does not cause additional abstraction (as water is returned to water body), severely affects water flows.

5.3.3 Initiatives for sustainable water management

Emilia Romagna (ER) is a pioneer in water conservation in agriculture: four decades of studies, research and experimentation carried out by the Consortium for the Remediation Channel Emilia Romagna (Consorzio di bonifica per il Canale emiliano –romagnolo, the CER) and funded by the region have allowed significant progress and improvement in terms of water use on all crops in the area. In 2006, a water conservation plan was implemented to save water from agriculture as well as civil and industrial sector (Draghetti, 2007).

According to the Professor Gandolfi (personal communication), the fact that the irrigation system is more recent compared to those of Piedmont and Lombardy regions can partially explain the dynamic observed in the region ER.

In addition, the competent authorities of the region seem very involved and very pro-active for this concern (Emilia-Romagna Region, 2003; Bortone et al., 2004; Bortone, 2008). The ER has developed a strategy on water demand management which aims to improve effectiveness and sustainability of existing drinking water, industrial process as well as irrigation systems. In this context, a Water Conservation Programme has been developed (see Figure 5-16).
Case studies

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Water saving potential in agriculture in Europe: findings from the existing studies and application to case studies

Figure 5-16: The Water Conservation Programme of Emilia-Romagna (Borton, 2008)

5.3.3.1 IRRINET: interactive service support to irrigation

Presentation of IRRINET

IRRINET is a free web service (www.consorziocer.it) that provides advices on irrigation timing and volume of intervention. It aims to ensure an efficient use of water resources in the agricultural sector by transferring to the farmers personalised technical indications.

IRRINET has been developed in ER by the Canale Emiliano Romagnolo (CER). CER's mission is both to ensure a suitable irrigation water availability for the high valuable crops, typical of the ER region, and to provide information and supporting tools to the farmers in order to optimise the use efficiency of the delivered water. This service has been operating since 1985 (Giannerini, 1993), with regular improvement, and actually manages irrigation scheduling over more than 23% of the regional plain surface, involving about 8,000 farmers. Operating and maintenance costs of the system are estimated to be of 55,000 EUR per year (Watercore, 2010). The costs of the web service and of the implementation of the CER's researches results were part of several projects carried out during the last decades; a rough estimation of the development costs sum is approximately 300,000 EUR (Watercore, 2010).

IRRINET system provides a real-time irrigation scheduling: day-by-day information on how much and when to irrigate farm crops. Actual data are gathered on daily basis in the Web DB server from several sources (meteo agencies, farms, agro-data networks). Irrigation scheduling is built by means of an irrigation model based on daily soil/plant/atmosphere water balance. The
irrigation model is run on the Web server every time the user clicks for information so the latest data are always taken into account.

Since 2009, IRRINET has become IRRINET Plus: in addition to the water balance, a budget statement is proposed to discourage irrigation contributions which are financially disadvantageous. This new version has been implemented following the drought of 2007. It aimed to save more water without reducing crop yield and thus the gain of the farmer. Therefore, they have decided to take into account the economic aspect of the irrigation and the return rate of this practice.

Structure of IRRINET

An irrigation experts network is in charge of both monitoring the information provided by the service and its tuning. The registered and non registered users can interact with a dedicated helpdesk in order to ask for support or to leave feedbacks. In the first case (register users), the service uses stored data for each specific farm, in the other case, non register users can question the service by furnishing indication about their farms.

The model considers the soil, plant, atmosphere continuum. It is based on water balance, where crop water requirement is calculated from evaporimetric data (soil evaporation and evapotranspiration of the crop), corrected for crop coefficients and modulated according to local information, accounting for reduced water uptake by the crop due to water stress. Water table depth data are also taken into account as water supply, in order to reduce crop irrigation needs.

The input data are: type of crop and soil, geographic location, meteorological and soil data and the characteristics of the irrigation system used in the farm. Meteorological data are from Regional Agro meteorological Service Net, the soil database is from Regional Geological Service, and crop parameters obtained from local experiment are from CER databases. Outputs are given about expected effective crop evapotranspiration, the cumulated water deficit, the date of the next irrigation and the relative amount of water to be distributed.

In 2008 the model has been extended with an economic algorithm that evaluates in real time the profitability of the irrigation supply. This evaluation is displayed on the Web page as a traffic light to evaluate the economic opportunities of the irrigation:

- green light: irrigation is definitely economically advantageous;
- red light: irrigation is economically not recommended
- yellow light: irrigation presents an uncertain or not evaluable economic advantage

Results obtained with this programme

The system greatly improves irrigation: in 2006 and 2007, the CER has estimated that this system has allowed a total saving of almost 50 million m³, which corresponds to an estimated reduction of 20% of the water used in agriculture (Mannini et al., 2008).

In addition, IRRINET is also an important tool for farmers to comply with the Integrated Productions rules (according to the EC Reg. 1257/99). The Online support allows farmer to easily match the Integrated Productions rules in scheduling their irrigations and regulating the water amounts according to the e-mail or SMS suggestions. The irrigation records are stored in the
database of the service, thus making it unnecessary for the farmer to keep archives, and the farmer do not need to provide rain data, since precipitation is measured by the Regional Meteorological Service.

IRRINET awareness is very high in Emilia Romagna region and all the farms involved with Best Practice Guidelines and/or Quality insurance programmes can use it (Draghetti, 2007). Currently, the University of Bologna is improving and validating the decision support IRRINET Plus for the cultivation of pear and peach.

Now the challenge is represented by the extension of the service to new areas where IRRINET is not yet been implemented. A national project called Irriframe will bring the service to all the area managed by the Italian reclamation boards and irrigation agencies by the end of 2011. As for Irrinet, Irriframe aims to:

- calculate the water balance,
- provide guidance on when and how much to irrigate in order to maximise the use of water,
- save the consumption,
- reduce the production cost,
- increase the competitiveness of the Italian agriculture and
- stabilise the quality and the yield of the crops.

### 5.3.3.2 A Decision Support for IRRigated agriculture (DSIRR) to evaluate the impact of policies on water savings

#### Presentation of the tool

The tool focuses on water use in agriculture by integrating economic models with agronomic, engineering and environmental information. The programme describes the effect at catchment scale of choices taken at micro scale by independent actors, the farmers, by simulating their decision process. The decision support (DS) was developed as a support tool for participatory water policies as requested by the WFD and aims at analysing alternatives in production and technology, according to different market, policy and climate conditions.

The tool uses data and models, provides a graphical user interface and can incorporate the decision makers’ own insights. Heterogeneity in preferences is admitted since it is assumed that irrigators try to optimise personal multi-attribute utility functions, subject to a set of constraints. Consideration of agronomic and engineering aspects allows an accurate description of irrigation. Mathematical programming techniques are applied to find solutions.

A set of indicators has been identified for a multidimensional assessment of the impacts on the economic, social and environmental dimensions of sustainability. All indicators are comparable among farms and cropping systems since they express the impact per hectare of total farm surface.

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51 The website of this national project is available from: [www.altavia.eu/Agriculture.htm](http://www.altavia.eu/Agriculture.htm)
Four indicators are defined in the economic area:

- Net farm income (NI).
- Profit (PR) which is calculated by subtracting rent, depreciation and farm household labour remuneration from NI.
- Farm contribution to gross domestic product (GDP) which is estimated as the added value produced at farm level
- Public support (payment accorded to the farm) which measures the payment accorded to the farm.

Three indicators deal with water:

- The first one quantifies the total use of water (WQ) for irrigation by period, thus including inefficiencies at farm level
- The second estimates the marginal value of water (WV), which represents the farmers’ willingness to pay
- The third describes irrigation technology (IT).

**Application of the programme in the Po river basin**

This programme has been applied in the Po river basin to analyse the impact of a pricing policy in a context of irrigation technology innovation. Water demand functions and elasticity to water price have been estimated.

Results demonstrate how different areas and systems react to the same policy in quite a different way. While the annual cropping systems pricing seems effective to save the resource at the cost of impeding Water Agencies cost recovery, the same policy has an opposite effect in the perennial fruit system, which shows an inelastic response to water price.

In the annual cropping system (see Figure 5-17 left), according to this simulation, at a null water pricing, the water consumption is 4056 m$^3$ and the net income for farmer is 803 EUR. Rising water price determines a complex adaptation strategy by the farmers: crop mix, irrigation level and irrigation methods are all changed to mitigate the adverse impact of this policy. The water demand curve, continuous line, shows an impressive decreasing pattern: 1993 m$^3$ at 0.03 EUR, 902 m$^3$ at 0.06 EUR and only 92 m$^3$ at 0.15 EUR. The high response to price of the demand suggests that a pricing policy could be very effective to save water, but the impact of such policy should be assessed considering also other indicators like water agency revenue, profit, subsidy, gross domestic product, family labour, etc. It should be noted that the Water Agency could increase its revenue to a maximum of 62 Euro/ha by rising the water pricing up to 9 Eurocents/m$^3$. Higher prices would have negative effects on collected revenue since the reduction in quantity would be higher than the price increase.

In the perennial crop system (see Figure 5-17 right), the overall picture appears very different from the annual crop system. The net income for farmers is about 5 times higher than in the previous case. Water demand (WQ) is quite stable around 1700 m$^3$/ha and WP increases do not relevantly change water uses. Only farms having a high percentage of annual crops show changes, usually characterised by shift to rain fed annual crops. Nevertheless, once this
adaptation has taken place, the water demand curve is rather unresponsive to further water price increases. Two main reasons explain this pattern. The profitability of fruit cultivation is much higher than any feasible alternative. The high efficiency in water use due to the adoption of drip irrigation leaves little margin for any further innovation. The explanation done for this phenomenon is the fact that existing irrigated fruit system needs to be consider as the result of a process of transformation of the local agriculture carried out over the last 20 years which completely modified land uses by favouring the introduction of new fruit varieties. Since fruit is perennial and most of the costs are supported at the beginning of the production cycle, farmers will respond to external change, such as a WP increase, mainly on the basis of gross margin, given by the difference of income and operating costs. As long as gross margin is positive farmers will keep producing. In this context a complete adaptation could require more than a decade.

The multidimensional assessment conducted clarified the trade-off among conflicting economic-social-environmental objectives, thus generating valuable information to design a better tailored mix of measures.

Figure 5-17 Possible impact of a water pricing increase on annual crops (left) and perennial crops (right). WP = water pricing, NI = net farm income and WQ = total use of water for irrigation (Bazzani, 2005)

Therefore, DSIRRR appears to be an interesting tool to evaluate the water saving potential of the current and future implemented policy.

5.3.3.3 The COLT project

Presentation of the project

The COLT project was launched in 2008 and aims to save water used for seasonal irrigation. It has a yearly budget of 40 000 EUR/year. The project supports the Reclamation Consortia and the Agriculture Department by using remote sensing images to classify crops and fruit orchards, acquired before the beginning of the irrigation season, and by applying a soil water balance modelling system.

The goal of the project is the assessment and the definition of a protocol applicable at regional level to monitor land-use for both annual scale geo-referenced statistical purposes and management of irrigation water.

Study area

The area concerns the whole plain of Emilia-Romagna region, which after removing manmade, forest and wetland features corresponds to 650 000 ha.
This area is mainly characterised by arable land and extensive vineyards of Lambrusco. Roughly, crops such as corn and cereals are cultivated in the north of Bologna while fruits and vegetables prevail in the south of Bologna. Melons, cereal and medical crops are cultivated in the lowlands of Mirandola while medical crops and pear and grape vines prevail in Nonantola.

**Conclusion of the project**

The project established a successful pre-operational service for real time monitoring of crop in order to define water needs for agriculture by an extended water balance model application. The extracted data from satellite images are exploited in an operational chain as a decisional support for water distribution priority according to crop types operated by Reclamation Consortia.

The map below (left side of the Figure 5-18) shows an example of the remote sensing classification results obtained by the programmed acquisitions, while the image on the right shows a model output related to irrigation needs for the agricultural season. Results are available as raster and vector files. The images refer to the Renana Reclamation Consortium located around the city of Bologna.

A good use of these data would allow to a better assessment of water need for crops and so an optimisation of the irrigation.

![Remote sensing classification](image1.png)

![CRITERIA water balance modelling](image2.png)

**Figure 5-18:** Remote sensing classification and criteria water balance modelling obtained during the CORE project (WaterCore, 2010)

Integrations of summer seasonal forecast and climate change prediction are be able to predict water requirements for 3 months ahead and their trend in the next years. Efforts are also given to integrate COLT and cadastral vector data with EU agricultural compensation requests to build up a GIS able to assist all the Reclamation Consortia’s procedures at cadastre basis. This development should determine payments based on actual consumption.
5.3.4 Conclusion

To date, the Po river basin has never had to face a severe water deficiency thanks to its ideal localisation at the feet of Alps mountains. The increase in drought years since the last decade has contributed to a growing awareness and now initiatives aiming to decrease water consumption in agriculture are increasingly implemented.

Moreover, it appears important to keep in mind that irrigation practices are widespread in northern Italy. With the increase of sealed soils and the decrease of natural soils, irrigation practices can play a role in the recharge of the aquifer (Gandolfi, personal communication), but a risk of contamination linked with the transfer of pesticides or fertilisers until the aquifer also exists. Ensuring how much water is abstracted compared to how much water is recharged, as well as in water bodies under which status, needs to be assessed for identifying what would be best in such cases. In addition, some practices are more efficient than others. As an example, sprinkler and micro-irrigation seem to be the best irrigation methods compared to flood irrigation which is considered by the experts as a low efficient irrigation practice.

According to some researchers, the main problem in this region is "knowledge". Many water management plans have been implemented and many water savings practices have been developed, but the farmers are rarely aware of their existence showing that good practices need to be disseminated in a more efficient way.

Finally, best practices to reduce water consumption are not applicable in the same manner for all the regions of the Po Valley and there is a need to collect more data at the local level to better understand the specificity of each situation.
5.4 UK: Use of storage reservoirs to reduce water stress from spray irrigation

5.4.1 Introduction

The Anglian River Basin District (RBD) is located in eastern England and covers an area of 27,890 km² (Figure 5-19). The RBD is the most intensively cultivated region in the UK, producing more than a quarter of England’s wheat and barley and over half of England’s sugar beet (EA 2009).

Many of the most important wildlife sites in the Anglian RBD rely on a reliable supply of water and the Anglian RBD contains many sites of both national and international importance52. It is also the richest region in the UK for wetland wildlife (EA 2011).

Some of the most stressed catchments in the UK are located in the Anglian RBD. Although the largest demands for water come from public water supply, the industrial and energy sectors, there are a large number of smaller abstractions across the district to supply agriculture users, with around 164 million m³/year licensed for spray irrigation53. Several factors in the Anglian RBD are having an adverse effect on the availability of water for irrigation however. These include the increasingly strenuous requirements of the Catchment Abstraction Management Strategy (CAMS) process and Water Framework Directive (WFD) to protect the rights of the environment and other water users, increasing demand from other sectors (particularly public water supply) and uncertainty regarding the future availability of supplies due to climate change. Farmers in the Anglian RBD are finding it increasingly difficult to obtain a licence for abstraction during the summer months and existing water sources for summer abstraction are becoming less reliable (due to restrictions on abstraction).

Even in “over-abstracted” catchments within the Anglian RBD54, however, water may still be available at times of high flow and so one strategy being adopted by some farmers is to abstract water in ‘high flow’ periods (typically during the winter months) and store the water in on-farm reservoirs ready for use during drier periods (typically the summer).

This case study looks at the importance of irrigation and levels of water stress in the Anglian RBD to assess the costs and benefits of moving to irrigation reservoirs.

52 including 46 European designations under the Habitats Directive for water dependent features, many important Sites of Special Scientific Interest and National Nature Reserves designated at a national and regional level
53 Based on EA NALD 2010 data.
54 “Over-abstracted” is defined by the UK Environment Agency as ‘existing abstraction is causing unacceptable environmental impact at low flows. Water may still be available [for abstraction] at high flows with appropriate restrictions’.
Figure 5-19: Map of catchments in the Anglian RBD (EA, 2009a)
5.4.2 Characteristics of the Anglian RBD

5.4.2.1 Characteristics of Agriculture and its Use

Types of agriculture

More than 75% of the land area of the Anglian RBD (around 1.5 million hectares) is used for agriculture and horticulture (EA 2009b). According to statistics from Defra (2009) wheat is the dominant crop in the Anglian RBD, totalling nearly 600,000 hectares and accounting for 46% of the total land area under arable crops (73% of cereal crops). Winter barley and spring barley are also widely grown, with each crop totalling nearly 100,000 hectares. With regard to non-cereal crops, oilseed rape and sugar beet are the dominant crops, totalling 170,000 and 94,000 hectares respectively. Vegetables and salad, in particular peas and beans, are also widely grown, although the percentage of total cropped area is much smaller than for cereal and non-cereal crops. For example, the total land area under peas and beans (20,795 ha) was less than 4% of the area under wheat in 2009.

5.4.2.2 Soils and Landscape

With regard to the construction of irrigation reservoirs, an important consideration is the permeability of the local soil surface and superficial geology. The Anglian RBD has a great diversity of different soil types (Oram 1995). Although clayey or heavier soils generally dominate, medium textured soils also feature throughout the region (particularly in the counties of Norfolk and Suffolk), with more sandy type soils located closer to the coastline (EA 2009). In Lincolnshire there are also shallow calcareous soils present and chalk underlies parts of Cambridgeshire and north-west Essex.

The landscape of the Anglian RBD is relatively flat to gently undulating and there are large areas of low-lying land. These are favourable conditions for the construction of a reservoir (EA/Cranfield University 2008).

5.4.3 Climate and Vulnerability to Climate Change

Annual average rainfall is around 600mm per year and reference evapotranspiration rates are around 530mm per year, making the region one of the driest areas in the country (Holman and Trawick 2011). Rainfall is fairly evenly distributed throughout the year, with the main growing season extending from around March until October.

In recent months (from June 2011), drought has been declared in parts of the Anglian RBD (Defra 2011, EA 2011a). These have highlighted the vulnerability of agriculture in the region to water scarcity and drought. The dry weather has resulted in very early high demands for spray irrigation water and voluntary restrictions are taking place on licences for abstraction from rivers throughout the Fens (EA 2011). Lincolnshire, Cambridgeshire, parts of Bedfordshire and Northamptonshire, and west Norfolk remain in drought at the time of writing (Mid-August 2011).

55 Most land in the Anglian RBD lies below 60m above sea level.
Climate change projections for the East of England suggest that winters will become warmer and wetter, while summers will become warmer and drier (UKCIP 2009). There is little change in the amount of precipitation that will fall on an annual basis, however, more precipitation is likely to fall during the winter months with summers becoming relatively drier56.

For irrigation, the likely impacts of climate change in the Anglian RBD include (Street, 2007, Holman and Trawick 2011, Holman 2006):

- changes to the rate of groundwater recharge: reductions in groundwater recharge may result from increased potential evapotranspiration in summer and autumn and drier summers, or recharge may increase due to increased rainfall intensity and wetter winters;
- increase in demand for irrigation water during summer due to reduced rainfall and higher levels of evapotranspiration (this is likely to be exacerbated by socio-economic factors (e.g. increased demand for high-value produce that meets specific quality requirements); and
- increasing demand for water by other users (e.g. public water supply, the environment) whose demand for water will reflect both climatic and socio-economic changes. Increasing competition for available water resources could lead to abstraction and irrigation restrictions to protect water bodies and address water resource shortages in other sectors.

Demand forecasts for the Environment Agency’s (EA’s) water resources strategy for England and Wales suggested an increase in national demand for irrigation water of 25% by 2020 (EA, 2009c), equivalent to demand of 353 000 m$^3$/day (EA, 2009b). Future water availability and licensing policy will restrict demand for water, so it is more likely that farmers will have to adapt through changing to crops that require less irrigation or storing water in the winter for use in the summer.

5.4.4 Demand for Water and Impacts of Abstraction

5.4.4.1 Water Abstraction for Irrigation in the Anglian RBD

There are 5 069 abstraction licences in the Anglian RBD, of which 4 193 are for agriculture (Defra/EA 2009). The annual licensed volume for agricultural abstraction (from both surface and ground water sources) is 160 681 000 m$^3$/year. This is much lower than the volume licensed for public water supply (978 237 000 m$^3$/year), electricity production (760 428 000 m$^3$/year) or industry (411 678 000 m$^3$/year) (Defra/EA, 2009).

56 Though it should be noted that the uncertainty ranges for estimated changes to precipitation are relatively high (particularly for the summer months).
Table 5-8: Breakdown into Use of Licences, Timing and Source for Spray Irrigation
(in 10^3 m^3/year) (EA NALD 2010)

<table>
<thead>
<tr>
<th>Licence Type</th>
<th>Summer</th>
<th>Winter</th>
<th>All Year</th>
<th>Summer</th>
<th>Winter</th>
<th>All Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface</td>
<td>Ground</td>
<td></td>
<td>Surface</td>
<td>Ground</td>
<td></td>
</tr>
<tr>
<td>Spray irrigation – direct</td>
<td>49,900</td>
<td>320</td>
<td>780</td>
<td>42,690</td>
<td>480</td>
<td>4,420</td>
</tr>
<tr>
<td></td>
<td>(30%)</td>
<td>(0,2%)</td>
<td>(0,5%)</td>
<td>(26%)</td>
<td>(0,3%)</td>
<td>(3%)</td>
</tr>
<tr>
<td>Spray irrigation – storage</td>
<td>2,990</td>
<td>54,140</td>
<td>160</td>
<td>3,380</td>
<td>1,970</td>
<td>2,550</td>
</tr>
<tr>
<td></td>
<td>(2%)</td>
<td>(33%)</td>
<td>(0,1%)</td>
<td>(2%)</td>
<td>(1%)</td>
<td>(2%)</td>
</tr>
</tbody>
</table>

Note: Excludes anti-frost as this accounts for (<1%) of the volume licensed for spray irrigation.

Table 5-8 shows the volume of water licensed for agricultural spray irrigation in the Anglian RBD by season and by source. Although the exact number of irrigation reservoirs in the Anglian RBD is not known to the Environment Agency (pers. comm. EA, 11/08/2011) the number can be implied from the number of licences for spray irrigation storage. According to the EA NALD (2010) there are 895 licences for spray irrigation storage in the Anglian RBD and, according to the EA (pers. comm. 09/08/2011), there are approximately 1800 licences to fill storage reservoirs in the UK. As shown in Table 5-8, most water for spray irrigation storage is taken from surface water sources during the winter, with most water for direct spray irrigation taken from surface water sources during the summer.

Table 5-9: Volume (m^3/year) licensed for spray irrigation (direct) by catchment, source and time of year (EA NALD 2010).

<table>
<thead>
<tr>
<th>CAMS</th>
<th>Surface</th>
<th>Ground</th>
<th>Surface</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadland Rivers</td>
<td>4,500,000</td>
<td>11,000,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cam &amp; Ely Ouse Including South Level</td>
<td>15,000,000</td>
<td>11,000,000</td>
<td>27,000</td>
<td>340,000</td>
</tr>
<tr>
<td>East Suffolk</td>
<td>5,000,000</td>
<td>6,300,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Essex</td>
<td>4,100,000</td>
<td>2,100,000</td>
<td>160,000</td>
<td>74,000</td>
</tr>
<tr>
<td>Grimsby, Ancholme &amp; Louth</td>
<td>1,200,000</td>
<td>1,000,000</td>
<td>0</td>
<td>910</td>
</tr>
<tr>
<td>Nene</td>
<td>1,300,000</td>
<td>160,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>North Norfolk</td>
<td>640,000</td>
<td>3,700,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>North West Norfolk</td>
<td>2,100,000</td>
<td>4,500,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Old Bedford Including Middle Level</td>
<td>7,100,000</td>
<td>240,000</td>
<td>10,000</td>
<td>0</td>
</tr>
<tr>
<td>Roding, Beam &amp; Ingrebourne</td>
<td>410,000</td>
<td>0</td>
<td>28,000</td>
<td>0</td>
</tr>
<tr>
<td>Steeplings, Great Eau &amp; Long Eau</td>
<td>300,000</td>
<td>50,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Upper Ouse &amp; Bedford Ouse</td>
<td>1,300,000</td>
<td>700,000</td>
<td>73,000</td>
<td>54,000</td>
</tr>
<tr>
<td>Welland</td>
<td>1,400,000</td>
<td>420,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Witham</td>
<td>5,400,000</td>
<td>2,000,000</td>
<td>20,000</td>
<td>4,500</td>
</tr>
</tbody>
</table>
Summer | Winter
--- | ---
CAMS | 50,000,000 | 43,000,000 | 320,000 | 470,000
Surface | Ground | Surface | Ground

**Grand Total**

*Note:* Excludes 'spray irrigation - anti-frost' as this only accounts for <1% of the total volume licensed for spray irrigation in the Anglian RBD. Also excludes licences for year round abstraction.

Table 5-9 shows the total licensed volume for direct spray irrigation by Anglian RBD catchment, by source and by time of year. The catchment with the greatest quantity licensed for direct spray irrigation is the Cam & Ely Ouse, with most water for direct spray irrigation taken from surface water sources during the summer.

Table 5-10 shows the area irrigated in the Anglian RBD and the volumes applied, by crop. The Table shows changes over the last 20 years in the composition of crops that are irrigated, and volume and depth of water applied. While the proportion of irrigation on grass, sugar beet and cereals has declined, there has been a marked increase in irrigation of high value crops (potatoes and vegetables). Historically, water abstraction for irrigation in the UK has been increasing steadily at around 2% to 3% per year, though this demand may have slowed in recent years (Weatherhead 2007)\(^5\).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maincrop potatoes</td>
<td>25,500</td>
<td>+3.0%</td>
<td>29,400</td>
<td>+3.5%</td>
<td>+1.6%</td>
</tr>
<tr>
<td>Vegetables</td>
<td>18,800</td>
<td>+3.0%</td>
<td>16,400</td>
<td>+3.9%</td>
<td>+2.0%</td>
</tr>
<tr>
<td>Early potatoes</td>
<td>3,630</td>
<td>+0.3%</td>
<td>3,880</td>
<td>+2.1%</td>
<td>+2.1%</td>
</tr>
<tr>
<td>Cereals</td>
<td>8,690</td>
<td>-2.4%</td>
<td>1,920</td>
<td>-2.9%</td>
<td>-0.8%</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>4,520</td>
<td>-1.6%</td>
<td>1,740</td>
<td>-1.2%</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Small fruit</td>
<td>1,080</td>
<td>+0.3%</td>
<td>792</td>
<td>+2.6%</td>
<td>+2.4%</td>
</tr>
<tr>
<td>Grass</td>
<td>1,050</td>
<td>-7.1%</td>
<td>366</td>
<td>-4.8%</td>
<td>+0.3%</td>
</tr>
<tr>
<td>Orchards</td>
<td>195</td>
<td>-2.5%</td>
<td>92</td>
<td>-2.7%</td>
<td>-0.5%</td>
</tr>
<tr>
<td>Other</td>
<td>3,790</td>
<td>No data</td>
<td>1,500</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td>Total</td>
<td>67,000</td>
<td>+0.9%</td>
<td>55,800</td>
<td>-2.9%</td>
<td>+1.7%</td>
</tr>
</tbody>
</table>

\(^5\) Weatherhead (2007) suggests that this may be due to uncertainty in the farming industry, an emphasis on increasing efficiency, and the fact that some farmers cannot obtain new abstraction licences.
5.4.4.2 Impacts of Abstraction

In the Anglian RBD, 1,593 km (21%) of river length is considered at risk or probably at risk from abstraction and flow regulation. The impacts are much greater for groundwater bodies, with 87% (by area, 14,577 km²) considered to be at risk. This is having knock-on effects on groundwater dependent terrestrial ecosystems, with 68% thought to be at risk from abstraction and flow regulation (Defra/EA, 2009). Table 5.11 summarises the number and percentage of water bodies within each catchment that are considered to be at risk or probably at risk in 2015 due to impacts on quantity and dynamics of flow.

Table 5.11: Breakdown of Anglian RBD into Catchments and Water Bodies at Risk from Abstraction (Defra/EA 2009)

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Number of Water Bodies at Risk</th>
<th>% of River Water Bodies at Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Suffolk</td>
<td>27</td>
<td>42% (65)</td>
</tr>
<tr>
<td>Old Bedford</td>
<td>3</td>
<td>25% (12)</td>
</tr>
<tr>
<td>Broadland Rivers</td>
<td>22</td>
<td>24% (93)</td>
</tr>
<tr>
<td>Cam &amp; Ely Ouse</td>
<td>19 (+1 currently at risk improved to good status by 2015)</td>
<td>23% (83)</td>
</tr>
<tr>
<td>Essex</td>
<td>29</td>
<td>23% (125)</td>
</tr>
<tr>
<td>Welland</td>
<td>10</td>
<td>22% (46)</td>
</tr>
<tr>
<td>North Norfolk</td>
<td>1</td>
<td>17% (6)</td>
</tr>
<tr>
<td>North West Norfolk</td>
<td>3</td>
<td>16% (19)</td>
</tr>
<tr>
<td>Witham</td>
<td>14</td>
<td>11% (125)</td>
</tr>
<tr>
<td>Upper &amp; Bedford Ouse</td>
<td>7</td>
<td>7% (94)</td>
</tr>
<tr>
<td>Nene</td>
<td>1</td>
<td>1% (69)</td>
</tr>
<tr>
<td>Groundwater*</td>
<td>8</td>
<td>26% (31)</td>
</tr>
</tbody>
</table>

Note: * For groundwater, the water body is assumed to be at risk if the water balance is less than good. A further three groundwater bodies are assigned a ‘poor’ status due to impact on wetlands or impacts on surface waters.

Since 2001, the availability of water resources for abstraction in England and Wales has been assessed through the Catchment Abstraction Management Strategy (CAMS) process. By taking into account the amount of water already licensed for abstraction and how much water the environment needs, the CAMS process determines how much water is reliably available for future abstraction on a catchment by catchment basis (EA 2010). Some of the most water stressed catchments in the UK are located in the Anglian RBD. As shown in Figure 5.20, summer surface water abstraction to the north and south of the Anglian RBD is unsustainable or unacceptable, and there is no additional water available across the Anglian RBD.

Table 5.12 shows the total licensed volume for spray irrigation (direct only, from surface water sources) for water bodies that are at stress (i.e. for water bodies at a CAMS status of red or purple). In the Anglian RBD, 26 million m³ per year is licensed for direct spray irrigation from...
surface water sources which are at stress, with nearly 10 million m$^3$ per year licensed for direct spray irrigation from surface water sources at stress in the Cam & Ely Ouse. No winter licences for spray irrigation from groundwater sources are for abstraction from water bodies at stress.

There is a significant disparity in the Anglian RBD between the total licensed volume and the amount of water abstractors actually take (RPA 2011). Levels of water abstraction for agricultural use are highly variable over time and are greatly influenced by annual rainfall, particularly during the growing season (Defra 2010). In the Anglian RBD some licences are probably unused or are not fully-utilised as they are held for abstraction during particularly dry years.
Table 5-12: Licensed volume (m$^3$/year) for direct spray irrigation from surface water sources in water bodies under stress (CAMS status red or purple) (EA NALD 2010)

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadland Rivers</td>
<td>1 500 000</td>
<td>0</td>
</tr>
<tr>
<td>Cam &amp; Ely Ouse Including South Level</td>
<td>9 800 000</td>
<td>27 000</td>
</tr>
<tr>
<td>East Suffolk</td>
<td>4 000 000</td>
<td>0</td>
</tr>
<tr>
<td>Essex</td>
<td>1 900 000</td>
<td>160 000</td>
</tr>
<tr>
<td>Grimsby, Ancholme &amp; Louth</td>
<td>840 000</td>
<td>0</td>
</tr>
<tr>
<td>Nene</td>
<td>87 000</td>
<td>0</td>
</tr>
<tr>
<td>North Norfolk</td>
<td>350 000</td>
<td>0</td>
</tr>
<tr>
<td>North West Norfolk</td>
<td>860 000</td>
<td>0</td>
</tr>
<tr>
<td>Old Bedford Including Middle Level</td>
<td>4 700 000</td>
<td>10 000</td>
</tr>
<tr>
<td>Roding, Beam &amp; Ingrebourne</td>
<td>0</td>
<td>28 000</td>
</tr>
<tr>
<td>Steepings, Great Eau &amp; Long Eau</td>
<td>22 000</td>
<td>0</td>
</tr>
<tr>
<td>Upper Ouse &amp; Bedford Ouse</td>
<td>270 000</td>
<td>73 000</td>
</tr>
<tr>
<td>Welland</td>
<td>60 000</td>
<td>0</td>
</tr>
<tr>
<td>Witham</td>
<td>2 000 000</td>
<td>20 000</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>26 000 000</strong></td>
<td><strong>320 000</strong></td>
</tr>
</tbody>
</table>

**Note:** exclude "spray irrigation – anti-frost"

5.4.4.3 Restrictions on Abstraction

Abstractions for irrigation must cease when the annual licensed quantity is reached or when restriction orders are enforced. In England and Wales abstraction licences are subject to two levels of potential restriction on their activities. These are:

- Hands off Flow (HoF) conditions, these require the licence holder to reduce or cease taking water once river flows drop to a certain level; and
- Section 57 restrictions (under the Water Resources Act 1991), where HoFs do not apply.

In the Anglian RBD, all new licences for abstraction (both summer and winter) are subject to a HoF condition. Different Water Resource Management Areas within different catchments have different HoF levels and the HoF conditions on a licence depend on the amount of water available when the licence is granted. In the Anglian RBD, 412 direct spray irrigation licences and 9 licences...

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58 In most catchments in the UK the amount abstracted is much lower than the licensed volume (except when there are peak demands).

59 These are designed to protect the rights of the environment and other water users (particularly public water supply).
for spray irrigation storage have a HoF restriction. The catchment with the largest number of summer spray irrigation licences subject to HoF conditions is the Cam & Ely Ouse.

As some older licences are not subject to HoF conditions, the EA can use Section 57 of the Water Resources Act 1991 to alter the right of some agricultural users to abstract under specific predefined conditions, such as during a drought. These orders can involve a reduction in volume, a limit on volumes abstracted during particular periods of the day or a total ban on abstraction (Morris et al. 1997). Farmers who are given a Section 57 order or subject to HoF are not given any financial compensation.

5.4.4.4 Abstraction Charges

Abstraction charges vary widely across the UK and have risen sharply for 2010/11 (Nix 2010). They are calculated according to a combination of the following factors: volume (annual licensed), source (whether the source is EA supported, unsupported or tidal\(^{60}\)), season (whether abstraction is licensed for summer, winter or year round) and loss (high, medium, low or very low).

Abstraction charges for the EA regions in England and Wales are variable across the charging regions. The standard unit charge in the Anglian RBD is 31.49 EUR /1000m\(^3\). This is higher than for any other region of England and Wales (the lowest charge is 13.31 EUR /1000m\(^3\) in Yorkshire. Costs in other regions in the South East of England are 22.01 EUR/1000m\(^3\) in Southern region and 15.48 EUR/1000m\(^3\) in Thames region).

Abstraction during the winter (1\(^{st}\) November to 31\(^{st}\) March inclusive) costs 16\% of the year-round charge, while abstraction during the summer (1\(^{st}\) April to 31\(^{st}\) October inclusive) costs 160\% of the year-round charge. This means that licence charges for summer abstraction are ten times more than for winter abstraction. This means that a summer spray irrigation licence for 20 000 m\(^3\) in the Anglian RBD costs 1 248 EUR, while a licence for the same quantity in winter costs only 125 EUR.

5.4.5 The Costs and Benefits of Irrigation Reservoirs

5.4.5.1 The Benefits of Moving to Irrigation Reservoirs\(^{61}\)

Benefits for Farmers

Farmers in the Anglian RBD are finding it increasingly difficult to obtain a licence for abstraction during the summer, while farmers with licences are finding that existing water sources for summer abstraction are becoming less reliable (due to HoFs and Section 57 restrictions).

\(^{60}\) Supported sources are defined as rivers or canals that are supplemented with water from reservoirs or boreholes to maintain or increase flow levels.

\(^{61}\) Weatherhead et al. (1997) make an important distinction between ‘non-impounding’ reservoirs (i.e. reservoirs built on impermeable clay or with an impermeable lining to prevent seepage into or out of the reservoir\(^{62}\)) and ‘impounding’ (on-stream) or seepage reservoirs which are also used for irrigation but which will affect low-flow water resources\(^{63}\). Here the discussion focuses on non-impounding reservoirs.
However, water may still be available at times of high flow even in “over-abstracted” catchments. One strategy being adopted by some farmers is to abstract water in high flow periods (typically during the winter) and store the water in on-farm reservoirs ready for use during drier periods (typically the summer).

Reservoirs provide farmers with benefits because they give greater security of water supply and can be used more flexibly than pumping directly from surface or ground water sources. This includes:

- scope to carry water over from one year to the next;
- option to take water whenever it is required with benefits in terms of ability to secure supermarket contracts that include specifications on size, quality and volume;
- potential to use the reservoir to store low flows from small streams and low-yielding aquifers to be used at much higher rates, and for shorter periods of time, to meet peak demands (EA/Cranfield University 2008);
- potential to pump water from the reservoir to better utilise the full capacity of modern irrigation machinery (i.e. a reservoir can effectively be treated as a header tank) (pers. comm., ESWAG, 22/08/2011);
- increase in abstraction licence renewal period from 12 years to 24 years with benefits for long-term planning. There will also be savings in water bills as winter charges (EUR/1000m$^3$) are just 10% of those in summer.

The benefits of irrigation are that it increases crop yield and quality over and above that obtained through rain-fed production. It can also enable multiple cropping (where two or more crops are grown in the same space during a single growing season) and increase the diversity of crops that can be grown, helping to reduce business risk. Consultation (pers. comm., ESWAG, 22/08/2011) has indicated that in East Suffolk, most irrigation is used to ensure crop quality. Quality criteria are increasingly specified by buyers, with failure to meet quality requirements potentially leading to a price reduction and, in some circumstances, loss of a contract (WS Atkins Ltd & Cranfield University 2000). If the quality of a crop is not sufficient, then there is unlikely to be a market for the crops.

Table 5-13 shows estimated average yield benefits per unit of water applied to selected irrigated crops on a medium AWC soil at Mepal, Cambridge (based on WS Atkins & Cranfield University 2000 and updated using average gross margins per hectare from ABC 2009). These data are likely to underestimate the yield benefits of most crops due to the rapidity at which prices for agricultural produce are changing. In addition, the benefits of irrigation per hectare in a dry year

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62 Earlier research (WS Atkins Ltd & Cranfield University 2000) has indicated that the quality benefits of irrigation can be substantial (e.g. the quality premia for maincrop potatoes has been estimated at 30%).

63 Supermarkets in particular are unlikely to place future contracts if they believe that water is not (or will not) be available.
(such as 2011) will be much higher than in a wet year, as farmers benefit from ‘preserved yield potential’ due to the higher commodity prices associated with reduced market supply.

Table 5-13: Average yield benefits attributable to irrigation on a medium AWC soil at Mepal, Cambridge, yield benefits calculated using ABC (2009)

<table>
<thead>
<tr>
<th>Net depth (mm)</th>
<th>Unirrigated yield (t/ha)</th>
<th>Av. gross margin (€/ha)</th>
<th>Yield benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>t/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>€/ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>€/m$^3$</td>
</tr>
<tr>
<td>Maincrop potatoes</td>
<td>125</td>
<td>40</td>
<td>2 048</td>
</tr>
<tr>
<td>Early potatoes</td>
<td>44</td>
<td>21.5</td>
<td>2 076</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>77</td>
<td>32</td>
<td>1 316</td>
</tr>
<tr>
<td>Cereals *</td>
<td>37</td>
<td>6.3</td>
<td>656</td>
</tr>
<tr>
<td>Peas - vining</td>
<td>44</td>
<td>3.2</td>
<td>406</td>
</tr>
<tr>
<td>Carrots</td>
<td>77</td>
<td>35</td>
<td>3 451</td>
</tr>
<tr>
<td>Parsnips</td>
<td>66</td>
<td>31.4</td>
<td>3 229</td>
</tr>
<tr>
<td>Swede (culinary)</td>
<td>74</td>
<td>21.7</td>
<td>4 593</td>
</tr>
<tr>
<td>Leeks</td>
<td>92</td>
<td>17.6</td>
<td>1 932</td>
</tr>
<tr>
<td>Cabbage (spring)</td>
<td>74</td>
<td>24.7</td>
<td>1 614</td>
</tr>
<tr>
<td>Calabrese</td>
<td>81</td>
<td>4</td>
<td>2 502</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>74</td>
<td>10.1</td>
<td>6 065</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>74</td>
<td>9.9</td>
<td>1 405</td>
</tr>
<tr>
<td>Strawberries</td>
<td>40</td>
<td>6.8</td>
<td>5 769</td>
</tr>
<tr>
<td>Raspberries</td>
<td>37</td>
<td>4.9</td>
<td>6 110</td>
</tr>
<tr>
<td>Blackcurrants</td>
<td>37</td>
<td>4.9</td>
<td>2 404</td>
</tr>
<tr>
<td>Dessert apples</td>
<td>74</td>
<td>13.5</td>
<td>4 067</td>
</tr>
<tr>
<td>Pears</td>
<td>74</td>
<td>7.8</td>
<td>1 777</td>
</tr>
</tbody>
</table>

Note: *For cereals, the average gross margin for winter wheat (milling) has been used to calculate the yield benefits of irrigation (EUR/ha and EUR/m$^3$)

Data sources: Net depth, unirrigated yield and yield benefits (t/ha) are taken from WS Atkins & Cranfield University 2000. Yield benefits (EUR/ha) have been updated using ABC (2009). Yield benefits of irrigation on potatoes are calculated as (40t/ha x 2 048 EUR) / (125 ha mm x 10 m$^3$ / ha mm).

Benefits for the Environment Agency

Under the current licensing regime, there is a legal obligation for the Environment Agency to pay compensation to a licence holder whenever they restrict or revoke an abstraction licence. This can be a time-consuming, costly and bureaucratic process. By enabling farmers to switch to winter abstraction, irrigation reservoirs may reduce the need for the Environment Agency to restrict or revoke existing licences for summer abstraction.
Opportunities for the environment and wildlife

Unlike natural lakes and ponds, irrigation reservoirs that are built on-farm do not necessarily have a high wildlife value. However, reservoirs can be resources for wildlife and add valuable biodiversity to the farmed landscape if wildlife-friendly features are deliberately built into them. These can often be incorporated into reservoir design at little extra cost (Suffolk Coasts and Heaths AONB, n.d.) and such multiple benefits could be worth promoting.

At the national scale, increasing the diversity of crops that are grown can also provide additional benefits in terms of soil protection, biodiversity and food security.

5.4.5.2 Costs, Barriers and Risks

Capital costs

The capital costs of constructing a reservoir depend on the following factors:

- location and soil type;
- reservoir size (this will need to take account of ‘dead storage’ [i.e. storage not used for irrigation] to take account of evaporation/seepage losses);
- construction, design and management Regulations;
- planning requirements, including the need for environmental impact assessments, archaeological surveys and reports;
- permissions and licences (e.g. abstraction licence costs);
- price of raw materials (e.g. liners), which will be affected by oil prices (e.g. for lined reservoirs) and fuel prices (e.g. diesel for construction);
- labour costs (e.g. construction and supervision fees);
- costs of importing or disposing of excavation materials (unless these can be reused on-site or sold);
- need for additional pumping, distribution (e.g. pipes) and irrigation equipment (e.g. booms, reels, guns). Pumps can cost between 3,200 EUR to 46,000 EUR (depending on whether they are diesel or electric and the monitoring controls and switch gear that are included). Pipeline costs vary from 3,20 EUR/m to 9,80 EUR/m for portable pipes, or from 5,70 EUR/m to 18,50 EUR/m for permanent underground pipes (supplied and laid) (Nix, 2010), based on pipe diameter.
- need for additional landscaping, fencing, planting, access roads and drainage; and
- inflation and land values (linked to the opportunity cost of the capital involved).

The most significant capital cost associated with building an irrigation reservoir is the reservoir lining (EA/Cranfield University 2008). Permeability of the local soil surface and geology will...
Case studies

determine the types of material available to build embankments, whether a synthetic lining is needed and whether it is safe/practicable to build. To ensure an adequate understanding of the local soil and geology, it may be necessary to excavate trial pits across the potential reservoir site (EA/Cranfield University 2008).

Clay is a very good material for building reservoirs but its availability in the Anglian RBD is geographically limited. Even where only a limited amount of clay is available, it may still be possible to build a clay-lined reservoir. Alternatively, a synthetic lining is likely to be required. EA/Cranfield University (2008) compared earthworks and lining costs for 20 reservoirs (both on farms and golf courses):

- cost of earthworks (clay reservoir): 1.1-1.4 EUR/m³ of water stored; and
- cost of earthworks plus synthetic liner costs: 2.3 EUR -4.6 EUR/m³ of water stored (synthetic liners deteriorate over time, mainly due to solar radiation, with a typical lifespan of about 20-25 years. Replacing them is likely to be expensive).

There were some economies of scale, so average costs were slightly lower for larger reservoirs. However, EA/Cranfield University (2008) estimate that for larger clay reservoirs, site investigation, design and supervision fees, and statutory provisions to the 'Final Certificate' stage can add around 15% to the cost of reservoir construction.

**Operating costs**

In addition to the capital costs required to build the reservoir, reservoirs have ongoing operating and maintenance costs. These include:

- maintenance and repairs: estimated at 1% (EA/Cranfield University 2008) to 10% (Robin Turney Ltd 2008) of the overall capital cost of the reservoir;
- fuel and energy (e.g. for pumping) and labour: these costs will be greater because water will need to be pumped twice. The costs will depend on the proximity of the reservoir to the water source (e.g. river) and the irrigation demand area;
- water: the costs of filling the reservoir;
- reservoir engineer fees: under The Reservoirs Act (1975) and The Flood and Water Management Act (2010), reservoir owners must appoint a specialist civil engineer (who is qualified and experienced in reservoir safety) to supervise the reservoir and carry out periodic inspections. The Flood and Water Management Act 2010 brought in new arrangements for reservoir safety which (when implemented) will reduce the threshold for registering reservoirs from above 25,000 m³ capacity to above 10,000 m³. Given that many farm reservoirs exceed this new threshold, it has been suggested that the Act represents an additional burden and it has been recommended that, unless there is strong evidence to the contrary, Ministers set the threshold which
triggers registration of reservoirs back to 25 000 m³ (Farm Regulation Task Force 2011);

- finance charges against any borrowed funds;
- insurance costs; and
- depreciation costs (depending on the lifetime of the reservoir components).

**Loss of land**

An important cost to consider when building an irrigation reservoir is the cost associated with the loss of productive land occupied by the reservoir (EA/Cranfield University 2008). This can be a capital cost (if the land has to be purchased) or an operating cost (an ongoing crop loss) (EA/Cranfield University 2008). These costs may be offset by the increase in value of land that would become irrigated and the additional income from irrigated production (EA/Cranfield University 2008).

**Overall Cost Estimates**

Table 5-14 provides indicative cost estimates for planning, design and construction of a reservoir. It also provides an indication of the operating and maintenance costs and the costs associated with loss of land. The Table shows that the overall costs can vary widely from 130 000 EUR for a low cost clay-lined reservoir to 630 000 EUR for a high cost synthetic-lined reservoir.

<table>
<thead>
<tr>
<th>Cost Type</th>
<th>Clay-Lined</th>
<th>Synthetic Liner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>€34 000 to €57 000</td>
<td>€55 000 to €70 000</td>
</tr>
<tr>
<td>Construction (44 000 m³ to allow 10% for evaporation, seepage and ‘dead water’ to prevent clay shrinkage)¹</td>
<td>€55 000 to €70 000</td>
<td>€115 000 to €230 000</td>
</tr>
<tr>
<td>Electricity (for pumping)</td>
<td>€20 000 (where supply is not already available)</td>
<td></td>
</tr>
<tr>
<td>Final Certificate (15% of construction costs)</td>
<td>€8 250 to €10 500 (if needed)</td>
<td>€17 250 to €34 500 (if needed)</td>
</tr>
<tr>
<td>Maintenance Costs (1% to 10% of construction costs over 25 years (year 3 to 27), discounted at 4% per year)</td>
<td>€7 000 to €89 000 (over 25 years)</td>
<td>€15 000 to €290 000 (over 25 years)</td>
</tr>
<tr>
<td>Loss of Land (loss of output from 1,5 ha of marginal land with capitalised value of 20 000 EUR/ha)²</td>
<td>€30 000</td>
<td>€30 000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>€130 000 to €270 000</strong></td>
<td><strong>€190 000 to €630 000</strong></td>
</tr>
<tr>
<td>EUR/m³ (based on 40 000 m³ reservoir with a lifetime of 25 years)</td>
<td>€3,20 to €6,70</td>
<td>€4,90 to €15,80</td>
</tr>
</tbody>
</table>

**Notes:**
1. Based on average size of reservoirs receiving RDPE funding (16 reservoirs storing 614,000 m³), with 10% allowed for ‘dead storage’
2. Loss of land assumed to include site of reservoir itself, area of embankments, supporting infrastructure, conservation/environmental enhancements, etc.
Barriers and Risks

Moving to irrigation reservoirs is not without its risks. The construction of a reservoir is a long-term strategic investment that requires confidence in the future availability of water (Holman and Trawick 2011). Reasons why more farmers have not invested in irrigation reservoirs include (Weatherhead et al. 1997):

- **financial constraints**: cost of reservoir, access to finance (loans/grants), availability of lower cost alternatives (e.g. efficiency measures, trickle irrigation);
- **uncertainties**: site conditions/difficult access/fragmented landholdings, insecure land tenure, uncertain long-term cropping patterns, uncertain farming futures;
- **availability of water**: water availability (with all new licences including HoF conditions), renewal of licences (although there is a general presumption of renewal as long as the abstractor can demonstrate ‘reasonable need’ for the water), concern that water supply is too unreliable to ensure the viability of a reservoir;
- **farmer attitudes**: legal obligations and liability for reservoir safety;
- **conflict with conservation interests**;
- **planning constraints**.

Reservoir sharing has emerged as a means of spreading these costs and risks (Holman and Trawick 2011), with reservoir sharing discussed further in Section 5.

Some financial assistance is available for the development of irrigation reservoirs (with grants of up to 50% available from the Department for Environment, Food and Rural Affairs (Defra). In 2010/11, £2.8 million (3.2 million EUR) of funding was awarded towards the construction of 16 water storage reservoirs and irrigation schemes in the East of England storing over 614 000 m$^3$ of water (EEDA 2011). However, Holman and Trawick (2011) and the EA (pers. comm., 11/08/2011) indicate that limited state financial support for capital investment remains a significant barrier to irrigation reservoir development. Considerable investment (30 000 EUR to 60 000 EUR) may be needed before the reservoir is even given permission to be constructed, with there being no grant available to cover such costs (pers. comm., ESWAG, 22/08/2011). Further, small farms may find it harder to access finance to build a reservoir than larger farms (pers. comm., EA 11/08/2011).
5.4.5.3 Benefits for Farmers in the Anglian RBD

Table 5-10 shows the total area by crop that is irrigated in the Anglian RBD. From this and the depth to which each crop is irrigated, an estimate can be made of the volume of water used for irrigation\textsuperscript{64}. Table 5-15 presents these volumes.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Total Irrigated Area in Anglian RBD (ha)</th>
<th>Depth (mm)</th>
<th>Volume of Water used for Direct Irrigation and Irrigation Storage (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maincrop potatoes</td>
<td>25 500</td>
<td>125</td>
<td>31 875 000</td>
</tr>
<tr>
<td>Vegetables</td>
<td>18 800</td>
<td>76,5</td>
<td>14 382 000</td>
</tr>
<tr>
<td>Early potatoes</td>
<td>3 630</td>
<td>44</td>
<td>1 597 200</td>
</tr>
<tr>
<td>Cereals</td>
<td>8,690</td>
<td>37</td>
<td>3 215 300</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>4,520</td>
<td>77</td>
<td>3 480 400</td>
</tr>
<tr>
<td>Small fruit</td>
<td>1 080</td>
<td>38</td>
<td>410 400</td>
</tr>
<tr>
<td>Orchards</td>
<td>195</td>
<td>74</td>
<td>144 300</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>62 415</strong></td>
<td></td>
<td><strong>55 000 000</strong></td>
</tr>
</tbody>
</table>


Table 5-15 shows that the total volume of water abstracted for spray irrigation in the Anglian RBD is around 55 million m$^3$. Of this, the EA NALD shows that 60% (33 million m$^3$) is abstracted for direct irrigation. Relying on direct abstraction carries a risk, as water may not always be available. In the Anglian RBD, 421 licences for summer abstraction for spray irrigation include Hands-off-Flows (HoF). Water would not be available if the river levels fall below the HoF. The HoFs are set for each licence and vary by catchment and sub-catchment but an approximate average for the Anglian RBD could be that HoFs would reduce water availability when the river flow falls below that exceeded 81% of the time (i.e. Q\textsubscript{81})\textsuperscript{65}. Table 5-16 identifies the benefits that could be lost due to reliance on water being available for direct spray irrigation.

Table 5-16 shows that the total benefits that could be lost due to the uncertainty of abstracting water when there is a risk of HoFs are around 115 million EUR per year. This is equivalent to 19% of the total crop yield benefits and assumes that the reduction in water for irrigation results in an equivalent loss of yield. While this is likely to be an over-estimation, the estimate does not

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\textsuperscript{64} Water used for irrigation includes all water whether abstracted and used directly and stored first. Water used directly for irrigation means that water used as soon as it is abstracted. Water used for irrigation storage is water that is held in a reservoir before being used for irrigation.

\textsuperscript{65} This is a simplification to enable the calculated losses due to lack of water to be calculated. HoFs are usually allocated at three levels. HoF1 is usually (but not always) at around the Q\textsubscript{95}, HoF2 is based on Q\textsubscript{81} (based on average number of days that abstraction is allowed from EA (2007) and EA (2008)).
include quality benefits and, as a result may under-estimate total losses. Since the total benefits are estimated at 11,20 EUR/m³, the reduction of benefits by 19% is assumed to result in a loss of 2,10 EUR/m³ (rounded).

Table 5-16: Benefits Lost due to use of HoFs

<table>
<thead>
<tr>
<th>Crop</th>
<th>Total Crop Yield Benefits</th>
<th>% of Time when Water is not Available due to HoFs</th>
<th>Reduced Benefits due to Lack of Water</th>
<th>Benefits ‘Lost’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maincrop potatoes</td>
<td>€313 million</td>
<td></td>
<td>€255 million</td>
<td>€58 million</td>
</tr>
<tr>
<td>Vegetables</td>
<td>€247 million</td>
<td></td>
<td>€201 million</td>
<td>€46 million</td>
</tr>
<tr>
<td>Early potatoes</td>
<td>€15,8 million</td>
<td></td>
<td>€13 million</td>
<td>€2,9 million</td>
</tr>
<tr>
<td>Cereals</td>
<td>€2,4 million</td>
<td>19%</td>
<td>€1,9 million</td>
<td>€0,45 million</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>€36 million</td>
<td>(based on average number of days when abstraction is likely to be restricted under HoF2, across Cam and Ely Ouse and Broadland Rivers)</td>
<td>€29 million</td>
<td>€6,6 million</td>
</tr>
<tr>
<td>Small fruit</td>
<td>€3,5 million</td>
<td></td>
<td>€2,9 million</td>
<td>€0,64 million</td>
</tr>
<tr>
<td>Orchards</td>
<td>€0,59 million</td>
<td></td>
<td>€0,48 million</td>
<td>€0,11 million</td>
</tr>
<tr>
<td>TOTAL</td>
<td>€618 million</td>
<td></td>
<td>€503 million</td>
<td>€115 million</td>
</tr>
</tbody>
</table>

Notes: based on yield benefits by crop from Table 4.1 and volumes of water used for irrigation (Table 4.3), taking account of the amount of time that water may not be available for abstraction due to HoF. The benefits are calculated as losses avoided.

There would also be savings from reduced water abstraction costs as the costs of abstracting in summer are 160% of the year-round charge, while in winter the costs are 16% of the year-round charge. The costs of abstracting 55 million m³ in summer would be 1,7 million EUR (at 31,49 EUR /1000m³) and in winter would be 0,17 million EUR. Abstraction in winter would, therefore, save 1,5 million EUR per year. If all of the 55 million m³ were stored in reservoirs, the savings would be 0,05 EUR/m³ per year.

In total, therefore, the benefits of moving to winter abstraction and use of a storage reservoir could be around 2,14 EUR/m³ per year. Over an estimated 25-year life of a reservoir, this would be equivalent to benefits of around 30 EUR/m³ (assuming that the benefits would not accrue until the reservoir is in place, estimated as year 3). In addition, the security and flexibility benefits described in section 5.4.5.1 may also be realised. These are not included in the 30 EUR/m³ per year benefits.
5.4.5.4 **Comparison with Costs**

The overall benefits of reservoirs are estimated as the Present Value (i.e. discounted) quality and yield benefits of 30 EUR/m$^3$ (over 25 years at 4%) compared with costs of 3,20 EUR/m$^3$ to 6,70 EUR/m$^3$ (clay lined) and 4,90 EUR/m$^3$ to 15,80 EUR/m$^3$ (synthetic liners). Thus, reservoirs offer overall benefits (to farmers) of 14 EUR/m$^3$ to 27 EUR/m$^3$ over 25 years, or annualised benefits of 0,80 EUR/m$^3$ to 1,55 EUR/m$^3$ per year.

If the total volume stored in the irrigation reservoir is used, the payback periods range from four to twelve years (for a reservoir with capacity of 40 000 m$^3$). If only half the water stored in the reservoir is used for irrigation in any one year (20 000 m$^3$), the payback periods increase to six to thirty years. This may suggest that where there is a need for synthetic liners, where ground conditions are difficult and/or high planning and maintenance costs, it may not be cost-beneficial to construct a reservoir. However, if grants are available (currently up to 50% and potentially increasing to 60%), the payback periods would be reduced.

5.4.6 **The Potential Benefits for Water Stress in the Anglian RBD**

5.4.6.1 **Level of Irrigation Use**

Table 5-17 presents the volumes of water licensed during the summer for direct spray irrigation from all catchments in the Anglian RBD. The Table shows that East Suffolk has the highest proportion of water licensed for direct spray irrigation from stressed catchments (80%). This is also the catchment with the highest proportion of water bodies at risk of not meeting good status due to abstraction and flow regulation (42%, Table 5-11). Table 5-17 also shows that, out of the total proportion licensed for spray irrigation from stressed catchments, the highest proportion of water licensed for direct spray irrigation is in Broadland Rivers (85%), with North Norfolk second (80%) and East Suffolk third (79%).

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66 The payback period for the highest cost estimate exceeds the expected 25 year life of the reservoir. However, this calculation excludes the additional benefits associated with quality, security of supply for supermarket contracts, environmental benefits as well as providing farmers with a potential adaptation measure for climate change.
### Table 5-17: Volume of Water Licensed for Spray Irrigation in the Summer in Anglian RBD from All Catchments and Stressed Catchments (m³)

(based on EA National Abstraction Licensing Database 2010)

<table>
<thead>
<tr>
<th>CAMS Catchment</th>
<th>Volume Licensed from All Catchments</th>
<th>Volume Licensed from Stressed Catchments</th>
<th>% of Water Licensed for Spray Irrigation from Stressed Catchments</th>
<th>% of Water Licensed from Stressed Catchments for Direct Spray Irrigation</th>
<th>% of Water Licensed from Stressed Catchments for Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Suffolk</td>
<td>7 100 000</td>
<td>4 000 000</td>
<td>80%</td>
<td>79%</td>
<td>21%</td>
</tr>
<tr>
<td>Grimsby, Ancholme &amp; Louth</td>
<td>640 000</td>
<td>840 000</td>
<td>70%</td>
<td>41%</td>
<td>59%</td>
</tr>
<tr>
<td>Old Bedford Including Middle Level</td>
<td>4 500 000</td>
<td>4 700 000</td>
<td>67%</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>Cam &amp; Ely Ouse Including South Level</td>
<td>1 200 000</td>
<td>9 800 000</td>
<td>65%</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>North Norfolk</td>
<td>2 100 000</td>
<td>350 000</td>
<td>54%</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Essex</td>
<td>15 000 000</td>
<td>1 900 000</td>
<td>46%</td>
<td>36%</td>
<td>64%</td>
</tr>
<tr>
<td>North West Norfolk</td>
<td>5 400 000</td>
<td>860 000</td>
<td>41%</td>
<td>59%</td>
<td>41%</td>
</tr>
<tr>
<td>Witham</td>
<td>410 000</td>
<td>2 000 000</td>
<td>38%</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>Broadland Rivers</td>
<td>5 000 000</td>
<td>1 500 000</td>
<td>33%</td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>Upper Ouse &amp; Bedford Ouse</td>
<td>300,000</td>
<td>270,000</td>
<td>21%</td>
<td>52%</td>
<td>48%</td>
</tr>
<tr>
<td>Nene</td>
<td>4 100 000</td>
<td>87 000</td>
<td>7%</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>Steepings, Great Eau &amp; Long Eau</td>
<td>1 300 000</td>
<td>22 000</td>
<td>7%</td>
<td>49%</td>
<td>51%</td>
</tr>
<tr>
<td>Welland</td>
<td>1 400 000</td>
<td>60 000</td>
<td>4%</td>
<td>61%</td>
<td>39%</td>
</tr>
<tr>
<td>Roding, Beam &amp; Ingrebourne</td>
<td>1 300 000</td>
<td>0</td>
<td>0%</td>
<td>41%</td>
<td>59%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>50 000 000</td>
<td>26 000 000</td>
<td>53%</td>
<td>60%</td>
<td>40%</td>
</tr>
</tbody>
</table>
5.4.6.2 Opportunities to Move to Winter Abstraction

Table 5-18 presents the costs (based on the mean costs for clay-lined and synthetic lined reservoirs from Table 5-14) that could be incurred in each of these catchments if all the water currently licensed for direct spray irrigation in summer were instead licensed for the winter, with water abstracted being stored in reservoirs. The Table also gives cost estimates for 50% and 33% of the water licensed for direct spray irrigation in the summer moving to winter storage. The figures in the table relate to the costs of design, planning, construction and maintenance of a reservoir. They do not include the benefits that could be realised from quality and yield benefits associated with irrigated crops. These benefits could be considerable and could result in payback on the costs of a reservoir within a few years.

Table 5-18: Cost of Moving from Direct Spray Irrigation in Summer to Winter Storage

<table>
<thead>
<tr>
<th>CAMS Catchment</th>
<th>100% Water to Winter Storage</th>
<th>50% Water to Winter Storage</th>
<th>33% Water to Winter Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clay-Lined</td>
<td>Synthetic Lined</td>
<td>Clay-Lined</td>
</tr>
<tr>
<td>Broadland Rivers</td>
<td>€7,5m</td>
<td>€15m</td>
<td>€3,7m</td>
</tr>
<tr>
<td>North Norfolk</td>
<td>€1,75m</td>
<td>€3,5m</td>
<td>€0,85m</td>
</tr>
<tr>
<td>East Suffolk</td>
<td>€20m</td>
<td>€40m</td>
<td>€10m</td>
</tr>
<tr>
<td>Welland</td>
<td>€0,3m</td>
<td>€0,6m</td>
<td>€0,15m</td>
</tr>
<tr>
<td>Cam &amp; Ely Ouse</td>
<td>€4,9m</td>
<td>€9,8m</td>
<td>€25m</td>
</tr>
<tr>
<td>North West Norfolk</td>
<td>€4,3m</td>
<td>€8,6m</td>
<td>€2,2m</td>
</tr>
<tr>
<td>Witham</td>
<td>€10m</td>
<td>€20m</td>
<td>€5m</td>
</tr>
<tr>
<td>Old Bedford</td>
<td>€23,5m</td>
<td>€47m</td>
<td>€12m</td>
</tr>
<tr>
<td>Nene</td>
<td>€0,44m</td>
<td>€0,87m</td>
<td>€0,22m</td>
</tr>
<tr>
<td>Upper &amp; Bedford Ouse</td>
<td>€1,4m</td>
<td>€2,7m</td>
<td>€0,65m</td>
</tr>
<tr>
<td>Steeping, Great Eau and Long Eau</td>
<td>€0,11m</td>
<td>€0,22m</td>
<td>€0,06m</td>
</tr>
<tr>
<td>Roding, Beam and Ingrebourne</td>
<td>€0 million</td>
<td>(no water licensed for direct spray irrigation in stressed catchments)</td>
<td></td>
</tr>
<tr>
<td>Grimsby, Ancholme and Louth</td>
<td>€4,2m</td>
<td>€8,4m</td>
<td>€2,1m</td>
</tr>
<tr>
<td>Essex</td>
<td>€9,5m</td>
<td>€19m</td>
<td>€4,8m</td>
</tr>
<tr>
<td>TOTAL</td>
<td>€130m</td>
<td>€260m</td>
<td>€65m</td>
</tr>
</tbody>
</table>

Data Source: Based on EA National Abstraction Licensing Database (2010)

67 No information is available on the extent to which reservoirs could be constructed, or the extent to which actual abstractions or licensed volumes need to be reduced to reduce the risk that water bodies fail to meet good status. Hence, assumptions are made that 33%, 50% or 100% of licensed volumes that are currently used for direct spray irrigation could be moved to winter licences to give an indication of the water savings that might be possible.
The EA does not have any quantitative information on the role that storage reservoirs can play in reducing environmental pressures but it is generally agreed that moving to winter abstraction would reduce environmental pressures and help deliver the WFD objectives/improve the CAMS status (pers. comm., EA, 11/08/2011). There is also no information available on the extent to which reservoirs could be constructed. Hence, assumptions are made that 33%, 50% or 100% of licensed volumes could move to winter licences to give an indication of the water savings that might be possible. Table 5-19 presents the results. Note that no information is available on the environmental impacts of moving a particular percentage of water from summer to winter abstraction, although it is important to recognise that environmental impacts may occur (see also section 5.4.6.6).

Table 5-19: Volume of Water that could move to Winter Licences (m$^3$). Source: Based on EA National Abstraction Licensing Database (2010)

<table>
<thead>
<tr>
<th>CAMS Catchment</th>
<th>Total Volume Licensed for Direct Spray Irrigation in Summer from Stressed Catchments</th>
<th>Volume of Water Licensed in Winter if...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>33% of Summer Licensed Volumes move</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500 000</td>
</tr>
<tr>
<td>Broadland Rivers</td>
<td>1 500 000</td>
<td>480 000</td>
</tr>
<tr>
<td>North Norfolk</td>
<td>350 000</td>
<td>120 000</td>
</tr>
<tr>
<td>East Suffolk</td>
<td>4 000 000</td>
<td>1 300 000</td>
</tr>
<tr>
<td>Welland</td>
<td>60 000</td>
<td>20 000</td>
</tr>
<tr>
<td>Cam &amp; Ely Ouse Including South</td>
<td>9 800 000</td>
<td>3 200 000</td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Norfolk</td>
<td>860 000</td>
<td>280 000</td>
</tr>
<tr>
<td>Witham</td>
<td>2 000 000</td>
<td>670 000</td>
</tr>
<tr>
<td>Old Including Bedford Level</td>
<td>4 700 000</td>
<td>1 600 000</td>
</tr>
<tr>
<td>Nene</td>
<td>87 000</td>
<td>29 000</td>
</tr>
<tr>
<td>Upper Ouse &amp; Bedford Ouse</td>
<td>270 000</td>
<td>89 000</td>
</tr>
<tr>
<td>Steeplings, Great Eau &amp; Long Eau</td>
<td>22 000</td>
<td>7 200</td>
</tr>
<tr>
<td>Roding, Beam &amp; Ingrebourne</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grimsby, Ancholme &amp; Louth</td>
<td>840 000</td>
<td>280 000</td>
</tr>
<tr>
<td>Essex</td>
<td>1 900 000</td>
<td>620 000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>26 000 000</td>
<td>8 700 000</td>
</tr>
</tbody>
</table>
Additional volumes of water may be needed to fill winter storage reservoirs than may have been required in the summer because risk aversion may mean that worst case scenarios are used to estimate the predicted irrigation need for the following summer. Account also needs to be taken of evaporation and seepage from the reservoir and to prevent shrinkage of clay liners or solar radiation affecting synthetic liners.

Table 5-19 shows that the greatest opportunities for moving to winter storage reservoirs to help reduce the effect of water stress are in the Cam & Ely Ouse, Old Bedford and East Suffolk catchments. These three catchments could account for a reduction of around 71% of licensed volumes for direct spray irrigation from summer.

### 5.4.6.3 Approaches to Enable Move to Winter Licences

There may be opportunities to reduce some of the costs of constructing reservoirs through sharing of reservoirs, or sharing/trading of water stored in reservoirs. Shared reservoirs could be organised in a number of different ways, for example:

- a single farmer could build a large reservoir and sell water to other farmers; or
- a co-operative of farmers could come together to build a reservoir, and abstract under a single abstraction licence (or multiple licences).

There are already a number of shared reservoirs in the Anglian RBD. In some cases, shared reservoirs have been used as an opportunity to provide additional income with excess water sold to other abstractors. For example, in East Suffolk, the Benacre Estate have provided the capital financing for irrigation reservoirs, selling water to their tenant farmers through a co-operative approach (pers. comm., ESWAG 22/08/2011). Small farms in particular may stand to benefit from being able to invest in a shared reservoir as they may not otherwise have sufficient space and/or resources to do so. There is potential for difficulties if all parties require access to the water at the same time. This means formal agreements are required and the costs of setting these up would need to be added to the cost of constructing the reservoir.

Water rights trading could enable more efficient exploitation of available water resources and could help to facilitate reservoir construction where additional water is not available for a new licence. The potential for sharing of water through abstraction licence trading is significant but there are a number of key barriers to greater abstraction licence trading. An important consideration is the risk that unused or under-utilised licences could be reactivated through the trading process.

Some abstractors have already formed co-operatives to share limited water resources. At least six water abstractor groups (WAGs) are already operating in the UK, with five of these located in the Anglian RBD (Cranfield et al. n.d.). An overview of the characteristics of selected WAGs in the Anglian RBD is given in Table 5-20.
Case studies

Table 5-20: Characteristics of selected Water Abtractor Groups in the Anglian RBD. Source: Leathes et al. (2007)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ESWAG</th>
<th>BAWAG</th>
<th>LWT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Type</td>
<td>Spray irrigators</td>
<td>Spray irrigators</td>
<td>Spray irrigators</td>
</tr>
<tr>
<td>Group Size</td>
<td>80 members</td>
<td>170 members</td>
<td>19 members</td>
</tr>
<tr>
<td>Formation</td>
<td>Reactive</td>
<td>Reactive</td>
<td>Proactive</td>
</tr>
<tr>
<td>Licence Conditions</td>
<td>Individual licences</td>
<td>Individual licences</td>
<td>Communal licence</td>
</tr>
<tr>
<td>Water Source</td>
<td>Mainly groundwater</td>
<td>Mainly groundwater</td>
<td>Surface water</td>
</tr>
<tr>
<td>Resource Usage</td>
<td>External system of allocation</td>
<td>External system of allocation</td>
<td>Internal system of allocation</td>
</tr>
<tr>
<td>Monitoring</td>
<td>External</td>
<td>External</td>
<td>Mainly internal</td>
</tr>
<tr>
<td>Collaborative Venture</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Classification</td>
<td>Evolving</td>
<td>Evolving</td>
<td>Mature</td>
</tr>
</tbody>
</table>

WAGs could provide the organisational structure for developing shared reservoirs and help facilitate trading of abstraction licences in shared reservoirs. WAGs often include agricultural and non-agricultural members. For example, the BAWAG includes members from breweries, glasshouses, and processors (pers. comm., EA, 16/06/2011). There may be opportunities for agricultural irrigators to work together with non-agricultural users to construct irrigation reservoirs.

There may also be opportunities to involve organisations such as Internal Drainage Boards (IDBs). IDBs manage water within their districts to reduce the risk of flooding of land in the winter and to provide sufficient water to farmers in the summer. There may be opportunities to store water in winter and release it into drainage channels from where it could be abstracted in the summer. Those abstracting water from the drainage channels are likely to require abstraction licences and more water would have to be released than is to be abstracted to account for evaporation. Many IDBs are located on low-lying areas where ground conditions may be less suitable for construction of embankments. The result could be that the costs of storing water are much higher.

Better use could also be made of groundwater sources. A total of 87% of groundwater bodies (by area) in the Anglian RBD are at risk or probably at risk of failing to meet good status due to abstraction and flow regulation. Opportunities to use groundwater as natural ‘reservoirs’ may, therefore, be limited. There is potential for trading from groundwater bodies that are not at risk and it may be possible to allow trades between Groundwater Water Management Units (GWMUs). Consideration could also be given to aquifer storage and recovery as a method for increasing recharge of GWMUs to support increased abstraction during summer.

Table 5-21 identifies which of the approaches described above may be applicable to each of the three catchments that could benefit most from a move to winter licences.
Table 5-21: Approaches that could be used to move to winter licences

<table>
<thead>
<tr>
<th>CAMS Catchment</th>
<th>Volume Licensed for Direct Spray Irrigation in Summer (Stressed Catchments)</th>
<th>Approach to Enable Winter Storage</th>
<th>Use of Groundwater as Natural Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cam &amp; Ely Ouse Including South Level</td>
<td>9,800,000 m³</td>
<td>Construction of Reservoirs in Co-operative</td>
<td>Water could be stored rather than evacuated through Relief Channel, ditches could be used to transport water</td>
</tr>
<tr>
<td>Old Bedford Including Middle Level</td>
<td>4,700,000 m³</td>
<td>Encouragement for increased winter use (40% of abstractions are for storage)</td>
<td>Transfers and movement of water already takes place for spray irrigation</td>
</tr>
<tr>
<td>East Suffolk</td>
<td>4,000,000 m³</td>
<td>WAG in place, some reservoirs already constructed</td>
<td>IDB in place but much of infrastructure needs to be replaced</td>
</tr>
</tbody>
</table>

5.4.6.4 **Potential Reduction in Water Stress**

Reductions in abstraction during the summer may help to reduce water stress, especially in catchments identified as being at risk of not meeting good status due to abstraction. The environmental impacts of abstraction include reduced depths of water, lower velocities and reduced flow continuity leading to impacts on ecology (Defra/EA, 2009). The volume of water that could move from summer to winter licences in stressed catchments is estimated at 8.7 million m³ (33%) to 26 million m³ (100%), or between 5% and 16% of total licensed volume in the Anglian RBD.

The ability to realise these water savings and the associated environmental benefits will depend on:

- the availability of finance (farmers and, where available, grants);
- the availability of suitable land (especially where clay soils would allow the costs of reservoirs to be reduced); and
- the availability of water in winter (although licences that ‘swap’ summer for winter water may be viewed as more sustainable).

The EA already identifies the need to encourage farmers to build storage reservoirs, to establish water abstractor groups and to promote water efficiency on farms (Defra/EA, 2009a). In addition, the EA aims to add cessation conditions on surface water abstraction licences to protect low
flows and levels. This may increase the risk that water is not available for irrigation in the summer and may increase the benefits of moving to winter storage. Increasing winter abstraction may also provide an adaptation measure, due to projections under climate change of wetter winters but drier springs and summers. Hence, increasing winter storage may help reduce future environmental impacts, and maintain quality and yield benefits for farmers.

5.4.6.5 **Knock-on Benefits from Construction of Reservoirs**

If designed appropriately, reservoirs provide the opportunity to deliver direct wildlife and biodiversity benefits (as well as the indirect environmental benefits associated with reducing water stress in rivers). This requires environmentally friendly features to be designed and built (at additional cost) including trees and shrubs around the reservoir, floating islands, shallow muddy margins or boggy areas and/or deep areas at the bottom of the reservoir below the abstraction level to act as a wildlife refuge.

5.4.6.6 **Knock-on Negative Effects from Construction of Reservoirs**

Negative effects could arise if there is a significant increase in abstractions during the winter that could affect the natural variability of flow. Reductions in periods of high flow could reduce flushing of sediments, leading to sediment build-up over time. This could affect spawning grounds for fish and invertebrates. Low flows may also impact on fish migration.

Large numbers of reservoirs could affect the landscape, although this can be managed by careful positioning of reservoirs and screening (e.g. by trees and shrubs).

5.4.7 **Conclusions**

Farmers in the Anglian RBD are finding it increasingly difficult to maintain access to a secure supply of irrigation water: licences for summer abstraction are becoming increasingly difficult to obtain and existing water sources for summer abstraction are becoming less reliable (due to HoFs and Section 57 restrictions). In most over abstracted catchments, however, water is still available at times of high flow and so farmers are showing increasing interest in building irrigation reservoirs to store water to meet peak demands. As a result, the volume of water used for irrigation that is stored in reservoirs has grown from 13% in 1982 to 39% in 1995 (based on MAFF/Defra Irrigation surveys) to more than 40% in 2010 (based on the EA NALD data). While this suggests that growth the quantity of water coming via storage reservoir has slowed in recent years, consultation indicates that this is unlikely to be the case, with farmers increasingly turning to the use of irrigation reservoirs to secure their water supply. There are still barriers that affect the ability of farmers to construct reservoirs though, with the most important being:

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68 The 2005 Defra Irrigation Survey (Weatherhead et al. 2005) reports that only 30% of the total water used in 2005 came via storage reservoir. This apparent reduction from 1995 to 2005 probably relates to a change in the question format and reflects the difficulty of obtaining reliable trend data on irrigation water use.
cost: investment in reservoirs is expensive and, even if grants are available, there is a need for a lot of investment to determine if a reservoir is viable; and

planning: planning controls and regulations can affect whether reservoirs can be constructed, but the requirements can also result in significant costs.

A secure supply could deliver significant benefits to farmers (e.g. through increasing their ability to meet contractual quality requirements) with the monetised benefit of moving to irrigation reservoirs estimated as 30 EUR/m$^3$ (present value). This compares with estimated costs of 3,20 EUR/m$^3$ to 6,70 EUR/m$^3$ (for clay-lined reservoirs) and 4,90 EUR/m$^3$ to 15,80 EUR/m$^3$ (for reservoirs with a synthetic liner). Thus, the overall benefit (to farmers) of moving to irrigation reservoirs can be estimated at 14 EUR/m$^3$ to 27 EUR/m$^3$ (discounted over 25 years at 4%), or annualised benefits of 0,80 EUR/m$^3$ to 1,55 EUR/m$^3$ per year.

Based on mean costs for clay-lined and synthetic-lined reservoirs, the cost of moving from direct spray irrigation in summer to winter storage for the Anglian RBD as a whole have been estimated at (the lower estimate is for clay-lined reservoirs and the upper estimate is for synthetic-lined reservoirs):

- 130 million EUR to 260 million EUR (100% water moved from abstraction for direct spray irrigation in the summer to winter storage);
- 65 million EUR to 130 million EUR (50% moved to winter storage); or
- 44 million EUR to 87 million EUR (33% moved to winter storage).

In terms of the potential benefits for water stress in the Anglian RBD, it is generally agreed that moving to winter abstraction would reduce environmental pressures and help to deliver the WFD objectives/improve the CAMS status. It is not possible to quantify the environmental benefits as the EA does not have any quantitative information on the role that storage reservoirs can play in reducing environmental pressures. The total volume of water that could be moved from summer to winter licences in stressed catchments is estimated at 8,7 million m$^3$ (assuming that 33% of water licensed for abstraction in the summer is moved to winter) to 26 million m$^3$ (assuming that 100% of summer water is moved to winter). This is equivalent to 8 700 to 26 000 Ml/year, or between 5% and 16% of the total licensed volume.

### 5.4.7.1 Data gaps and uncertainties

Due to data gaps and uncertainties, the calculation of costs and benefits in this assessment has relied on a number of key assumptions. These are:

- Case study approach

The assessment of costs and benefits are for the Anglian RBD as a whole. As a result, assumptions have been applied that are generic to the Anglian RBD, rather than specific to catchments or sub-catchments. While this simplification allows overall costs and benefits to be derived, it will result in considerable uncertainty over the accuracy of the costs and benefits.
Estimates of costs of constructing reservoirs

Costs are based on generic estimates, with insufficient information available on where it may be possible to construct clay-lined reservoirs and where it will be necessary to use synthetic liners, hence, a range of costs is given.

The types of cost included within the cost estimates are those that are typically incurred. Other costs may also arise, for example, if archaeological investigations are required. As a result, it is likely that the cost estimates are an under-estimate of the total costs across the Anglian RBD as a whole.

Estimates of benefits to farmers

Benefits have been calculated based on an estimated increase in crop yield, this will be an under-estimate as benefits that cannot be easily monetised are not included.

The assumption used to estimate the lost benefits avoided is based on an assessment of the number of days that irrigation water is not available using HoFs for two catchments (Cam & Ely Ouse and East Suffolk). This generic assumption (i.e. that abstraction is not permitted, on average, when the flow falls below the $Q_{81}$) is applied across the whole of the Anglian RBD and is a significant simplification.

The impact of climate change on future demand has not been quantified in terms of increasing benefits over time. Projections of increased in future demand are highly variable and are likely to be limited by controls on abstraction (through licensing). As a result, no attempt is made to estimate an increase in future benefits as this could be misleading in terms of the future balance between costs and benefits of reservoirs.

Estimates of benefits to the environment (reduced water stress)

No data are available to identify target levels of reduction of summer abstractions that might be required to reduce the environmental risks. This means that it is not possible to quantify the environmental benefits that could occur. Assumptions have been made that 33%, 50% or 100% of licensed volumes could move to winter licences to give an indication of the water savings that might be possible.

5.4.7.2 Transferability within the EU

With regard to the transferability of irrigation reservoirs to other catchments across the EU, important considerations are:

- the permeability of the local geology and availability of clay, which may affect the feasibility of moving to irrigation reservoirs in some catchments;
- surface versus groundwater abstraction, where reservoirs are best used in catchments where most water is taken from surface water bodies;
- current and future availability of water, where reservoirs will be most beneficial where water is available when it is needed to fill the
reservoir (e.g. in winter) but where there are not sufficient supplies to meet peak demands (e.g. in summer). In some areas, climate change may increase the financial viability of irrigation reservoirs. In other areas, where high flows may be reduced due to climate change (e.g. due to reduced snowmelt), the potential benefits from reservoirs and, hence, their viability may be reduced; and

- **farm size and the potential for reservoir sharing**, since building a reservoir is expensive. Consultation has indicated that many smaller farms may find it difficult to access sufficient capital. Consultation indicates that there is potential for co-operative approaches among smaller farms based on reservoir sharing, where the costs can also be shared, although grants may be required. This will impact where access to water is necessary to secure contracts (for example with supermarkets where quality of crops needs to be ensured). If access to reservoirs was restricted because of access to finance, there is a risk that some smaller farms could become less competitive.

### 5.5 Synthesis of the case studies

The case studies present the situation in four different contexts with differing responses to the need to reduce pressure on water bodies by agriculture. The context of the case studies are following:

<table>
<thead>
<tr>
<th>Case study</th>
<th>Water use</th>
<th>Main issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyprus (one RB)</td>
<td>Water demand: about 250 million m$^3$/year</td>
<td>Water stressed area</td>
</tr>
<tr>
<td></td>
<td>Agricultural use: about 160 million m$^3$</td>
<td>Overabstraction (saline intrusions)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Competition for water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Difficulties to treat and discharge treated wastewater</td>
</tr>
<tr>
<td>Adour-garonne RB (France)</td>
<td>Water consumption for agriculture: between 650 million m$^3$ and 1 200 million m$^3$/year</td>
<td>Water shortages (regulatory limitations)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limited economically viable solutions for other crops</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strong network of FAS</td>
</tr>
<tr>
<td>Po RB (Italy)</td>
<td>Total water abstractions: more than 21.7 billion m$^3$ per year</td>
<td>Relatively high availability of water currently, but adaptation to climate change required (in recent years dry periods occurred)</td>
</tr>
<tr>
<td></td>
<td>Agriculture use: 17.7 billion m$^3$ (including livestock)</td>
<td></td>
</tr>
<tr>
<td>Anglian RB (UK)</td>
<td>160.7 million m$^3$/year licensed for irrigation around 55 million m$^3$ abstracted for spray irrigation</td>
<td>Water stressed area in the summer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of water in the winter</td>
</tr>
</tbody>
</table>

Table 5-22 and Table 5-23 synthesise the relative drivers, barriers, water saved, costs, benefits, opportunities and support measures for the initiatives identified.
### Table 5-22: Synthesis of the case studies (1/2)

<table>
<thead>
<tr>
<th><strong>Response</strong></th>
<th><strong>Drivers for choosing the response</strong></th>
<th><strong>Main barriers</strong></th>
<th><strong>Water saved or volumes that were not abstracted</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water efficient irrigation systems (CY)</td>
<td>Increasing irrigation water efficiency</td>
<td>Capital costs (of new system)</td>
<td>Estimated to 75 million m³ per year</td>
</tr>
<tr>
<td></td>
<td>Saving water</td>
<td>Appropriateness of the crops/soils (e.g. for drip irrigation)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Training is required for farmers</td>
<td></td>
</tr>
<tr>
<td>Water allocation (CY)</td>
<td>Responding to competing water uses</td>
<td>Acceptability of the hierarchy proposed</td>
<td>Rule: The demand is met for:</td>
</tr>
<tr>
<td></td>
<td>Reducing pressure on stressed water bodies and ecosystems</td>
<td>Illegal abstractions</td>
<td>(1) 100% for drinking water uses, (2) 40% - 100% for greenhouses and permanent crops</td>
</tr>
<tr>
<td>Water reuse (CY)</td>
<td>Reducing pressure on stressed water bodies and ecosystems</td>
<td>Sanitary issues</td>
<td>About 10.5 million m³ of tertiary treated water effluent is reused (not only for agriculture)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public acceptability</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water treatment costs</td>
<td></td>
</tr>
<tr>
<td>Regulatory limitations (FR)</td>
<td>Reducing pressure on stressed water bodies and ecosystems</td>
<td>Acceptability by farmers and other stakeholders</td>
<td>Threshold depends on the defined minimal river flow in the river basin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Illegal abstractions</td>
<td></td>
</tr>
<tr>
<td>Change in cropping patterns (FR)</td>
<td>Limited water availability</td>
<td>Other economically viable solutions to grow other crops must be available</td>
<td>Depends on the crop chosen, may save no water, but use the same amount on smaller surfaces</td>
</tr>
<tr>
<td>Irrigation scheduling (FR)</td>
<td>Saving water</td>
<td>Cost (of measures, data, organisation)</td>
<td>High in wetter years, lower in scarce years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Requires a relative evenness in the crops grown in the region (since the scheduling is based on pilot fields)</td>
<td></td>
</tr>
<tr>
<td>Water &quot;turns&quot; (FR)</td>
<td>Increase the length of time in which water is available</td>
<td>Cost of organisation</td>
<td>None – better spread over time of water abstraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organisational issues (size of the river basin)</td>
<td></td>
</tr>
<tr>
<td>Irrigation scheduling IRRINET (IT)</td>
<td>Saving water</td>
<td>Training is required for the farmers</td>
<td>Estimated to almost 50 million m³ (20% of the water used in agriculture)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Precision of the model</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost (of the model, data)</td>
<td></td>
</tr>
<tr>
<td>Remote-sensing for irrigation, COLT project (IT)</td>
<td>Save water used in seasonal irrigation</td>
<td>Availability of remote sensing images</td>
<td>unknown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost (of images, interpretation)</td>
<td></td>
</tr>
<tr>
<td>Winter storage reservoirs (UK)</td>
<td>Reducing pressure on stressed water bodies and ecosystems</td>
<td>Cost (site investigation, planning, construction, etc.)</td>
<td>Reservoir capacity considered was 40 000 m³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planning restrictions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of land (on which to site reservoir)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5-23: Synthesis of the case studies (2/2)

<table>
<thead>
<tr>
<th>Option</th>
<th>Costs</th>
<th>Benefits</th>
<th>Most appropriate opportunities</th>
<th>Potential measures to increase uptake</th>
</tr>
</thead>
</table>
| Water efficient irrigation systems (CY) | Training of farmers to use new techniques  
Government subsidies and long-term low interest loans | In 2009, overall water use efficiency of above 80% | Where water demand is high  
As first option to consider in the water hierarchy | Subsidies and loans  
Advice on appropriate systems |
| Water allocation (CY)          | Organisation of the scheme  
Compliance checks | Reduced pressure on ecosystem  
Clear allocation rules for competing uses | Where competition for water is high  
Implemented best at river basin level | Regulatory means  
Collaborative organisation |
| Water reuse (CY)               | Water treatment  
Water pumping (energy and CO₂)  
average cost 0,23 EUR/m³ for tertiary treatment  
Salinisation of soils | Low prices for farmers (subsidised): 0,07 EUR/m³ for agriculture and 0,15 EUR/m³ for green areas etc.  
Security over water availability | Where wastewater discharge is an issue  
Treatment requirements depend on use (legumes, tree crops, golf courses, flowers, etc.) | Awareness-raising about the treated water  
Guidance and/or regulations to only allow low-risk uses  
Subsidies for treatment |
| Regulatory limitations (FR)    | Compliance costs  
Organisation of scheme  
Reliability of systems | Minimal water flow maintained | Everywhere | Regulatory means  
Collaborative organisation |
| Change in cropping patterns (FR) | Training/ knowledge of new practices | Possibly increased economic margins | Where alternative crops can be grown and sold  
Where climate and soils are appropriate | Organise alternative demand for crops |
| Irrigation scheduling (FR)     | 1,5 EFT for more than 3 months  
Costs of tensiometers (450 to 1 800 EUR, used for 6-10 years)  
380 EUR per year for climatic data | Precise scheduling of irrigation timing and amounts  
Saved water | Everywhere | Organisation and funding by FAS |
| Water “turns” (FR)             | One week full-time work (system with 20 farmers)  
More time and a computerised system may be needed for many farmers | Reduced pressure at a given time on the water body | Where collective organisation is possible | Organisation and funding by FAS |
## Case studies

<table>
<thead>
<tr>
<th>Option</th>
<th>Costs</th>
<th>Benefits</th>
<th>Most appropriate opportunities</th>
<th>Potential measures to increase uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation scheduling IRRINET (IT)</td>
<td>costs estimated to 55 000 EUR/year, and development costs around 300 000 EUR</td>
<td>Benefit to the farmer to identify economically beneficial agricultural systems Reduced water use</td>
<td>Everywhere</td>
<td>Awareness-raising and training about the tool Free access</td>
</tr>
<tr>
<td>Remote-sensing for irrigation, COLT project (IT)</td>
<td>unknown</td>
<td>Better assessment of water need by crops</td>
<td>Where remote sensing is available</td>
<td>Awareness-raising Subsidies for images</td>
</tr>
<tr>
<td>Winter storage reservoirs (UK)</td>
<td>Clay-lined reservoirs: €3.20/m³ to 6.70 EUR/m³ Reservoirs with a synthetic liner: 4.90 EUR/m³ to 15.80 EUR/m³, including energy (CO₂) from pumping twice (from borehole/river to reservoir; and from reservoir to field)</td>
<td>Overall benefit (to farmers) of moving to irrigation reservoirs can be estimated at around 30 EUR/m³ as well as additional (non-monetised) benefits associated with improved security and flexibility of supply Reduced pressure on water bodies from reduction in summer abstractions</td>
<td>Areas with clay soils/clay available to line reservoir Where there is a need to deliver high quality produce (to meet contracts/ customer requirements) Where water is available for abstraction in winter Where water bodies are most stressed from over-abstraction in spring/ summer</td>
<td>Grants (to help farmers with some of the upfront and/or construction costs) Opportunities for co-operation between farmers to construct shared reservoirs and trade water between themselves</td>
</tr>
</tbody>
</table>
Chapter 6: Findings, conclusions and recommendations

The European Commission is active in finding solution to a better usage of water in different sectors, including agriculture and this study is providing evidence to support and recommend possible actions in that specific field. The recent Communication from the Commission on its Roadmap to a Resource Efficient Europe\textsuperscript{69} includes a water milestone (see Box 4) that reaffirms the requirement of the WFD to attain a good status of waters in 2015. The Blueprint (expected to be released end of 2012) will propose a policy response at EU level to water scarcity and droughts.

The current Common Agricultural Policy (CAP) includes two measures related to water through Good Agricultural and Environmental Conditions (GAEC), one on establishing buffer strips along water courses (mainly targeting the reduction of water pollution), the other on water abstraction for irrigation (ensuring compliance with authorisation procedures)\textsuperscript{70}. Other measures from the current CAP include agri-environmental measures and payments linked to the implementation of the WFD (Article 38 of Regulation (EC) 1698/2005\textsuperscript{71}). Additionally, the future CAP post-2013 is also likely to take into account and support actions to ensure a sustainable use of agricultural water. As regards the proposals for the CAP reform made on the 12\textsuperscript{th} October 2011, article 46(3) of the proposed future rural development regulation\textsuperscript{72} states: "In the case of irrigation, only investments that lead to a reduction of previous water use by at least 25\% shall be considered as eligible expenditure. By way of derogation, in the Member States that adhered to the Union from 2004 onwards investments in new irrigation installations can be considered eligible expenditure in cases where an environmental analysis provides evidence that the investment concerned is sustainable and has no negative environmental impact". Additionally, greening measures such as permanent pastures, diversification and ecological set aside may have indirect beneficial impacts on the water cycle as well as the possible inclusion of relevant elements of the WFD in cross-compliance. If these measures are taken forward, the future CAP may include additional measures to improve water management in agriculture.

\textsuperscript{69} ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf
\textsuperscript{71} Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)
\textsuperscript{72} See ec.europa.eu/agriculture/cap-post-2013/legal-proposals/com627/627_en.pdf
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Box 4: Water milestone of the Roadmap to a Resource Efficient Europe.

By 2020, all WFD River Basin Management Plans (RBMPs) have long been implemented. Good status – quality, quantity and use - of waters was attained in all EU river basins in 2015. The impacts of droughts and floods are minimised, with adapted crops, increased water retention in soils and efficient irrigation. Alternative water supply options are only relied upon when all cheaper savings opportunities are taken. Water abstraction should stay below 20% of available renewable water resources.

Issues in ensuring water savings in agriculture

The development of recommendations for a sustainable use of water by agriculture, respectful of other legitimate uses first requires an understanding of the issues in ensuring that savings are obtained in agriculture.

While it is true that the amounts of water used by agriculture are relatively high (24% of overall abstractions in the EU, EEA 2009), the concept of ‘water loss’ is not easily defined, especially in the context of agriculture. From a hydrological point of view, much of the water that is not productively consumed in agriculture is generally returned to the environment – as runoff or percolation and is available for other uses. Where return flows carry high loads of potential pollutants, reducing losses may be beneficial for receiving waters (e.g. Lecina et al., 2010), however, reducing these losses may result in reduced water availability in other parts of the basin. For example, Ward and Pulido-Velazquez (2008) showed that increasing irrigation water use efficiency can reduce valuable return flows and limit aquifer recharge. Clearly an analysis at ecosystem or river basin level is required to ensure that reducing water losses does not result in unforeseen negative impacts.

Reducing the water used in agriculture may be achieved through improving techniques, that may result in water being saved compared to the same system, that is, an increase in efficiency. It is generally assumed that this will result in more water being available for other uses although evidence to support this is lacking. “Jevons’ Paradox” suggests that increased efficiency may not lead to water saving (Llop, 2008). Indeed, several studies have shown that although increasing water efficiency in irrigation may result in greater output and increased productivity of water use, it may not result in significant water being made available for other uses. The water saved is used to increase the irrigated area, or to increase the output from the existing area. For example, the introduction of hydraulic infrastructures in Spain, while having a positive impact on increasing productivity and rural incomes for farmers, tripled the areas under irrigation (Candela et al. 2008). The introduction of drip irrigation also increased areas under irrigation in Spain (Garcia 2002). Ward and Pulido-Velazquez (2008) present the results of an integrated basin-scale analysis of the Upper Rio Grande Basin (USA). Their results suggested that water conservation

73 e.g. increasing the area that is irrigated for agriculture, building new touristic, residential or office areas and supply them with freshwater, etc.
subsidies were unlikely to reduce basin water use. Lecina et al., (2010) drew similar conclusions from a study of irrigation modernisation in the Ebro River Basin (Spain) and Lecina et al. (2011) showed that increasing irrigation water efficiency in the Bear River Irrigation Project (USA) would result in little water available for other uses.

As stated several times in the report, the main goal is not necessarily to ‘save’ water, but rather to **reduce the pressure on ecosystems**, ensuring that enough water is available for all types of legitimate uses (including potable water, agriculture, tourism, industry, ecosystem needs). Reducing pressure on ecosystems does not necessarily mean reducing water abstraction. Reduced pressure on ecosystems may result from reducing the total volume of water that is used; reducing water abstraction at times when pressure is high (e.g. water could be abstracted in the winter and stored for use during the summer); relocating abstraction from areas with higher pressures; or through using ‘alternative’ sources of water (e.g. recycled greywater, harvested rainwater). The pressure on water bodies from the energy sector is considered (e.g. EEA 2009) to be relatively low, because while it is the sector with the highest water abstraction (44% of the total), it returns almost 100% of the cooling water to a water body. Agriculture returns about 30% of its share to a water body (Molle and Berkoff, 2007). This does not account for water that can be used by neighbouring ecosystems that use water “lost” by e.g. conveyance systems. While that water is definitely not efficient for agriculture as such, it may be interesting to assess on a case-by-case basis whether that is or not beneficial to those ecosystems.

When considering how to improve irrigation systems in agriculture two types of systems should also be differentiated. Systems that still rely on traditional systems, and modern systems that have not been set up in an efficient way and/or have not been maintained properly (e.g. leaks have not been fixed). In traditional irrigation systems, additional benefits may occur, such as cultural landscapes, provision of water to the plants along traditional canals and/or recharge of aquifers. In more intensive agricultural systems such benefits may be reduced or irrelevant. More specifically, intensifying agriculture or adding new lands to be irrigated may tip the previously existing balance in traditional systems. Any side-benefits in traditional systems may usefully be taken into consideration before a decision is taken on increasing a so-called efficiency.

To understand the ways in which water use can be made more sustainable in agriculture, it is also important to understand the **underlying reasons** for using water and for irrigating by farmers. At international level, the productivity of irrigated land is estimated to be approximately three times greater than that of rainfed land (FAO, 2005). The role of irrigation depends on the geographical situation, but also on the crops cultivated. In some regions, no farming would occur without irrigation; in certain countries (e.g. Spain), irrigation has allowed the cultivation of crops that would otherwise not have been cultivated there (Pinilla 2006); while in others, irrigation is an “insurance” for farmers that the crop yields and quality will be high, ensuring that crops will be sold, and at higher prices. The demand for high quality crops that may only be ensured by irrigation, is also an important driver for irrigating crops. For fruit and vegetable production, the quality premium is often more important than the yield increase from irrigation. The capacity to irrigate is also sometimes demanded in contracts with distributors and agri-food sector companies. For example, discussions with abstractors in the UK has highlighted that supermarkets are unlikely to place a contract if they thought that sufficient water was not (or would not be) available. This means that if quality cannot be guaranteed, then there is no market
for the crops. Whether or not it is desirable that those crops are cultivated there, with these yields and quality is a choice that must be made to decide whether to continue irrigation at those levels.

For the farmers, irrigation means additional work, investment, manpower and costs. In the decision by farmers to irrigate crops these factors are taken into account and the ways to reduce that workload, partly by making irrigation more efficient or better organised are considered. Thus while it is clear that the situation can be further improved, efforts are already made to reduce that workload, partly through improving techniques and practices.

Lastly, the economic return of irrigated crops is important for the decision by farmers (how much) to irrigate. Communicating about the fact that margins can be increased by reducing irrigation (through decreased costs for irrigation, especially in terms of energy costs but also partly water costs) is important. Another factor impacting the economic return is the CAP, which is both part of the problem and (hopefully increasingly) part of the solution. Improvements have occurred *inter alia* through the increasing decoupling of payments from production, thus reducing the incentives towards irrigated agriculture, and through introducing cross-compliance standards related to water management (see the two GAEC mentioned above). Further improvements are being proposed for the CAP post 2013 (see also the above-mentioned proposal for rural development article 46), but measures could still go further. Some Member States have designed agri-environmental measures in view of reducing or abandoning irrigation (e.g. in France). For providing “adequate incentives for users to use water resources efficiently” as underlined in article 9 of the WFD, such factors, that drive the decision by farmers to irrigate and how much to irrigate must be taken into account.

This requires the translation of an issue of “water savings” to an issue of “sustainable management of water quantities”, i.e. “reducing the pressure by agriculture on water bodies”. Indeed, how much water is saved is important for reducing water use at farm level, and can be used as an indicator by the farmer. However, at a more global level the risk is that the water saved by the farmer is used for increasing its irrigated land, by other farmers, or for other purposes. If the target implemented is to save water, it may thus hinder use at times or in areas where it is unnecessary to reduce abstractions. To ensure reduced pressure on water bodies by sustainably managing water quantities requires an understanding at river basin level, including knowledge of water availability; and an understanding of the water needs by all water users, so that water can be allocated in a relevant way, transparently and with involvement of the stakeholders where relevant (ensuring acceptability).

It also requires the identification of the trade-offs that are entailed in irrigation, so that they can adequately be taken into account and communication on the measures is facilitated. Trade-offs (Figure 6-1) include for instance the fact that with irrigation the risks to have low yields and/or low quality is reduced, but that it entails more work for the farmer and increases the risk of low flow (both a risk for the environment and for the farmer for using water later in the season).
Options for improving the sustainable use of water in agriculture

Policies can work on:

- Global actions, such as the level of governance and hierarchies
- Facilitating the uptake of technologies and practices
- Pricing (see parallel study on Water pricing and allocation in agriculture commissioned by the EC)

Measuring and monitoring water abstraction, consumption and use is key to understanding and allowing a better response to water scarcity and droughts. "You can't manage what you don't measure". Water metering may be a way to increase the understanding of water losses and thus improve the efficiency of the water used, but could be costly. This would increase understanding at all levels and allow to increase acceptability for farmers of reductions, as well as identifying most promising areas for improvement. Currently data are available at national level and annually, but data at river basin level and providing details on peak periods (seasonal monitoring) would be more relevant to collect. Additionally, the farm structure survey collects information on how much agricultural land is irrigated and irrigable (but not on how much water is used). The study showed that data are available, but are difficult to access and definitions require being streamlined, since the same data may be referred to by different organisations, complicating useful comparisons (e.g. the definitions by FAO and Eurostat). This was also the conclusion of the recent EEA presentation on water scarcity and droughts (Kristensen, 2010), that underlined the need for more data, more timely (to obtain data about the situation quickly, i.e. not several years later, in order to guide decision-making), but also for harmonisation in definitions and methodologies. A suggestion to monitor water quantity data by the river basin authority could be made. The data should be made available in a common format at EU level, so that data could easily be reported through Eurostat or the WISE\textsuperscript{74} system. Additionally, the data must be interpreted in context. The data would need to be linked to minimal river flows, based on ecosystem needs and competing uses, calculated for each river basin using a defined methodology (initiatives are under way in France, see Adour-Garonne case study). Another aspect to be taken into account is the need to reduce uncertainties linked to the data gathered.

\textsuperscript{74} The Water Information System for Europe, available from water.europa.eu/
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(Kristensen, 2010). In many countries data on water abstraction are only estimations, leading to uncertainties that may impede decision-making.

**Regulating water use** is implemented in several EU MS (e.g. detailed in the French, UK and Cyprus case studies), to cope with periods of water stress. During these times, water use by agriculture is restricted, using thresholds to limit progressively water use and allocating water to priority uses. While regulations require enforcement to ensure their effectiveness, they also foster adaptation by farmers and other stakeholders to be less impacted by such limitations.

**Appropriate pricing** of water is another way to limit the use of water, and is dealt with in the study commissioned by the European Commission “Water pricing and allocation in agriculture”.

Both regulatory and pricing instruments may lead to a reaction from farmers to reduce their water use where they can. This may have different impacts depending on how those instruments are used. If well implemented, the farmers will reduce their use of water so that it is most efficient for their own crops. This will reduce the pressure on water bodies from agriculture, while leaving the farmer choose the most efficient way to do so (either changing irrigation technique, reducing the surface of irrigated crops, changing cropping patterns, creating reservoirs, etc.). However, such instruments may also lead to land abandonment because of reduced certainty to have sufficient yields (and thus economic returns) and/or too high water prices compared to the benefits.

**Changing cropping patterns** is already a response used by farmers as a reaction to reduced water availability, and that is expected to be used increasingly to adapt to foreseen future scarcity and drought issues, potentially going back to traditional crops, modifying the quality requirements and/or cultivating crops not yet cultivated in that area. This requires to investigate economically viable options in terms of crops that will provide stable revenues for farmers; and require some time to be organised. Such solutions require local investigation, but are also very much driven by international market prices and forecasts, that may not easily be influenced by EU policies.

**Increasing advice and scheduling** has shown to deliver good results, as it answers farmers demand, and many RBMP identify advice as an important means to show ways to improve water performance of farmers, and to ensure that the efficient techniques introduced are used to their full potential. Advices are also locally adapted, as they are generally implemented by FAS, which is important for the relevance of the advice. Scheduling is spreading in the EU (e.g. France and Crete examples, IRRInet in Italy) and are shown to deliver good results (while it is difficult to have reliable estimates because some sort of scheduling based on farmer’s knowledge at a minimum is always used, the systems investigated in this report were shown to reduce water used for irrigation). However, such systems should be further analysed in terms of their benefits in very dry years. Indeed while scheduling may bring significant decreases in water uses in “wetter” years, due to forecasting future rainwater availability, in very dry periods, when water availability is limited, the amounts of water that is advised and that would be put on the fields without advice is quite similar.

**Improving techniques and practices** to increase the efficiency of irrigation, but also ensure that measures to reduce water lost that could easily be saved are taken. Several techniques are investigated in the responses (see Chapter 4) and show good results in improving water
performance, but each are adapted to certain crops, soil types and climate, requiring assessment of their relevance before implementation. They also require acquisition of new knowledge by farmers. The following responses have been investigated:

- Improvement of irrigation systems is an effective solution if the water is not used for other purposes, and the systems are adapted to soil and crop. An example where this was usefully implemented is Cyprus.

- Deficit irrigation strategies are adapted mainly for tree crops and vines, and require tools (e.g. for measuring water content in soils) and knowledge (e.g. for interpretation) by farmers, but are increasingly investigated in the EU and applied to other crops. Many scientific studies showed that if applied at the right time, the reduced water amount did not significantly impact yield or quality of crops and in some cases resulted in a better crop.

- Reduction of evaporation during storage reduces real water losses in areas with reservoirs, but depends on many parameters.

- Decreasing soil evaporation through mulching and new techniques can be promoted, at EU level, with mulching already implemented in many countries. A side benefit is the reduction in weeds’ occurrence.

- Irrigation scheduling is spreading and answering an identified need for advice and understanding, to take informed decisions, but an assessment of its relevance in dry years would be required.

- Reducing runoff may be implemented through tillage, but the practice also has negative effects on soils.

- Water-table management leads to little water saving, but there are areas in which the water gathered through controlled drainage is being re-used at other times of the year.

- Water reuse allows to use grey water and stabilise resources, but sanitary and environmental requirements must be met. Policies that organise for which purposes the water can be used depending on its level of treatment are for example in place in Cyprus. If such use is foreseen at EU level, standards may need to be put in place.

- Changing planting date is possible for certain crops in certain regions, and could be further investigated and implemented, as it brings benefits to the environment through reduced water required in times of scarcity, but also to the farmer who increases its certainty of having enough water for its crops.

- Crop selection currently generally is for increasing the resistance to droughts, not to save water, but could have side benefits for e.g. deficit irrigation strategies. More selection for changing planting dates and/or reducing the amounts of water needed could be fostered. However, time and research is required until efficient crops are selected.
Promoting collective organisation and responsibility, through water stewardship, fosters understanding of the issues in the river basin, going from water saved to reducing pressure on water bodies. Water is a shared resource, with each individual user having a low impact on it and considering its use as legitimate and insignificant. Raising awareness goes through a collective understanding and management of the issue. This both ensures that the needs of each user are understood and that the impacts and efforts of each are recognised. Common organisation, such as "water turns" or sharing of reservoirs are interesting options for this purpose, that can also lead to cost savings by common investments. The European Water Stewardship initiative\textsuperscript{75} organised by the European Water Partnership is interesting in this regard and results will need to be followed to assess how and whether it could be implemented across the EU.

Using alternative waters and creating "new" resources, such as wastewater recycling and reservoirs are interesting options in terms of reducing pressures on water bodies, but must be taken as a last resort as defined in the roadmap. The water hierarchy indeed requires that first options to reducing water use and improving efficiency are sought, before turning to 'alternative' or 'new' resources. The waste hierarchy however also requires to prevent, reuse, recycle, recover, then only dispose (article 4 of the Waste Framework Directive\textsuperscript{76}). Reusing grey water may be a way to reuse/ recycle such water, if sanitary and environmental issues (including impacts on soil quality) are controlled. This way both waste and pressure on water bodies are reduced (see Figure 6-2). The example of reservoirs in the UK also shows a way to reduce pressure on water bodies by modifying the seasonal demand for water, through abstracting water in the winter and storing it for summer use. An additional benefit of both using grey water and storing water is the increased reliability of water availability, which is important to farmers. To ensure water supply for a variety of purposes most European countries have built reservoirs with a total capacity of about 1400 km\textsuperscript{3} or 20\% of long-term annual average of freshwater resources (Kristensen, 2010).

The availability of alternative waters may however lead to unsustainable water management if led by supply. A demand-led approach is thus required, focused on conserving water and using it more efficiently, accounting for the need for healthy freshwater ecosystems, and considering the

\textsuperscript{75} Further information available from: www.ewp.eu/activities/water-stewardship/


additional advantage that less water use also means lower energy consumption (Kristensen 2010).

The share of water abstracted for, and consumed by agriculture is often pointed out as being significant (24% at EU level), but must be put in perspective. It is important to recognise that the share may remain large in the future, but that the abstraction volumes must not exceed the available water resource (after allowing for ecological flows and higher priority uses) at the given time in the local area, if the goal is to reduce pressure on water bodies.

As a concluding remark, is irrigation “good” or “bad” for the environment? As for many answers, the answer is not black or white, but rather grey. Water is the source for all life, and in many cases traditional agriculture has allowed to capture water to develop agri-ecosystems (e.g. in certain oasis, through channelling or capturing water or air moisture). Traditional agriculture also cultivated crops that were adapted to their environment, and were bred/selected for this purpose. In certain cases irrigation also benefits biodiversity close to the fields, through drained water, or losses that allow plants to grow or animals to drink. However, with recent trends to intensify agriculture, crops less adapted and/or that require certain amounts of inputs (fertilisers, chemicals, but also water) have spread. More water-intense crops have also been adopted and are now demanded by customers. The increase in irrigated areas, with more water being put to increase yields and quality are now driving the demand for water, which is becoming unsustainable in many river basins. From the results of this study, two main conclusions can be drawn. First, saving water does not necessarily allow to reduce pressure on waterbodies, since the water saved is often reused for other human purposes. Reducing the pressure on water bodies is in fact the objective targeted by the EU, as identified in the objective of “good ecological status of water bodies” required in the WFD. In order to translate water savings into reduced pressure on water bodies, the right level of governance is required, at the river basin scale, accompanied by the right level of knowledge. The situation needs to be known (i.e. How much water is available in the long-run for the river basin) and the people that are using water must be aware of the issues and competing uses to take actions. In that case, local actors may take responsibility for water management, developing stewardship, with relevant decisions taken by each stakeholder to jointly manage the resource. This could also increase respect of the rules, through a better understanding and enforcement. If the governance level is not at the right level, the benefits of saving water risk to not be realised.

Second, there are many possible ways to save water in agriculture, as shown in this study. However, there is no one-solution-fits-all that could be used, but many solutions that will need to be compatible with the climate, soil, crop and other factors of the local situation. Farmers must choose the most appropriate solution for reducing pressure on water bodies, through making their irrigation systems more efficient, deciding to change their production systems to plant other crops, building reservoirs, using wastewater, etc. While analysing the best solutions, the whole ecosystem surrounding the farm must be taken into account to identify any side-benefits or unintended consequences of “apparent” increased efficiency. Farmers will make their choices depending on the available information and economic situation, and through other beneficial aspects of the techniques (e.g. tillage or mulching do not only impact soil evaporation). Thus advice, incentives and economic alternatives to currently cultivated crops will allow to influence
future water savings by farmers. Similarly, information will influence customers and actors from the supply chain, and thus work on demand; indirectly also influencing water use by farmers.
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### Annex 1: List of the consulted sources used in the databases

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Annex 2: Share of irrigated and irrigable areas in each MS

The table below synthesises the farm specialisations along with irrigable areas and irrigated areas in each MS and at EU level. The MS with irrigated areas accounting for more than 5% of their utilised agricultural area (UAA) are highlighted in light blue and for more than 20% in darker blue. The countries irrigating more than 50% of their irrigable areas are highlighted in orange.

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<td>Austria</td>
<td>14% cattle, 11% cereals, 10% dairy farming, 10% vineyards</td>
<td>90 420</td>
<td>34 230</td>
<td>43 440</td>
<td>3 5%</td>
<td>4,5%</td>
<td>1,3%</td>
<td>1,7%</td>
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<td>Belgium</td>
<td>51% livestock, 18% cattle, 14% dairy farming, 14% general field cropping</td>
<td>21 810</td>
<td>18 850</td>
<td>5 680</td>
<td>1,6%</td>
<td>1,7%</td>
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<td>Bulgaria</td>
<td>21% general field cropping, 14% dairy farming, 11% crops+grazing, 10% mixed cropping, 9% grazing livestock</td>
<td>124 480</td>
<td>79 370</td>
<td>72 840</td>
<td>4,3%</td>
<td>3,6%</td>
<td>2,8%</td>
<td>2,5%</td>
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<tr>
<td>Cyprus</td>
<td>79% crops, 32% fruits and citrus fruits</td>
<td>44 930</td>
<td>35 410</td>
<td>31 260</td>
<td>32,1%</td>
<td>32,7%</td>
<td>25,3%</td>
<td>22,3%</td>
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<tr>
<td>Czech Republic</td>
<td>49% crops, 13% crops+grazing livestock</td>
<td>49 090</td>
<td>16 860</td>
<td>19 910</td>
<td>1,4%</td>
<td>1,1%</td>
<td>0,5%</td>
<td>0,6%</td>
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<td>Denmark</td>
<td>38% cereals, 17% general field cropping, 10% dairy farming</td>
<td>448 820</td>
<td>254 140</td>
<td>201 480</td>
<td>16,9%</td>
<td>16,4%</td>
<td>7,6%</td>
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<tr>
<td>Estonia</td>
<td>15% grazing, 14% cereals, 14% livestock</td>
<td>103 800</td>
<td>76 750</td>
<td>0 0</td>
<td>32,1%</td>
<td>32,7%</td>
<td>25,3%</td>
<td>22,3%</td>
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<tr>
<td>Finland</td>
<td>64% crops, 37% cereals, 23% general field cropping, 10% dairy farming</td>
<td>27 390</td>
<td>24 150</td>
<td>21 490</td>
<td>8,4%</td>
<td>8,3%</td>
<td>6,3%</td>
<td>6,1%</td>
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<tr>
<td>Greece</td>
<td>26% olives, 13% general field cropping, 12% mixed cropping, 10% crops+livestock, 10% cereals, 10% grazing livestock</td>
<td>1 521 600</td>
<td>1 294 400</td>
<td>1 279 520</td>
<td>38,0%</td>
<td>38,9%</td>
<td>32,4%</td>
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<td>Hungary</td>
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<td>242 170</td>
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<td>Ireland</td>
<td>85% livestock, 54% cattle, 21% grazing livestock, 16% dairy farming</td>
<td>27 230</td>
<td>2 196 300</td>
<td>1 511 730</td>
<td>9,9%</td>
<td>9,7%</td>
<td>7,1%</td>
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<td>Italy</td>
<td>71% cattle, 21% dairy farming, 14% cereals, 10% grazing livestock</td>
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<td>2 732 730</td>
<td>2 666 210</td>
<td>31,8%</td>
<td>31,6%</td>
<td>21,9%</td>
<td>21,3%</td>
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<td>Latvia</td>
<td>17% livestock, 31% dairy farming, 19% fields crops+grazing livestock, 15% mixed livestock</td>
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<td>1 000 000</td>
<td>0 0</td>
<td>0,1%</td>
<td>0,1%</td>
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<td>0,0%</td>
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<tr>
<td>Lithuania</td>
<td>45% mixed livestock, 33% mixed cropping, 22% mixed farms</td>
<td>740</td>
<td>1 340</td>
<td>0 1 000</td>
<td>0,0%</td>
<td>0,1%</td>
<td>0,0%</td>
<td>0,0%</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>62% livestock, 25% dairy farming, 17% vegetables, 12% cattle</td>
<td>2 300 320</td>
<td>2 130 210</td>
<td>2 810</td>
<td>31,9%</td>
<td>44,4%</td>
<td>29,6%</td>
<td>39,0%</td>
</tr>
<tr>
<td>Malta</td>
<td>31% horticulture, 22% mixed cropping, 16% livestock, 3% mixed farms</td>
<td>3 570 510</td>
<td>2 200 000</td>
<td>1 370 510</td>
<td>17,9%</td>
<td>24,6%</td>
<td>19,9%</td>
<td>19,3%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>59% livestock, 25% dairy farming, 22% grazing livestock, 13% general field cropping</td>
<td>250 570</td>
<td>190 200</td>
<td>202 260</td>
<td>18,4%</td>
<td>23,9%</td>
<td>3,3%</td>
<td>10,8%</td>
</tr>
<tr>
<td>Poland</td>
<td>38% mixed cropping, 36% mixed livestock, 26% mixed farms</td>
<td>98 420</td>
<td>46 910</td>
<td>72 960</td>
<td>0,7%</td>
<td>0,6%</td>
<td>0,3%</td>
<td>0,5%</td>
</tr>
<tr>
<td>Portugal</td>
<td>49% vegetable production (sunflowers), 16% livestock, 18% mixed cropping, 11% ungrazed, 10% crops and citrus fruits</td>
<td>674 800</td>
<td>424 040</td>
<td>421 520</td>
<td>20,4%</td>
<td>17,7%</td>
<td>7,5%</td>
<td>12,8%</td>
</tr>
<tr>
<td>Romania</td>
<td>52% grazing livestock, 21% mixed cropping, 12% crop+livestock, 11% general field cropping, 7% crops+livestock</td>
<td>1 510 820</td>
<td>615 330</td>
<td>400 520</td>
<td>15,0%</td>
<td>6,5%</td>
<td>4,2%</td>
<td>1,8%</td>
</tr>
<tr>
<td>Slovakia</td>
<td>25% cereals, 15% fall crops+grazing livestock, 13% general field cropping</td>
<td>209 070</td>
<td>104 560</td>
<td>39 090</td>
<td>11,0%</td>
<td>9,6%</td>
<td>5,5%</td>
<td>2,1%</td>
</tr>
<tr>
<td>Slovenia</td>
<td>44% livestock, 15% grazing livestock, 14% mixed meat, 13% mixed livestock</td>
<td>1 880 4 100</td>
<td>1 880 1 620</td>
<td>0,4%</td>
<td>0,9%</td>
<td>0,4%</td>
<td>0,4%</td>
<td>0,4%</td>
</tr>
<tr>
<td>Spain</td>
<td>31% olives, 19% fruits and citrus fruits, 11% cereals, 8% vineyards, 7% permanent crops</td>
<td>3 682 110</td>
<td>3 437 370</td>
<td>3 266 330</td>
<td>16,0%</td>
<td>15,4%</td>
<td>14,4%</td>
<td>13,7%</td>
</tr>
<tr>
<td>Sweden</td>
<td>54% crops, 30% general cropping, 21% cereals, 16% cattle</td>
<td>188 460</td>
<td>54 170</td>
<td>53 440</td>
<td>6,3%</td>
<td>5,3%</td>
<td>1,8%</td>
<td>1,8%</td>
</tr>
<tr>
<td>UK</td>
<td>75% livestock, 36% grazing livestock, 17% cereals, 16% cereals</td>
<td>228 930</td>
<td>138 190</td>
<td>138 190</td>
<td>1,5%</td>
<td>0,9%</td>
<td>1,5%</td>
<td>0,9%</td>
</tr>
<tr>
<td>EU-27</td>
<td>2905 1496</td>
<td>1581 6926</td>
<td>2130 4430</td>
<td>1081 3812</td>
<td>18,0%</td>
<td>9,6%</td>
<td>13,2%</td>
<td>6,7%</td>
</tr>
</tbody>
</table>